WATER RESOURCES STUDY

of the

PROVINCE OF NEWFOUNDLAND AND LABRADOR

for

ATLANTIC DEVELOPMENT BOARD

Volume EIGHT

APPENDICES

THE SHAWINIGAN ENGINEERING COMPANY LIMITED
JAMES F.MacLAREN LIMITED

Report 3591-1-6
September 196

VOLUME EIGHT

APPENDICES

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Water Resources Study - Newfoundland and Labrador

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COMPUTER TECHNIQUES APPLIED TO THE WATER RESOURCES STUDY

A.1 Initial Considerations

In the initial stages of the study it became apparent that it would be necessary to process a large quantity of data as the area to be studied was extensive and the problems to be solved were complex. The use of a computer to store, organize, process, and retrieve this data was mandatory, as noted in Volume Two A, Section 1.

The Shawinigan Engineering Company Limited has an IBM 1130 computing system, and this is well suited to this study since it has a mass storage disk cartridge attached. The only viable alternative was the McGill University Computing Centre, but this was rejected because the University had undertaken major hardware changes during 1966 and 1967. The advantages of using the larger machines were outweighed because of the temporary uncertainty of hardware and software, the turn-around time was likely to be longer than by using the Shawinigan system, and because hands-on facilities would not be available.

A.2 The IBM 1130 Computing System

Shawinigan Engineering has the following equipment configuration:

1131 Central Processing Unit (Model 2)

Core storage of 8192 addressable words of 16-bits each

Storage access cycle - 3.6 microseconds

Floating-point storage in two words

Access to information stored on a single 2315 disk cartridge via a data channel having a transfer rate of 35,000 words per second.

The disk cartridge contains a single disk made up of 200 cylinders each accessible by a single read/write mechanism. Up to 2560 16-bit words are available at each cylinder without further access motion. Total storage capacity of the disk is 512,000 words.

1442 Card Read/Punch (Model 6)

Reads up to 300 cards per minute and punches up to 80 columns per second

Sequential read/punch positions

Direct connection with central processing unit

1132 Printer

Uses typewheel printing concept - 120 typewheels each having a 48-character set including FORTRAN special characters.

Printing speed is 80 alphameric or 110 numeric lines per minute, 120 print line positions at 10 characters per inch.

Direct connection to central processing unit through 1132 printer attachment.

300A Model 305 Benson Lehner Incremental Plotter

Up to 300 increments per second

Increments of .005 inches

Uses 29-inch wide or 11-inch wide paper on 120-foot rolls

Direct connection to central processing unit through plotter interface

A.3 The Grid System

As has been explained in Volume Two A, Section 1, it was decided to collect data relating to each of the 10 kilometer squares on the 1:250,000 scale transverse mercator projection maps. The grid formed by these maps effectively divides the Island of Newfoundland into 1600 squares, and the study area of Labrador into 3000 squares. Each square forms one record of a disk data file containing physiographic and economic information. (Detailed descriptions of this and other related files are shown in Appendix A.4 and in Tables A.1, A.2, A.3, A.4, and A.5).

Each square is identified on the map by a five-character identification code (example: 2 UC 34), and any reference to a square on a data card uses this code. However, the data file records are not referenced in this way, but use a cartesian co-ordinate system having an origin positioned so that every square lies in the first quadrant of the system. Each square, therefore, is defined by two integers giving the co-ordinates of its central point. A program was written to convert the identification code into X - Y co-ordinates, taking into account that the areas under study extend over several transverse mercator projection regions. For simplicity and fast processing only two co-ordinate systems were used, one for the Island and one for Labrador. However, this simplification causes some distortion of a relatively small portion of the area, and discontinuities arise with a magnitude of up to 10 kilometers. This is not significant in the analyses which use location as a variable.

Figure A.1 illustrates the procedure followed in transforming the square identifications into co-ordinates of the cartesian system.

Figure A.1 (a) shows the network depicted on the transverse mercator projection maps. Each of the numbered areas has a unique identification code and A - B is the dividing line between mercator regions X and Y, p and q are two adjacent points in different areas.

Figure A.1 (b) shows the first stage of the transformation. The grid near the mercator region division has been redrawn so that some of the smaller areas have lost their identities, and have become associated with neighbouring areas. C - D is now the boundary between X and Y, and only whole squares exist in the Y region. The rule followed for the X mercator region is that, if an area is greater than half a square, it is allowed a separate identification; otherwise it is merged with its neighbouring square.

Figure A.1 (c) shows the last stage of the transformation. Each of the uniquely identified areas of Figure A.1 (b) is drawn as a square, and the mercator boundary line A - B in Figure A.1 (a) is now represented by its approximation, the line E-F. The erstwhile adjacent points p and q are now shown 10 kilometers apart, and, in fact, all along the line G - H in the Y mercator region a 10 kilometer discontinuity exists. The number of distorted squares in the Island is 35 compared to a total of 1,600; the corresponding figures for Labrador are 75 and 3,000.

A.4 Disk File Operations

A brief description of the major data files is given in Table A.l. In addition, several other files exist to enable the data files to be processed. The record layouts for the major files are presented in Tables A.2, A.3 and A.4. The master file shown in Table A.2, the most important file, was so large that every effort was made to keep the record length as small as possible. Therefore, numeric data have been sorted in integer mode (one word) instead of floating-point mode (two words). Though since the largest integer which can be stored in a 16-bit word is 32,767, it has sometimes been necessary to record data to the nearest ten units (population data fall into this category).

The disk input-output system on the IBM 1130, in conjunction with Shawinigan Engineering's disk record read-write buffering programs, afford some advantage in both speed and file size if the record length is a submultiple of 320 words. Since 64 words is the next submultiple larger than 40, a 60 percent size increase, it was felt that 40 words should be made the limit so as to secure these advantages.

The processing of these larger data files presents essentially the same problems as are encountered in commercial applications, and it was decided to apply techniques developed by Shawinigan Engineering for its own accounting Systems.

These techniques include a general file maintenance program and a standard report writing system, both of which permit a user to perform quite complex operations without becoming involved in the overall logic of the problem. The user can concern himself with the specific difficulties of the particular problem. Also included is a disk file search program which uses a binary approach method for fast record access and a high efficiency sorting program.

In conjunction with these commercial techniques, a multiple linear regression analysis was used. The program was initially written by Professor Thorpe of McGill University using an algorithm set out in "Mathematical Methods for Digital Computers" compiled by Ralston and Wilf. The IBM 1130 Scientific Subroutine Package was also a valuable source for mathematical and statistical programs.

A data tape containing daily flows for all gauging stations in the Province of Newfoundland and Labrador was obtained from the Department of Energy, Mines and Resources. Since the IBM 1130 system does not have tape handling facilities, it was necessary to process this tape at McGill University. All the programs employed made use of the report writing system, and as much testing as possible was done on the IBM 1130.

A.5 Input and Output

The major data used are shown in condensed form under the heading "Input" on Table A.5, and this initial data has been processed to produce the results shown under "Output" of the same table. Many of these results have been permanently stored in one or more of the data files. (Tables A.2, A.3, A.4, and A.5). Table A.5 also gives a brief description of the methods used, and demonstrates the potential and flexibility of the system.

Note The above description refers to the work done for the Island of Newfoundland. For Labrador the same basic techniques were used, but the scope of the work was more limited because of lack of available data.

TRANSFORMATION OF MERCATOR PROJECTION GRID TO CARTESIAN COORDINATE SYSTEM

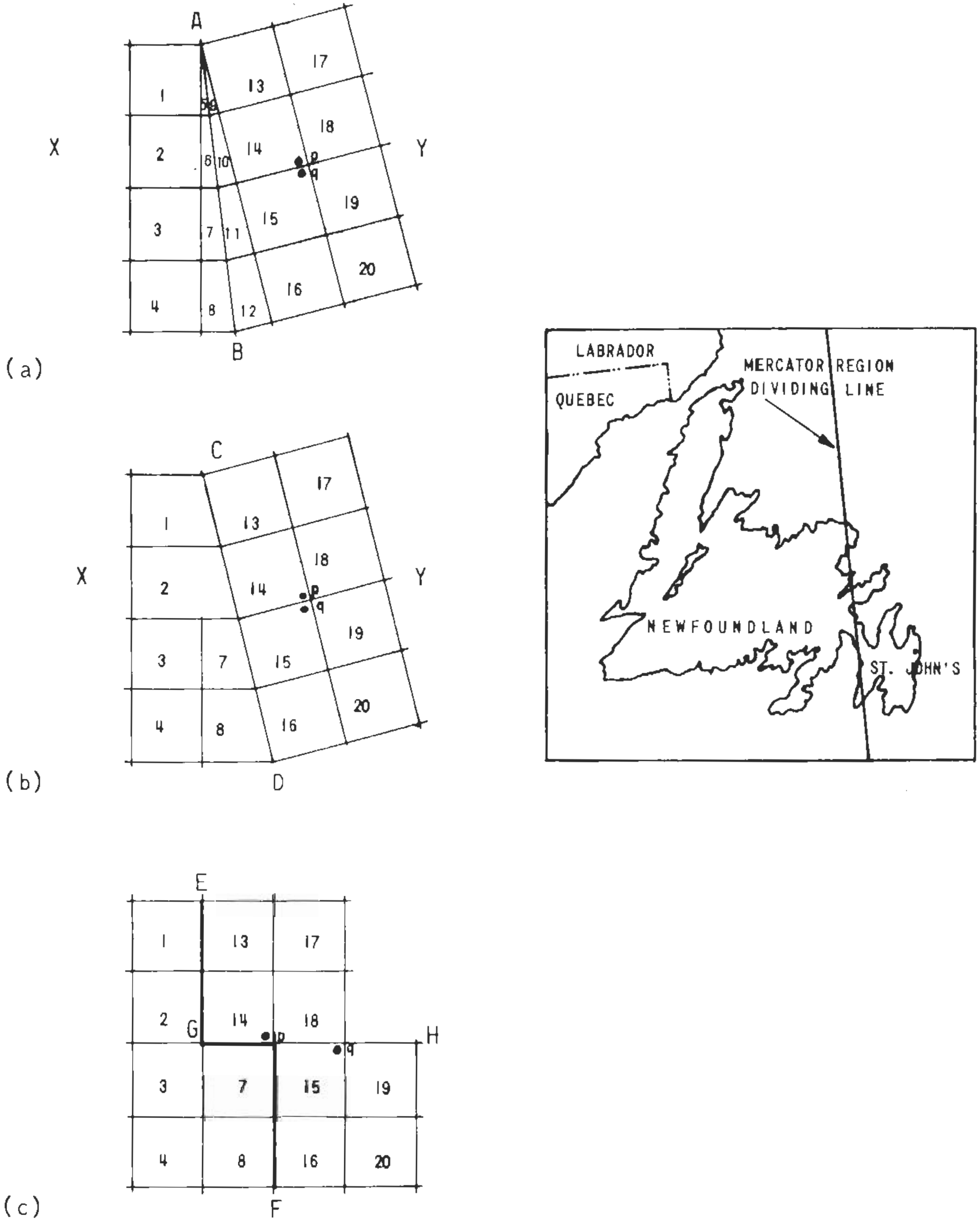


FIGURE A-1

NEWFOUNDLAND DISK DATA FILES

Purpose	Record Length Words	Number of Records
MASTER FILE	40	1600
Record represents one square. Contains general physical, meteorological and demographic data for each square in the Island		
RUNOFF FILE	32	600
Record represents one square. Contains general physical and meteorological data for each square in each watershed.		
WATERSHED FILE	40	25
Record represents one watershed. Contains general physical, meteorological, and hydrological data for each watershed.		

TABLE A. 1

MASTER FILE RECORD LAYOUT

RECORD LENGTH 40 WORDS
RECORD REPRESENTS ONE SQUARE
ONE RECORD FOR EACH SQUARE IN AREA

WORD NO.	WORD	UNIT	REF. TO TABLE A.5.2.
1	I COLUMN		1/2
2	J ROW NUMBER		1/2
3			
4	IDENTIFICATION CODE (words 3–5)		1/2
5			
6	AREA OF SQUARE	SQ. KM.	
7	AREA OF SEA	SQ. KM.	
8	AREA OF LAKE	SQ. KM.	1/3
9	AREA OF FOREST	SQ. KM.	1/4
10	AREA OF SWAMP	SQ. KM.	1/5
11	AREA OF BURNT FOREST	SQ. KM.	1/6
12	AREA WITH THICK OVERBURDEN	SQ. KM.	1/9
13	AREA WITH MEDIUM OVERBURDEN	SQ. KM.	1/9
14	AREA WITH THIN OVERBURDEN	SQ. KM.	1/9
15	POPULATION 1951	10'S	1/15
16	POPULATION 1956	10'S	1/15
17	POPULATION 1961	10'S	1/15
18	POPULATION 1966	10'S	1/15
19	POPULATION 1971	10'S	0/60
20	POPULATION 1976	10'S	0/60
21	POPULATION 1981	10'S	0/60
22	ELEVATION SOUTH WEST CORNER	FT x 10	1/1
23	ELEVATION MID POINT SOUTH SIDE	FT x 10	1/1
24	ELEVATION MID POINT WEST SIDE	FT x 10	1/1
25	ELEVATION CENTRE	FT x 10	1/1
26	SHORTEST DISTANCE TO SEA	KM.	0/9
27	DISTANCE TO SEA IN SOUTH EAST DIRECTION	KM.	0/8
28	DISTANCE TO SEA IN SOUTH WEST DIRECTION	KM.	0/8
29	SLOPE	$(ft/ft \times 10^{-5})$	0/3
30	AZIMUTH OF SLOPE (FROM NORTH)	DEGREES	0/3
31	AVERAGE ELEVATION OF SQUARE	FT x 10	0/1
32	MEAN ANNUAL PRECIPITATION	INS $\times 10^{-2}$	0/38
33	LONG TERM AVERAGE TEMPERATURE	°F $\times 10^{-1}$	0/22
34	MEAN ANNUAL EVAPORATION	INS $\times 10^{-2}$	0/40
35	MEAN ANNUAL RUNOFF	INS $\times 10^{-2}$	0/36
36	COEFFICIENT OF OVERBURDEN		0/18
37	GROSS SURFACE POTENTIAL	KW.	0/45
38	AVERAGE SOUTH-EAST BARRIER HEIGHT	FT x 10	0/6
39	AVERAGE SOUTH-WEST BARRIER HEIGHT	FT x 10	
40			

TABLE A.2

RUNOFF FILE RECORD LAYOUT

RECORD LENGTH 32 WORDS
RECORD REPRESENTS ONE SQUARE
ONE RECORD FOR EACH SQUARE IN
EACH WATERSHED.

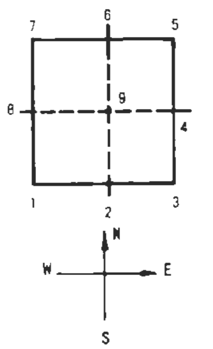
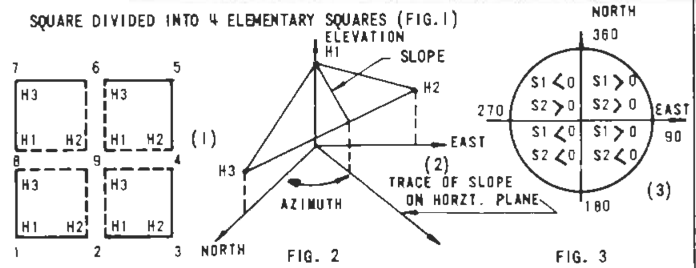
WORD NO.	WORD	UNIT	REF. TO TABLE A.5.2.
1	WATERSHED NUMBER		1/10
2	I (COLUMN ORDER)		1/2
3	J (ROW ORDER)		1/2
4			
5	IDENTIFICATION CODE (WORDS 4–6)		1/2
6			
7	AREA OF SQUARE IN WATERSHED	SQ. KM.	1/1
8			
9	WATERSHED WEIGHTING FACTOR		1/10
10	LONG TERM AVERAGE FLOW AT BASIN STATION	CFS	0/32
11	AREA OF FULL SQUARE	SQ. KM.	
12	AREA OF SEA	SQ. KM.	
13	AREA OF LAKE	SQ. KM.	1/3
14	AREA OF FOREST	SQ. KM.	1/5
15	AREA OF SWAMP	SQ. KM.	1/4
16	COEFFICIENT OF OVERBURDEN		0/18
17	ELEVATION AT CENTRAL POINT	FT x 10	1/1
18	SHORTEST DISTANCE TO SEA	KM.	0/9
19	DISTANCE TO SEA IN SOUTH-EAST DIRECTION	KM.	0/8
20	DISTANCE TO SEA IN SOUTH-WEST DIRECTION	KM.	0/8
21	SLOPE	(ft/ft x 10^{-5})	0/3
22	AZIMUTH OF SLOPE FROM NORTH	DEGREES	0/3
23	AVERAGE ELEVATION	FT x 10	0/1
24	MEAN ANNUAL PRECIPITATION	INS x 10^{-2}	0/22
25	LONG TERM AVERAGE TEMPERATURE	°F x 10^{-1}	0/22
26	MEAN ANNUAL EVAPORATION	INS. x 10^{-2}	0/25
27	BARRIER HEIGHT IN SOUTH-EAST DIRECTION	FT x 10	0/6
28	BARRIER HEIGHT IN SOUTH-WEST DIRECTION	FT x 10	
29	K*(PRECIPITATION - EVAPORATION)	INS x 10^{-2}	0/34
30	K* (RUNOFF)	INS x 10^{-2}	0/37
31	MEAN ANNUAL RUNOFF (FROM CORRELATION)	INS x 10^{-2}	0/36
32			

TABLE A. 3

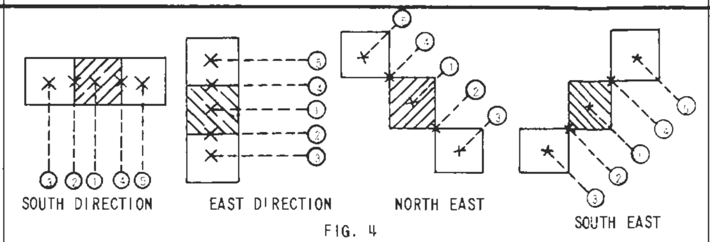
WATERSHED FILE RECORD LAYOUT

RECORD LENGTH: 53 WORDS
RECORD REPRESENTS ONE WATERSHED
ONE RECORD FOR EACH WATERSHED STUDIED.

WORD NO.	WORD	UNIT	REF. TO TABLE A.5.2.
1	WATERSHED NUMBER		1/10
2	WATERSHED WEIGHTING FACTOR		1/10
3	AREA OF WATERSHED	SQ. KM.	
4	AREA OF LAKE	SQ. KM.	0/12
5	AREA OF FOREST	SQ. KM.	0/14
6	AREA OF SWAMP	SQ. KM.	0/13
7	AVERAGE COEFFICIENT OF OVERBURDEN		0/18
8	AVERAGE SHORTEST DISTANCE TO SEA	KM.	0/10
9	AVERAGE DISTANCE TO SEA IN SOUTH EAST DIRECTION	KM.	0/10
10	AVERAGE DISTANCE TO SEA IN SOUTH WEST DIRECTION	KM.	0/10
11	AVERAGE SLOPE	(ft/ft x 10^{-5})	0/4
12	AVERAGE AZIMUTH OF SLOPE FROM NORTH	DEGREE	0/5
13	AVERAGE ELEVATION	FT x 10	0/1
14	AVERAGE BARRIER HEIGHT IN SOUTH DIRECTION	FT x 10	
15	LENGTH OF BASIN: L	MI.	1/14
16	LENGTH FROM CENTER OF GRAVITY TO MOUTH: Lc	MI.	1/14
17	$(L \times Lc)^{.3}$	MI.$^{.6}$	
18	SLOPE OF RIVER		
19	MEAN ANNUAL PRECIPITATION	INS x 10^{-2}	0/38
20	LONG TERM AVERAGE TEMPERATURE	F x 10^{-1}	0/22
21	MEAN ANNUAL EVAPORATION	INS x 10^{-2}	0/40
22	MEAN ANNUAL RUNOFF	INS x 10^{-2}	0/36
23	COEFF. OF VARIATION: AVERAGE ANNUAL FLOW		0/53
24	COEFF. OF VARIATION: SNOW MELT MAX. DAILY FLOW		0/53
25	COEFF. OF VARIATION: SNOWMELT MAX. MONTH. FLOW		0/53
26	COEFF. OF VARIATION: STORM MAX. DAILY FLOW		0/53
27	COEFF. OF VARIATION: STORM MAX. MONTHLY FLOW		0/53
28	COEFF. OF VARIATION: WINTER MIN. DAILY FLOW		0/53
29	COEFF. OF VARIATION: WINTER MIN. MONTHLY FLOW		0/53
30	COEFF. OF VARIATION: SUMMER MIN. DAILY FLOW		0/53
31	COEFF. OF VARIATION: SUMMER MIN. MONTHLY FLOW		0/53
32	COEFF. OF SKEW: AVERAGE ANNUAL FLOW		0/53
33	COEFF. OF SKEW: SNOW MELT MAX. DAILY FLOW		0/53
34	COEFF. OF SKEW: SNOW MELT MAX. MONTHLY FLOW		0/53
35	COEFF. OF SKEW: STORM MAX. DAILY FLOW		0/53
36	COEFF. OF SKEW: STORM MAX. MONTHLY FLOW		0/53
37	COEFF. OF SKEW: WINTER MINIMUM DAILY FLOW		0/53
38	COEFF. OF SKEW: SUMMER MINIMUM MONTHLY FLOW		0/53
39	COEFF. OF SKEW: SUMMER MINIMUM DAILY FLOW		0/53
40	COEFF. OF SKEW: SUMMER MINIMUM MONTHLY FLOW		0/53
41	FULL REGULATION STORAGE	CU.FT x 10^{10}	0/49
42			
52			
53			

INPUT	INPUT NUMBER	OUTPUT	PLOTTER	OUTPUT NUMBER	TERMS OF REF.	METHOD	NOTATION NOTE: O = OUTPUT I = INPUT
ELEVATION AT CORNERS, MIDPOINTS AND CENTER OF SQUARE (9 POINTS) AND LIST OF SQUARES INCLUDED IN EACH BASIN  (INPUT ENTERED BY FILE MAINTENANCE SYSTEM)	I	AVERAGE ELEVATION OF BASINS		1	PHASE B SEC I PAR 2	FOR EACH SQUARE: $H_j = \sum_{i=1}^{9} n_i/9$ ADBPD PROGRAM FOR EACH BASIN: $\bar{H} = \sum_{i=1}^{m} H_j * A_j / \sum_{i=1}^{m} A_j$ REPORT WRITING SYSTEM	H_j: AVERAGE ELEVATION OF SQUARE n_i: INPUT ELEVATION $\bar{H}$: AVERAGE ELEVATION OF BASIN A_j: AREA OF SQUARE IN BASIN
	I	HYPSOGRAPHIC DISTRIBUTION CURVE OF BASIN	YES	2	PHASE B SEC I PAR 2	$P_x = \frac{\sum(I_{h \geq x})}{\sum I} * 100$ REPORT WRITING SYSTEM N.B.: ALL 9 INPUT POINTS OF A SQUARE TAKEN IN COMPUTATION EVEN IF ONLY PART OF SQUARE BELONGS TO BASIN. NOT USABLE FOR DRAINAGE BASINS SMALLER THAN 200 SQ. MI.	P_x: PERCENT OF AREA WITH ELEVATION $\geq x$ $\sum(I_{h \geq x})$: NUMBER OF POINTS WITH ELEVATION $\geq x$ x : GIVEN ELEVATION I : NUMBER OF POINTS WITH KNOWN ELEVATION IN SQUARES BELONGING TO WATERSHED
	I	SLOPE IN EACH SQUARE AND SLOPE ORIENTATION (AZIMUTH OF SLOPE)		3	PHASE B SEC I PAR 2	SQUARE DIVIDED INTO 4 ELEMENTARY SQUARES (FIG. I)  FIG. I FIG. 2 FIG. 3 FOR EACH ELEMENTARY SQUARE: $S_i = \sqrt{\left(\frac{H1-H2}{\Delta L}\right)^2 + \left(\frac{H1-H3}{\Delta L}\right)^2}$ (FIG. 2) FOR EACH SQUARE $S = \sum_{i=1} (S_i/4)$ $A_z = TAN^{-1} \left(\sum_{i=1}^{4} \Delta H2_i / \sum_{i=1}^{4} \Delta H3_i\right)$ NOTE: THE AZIMUTH IS MEASURED FROM NORTH IN CLOCKWISE DIRECTION (0°-360°) BOTH SIGNS OF NUMERATOR AND DENOMINATOR SHOULD BE ANALYSED ACCORDING TO FIG. 3 TO ESTABLISH THE VALUE OF THE ANGLE. FOR HYDROLOGICAL CORRELATIONS THE AZIMUTH OF SLOPE VARIES FROM 0° TO 180° (IF $A_z > 180°$, $A_z' = 360 - A_z$ IS CONSIDERED) ADBPD PROGRAM	S_i: SLOPE OF ELEMENTARY SQUARE H1: ELEVATION OF SOUTH WEST POINT IN ELEMENTARY SQUARE H2: ELEVATION OF SOUTH EAST POINT IN ELEMENTARY SQUARE H3: ELEVATION OF NORTH WEST POINT IN ELEMENTARY SQUARE ΔL: HORIZONTAL DISTANCE H1 ⟷ H2 = H1 ⟷ H3 S: SLOPE OF GRID SQUARE $\Delta H2$: H1 - H2 $\Delta H3$: H1 - H3 A_z: AZIMUTH OF SLOPE MEASURED IN CLOCKWISE DIRECTION FROM NORTH (THROUGH 360°)
	I	AVERAGE SLOPE OF BASIN		4	PHASE B SEC I PAR 2	$\bar{S} = \sum S_i * A_i / \sum A_i$ REPORT WRITING SYSTEM	$\bar{S}$ = AVERAGE SLOPE OF BASIN (03) A_i = AREA OF SQUARE WITHIN WATERSHED
	I	AZIMUTH OF AVERAGE SLOPE OF BASIN		5	PHASE B SEC I PAR 2	$S1_i = \sin(A_{zi})$: $S2_i = \cos(A_{zi})$ REPORT WRITING SYSTEM $\bar{A}_z = TAN^{-1}\left[(\sum S1_i * S_i) / (\sum S2_i * S_i)\right]$ FOR VALUE OF AZIMUTH ANGLE SEE FIG. 3 AND NOTE IN OUTPUT NO. 3	A_{zi} = AZIMUTH OF S_i (03) S_i = SLOPE OF SQUARE INCLUDED IN BASIN $\bar{A}_z$ = AZIMUTH OF MEAN SLOPE OF BASIN (DEFINED LIKE A_{zi})
	I	BARRIER HEIGHT IN A GIVEN DIRECTION		6	PHASE B SEC I PAR 2	USING THE GRID ELEVATION DATA, THE BARRIER HEIGHT CAN BE DETERMINED ALONG THE NORTH, SOUTH, EAST, WEST, NE, SE, NW AND SW DIRECTIONS. THE PRINCIPLE IS SHOWN IN FIG. 4, WHERE THE B.H. IS SOUGHT FOR THE SHADED SQUARE.	

COMPUTER APPLICATIONS

INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
ELEVATIONS (CONTD)	1	BARRIER HEIGHT (CONTD)		6	PHASE B SEC. 1 PAR 2	 FIG. 4 FOR EACH GROUP OF FIVE LINES THE HIGHEST ELEVATION IS FOUND ALONG THE LINE BETWEEN THE SEA AND THE CORRESPONDING POINT X. THEN B.H. = $\frac{3H_1 + 2(H_2 + H_4) + H_3 + H_5}{9} - hg$ PROGRAM ADBHI	B.H. = WEIGHTED BARRIER HEIGHT OF SQUARE IN GIVEN DIRECTION Hi = HIGHEST ELEVATION ALONG LINE i IN DIRECTION SOUGHT hg = ELEVATION AT CENTER OF SQUARE FOR WHICH B.H. IS COMPUTED NEGATIVE B.H. IS EQUATED TO ZERO.
COORDINATE SYSTEM AND COORDINATES OF COASTAL SQUARES	2	DISTANCE TO SEA IN A GIVEN DIRECTION		8	PHASE B SEC. 1 PAR 2	8 DIRECTIONS CAN BE STUDIED (NORTH, SOUTH, EAST, WEST, NE, SE, NW, SW). THE METHOD CONSISTS OF COMPUTING THE NUMBER OF SQUARES FROM THE SEA TO THE CONSIDERED SQUARE BY MEANS OF THEIR COORDINATES. PROGRAM DIAG.	
	2	SHORTEST DIST TO SEA		9	PHASE B SEC. 1 PAR 2 (See Note)	FOR EACH SQUARE L MIN=MIN OF $L = \sqrt{(i_1 - i_2)^2 + (j_1 - j_2)^2}$ NOTE: FOR EACH SQUARE, DISTANCE TO ALL POINTS ON SHORE TO BE COMPARED TO GET MINIMUM DISTANCE	L = DISTANCE TO THE SEA i_1 = I COORDINATE OF CENTER OF SQUARE j_1 = J COORDINATE OF CENTER OF SQUARE i_2 = I COORDINATE OF POINT ON SHORE j_2 = J COORDINATE OF POINT ON SHORE
	2	AVERAGE DISTANCE TO SEA IN GIVEN DIRECTION OR SHORTEST DISTANCE FOR BASIN		10		$\bar{L} = \sum Li * Ai \ / \sum Ai$ WRITING SYSTEM	$\bar{L}$ = DISTANCE TO SEA FOR BASIN Li = DISTANCE TO SEA FOR ANY SQUARE IN BASIN (O 8 or O 9) Ai = AREA OF SQUARE WITHIN BASIN
	2	AVERAGE LONGITUDE AND LATITUDE OF BASIN: COORDINATES OF CENTER OF GRAVITY OF BASIN		11		$\bar{I} = \sum Ii * Ai \ / \sum Ai$ $\bar{J} = \sum Ji * Ai \ / \sum Ai$ KNOWING $\bar{I}, \bar{J}$ LATITUDE AND LONGITUDE OF CG OF BASIN CAN BE FOUND PROGRAM WSDCG	$\bar{I}, \bar{J}$ = COORDINATES OF CENTER OF GRAVITY OF BASIN Ii, Ji = COORDINATES OF CENTER OF SQUARE Ai = AREA OF SQUARE WITHIN BASIN

COMPUTER APPLICATIONS

INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
LAKE AREA IN EACH SQUARE	3	LAKE AREA IN EACH BASIN OR STUDY AREA		12	PHASE B SEC I PAR 2	$\bar{A}_L = \sum A_{L_i}$ REPORT WRITING SYSTEM	$\bar{A}_L$ = LAKE AREA IN BASIN A_{L_i} = LAKE AREA IN SQUARE i OF BASIN
MARSH AREA IN EACH SQUARE	4	MARSH AREA IN EACH BASIN OR STUDY AREA		13	PHASE B SEC I PAR 2	$\bar{A}_m = \sum A_{m_i}$ REPORT WRITING SYSTEM	$\bar{A}_m$ = MARSH AREA IN BASIN A_{m_i} = MARSH AREA IN SQUARE i OF BASIN
FOREST AREA IN EACH SQUARE TODAY	5	FOREST AREA IN EACH BASIN OR STUDY AREA		14	PHASE B SEC I PAR 2	$\bar{A}_t = \sum A_{t_i}$ REPORT WRITING SYSTEM	$\bar{A}_T$ = FOREST AREA IN BASIN A_{T_i} = FOREST AREA IN SQUARE OF BASIN
AREA AND RELATIVE DEPTH OF OVERBURDEN IN EACH SQUARE	9	AVERAGE INDEX OF OVERBURDEN IN EACH BASIN		18	PHASE B SEC I PAR 2	FOR EACH SQUARE: $I_{ov_i} = A_1 + 2A_2 + 3A_3$ FOR EACH BASIN: $\bar{I}_{ov} = \sum I_{ov_i} * A_i / \sum A_i$ FILE MAINTENANCE SYSTEM	I_{ov_i} = INDEX OF OVERBURDEN FOR A SQUARE A_1 = AREA OF THIN OVERBURDEN IN SQUARE A_2 = AREA OF MEDIUM OVERBURDEN IN SQUARE A_3 = AREA OF THICK OVERBURDEN IN SQUARE $\bar{I}_{ov}$ = INDEX OF OVERBURDEN IN BASIN A_i = AREA OF SQUARE IN BASIN

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COMPUTER APPLICATIONS

INPUT	INPUT NO.	OUTPUT
MEAN MONTHLY PRECIPITATION AND TEMPERATURE DATA AT THE METEOROLOGICAL STATIONS + FOLLOWING PHYSIOGRAPHIC CHARACTERISTICS AT STATION LOCATION OR APPURTENANT SQUARE. - LATITUDE (STATION) - DISTANCES TO SEA IN VARIOUS DIRECTIONS (STATION) - SLOPE (SQUARE) - AZIMUTH OF SLOPE (SQ.) - BARRIER HEIGHTS IN VARIOUS DIRECTIONS (SQ.) - ELEVATION OF STATION - AVERAGE ELEVATION OF SQUARE - PRECIPITATION WEIGHTING FACTOR ACCORDING TO PERIOD OF RECORD - TEMPERATURE WEIGHTING FACTOR ACCORDING TO PERIOD OF RECORD.	9	CHECK OF DATA
	9	COMPLETION OF MISSING DATA
	9	COMPUTATION OF MEAN ANNUAL PRECIPITATION AND AVERAGE TEMPERATURE AT GAUGING STATION
	9	PRELIMINARY CORRELATION OF MEAN ANNUAL PRECIPITATION AND TEMPERATURE TO PHYSIOGRAPHICAL CHARACTERISTICS OF STATION
	9	PRELIMINARY MAPS OF AVERAGE PRECIPITATION AND TEMPERATURE
	9	AVERAGE PRECIPITATION AND TEMPERATURE OF EACH BASIN
	9	PRELIMINARY ACTUAL EVAPORATION IN EACH SQUARE
	9	PRELIMINARY ACTUAL EVAPORATION MAP
	9	PRELIMINARY ACTUAL EVAPORATION OF EACH BASIN
	9	PRELIMINARY RUNOFF OF EACH BASIN
	9	PRELIMINARY RUNOFF IN EACH SQUARE

COMPUTER APPLICATIONS

TABLE A. 5
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INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
MEAN MONTHLY FLOWS AT GAUGING STATIONS OR FLOW REPORTING PLANTS FOR THE PERIOD OF RECORD. LIST OF SQUARES INCLUDED IN THE BASIN + FOLLOWING PHYSIOGRAPHIC DATA OF SQUARES INCLUDED IN THE BASIN - LATITUDE - DIST. TO SEA IN DIFFERENT DIRECTIONS - SLOPE - AZIMUTH OF SLOPE - BARRIER HEIGHT IN DIFFERENT DIRECTIONS - AVERAGE ELEVATION OF SQUARE - LAKE AREA - SWAMP AREA - FOREST AREA - COEFF. OF OVERBURDEN	10	CHECK OF DATA		30	PHASE B SEC. I PAR I	DOUBLE MASS CURVE TECHNIQUE	
	10	COMPLETION OF MISSING DATA	YES	31	PHASE B SEC. I PAR (b)	SELECTION OF BEST CORRELATION BETWEEN FLOWS AT TWO OR SEVERAL STATIONS - AND COMPLETION OF MISSING DATA	
	10	AVERAGE LONG TERM FLOWS AT GAUGING STATIONS		32	PHASE B SEC. I PAR (b)	$\bar{Q} = \sum_{j=1}^{n} \sum_{i=1}^{12} Q_{ij}/12n$ STANDARD PROGRAM	$\bar{Q}$ = LONG TERM AVERAGE FLOW AT STATION Q_{ij} = MONTHLY AVERAGE FLOW AT STATION n = NUMBER OF YEARS OF RECORD
	10	RATIO BETWEEN ACTUAL RUNOFF AND PRELIMINARY COMPUTED RUNOFF (K)		33	PHASE B SEC. I PAR (b)	$K = \bar{Q}/\bar{R} * \bar{A}$ PROGRAM RUNF I	$\bar{Q}$ = LONG TERM AVERAGE FLOW AT STATION (O 32) $\bar{R}$ = PRELIMINARY RUNOFF (O 28) $\bar{A}$ = AREA OF WATERSHED
	10	CORRECTED RUNOFF FOR EACH SQUARE IN WATERSHED		34	PHASE B SEC. I PAR (b)	$Rn_i = Ro_i * K$ PROGRAM RUNF I	Rn_i = CORRECTED RUNOFF FOR A SQUARE OF WATERSHED (O 29) Ro_i = PRELIMINARY RUNOFF FOR A SQUARE OF WATERSHED (O 29) K = OUTPUT 33
	9 AND 10	CORRECTION OF PRECIPITATION AND ITERATION OF CORRELATION BETWEEN PRECIPITATION AND PHYSIOGRAPHIC CHARACTERISTICS		35	PHASE B SEC. I PAR (b)	FOR EACH SQUARE OF EACH BASIN: $Pn_i = Rn_i + E_i$ THE CORRECTED PRECIP. OF EACH SQUARE AS WELL AS ACTUAL PRECIP. OF STATION ARE CORRELATED WITH PHYSIOGRAPHIC DATA (OUTPUT 1 TO 9) NOTE: OUTPUTS 22 TO 29 AND 33 TO 35 ARE REPEATED UNTIL K FACTORS (O/33) ARE AS CLOSE TO 1 AS INDICATED IN INITIAL CONDITIONS GIVEN IN THE PROGRAM	Pn_i = CORRECTED PRECIPITATION FOR A SQUARE Rn_i = CORRECTED RUNOFF FOR A SQUARE (O 34) E_i = PRELIMINARY EVAP. FOR A SQUARE (O 25)
	10	FINAL RUNOFF		36	PHASE B SEC. I PAR (b)	LAST CORRECTED RUNOFF (O 34) IS CORRELATED WITH PHYSIOGRAPHIC DATA (OUTPUT 1 TO 9, INPUTS 3, 4, 5 AND 9) FINAL RUNOFF PRODUCED FOR ALL SQUARES ON ISLAND	
		FINAL K		37		STEPS 33 & 34 PRODUCED WITH FINAL RUNOFF (O 36)	
	9	FINAL PRECIPITATION		38	PHASE B SEC. I PAR (b)	FINAL PRECIPITATION PRODUCED BY REPEATING STEP 35 ONCE COMPUTATION EXTENDED TO ALL GRID SQUARES - PROGRAM HYDRI	
	9	FINAL ACTUAL EVAPORATION COMPUTED USING TURC'S		39		STEP 25 REPEATED FOR EACH SQUARE ON ISLAND USING FINAL PREC. AND TEMP.	
	9 & 10	EVAPORATION COMPUTED FROM FINAL PRECIPITATION AND RUNOFF		40	PHASE B SEC. I PAR (a)	$Et_i = Pt_i - Rt_i$ PROGRAM HYDRI	Et_i = FINAL ACTUAL EVAPORATION IN SQUARE Pt_i = FINAL PRECIPITATION IN SQUARE (O 38) Rt_i = FINAL RUNOFF IN SQUARE (O 36)
	9 & 10	ROUGH PRELIMINARY ESTIMATE OF POSSIBLE INFILTRATION AND ACTUAL EVAPORATION CORRECTION	YES	41	PHASE B SEC. I PAR (a)	$In_i = Ec_i - Et_i$ REPORT WRITING SYSTEM (SEE O/23 FOR MAP EXPLANATION)	In_i = POSSIBLE INFILTRATION OR EVAPORATION CORRECTION IN EACH SQUARE Ec_i = EVAPORATION IN EACH SQUARE FROM OUTPUT 39 Et_i = EVAPORATION IN EACH SQUARE FROM OUTPUT 40

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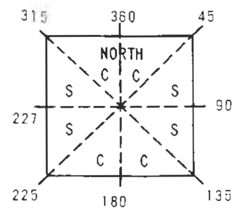
COMPUTER APPLICATIONS

INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
	9 & 10	AVERAGE ANNUAL RUNOFF MAP	YES	42	PHASE B SEC. I (B)	SEE OUTPUT 23	
		AVERAGE ANNUAL PRECIP. MAP	YES	43	PHASE B SEC. I (a)	SEE OUTPUT 23	
		AVERAGE ANNUAL EVAPORATION MAP	YES	44	PHASE B SEC. I (a)	SEE OUTPUT 25	
		AVERAGE GROSS SURFACE POTENTIAL IN EACH SQUARE	YES	45	PHASE A PAR. (u) V	$P_i = (S_i * L * R_i * A_i) / [2 * F(Az_i)]$ PROGRAM HYDRI 	Pi = GROSS SURFACE POTENTIAL IN SQUARE Si = SLOPE OF SQUARE (03) Ri = RUNOFF IN SQUARE (036) Ai = AREA OF LAND IN SQUARE (AREA OF SQUARE-AREA OF SEA) L = LENGTH OF SIDE OF SQUARE F(Azi) = FUNCTION OF AZIMUTH OF SQUARE EITHER F(Azi) = Sin (Az_i) OR COS (Az_i) DEPENDING ON OCTANT OF AZIMUTH (S OR C IN SKETCH)
	9 & 10	AVERAGE GROSS SURFACE POTENTIAL MAP	YES	46	PHASE A PAR (u)	SEE OUTPUT 2?	
AREA OF WATERSHED CONTAINED BETWEEN 2 POINTS ON RIVER FROM LIST OF SQUARES (IF AREA > 200 SQ. MI.)	11	AVERAGE DISCHARGE AT MAIN POINTS ALONG RIVER (WATERSHEDS > 200 SQ. MILES)	YES	47	INTROD. PAR 2	$Q_2 = Q_1 + \sum R_i * A_i$ REPORT WRITING SYSTEM	Q_1 = DISCHARGE AT PRECEDING RIVER BASIN OUTLET Q_2 = DISCHARGE AT POINT INVESTIGATED RIVER BASIN OUTLET Ai = AREA OF SQUARE (i) BELONGING TO PORTION OF WATERSHED BETWEEN POINTS (1 AND 2) Ri = RUNOFF OF SQUARE (i) (036)
PROFILE OR RIVER - DISCHARGE VARIATION ALONG RIVER (0/47)	12	GROSS HYDRO ELECTRIC POTENTIAL ALONG RIVERS (WATERSHEDS > 200 SQ. MILES)	YES	48	INTROD. PAR. 2 AND PHASE A PAR (u) V	$S = \frac{H1 - H2}{L1 - L2}$ (CONSTANT BETWEEN 2 ADJACENT PROFILE INPUT POINTS) $P = \int_0^L S * Q * dL$ REPORT WRITING SYSTEM	H1 - H2 = DIFFERENCE IN ELEVATION OF 2 GIVEN ADJACENT POINTS ALONG RIVER L1 - L2 = DISTANCE BETWEEN ABOVE POINTS S = SLOPE OF RIVER BETWEEN ABOVE POINTS Q = DISCHARGE AT GIVEN POINTS ALONG RIVER (047) L = LENGTH OF RIVER P = HYDROELECTRIC GROSS POTENTIAL
	10	VOLUME OF STORAGE REQ'D FOR DIFFERENT LEVELS OF REGULATION		49	PHASE B SEC. 3	MASS CURVE METHOD REPORT WRITING SYSTEM	
AVERAGE PHYSIOGRAPHIC CHARACTERISTICS OF BASIN	10	CORRELATION BETWEEN FULL REGULATION STORAGE VOLUME AND AVERAGE PHYSIOGRAPHIC CHARACTERISTICS OF BASIN		50	PHASE B SEC. 3	STANDARD MULTIPLE REGRESSION PROGRAM	

COMPUTER APPLICATIONS

INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
MEAN VALUES AND TIME SERIES AVAILABLE FOR THE FOLLOWING MAIN HYDROLOGIC CHARACTERISTICS (FOR EVERY YEAR DURING PERIOD OF RECORD) - AVERAGE ANNUAL FLOW - SNOWMELT MAX. FLOW - SEASONAL FLOW - MONTHLY FLOW - STORM MAXIMUM FLOW - WINTER MINIMUM FLOW - SUMMER MINIMUM FLOW - LISTING OF SQUARES CONTAINED IN THE BASINS ABOVE GAUGING STATIONS AND COMPUTATIONAL LOCATIONS	13	COMPLETION OF MISSING DATA AFTER SELECTION OF BEST CORRELATION	YES	51	PHASE B SEC. I PAR (b)	- STANDARD MULTIPLE REGRESSION PROGRAM	
	13	COEFFICIENT OF VARIATION COEFFICIENT OF MAIN HYDROLOGIC VARIABLES. AVERAGE LONG TERM VALUES OF INPUT		52		- STANDARD PROGRAMS	
	13	CORRELATION OF LONG TERM AVERAGE HYDROLOGIC CHARACTERISTICS OF BASINS AND COEFFICIENTS OF VARIATION AND SKEW TO THE BASIN CHARACTERISTICS		53		- STANDARD MULTIPLE REGRESSION PROGRAM	
	13	AVERAGE HYDROLOGIC CHARACTERISTICS COEFFICIENTS OF VARIATION AT COMPUTATIONAL LOCATIONS (BY BASINS)	YES	54		PHYSIOGRAPHIC CHARACTERISTICS AT COMPUTATIONAL POINTS, AND OUTPUT 53.	
	13	ANNUAL MAXIMUM FLOWS, SEASONAL FLOWS, MONTHLY FLOWS, SNOW MELT AND STORM FLOWS, AND MINIMUM FLOWS (SUMMER AND WINTER) WITH DIFFERENT PROBABILITIES AT COMPUTATIONAL LOCATIONS	YES	55		SAME METHOD AS FOR OUTPUT 54, PLUS PROBABILITY CURVE FITTING PROGRAMS (GUMBEL AND PEARSON TYPE III)	
UNIT HYDROGRAPH CHARACTERISTICS FOR DIFFERENT BASINS ① q_{max}, Lag_{tr}, T_{75}, T_{50}, T_{total}, C_1, C_p ② L, L_c ③ LISTINGS OF SQUARES CONTAINED IN THE BASINS ABOVE GAUGING STATIONS.	14	CORRELATION BETWEEN EACH OF ① AS DEPENDENT VARIABLES AND ② PLUS AVERAGE BASIN CHARACTERISTICS		56		STANDARD MULTIPLE REGRESSION PROGRAM	NOTATIONS FOR UNIT HYDROGRAPH AS IN THE STANDARD TEXT BOOKS
	14	UNIT HYDROGRAPH CHARACTERISTICS AT GAUGING STATIONS AND COMPUTATIONAL LOCATIONS	YES	57		SAME METHOD AS FOR OUTPUT 54	

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INPUT	INPUT NO.	OUTPUT	PLOTTER	OUTPUT NO.	TERMS OF REF.	METHOD	NOTATION
POPULATION BY TOWNS FOR AVAILABLE CENSUS YEARS 1951, 1956, 1961 1966	15	MAPS OF POPULATION DISTRIBUTION AT CENSUS YEAR (PER SQUARE)	YES	58	AGREEMENT WITH ADB	REPORT WRITING SYSTEM	
	15	POPULATION TRENDS BY SQUARE		59		THE FOUR POPULATION DATA FITTED BY LEAST SQUARES METHOD. (POPULATION VS YEAR). WEIGHTING FACTORS Wi APPLIED TO PAST YEARS	1951 1956 1961 1956 Wi = CENSUS WEIGHTING FACTOR 1 10 100 100
	15	PRELIMINARY ROUGH PROJECTION ESTIMATES OF POPULATION DISTRIBUTION OVER THE STUDY PERIOD	YES	60		STRAIGHT LINE EXTRAPOLATION OF OUTPUT 59 FOR YEARS 1971, 1976, 1981.	

COMPUTER APPLICATIONS

PART I - THE PULP AND PAPER INDUSTRY

1 INTRODUCTORY COMMENTS

For many decades the pulp and paper companies have formed one of Canada's largest and most significant industries. Today there are some 140 mills operated by 60 companies in nine of the ten Canadian provinces (Prince Edward Island is the lone exception). Their aggregate production now exceeds two billion dollars per year and in 1966 this was distributed as follows:

Quebec 37 percent, Ontario 24 percent, British Columbia 23 percent, Atlantic Provinces 14 percent, Prairie Provinces 2 percent.

The manufacture of paper from wood may be broken down into two very broad and distinct processes:

The manufacture of different pulps from wood or textile fibres.

The manufacture of a variety of papers from pulp.

1.1 Types of Pulp

The most common types of pulp manufactured today are: kraft (or alkaline sulphate); mechanical (including conventional groundwood and groundwood from chips); acid bisulphite; and semi-chemical (including the neutral sulphite). Limited quantities are also produced by the soda, cold soda, chemi-mechanical, and other processes. The various pulp types and processes are summarized in Table BI-1

Wood is unquestionably the major source of pulp, but limited quantities of pulp are also made from textile fibres such as flax, cotton, rag, and jute.

1.2 Types of Paper

Gehm [2] suggests grouping paper products into four general categories as follows:

a) Fine Papers - bond, book, mimeo, and other quality white papers.

b) Coarse Papers - newsprint, wrapping, container board, and building products.

c) Tissues - utility tissues, paper handkerchief.

d) Specialty Papers - photographic, monetary, electrical insulating, etc.

There are two newsprint mills currently operating in Newfoundland. The one at Corner Brook, Bowaters Newfoundland Limited, produces approximately 1200 tons per day of newsprint and 100 tons per day of sulphite pulp while the one at Grand Falls, Price (Newfoundland) Pulp and Paper Limited, produces about 800 tons per day of newsprint and about 30 tons per day of sulphite pulp. Figures BI-1, 2, 3, and 4 are included to show various processes used.

2 INDUSTRY TRENDS

For sometime most of the pulp produced in Canada was of the mechanical type; however, chemical pulps are now somewhat in the forefront and it would appear that their production will continue to increase at a faster rate in future. For example, it has been estimated that the production of pulp in Canada in 1967 will be made up of 54 percent chemical and 46 percent mechanical[3]; the comparable figures for 1966 were 52 percent chemical and 48 percent mechanical. This trend towards chemical pulping is much more pronounced in the United States where more than 80 percent is now produced by chemical means[4].

Probably the most significant development in the pulp and paper industry during the past two decades has been the spectacular growth of the kraft pulping process. By 1965, kraft pulp production in the United States amounted to some 20. 5 million tons or 61. 6 percent of the total output[5].

During the 1960's the kraft process enjoyed unprecendented growth in Canada and outstripped all other processes in terms of new construction; several large mills were constructed some existing ones were enlarged, and a few were converted to kraft from sulphite. The following is a partial list of new kraft mills constructed in Canada during the 1960's:

Mill Name and Location	Mill Capacity
Extension to Crown Zellerbach Elk Falls, B. C. (total cost 1952 to 1966 - $120 million)	900 tons/day (total)
Prince George Pulp & Paper Ltd. Prince George, B. C.	750 tons/day
Skeena Kraft Limited Prince Rupert, B. C. (total cost = $80 million)	750 tons/day
Domtar, Quevillon P. Q. (cost = $73 million)	750 tons/day
Northwood Mill, Prince George, B. C. (cost - $56 million)	625 tons/day
Bathurst Paper Limited New Richmond, P. Q.	600 tons/day
Great Lakes Pulp & Paper Company Fort William, Ont.	600 tons/day
Celgar Mill, Castlegar, B. C.	575 tons/day
Consolidated Paper Corporation, Portage Du Fort, P. Q.	500 tons/day

The production of groundwood remains an important industry in Canada largely because of the markets it has served on a long time basis (notably newsprint and tissue). It has not, however, enjoyed the spectacular growth in recent years that the kraft process has.

A number of authorities have described the sulphite process for pulp manufacture as a "dying industry". For example, in 1958 Janes[6] commented, "Only about three new sulphite mills have been built in the world in the past 10 or 15 years because of the wood species problem and the rise in versatility of kraft and semi-chemical pulps". In commenting on the Canadian scene, Rapson[7] stressed that several bleached sulphite mills have been converted to the kraft process but the same did not apply to unbleached sulphite mills. He went on to suggest that the following advantages are largely responsible for growth of the kraft process:

a) Almost any species of wood, hard or soft can be pulped by the kraft process.

b) Strong, high quality products result from kraft pulping.

c) Advances in bleaching technology have made it possible to bleach kraft pulps to virtually any degree of brightness with minimal loss in strength of fibre degradation.

d) The extensive recovery system inherent in the kraft process tends to minimize wastewater volumes and hence minimize stream pollution.

e) Pitch problems with resinous woods are almost non-existent.

f) Tall oil and turpentine are useful by-products.

In addition to the two existing mills established in the Province two new mills are being planned for the Island, a 600 tons/day newsprint mill to be located at Come By Chance and a 1000 tons/day linerboard mill to be located at Stephenville. It is expected that both may be in production by 1970 or soon thereafter.

3 WATER QUALITY REQUIREMENTS

3.1 General Discussion

At any particular pulp, paper, or integrated mill, the water quality requirements will vary appreciably with the process used, the nature of the raw water, and the finished product. Processes such as de-barking frequently utilize untreated water whereas paper making and bleaching require water of reasonably high quality.

The importance of water treatment facilities to some mills is well exemplified by the data from a relatively new (1960) mill in the Southern United States: [10]

Mill capacity	-	350 tons per day bleached kraft pulp and paper board
Capacity of water treatment plant	-	18 million imp gpd
Cost of water treatment plant	-	$1,745,000
Water requirements	-	51,500 gal.* per ton of product
Treatment sequence:	-	liquid alum dosing at 8-10 ppm
	-	hydrated lime feed
	-	flocculation
	-	sedimentation
	-	sand filtration
	-	chlorination at 3 to 4 ppm

* Wherever the term "gallon" is used in this part it implies the imperial gallon.

In contrast to the foregoing, many mills are located near large supplies of good quality raw water, in which case the water treatment facilities can be simpler and less costly.

For the manufacture of a few of the more common papers, TAPPI [9] has recommended the following tentative standards for process water:

Substance	Fine Paper	Bleached	Unbleached	Ground-wood Papers	Soda & Sulphate Pulp
Turbidity as SiO_2 Max mg/l	10	40	100	50	25
Colour in platinum units " "	5	25	100	30	5
Total hardness as $CaCO_3$ " "	100	100	200	200	100
Calcium hardness as $CaCO_3$ " "	50	-	-	-	50
Alkalinity to M. O. as $CaCO_3$ " "	75	75	150	150	75
Iron as Fe " "	0.1	0.2	1.0	0.3	0.1
Manganese as Mn " "	0.05	0.1	0.5	0.1	0.05
Residual chlorine as Cl_2 " "	2.0	-	-	-	-
Silica (soluble) as SiO_2 " "	20	50	100	50	20
Total disolved solids " "	200	300	500	500	250
Free carbon dioxode as CO_2 " "	10	10	10	10	10
Chlorides as Cl " "	-	200	200	75	75
Magnesium hardness as $CaCO_3$ " "	-	-	-	-	50

Except for the colour counts which are generally in the 20 - 40 range, the waters of Newfoundland are generally satisfactory for most pulping and paper making processes.

3.2 Dissolved Mineral Salts

Calcium and magnesium occur in most natural waters (especially in groundwaters) in association with bicarbonates, sulphates, and chlorides and determine the water's "hardness". Waters which are excessively hard will require treatment to avoid "build-up" of scale in mill equipment and boilers and to minimize alum consuming tendencies in sizing operations.

Sodium and potassium are frequently present in natural waters in association with chlorides, sulphates, nitrates, and other anions; but concentrations are generally low and cause few problems. If their concentration is excessive, the water can cause severe corrosion of plant equipment and foaming in boilers.

Iron and manganese in water are among the most troublesome minerals for the bleaching plant. If either is present to the extent of a few milligrams per litre, serious problems will arise in bleaching pulp to the desired brightness.

3.3 Turbidity and Colour

Turbidity in water is caused by a variety of suspended materials ranging in size from colloidal to coarse and may include both organic and inorganic subtances. Colour is usually caused by organic colloids. The amount of turbidity and colour which a mill can tolerate in its water will be dictated by the desired characteristics of the end-product and the degree of treatment allowed economically.

3.4 Dissolved Gases

Clean, unpolluted waters tend to be saturated or nearly saturated in dissolved oxygen; they may also contain dissolved carbon dioxide. In applications such as boiler feed waters, dissolved gases must be removed.

In summary, it should be emphasized that naturally occurring waters usually contain a variety of constituents that can adversely affect various pulp and paper processes.

4 WATER CONSUMPTION

4.1 General

With the exception of wood, water is probably the most important raw material of the pulp and paper industry as it is fundamental to such operations as pulping, washing, bleaching, and paper making. Less obviously perhaps but equally important, water serves the pulp and paper industry by transporting logs to mills, furnishing steam for power and process lines, generating hydro-electric power, carrying away wastes and by-products, and by protecting mills and forests from fire.

There are several fundamental processes in pulp and paper manufacturing mills which use vast quantities of water. Fortunately, recycle and reuse of a good deal of the process waters is possible and occurs to varying degrees in different mills. From mill site to mill site, water availability tends to vary considerably resulting in appreciable differences in water consumption per ton of product. For example, mills producing a single product such as groundwood pulp may use from 3000 to 9000 gallons per ton of product, whereas integrated pulp and paper mills producing several grades of paper may use from 20,000 to 1,000,000 gallons per ton of product, with the higher figure probably applying mainly to specialty papers.

From recent discussions with the chief engineers of two large Canadian pulp and paper companies, it would appear that the cost of water in most cases will have little statistical correlation with the quantity of water used in pulp and paper mills. Confirming this statement to a degree is a TAPPI [9] survey of over 100 mills in the USA which showed that the water costs varied from \$0.67 to \$100.00 per million gallons. The lower figure of \$0.67 is believed to cover the cost of chlorinating a water supply only while the higher figure probably covers the cost of purchasing municipal water or operating a water treatment plant at the mill site.

4.2 Recycle

The extent to which water is recycled and re-used in any particular mill varies widely. A small mill discharging into a large river with an unlimited supply of good quality fresh water may comply with stream pollution regulations by simply discharging an untreated effluent; in such a situation, water re-use would be nil. Alternatively, a mill relying on a limited water supply, will tend to conserve and re-use water at every opportunity. Mills located on tidal waters may use salt or brackish waters for cooling and discharge it after a single pass. Inland mills, on the other hand may utilize their cooling water for debarking or some other process.

The main sources of re-usable water are:

White water from paper machines, deckers and screens.

Condenser cooling water.

These waters may or may not be treated prior to re-use and are generally employed for stock dilution, paper machine showers, washing stock, blow pits, mechanical pulping, and debarking. Britt [19] has suggested that in a well-closed white water system, 85 percent of the water can be re-used with a resultant recovery of valuable fibres, chemicals, and heat.

A TAPPI survey [9] reports that certain integrated pulp and paper mills which rely on well water have found it possible to reduce water consumption to 5000 imperial gallons per ton of product by using white water exclusively in the groundwood mill, and only minor quantities of fresh water together with white water or cooling water in chemical pulp mills.

Unfortunately, the wide variation in recycle possibilities makes it extremely difficult, if not impossible, to indicate in general terms its effect on water consumption.

A 1959 survey [19] of 439 US mills representing over 78 percent of that country's output of pulp and paper products revealed that on an average, water was used 2.02 times before being discharged as effluent. (following its initial usage, water was re-used a further 1.02 times).

No major program of water recycling is practiced at the two existing Newfoundland mills at this time.

4.3 Water Quantities

Some reasonable ranges of fresh water consumption in pulp and paper mills as obtained from a number of sources, 2, 9, 11, 18, 19, are:

Type of Mill (or product)	Fresh Water Withdrawal (imperial gallon per ton of product)
Unbleached kraft pulp	12,000 - 33,000
Pulp mill producing bleached kraft pulp only	25,000 - 80,000
Paper mill producing kraft paper from imported pulp	2,000 - 8,500
Kraft pulp and paper mill (no bleachery) producing kraft papers and/or linerboard	14,000 - 42,000
Kraft pulp and paper mill (with bleachery) producing fine papers	40,000 - 100,000
Unbleached sulphite pulp	33,000 - 50,000
Pulp mill producing bleached sulphite pulp only	55,000 - 80,000
Sulphite pulp and paper mill (with bleachery) producing fine papers	60,000 - 100,000
Groundwood pulp	3,300 - 8,500
Integrated pulp and paper mill producing groundwood pulp, sulphite pulp and newsprint	20,000 - 45,000
Paper mill producing fine papers from imported pulp	16,000 - 40,000
Mill producing groundwood pulp and papers	10,000 - 40,000
Paper mill producing tissue from imported pulp	3,000 - 30,000
Pulp and paper mill (with bleachery) producing groundwood pulp sulphite, and fine papers	40,000 - 70,000
Pulp and paper mill (with bleachery) producing groundwood, kraft and sulphite pulps, and various paper products	70,000 - 100,000
Paperboard produced from imported pulp	1,500 - 12,000
Specialty papers produced from imported pulp (e.g. monetary or photographic papers)	15,000 - 80,000

It should be emphasized that the foregoing table represents approximate fresh water quantities used in the mills cited per ton of air dried finished product. (Air dried implies 10 percent moisture content). Almost 90 percent of these water quantities end up as wastewater effluents with balance being lost through evaporation or as moisture content in the finished product. Isolated cases of mills using more water than indicated by the table are cited in the literature. However, these are usually older mills or mills that have unlimited supplies of good quality fresh water available. The large modern mills are generally oriented towards water conservation and their water consumption tends to lie close to the lower end of the ranges in the table.

Bowaters mill in Newfoundland reports using approximately 33, 000 gallons of water per ton of newsprint produced while the Price mill reports using approximately 42, 000 gallons per ton of newsprint, so that in relation to the unbleached sulphite pulp figures for water consumption shown on the foregoing table, these figures are within the normal range.

5 WASTEWATER QUANTITIES

5. 1 General

Suspended solids and dissolved organic substances are the major stream pollutants present in pulp and paper mills' effluents. Mills with bleacheries also contribute acidic and alkaline wastewaters together with some inorganics. Often overlooked, but still significant at times, are the effects of cooling waters on the temperature of the receiving body of water.

The suspended solids present in pulp and paper mill effluents tend to settle to the bottom of the receiving body of water where they gradually decompose. During this period of decomposition, gases are given off, the dissolved oxygen resources of the receiving waters are taxed, and an unfavourable environment for aquatic life usually results.

Dissolved organic substances have a variety of adverse effects on receiving waters. For example, the biological oxidation of wood sugars can reduce levels of dissolved oxygen to a point where natural forms of aquatic life die off and slime organisms flourish; other organic pollutants such as lignins and tannins can discolour the receiving waters and create an unpleasant appearance aesthetically. Organics such as mercaptans and resin acid soaps in sufficient concentrations tend to be toxic to several forms of aquatic life.

Effluents from bleach plants usually consist of two distinct streams, one acidic and one alkaline. Blending of these streams usually results in an acidic effluent which should be neutralized prior to disposal.

Cooling waters in themselves may be devoid of polluting substances. However, in some instances, they may still act as pollutants by increasing the temperature of receiving waters and thereby retarding atmospheric reaeration. (Atmospheric oxygen being less soluble at elevated temperatures).

5.2 Effluent Volumes

The volumes of wastewater discharged by pulp and paper mills vary widely depending on such factors as:

The availability of water
Age of the mill
Degree of recycle and water re-use that is practiced
Process used and type of end-products
Nature of the mill, whether integrated pulp and paper, or pulp mill only, with or without bleachery works, etc.

Recent data on effluent volumes from pulp and paper processes as published by various authorities 2, 9, 11, indicate that the following ranges may be expected:

Process	Effluent Volume (Imp. gallons per ton of air dried product)
Pulp Manufacture	
Kraft and soda pulps	12,000 - 30,000
Sulphite pulp	33,000 - 50,000
Semichemical pulp	25,000 - 34,000
Groundwood pulp	3,300 - 8,500
De-inked pulp	17,000 - 30,000
Pulp Bleaching	
Kraft and soda pulp	13,000 - 50,000
Sulphite pulp	24,000 - 43,000
Neutral sulphite pulp	33,000 - 50,000
Paper Manufacture	
White papers from imported pulp	17,000 - 33,000
Tissue " " " "	1,000 - 30,000
Kraft " " " "	1,700 - 8,500
Paper board " " "	1,700 - 13,000
Specialty papers from " "	17,000 - 100,000

It should be emphasized that the foregoing figures are approximate wastewater quantities generated in various unit processes. Since the extent of recycle and water re-use varies widely from mill to mill, it would be erroneous to total figures from this table to compute wastewater quantities for an integrated complex consisting of pulp mill, bleachery, and paper mill. Wastewater volumes from an integrated complex would amount to some 90 percent of the water quantities shown in Section 4. 3 of this report.

Bowaters mill in Newfoundland discharges approximately 36 million imp gpd of wastewater (about 30, 000 gallons per ton of newsprint); and Price's mill discharges about 28 million imp gpd (about 35, 000 gallons per ton of newsprint).

5. 3 Waste Strengths

The average strength of various pulp and paper mill effluents has been investigated by Gehm[2], and the results are shown in the table below.

Effluent Loads from Pulp and Paper Manufacture

Effluent	Suspended Solids (lb/ton of product)	5-day BOD (lb/ton of Product)
Kraft and soda pulp	20 - 30	25 - 50
Groundwood pulp	40 - 80	15 - 25
Sulphite pulp (no liquor recovery)	20 - 40	400 - 600
Neutral sulphite semi-chemical pulp	100 - 180	250 - 450
Textile fibre pulps	300 - 500	200 - 300
Straw pulp	400 - 500	400 - 500
Bleaching	6 - 35	12 - 200
De-inked pulp	500 - 800	100 - 130
Fine papers:		
Tissue	50 - 100	15 - 30
Bond, mimeo, printing	50 - 100	20 - 40
Glassine	10 - 15	15 - 25
Coarse papers:		
Boxboard	50 - 70	20 - 40
Corrugating board	50 - 70	25 - 60
Kraft wrapping	15 - 25	5 - 15
Newsprint	20 - 60	10 - 20
Specialty papers:		
Fibre	200 - 300	140 - 170
Asbestos	300 - 400	20 - 40
Roofing felt	50 - 100	40 - 60
Insulating board	50 - 100	150 - 250

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Variations from the foregoing values may be expected from mill to mill depending on the type of wood being pulped, the season in which it was harvested, the cooking period, frequency of spills, etc..

Neither of the two Newfoundland mills treat their wastewaters at present and only limited data is available on the strength of these wastes. It is believed, however, that the suspended solids and BOD counts would be within the range listed above for sulphite pulp and newsprint and likely near the high end of the range.

In terms of the parameter BOD_5, waste sulphite liquor is perhaps the strongest individual waste generated at pulp mills. In undiluted form, this waste exerts a BOD_5 of between 16,000 and 25,000 mg/l[20]. Also, from 1700 to 3000 gallons of waste sulphite liquor is discharged for each ton of sulphite pulp produced[20].

5.4 Methods of Wastewater Treatment

Various chemical, physical, and biological processes have been employed in the treatment of pulp and paper mill effluents. Chlorination of water and neutralization of acidic bleachery wastes by adding an alkaline material are perhaps the most common types of chemical treatment employed at pulp and paper mills. Physical treatment involves such common phenomena as sedimentation, filtration, flotation, and centrifugation. Biological treatment is exemplified by the activated sludge process.

Most pulp and paper mill wastes are treated in one or two stages, with the initial one being termed "primary treatment" and the subsequent one being "secondary treatment". Occasionally the term "pre-treatment" is used to describe a form of treatment that precedes primary treatment. A coarse bar screen to remove large floating or suspended objects from a wastewater flow is an example of a pre-treatment device.

The main objective of primary treatment usually is to remove settleable suspended solids while in secondary treatment both dissolved and suspended solids are removed. (This generalization is reasonably applicable to the pulp and paper industry but should not be considered as entirely descriptive of all industrial wastes). Examples of primary treatment devices in the pulp and paper industry are:

Clarifiers (or sedimentation basins)
Filtration units such as vacuum filters
Centrifuges
Flotation towers

Examples of secondary treatment devices include:

Aeration tanks in combination with secondary clarifiers as in the case of the activated sludge process.
Trickling filters
Lagoons

Final disposal of treated wastes follows primary or secondary treatment; some common methods of final disposal are:

Discharge of partially purified water to a receiving river or lake.
Incineration of materials such as bark or waste sulphite liquor
Landfill burial of settled sludges
Deep well disposal of concentrated liquid wastes

Some of the more common treatment methods and devices are described briefly below:

5.4.1 Sedimentation Savealls

Sedimentation is a physical process in which the solid particles in a suspension are settled out by gravity yielding a clarified liquid and a more concentrated suspension. The clarified liquid may receive additional chemical treatment such as chlorination or biological treatment before being discharged to a receiving body of water, or it may be returned to the mill for some operation such as debarking. The concentrated suspension may be treated to achieve further dewatering or may be disposed of in a landfill scheme.

Continuous sedimentation is usually carried out in a quiescent basin such as a lagoon or an open concrete tank; the latter may be square, circular, or rectangular, and is equipped with scraper mechanisms to carry away the concentrations of suspended solids.

5.4.2 Vacuum Filter Savealls

Vacuum filters are slowly rotating drums whose outer surface is covered with a fine filtering medium. The drum is supported on a horizontal shaft and partially submerged in a vat of the suspension to be dewatered. The internal portion of the drum is maintained under sufficient vacuum at all times to pull water through the filter medium pores while leaving a partially dewatered mat of solids on the outer surface.

5.4.3 Flotation Savealls

Flotation savealls consist of two separate tanks. The first is a pressure vessel into which air and a suspension of solids in water are pumped; the pressure is sufficient to maintain the air in solution. From the pressure vessel, the suspension flows into a second tank under atmospheric pressure where the gases immediately come out of solution and form bubbles that carry the suspended solids to the tank surface; on reaching the liquid surface the solids are removed by a scraper blade operating much like a windshield wiper.

5.4.4 Lagoons

Possibly the most common form of lagoon (sometimes termed "conventional lagoon") consists of a shallow basin (usually 4 feet or less) excavated in the ground for the purpose of treating wastewaters under warm climatic conditions that favour the growth of algae. Organic waste matter is decomposed by bacteria and a high level of dissolved oxygen is maintained in the water through the photosynthetic activity of the algae. Given sufficient retention time, lagoons can achieve reductions in BOD in excess of 90 percent. In severe climates which prevail in many parts of Canada, conventional lagoons lose much of their effectiveness and may cause operational difficulties during the winter months. Advantages of conventional lagoons include: relatively low capital costs of construction, low operating costs, and simplicity of design. Disadvantages include: large areas of land are required (roughly 20 to 50 acres for each million gallons per day of effluent), and their effectiveness is dependent on warm climatic conditions.

Aerated lagoons are generally deep basins (10 to 15 foot depths are common) equipped with aeration equipment designed to maintain an aerobic environment for stabilizing organic wastes. As compared with conventional lagoons, they have the advantages of requiring much less land area (usually less than 10 percent of a conventional lagoon) and they are much more effective in treating wastes under severe winter conditions. Power costs associated with the aeration equipment make the operating costs for aerated lagoons almost double that of conventional ones.

Generally, lagoons are used as a form of secondary treatment at pulp and paper mills with many of the suspended solids having been previously removed by savealls.

5.4.5 Spray Irrigation

As the name implies, spray irrigation consists of land disposal of wastewater using irrigation techniques. A few U.S. mills have attempted to utilize this waste disposal method but most have been abandoned according to Bodenheimer [12]. The principal disadvantages of spray irrigation are:

Large areas of land are required (figures of 30 to 50 acres per million gallons per day depending on soil porosity are frequently quoted).

The method could pollute nearby lakes and rivers or groundwater during rainy weather when permeability is inadequate.

Power costs for the associated pumping are moderately high.

Nozzle clogging seems to be quite common and causes relatively high operating costs.

The method is unsatisfactory on frozen ground.

In pulp and paper mills, spray irrigation is usually used as a means of final disposal of an effluent which has at least undergone some form of primary treatment.

5.4.6 Deep Well Disposal

Deep well disposal involves the pumping of mill effluents to depths of 1500 feet or more through strong casings, and has been practiced to a limited extent. The operating and capital cost of such installations is very high and can only be undertaken after extensive subsurface explorations. Even with exploration, the possibility of groundwater contamination is not completely eliminated. Experience to date would seem to indicate that average wells can handle a maximum flow of one million gallons per day only, and their life is limited due to clogging with fibrous materials. For the large modern mills producing several millions of gallons of effluent daily, deep well disposal is not regarded as the answer for all disposal problems but rather a possible means of disposing limited volumes of concentrated or partially treated wastes.

5.4.7 Incineration

Incineration of certain mill effluents is practiced at a few sites. For example, the neutral sulphite semi-chemical pulp mill at Carthage, Indiana, has been incinerating its waste cooking liquor for over three years now and recovers chemicals in the process. The patented Container-Copeland Process consisting of a multiple effect evaporator and a fluidized bed incinerator is used at that mill and is reported to be highly successful [13].

For general mill effluents which are very dilute, the high fuel costs associated with converting large volumes of water to steam tend to make this disposal method impractical. With incineration too, there is a constant threat of air pollution by sulphur compounds present in mill effluents. So far as can be determined, this method has not been used for any other mill effluents apart from the aforementioned sulphite liquor application.

Generally speaking, incineration may be considered as a means of chemical recovery or a means of final disposal for material such as bark.

5.4.8 Trickling Filters

Trickling filters are widely used for treating domestic sewage and some industrial wastes, especially in the southern United States. However, their performance at pulp and paper mills has been rather disappointing so far. Essentially, they consist of a circular bed of boulders or other coarse filtering material (6 to 10 feet deep) over which waste effluent is sprayed by a rotating arm. A biological slime forms on the surface of the filter media which utilizes organic pollutants in the waste for growth and energy. By removing many organics from the waste, the slime organisms effect a degree of purification.

Although the capital and operating costs for trickling filters is quite high, space and land requirements tend to be minimal. Recent developments involving plastic filter media have shown considerable promise, and may result in a more widespread use of trickling filters at pulp and paper mills.

Trickling filters are used as a means of secondary treatment for wastes that have had some primary treatment.

5.4.9 Activated Sludge

The activated sludge process is one of the costlier but probably the most effective means of treating certain pulp and paper mill effluents. The land area required for such a system is minimal but a high degree of surveillance is needed. The process is biological in nature, employing micro-organisms to stabilize organic wastes in an aerobic environment. Phosphorus and nitrogen are added as nutrients, frequently in the form of ammonium phosphate. The process is normally preceded by some form of physical treatment such as screening, sedimentation, flotation, or vacuum filtration. The principal advantages of the activated sludge process are:

Its ability to effectively treat organic wastes under both summer and winter conditions.

Land area required is minimal when compared with lagoons.

Disadvantages include:

Capital expenditures needed to provide an activated sludge plant are very high, usually about 3 to 5 percent of the total mill cost.

Operating and maintenance costs are generally higher than the other systems mentioned.

Close surveillance and competent plant operators are required.

Reasonably large volumes of stabilized sludge are produced and have to be disposed of.

5.4.10 Neutralization

As mentioned previously, the blending of various streams from different bleaching stages generally results in a wastewater whose pH is in the acidic range. Solutions of lime (calcium hydroxide) are frequently employed for neutralizing such wastes prior to subjecting them to biological treatment for the removal of organics such as lignin and tannins. The lime used for neutralizing is relatively inexpensive but unfortunately the process produces sludge volumes which are moderately costly to dispose of. The sludge problem can be overcome by using alkaline material such as caustic soda or soda ash which give rise to highly soluble salts during the neutralization reaction. Unfortunately, these chemicals generally cost from five to ten times as much as lime.

In some instances, neutralization would be considered as a form of pre-treatment to be followed by primary treatment. Alternately, it could be a form of primary treatment in itself in some instances with secondary treatment following directly.

5.4.11 By-Product Production

At some sulphite mills, limited quantities of spent liquor are used in the manufacture of by-products such as lignin sulphonates, acetic and formic acid, torula yeast, and ethyl alcohol. Unfortunately, the market for these products is generally limited in comparison to the volumes of spent liquor produced. In Canada and the United States, the production of ethyl alcohol from sulphite liquor has not proved competitive with that produced from molasses and other fermentation processes and, consequently, it is manufactured at very few mills.

5.4.12 Costs of Wastewater Treatment

The cost of treating wastewaters from pulp and paper mills has been investigated by the Canadian Pulp and Paper Association and the Ontario Water Resources Commission. They report that for the new mills constructed in Canada during the 1960's the capital costs of wastewater treatment facilities vary from 3 to 5 percent of the total capital expenditure [14]. For example, a 700-ton per day pulp and paper mill costing $70 million to construct could expect to pay from $2,100,000 to $3,500,000 for wastewater treatment facilities.

A survey conducted from June to November 1966 covering 415 mills which account for 82 percent of the pulp and paper production in the United States revealed the following:

Mill Type	Capital Costs $/T.P.D*. Mill Capacity	Treatment Costs $/ton of Product
Kraft pulp & paper mills	$ 350- $2,500	$ 0.15 - $1.35
Sulphite pulp & paper mills	2,000- 5,000	0.80 - 1.50
Neutral sulphite semi-chemical pulp and paper mills	5,000	0.80
Mixed chemical pulp & paper mills	1,000- 2,000	0.20 - 0.90
Non-integrated paper mills	1,000- 2,500	0.40 - 0.90

* T. P. D. represents Tons Per Day (24 hr) of paper produced.

Costs of Various Treatment Methods *

Treatment Method	Capital Costs $/tons per day Mill Capacity	Treatment Costs $/ton of Product
Primary sedimentation in lagoons	500	0.25 - 0.30
Primary settling tanks with mechanical scrapers	1,000 - 1,500	0.45 - 0.75
Primary settling tanks, mechanical scrapers & dewatering facilities	1,500 - 1,750	0.55 - 1.30
Secondary treatment involving activated sludge process	5,000	2.45
Spray irrigation	2,000	N/A

* Blosser [15]

Effluent treatment facilities at the relatively new Prince George Pulp and Paper mill include lime neutralizing facilities and an activated sludge plant with mechanical aerators. Cost data for the first year of operation has been reported by Charles, et al[16] as follows:

Treatment Costs At Prince George Pulp & Paper -(Dollars per ton of product)

Chemical Costs	(Lime	$ 0.79
	(Nutrients	0.20
	(Seed	0.01
Power		0.06
Operating Labour Costs		0.10
Maintenance Costs		0.10
Technical Service Costs		0.16
		$ 1.42

With peak production of 750 tons per day at Prince George this implies a daily cost of wastewater treatment of $1,065.

At the new Kamloops mill opened late in 1965 (capacity 250 tons per day) waste treatment costs have amounted to approximately $550 per day [17] to date.

It is believed that both the Prince George and Kamloops figures will be reduced as the mill staff become more familiar with the new treatment plants.

The $1.42 figure noted above for treatment by the activated sludge process is substantially lower than the $2.45 mentioned by Blosser [15]. However, the higher figure is believed to include amortization costs whereas the lower one does not.

Treatment Costs Reported [12]

Activated sludge treatment including operating, maintenance and amortization costs	- $1.50 to 4.50 per ton of product (or $120 per million imperial gallons of effluent waste
Spray Irrigation	- About $60 per million imperial gallons of effluent
Lagoon Settling Basin including operating maintenance and amortization costs	- About $21 per million imperial gallons of effluent
Aerated Lagoon	- About $36 per million imperial gallons of effluent.

In summary, it may be stated that there is no universal and inexpensive treatment method for all pulp and paper mill wastes. Each mill must be treated as a separate entity and studied carefully before selecting the effluent treatment facility which is most suitable. Major factors which must be considered in such a study are:

The possibilities of water conservation through re-use and recycle of certain effluents.

The effluent volumes involved and their strength.

The nature and size of the body of water into which the effluent is to be discharged.

Requirements of the regulatory agencies.

Climatic conditions.

Many mills turn out two or more different products (newsprint and sulphite pulp are produced by the two existing Newfoundland mills); consequently, it is difficult to relate wastewater costs to the value of the products marketed. However, a review of the foregoing data suggests that wastewater treatment costs could vary between 0.5 and 4.0 percent of the value of the final product with perhaps 1 percent being about average.

6 STATISTICAL ANALYSES OF WATER USAGE IN THE PULP AND PAPER INDUSTRY

6.1 Introduction

A statistical processing of the data available from the 1964 U.S. Census on Industrial Water Use and from the Newfoundland and Labrador questionnaires has been undertaken for the purpose of establishing relationships between intake water and process water on one hand and water availability and industry characteristics on the other. Unfortunately, data on the cost of water were not available and the U.S. Census data are based on regionally averaged means which lump together plants of different types and sizes. Data are available for 13 U.S. regions as follows:

Region Number (Shown in Figures BI-4 to BI-7)	U.S. Census Region
1	New England
2	Delaware and Hudson
3	Chesapeake
4	Southeast
5	Tennessee
6	Ohio
7	Eastern Great Lakes
8	Upper Mississippi
9	Western Great Lakes
10	Lower Mississippi
11	Arkansas - Red and White
12	Pacific Northwest
13*	California

* In Figures BI-4, BI-5, and BI-7 which include Newfoundland, Region No. 14 is California, whereas No. 13 pertains to Newfoundland.

It is felt, however, that the characteristics of the mills in a region are not too dissimilar and that the individual figures do not have a very wide spread around their mean. It is therefore considered that for a preliminary exploration of the problem the results of this statistical processing are of some value. It is suggested that, since the results of these preliminary investigations are encouraging, further detailed studies in this field should be pursued by using individual data for all Atlantic Provinces and more detailed data from the U. S. Census Bureau, if these can be obtained. As already mentioned in Volume Three A, Section 2.1.6, indications obtained from these relationships can be useful for planning purposes, but under no circumstances could they be considered for estimating demand of specific mills in the design stages. This will have to be established in each case on the basis of the technologic, economic, and environmental conditions of the plant under consideration.

6.2 Notation

Throughout the study, the following notations have been used:

6.2.1 Independent Variables

X_1 Average value added per worker (in millions of dollars per worker) which is referred to in this discussion for brevity as productivity.

X_2 Size of plant first index expressed as value added per plant (in millions of dollars per plant).

X_3 Water availability in the area expressed as average runoff divided by population density (in inches per year per person per square mile).

X_4 Climatic conditions index represented by potential evaporation (in inches).

X_5 Size of plant second index expressed as number of workers per plant.

Note that X_1, X_2, and X_5 are not actually independent variables, since $X_2 = X_1 X_5$.

6.2.2 Dependent Variables

X_6 — Specific water intake all purposes expressed as ratio of intake water per value added (in billions of U.S. gallons per millions of dollars).

X_7 — Specific process water expressed as ratio of process water per value added (in billions of U.S. gallons per millions of dollars).

X_8 — Process water per establishment per year (in billions of U.S. gallons).

6.3 Specific Water Intake All Purposes

These correlations attempted to relate the dependent variable X_6 to the independent variables. When only the U.S. Census data were used, the computations resulted in a non-significant correlation (coefficient of correlation not significant at the 5 percent level). This is probably related to the fact that the water intake for all purposes includes cooling water for thermal plants included in the mill, and this is not sufficiently related to the independent variables. Nevertheless, it is considered interesting to indicate the shape of the correlation obtained:

$$X_6 = -30.2X_1 + 0.43X_3 + 1.0 \qquad \text{(Eq. 1)}$$

indicating that intake water for all purposes decreases with average productivity and increases with water availability.

When data for Newfoundland are added to the series, the correlation becomes significant at the 1 percent level (R = 0.835, compared to 0.694, the correlation coefficient significant at the 1 percent level).

The general shape of the correlation does not change too much from that previously obtained:

$$X_6 = -25.4X_1 + 0.21X_3 + 0.98 \qquad \text{(Eq. 2)}$$

indicating that productivity and water availability are significant factors in determining the intake water amount.

A comparison between recorded and computed (using Equation 2) intake water for specific all purposes water intake is shown in Figure BI-4.

6.4 Specific Process Water

These correlations attempted to relate the dependent variable X_7 to the independent variables.

When only U. S. Census data were used a correlation significant at the 5 percent level has been obtained (R = 0.623 compared to 0.608, the correlation coefficient significant at the 5 percent level).

The correlation equation obtained was:

$$X_7 = 0.55X_3 + 0.31 \qquad \text{(Eq. 3)}$$

indicating that the essential factor in the specific process water used is the availability of water.

When the data for Newfoundland were added, the coefficient of correlation improved significantly, mainly because the data introduced represents a point with much larger co-ordinates than the remaining group of data. The correlation obtained is significant at the 1 percent level (R = 0.895). The significant variable was the same as in the previous case but the slope of the correlation did change significantly, however:

$$X_7 = 0.30X_3 + 0.36 \qquad \text{(Eq. 4)}$$

A comparison between recorded and computed data for specific process water using Equation 4 is shown in Figure BI-5.

6.5 Process Water per Establishment

These correlations tried to relate the dependent variable X_8 to the independent variables.

When only U. S. Census data were used the correlation obtained proved to be very significant (R = 0.969 compared to 0.740, the correlation coefficient significant at the 1 percent level).

The correlation equation obtained was:

$$X_8 = -480.2X_1 + 1.0X_2 + 5.1X_3 + 0.07X_4 - 0.011X_5 + 4.2 \quad \text{(Eq. 5)}$$

which indicates a decrease with productivity and number of workers per plant, and an increase with the value added per plant, the water availability, and potential evaporation. The relation makes sense except for the decrease with the number of workers per plant, but the corresponding coefficient is low and the inconsistency is probably related to the high inter-correlation between the variables.

Figure BI-6 presents a comparison between actual and computed (using Equation 5) process water data. When data for Newfoundland are added, the correlation improves its statistical significance ($R = 0.987$) but this seems to be due mainly to the large co-ordinates of the added data. This resulted in the elimination of three of the independent variables, and in a correlation equation as follows:

$$X_8 = 4.609X_3 + 0.006X_5 - 0.859 \quad \text{(Eq. 6)}$$

indicating an increase of process water with water availability and the second size index (number of workers). It should be noted that the Newfoundland figure includes a large proportion of water used for wood handling.

A comparison of recorded and computed (using Equation 6) data on process water per establishment is shown in Figure BI-7.

Using averaged data available for two plants in Nova Scotia and two plants in New Brunswick, recorded average process water values were compared to those computed by using Equation 6. The results as shown on Figure BI-7 indicate a good agreement between the recorded and computed values.

Although the results of these computations have to be considered with caution since they are based on average lumped data, they can be used for a preliminary indication of the probable water use for planning purposes, especially when the technologic process of the mill is not sufficiently elaborated to allow more accurate estimates. Extrapolation outside the range on which the correlations are based is not recommended.

Since both Equations 5 and 6 yield comparable results where information on all 5 variables is available, it is felt that the use of Equation 5 should be preferred, especially for mills which do not use large amounts of water for wood handling. Otherwise, Equation 6 which required less information about the new mill gives an indication of the order of magnitude of the process water. A parallel computation of the specific intake water by Equation 2 and specific process water by Equation 4 might be helpful in establishing the possible demand and provide a means to cross-check the estimates.

It should be mentioned that attempts were made to process data statistically on other demand data such as specific and total gross water applied and water depleted. However, in most cases, the results were not significant, and in some cases, although the statistical significance was apparently high, the results were discarded because of apparent unreliability of the basic data. This applies especially to water depleted (consumed).

6.6 Conclusions on Statistical Analysis of Water Demand

a) The results of statistical processing of the available data on intake water for all purposes and process water are interesting and offer a possibility of roughly estimating water demand in cases when the technology is not sufficiently defined to allow more accurate computations. Such estimates are valid only for general planning purposes and should only be used within the limits of the data included in the sample.

b) These preliminary results, which are based on average lumped data, have to be considered only as preliminary indications that more informative correlations could be eventually obtained if more detailed data are made available. Consequently, it would be advisable to investigate the possibilities of obtaining more detailed data on individual mills (including cost of water and effluent charges, technology used, type and characteristics of output) to derive more meaningful results.

7 SUMMARY AND CONCLUSIONS

a) Several surveys dealing with water usage in pulp and paper mills have shown that water intakes per ton of product vary widely, even at mills turning out similar products. A major reason for this lack of uniformity in water intake is the variation in recycle and re-use of water that is practised at different mills; some practise little or no water re-use while others practise extensive re-use (especially in water-scarce areas).

b) Depending on the end product, anywhere from 5000 to 100, 000 gallons per ton of products may be used at a pulp and paper mill. The lower figure might apply to an end product such as kraft pulp while the higher one might apply to special photographic or monetary papers.

c) Wastewater volumes are generally about 10 percent less than water intake, the difference being water lost through evaporation or water incorporated into the final product.

d) In most instances, nominal increases (10 to 25 percent) in water costs are not expected to have any statistical effect on water intake by pulp and paper mill complexes. The principal reason for this conclusion is the literature reference cited that indicated current water costs for pulp and paper mills vary between 67 cents and $100 per million gallons.

e) Increasingly stringent pollution control legislation is tending to reduce water intake per unit of production at pulp and paper mills, and this trend is expected to continue. Before the end of the study period, it is believed that some existing mills will be using about one-half the volume of water used at present and eventually paper making in new mills could become an essentially "dry process" or one requiring minimal water. (It may be pertinent to mention that a dry paper making process was recently patented in Scandinavia.)

f) Because of technological changes in process, complete information on quality was not available at the two Newfoundland mills. Further investigation of an on-site nature with regard to these mills is recommended.

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The Shawinigan Engineering Company Limited
James F. MacLaren Limited

SIMPLIFIED FLOW DIAGRAM FOR NEUTRAL SULPHITE SEMI-CHEMICAL PULPING PROCESS

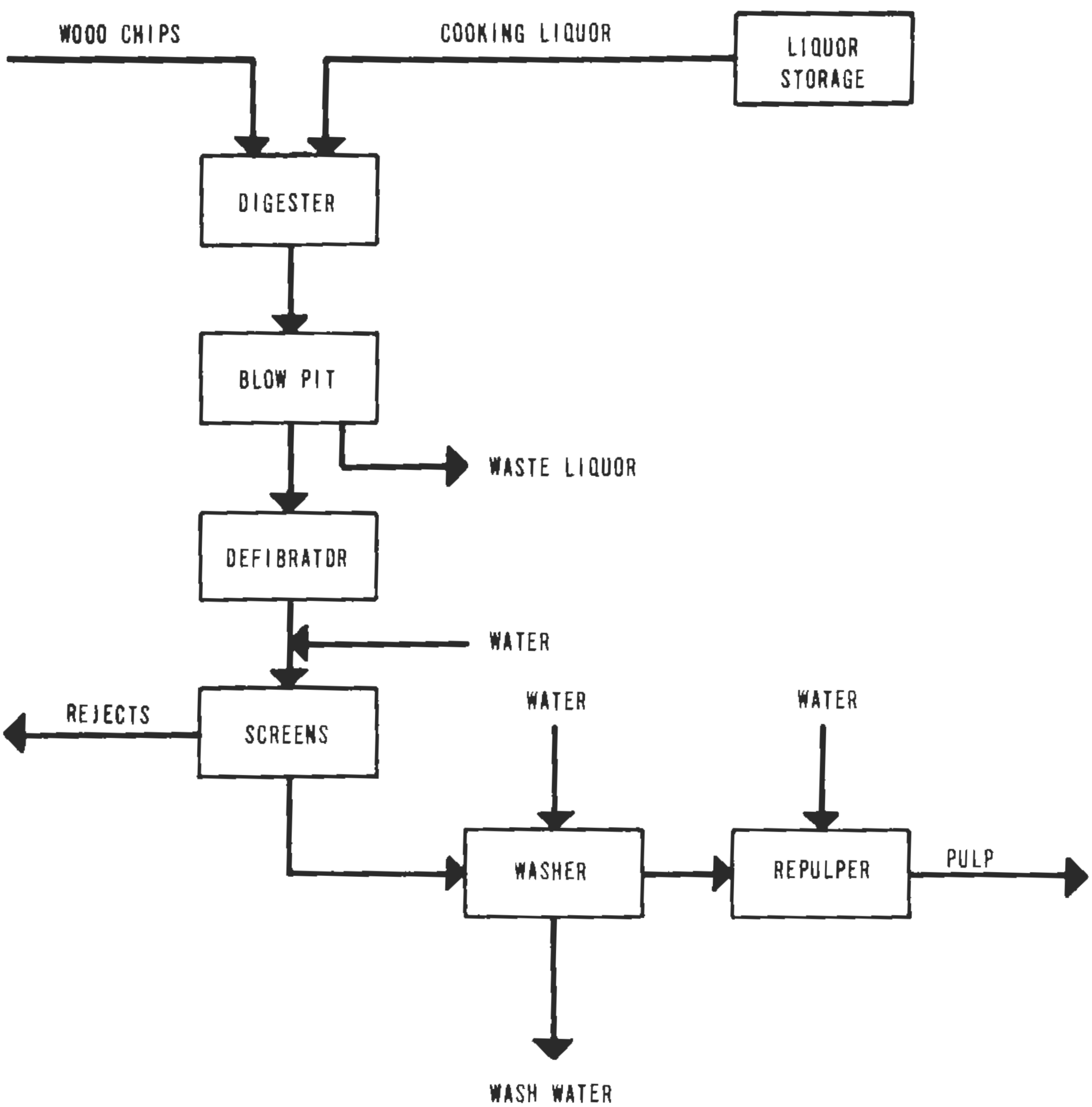


FIGURE B.I.-3

ACTUAL VERSUS PREDICTED (BY CORRELATION) WATER INTAKE ALL PURPOSES PER VALUE ADDED INCLUDING NEWFOUNDLAND DATA

	ACTUAL	PREDICTED	DEVIATION
1	0.59000	0.66663	-0.07663
2	0.77300	0.63179	0.14120
3	0.67300	0.66230	0.01069
4	0.89900	0.58687	0.31212
5	0.62100	0.64686	-0.02586
6	0.29300	0.58933	-0.29633
7	0.72500	0.68188	0.04311
8	0.60100	0.69033	-0.08933
9	0.64400	0.58850	0.05549
10	0.31600	0.41187	-0.09587
11	0.55900	0.65159	-0.09259
12	0.87100	0.71824	0.15275
13	1.43000	1.45982	-0.02982
14	0.41200	0.42092	-0.00892

INDEPENDENT VARIABLES

X-1 VALUE ADDED/NO.OFWORKERS

X-2 VALUE ADDED/NO.OF EST.

X-3 AVERAGE RUNOFF/UNIT POPULATION

X-4 AVERAGE EVAPORATION

X-5 NO.OF WORKERS/NO.OF EST.

DEP.VAR.X-6 WATER INTAKE ALLPURPOSE/VALUE ADDED

COEFFICIENT OF CORRELATION R=0.8355

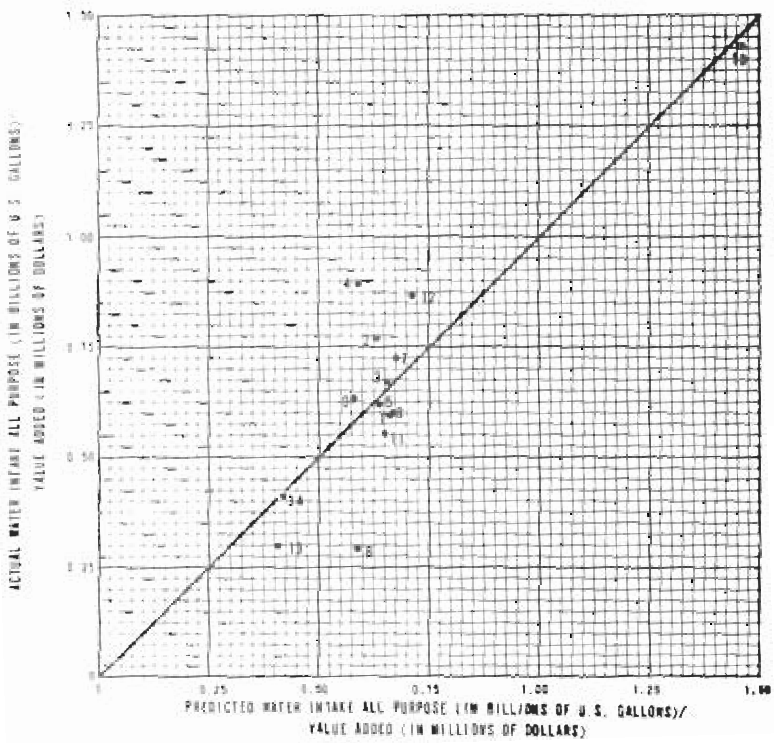


FIGURE B.1-4

ACTUAL VERSUS PREDICTED (BY CORRELATION) PROCESS WATER PER VALUE ADDED INCLUDING NEWFOUNDLAND DATA

	ACTUAL	PREDICTED	DEVIATION
1	0.46000	0.38538	0.07461
2	0.35900	0.37154	-0.01254
3	0.32700	0.37906	-0.05206
4	0.49100	0.41697	0.07402
5	0.36900	0.43051	-0.06151
6	0.14300	0.38358	-0.24058
7	0.47100	0.37064	0.10035
8	0.39900	0.38298	0.01601
9	0.33500	0.38237	-0.04737
10	0.66700	0.45759	0.20940
11	0.52900	0.40042	0.12857
12	0.73700	0.60861	0.12838
13	1.43000	1.46845	-0.03845
14	0.11800	0.39681	-0.27881

INDEPENDENT VARIABLES

X-1 VALUE ADDED/NO.OFWORKERS

X-2 VALUE ADDED/NO.OF EST.

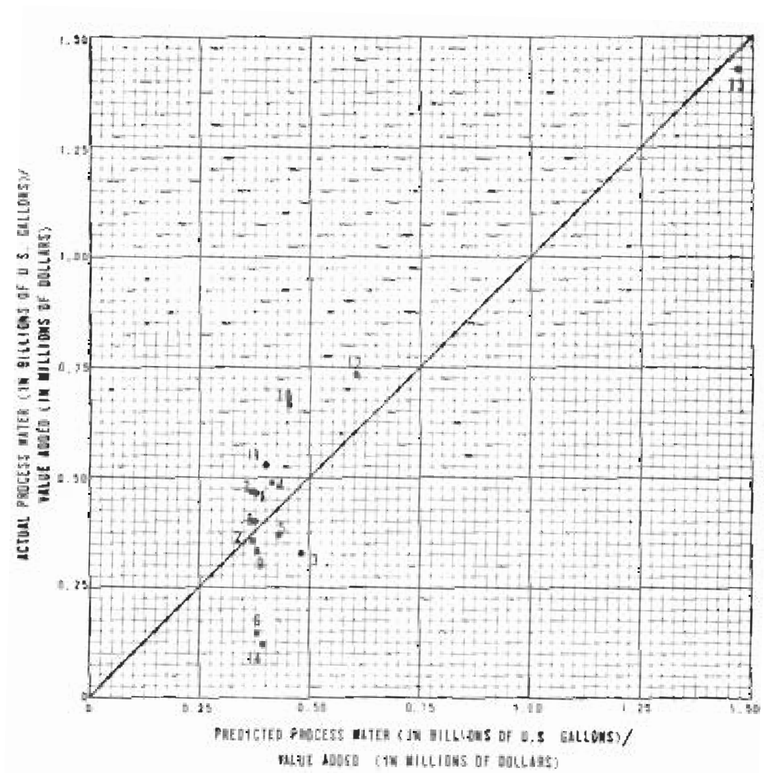
X-3 AVERAGE RUNOFF/UNIT POPULATION

X-4 AVERAGE EVAPORATION

X-5 NO.OF WORKERS/NO.OF EST.

DEP.VAR.X-6 PROCESS WATER/VALUE ADDED

COEFFICIENT OF CORRELATION R=0.8948



ACTUAL VERSUS PREDICTED (BY CORRELATION) PROCESS WATER PER ESTABLISHMENT

	ACTUAL	PREDICTED	DEVIATION
1	2.11100	1.40802	0.70298
2	1.71100	2.03853	-0.32753
3	2.64300	3.02706	-0.38406
4	9.75000	9.17677	0.57323
5	9.50000	9.77599	-0.27599
6	1.05600	2.81589	-1.75989
7	2.18200	1.81378	0.36822
8	2.90500	2.78287	0.12213
9	1.64100	1.12436	0.51664
10	2.00000	2.00149	-0.00149
11	7.20000	7.00558	0.19441
12	7.61100	7.69027	-0.07927
13	0.40000	0.11927	0.28073

INDEPENDENT VARIABLES

X-1 VALUE ADDED/NO.OFWORKERS

X-2 VALUE ADDED/NO.OF EST.

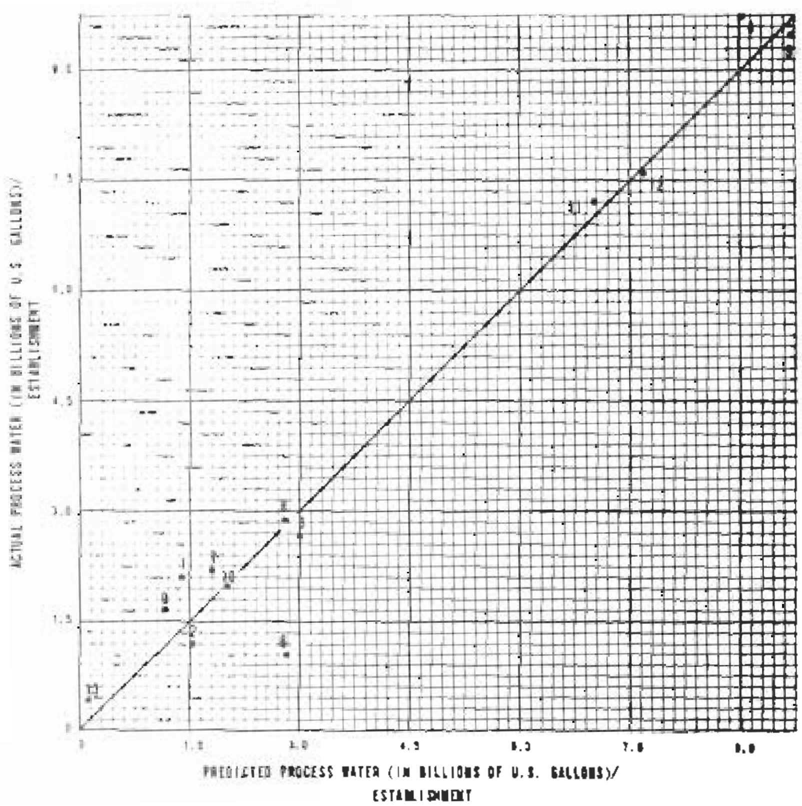
X-3 AVERAGE RUNOFF/UNIT POPULATION

X-4 AVERAGE EVAPORATION

X-5 NO.OF WORKERS/NO.OF EST.

DEP.VAR.X-8 PROCESS WATER/ESTABLISHMENT

COEFFICIENT OF CORRELATION R=0.9693



ACTUAL VERSUS PREDICTED (BY CORRELATION) PROCESS WATER PER ESTABLISHMENT PER VALUE ADDED INCLUDING NEWFOUNDLAND DATA

	ACTUAL	PREDICTED	DEVIATION
1	2.11100	1.87406	0.23693
2	1.21100	0.96241	0.24858
3	2.64300	3.36301	-0.72001
4	9.75000	7.34061	2.40938
5	9.50000	11.10230	-1.60229
6	1.05600	2.50828	-1.45228
7	2.18200	1.89850	0.28349
8	2.90500	3.34955	-0.44455
9	1.64100	1.55006	0.09093
10	2.00000	2.34261	-0.34261
11	7.20000	6.24251	0.95748
12	7.61100	6.79495	0.81604
13	26.20000	26.35908	-0.15908
14	0.40000	0.72200	-0.32200

INDEPENDENT VARIABLES

X-1 VALUE ADDED/NO.OFWORKERS

X-2 VALUE ADDED/NO.OF EST.

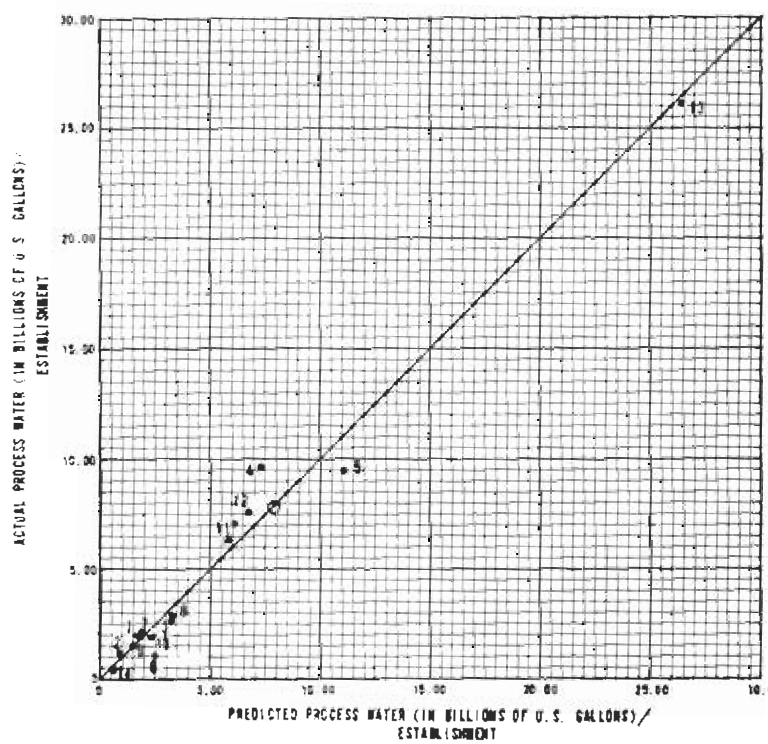
X-3 AVERAGE RUNOFF/UNIT POPULATION

X-4 AVERAGE EVAPORATION

X-5 NO.OF WORKERS/NO.OF EST.

DEP.VAR.X-8 PROCESS WATER/ESTABLISHMENT

COEFFICIENT OF CORRELATION R=0.9868



* PLOT OF AVERAGE RECORDED AND COMPUTED VALUES OF PROCESS WATER FOR PLANTS IN NOVA SCOTIA
○ PLOT OF AVERAGE RECORDED AND COMPUTED VALUES OF PROCESS WATER FOR PLANTS IN NEW BRUNSWICK

FIGURE B.1-7

PULP AND PAPER INDUSTRY
PULP TYPES AND PROCESSES

Type of Pulp	Process	General Comments
CHEMICAL	- Acid Bisulphite (often termed "sulphite") - Alkaline (includes kraft and soda processes)	Chemical pulping involves the use of chemical solutions to free cellulose fibres (pulp) from the other constituents of the wood. Pulp yields are in the 40% - 55% range usually.
SEMI-CHEMICAL	- High Yield Chemical (these processes are slight modifications of the kraft and sulphite processes) - Cold Caustic Semi-chemical - Neutral Sulphite Semi-chemical (often abbreviated "N. S. S. C.")	Semi-chemical pulping relies on a moderate chemical treatment together with some mechanical attrition to free cellulose fibres. Yields are usually in the 65% to 85% range.
CHEMI-MECHANICAL	- Cold Caustic - Chemi Groundwood	Chemi-mechanical pulping relies on mechanical attrition together with a very mild chemical treatment to free cellulose fibres. Yields are usually in the 85% to 95% range.
MECHANICAL	- Mechanical Attrition with Heat and Pressure - Mechanical Attrition	Mechanical pulp (usually called "groundwood") is produced by a grinding action on logs or wood chips. No chemicals are used and yields generally exceed 92%.

PART II - THE FISH PROCESSING INDUSTRY

1 INTRODUCTORY COMMENTS

In 1967, Canada exported a record $235,500,000 worth of fish products, with an estimated 70 percent going to the United States [1,2]. This volume of business represented an increase of $16,400,000 over the previous year and placed Canada second in the world to Japan among fish-exporting nations.

The Province's contribution to the Canadian total is reported to be 25 percent of the fish tonnage landed, but only about 15 percent in terms of dollar value[3]. The principal fish taken by Newfoundland fishermen are listed below in the same groupings as used by the Dominion Bureau of Statistics:

Category	Species of Fish Included
Groundfish	Cod, halibut, haddock, plaice and greysole, redfish (ocean perch), catfish, pollock, turbot
Pelagic and Estuarial	Herring, tuna, salmon, smelts, mackerel, capelin
Molluscs and Crustaceans (shellfish)	Scallops, squid, mussels, crab, lobster

Of the species listed, cod is by far the most important, accounting for almost two-thirds of the total tonnage taken[4].

Water plays a very vital role in the processing of fish products, and accordingly, the objectives of this section will be:

a) To investigate water usage in the existing fish processing plants of Newfoundland.

b) To report on industry trends and the water requirements of future fish processing plants.

2 METHOD OF STUDY

Data for this report were obtained from four principal sources:

a) Questionnaires sent to all known fish processing plants in Newfoundland.

b) A review of several engineering reports dealing with proposed water supply systems for Newfoundland communities with fish plants.

c) Discussions with officials of the Federal and Provincial Departments of Fisheries.

d) A review of pertinent technical literature.

e) Draft report by Montreal Engineering Company, Limited on the use of water in the fish processing industry.

In general, it was found that very little useful data on water intake were available for the fishing industry as a whole, and, in Newfoundland, data seemed to be particularly scarce. A statistical analysis was attempted in order to obtain a relationship between specific water use and various technical and economic indices.

3 FISH PROCESSING IN NEWFOUNDLAND

Several methods of processing fish are practised in Newfoundland, all of which require water, be it for fish washing, domestic purposes, boiler water, waste disposal, or some other purpose. Only those methods of principal economic importance, including the production of frozen and fresh fillets, salt fish and fish meal, will be discussed here. Typical flow diagrams, showing points of water use and waste production relative to the major operations involved, are presented in Figures BII-1, 2 and 3.

Uses of water for compressors, condensors, boilers, domestic demand and fire protection are not shown, but they do represent an appreciable portion of the total water requirements. One industry spokesman representing a large frozen fish products plant estimates that the water required for these purposes varies from 5 to 10 percent of their total intake[5].

3.1 Fish Processing at Sea

The majority of the fish caught by Newfoundland fishermen are brought ashore guts-in and with heads on (as distinct from gutting which implies cleaning out and washing of the belly cavity, taking special care to remove the entire liver).

3.2 Fresh Fish Plants

Fresh fish plants usually process fish from the small inshore boats. At these plants, fish may or may not be scaled, depending on whether the fish is of the scaly variety and whether it is to be sold skin-on or skin-off. The washing may be carried out in a rotary-type machine, but more often with rather primitive equipment. Such plants produce fish for local sale or may sell fillets on a "feeder" basis to a large establishment producing frozen fish products.

The brine or phosphate dips to lessen thaw drip are seldom used and ice-making equipment is similarly rare. In general, each small fresh fish plant processes about one million pounds of landed fish per year in a seasonal operation that employs a minimum of equipment. The Canada Department of Fisheries reports that there are eight fresh fish processing plants in Newfoundland at present.

3.3 Frozen Fish Production (Figure BII-2)

For purposes of this discussion, frozen fish processing plants will be categorized as follows:

a) Small Plant - A plant processing up to one million pounds of landed fish per year.

b) Intermediate Plant - A plant processing from one to six million pounds of landed fish per year.

c) Large Plant - A plant processing over six million pounds of landed fish per year.

The flow diagram shown in Figure BII-2 is typical for an intermediate plant. The diagram for a small plant is similar except that machine filleting and skinning would not apply. For a large plant, the diagram would include several machine and hand filleting lines as well as facilities for unloading several vessels simultaneously.

Only a few plants are currently capable of maintaining low temperature storage areas at -15 deg F as shown on Figure BII-2. However, this is now a Fisheries regulation and storages will be modified to conform over the next few years[14].

Filleting wastes from small plants may be disposed of by land burial or by dumping into the sea. Intermediate plants often have their own fish meal plants for processing filleting wastes or they may truck their offal to a larger plant if one is conveniently located. All large plants operate their own fish meal plants.

Fish of suitable size may be machine-filleted, and those which are too small, too large or too soft for the machines are hand-filleted.

The Economics Branch of the Canada Department of Fisheries advises that there are thirty-two frozen fish processing plants in Newfoundland at present, twenty large ones, seven of intermediate size, and five small ones according to the definition established in this sub-section.

3.4 Salt Fish Production

Figure BII-3 shows a typical flow diagram for a salt fish processing plant. There are twenty-six such plants in Newfoundland at present, with the five largest being capable of handling over five million pounds per year of wet-salted fish. Processing here does not include the stage from fresh to wet salted which is normally done by fishermen.

Washing at salt fish plants is carried out by mechanical equipment utilizing both brushes and water sprays, after which "water horsing" takes place (this is a waiting period rather than a processing step, in which fish are piled to a height of about 3 or 4 feet to allow surface water to drain off and to smooth and minimize surface irregularities).

4 INDUSTRY TRENDS

From the point of view of water supply for the fish processing plants, the most important trend envisioned by officials in the industry would seem to be a gradual closing down of all existing small and intermediate-sized plants. In their place, a lesser number of large, modern, and mechanized complexes will be built. At present, there are over sixty fish processing plants in Newfoundland and one industry spokesman[5] has predicted that this number will be less than ten by 1985. Reasons cited for this prediction include:

a) The small fish plants with a minimal of processing equipment are finding it increasingly difficult to compete with large modern and more efficient plants.

b) Many of the small and intermediate-sized plants are able to offer seasonal employment only. As a result of this, they are finding it increasingly difficult to compete on the labour market with establishments that can offer full-time employment.

c) Increasingly stringent legislation covering such matters as low-temperature storage of fish products presents some establishments with capital expenditures which they cannot afford.

d) A large percentage of Newfoundland fish plants are located on polluted bays or inlets with the water near shore being unsuitable for fish processing. When unpolluted sea water is not available near shore, fish plants are forced to treat the water or build long water supply lines out to sea or inland in order to obtain water of suitable quality. The capital costs associated with water treatment plants or water supply lines is generally beyond the financial capabilities of the small and intermediate-sized fish processing plants.

Provincial and Federal Fisheries officials have been similarly definitive in their outlook, and are essentially in agreement with the industry spokesmen. One official has commented that the fish processing industry's survival is dependent upon the establishment of large, versatile, and mechanized complexes having intake capacities of 100 million pounds of fish per year or more. Such complexes would operate on a continuous basis (or nearly so) and probably two to five of these complexes would be served by a fleet of perhaps 60 trawlers with one or two trawlers being unloaded at each complex each day. Such an arrangement would tend to ensure a continuous supply of fish for the plant, thereby promoting maximum plant efficiency with a minimum of shutdown periods. It is possible that future complexes might consist of more than one building situated around a bay or harbour rather than being under a single roof; one building might produce fresh and frozen fish products only, another salt cod, and others fish meal products, etc.

Using the water intake of the new Marystown plant as a guide, it is estimated that a modern complex handling 100 million pounds of landed fish per year would require approximately 2 million gpd of water.

With the advent of larger plants, increased harbour pollution may be expected unless steps are taken to combat this eventuality. Regardless of the steps taken, it would appear unlikely that the degree of treatment of municipal sewage and fish plant effluent achieved during the study period will be sufficient to ensure an adequate supply of unpolluted sea water at all times. Accordingly, it is believed that the process water needed for future fish processing plants will have to be met by fresh water supplies. Polluted sea water, if necessary, may be used for such purposes as cooling where bacteriological quality is not a major consideration. This matter will receive further attention in Section 7.

5 WATER QUALITY REQUIREMENTS

The principal uses of water in the fish processing industry are:

a) Fluming whole fish, fillets, offal, etc. from one point to another.

b) Continuous washing of fish during such operations as filleting and scaling.

c) Clean-up operations in boats, wharves, and processing plants.

d) Equipment requirements, including boiler feed water and cooling water for condensers, marine engines, etc.

e) Domestic uses, such as washrooms and locker rooms.

f) Production of ice.

g) Fire protection systems.

The production of fish protein concentrates (FPC) in Newfoundland, though not envisaged in the near future, may have a significant effect on the use of wastes and hence the quality of wastewater (see Section 7).

Fresh water, if available in sufficient quantity, may be used for all of the foregoing operations and is generally preferred over sea water since it is less corrosive to metals, piping and machinery[5]. It is of course mandatory that it be utilized for boiler feed water. Unfortunately, most of Newfoundland's fish processing plants are not situated near large fresh water sources and, consequently, they tend to use both fresh and saline water supplies. In many plants, over 90 percent of the total water requirements are met by sea water[6].

All water used directly in fish processing, whether fresh or saline, should conform to the following general requirements:

i) The water must be bacteriologically safe, i.e., free of harmful bacteria and other micro-organisms.

ii) The water must be chemically safe, i.e., free from toxic concentrations of chemicals.

iii) The water must be cool (preferably less than 65 deg F) and relatively free of turbidity.

5.1 Bacteriological Safety

The Canada Department of Fisheries has introduced regulations[7] to ensure that fish plant water supplies will not be a source of contamination to the plant's products. A portion of these regulations read as follows:

"12. (1) An adequate supply of safe, sanitary water having a most probable number of coliform bacteria of two or less per hundred millilitres, or water from a source approved by the Minister, under a minimum operating pressure of twenty pounds per square inch, shall be provided.

(2) Notwithstanding subsection (1), an establishment may use water other than water referred to in subsection (1) for fire protection, boilers or auxiliary services if there is no connection between the systems providing water to the establishment."

The Department's requirements will be satisfied when the source and supply of water are approved by the Fish Inspection Laboratory. Approval would be based on the general sanitary conditions of the area and the results of standard bacteriological analysis of water. In many instances, it will probably be found that the only available source is either contaminated or so located that it may be subject to contamination from time to time. In such instances, chlorination of the water supply is required. Grossly contaminated sources will not be approved.

These new Federal regulations have a twofold effect on fish processing methods, viz:

a) Where plants allow water to come into contact with fish or fish processing equipment more than once without ensuring that the water meets the required standard before each re-use, the re-use will have to stop or the water be treated to meet the quality required.

b) Plants whose water supply qualities do not meet the Federal regulations will have to introduce adequate water quality treatment equipment, use an alternative source of water supply which is satisfactory, or introduce methods or equipment which do not use water.

Process water supplies for fish plants are invariably disinfected, using aqueous or gaseous solutions of chlorine or other chlorine compounds. Chlorine dosages will vary depending on the method of applying it to the water and the chlorine demand of the water itself. However, the following guidelines are offered by the Federal Department of Fisheries[8]:

Water Use	Recommended Free Chlorine Residual
Fluming, filleting, gutting, etc.	8-12 ppm
Washing-down operations, plant clean-up, etc.	50 ppm
Fish hold sanitizing	150-200 ppm

5.2 Chemical Safety

Water for the processing of fish must be free of heavy metals and other chemical substances in concentrations which would endanger the consumer. In general, this means that water to be used in the processing of fish should not contain heavy metals or chemical substances in excess of those concentrations permitted in potable water by the Public Health Service Drinking Water Standards[9].

5.3 Physical Requirements

In order to preserve the quality of the fish during processing, the water used should be less than 65 deg F and relatively free of turbidity which may discolour the flesh. Water with a turbidity of less than 5 units is desirable for fish processing[9].

6 WATER INTAKE

The questionnaire survey[6] aimed at determining water usage in existing fish plants turned up very little useful data, largely because of the lack of adequate metering devices in the plants.

Attempts to estimate water usage on the basis of pump capacities were made in a few instances, but the reliability of such data is questionable since pump efficiencies and discharge pressures were not known, nor was it possible to determine them with any degree of accuracy in the time available.

Three of the questionnaires provided data showing water intakes that varied between 3.6 and 4.9 gallons* per pound of landed fish, while four others indicated much higher intakes in the region of 11 to 16 gallons per pound of landed fish. Explanations for these differences are not readily apparent, but output variables from plant to plant are believed to be the principal cause. For example, some plants produce only frozen fish products, others produce only salt fish products, and some produce both. Some plants flume offal and process it in an associated fish meal plant, while others neither flume it nor process it. Also, within the same plant there is not a linear relationship between water usage and tonnage of fish processed, because certain operations, such as plant and vessel clean-up, require essentially the same volume of water regardless of whether the plant is operating at full or half capacity.

A review of technical literature indicates that data on water intake quantities by fish processing plants are extremely sparse. However, the following information from the New Brunswick Research and Productivity Council[10], based on a survey of seven fresh and frozen fish plants, is considered pertinent:

* Wherever the term gallon is used, it means the imperial gallon.

Range of water usage per pound of product	1.8 to 5.8 gallons (average value 3.6 gallons)

By assuming that the "products" are fish fillets, and further assuming the maximum water usage of 5.8 gallons per pound of fillets, the following may be deduced:

a) 5.8 gallons of water are used in the production of 1 pound of fillets.

b) 1 pound of fillets are produced from 3 pounds of landed fish.

c) Consequently, 5.8 gallons of water are used in processing 3 pounds of landed fish; i.e., almost 2 gallons of water for each pound of landed fish.

In addition to the foregoing, the following guidelines were found in consulting engineers' reports dealing with proposed water supply systems for Newfoundland communities with fish processing plants:

i) Design Criteria after R. J. Noah[11]

For the production of frozen fish products, provide an average flow of 2.5 gallons per minute for each pound per minute of fish being processed.

For salt fish plants, the 2.5 gpm is reduced to 1.5 gpm.

Peak flow rates to fish plants are considered to be approximately 3 times the average flow rate.

ii) Design Criteria after Canadian British Engineering Consultants[12]

Provide 4 gallons per pound of fish landed.

Because of the lack of metering devices on the water supply lines within Newfoundland fish plants, it has been virtually impossible to determine a breakdown of the water needed for the various processes and operations. However, after consultation with officials of two fish processing companies, it has been established that the following figures represent reasonable approximations for modern plants of intermediate and large size producing frozen fish products:

Fluming of whole fish, fillets and offal	50 to 65 percent
Fish washing, scaling, filleting and skinning	15 to 25 percent
Clean-up operations in plant, vessel, wharf, etc	12 to 18 percent
Fish meal plant	2 to 4 percent
Ice making	1 to 3 percent
Vessels' fresh water	1 to 2 percent
Toilets and washrooms	1 to 2 percent
Boiler feed water, cooling water, etc	1 to 2 percent

Water is not recycled or re-used in fish processing plants at present, because such practice causes a bacterial build-up in the water and this in turn accelerates fish contamination and spoilage.

From the foregoing breakdown of water uses, one might reasonably expect that water intake could be reduced by as much as 50 percent if fluming operations were eliminated or reduced and replaced by such equipment as dry belt conveyors. Unfortunately, experience has shown that dry belt conveyors do not effect savings in water intake quantities because:

a) Fluming accomplishes two basic objectives, viz., it partially washes the fish and transports them from one process area to another. If fluming were eliminated, more water would be used for the washing and scaling operations.

b) The clean-up of dry belt conveyors carrying fish would require substantial quantities of water.

An additional reason for favouring flumes over dry belt conveyors is that flumes cause less bruising of the fish flesh.

In general, the opportunities for conserving significant quantities of water in fish processing plants would appear to be very limited at this time.

7 PROCESS WASTES

Fish processing operations give rise to a variety of solid and liquid wastes, including the following:

a) Solid wastes from such operations as gutting, skinning, filleting, and scaling.

b) Liquid wastes from such operations as fish washing, fluming of fish and offal, plant and vessel clean-up, canning, and fish meal production.

Solid wastes from gutting operations are disposed of at sea, by land burial, or by processing to recover various oils. The oils are used in the manufacture of such products as margarine, paints, tanning chemicals, and industrial oils. In Newfoundland, the bulk of the waste from gutting operations is disposed of at the water line. Wastes from scaling and filleting operations, including scales, fins, heads, back bones, etc., are either processed into fish meal, disposed of by burial on land, or dumped into the harbour. Skins may be used for manufacturing glue or may be dumped with other wastes. A number of glue factories were operating in Newfoundland, but all have closed down in recent years[5].

Liquid wastes from fish plants vary extensively depending on such factors as the type of fish being processed, degree of in-plant mechanization, whether fish are gutted at sea or not, and nature of the end products. However, these wastewaters do customarily contain slime, blood, scales, fins, oil and trimmings of fish flesh or viscera. As far as can be determined, these wastes are generally discharged without treatment into the harbour areas. Steps taken to combat pollution of this type include the use of traps, separators or rotating screens to remove solids from the wastewater. The solids may be taken to fish meal plants and the screened effluent discharged to municipal sewers or to the harbour. More elaborate systems include settling tanks and skimmers to remove settleable and floating solids.

The relative strength of some typical wastewaters from fish processing plants, as reported by the New Brunswick Research and Productivity Council[10], is shown in the following table:

ANALYSES OF SELECTED FISH PROCESSING WASTEWATERS
(after Gallop et al[10])

SOURCE OF SAMPLE	BOD (mg/l)	COD (mg/l)	TOTAL SOLIDS (mg/l)
Total effluent (cod line)	110	273	-
Unscreened stickwater	110,700	342,000	-
Total effluent (sole line)	400	1,163	27,100
Effluent from filleting line	-	107	6,940
Total effluent from lobster plant	-	427	5,780
Total effluent (cod filleting and lobster washing lines)	-	859	12,710
Washer effluent (lobster meat line)	217	50	632
Total effluent (cod and sole filleting lines)	174	370	10,190
Effluent from lobster cooking	354	353	7,860
Effluent from spray washing of fish	450	1,165	1,306
Effluent from skinning and filleting line, plus sea water from heat exchanger	465	486	340
Effluent from skinning and filleting line, plus sea water from heat exchanger	222	1,125	424
Effluent from lobster packing line	1,600	1,856	5,600
Stickwater (fish meal plant)	38,000	45,112	68,010
Effluent from gurry (offal) pit	-	1,420	35,200
Effluent from wash-down of filleting room	30	1,155	23,300
Effluent from fish meal plant	257	756	33,500
Waste flume water from filleting lines	852	1,145	870

7.1 Biological Treatment of Liquid Wastes

So far as can be reasonably determined, there are no existing biological treatment plants in Canada or the United States that treat only liquid wastes from fish processing plants. A few general statements have been found in the literature[16] which suggest that these wastes are discharged to city sewers in some areas but specifics are lacking. Matusky, F.F., et al[17] have described a proposed biological treatment plant to handle approximately 1 million imperial gpd of wastewater having the following makeup:

69 percent of the flow from a fish processing plant.

10 percent of the flow from a potato processing plant.

21 percent of the flow is domestic sewage.

The cost of this plant has been estimated to be $832,000. A slightly larger plant (1.15 M gpd) designed for Georgetown, P.E.I., and put out to tender about two years ago would have cost about $800,000, according to Hiscock[18], if it had been built at the time. The latter plant was designed to treat 600 gallons per minute of wastewater from fish processing operations and 200 gallons per minute of domestic sewage (75 percent of the flow was wastewater from fish processing operations).

7.2 Fish Meal Production

The fish meal plants of Newfoundland fall into two broad categories:

i) Non-oily fish meal plants (often called ground fish meal plants).
ii) Oily fish meal plants

Groundfish meal plants process the offal of non-oily fish and unsold groundfish into meal by steam or flame drying, grinding and bagging the raw materials. These plants do not have the requisite presses and centrifuges for processing oily fish. The importance of groundfish meal plants and the tonnage of wastes which they handle is best appreciated by referring to a statement made by Foley[14]: "3 pounds of landed fish yield about 1 pound of processed fillets and 2 pounds of waste".

Figure BII-4 is the flow diagram of a typical oily fish meal plant. These plants receive "trash" and surplus fish (including oily fish) from various processing plants, offal from filleting plants, and, in some cases, may also receive liquids from canning plants, fish scraps, bones, etc. Wastes are initially cooked to facilitate dewatering, pressed, dried, ground and bagged. The pressing operation releases "press cake" and a liquid, termed "press liquor", which contains both dissolved solids and fine suspended solids. "Press liquor" is screened to remove suspended solids and centrifuged to separate its basic components, oil and stickwater. The stickwater can be concentrated in multiple-effect evaporators to a solid content of some 40 to 50 percent and then mixed with the "press cake" to form the "whole meal". The concentrated stickwater leaving the multiple-effect evaporators is usually termed "condensed fish solubles".

The raw materials processed by oily-fish meal plants vary appreciably depending on the species of fish being caught at the time. For example, at some plants only whole herring may be processed while for other plants a typical breakdown could consist of the following[13]:

Groundfish offal (mainly heads and backbones from filleting operations)	80 percent
Unsold groundfish	10 percent
Surplus oily fish, such as herring	10 percent

Similarly, if limited gutting operations are carried out on land rather than at sea, solid wastes from gutting may also be included in the fish meal. Skins may or may not be included in the raw wastes.

Since the make-up of raw materials to oily-fish meal plants is not constant, variations may be expected in the plants' yields. However, an indication of yields is provided by the following:

i) 1 ton of fish waste may yield about 400 pounds of dry fish meal and 1,600 pounds of "press liquor".

ii) The 1,600 pounds of "press liquor" may yield about 280 pounds of oil, 65 pounds of solid protein, and 1,255 pounds of water (depending on fish species).

According to the Canada Department of Fisheries there are twenty-one fish meal plants in Newfoundland at present. Three of these plants process only herring into fish meal and oil, four process both herring and filleting scraps into fish meal and oil, and 14 process only filleting scraps into groundfish meal. The two largest plants are capable of processing 800 tons of herring per day while the others process from 50 to 250 tons of waste per day.

7.3 Fish Protein Concentrates (FPC)

Several groups of research workers in various parts of the world (notably in Canada, South Africa, United States, Germany, Great Britain, and Russia) have developed processes for dehydrating and deodorizing fish to produce "fish protein concentrates". In general, these products are nutritious, white powders that resemble flour in appearance.

One process, described by Swendsen[15], separates water and oil from proteinaceous fish tissue by solvent extraction and distillation steps. The resulting FPC is reported to contain over 70 percent protein normally and may be used as an animal feed or may be deodorized and added to cereal-type foods for human consumption. In New Bedford, Mass., a plant based on this process has been turning out 72 tons of animal feed per day for a number of years. Permission to market this product for human consumption was granted by the U.S. Food and Drug Administration on February 1, 1967[15]. Similar legislation has not been passed in Canada. The water requirements for a plant of this type processing 200 tons per day are reported to be:

- i) 10 gallons per minute for boiler make-up water.
- ii) 2,500 gallons per minute of cooling water at 80 deg F. (This may be fresh or sea water).

A process developed in Canada (often termed the "Halifax Process") utilizes an isopropyl alcohol solution for extracting water and oil from gutted fish. After dehydration is complete, the fish is ground up to a white powder-like substance. The recovery of alcohol is an integral part of this process and a nominal volume of cooling water is needed for this purpose. If necessary, this cooling water requirement can be met by using either fresh or sea water. Since the cooling water does not come into contact with the product, the bacteriological and chemical quality need not be high.

A plant designed to turn out 25 tons per day of fish protein concentrates (FPC)[19] by the "Halifax Process" is reported to require less than 3,000 gallons per day of fresh water for boiler feed, process, and general plant sanitation, plus a nominal (but as yet undetermined) volume of cooling water. It is not known at this time if or when the particular plant might be built. However, a recent announcement[20] indicates that a plant of similar capacity and estimated to cost $4 million is being planned for eastern Canada (probably Nova Scotia). The plant is being designed now and production is expected to start during the early 1970's.

In Great Britain, workers at the Torry Research Station have developed a unique product from fish which is reported to be an attractive and nutritious food for both human and animal consumption. In this process the fish is macerated, cooked to some extent, and a crude oil is pressed from it. This oil is then hydrogenated up to a fat composition similar to margarine by using an inoculum of bacteria isolated from the rumen of cattle. This stabilized fat is then mixed with the proteinaceous "press cake". It is possible that this process will be commercial before long and it might provide a means of disposing of fish wastes, including whole fish, which are currently of low economic value.

In summary, it may be stated that dehydrating is perhaps the most important single operation in the production of both fish meal and fish protein concentrates. As a result, the water requirements of plants turning out these products tend to be very nominal when compared to the water requirements of fish processing plants. Although precise data are generally lacking (especially in the case of FPC plants), it is believed that their water requirements will generally be about 5 percent or less of the intake of fish processing plants handling comparable tonnages.

7.4 Other Methods of Solid Waste Disposal

Unsold fish without the viscera may be processed into food for mink. Cod is preferred for this purpose, but other non-oily fish may also be used.

8 STATISTICAL ANALYSIS

An attempt was made to process statistically the information obtained from the questionnaires circulated at the fish processing industries, to obtain a statistical relationship enabling the computation of specific fresh water use as a function of the technical and economical indices of the plant.

Because of the incompleteness of the replies to the questionnaires, the analysis was limited to a sample of only 11 plants. Even for this sample, there are some doubts about the accuracy of the data, as in the case of an exceptionally large specific consumption (over seven gallons per pound of fish input compared to an average of less than 2 gallons per pound). Some of the basic data were computed indirectly, for example, the amount of fish input which was estimated in several cases from an average ratio between input and output. Finally, not all the data which could be of significance for the relationship were available at all plants (e.g., plant capacity), and therefore these data were not used in the analysis. Consequently, the latter was limited to attempting a correlation between fresh water use (withdrawn) per pound of input fish (X_5) in gallons per pound and the following "independent" variables:

- X_1 - specific cost of water in cents per thousand gallons (price charged by supplier or capital and operating costs for plant owned facilities);
- X_2 - number of working hours per thousand pounds of fish input;
- X_3 - number of permanent workers per million pounds of fish input;
- X_4 - type of plant index defined as:

  1 for salt fish

  2 for fish meal

  3 for fresh and frozen fish, and other products excluding fish meal

  4 for fresh and frozen, and other products including fish meal

The correlation obtained has the following equation:

$$X_5 = \frac{3.4\, X_3^{0.23} \quad X_4^{0.49}}{X_1^{0.55}}$$

The variable X_2 was not included as it was not significant for the sample analyzed.

The correlation coefficient (R=0.786) is significant at the 5 percent level, but not at the 1 percent level (for which the significance limit is 0.79). Of all the regression coefficients, the most significant is the cost of water, which is significant at the 1 percent level.

A comparison between recorded and computed (using Eq. 1) specific fresh water consumption is shown in Figure B II-7. It is seen from the figure that in 8 cases out of 11 the computed values closely estimated the actual ones. The largest error is obtained for the exceptionally high consumption for which the basic data seem to be inaccurate.

Although this analysis has yielded an interesting and reasonable relationship, it should be considered only as an indication that further investigation might yield satisfactory results.

A larger sample, more accurate data, and the introduction of other variables (in the first place plant capacity) are required to develop a more reliable relationship for estimating specific fresh water use from the plant technical and economical indices.

It is worth mentioning that out of the 11 plants included in the sample, only one is from Newfoundland, the remainder being from Nova Scotia and New Brunswick. This plant, which was selected at random (because of available data), has indices which are not uncharacteristic for Newfoundland's fish processing industry. Thus, the specific water consumption (4 gallons per pound of input fish) is the second largest (the largest being doubtful data), the number of working hours per pound of input fish is the largest for the type of plant, and, in general, (87.8 hours/1,000 pounds compared to the second largest which is 46.0 hours/1,000 pounds) the number of permanent workers per pound of fish input is also the largest (30 workers/10^6 pounds compared to the second largest which is 17.5 workers/10^6 pounds).

9 SUMMARY AND CONCLUSIONS

The amount of water required for fish processing is extremely variable according to the data obtained during this investigation. It is believed, however, that modern frozen fish processing plants require about four gallons of water to process one pound of landed fish. This figure includes the water used for fish meal production, plant, wharf and vessel clean-up, boiler feed, as well as the fluming, filleting, fish washing, scaling, and other process operations. On this basis, a large modern complex such as the new Marystown plant of Atlantic Fish Processors (capacity of 60 million pounds of fish per year) would require about one million gallons of water per day, assuming the fish were processed at an average rate of 250,000 pounds per day over a period of 240 working days each year. Plants larger than the Marystown complex are expected in future, possibly with capacities in the region of 100 to 120 million pounds of landed fish per year. It is expected that their daily water requirements will be in the order of 2 million imperial gpd.

Either fresh or sea water may be used for fish processing provided it is bacteriologically and chemically safe except that fresh water would be required for boiler feed water.

At many fish processing plants, solid wastes are processed into fish meal. Large and intermediate-sized plants usually operate their own fish meal plants, while the small plants either truck their solid wastes to a nearby meal plant or dispose of it by land burial or into the sea.

Liquid wastes from fish processing plants are invariably discharged into harbour areas or the sea immediately adjacent to the plants. In some instances, these wastes may be rapidly diluted and dispersed by tidal waters, but this does not happen in protected harbours, where most fish plants are located. Accordingly, with the present trend towards larger processing plants, increased harbour pollution may be expected unless steps are taken to reverse this trend; such steps could include the disposal of liquid wastes to a biological treatment plant, or through a suitably located outfall.

In most of the Island's sea coast communities, harbours have been continuously polluted over the years by untreated domestic sewage and wastewaters from the local fish plant. As a result of this continuous pollution, the bacteriological quality of the water becomes suspect. Accordingly, the new large fish plants with growth potential are expected to use water from a suitable source for all processing purposes since it appears unlikely that the degree of treatment of municipal sewage that will be achieved during the study period would guarantee unpolluted sea water at all times.

The current cost of constructing a biological treatment plant to treat a total flow of one million imperial gpd of wastewater from a fish processing plant and a surrounding community is expected to approach one million dollars.

During the next 15 years or less, it is expected that a trend will develop to reduce the number (and waste treatment costs) of small and intermediate sized fish plants in Newfoundland and replace them by a few (probably less than 10) large versatile complexes, with a fleet of modern stern trawlers, serving two to five of these complexes. The capacity of each complex is expected to be in excess of 100 million pounds of landed fish per year.

The production of fish protein concentrates is technologically feasible but limited markets for the product have precluded the possibility of building any commercial plants to date in Canada. Based on research carried out, it is expected that fresh water requirements of a frozen fish processing plant or possibly as low as one gallon for every 20 pounds of FPC.

Although market analyses and evaluation of fishing methods have been made to improve the competitive position of the industry in Newfoundland, a comprehensive study of the processing aspects of the industry is required to ensure that all segments of the industry are being pursued efficiently. Included in this study, should be a detailed investigation of fresh water and sea water use in fish plants and means for reducing quantities and minimizing waste loads, since it is believed although not proven, that fish processing plants are very sensitive to water supply.

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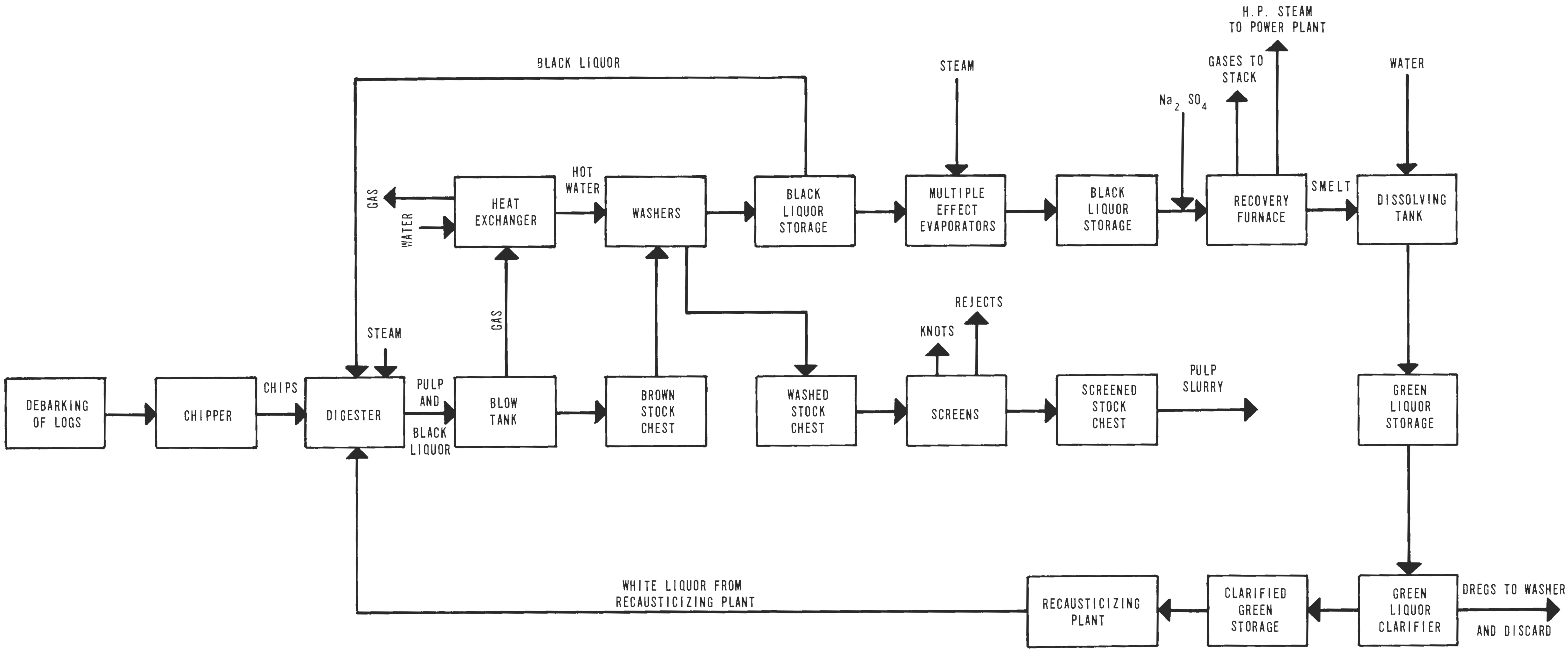
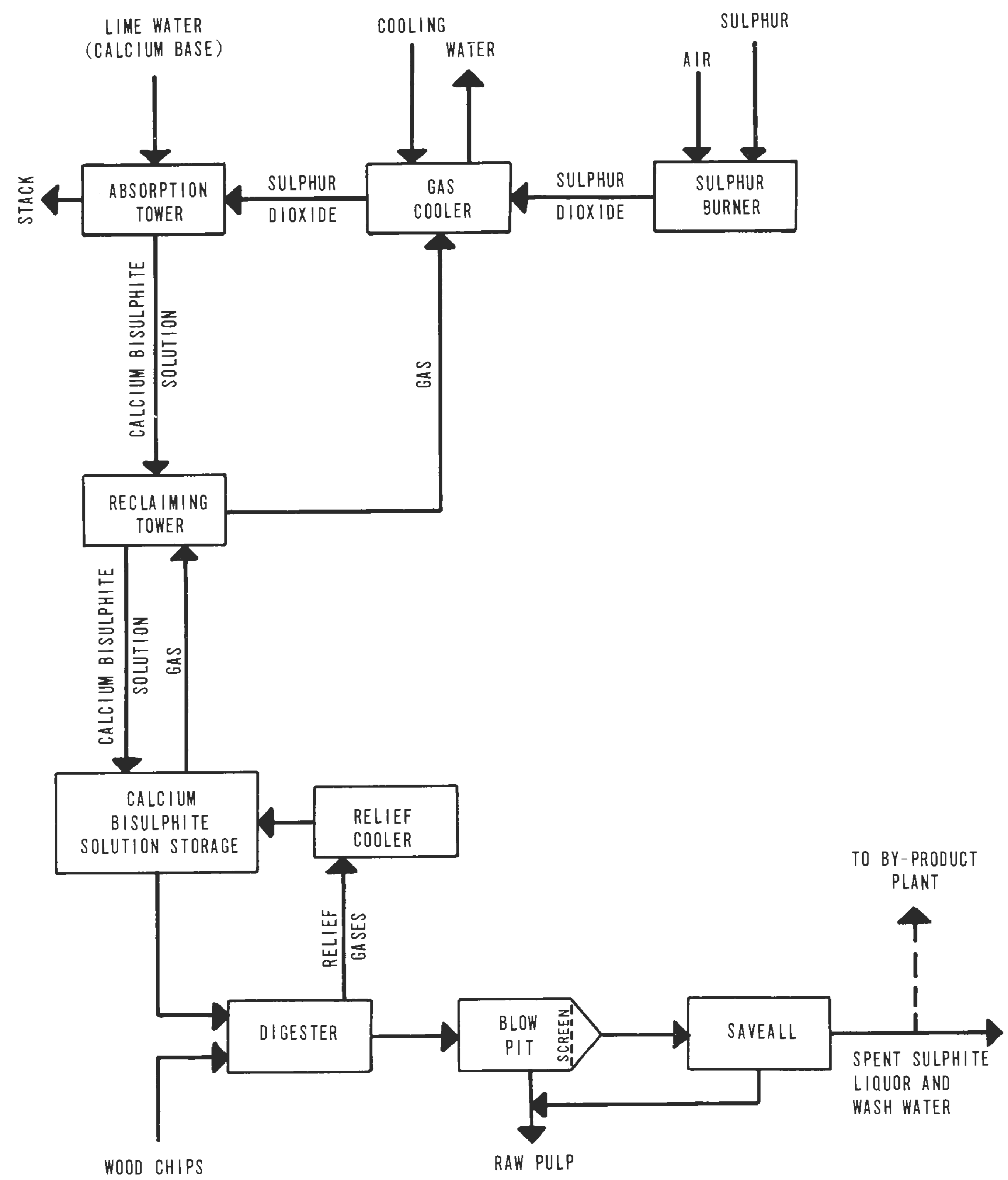


SIMPLIFIED FLOW DIAGRAM FOR KRAFT PULPING PROCESS

FIGURE BI-1

The Shawinigan Engineering Company Limited
James F. MacLaren Limited

SIMPLIFIED FLOW DIAGRAM FOR SULPHITE PULPING PROCESS

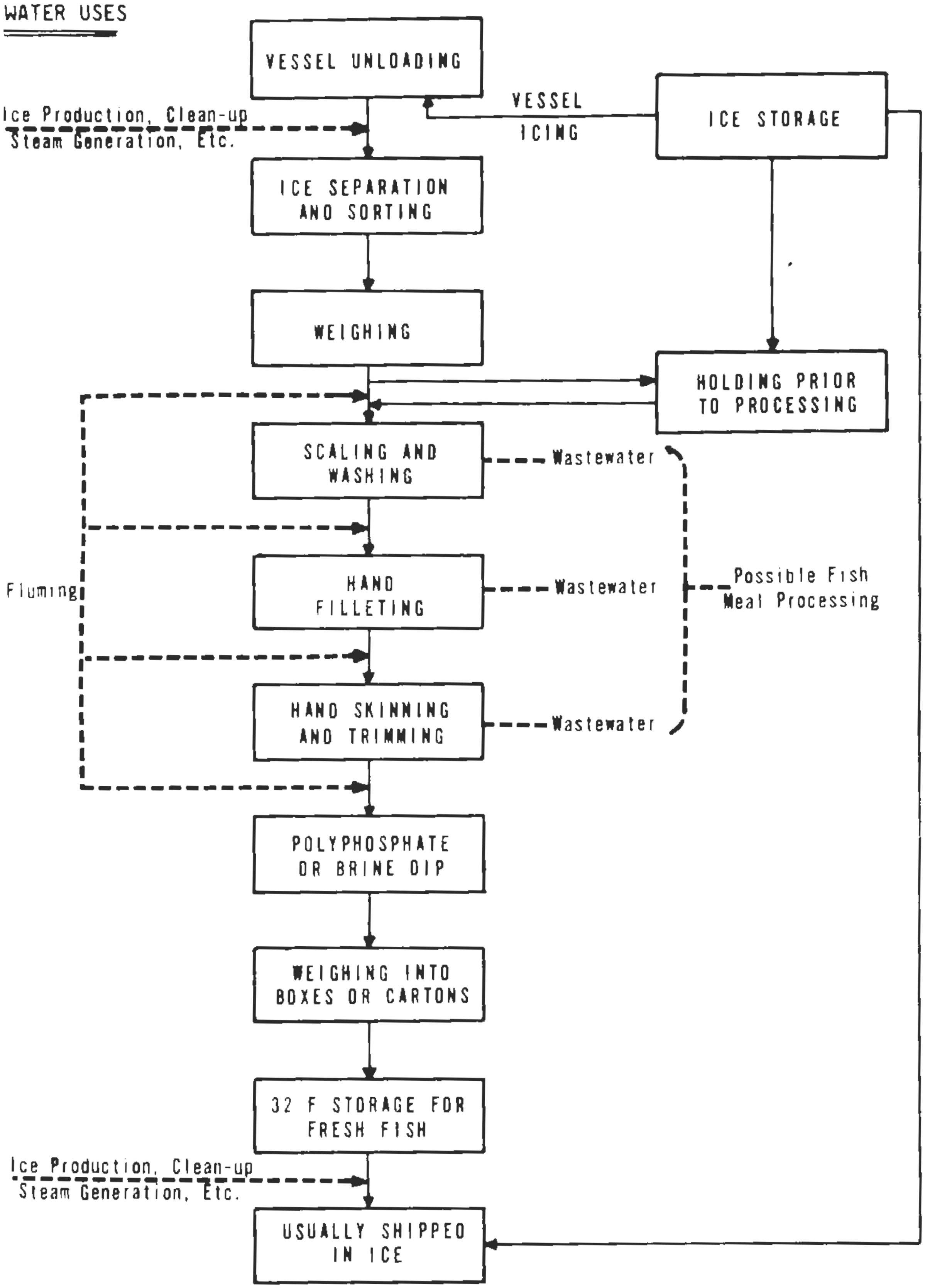


NOTE:
MAGNESIUM, SODIUM AND AMMONIA BASES ARE OFTEN SUBSTITUTED FOR THE CALCIUM BASE SHOWN

FIGURE B.I-2

The Shawinigan Engineering Company Limited
James F. MacLaren Limited

TECHNOLOGIC FLOW CHART OF A SMALL FRESH FISH PLANT



NOTE: CAPACITY OF ABOUT ONE MILLION POUNDS OF LANDED FISH PER YEAR.

SOURCE: FEDERAL DEPARTMENT OF FISHERIES.

FIGURE B.II-1

TECHNOLOGIC FLOW CHART FOR A FROZEN FISH PROCESSING PLANT

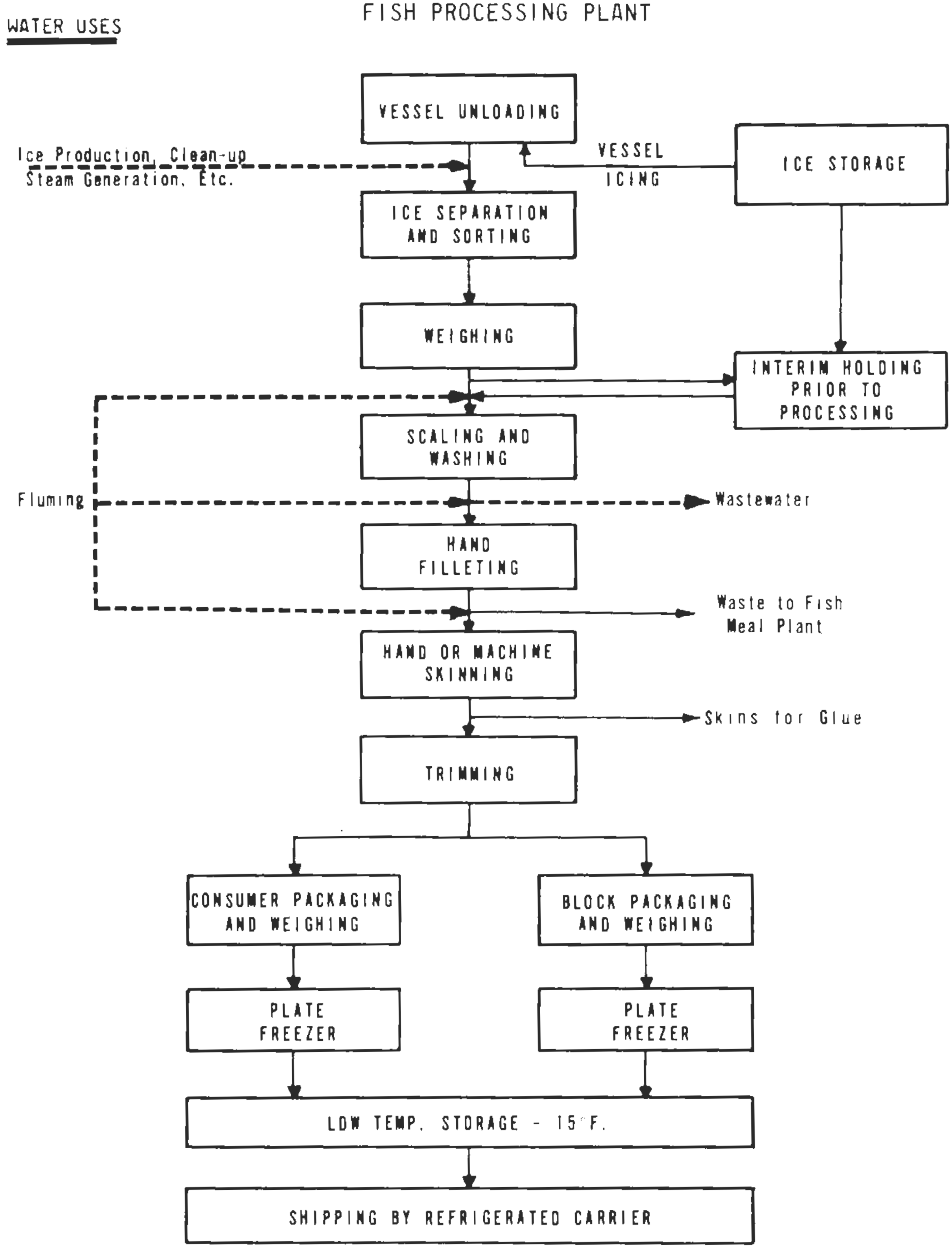
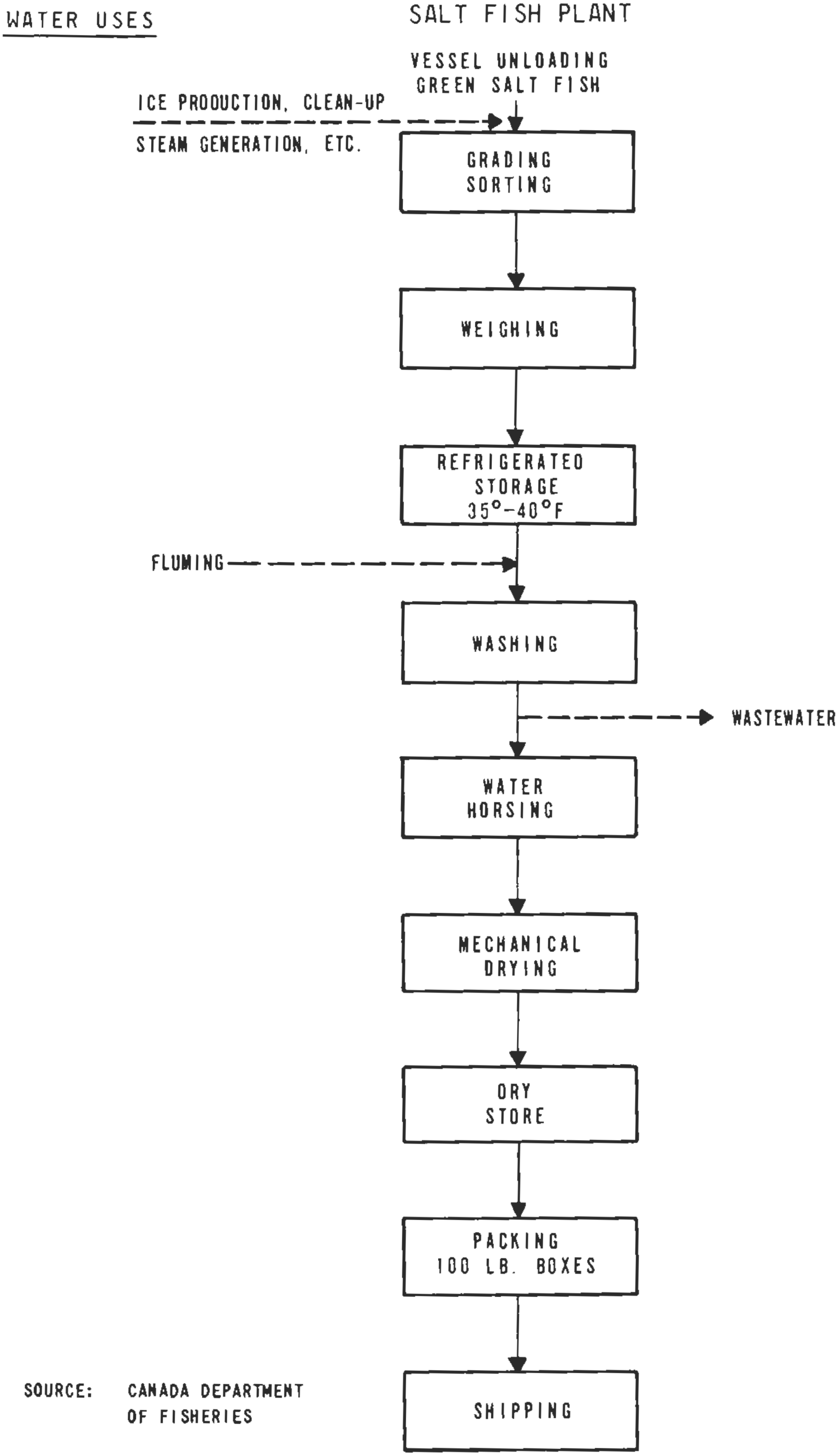


FIGURE B.II-2

SOURCE: FEDERAL DEPARTMENT OF FISHERIES

TECHNOLOGIC FLOW CHART OF A SALT FISH PLANT



SOURCE: CANADA DEPARTMENT OF FISHERIES

FIGURE B.II-3

The Shawinigan Engineering Company Limited
James F. MacLaren Limited

TECHNOLOGIC FLOW CHART OF LARGE OILY FISH MEAL PLANT

WATER USES

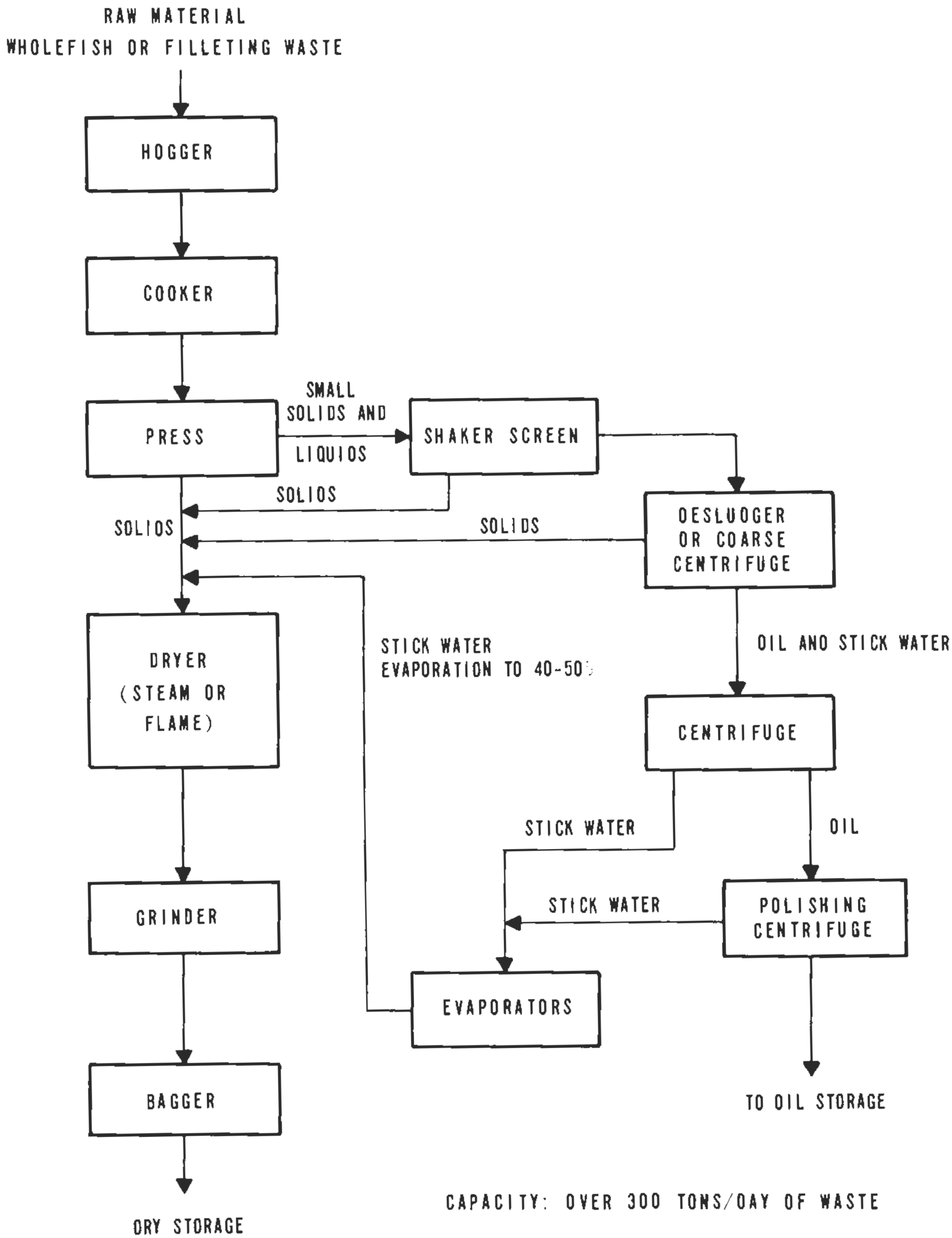
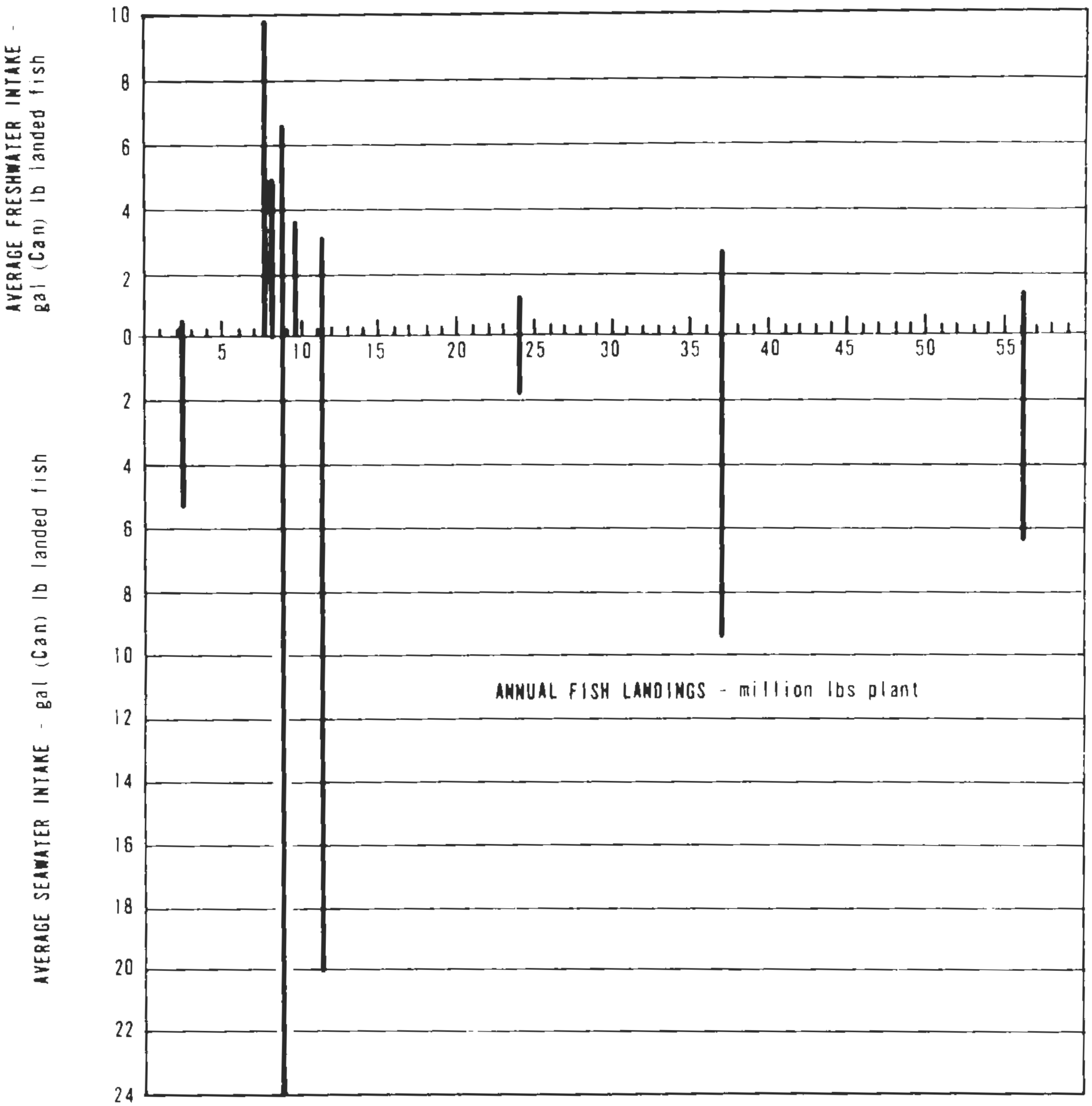


FIGURE B.II-4

SOURCE: CANADA DEPARTMENT OF FISHERIES

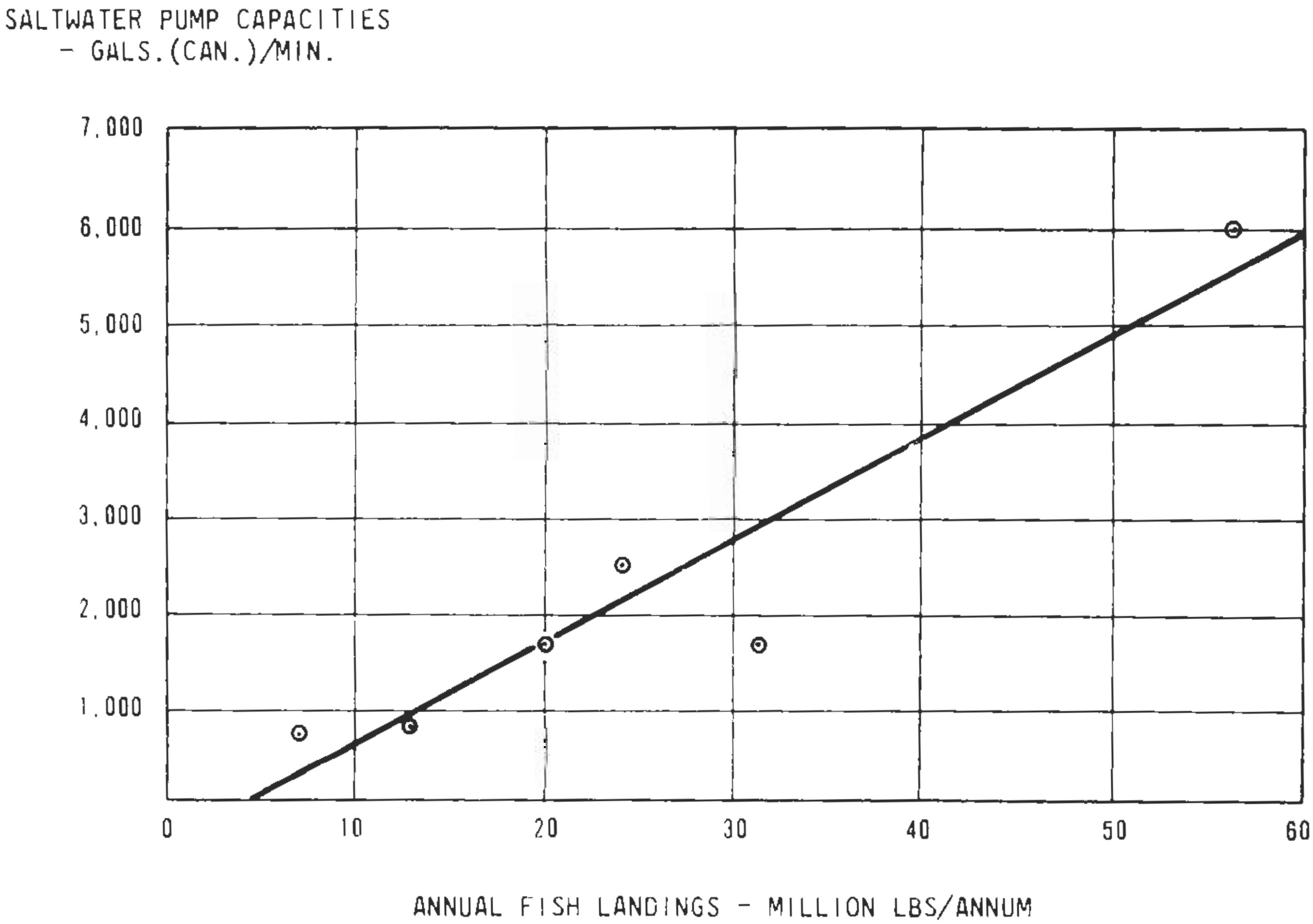
INTAKE WATER QUANTITIES FOR MARITIME FISH FILLETING PLANTS



SOURCE: DRAFT REPORT ON THE USE OF WATER IN THE FISH PROCESSING INDUSTRY BY MONTREAL ENGINEERING COMPANY, LIMITED

FIGURE B.II-5

FILLETING PLANT SALTWATER PUMP CAPACITIES VS ANNUAL FISH LANDINGS



SOURCE: DRAFT REPORT ON THE USE OF WATER IN THE FISH PROCESSING INDUSTRY BY MONTREAL ENGINEERING COMPANY, LIMITED

FIGURE B.II-6

FISH PROCESSING

COMPARISON OF RECORDED AND COMPUTED (BY CORRELATION) SPECIFIC FRESH WATER USE

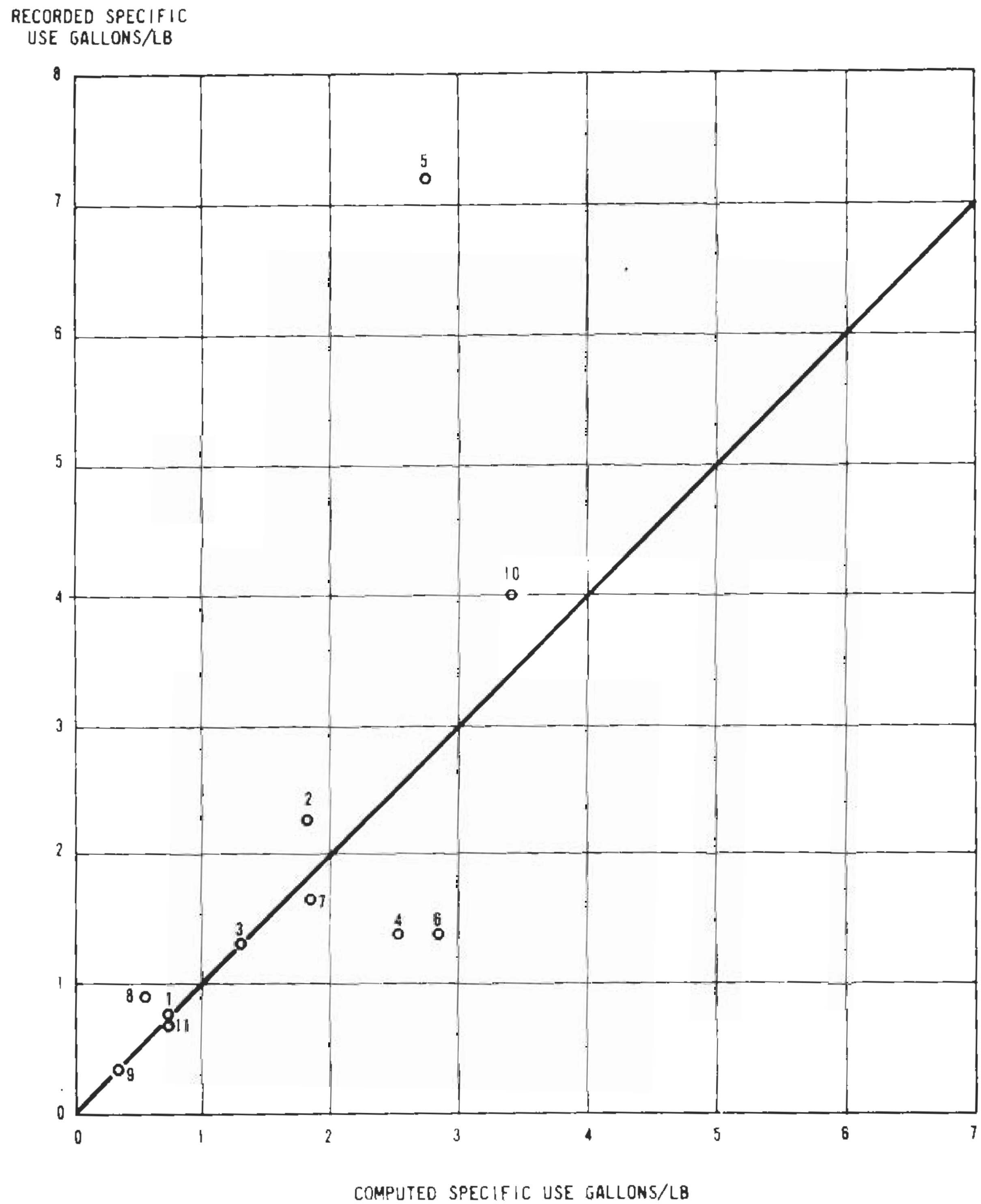


FIGURE B.II-7

PART III - THE BREWING INDUSTRY

1 INTRODUCTION

Beer is a carbonated, alcoholic beverage (2 to 7 percent by volume) prepared by fermenting a solution containing the extracts of malt, cereal grains and hops. Although scientific and technological advances have provided the brewing industry with a better understanding of fermentation reactions, the basic brewing processes used today are essentially the same as those used in ancient times.

In Canada, the brewing of beer is a large and expanding industry, having grown at an average annual rate of 4.4 percent since 1946 [1]. In 1966 the annual consumption of beer in Canada stood at 14.6 imperial gallons per capita, a figure which ranked tenth among countries of the world [2] (Czechoslovakia led at 29 gallons). On a regional basis, consumption was highest in the Yukon at 20.6 gallons and lowest in Newfoundland at 8.1 gallons.

Breweries have long recognized the importance of suitable brewing water to the production of distinctive beers; and, for many years, proximity to water of suitable quality and quantity was perhaps the major consideration in determining a brewery's location. As water treatment technology improved, this factor became less dominant, and currently breweries tend to locate as close to major markets as practical. For example, as at September 1967, all three of Newfoundland's existing breweries were located in St. John's, and a fourth brewery near Stephenville began production in 1968.

2 BREWING PROCESS

The brewing and marketing of beer comprises three major operations, viz:

The brewing of "mash" (milled malt mixed with boiled cereal adjuncts) to form a "hopped wort".

Fermentation

Storage, finishing, pasteurization, and packaging.

A typical flow diagram of the brewing process is shown on Figure B III-1. Apart from water, the main ingredient in beer is malt. At some breweries the malt is prepared on the premises (usually from barley) while at other establishments it is imported. It is believed that the majority of today's breweries use imported malt. Corn and rice are generally used as adjuncts to obtain the paler, snappier beers which seem to be preferred by many of today's consumers.

Mashing, the initial operation shown on the flow diagram, involves the blending of water, milled malt, and boiled adjuncts (usually corn and/or rice) to form a mash mixture.

This passes to a lauter tub where grain husks collect on a false bottom and act as a filter medium through which the sugar-containing liquid called "wort" is strained. The wort is next boiled for approximately 2.5 hours with hops and some added dextrose, filtered, cooled, and settled before being pumped to fermentation tanks. It is fermented until essentially all sugars have been converted to ethyl alcohol and carbon dioxide. The beer resulting from fermentation is then stored, filtered, adjusted for carbon dioxide contents, packaged, and pasteurized.

The principal difference between the various beers lies in the type of brewing water employed, the proportion of ingredients used, and the details of their preparation. For example, the term "lager" implies that the beer has been aged after fermentation; "pilsener" is applied to beers with a high hop rate and a stable head. "Munich" beer is darker and sweeter than "pilsener" and has a strong malt flavour, and it is produced using a darker malt and a lower hop rate as compared to "pilsener".

Most beers are produced using yeasts that settle to the bottom of fermentation tanks ("bottom fermentation"). Top fermenting yeasts are used to produce ale, porter, and stout.

3 WATER QUALITY REQUIREMENTS

It is not within the scope of this report to enumerate all water quality requirements of the brewing industry since these can vary appreciably from one brewery to another. However, the following general requirements are believed to have fairly universal application:

The water must be potable (bacteriologically and chemically safe for human consumption).

The water should be clear, colourless and free from objectionable tastes and odours.

The water should be free of manganese and iron.

Other water quality requirements will depend on the purpose for which the water is used. For example, soft water is preferred over hard for bottle and keg washing; boiler feed water is often demineralized and degasified regardless of its original quality. Frequently, breweries degasify and demineralize brewing process water and "build it up" to their own specifications by adding the requisite quantities of mineral salts. The mineral content of some typical brewing waters is shown in the table below [3].

Composition of Various Brewing Waters (mg/l.)

	Pilsener	Dortmund	Munich	Burton
Total solids after evaporation	51	1,110	284	1,790
Calcium (CaO)	9.8	367	106	520
Magnesium (MgO)	1.2	38	30	145
Sulphates (SO_4)	4.3	240	7.5	756
Chlorides (Cl)	5.0	107	2.0	34
Nitrates (N_2O_5)	Trace	Trace	Trace	22

Calcium sulphate plays a particularly prominent role in the brewing of pale ales by performing the following significant functions [13]:

a) It neutralizes the acidity of the wort and the beer.

b) It catalyzes the production of peptones and amides during brewing.

c) It causes albuminoids to coagulate in separable form during the boiling of the wort resulting in a clear product with long "shelf life".

Bicarbonates are undesirable in brew waters since they precipitate phosphates (essential yeast nutrients) and this has the effect of retarding fermentation. Magnesium sulphate is undesirable in malting operations where it retards the extraction of malt, and in brewing where it imparts an unpleasant taste to the product. Iron in excess of 0.1 ppm is undesirable in brewing water since it can impart an unpleasant taste and a greenish tint to the beer.

Common salt (sodium chloride) and/or potassium chloride in minute quantities impart a universally accepted flavour to beer that is noticeably lacking if they are absent. However, salt concentrations in excess of 350 ppm deter the production and activity of the yeasts.

4 WATER QUANTITIES

The principal uses of water in a brewery are:

a) Bottle, keg, kettle, and tank washing

b) Cooling and refrigeration

c) Brewing process water

d) Plant sanitation, washrooms etc.

e) Boiler feed water

f) Pasteurization

Although precise data are not readily available, it would appear that approximately 50 percent of the water is used for bottle and keg washing alone [4]. Data published in the United States and Canada indicate that some 5 to 35 gallons of water may be used in the production of one gallon of beer [4,6]. Present data obtained from the breweries in Newfoundland indicate that water consumption runs as high as 30 gallons per gallon of product [5]. This large spread in water usage probably results from such factors as water cost, its availability, cost of in-plant treatment, type of bottle washing equipment used, type of equipment used for cooling, and cost of wastewater disposal. For example, plants located near abundant supplies of good quality water which requires minimal in-plant treatment may be inclined to use excessive volumes of water for such purposes as cooling and bottle washing. Conversely, if the brewery were levied a surcharge by the municipality for discharging large volumes of moderately high strength wastes to the sewers, a strong incentive to conserve water and reduce wastewater volumes might result.

A limited number of opportunities exist in breweries for water recycling and re-use, but no universal pattern seems to have evolved. For example, cooling water effluents may be used in bottle washing or for pasteurization; similarly, solutions of caustic soda used for bottle washing may be screened to remove suspended solids, strengthened and re-used.

5 WASTEWATERS

5.1 Sources

The principal liquid wastes generated in a brewery result from the following operations:

a) Washing of bottles, cans, and kegs.

b) Washing of cooking kettles, aging vats, fermentation, and storage tanks.

c) Cooling waters.

d) General plant sanitation and washrooms.

e) Effluents from the dewatering or screening of spent grains and hops.

f) Wastes from water treatment operations including filter backwashing, regeneration of ion exchange towers, sedimentation tank underflows, etc.

g) Accidental spills.

Other wastes shown on the flow chart Figure B 111-1, such as spent grains and waste yeast are generally sold by breweries at a profit for processing into animal feed. Spent hops are often disposed of as soil conditioners on farms.

5.2 Nature

The composite wastewater leaving a brewery results from several individual batch operations which discharge wastes intermittently. At various times of the working day, therefore, the strength of the composite waste will vary appreciably depending on which of the individual wastes streams predominates.

Various researchers [4,7,8,9] have conducted studies on composite wastewaters from breweries and some of their more important findings include the following:

Five day BOD - 420 to 1200 mg/l.

Suspended Solids - 200 to 500 mg/l.

pH -5.5 to 7.4

Generally, these wastewaters are slightly acidic and contain many harmless bacteria and yeast cells.

Studies on individual waste streams by the same research workers revealed the following:

a) Strongest wastes with respect to BOD_5 seem to be the effluents from the screening and dewatering of spent grains and wastewaters with a yeast content (water used in washing fermentation tanks). The BOD_5 of these wastes generally exceeds 25,000 mg/l and the suspended solids exceed 8,000 mg/l.

b) The pH of brewhouse wastes varies from 3.6 to 7.1 while those from the bottling works vary from 2.4 to 12.1. The high pH in the latter instance was caused directly by dumping spent caustic cleaning solution used for bottle washing. Generally, the pH of both the brewhouse and the bottling works was between 4.0 and 7.0

c) The concentration of biologically and degradable organic material as measured by the BOD_5 test may vary from 24 to 4800 mg/l - a 200 fold variation.

5.3 Volumes

The volume of water used in breweries was previously quoted as varying between 5 and 35 gallons per gallon of product. Usually 80 to 95 percent of this subsequently discharged as wastewater. The 5 to 20 percent which is not discharged as wastewater is either incorporated into the product, lost through evaporation, or trucked away as moisture content of spent grains, waste yeast, and spent hops. (Many breweries, especially the smaller ones, do not dewater their spent grains).

Bottle washing is usually the principal source of wastewater, and accounts for more than 40 percent of the total plant intake. However, cooling water quantities can exceed the volumes used in bottle washing if " once-through" cooling systems are used instead of a system of cooling towers, (a once-through system uses approximately 33 times as much cooling water as a cooling tower system of comparable capacity).

Mohlman [9] has reported that wastewater resulting from the drying of spent grains accounts for approximately 7.5 percent of the total wastewater flow.

5.4 Treatment Methods

Most breweries discharge their wastewaters to municipal sewers. In general, these wastes can be satisfactorily treated in municipal plants employing biological processes, especially in large centres where the volume of brewery wastes is low in proportion to the total sewage flow. In smaller centres where the volume of brewery waste might represent a large percentage of the total sewage flow (say 25 percent), periodic shock loads from a brewery could seriously upset the municipal treatment plant if it was neither designed nor operated with these eventualities in mind.

Some municipalities levy a surcharge on industries that discharge high strength wastes to municipal sewers. To minimize these surcharges, breweries often implement some form of in-plant treatment to reduce the strength of their wastewaters; these include:

a) Selling spent grains in the wet state rather than dewatering them (press water from the dewatering of spent grains is estimated to account for over 30 percent of the BOD and suspended solids found in brewery wastes).

b) Treatment of press waters in a settling tank and sale of the settled sludge as hog feed.

Breweries which are not serviced by municipal sewers may be required to construct their own wastewater treatment facilities. In situations such as this, trickling filters are known to be highly effective and have been successfully used for over thirty years [10]. More recently, Eckenfelder [11] reported success in treating brewery wastes by the activated sludge process. Based on experience in Ontario [12], it is estimated that the cost to a brewery operating its own treatment plant would amount to some 4 to 20 cents per 1000 gallons of wastewater.

6 SUMMARY AND CONCLUSIONS

a) The water requirements of Canadian and American breweries have been found to vary between 5 and 35 imperial gallons per gallon of beer brewed (10 to 15 gallons per gallon of beer appears to be common average range). Care should be taken in converting these figures to barrels since Canadian and U. S. practices differ slightly and conversions should be made as follows:

1 Canadian barrel = 25 imperial gallons (or 30 U. S. gallons).

1 U. S. barrel = 25. 83 imperial gallons (or 31 U. S. gallons).

On this basis, the foregoing water intake figures may be restated as 125 to 870 imperial gallons per barrel (Canadian) of beer.

b) Washing of bottles, kegs, kettles, tanks, etc., is the largest user of water in breweries, and accounts for 50 percent of the total intake in many instances. Other uses include: cooling and refrigeration, boiler feed, pasteurization, process water, and general plant sanitation and washrooms.

c) An increased use of cans instead of returnable bottles has been observed in the brewing industry in recent years. If this trend continues, reductions in intake water by as much as 25 percent may be reasonably expected since cans require only a token wash as compared to the thorough washing given to returnable bottles.

d) It has not been possible to develop figures to show the effect on water intake of an increase in water cost. However, it is felt that nominal increases in water cost (say 10 percent) are not likely to affect intake to any significant degree since current water costs only amount to a fraction of 1 percent of the selling price of the product.

e) Wastewater volumes from breweries are usually 5 to 20 percent lower than water intake, largely because of the quantity that is incorporated into the final product.

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SIMPLIFIED FLOW CHART FOR
THE BREWING PROCESS

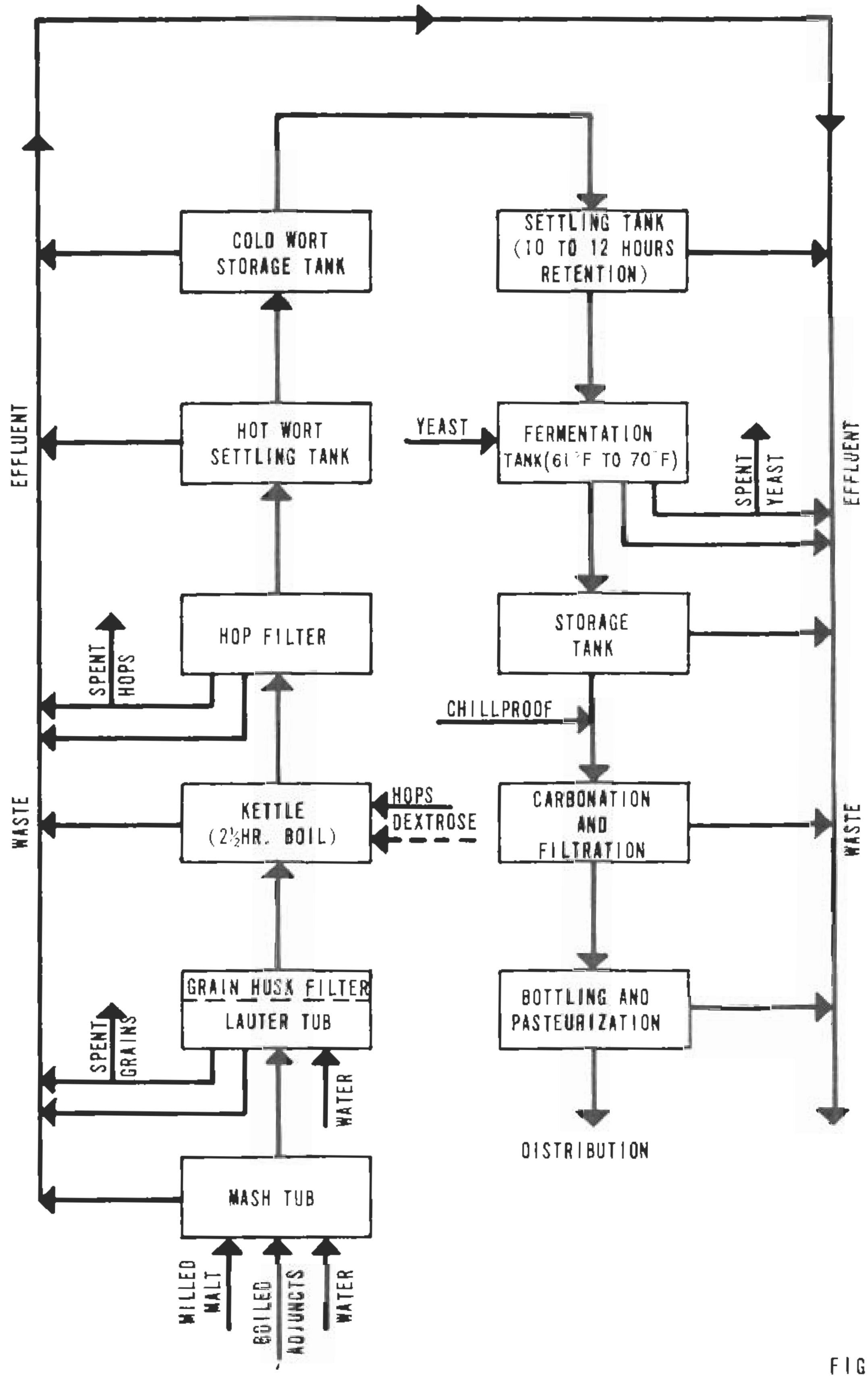

FIGURE B.III-1

PART IV - THE SOFT DRINK INDUSTRY

1 INTRODUCTION

The term "soft drinks" herein refers to those carbonated, non-alcoholic beverages that are generally sweetened, flavoured, coloured, sometimes acidified, and artificially impregnated with carbon dioxide. Many soft drinks also contain salts or mineral additives.

Naturally occurring carbonated waters have been traced back to the days of the Greeks and the Romans. However, it was not until the eighteenth century that an artificial carbonated water was produced.

Today, production of carbonated beverages with distinctive flavours and blends has become classified as a "High Growth Industry" in Canada. Records indicate that during the period 1946 to 1965 the industry has grown at the average annual rate of 5.6 percent[1]. Continued expansion is anticipated as the nation's population and economy increases.

Bottled carbonated beverages give rise to a bulky product which would be moderately costly to transport to distant points. To avoid high transportation costs and to ensure economical manufacture of the drinks, most companies locate in or near urban areas. These plants usually rely on municipalities for water supply and wastewater disposal. Hence, these services become significant factors when considering plant location or expansion.

In Newfoundland, seven soft drink plants were visited[8]; four in St. John's; one each in Corner Brook, Grand Falls and Bishops Falls All of these used municipally supplied water and discharged wastewaters to municipal sewers.

The importance of water to the soft drink industry becomes especially apparent when it is realized that over 80 percent of the product itself is water.

Generally, soft drink firms find it necessary to treat all, or at least part, of the incoming water. For example, the water used in the final product must be degasified and demineralized, whereas, the water used for bottle washing may or may not require treatment. These operations are described in greater detail later in this report.

2 MANUFACTURING PROCESS

The basic manufacturing process of soft drinks involves the blending of carbonated water and a "stock syrup" that has been flavoured, coloured, and in most instances acidified in a sterile container.

A typical flow chart for a soft drink bottling plant is shown on Figure B IV-1. Some plants eliminate the syrup mixing and blending procedure by having the "Stock syrup" supplied from an outside source.

3 WATER QUALITY REQUIREMENTS

The water used in bottling plants must be potable and must conform to the requirements for water used in food preparation. Essentially the water must be clear, colourless, and free from objectionable tastes, odours and organic matter. It should also be low in minerals such as iron and manganese.

3.1 Standards

In the United States, water used in the manufacture of soft drinks must conform to the following standards[2]:

a) Turbidity should not exceed 10 ppm on the silica scale.
b) Colour not to exceed 20 ppm on the cobalt scale.
c) No objectionable odour.
d) No objectionable taste.
e) Manganese content not to exceed 0.1 ppm.
f) Iron content not to exceed 0.1 ppm.
g) Bacteriological quality to be the same as required for drinking water.

3.1.1 Turbidity

Turbidity in waters is usually caused by a variety of suspended materials ranging in size from the colloidal to coarse. Removal of turbidity insures that the final product will have a satisfactory appearance and eliminates any nuclei that would tend to liberate dissolved carbon dioxide or react with colouring and flavouring materials. Turbidity may be removed by coagulation, followed by filtration.

3.1.2 Colour

Colour in water is usually caused by organic colloids which may cause undesirable tastes or odours, or could themselves precipitate out on standing. Colour removal is therefore essential to produce a drink of uniform colour and flavour. In soft drink plants, colour is frequently removed by oxidation with chlorine and/or with coagulation and filtration.

3.1.3 Taste and Odour

A tasteless, odourless water is required to control the flavour and taste of the soft drink being produced. Objectionable tastes in water may result from a variety of causes such as a high alkalinity, excessive iron, or chlorophenolic compounds.

Odours are generally caused by the presence of sulphides (mainly hydrogen sulphide), excess chlorine, and chlorophenols.

Sulphides, chlorine, and chlorophenols, if present in the water supply, can usually be removed or reduced to satisfactory levels by means of activated carbon filters.

3.1.4 Iron and Manganese

The limitation of iron and manganese to concentrations of 0.1 ppm is necessary to prevent the precipitation of salts or compounds of iron and manganese and to avoid chemical reactions with artificial colouring or flavouring matter.

Iron may be removed by various methods including the following:

Oxidation followed by sedimentation and filtration.
Manganese zeolite treatment.
Cation exchange.

3.1.5 Alkalinity

Alkalinity in potable waters is usually due to the presence of carbonate and bicarbonate ions with bicarbonates being the more common form in most waters. Other ions such as hydroxyl, borates, silicates, and phosphates may also be present and contribute to the total alkalinity.

Careful control of alkalinity helps the beverage manufacturer to achieve a high degree of uniformity in his products. Excessive alkalinity tends to neutralize the acid in certain types of soft drinks; and this usually results in a variation of flavour, tang, taste, or a reduction in the shelf-life of the beverage.

Each manufacturer sets his own limits on alkalinity with 80 ppm as $CaCO_3$ being generally considered an upper limit for most soft drinks. However, standards as high as 110 ppm and as low as 20 ppm have been cited.

Alkalinity may be reduced by adding lime or by ion exchange methods to remove calcium and magnesium bicarbonates followed by coagulation, sedimentation, and filtration processes. "The alkalinity of most natural waters is considered to be equal to the carbonate hardness"[11].

3.2 Treatment Equipment

The amount and type of treatment applied to water used in soft drink manufacture is largely governed by the quality of the incoming water. However, a very common arrangement of water treatment equipment is as follows:

a) Chemical feeders for treating water with such chemicals as ferrous sulfate (copperas), alum, lime, and hypochlorite.
b) Cold lime process water-softener.
c) Sand or calcite filters.
d) Activated carbon filters.
e) Polishing filter for special problems.

In addition to treating process water, many companies find it advisable to soften at least part of the water used for bottle washing.

The individual treatment units such as filters, softeners, etc., used for the conditioning of water are often marketed by individual manufacturers as "package plants". Typical package plants with capacities of 6,000 to 10,000 imp. gpd will cost approximately $10,000 and $12,000, respectively[3].

4 WATER CONSUMPTION

The principal uses of water in a soft drink plant are:

a) Bottle or can washing.
b) Syrup mixing (provided the syrup is mixed on site rather than being imported).
c) Process water (usually demineralized and carbonated) that is, incorporated into the final product.
d) Filter backwashing.
e) Cleaning of syrup vats and mixing tanks.
f) General plant sanitation, washrooms, etc.
g) Boiler feed and cooling water.

An estimated 65 to 70 percent of the total plant intake is used for bottle washing while 10 to 25 percent is incorporated into the final product. The balance is used for filter back-washing, boiler feed, cooling, and general sanitation. Those plants with their own syrup mixing facilities tend to incorporate close to 25 percent of the plant intake into the final product while those using imported syrup incorporate a lower percentage (sometimes as low as 10 percent).

Depending on the methods of manufacture, anywhere from 4 to 10 imperial gallons of water may be used to produce one gallon of soft drink. It is believed that the upper limit of 10 gallons reflects a high consumptive use of water for such purposes as cooling, filter backwashing, and bottle washing. Water intake at the Newfoundland plants visited[8] varied from 5.1 to 10.4 gallons per gallon of product.

Very little water is recycled or re-used in soft drink plants. An exception to this could be the caustic soda cleaning solutions which may be screened to remove suspended solids, strengthened, and re-used. Similarly, cooling water may be used for other purposes such as bottle washing in some plants. Variations from plant to plant make it virtually impossible to establish meaningful figures on the re-use of water.

It may be seen from the foregoing that efforts to conserve water in soft drink plants will be most successful if reductions in bottle washing can be achieved. To this end, significant savings in water consumption have been realized through the substitution of cans for bottles. Bottles returning to a soft drink plant from the consumer require a thorough cleaning and rinsing whereas new cans only require a token rinse. Other advantages are claimed for cans:

i) They occupy less space than bottles of comparable volumetric content.

ii) Handling costs associated with empty bottles are eliminated.

iii) Convenience to the consumer who is spared the task of returning "empties".

The use of cans in lieu of bottles has increased at an accelerated rate in recent years, largely because of the advantages cited above. One large Canadian beverage firm[4] advises that 17 percent of their 1967 output was put in cans, and that this represented an increase of about 500 percent over the comparable 1965 figures. It has been estimated that a 10 percent water reduction in overall plant intake was realized by using cans to the extent of 17 percent as compared with a 100 percent bottling operation.

5 WASTEWATER

Wastewaters in soft drink plants originate from the following operations:

a) Bottle and can washing
b) Filter backwashing
c) Bottom deposits from sedimentation tanks used for treating water
d) Washing of syrup mixing and storage vats
e) General plant sanitation, washrooms, etc.

Item d) would not apply to plants which import syrup from an outside source. Similarly, item c) does not apply to all plants.

From 75 to 90 percent of the fresh water entering a soft drink plant is subsequently discharged as wastewater. Of the total wastewater volume, usually 80 to 90 percent results from bottle washing operations.

Bottle washers usually have separate compartments for pre-rinsing, alkaline cleaning solution, and final rinsing. The preliminary and final rinse compartments discharge wastewater continuously while the alkaline cleaning compartment discharges only intermittently. Wastewaters resulting from the cleaning of syrup tanks and filter backwashing are also discharged on an intermittent basis. Spent alkaline cleaning solutions invariably have a high pH and should be diluted or neutralized before being discharged to a municipal sewer. Failure to do this could seriously upset a sewage treatment plant employing biological processes. To guard against this eventuality, spent cleaning solutions may be stored in a separate holding tank from which they may be discharged continuously or intermittently so as to achieve maximum dilution.

In general, the wastewaters from soft drink plants are alkaline in nature and moderately high in both suspended solids and BOD.

Porges[5] conducted a study on the wastewaters of three medium to large bottling plants and reported the following:

i) pH range - 10.0 to 11.4

ii) BOD range - 250 to 660 ppm with an average of 430 ppm (the lower figure was applicable to the largest establishment).

iii) Suspended solids range - 160 to 340 ppm with an average of 220 ppm.

iv) Total alkalinity - 220 ppm as $CaCO_3$ average.

v) Wastewater quantities - 3 to 11 imperial gallons per gallon of product with an average of 6 gallons.

Most soft drink plants discharge their wastewaters to municipal sewers without treatment except for screening to remove the largest of the suspended solids. In some situations, the spent cleaning solutions may be neutralized or diluted so as to reduce their pH.

The production of soft drinks is to a degree seasonal in Canada with the result that sewers and treatment plants which serve them must be designed with this factor in mind. This is particularly applicable to small soft drinks plants which may close down for brief periods during the winter months. During the warmer months, the larger plants may exceed their average annual production rate by some 25 to 50 percent; smaller plants may experience increases greater than 50 percent of average annual production.

6 SUMMARY AND CONCLUSIONS

a) In the production of soft drinks, from 4 to 10 imperial gallons of water are used to manufacture 1 gallon of product. About 65 to 70 percent of this water is used for bottle and can washing, 10 to 25 percent is incorporated into the product, and the balance is used for such purposes as general plant sanitation and washrooms, cooling, filter backwashing, and boiler feed.

b) Production of many soft drink plants is quoted in "cases" when a case consists of 24 bottles of varying volumetric content. Where bottles of 6.5 US fluid ounces are used, a case contains about 1.0 imperial gallons of product. To avoid confusion resulting from variations in bottle size, gallons of product rather than cases have been used in this report.

c) In recent years, the increased use of cans and non-returnable bottles in place of returnable bottles has tended to reduce water intake for bottle washing. Since the trend towards the use of cans and non-returnable bottles has been steadily increasing in recent years, it is expected that the water intake of future plants may be less than the quantities quoted in a) above.

d) Wastewater volumes from soft drink plants are usually 10 to 25 percent lower than the water intake largely because of the quantity of water that is incorporated into the final product.

e) Soft drink plants tend to locate in urban centres for the following reasons:

   i) Urban centres are the major outlets for their products. By locating in those centres, the costs of bringing products to markets are minimized.

   ii) Availability of municipal water eliminates capital expenditures associated with the development of private water supplies.

   iii) Availability of municipal sewers provides a convenient outlet for wastewaters.

f) It has not been possible to develop figures to show the effect of an increased water cost on water intake. However, it is felt that nominal increases in water cost (10 percent) are not likely to affect the water intake to a significant degree since current water costs only amount to a fraction of 1 percent of the selling price of the product.

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SIMPLIFIED FLOW CHART FOR SOFT DRINK PLANT

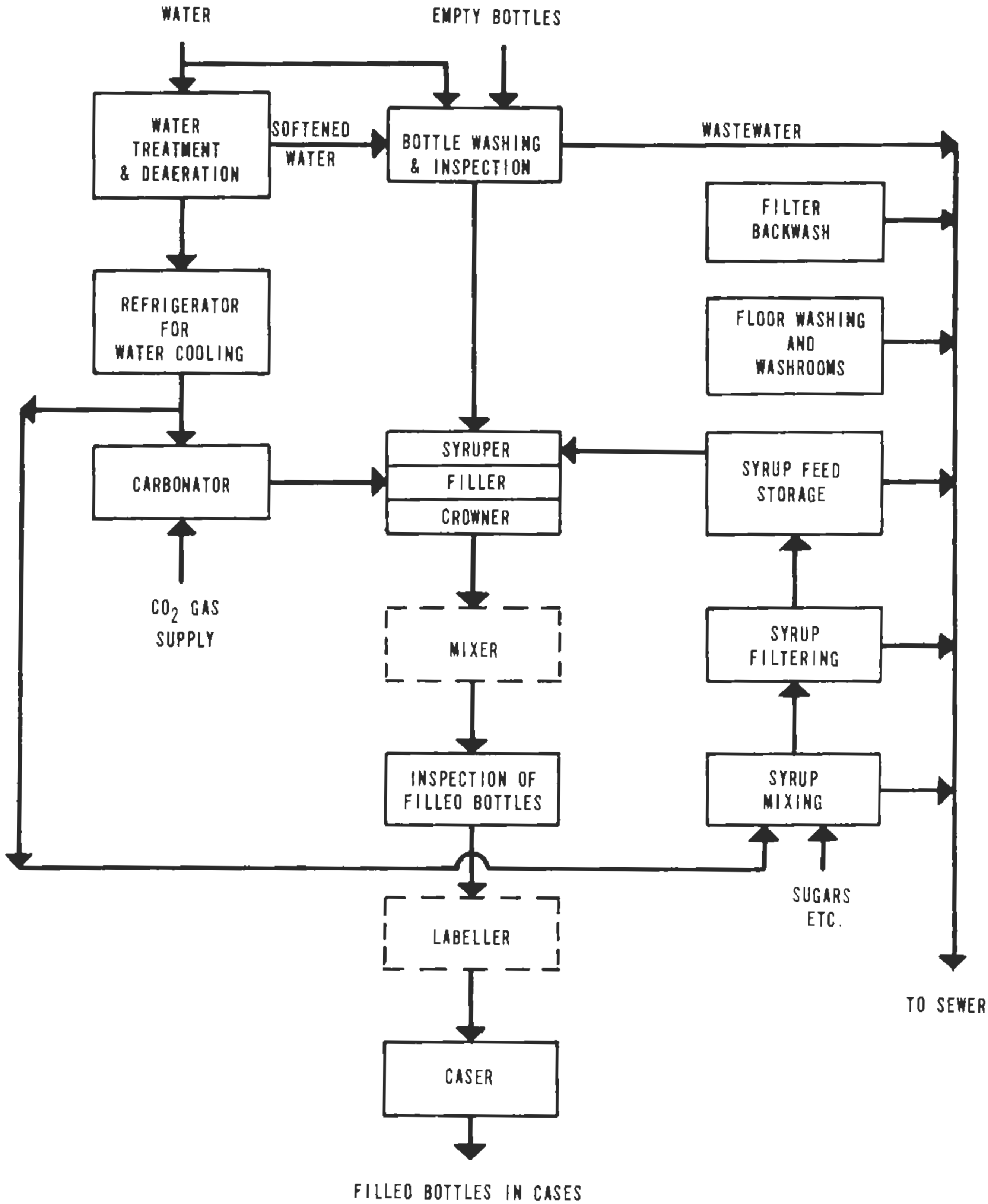

FIGURE B.IV-1

PART V - THE REDUCTION OF ALUMINA TO ALUMINUM

1 INTRODUCTION

Aluminum oxide or alumina (Al_2O_3) comprises an estimated 15 percent of the earth's crust, ranking second only to silica in abundance. Ore reserves of this most abundant of all metallic elements are therefore virtually unlimited. Bauxite, the most important of the aluminum ores, contains over 50 percent alumina and is found mainly in tropical areas. Because of its low density, its strength, conductivity, and ductility, aluminum by itself or alloyed with other metals serves many uses that range from packaging foil to machinery and aircraft.

The production of aluminum from bauxite is usually carried out in two basic stages:

a) The manufacture of anahydrous aluminum oxide (called alumina, Al_2O_3) from bauxite ($Al_2O_3 \cdot x H_2O$).

b) The electrolytic reduction of alumina to aluminum.

This report will investigate the in-plant water requirements of the latter process. Water used for the generation of electrical power is not included in this study, but its importance is worthy of mention thus:

i) From 6 to 9 kwh of electrical energy are needed to produce 1 pound of aluminum[1].

ii) The current selling price (June 1968) of aluminum is 27.5¢ Canadian per pound[2].

iii) If the price of electrical energy were 1¢ per kwh, it may be seen from the foregoing that electricity costs could amount to about 25 to 30 percent of the selling price.

Because electrical power is so vital in the electrolytic reduction of alumina, it is customary to locate reduction plants where relatively cheap power is available.

Essentially all aluminum today is manufactured from alumina by the Hall-Heroult or the Soderberg processes. In both processes alumina is dissolved in a molten bath of cryolite (3 Na F . Al F_3) and electrolyzed to liberate aluminum at the cathode and oxygen at the anode; the oxygen reacts with the carbon anode to form carbon dioxide and/or carbon monoxide which are liberated to the atmosphere. Gaseous fluorides are also liberated during the electrolysis of alumina, and these can have toxic effects on surrounding livestock and vegetation if allowed to escape to the atmosphere. Most plants combat this by scrubbing the gases with water to remove some 90 to 99 percent of the fluorides. The alumina reduction process is shown schematically on Figure BV-1.

2 INDUSTRY SIZE AND GROWTH

The aluminum industry has expanded tremendously since the turn of the century as indicated by the following US production figures:

Year*	Output (tons)
1913	24,000
1938	143,000
1943	920,000
1952	937,000
1964	2,552,000
1975 (estimated)	7,200,000

* Total production in the western world in 1961 was estimated at 4,700,000 tons.

In the western world, Canada ranks second to the US in aluminum production with the following outputs recorded in recent years:

Year	Output (tons)
1965	840,348
1966 (record year)	1,115,000
1967	1,104,000

Over 80 percent of the aluminum produced in Canada is exported. Although a drop of 1 percent in output was experienced in 1967 as compared with the record output of 1966, the world demand for aluminum is increasing, and this slight downward trend is not expected to continue.

3 WATER QUANTITY REQUIREMENTS

Recent surveys[3, 4] reveal that from 1 to 30 imperial gallons of water are commonly used at reduction plants to produce one pound of aluminum. Approximately 12 gallons per pound would appear to be average. Plants located near the ocean may use as much as 100 gallons per pound with 90 percent of this being sea water[4].

From the foregoing, it may be seen that a plant using 12 gallons per pound of product and turning out 100,000 tons of aluminum per year would require almost 7 million imp. gpd.

In spite of the wide variation in water consumption from plant site to plant site, the following breakdown of in-plant usage is believed to be fairly representative of most complexes:

Water Use	Percent of Total Intake
Gas scrubbing	72
Rectifier and transformer cooling	12
Sanitary and plant services	8
Boiler feed	4
Electrode plant	2
Engine cooling	1
Compressor cooling	1
	100

Appreciable variations from the foregoing percentages may apply at some reduction plants while at others, water may be required for additional uses. For example, plants located near abundant water supplies may use over 90 percent of the total plant intake for gas scrubbing. Still other plants may use as much as 2 percent of the total water intake for quenching cast billets and pigs.

From the foregoing it may be seen that gas scrubbing is by far the largest consumer of water at alumina reduction plants. Whether this wastewater is cooled and re-used or not accounts largely for the variation in water intake. Conklin's[3] survey covering all reduction plants in the United States revealed the following:

a) One plant with an abundant water supply used 24 gallons per pound of aluminum (95 percent of total intake) for gas scrubbing alone. A second plant using water from cooling ponds used only 3 percent of its intake amounting to 0.04 gallons per pound of product for gas scrubbing. If both plants achieved comparable air pollution control as is claimed, then the concentration of fluoride in the one effluent would be 700 times the other.* These extreme cases point up the difficulty in accurately predicting water requirements and wastewater characteristics for alumina reduction plants.

b) Transformer and rectifier cooling, the second largest consumer of water after gas scrubbing, showed a variation in water consumption from 0.6 to approximately 8 gallons per pound of product. The plant with the minimum water consumption recirculated its water through an air-cooled heat transfer unit, and the other presumably ran the water once through the system and then wasted it.

c) No fixed pattern of water re-use and recycle was detected. Plants situated near abundant water supplies which required little or no treatment tended to use the water once and waste it rather than to pump it to another location for treatment and re-use. Other plants with limited water supplies or with waters that required extensive treatment practised extensive re-use.

* However, fluoride recovery from wastewater is sometimes practised.

It would appear from the foregoing that availability of water above all else dictates the quantity actually used in an alumina plant. Furthermore, it does not appear possible to make any general statements about the reaction of the industry as a whole to an increase in water costs. Rather, it is believed that each plant would react differently depending on the actual amount of the increase. Consider, for example, two reduction plants with similar production outputs, each of which bought water at 10¢ per 1,000 gallons; further, assume the water intake of one to be 12 gallons per pound of product and the other 24 gallons. It may be deduced from this that water costs amount to 1/8¢ per pound of product for one plant and 1/4¢ per pound for the other. With the selling price of aluminum now set at 27.5¢ per pound, a minor increase in water costs (say 10 percent) is not likely to result in major changes in intake water quantities at either plant. A doubling of the water costs, on the other hand, could conceivably induce both plants to reduce their water intake.

4 WATER QUALITY REQUIREMENTS

Water used for gas scrubbing and cooling requires very little treatment in most cases and instances are cited where both fresh and brackish water have been employed for these purposes[3]. If the raw water is highly turbid, treatment by coagulation and sedimentation may be justified. In addition, unstable waters may require treatment to reduce their scale-forming or corrosive characteristics.

Potable water is required for human consumption and the same water is often degasified and softened to render it suitable for use as boiler feed makeup.

Most plants chlorinate all or part of their water intake to ensure satisfactory bacteriological qualities. Water used at some complexes requires additional treatment such as sedimentation and filtration.

5 WASTEWATERS

Sources of wastewater in alumina reduction plants include the following:

Cooling waters (thermal pollution)
Effluents from gas scrubbing equipment
Sanitary sewage

5.1 Cooling Waters

Cooling waters which pass once through a heat exchanger before being run to waste may have adverse effects on the receiving bodies of water due to their elevated temperatures. Adverse effects of this type may be termed "thermal pollution" for purposes of this discussion. Objections to thermal pollution arise from the fact that it reduces the dissolved oxygen saturation level of receiving waters and thereby retards the natural forces of self-purification. At the same time, elevated water temperatures may stimulate undesirable growths of algae and bacteria while hindering the growth of certain beneficial aquatic organisms. Cooling towers are frequently used to control thermal pollution since they offer two distinct advantages:

a) Thermal pollution is essentially eliminated by means of an inherent water recycle system. That is, water is continuously recycled and re-used for cooling purposes rather than being wasted after going once through the system.

b) Water intake for cooling purposes is reduced to approximately 1/30 of that required in a once-through system.

Because of the moderately high capital costs associated with cooling towers, it would appear that their use in the aluminum industry has been limited to water-scarce areas.

5.2 Gas Scrubbing

The electrolytic reduction of alumina liberates various "off-gases", mainly carbon monoxide, carbon dioxide, and fluorine (usually as hydrogen fluoride).

The concentration of fluorides in these "off-gases" has been reported to be in the region of 0.1 to 0.2 percent, comparable to a discharge rate of approximately 0.015 to 0.03 pounds of fluorine per pound of aluminum[5,6].

In the casting operations that follow electrolysis, it is customary to employ a purge gas (usually chlorine) to prevent formation of hydrogen bubbles in the billets or other cast products.

The foregoing halogens (chlorine and fluorine) if discharged to the atmosphere can be highly toxic to nearby animal and plant life. Accordingly, it has become customary to dissolve the fluoride in water at most plants and in some instances, to scrub the chlorine also. At the moment, however, it would appear that only the largest reduction works or those situated fairly close to populated areas remove chlorine with scrubbers.

Various scrubbing devices have been developed for the aluminum industry over the years and the ones currently in use are capable of removing from 90 to 99 percent of the halogens emitted.

Some scrubbers have been designed to operate on relatively low water flow rates while others operate on much higher rates. The former have been reported to turn out effluent wastewaters with a content as high as 20 grams of fluorine/liter[7].

A 1952 survey[3] of all reduction works in the United States showed that water used for gas scrubbing varied from approximately 0. 04 to 23 gallons per pound of aluminum produced. It is believed that the plant using minimum water for scrubbing practised extensive water recycling and water re-use.

The scrubbing of gases containing fluorine and chlorine gives rise to acidic wastewaters which may or may not be treated depending on plant location. For example, plants located near the ocean may use large quantities of salt water for scrubbing so as to discharge a highly diluted waste with a relatively low fluorine concentration. Alternately, scrubber wastewaters may be discharged to holding ponds or thickener tanks where lime is added to neutralize the acids. The resulting sludge which is precipitated (mainly calcium fluoride) may or may not be dewatered before being disposed of by burial in landfill sites. The effluent from this neutralization treatment may be discharged to waste or may be re-used for gas scrubbing.

In those plants where chlorine gas is removed by scrubbing, the resulting wastewater is often discharged without further treatment or in some instances, may be treated by a thiosulphate reduction method. In this process, chlorine gas is scrubbed with a solution of sodium hydroxide, most of which is recycled. The discarded portion is treated with sodium thiosulphate to reduce sodium hypochlorite to sodium chloride after which it is discharged as "salt water".

At some plants fluorine is recovered for re-use in the electrolysis process, but this practice is by no means universal. This involves scrubbing of the gases with aqueous sodium hydroxide to produce sodium fluoride solution; the sodium fluoride is then reacted with sodium aluminate to precipitate cryolite.

The quantity of wastewater generated at an alumina reduction plant is usually equal to or slightly less than the water intake. (This was quoted earlier as varying from 1 to 30 gallons per pound of aluminum with about 12 gallons being average).

Plants having limited water supplies are forced to recycle and re-use both cooling water and gas scrubber effluents. Under these circumstances appreciable quantities of water are lost to the atmosphere as steam and the wastewater quantities may drop to a small fraction of the total water intake. Cases are cited[3] where approximately 80 percent of the plant's water intake is lost as steam to the atmosphere from cooling towers and scrubbers leaving only 20 percent of the intake as wastewater. (The foregoing figure of 80 percent might appear at first glance to represent a very sizeable volume of water lost through evaporation. In order to keep the statement in proper perspective, it should be recalled that cooling tower systems require only 1/30 the volume of water used by once-through systems.) It follows from the foregoing that wide variations in wastewater quantities per unit of production may be expected from plant to plant depending on such factors as:

a) Availability of water, which affects intake volume.

b) The degree of re-use and recycle that is practised.

c) Types of gas scrubbers that are employed.

d) The amount of air-cooled equipment used.

e) Quantity of water lost as steam to the atmosphere.

6 SUMMARY AND CONCLUSIONS

a) Surveys have shown that the water requirements of aluminum reduction plants vary between 1 and 30 gallons per pound of product with 12 gallons being considered a reasonable average.

b) Availability (or non-availability) appears to be the major cause of water intake variations. In areas where water is relatively scarce, extensive recycling and re-use of water may be practised, whereas in areas of abundance (near the ocean) less recycle is noted.

c) The cost of water to a plant whose intake is 12 gallons per pound or less will generally be less than 1 percent of the selling price of aluminum. Accordingly, it is believed that minor increases in water cost (say 10 percent) would not affect intake to any significant degree. Major changes such as a doubling of water costs could conceivably result in certain plants introducing water conservation measures. It is extremely difficult to generalize on this point for the industry as a whole.

d) With the increased emphasis that is being place on pollution control, it is expected that future plants will be designed to minimize water intake through the use of air-cooled equipment and scrubbers with low water requirements.

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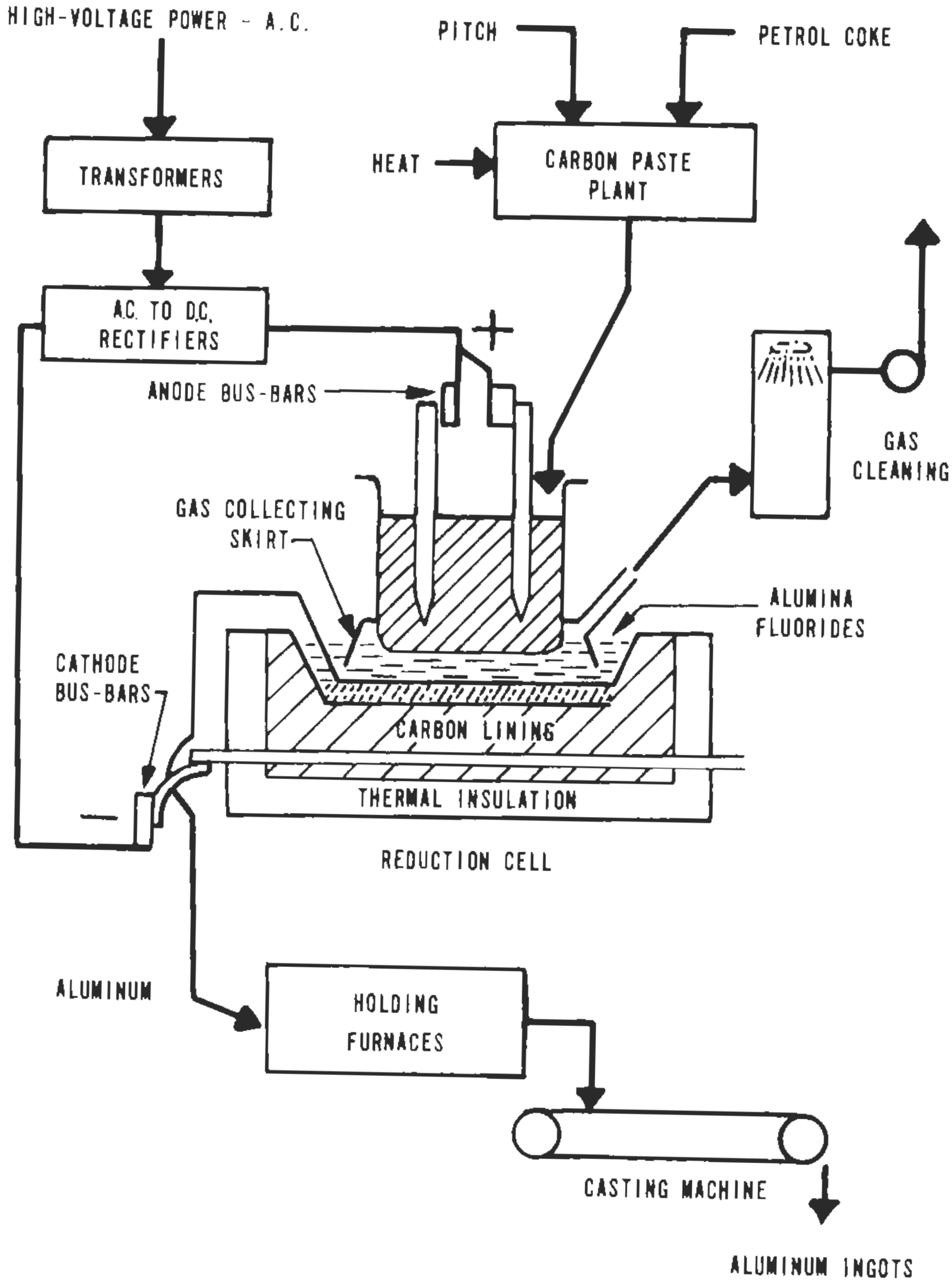
ALUMINUM REDUCTION FLOW SHEET



NOTE: THIS FLOWSHEET IS BASED ON THE SODERBERG SYSTEM

FIGURE B.V.-1

PART VI - THE OIL REFINING INDUSTRY

1 INTRODUCTION

The petroleum industry can be broken down into four phases of operation, viz:,

a) Mining of the crude oil.
b) Transporting of crude to refineries.
c) Refining of crude.
d) Marketing of saleable products.

This study is concerned only with the water requirements of the refining phase.

During the past twenty years, petroleum refining in Canada has experienced an average annual growth rate of 9.2 percent[1]. Statistics for 1964 indicate that it ranked third among Canadian industries with the gross value of its products being approximately $1,371,340,000[1]. It is expected that the industry will closely follow its present growth pattern in view of continuing expansions in the automotive, aircraft, railway, and allied industries as well as the continuing role of fuel oil in the heating of houses and other buildings.

Prospects for expanding the refining industry in Newfoundland appear to be very bright with plans being prepared for a $100 million refinery at Come By Chance[2]. With a rated capacity of 100,000 barrels per day, this complex is expected to be in operation within the next 2 to 3 years. (In the petroleum industry, one barrel contains 35 imperial gallons.) The only refinery in Newfoundland at present is the 10,000 barrel per day plant operating at Holyrood, some 30 miles west of St. John's.

Explorations are also underway for oil and gas deposits in Newfoundland which, if productive, would further boost the Province's economy.

2 PROCESS

Petroleum crude generally consists of 83 to 87 percent carbon, 11 to 14 percent hydrogen and, from trace quantities to 3 percent oxygen, nitrogen and sulphur. Other materials (both organic and inorganic) which are found in crude oil from time to time generally exist in trace quantities. In spite of this fairly narrow range of composition, a wide variety of products and product-yields from crude oil is possible. Some of the more common products from refineries are: gasoline, kerosene, lubricants, fuel oils, wax, asphalt, petroleum coke, insulating oils, insecticides, cutting oils and "raw materials" for a variety of chemical and petro-chemical companies.

Variations in refinery design are noted from one complex to another depending on the end-products desired and the quality of the crude oil being processed. For example, crude oil that is low in sulphur (termed "sweet crude") generally requires less refining than a crude with a relatively high sulphur content. Broadly speaking, the principal refinery processes are: distillation, cracking, polymerization, and alkylation. One or more of these processes may prevail at any given petroleum refinery.

Distillation is carried out at a "skimming" or "topping" refinery and involves the breakdown of crude into such products as gasoline, kerosene, fuel oil, gas oil, and reduced crude. Cracking involves the breakdown of very large organic molecules into smaller molecules to improve the yield of common products, such as automotive gasoline. The processes may depend largely on heat and/or catalysts.

Polymerization is the process of combining two or more unsaturated molecules into a larger molecule; it is used chiefly to convert gaseous products of the cracking process into high grade automotive and aviation fuels and to produce raw materials for petro-chemical complexes. Alkylation is similar to polymerization except that one of the re-acting molecules is saturated; like cracking, alkylation is thermally and/or catalytically induced.

Prior to being marketed, all refinery products are treated to remove impurities such as sulphur, gums, and other materials. The most common purification processes are:

a) treatment with an acid or caustic soda,
b) oxidation sweetening,
c) copper sweetening,
d) solvent extraction,
e) treatment with clay.

3 WATER USES

According to a 1956 survey[3] of refineries in the United States, the water used at oil refineries was as follows:

Purpose	Water Quantity Percent of Total Intake
Cooling	91
Boiler Feed	5
Fire protection, plant sanitation, washrooms, miscellaneous	4

In recent years, the newer refineries have reduced their cooling water requirements through increased use of air cooling and/or the use of cooling towers in lieu of once-through systems. Two interesting examples in support of the foregoing have been cited by Gotts[4]:

a) The Imperial Oil Refinery at Sarnia, Ontario was recently enlarged from a rated capacity of 100,000 to 130,000 barrels per day. In spite of this 30 per-cent increase in capacity, the total water intake of the enlarged complex is known to be less than that of the original one.

b) A comparison of two Shell Oil Refineries, one at Corunna, Ontario (built in the 1950's) and one at Oakville, Ontario (built in the 1960's) shows that the newer complex uses less than one-half the water (per barrel of processed crude) of the older plant.

4 QUANTITIES OF WATER

According to a 1942 survey[5] of 41 refineries in the Ohio River basin, the volume of water used in processing one barrel of crude oil generally exceeded 700 imperial gallons. In recent years improvements to refinery designs have reduced this figure to an average of approximately 330 gallons; many present day refineries use more water, however, and tenfold variations from 85 to 850 gallons per barrel have been cited[6]. Various reasons are given for the tenfold variation in water usage including the following:

a) Availability of water. Refineries located near the ocean or large lakes tend to use much more water than those located in arid regions.

b) Process used. Refineries with cracking processes generally use more water than those with non-cracking processes.

c) Types of cooling equipment used. Refineries constructed in the past decade generally use more air-cooled equipment and more cooling tower systems than older refineries; consequently their water requirements will be substantially lower.

d) The degree to which water is recycled and re-used.

e) The quality of the water. For example, raw waters with scale-forming tendencies might be dismissed as a means of cooling in favour of air-cooled equipment.

Two refineries having exceptionally low water intake requirements have been reported in the literature[12, 13]:

Sun Oil Refinery at Toledo, Ohio
(cap. 95,000 barrels per day) - 44 imperial gallons per barrel of crude processed

Shell Oil Refinery, Oakville, Ontario
(cap. 32,000 barrels per day) - 23 imperial gallons per barrel of crude processed

Newfoundland's only refinery at Holyrood has reported a water intake of approximately 248 Imperial gallons per barrel of crude processed[14].

A 1960 survey[6] conducted by the American Petroleum Institute covering 182 refineries in the USA revealed the following:

i) 52.2 percent of the total water used by the refineries came from fresh water sources (45 percent from surface supplies and 6.5 percent from wells). The remaining 47.8 percent was either salt water, brackish water, or treated sewage. Three refineries used effluent from municipal sewage treatment plants.

ii) On an average, water was used 3.5 times before being discarded as wastewater (stated another way, 3.5 times as much water would have been used if no recycle and re-use had been practised).

iii) If the refineries had chosen to use only fresh water, and if they had practised no recycle or re-use, 6.62 times as much fresh water would have been used.

iv) Approximately two-thirds of the wastewaters from refineries were discharged into rivers and almost one-third to the ocean. Relatively small quantities were discharged to fresh water lakes or into deep wells.

v) Between 1949 and 1959, the capacity of US refineries increased by 93 percent but the volume of fresh water used only increased by 21 percent. No data were given on increases in the use of saline or brackish water during the same period.

5 WATER QUALITY

Generally, oil refineries are far more concerned with the quantity of available water rather than its quality. However, certain qualities are desirable as indicated in the succeeding paragraphs.

Cooling waters used in once-through systems should be free of sediments, debris, and slime growths that could clog pipes.

Sediments and debris may be removed from turbid waters by screening and/or sedimentation while algae and slime growths are generally suppressed by chlorination.

Recirculated cooling waters should be non-corrosive, non-scale forming and generally conform to the following[7]:

Hardness as $CaCO_3$	-	not greater than 50.0 mg/l
Iron as Fe	-	" " " 0.5 mg/l
Manganese as Mn	-	" " " 0.5 mg/l
Iron plus Manganese	-	" " " 0.5 mg/l
Turbidity as SiO_2	-	" " " 50.0 mg/l

The usual path followed by recirculated cooling water is: cooled water is passed through heat exchangers and is warmed by the product being cooled; the water is then pumped through a cooling tower where its temperature is lowered by heat exchange with air and by evaporation of a small percentage of the water (usually less than 4 percent). Contact with the air results in the water picking up dissolved oxygen which could accelerate corrosion of the system; to minimize this tendency, the water is de-aerated or treated with corrosion inhibitors such as chromates or phosphates.

After the waters have been recirculated a number of times, the concentration of dissolved materials increases due to the evaporation of relatively pure water from cooling towers. This build-up of dissolved materials causes increased corrosion or the formation of scale. To reduce these corrosive and scale-forming tendencies, a portion of the recirculated cooling water (termed "blowdown") is continuously discarded and replaced with makeup water of lower dissolved solids content.

Waters used in boilers are invariably treated to reduce the dissolved solids and dissolved gases to satisfactory levels. The extent to which dissolved solids must be removed depends on the boiler's operating pressure. The table below[7] is considered to be a reasonable guide in this respect:

Boiler Operating Pressure (psi)	Permissible Dissolved Solids Level (mg/l)	Permissible Alkalinity (mg/l)
0-300	3500	700
600-750	2000	400
1000-1500	1000	200
2000 and higher	500	100

Boiler waters are generally treated by means of degasifiers and ion exchange softeners. In addition, a variety of chemicals may be added including:

Antifoam agents

Nitrates and tannins to prevent caustic embrittlement

Phosphates and chromates to reduce corrosion and scale deposits.

6 REFINERY WASTEWATERS

The wastewaters generated at oil refineries result from several processes and operations; consequently, they tend to vary widely in chemical makeup. Some of the more common pollutants include oil, phenols, sulphides, dissolved solids, suspended solids, toxic metals, and various substances which exert a biochemical and chemical oxygen demand. In addition, pollution often is catalyzed through the elevated temperatures of cooling waters. Some of the more common wastewaters and their pollutants are briefly described in the tabulation below.

In recent years there has been a tendency to categorize refinery wastewaters as follows:

Clean Water
Potentially Oily Water
Oily Water
Others

6.1 Clean Water

Clean water results from cooling systems whose design does not permit contact between coolant and process fluid. Usually this is achieved by maintaining the coolant pressure above that of the process.

6.2 Potentially Oily Water

Some cooling waters may pick up a variety of chemical pollutants such as phenols, sulphur, and nitrogen compounds from process leaks at heat exchangers or from air contact while passing through cooling towers. Usually the concentration of these chemical pollutants will be less than 1 mg/1; but, in case of breakdowns in heat exchanger, concentrations in excess of 1,000 mg/1 can result.

In case of systems that include cooling towers, cooling waters are usually treated with corrosion inhibitors, algacides, biocides, and other chemicals both organic and inorganic. The concentration of these various chemicals in the cooling tower blowdown is usually between 1 and 100 mg/1[8].

6.3 Oily Water

Oily waters result from a number of operations and processes of which the most common are given below:

6.3.1 Crude Oil Handling

These wastewaters result mainly from clean-up of leaks in transfer lines, accidental spills, ballast water, etc.

6.3.2 Processes

These wastewaters result from such processes as desalting of crude oil, fractional distillation, cracking, alkylation, and polymerization.

6.3.3 Miscellaneous

This category includes wastewaters from building clean-up and maintenance, fire fighting, recovery units, caustic scrubbing, all of which exhibit a highly variable makeup.

6.4 Other Wastewaters

Wastewaters which do not fall into the foregoing three categories include sanitary wastes and boiler room wastes. Most of these wastes may be discharged to municipal sewers if the refinery is located near such facilities.

Sanitary wastes result from the operation of cafeterias, washrooms, locker rooms, etc, and are essentially like "domestic sewage".

Boiler room wastes include boiler blowdown, waste condensate, effluents from ion exchange regenerators, and water softeners. The pollutants in the wastewater include a number of inorganic and organic chemicals such as phosphates, sulphates, nitrogenous compounds, acidic and alkaline materials, all of which appear in highly variable concentrations.

The precise nature of the pollutants present in wastewaters also depends on the composition of the crude oil and on the processes employed by the refinery. For example, "sweet crudes" (low sulphur content) give rise to wastewaters that are low in sulphur compounds; cracking processes produce more phenols than non-cracking processes. The concentration of pollutants in different wastewaters is principally dependent on the volumes of process steam, process water, and cooling water used. Plants using large amounts of stripping steam and once-through cooling systems will generate larger flows of wastewaters than plants designed to use minimum stripping steam and a maximum number of air-cooling devices.

6.5 Wastewater Volumes

In most refineries, cooling waters account for the bulk of the wastewater generated. This is especially true of coastal plants whose location permits them to use essentially unlimited quantities of saline water in once-through cooling systems. By comparison, inland refineries employing cooling towers and/or some air-cooled equipment normally use substantially less cooling water than coastal plants and hence, generate proportionately less wastewater.

It was pointed out in Section 4 that North American refineries use from 85 to 850 gallons of water per barrel of crude oil processed. In general, the volume of wastewater will be slightly less (perhaps some 3 percent less) than this quantity due to evaporation losses.

For inland refineries that do not use saline waters for cooling purposes, Freedman[8] has indicated that some 40 to 80 percent of the wastewater volume results from cooling processes. The balance is distributed approximately as follows:

Steam equipment including boiler blowdown, ion exchange regeneration, rinses following acid cleaning of equipment, etc	5-10 percent
Sanitary wastes	1-10 percent
Miscellaneous cleaning, plant maintenance (including oily wastes)	10-25 percent

In the case of coastal refineries using large volumes of sea water and once-through cooling systems, the cooling water generally accounts for more than 90 percent of the wastewater volume.

6.6 Wastewater Treatment

Apart from the elevated temperatures of the cooling waters (often called thermal pollution), the major pollutants in refinery wastewaters are:

Suspended solids
Oils
A variety of dissolved chemicals (both organic and inorganic)

Various treatment methods have been devised for handling refinery wastewaters and these are generally categorized as follows:

In-plant pre-treatment
Primary treatment (usually achieved by American Petroleum Institute separators or similar devices)
Secondary treatment

Possibly the most common facilities for in-plant pre-treatment are neutralizing tanks for adjusting the pH of certain wastes (spent caustic solutions) and sour water strippers for removing ammonia, mercaptans, and hydrogen sulphide from aqueous solutions. Spent caustic solutions are normally neutralized with sulphuric acid or flue gases containing carbon dioxide and sulphur dioxide. Sour waters are steam-stripped of their ammonia and hydrogen sulphide by passing them downward through a packed or trayed tower while steam is continuously forced upwards. Sulphur compounds and ammonia are produced in this way for use in other areas.

Primary treatment at oil refineries generally implies the removal of oils and suspended solids in API gravity-type separators. These separators are large settling basins (usually with an inlet bar, screen and oil sump) suitably baffled to take advantage of the difference in specific gravity between water and oil. Oil is removed from the surface for processing, settleable solids are scraped from the bottom for final disposal, and primary effluent flows to secondary treatment units for removal of dissolved solids as well as oil and suspended solids that were not trapped in the primary tank.

A number of methods have been devised for achieving secondary treatment of primary effluents. The more common of these include:

Flotation units

Biological processes (trickling filters, activated sludge plants, oxidation ditches and lagoons)

Chemical coagulation

Chemical oxidation

It should be noted that flotation units and coagulation tanks remove oils and suspended solids only. Biological processes, on the other hand, remove some dissolved solids by oxidation as well as oils and suspended solids.

Several sludges result from primary and secondary treatment methods including:

Primary sludge from chemical coagulation tanks and flotation tanks.

Sludge from chemical coagulation tanks and flotation tanks.

Microbial sludge from biological processes.

These are generally disposed of by one or more of the following methods:

Incineration.

To drying beds followed by burial of the dried sludge.

Anaerobic or aerobic digestion followed by burial.

Wet oxidation (Zimmerman process).

Centrifuging followed by burial or incineration of dried sludge.

A limited number of aqueous wastes (spent caustic solutions and phenolics) are sometimes disposed of by injection into deep wells. This method is by no means universal and is restricted to areas where sub-surface geology prevents or greatly reduces the possibility of groundwater contamination.

6.7 Wastewater Treatment Costs

Very little has been reported on the cost of refinery wastewater treatment. However, Quigley and Hoffman's[10] figure of approximately 14¢ per 1,000 Imperial gallons of effluent are believed to be reasonably representative. This figure does not include amortization costs, but does include the cost of labour, maintenance, chemicals, and utilities as required for operating a secondary treatment plant.

Eisenhauer[11] has reported that the chemical oxidation of phenol with hydrogen peroxide in combination with a ferrous iron salt costs approximately $2.40 per pound of phenol destroyed.

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PART VII - MINING AND CONCENTRATING

1 INTRODUCTION

1.1 Scope of Study

In mining, geological, and metallurgical circles the most common base metals are lead, zinc, and copper. This report will investigate water usage associated with the mining and concentrating of these three base metals and the comparable water usage for iron ore mining and concentrating. The water requirements of the smelting and refining processes will not form part of this study.

1.2 Newfoundland Mining

The first mine of importance in Newfoundland (on Bell Island) was exploited for its iron ore initially in 1895 and remained in production until 1966. The second major mining development occurred in 1928 when production of copper, zinc, and lead started in the Buchans area.

Since the end of World War II, new mines have opened in the following areas:

Tilt Cove, Notre Dame Bay - copper
Baie Verte - copper, zinc, some gold
Springdale - copper
Little Bay - copper, some gold - Whalesback Mine
Gull Pond - copper
Labrador City - iron ore
Wabush, Labrador - iron ore

The following data from the 1067 Canada Year Book indicates the tremendous importance of the mining industry to the economy of Newfoundland:

a) All metals produced in Newfoundland and Labrador during 1965 had a value of $203,100,000. Iron ore production accounted for $168,500,000, or 83 percent of this total.

b) The outputs of copper, zinc, and lead in 1965 were valued at $13,000,000; $11,200,000; and $7,200,000 respectively.

c) Metals produced in 1949 had a total value of $27,500,000. By referring to the comparable figure in (a) above, it may be seen that the Newfoundland mining industry has grown more than sevenfold in the period 1949 to 1965.

It has been reported[1] that Newfoundland now produces 37.5 percent of Canada's iron ore; 3.5 percent of its copper; 9.5 percent of its lead; and 8.5 percent of its zinc. These percentages acquire greater significance when it is realized that Canada is the world's leading producer of zinc; ranks third in the production of iron ore; fourth in the production of lead; and fifth in the production of copper[1].

2 MINING AND CONCENTRATING PROCESSES

Base metal ores are obtained by open pit or underground mining operations, depending on the physical location of the ore body. In both instances, ore removal involves drilling, blasting and transporting of the fragmented ore to a primary crusher. Often the crusher is located at the pit or mine site, but may be removed a short distance and form part of a mill complex where the ore is processed.

At the mill, ore which has passed through the primary crusher is further reduced in size by such devices as ball or rod mills and then subjected to various concentration or upgrading operations. "Mineral dressing" or "ore dressing" are the terms generally used in mining and metallurgical circles to describe the overall process of upgrading raw ores. Mineral dressing procedures may be as simple as water scrubbing of pulverized ores to remove clays and slimes or as sophisticated as the selective flotation procedures described later in this section.

A cursory glance at the metallic content of base metal ores is warranted at this point, since it gives a better appreciation of mineral dressing procedures. The various base metal ores that are mined around the world show a metallic content that is highly variable but usually it lies within the following limits[3]:

Type of Raw Ore	Metal Concentration in Raw Ore (percent by weight)
Copper	0.7 to 10
Lead	2 to 4
Zinc	3 to 8
Iron	35 to 60

In Newfoundland, both underground and open pit mining is being carried out, and the metallic content of the raw ores tends to be near the lower end of the ranges tabulated above.

After the raw ore has been upgraded, the following metal content results in the concentrate:

Types of Concentrate	Metal in Concentration (percent by weight)
Copper	25 to 30
Zinc	50 to 60
Lead	60 to 70
Iron	60 or higher

In Labrador, the iron ore is mined in open pits and concentrated by means of Humphrey spirals and electromagnetic drums. These spirals resemble a large auger or Archimedian screw mounted in a vertical position; unlike an auger, however, the spirals do not rotate about a central shaft. Pulverized iron ore mixed with water cascades down a spiral trough and in travelling downward iron ore particles tend to stay near the central shaft while the waste "gangue" or tailings material passes to the outer edge. Final separation and concentration of the iron ore is achieved with electromagnetic drums.

Since the 1950's, the flotation process has steadily increased in importance as a means of concentrating certain metal ores and, today, it is reported that more ore tonnage is concentrated by flotation than by any other single process[3]. Essentially the process is carried out as follows:

a) Pulverized raw ore together with water is placed in a metal tank equipped with an agitation or aeration device.

b) Reagents are added to the ore and water mixture which produce a froth when the mixture is agitated by a mechanical mixer or by a stream of compressed air bubbled through the tank from bottom to top.

c) Another reagent is then added which selectively coats the ore particles only, making them water repellent and giving them an affinity for the froth bubbles. At the same time, other unwanted particles are wetted and "depressed".

d) The water repellent ore particles attach themselves to froth bubbles, rise to the surface of the tank and float over the sides to collector troughs.

Many instances may be cited where two or more metals are present in the same ore body (the Buchans mine in Newfoundland). For situations such as this, some remarkable flotation reagents have been developed that permit concentration of the individual metals in the same ore by "selective flotation". For example, by adding the appropriate reagents, zinc sulphide particles may be removed in an initial flotation operation. Subsequently by adding different reagents to the same tank, lead sulphide particles may be selectively coated and concentrated; then, as a final step, copper sulphide particles may be concentrated.

It should be emphasized that flotation is not suitable for all base metal ores. For example, flotation is widely used for concentrating sulphide ores (copper sulphide) whereas leaching is used to concentrate a number of the oxide ores (copper oxide).

Flotation methods are used to concentrate all base metal ores in Newfoundland.

3 WATER QUANTITY REQUIREMENTS

In the course of mining and concentrating base metal ores, water is used for a variety of operations, including the following:

a) General dust control on roadways.

b) Dust control during rock drilling and crushing operations (including primary crushing, screening, and ball mill or rod mill pulverizing).

c) Scrubbing of ores to remove extraneous material such as clay, slimes, etc.

d) Preparation of acidic or other chemical solutions as required for such operations as leaching and timber preservation.

e) Froth flotation.

f) Gravity concentration and thickening.

g) Cooling water for machinery, bearings and other equipment.

h) Domestic and general sanitation (locker rooms, wash rooms and cafeterias, etc.).

i) Fluming of pulverized ore and tailings.

j) Boiler feed water.

3.1 Copper

In 1951, Sundstrom [5] conducted a survey of water usage by copper mines in the relatively arid regions of Texas and Arizona. His findings were as follows:

Operation	No. of Plants Studied	Water Used Minimum	(gal.* per ton of Ore) Average	Maximum
Mining	8	2	25	630
Concentration by Flotation	8	145	275	500
Concentration by Leaching	2	-	95	-

* Imperial gallons are used throughout this report.

More recently (1955), Mussey [4] has investigated water usage at over 20 copper mines that account for about 98 percent of the US output. His findings which include mining in Arizona, Michigan, Montana, Nevada, New Mexico, Pennsylvania, Utah, and Washington were as follows:

Operation	No. of Mines Studied	Water Used Minimum	(gal. per ton of ore) Average	Maximum
Mining	21	2	34	204
Concentration by Flotation	23	31	290	4370
Total for Mining and Concentration Processes		33	324	4574

A 1967 survey[6] of the Buchans mine in Newfoundland indicates that approximately 1800 gallons of water is used in processing each ton of raw ore. It should be emphasized, however, that the Buchan Mine turns out copper, lead, and zinc concentrates; but it was not possible to determine the water volume used for each individual ore. Kaufman and Nadler[10] have reported an average water use of 404 gallons per ton of raw copper ore.

In summary, it would appear that the mining and concentrating of copper ores can be readily carried out with about 400 gallons of water per ton of raw ore. Instances have been cited where less than 100 gallons per ton are used and it is believed that this would generally apply to water-scarce areas. Similarly, cases have been found where over 4000 gallons per ton are used. It should be noted that Canadian and American copper ores, for which the foregoing figures apply, are generally of low grade, often containing less than 1 percent copper. The water requirements of higher grade copper ores (say 5 percent or more) are believed to be lower than the figures cited here.

3.2 Iron

In a survey conducted during 1956-57, Walling and Otts[7] determined that the following ranges of water usage applied to the mining and concentrating of iron ore in the United States:

Operation	No. of Mines Surveyed	Water Used Minimum	(gal. per ton of raw ore) Average	Maximum
Mining and Concentration	14	60	795	3820
Mining only	15	0	10	62
Concentration (by difference)	-	60	785	3758

A 1967 survey [8] of the Wabush and Labrador City Iron Ore complexes established that the water used for mining and concentrating averaged from 500 to 700 gallons per ton of raw ore.

The foregoing volumes of water show excellent agreement with figures presented by Johannes [9] for the iron ore mines of the Mesabi Range in Northeastern Minnesota. (Johannes reported water usage to vary from 200 to over 2000 gallons per ton of raw ore).

3.3 Lead and Zinc

Water use in the mining and concentrating of lead and zinc ores is somewhat limited. Mussey [4] has indicated that these metals require less water than copper on average and Kaufman and Nadler [10] offer the following data:

Operation	Water Used
Concentration of lead and zinc ores by Selective Flotation	Approximately 465 gallons per ton of ore

It is believed that the mining and crushing operations prior to flotation would require less than 100 gallons per ton of raw ore; consequently, the total volume of water used for both mining and concentrating may conceivably be in the region of 550 to 600 gallons per ton of raw ore.

Lead and zinc ores are frequently found and mined simultaneously and the foregoing figures assume this situation. For individual deposits of lead and zinc, the flotation procedure would be simplified, and it is reasonable to assume that the water requirements of each ore would be approximately 400 gallons per ton of raw ore for mining and concentration (two-thirds of the 600 gallons previously quoted). Mussey [4] suggests that this assumption is realistic and possibly conservative. It should be emphasized, also, that in arid regions the volume of water used would probably be less than for regions having abundant supplies. For example, it was previously mentioned that the Buchans mine in Newfoundland (which has an abundant water supply) uses approximately 1800 gallons per ton of ore and simultaneously turns out concentrates of copper, lead, and zinc, as well as some cadmium, gold, and silver.

4 WATER QUALITY

Mining and concentrating complexes require minor quantities of high quality water for such purposes as boiler feed, human consumption, and drilling by "jet piercing". Water for these purposes is subjected to fairly conventional treatment methods where necessary, that is demineralization and degasification in the case of boiler feed waters or coagulation, sedimentation, filtration, and chlorination in the case of drinking water.

Water used in flotation processes may require treatment if oils or other "petroleum-like" pollutants are present since these reduce the effectiveness of the process. Similarly, cooling waters may be chlorinated to suppress the growth of algae and slime organisms.

Many underground mining operations, being well below the water table, pump large volumes of mine drainage water to the surface to prevent flooding in tunnels and shafts. Usually mine drainage waters are acidic and corrosive to metal and machinery if they are to be used for ore processing. Where mine drainage waters are used for ore processing, it is customary to elevate their pH to approximately 7.0 using lime or pulverized limestone.

5 WATER RE-USE

Prior to the 1940's, the mining industry tended to practise a reasonable degree of water re-use in arid regions where water was scarce and expensive, and a lesser degree of re-use in areas where water was abundant and cheap. More recently, the cost of industrial wastewater treatment resulting from increasingly restrictive pollution control legislation has altered this situation appreciably by encouraging both water re-use and water conservation in all areas.

Various data on the base metal mining industry [7,8,10,11], indicates that water is often used two or more times prior to being wasted, but no clear pattern or tendency seems to be evident. For example, Kaufman and Nadler's[10] survey revealed the following:

Commodity	Gallons of Water Used per Ton of Raw Ore				
Processed	New	Recirculated	Total	Discharged	Consumed
Copper Ores	404	467	871	253	151
Iron Ores	598	741	1339	561	37

By contrast, the Iron Ore Company's complex in Labrador City [6] reports that their ratio of reclaimed to fresh water is very nearly 4 to 1 (stated another way, very nearly five times as much fresh water would be used if no recycling took place).

Kaufman and Nadler [10] have summarized the topic of re-use as follows:

> " Analysis of the data on recirculation indicates that the quantities of water recirculated are apparently dependent on process requirements, on the manner in which water is used, on cooling requirements, on the quality of water available and on the necessity, either legal or other, of treating the mill effluent."

The same writers considered "... that the quantity of water recirculated was primarily a function of water availability" but were unable to prove this statistically.

6 WASTEWATER

6.1 Types of Wastewater

Mine drainage water that is regularly pumped from shafts and tunnels to avoid flooding often accounts for a high percentage of the total wastewater volume generated at a mine-concentrator complex; in extreme cases, mine drainage may dwarf all other wastewater volumes. In general, the volume of mine drainage varies widely from mine site to mine site being dependent on such factors as mine location, position of water table, permeability of overburden, and presence of rock faults; consequently, it is extremely difficult (if not impossible) to relate volume of mine drainage to ore or concentrate output. Although mine drainage waters are usually acidic, they are frequently used for dust control and mineral dressing, especially in water-scarce areas. (Drainage waters may require treatment with lime to elevate their pH and sedimentation to remove turbidity prior to being used.)

Ore crushing and concentration processes give rise to wastewaters with a high suspended solids content. This is not surprising if one recalls that most base metal ores in Canada (iron excepted) contain less than 10 percent of the desired metal, and this results in most of the processed ore being discarded. These suspended solids appear in a variety of forms including:

Mud and slimes from ore washing.

Gangue from wet gravity separation or froth flotation.

Undissolved residues if chemical leaching is used.

Chemical reagents used in froth flotation.

A limited number of metal ores are concentrated by using leaching chemicals such as soda ash, caustic soda, and sulphuric acid. When this is done, a variety of dissolved materials, such as ferrous sulphate, may be found in the resulting wastewaters in addition to the previously mentioned suspended solids. So far as can reasonably be determined, leaching processes have found negligible application in Newfoundland.

6.2 Wastewater Treatment

By far the most common method of treating wastewater from mines and concentration plants is through the use of lagoons, tailings pond, or similar impoundments. Frequently, these structures take advantage of local topography as, for example, in Labrador where tailings from Wabush Mines Limited are being impounded in Flora Lake (a small lake converted to impoundment basin to protect the larger and adjacent Wabush Lake). Alternately, tailings ponds may be constructed by damming, excavation and diking or a combination of all three. Tailings ponds are primarily a storage basin for tailings that may be further processed in future. However, they do serve a number of secondary functions as well. For example, tailings ponds:

a) Achieve a degree of clarification by removing many of the suspended solids and forms of turbidity.

b) Act as a reservoir of water for re-use in ore processing, dust control, etc.

c) Provide a disposal site for mine drainage water.

d) Act as a treatment tank for pH adjustment and chemical coagulation.

e) Serve as water storage reservoir for controlling wastewater discharge.

At some mine sites, tailings ponds are followed by large open sedimentation basins wherein the wastewater is further clarified through the sedimentation of suspended solids which did not settle in the tailings pond.

Sedimentation basins range from 3 to 300 acres in size with the majority being less than 50 acres; their depth varies between 2 and 10 feet in most instances. Tailings ponds are normally much larger than sedimentation basins, sometimes covering an area of 800 acres. In some instances, tailings ponds are constructed in two sections so that one section impounds the tailings and the second acts primarily as a clarification basin.

Other pollution control methods have been devised by the mining industry. For example, when the wastewater from a concentrator is alkaline (as happens with zinc processing) it may be mixed with acid mine drainage in the tailings pond to achieve a degree of neutralization. Alternately, if the concentrator's wastewater is acidic, it may be neutralized with lime prior to being discharged to the tailings pond.

Flotation reagents, untreated sanitary sewage, and other organic pollutants frequently receive separate treatment at mills, especially if their presence adversely affects the re-use of tailings pond water.

6.3 Effects on Receiving Bodies of Water

Effluents from tailings ponds have varying effects on the receiving bodies of water depending on the ore being processed. Usually, the effluent adds turbidity to the receiving waters and this in turn inhibits light penetration which is vital to photosynthetic organisms and plants. Colour may also be imparted to the water; this may range from red-orange or scarlet in the case of haematite ore to a greenish yellow for taconite ores. Appreciable discolouration (reddish-brown) was noted in Wabush Lake during 1967. Discolouration of receiving waters is aesthetically undesirable and may be indicative of iron concentrations that are toxic to fish and acquatic life. In addition, colour hinders light penetration and thereby inhibits the growth of photosynthetic organisms.

The effects of dissolved base metals on fish and aquatic life have been widely studied in many parts of the world and a complete summary of these findings would undoubtedly fill many volumes. A reasonable appreciation of the complexity of this topic may be obtained by reviewing the following statements by McKee and Wolf [12]:

a) Copper concentrations varying from 0.1 to 1.0 mg/l have been found by various investigators to be not toxic for most fish. On the other hand, concentrations of 0.015 to 3.0 mg/l have been reported as toxic, particularly in soft water, to many kinds of fish, crustacea, mollusks, insects, phytoplankton and zooplankton.

b) Dondoroff found that although fish could survive for eight hours at 8 mg/l of zinc alone and at 0.2 mg/l of copper alone, most fish died within eight hours when exposed to a mixed solution containing only 1.0 mg/l of zinc and 0.025 mg/l of copper.

c) Ferrous ions (Fe^{++}) are readily oxidized in natural surface waters to the ferric (Fe^{+++}) condition and form insoluble hydroxides. The deposition of iron hydroxides on the gills of fish may cause an irritation and blocking of the respiratory channels. Finally, heavy precipitates of ferric hydroxide may smother fish eggs.

d) A chart submitted by the Water Pollution Research Board indicates that the median period of survival of rainbow trout in soft water containing dissolved lead at 18.5 deg. C. was 18 to 24 hours at 1.6 mg/l and only 10 to 12 hours at 4.0 mg/l. The Board has also shown that the toxicity of lead towards rainbow trout increases with a reduction of the dissolved oxygen concentrations of the water.

Effluents from Newfoundland's mining and concentration operations will contain varying amounts of dissolved iron, copper, zinc, and lead. As far as human consumption is concerned, concentrations of 1 or 2 mg/l of iron, copper, and zinc can be safely tolerated. Comparable concentrations of lead, however, are known to be highly injurious to health and may be lethal if ingested continuously for several weeks.

Although dissolved iron in concentrations of 1 or 2 mg/l is not injurious to health, concentrations exceeding 0.3 mg/l are undesirable in a water supply because of the resulting taste and the brown coloured stains left on laundry and porcelain fixtures.

Most effluents from tailings ponds have a very low organic content as compared with domestic sewage for example; and, as a result, they tend to exhibit a low biochemical oxygen demand (BOD). However, the chemical oxygen demand exerted by the wastewaters may be appreciable; and, if so, this would adversely affect fish and aquatic life through partial dissolved oxygen depletion.

In summary, it may be said that turbidity, colour, and other pollutants from mine tailings ponds generally have adverse effects on fish aquatic life, and on downstream properties. If the downstream water is to be used as a water supply, difficulties could arise, especially if appreciable quantities of dissolved lead were present. Severe discolouration of surface waters tends to destroy recreation areas, devalue lakeshore properties, and will probably have some harmful effects on fish and aquatic life.

6.4 Wastewater Volumes

The wastewater volumes generated by mining and concentrate complexes is normally somewhat less than the quantity of fresh water supplied due to evaporation losses, and water retained in the concentrates. In their US survey, Kaufman and Nadler[10] established that approximately 96 percent of the water used for mining and concentrating lead, zinc, and iron ores in the USA was subsequently discharged as wastewater. For copper, larger evaporative losses were noted possibly because several of the mines surveyed were in arid regions such as Arizona and parts of Texas. If it is assumed that wastewater volumes are about 4 percent lower than the volumes of fresh water supplied, then the following figures should be representative:

Volumes of Wastewater Generated In Mining and Concentrating Base Metal Ores (gallons per ton of raw ore)

	Minimum	Average	Maximum
Copper	30	300	4500
Lead	30	300	4000
Zinc	30	300	4000
Iron	60	770	3700

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APPENDIX C - COST ESTIMATING CRITERIA

1 GENERAL

After the need for water resources development has been recognized, detailed study of the system and the formulation of the design parameters and operational characteristics are required. Capital and annual costs must be determined on a broad basis so as to establish at least "order of magnitude" figures in respect to obvious possibilities. Later studies on a fully comprehensive basis will be required including socio-economic analyses to establish the optimum program to be followed utilizing benefit-cost analyses.

2 FINANCIAL COMPARISON OF ALTERNATIVES

There is usually more than one alternative scheme available within the system to meet a given requirement and these alternatives may vary as to type and timing of scheme, equipment and size, or location. The comparison of the various alternatives requires firstly a forecast of future demands. This forecast should not only show the volume of water to be supplied or treated within a given financial interval (say a year), but it must also establish the peak requirement for the design of the capacity of the development and also the characteristics of the demand for estimating the operating costs. Forecasts should be made far enough into the future to ensure that the largest scheme being considered is completely absorbed and utilized. Once this is completed, schedules of providing services and additions should be developed in order to meet the forecast requirements in both volume and peak demand.

Once alternative methods of meeting the demand have been established, the cash flows showing the capital to be expended during construction and the operation and maintenance costs year by year should be determined. At this stage, the value to be placed upon direct benefits should be included in the analysis as most schemes do not perform the same function to exactly the same degree. A comparison of costs is not sufficient and an analysis of benefits as well as costs must be made. The final costs year by year are then discounted to present time to enable a true economic comparison to be made. Comparison of costs, however, is the means utilized in this study to identify possibilities and the evaluation of benefits must await detailed analyses of later studies.

In order to make current appraisal, it is necessary to specify interest rates, and service lives, as well as capital and annual operation and maintenance costs however. The first will be discussed under "Annual Cost Criteria" and the remaining two in the sections on "Cost Indices".

3 ANNUAL COST CRITERIA

3.1 Cost of Capital (Interest Rate)

In the financial comparison of alternatives, the rate at which the cash flows should be discounted in the present worth analysis may determine the choice of scheme. The cost of funds will differ substantially between all the possible groups undertaking the project from the Federal Government through Provincial and Municipal governments to private corporations. The analysis is further complicated by the fact that it should be conducted not in terms of borrowing costs of money but in terms of the opportunity costs of funds. In this context, "cost" is a payment necessary to keep monetary resources away from alternative investments, since a payment which is below economic cost will result in an eventual shift of the monetary resource to the alternative opportunity[1].

A study of the opportunity cost of capital for the Atlantic Provinces by one of Shawinigan-MacLaren's consultants[2] concludes that it is not possible to forecast appropriate interest rates and these costs should be determined at the decision-making level at the time a decision is required.

For the purposes of comparison of alternatives in subsequent Stage III studies, it is suggested that several rates of interest be used. In this way the effect of the interest rate on the ranking of the alternatives can be measured. It may be that the rank of a particular project is independent of interest rate or, if found to be dependent, the rate at which the ranking changes may then be compared with what is judged at that time to be the opportunity cost of capital.

3.2 Service Lives

The service lives or length of time over which the cash flows of alternative schemes should be discounted may also affect the ranking of these alternatives. Fortunately, there is general agreement on the physical service lives of most components of schemes. For these studies, it is recommended that the service life should be a maximum of fifty years, as this period is considered to be sufficiently long to write off large capital items and yet give recognition to the possibility of obsolescence due to technological change. The following service lives are recommended with no salvage value at the end of these periods. These lives do not take into account the life over which benefits are likely to accrue since such important aspects can only be revealed in detailed and comprehensive study.

TABLE OF SERVICE LIVES

Source of Water	Years
Reservoir Dams - Concrete	50
- Earth and Rockfill	50
- Timber Crib	20
Wells	20
Water Distribution	
Pipe - Concrete	50
- Iron	50
- Asbestos	50
- Woodstave	30
Canals	50
Pumping and Treatment Plant	
Structures and Equipment	35
Hydro-Electric Power	50
Thermal Power	30

3.3 Escalation

Escalation includes the effects of the rise in wage and price levels as well as the offsetting influence of improvements in productivity over given time periods. Advances in technology should also be considered. Its effects should be included in a systems analysis where alternatives are being considered. Escalation rates must be applied to present day capital costs of components required to be phased into the system sometime in the future. Also, the analyses should include the effects of escalation of annual operation and maintenance costs.

Experience indicates that the escalation rate on capital costs of water resources projects averages about 2 percent and on operation and maintenance between 3 and 5 percent per annum for Newfoundland conditions. It is recommended that a detailed review of this item should be made as part of any further studies.

3.4 Interim Replacement

Interim replacement costs for a plant (or system) represent a sum of money which is put aside annually to cover abnormal maintenance or replacement of major items of equipment during the lifetime of the plant. It is often included in the annual expenditures for operation and normal maintenance of the plant. The historic operation and maintenance costs developed in the following section "Cost Indices" include operation and maintenance costs for water treatment and sewage treatment plants as well as hydro-electric plants, but do not include an allowance for interim replacement.

Experience indicates that the following values for interim replacement be used as percentages of the original cost:

Dam, pipeline, structures	0.10 percent
Pumps, mechanical plant	0.25 percent

4 COST INDICES

Cost indices of some water resource developments have been derived from available data to enable order of magnitude costs to be evaluated.

Cost derived from these indices may be used for overall regional costing of several water resource developments or for the preliminary screening of the many initial alternatives that appear feasible.

The capital costs (except for hydro-electric power which is treated separately) include contingencies, engineering, owner's overhead, interest during construction, and indirect costs associated with construction, but exclude land purchase and the costs of access roads. These costs may be updated using generally available cost indices. The index chosen should preferably be based on current bids for similar types of constructions

4.1 Water Supply

4.1.1 Capital Costs

The capital costs of water supply schemes were obtained from feasibility studies of 27 projects carried out by various consultants to the Board in the period 1965 to 1967 (Figure C-1). These projects ranged from the 100 million gpd supply to the community and industry at Stephenville, to the 0.106 million gpd supply to the fish plant and inhabitants of Old Perlican on the Bay de Verde Peninsula. The costs cover the dam, intake, and pipeline. Since only a few of the recommended works have so far been constructed, it has been impossible to develop capital cost data from actual construction costs. A logarithmic correlation of 25 unit costs against capacity gave a coefficient of 0.924; the studies for the communities of Burgeo and Gaulois were not included in the correlation as pipelines in excess of three miles were required. Also included on this figure are actual costs of water supply schemes to four mines; these are older costs than the estimates by the consultants.

Two curves enclosing the majority of points show the range of costs about the most probable curve derived above. This range gives costs from $1,700,000 to $500,000 for a 6 million gpd plant and $241,000 to $114,000 for a 0.1 million gpd plant.

4.1.2 Annual Operation and Maintenance Costs

Annual operation and maintenance costs for water supply schemes in Newfoundland were not available due to the practice in Island communities of combining the operation and maintenance costs of water and sewage systems in their annual expenditure records. Because of the wide variation in power costs alone in supply schemes it is virtually impossible to generalize on the operation and maintenance costs of supply.

4.2 Municipal Water Treatment Plants

4.2.1 Capital Costs (Figure C-2)

The capital costs of water treatment plants per unit of plant capacity in millions of gallons per day have been developed from actual experience in Canada, from data of schemes constructed or estimated by consulting engineers in Newfoundland, and from the technical literature. The cost of treatment facilities has been based upon providing sedimentation, flocculation, filtration and chlorination. The costs are in 1968 dollars and do not include the costs of intakes or conveyance.

4.2.2 Annual Operation and Maintenance Costs (Figure C-3)

Annual operation and maintenance costs for water treatment in Newfoundland were not available except for simple chlorination of the water. A consultant's estimate for a water supply scheme for St. John's gave a figure of 0.3 cents per 1000 gallons for the cost of this item. However, a recent study of 30 plants in the United States[3] provided a considerable amount of useful data and indicated higher operating costs. The data on costs were adjusted for rate exchange and time and the design capacity and plant output adjusted for imperial gallons and plotted on Figure C-3. An initial correlation between design capacity and plant output at the time of the study gave a correlation coefficient of 0.89 which indicates that total annual costs are related to plant size and do not differ significantly for fractional outputs of the design capacity.

A logarithmic correlation between cost per 1000 gallons and output in millions of gallons per day gave a coefficient of correlation of 0.83; the curve on Figure C-3 may therefore be used as an indication of annual operation and maintenance costs per unit of output.

4.3 Municipal Sewage Disposal Plants

4.3.1 Capital Costs

Costs were established as for water treatment plants (Figure C-4). Primary treatment plants include the processes of sedimentation and digestion; complete treatment includes secondary treatment to a standard of 85 percent reduction of the 5-day BOD; and package plants are prefabricated plants available in small capacities and providing complete treatment. Costs were estimated especially for the smaller units at substantially in excess of mainland experience due to the high cost of importing equipment and skilled labour for this work.

4.3.2 Annual Operation and Maintenance Costs

Annual operation and maintenance costs for sewage treatment plants shown on Figure C-5 were taken from a survey of approximately 1000 plants in the United States[4]. The original cost data were given as a per capita cost which was converted to plant size by assuming a per capita consumption of 100 gpd (imp.). The primary treatment includes no allowance for the costs associated with sludge digestion and again the standard of 5-day BOD reduction for the secondary plants is 85 percent. The double curve for both primary and secondary treatment shows the range of costs for each size of plant covered in the survey.

4.4 Pumping Plants

4.4.1 Capital Costs

The capital costs of pumping plants for both water and sewage treatment plants were developed as previously noted for water supply plants, and are shown on Figure C-6 as one curve only since differences in estimated costs of water and sewage pumping stations were insignificant for the order of magnitude costs feasible for this study.

4.5 Water Mains and Sanitary Sewers

The capital costs per acre to install water mains and sewers have been determined for Newfoundland in 1968 and assume the following average conditions:

Lot size	60 x 150 ft
House connection per lot	60 ft
Invert to sewer in road	8 ft
Road allowance	66 ft
Cover to water main	5 ft

Capital Costs per Acre	Rock	Soil
Water mains	$ 4,200	$ 3,150
Sanitary sewers	$ 7,100	$ 4,300

This data would be applicable for communities of at least 1000 or greater with a population density of about 15 per gross acre.

4. 6 Industrial Sewage Disposal Plants

4. 6. 1 Capital Costs

The treatment required to bring industrial wastes to a standard quality before disposal varies from industry to industry. However, the Federal Water Pollution Control Administration of the US Department of the Interior has recently completed a study of the waste disposal of American industry to determine the cost of carrying out the Federal Water Pollution Control Act[4]. In this study curves have been developed relating capital cost of construction to hydraulic loading and are shown on Figure C-7. Curves were developed for wholly-industrial plants and combined plants treating both industrial and municipal wastewaters. It was found that the cost of plants for industry as a whole were generally uniform and related to hydraulic loading. Costs were found to be higher for petroleum refineries and the chemical industry necessitating a separate curve of costs.

The curve of costs of municipal plants was also included in this family of curves which enabled determination of the ratios of the industrial, combined industrial and municipal, and petro-chemical costs to the municipal costs. By applying these same ratios to the capital costs of constructing municipal plants in Newfoundland, the grouping of the industrial, combined industrial and municipal, and petro-chemical curves about the municipal curve was repeated. Each of these curves is for plants which reduce the 5-day BOD of the raw wastewaters by 85 percent and are completely converted to Newfoundland experience and 1968 dollar values. For the equivalent of primary treatment, allow 60 percent of the values shown.

4. 6. 2 Annual Operation and Maintenance Costs

Preliminary annual operation and maintenance costs for plants treating industrial wastewaters may be taken from Figure C-5. Due to the generally higher concentration of industrial wastewaters, it is suggested that the upper curve be used for Newfoundland conditions.

4.7 Pipelines (Figure C-8)

To allow for the costs of extra long water supply pipelines or intercepting sewers, the curve of costs of pipelines has been included on Figure C-8. These costs are in 1968 dollars and are applicable to Newfoundland.

4.8 Non-withdrawal (non-consumptive) Developments

Non-withdrawal developments comprise demands which do not generally require an abstraction of water from the source and especially do not involve depletion or a change in the water quality. These developments include the use of water for hydro-electric power, fisheries, logging, navigation, and recreation, and, where possible, cost indices were established for each of these demands.

4.8.1 Hydro-electric Power

It has been estimated that about 80 percent of the cost of developing a hydro-electric power site is influenced by the topography and geology of the site[6]. In addition to this factor, which tends to make each power site individualistic, there is also the question of the capacity factor for which the plant is designed. The choice of capacity factor determines subsequent plant operation within the range from continuous base load operation to intermittent peaking. The total capital cost of a project comprises a fixed portion that is generally independent of installed capacity and represents the cost of land, riparian rights, relocation of utilities and cost of the dam, and a variable portion dependent on the amount of capacity installed. In this variable portion would be included the cost of the powerhouse and equipment, intakes, and water conveyance structures.

The determination of the capital cost of a hydro-electric plant is therefore difficult to simplify when unrelated to its geographical location and operational requirements. Indices have been developed, however, mainly related to those components which vary with installed capacity as a rough guide to preliminary estimating. It should be realized that within each of these variable costs there is also an undetermined fixed cost and therefore costs determined from these curves should only be considered as 'order of magnitude'.

The total capital cost of a hydro-electric scheme could typically include all the items in the following table:

1	Land purchase
2	Land clearing
3	Roads and bridges
4	Railways, diversion of power lines
5	Dams, spillways, and reservoirs
6	Headworks, water conduits, tailrace
7	Powerhouse and equipment, substation including transformers
8	Transmission lines and terminal stations
9	Construction indirect costs
10	Project management and engineering
11	Contingency
12	Owner's cost
13	Interest during construction

The costs shown in items 1 to 4 are fixed costs which depend upon the topography and location conditions of the site and must be estimated individually. Costs in items 9 to 13 can normally be expressed as percentages of previous sub-totals, and the costs given in items 5 to 8, inclusive, are given as figures or tables as follows:

ITEM 5

Dams (Figure C-9) - Direct construction cost of fill dams against finished volume of contents in cubic yards. This curve was developed from previous engineering work in Newfoundland on rockfill impervious core dams, with heights up to 200 feet. However, for order of magnitude costs, the type of dam will not influence the costs significantly.

Spillways (Figure C-10) - Direct construction costs against maximum discharge for gated and ungated spillways is shown on Figure C-10. These curves were developed from data obtained from ShawMont Report SM-4-65. In this report an envelope curve of maximum flows per unit of drainage area was derived by statistical projection of historic floods up to floods with recurrence probabilities of 0.1 percent for several rivers in Newfoundland.

From a study of several feasibility schemes, some spillway characteristics were found to be similar enabling spillway costs per foot run to be related to maximum expected runoffs. These figures apply to spillways in which the crest of the rollway is no more than ten feet above bedrock. More massive structures have to be estimated individually.

Reservoirs - Costs associated with reservoirs vary from those required for the provision of level recording instruments to major costs associated with ensuring that the reservoir rim is competent. These costs must be estimated on an individual basis.

ITEM 6

Water Conduits

Canals - Direct unit cost of excavation against total cubic yards excavated for cut in earth and rock is shown on Figure C-11. To use these curves the section in earth cut is first determined at the lowest storage level. From these sections the volume of excavation is determined, of which some proportion may be rock. The unit prices are then applied to these quantities.

Penstocks - Direct total cost of steel penstocks against horsepower times length of penstock is shown on Figure C-12. These data were prepared from actual costs of steel penstocks built in Newfoundland and from several feasibility study estimates of schemes carried out by ShawMont.

Tailrace - The excavation costs for canals can also be used for construction estimates of tailraces.

ITEM 7

Powerhouse, and Equipment,
Substation Including Transformers - Direct costs per kilowatt of installed capacity against gross head for a family of curves of different installed capacities are shown on Figure C-13. These curves were developed from a number of feasibility study estimates carried out for the Newfoundland and Labrador Power Commission by Shaw Mont and from eight estimates made for this report and noted in Volume Four, Section 1. The costs for these eight schemes have been indicated on this graph.

ITEM 8

Transmission Lines and Terminal Stations - The direct costs of transmission lines for three voltages and a power capability up to 200 Mw transmitted over a length not exceeding 100 miles are shown in the following table. Also included are the direct costs of a one-bay terminal station. These costs are for steel towers for the 230 and 138 kv lines and wood-pole for the 66 kv line; all lines are single circuit. The order of magnitude costs were derived from actual costs of installations in Newfoundland.

		COST	
Voltage kv	Power Mw Capability	Line per Mile	One Line Terminal
230	200 - 80	$ 30,000	$ 140,000
138	100 - 24	$ 24,000	$ 90,000
66	50 - 10	$ 15,000	$ 60,000

4.8.2 Annual Operation and Maintenance Costs

Costs were derived from data collected from 275 hydro-electric plants in the United States by the Federal Power Commission[7] (Figure C-14) and are considered applicable in Newfoundland and Labrador in 1968.

Annual operation and maintenance costs for transmission lines may be taken as 0.5 percent of capital cost for steel towers and 1.2 percent of capital cost for wood-pole lines. Terminal station annual costs may be taken as 3 percent of capital cost for small stations.

4.8.3 Fisheries

The costs associated with this activity include channel or waterway improvement to enable fish to migrate upstream past dams, waterfalls, and rapids and costs of measures to augment the stock of fish in a river or lake.

The Canada Department of Fisheries indicate that the costs of fishways around natural obstructions up to 100 feet in height are about $4000 per foot of obstruction height. At dams where more complicated structures would be required, this unit cost may increase up to 50 percent. For heights greater than 100 feet, it is more economic to collect the fish and truck them around the obstruction.

The unit cost of artificial spawning channels depends upon size which in turn depends upon the area required by a spawning fish pair as well as the production of fry desired. The Canada Department of Fisheries advises that an approximate unit cost would be $10 per square foot.

The same authority indicates that the cost of hatcheries to produce 500,000 smolts per year would be about $1,500,000.

4.8.4 Recreation

Water-based recreation requires developments such as access roads, wharves, camping facilities including utilities, shoreline improvement, etc. The following costs have been obtained from available literature.

	Investment (dollars)	Annual Maintenance (dollars)
All-weather roads per mile (2-lane, 28 feet wide)	35,000	2,600
Paved roads per mile (24 feet wide)	80,000	1,500
Water access wharf for pleasure boats with launching ramp and nearby parking facilities	15,000	-

From the South East Basin Studies[8] capital costs of providing facilities for a variety of recreation activities have been obtained. Costs have been estimated and expressed in dollars per person capacity interpreted and are presented in the following tabulation:

Activity	% Participation by Activities	Annual Activity Drop	Design Capacity Factor	Design Capacity	$ Activity Costs for Facilities Per Person Capacity	$ Total Facility Costs For Single Activity
Sightseeing	-	-	0.2	-	2.00	-
Cultural	-	-	0.5	-	5.00	-
Picnicking	-	-	0.8	-	40.00	-
Swimming	-	-	1.2	-	20.00	-
Hiking	-	-	0.5	-	100.00	-
Camping	-	-	2.0	-	100.00	-
Boating	-	-	0.7	-	20.00	-

The design capacity is determined by first assigning a percentage of the estimated total annual user-days for a recreation area to each activity to be included in the area. The annual activity days thus established are then multiplied by an empirical design capacity factor based on experience records giving the capacity requirements for a typical high use day and providing the basis for facility cost estimates. In addition to the activity costs certain common use facilities must be considered and their costs used where applicable. These are as follows:

Parking	-	$50 per person capacity
Water Supply	-	$25 per person capacity
Sanitary Facilities	-	$50 per person capacity
Roads - (200 vehicles per day maximum)	-	$44,000 per mile average
(50 vehicles per day maximum)	-	$19,000 per mile average
Administrative Facilities	-	$0.05 per annual activity day

The above cost data is in terms of 1960 U. S. dollars. It is likely that the cost of similar facilities in Newfoundland in terms of 1968 Canadian dollars would be in the order of 150 percent of the cost figures shown.

4.8.5 Logging

River driving of pulpwood to the mills is declining with increased mechanization though it is still a relatively inexpensive form of transport under certain circumstances. A factor which is unfavourable to river driving is that pulpwood deliveries are restricted to the ice-free period each year which requires a careful investigation of annual requirements and large stockpile areas located near the mill. In Newfoundland, some cutting is being carried out in drainage basins adjacent to the mill drainage basin and therefore some form of truck transport is required. This may be all the way to the mill or to the closest water access to the mill.

Alternative means of transport are becoming increasingly competitive and on the mainland are displacing the river driving of logs, and it is likely that this situation will exist in Newfoundland within the next decade.

4.8.6 Navigation

River channel improvements to permit navigation may range from some local enlargement of river sections to major activities such as raising or replacement of bridges and construction of locks. No generalized costs can be given for these items until the scope of the requirement is known.

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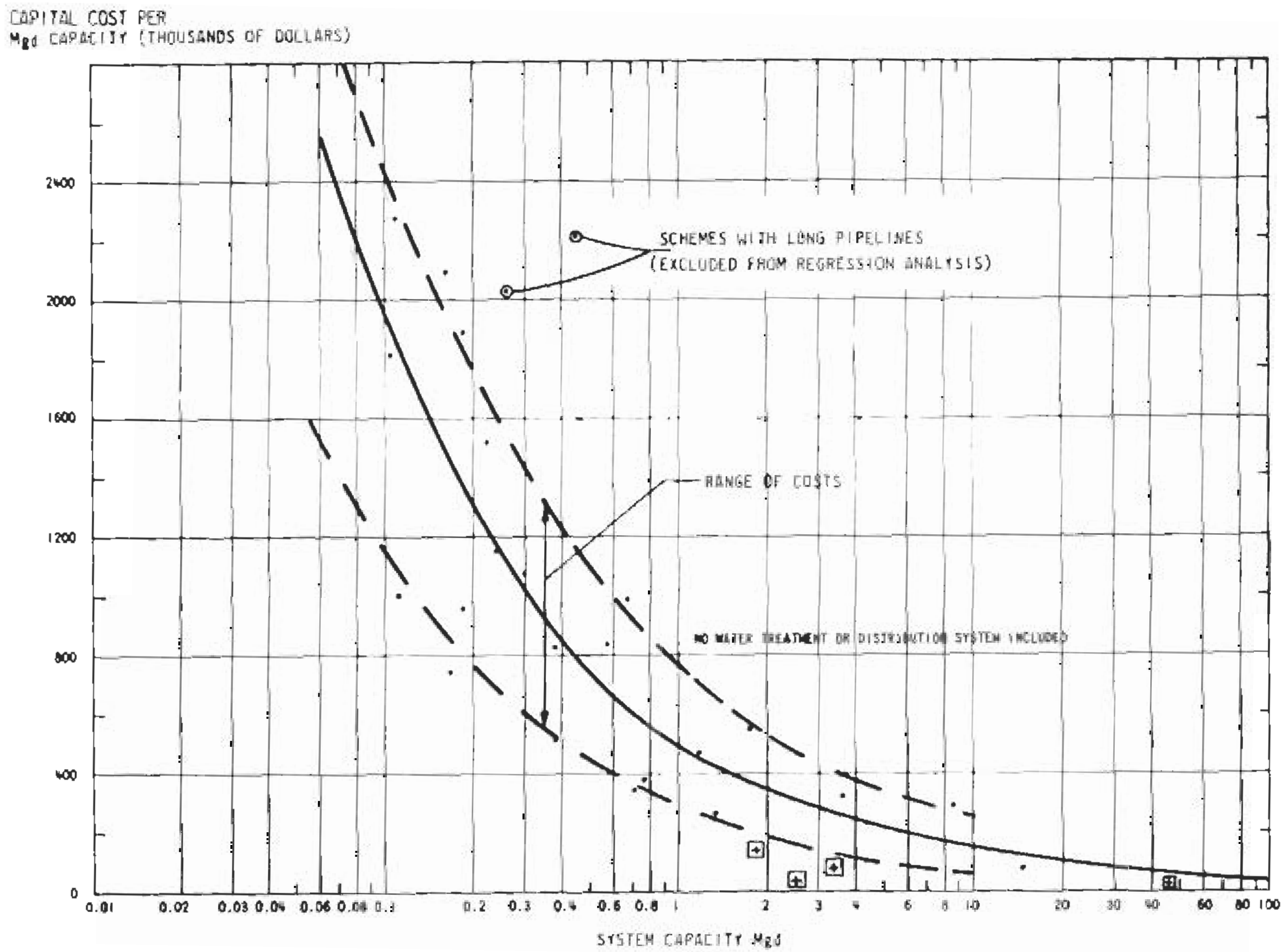
6 Creager, W. P., and Justin, J. D. Hydro-electric Handbook. New York, Wiley.

7 US Federal Power Commission. Instruction for Estimating Electric Power Costs and Values. Technical Memorandum No. 1. Washington, GPO, 1958.

8 United States Study Commission. South East River Basins. Plan for the Development of the Land and Water Resources of the South East River Basins. 1963.

CAPITAL COSTS OF WATER SUPPLY SCHEMES



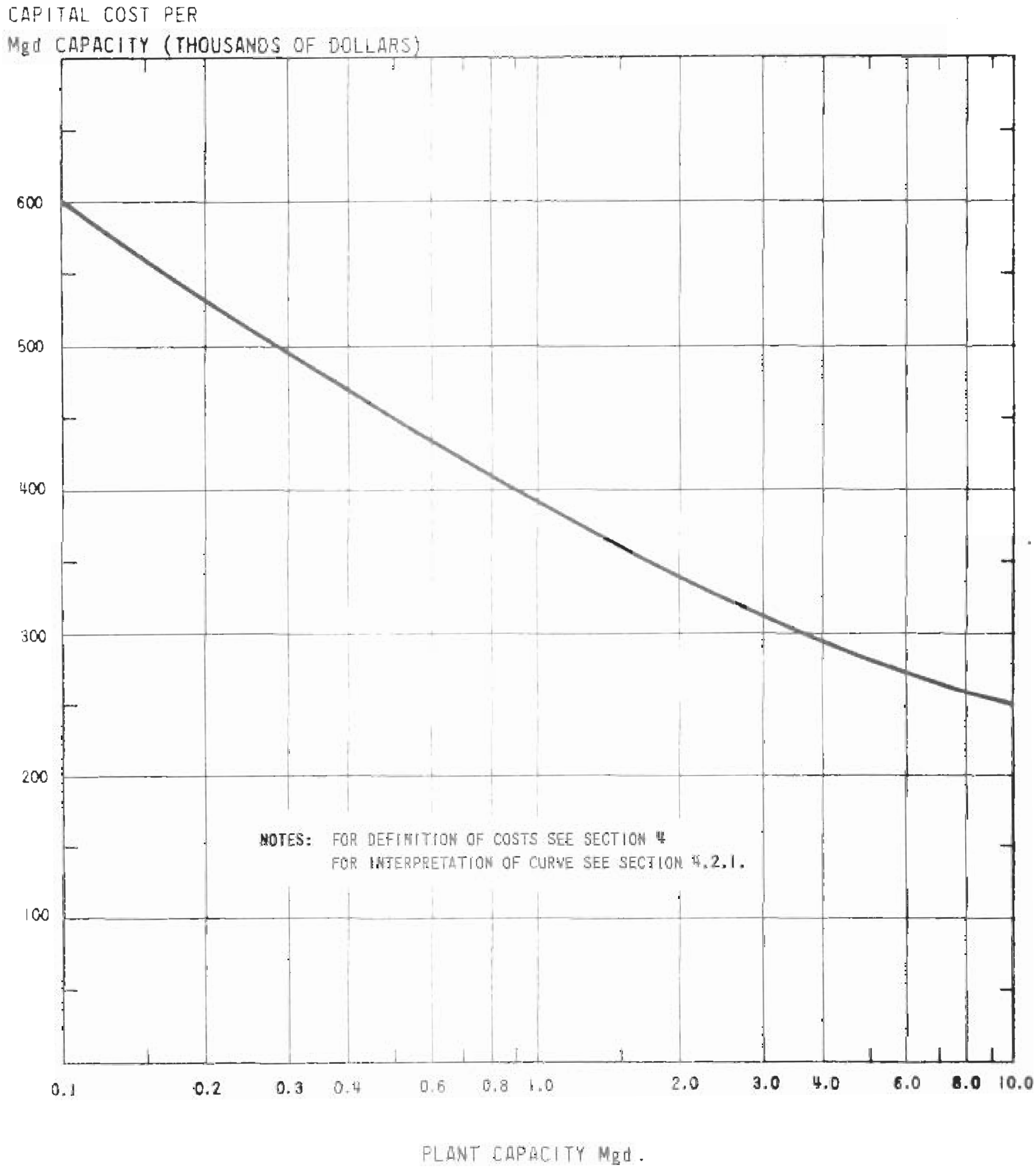
NOTES: FOR DEFINITION OF COSTS SEE SECTION 4
FOR INTERPRETATION OF CURVES SEE SECTION 4.1.1

SOURCE: CONSULTANTS REPORTS
TO ATLANTIC DEVELOPMENT BOARD

- ● WATER SUPPLY SCHEMES TO COMMUNITIES OR FISH PLANTS
- ⊞ SUPPLY SCHEME TO MINES

FIGURE C1

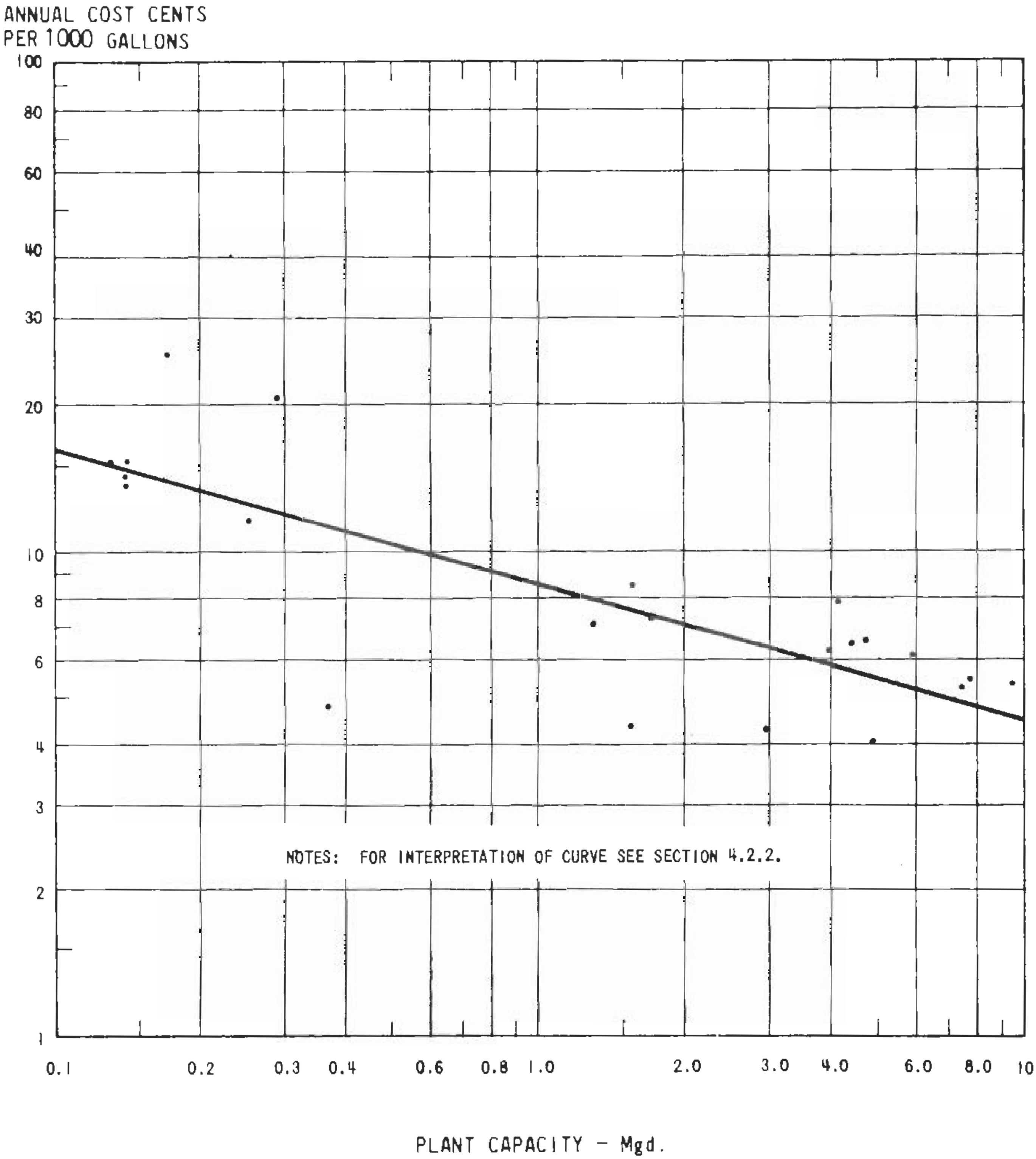
CAPITAL COSTS OF WATER TREATMENT PLANTS



SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C2

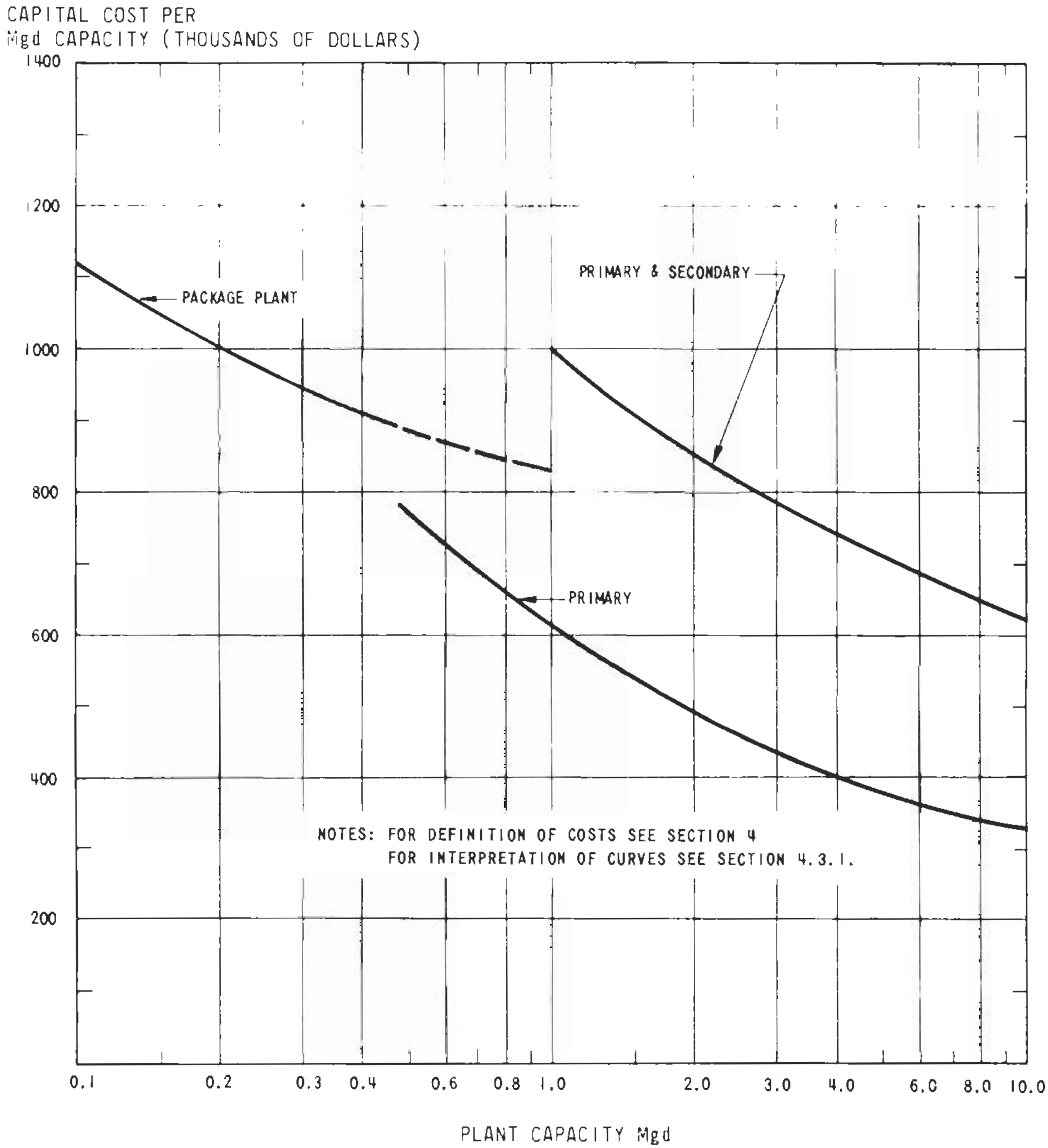
ANNUAL OPERATION AND MAINTENANCE COSTS OF WATER TREATMENT PLANTS



SOURCE: "THE COST OF WATER TREATMENT" - A.W.W.A., VOL.59 No.3

FIGURE C3

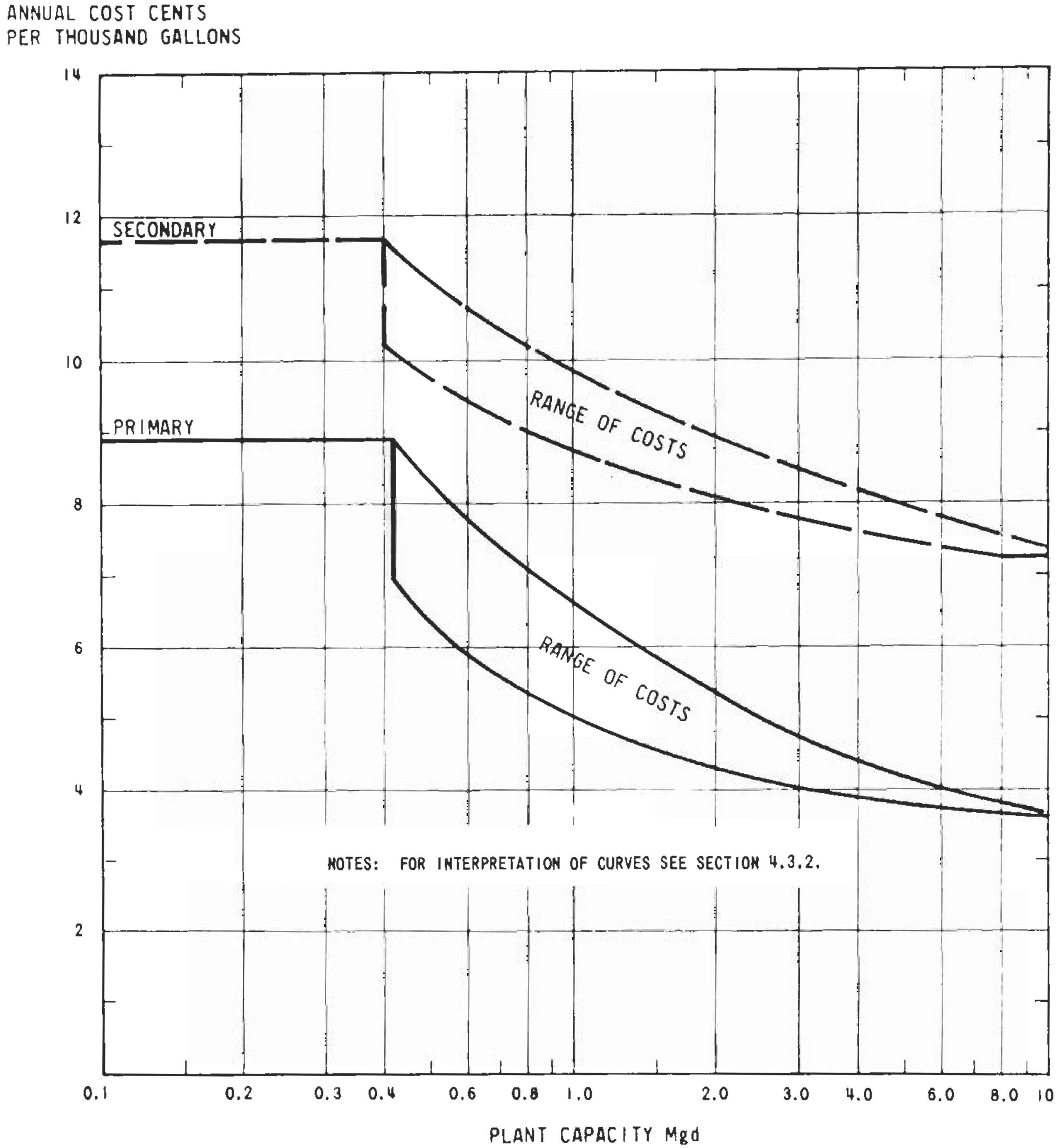
CAPITAL COSTS OF SEWAGE TREATMENT PLANTS



SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C4

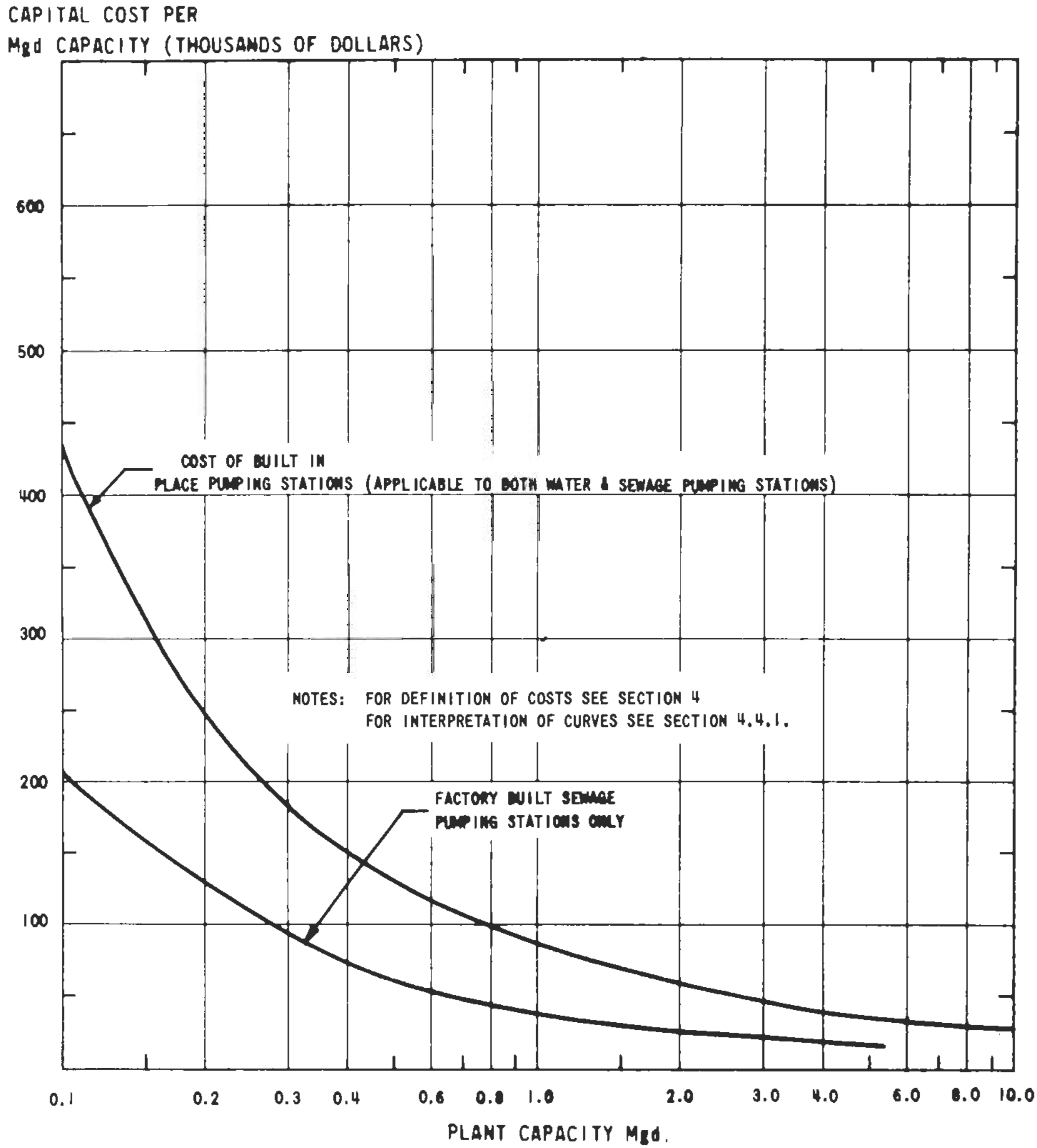
ANNUAL OPERATION AND MAINTENANCE COSTS OF SEWAGE TREATMENT PLANTS



SOURCE: "THE COST OF CLEAN WATER"
F.W.P.C.A. VOLUME II

FIGURE C5

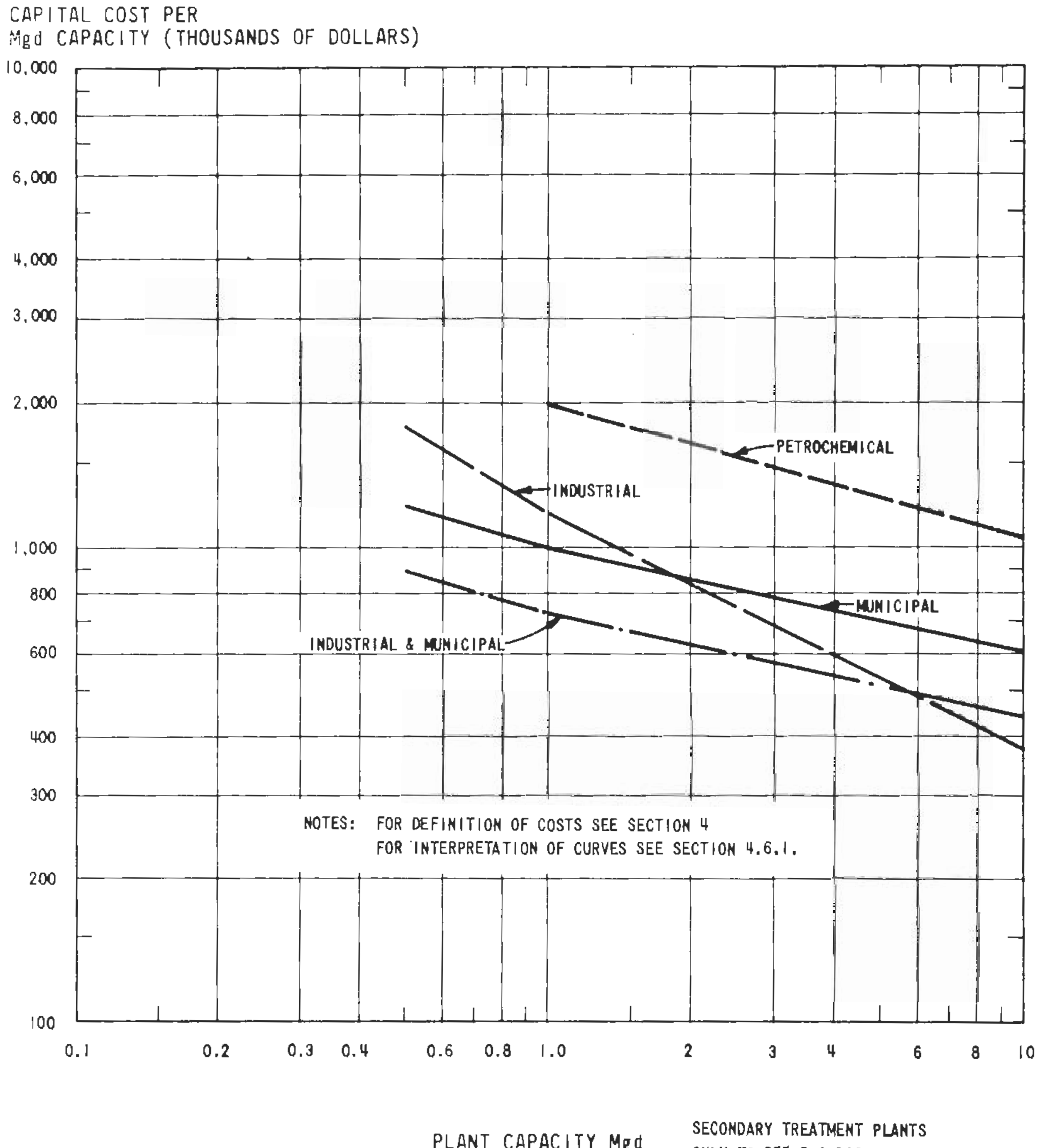
CAPITAL COSTS OF PUMPING PLANTS



SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C6

CAPITAL COSTS OF COMBINED INDUSTRIAL AND MUNICIPAL AND INDUSTRIAL SEWAGE TREATMENT PLANTS

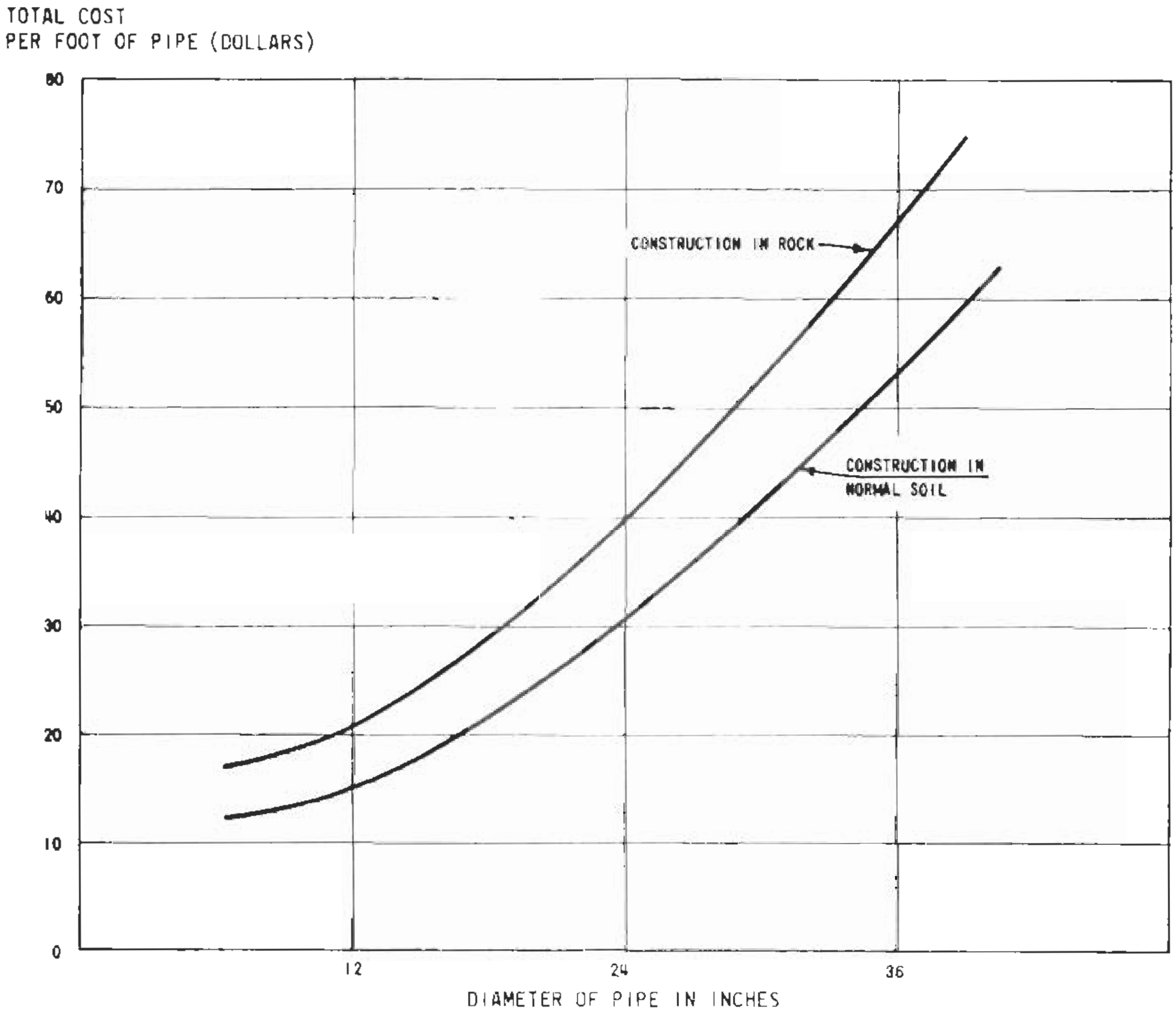


SECONDARY TREATMENT PLANTS ONLY TO 85% B.O.D'S REMOVAL

SOURCE: "THE COST OF CLEAN WATER"
F.W.P.C.A. VOLUME II

FIGURE C7

CAPITAL COST OF PIPELINES

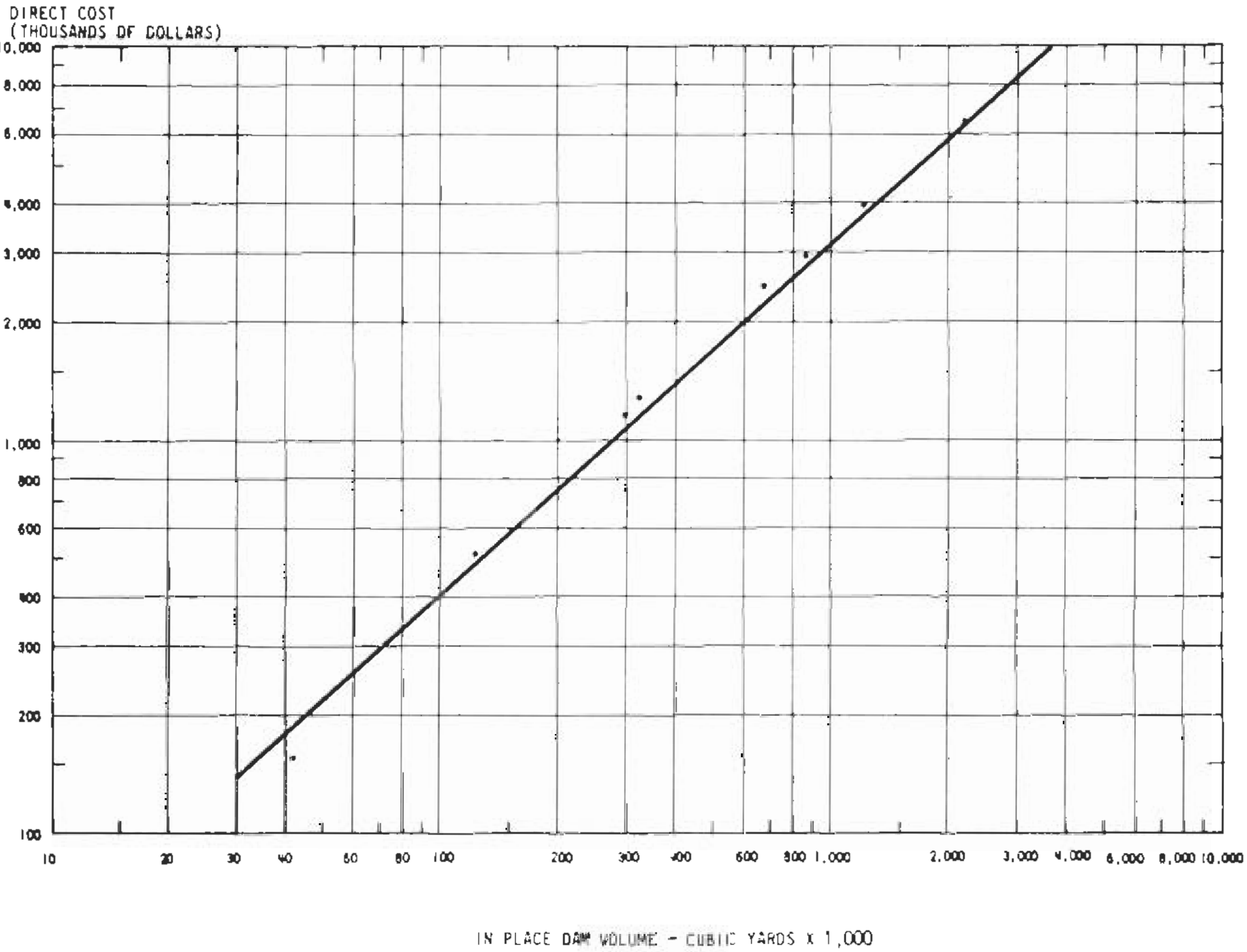


NOTES: FOR DEFINITION OF COSTS SEE SECTION 4
FOR INTERPRETATION OF CURVES SEE SECTION 4.7.

SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C8

DIRECT COSTS OF DAMS

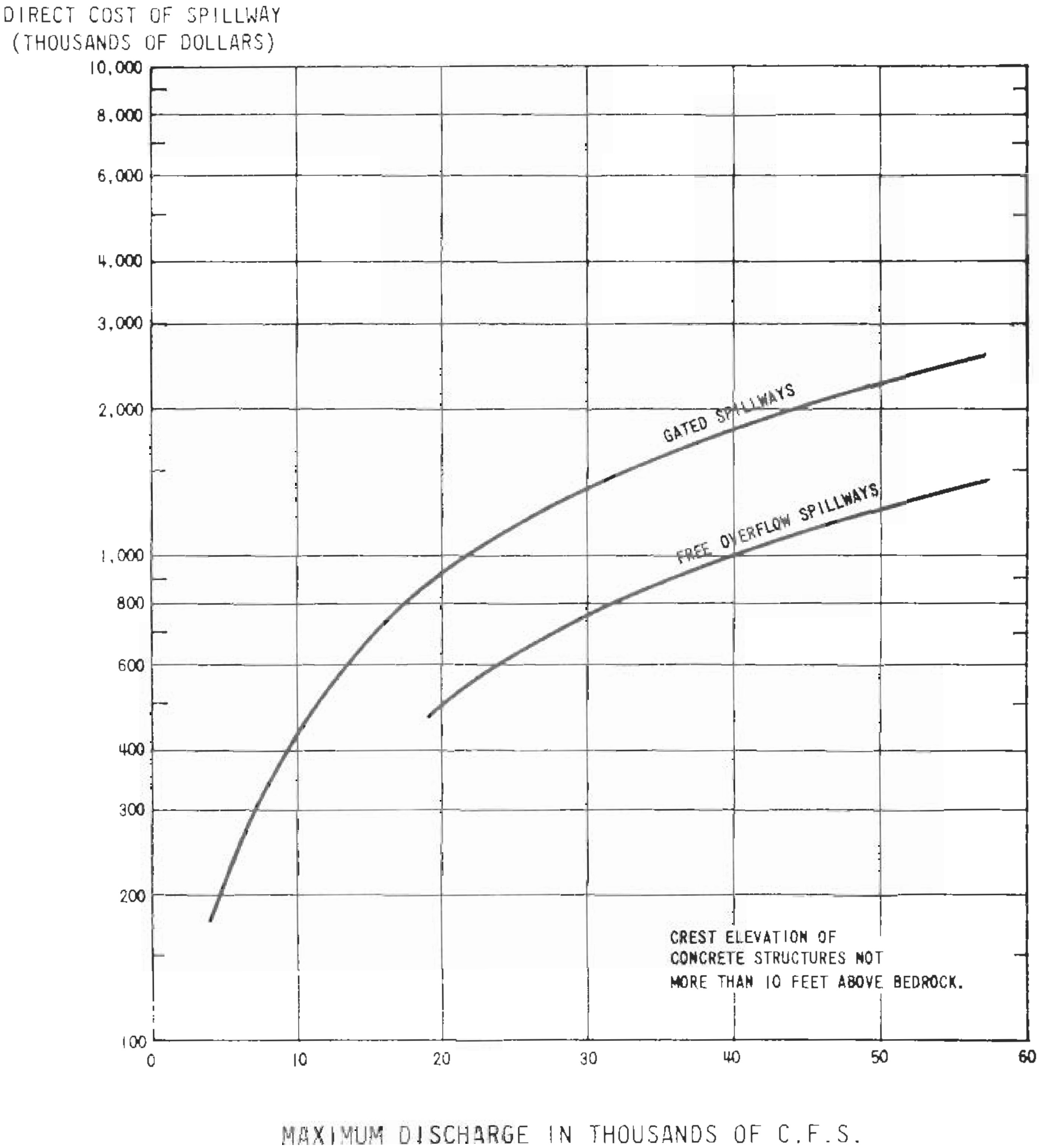


NOTES: FOR INTERPRETATION OF CURVES SEE SECTION 4.8.1 ITEM 5

SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C9

DIRECT COSTS OF SPILLWAYS

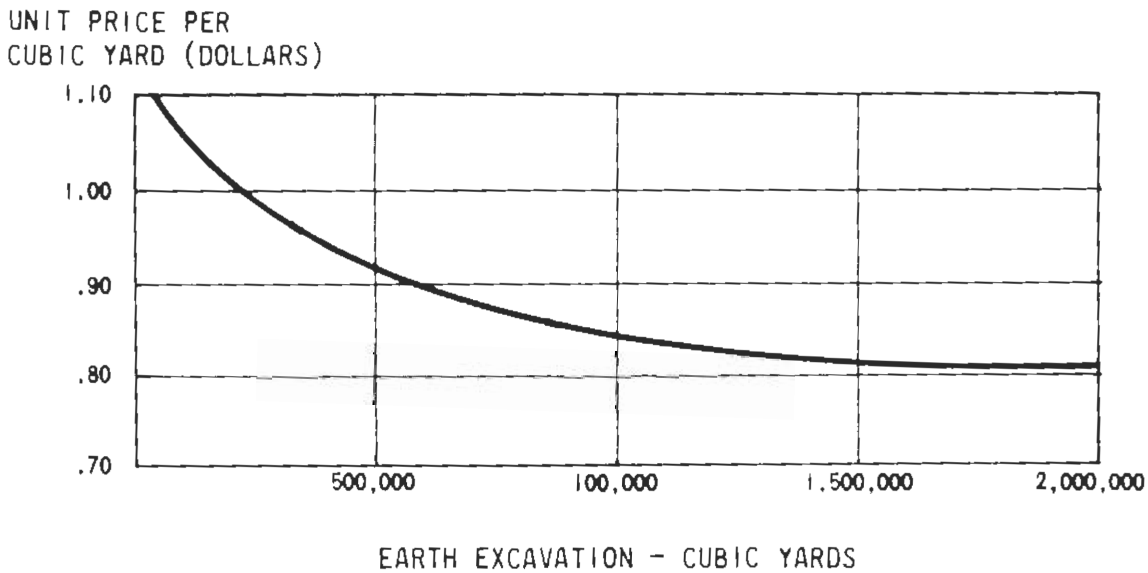


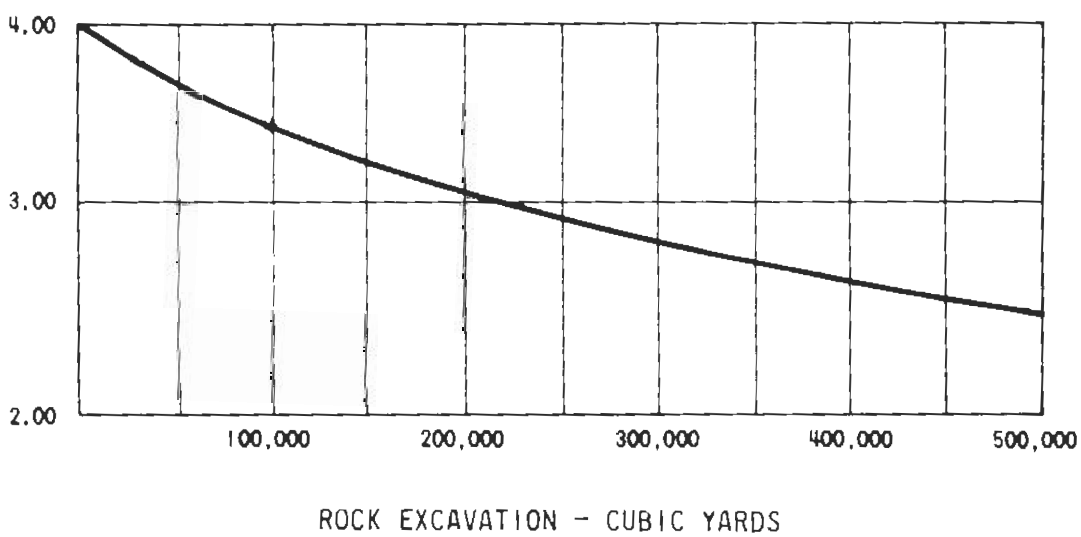
NOTES: FOR INTERPRETATION OF CURVE SEE SECTION 4.8.1 ITEM 5

SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C10

DIRECT COSTS OF EXCAVATION



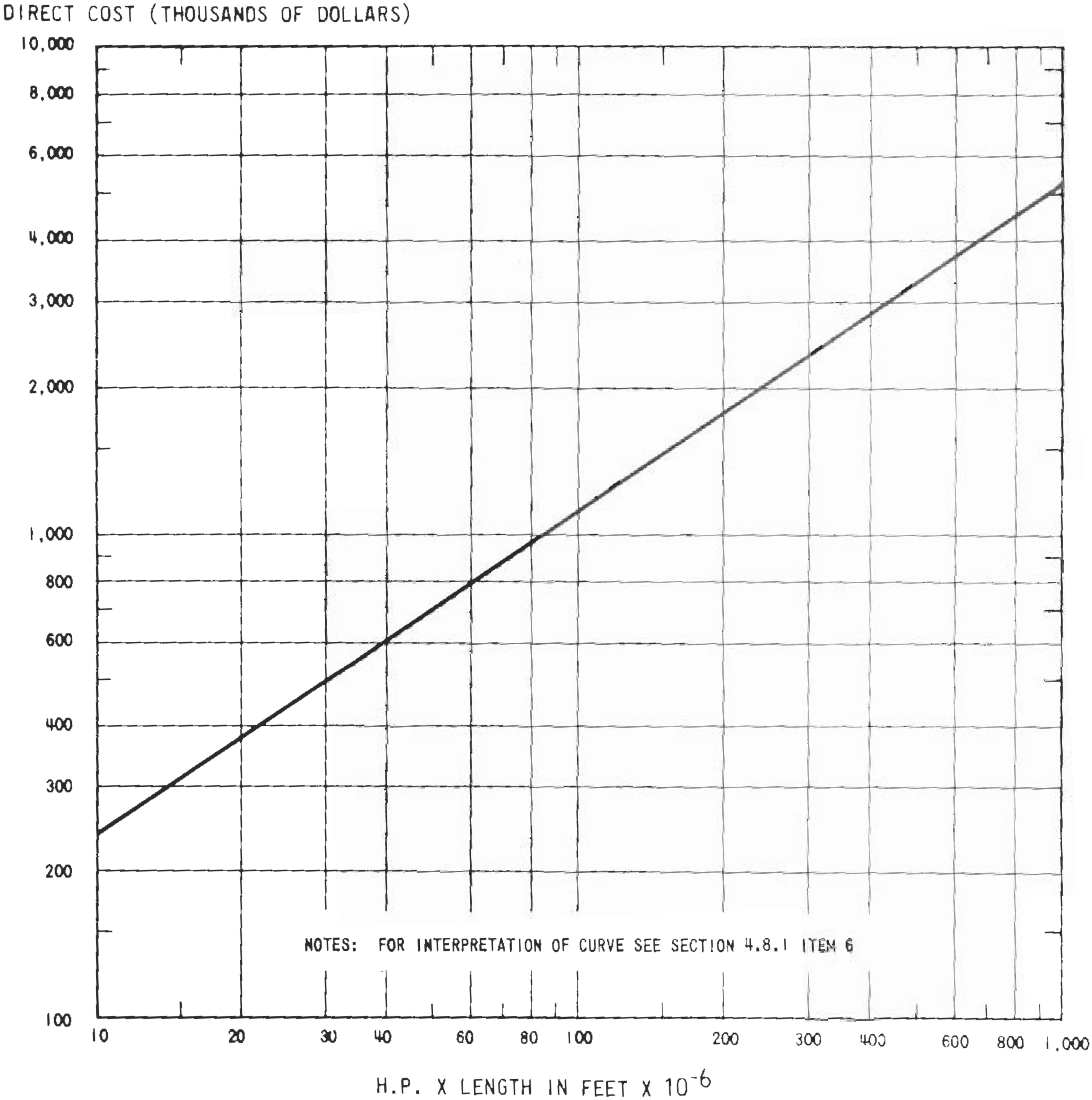


NOTES: FOR INTERPRETATION OF CURVES SEE SECTION 4.8.1 ITEM 6

SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C11

DIRECT COSTS OF PENSTOCKS

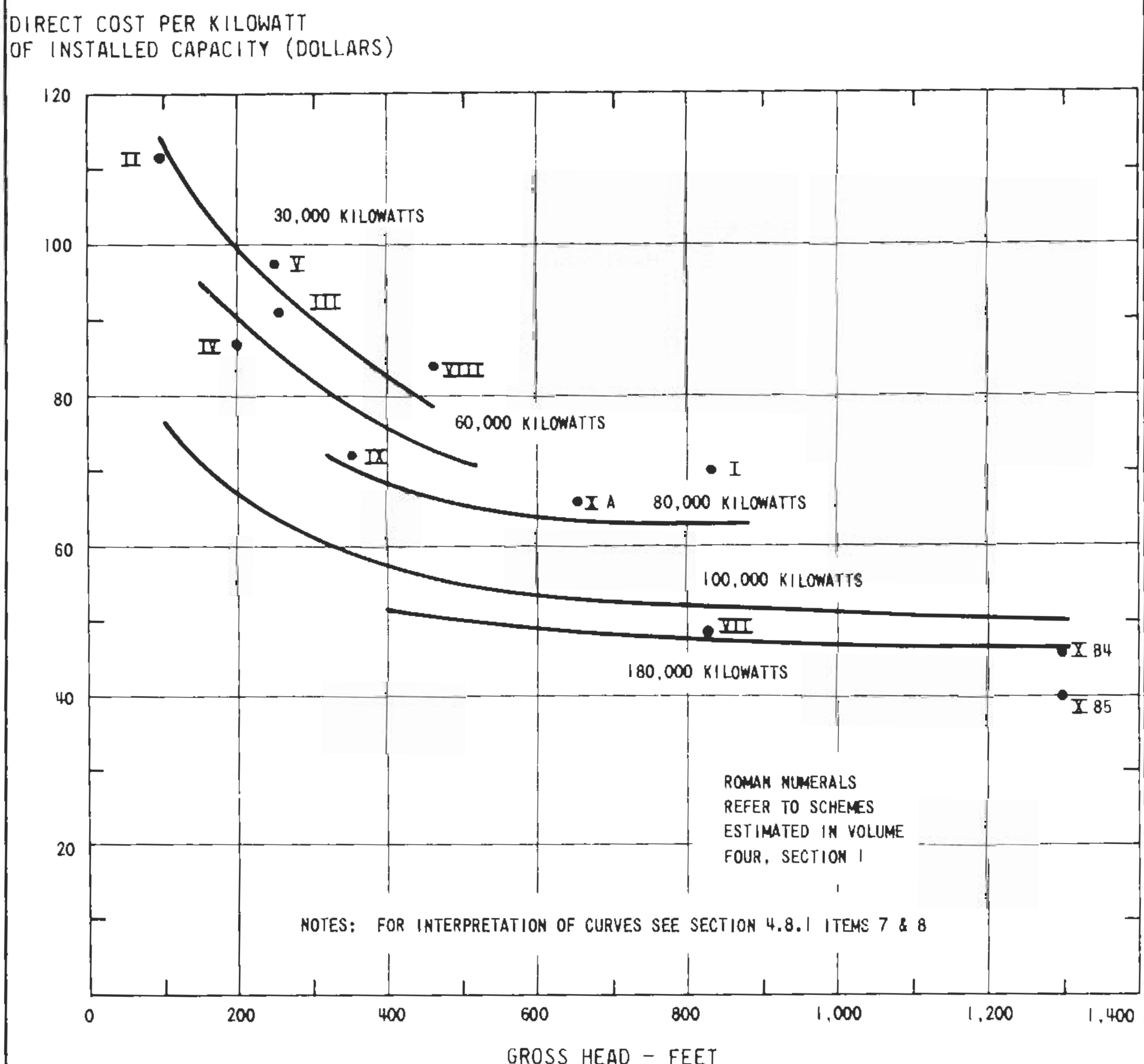


SOURCE: UNPUBLISHED WORKING DOCUMENTS

FIGURE C12

DIRECT COSTS OF POWERHOUSES

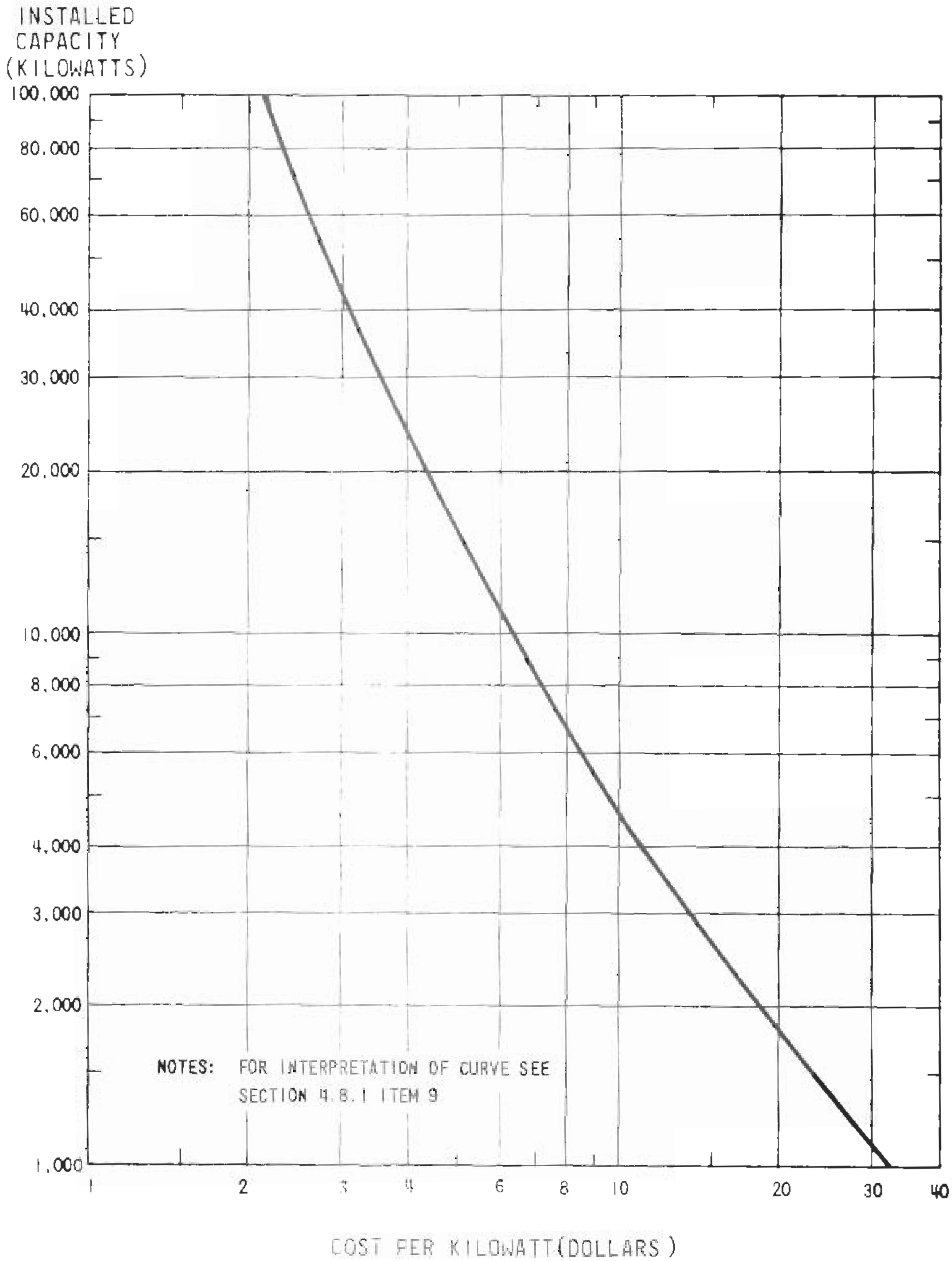
INCLUDING EQUIPMENT



SOURCE: - UNPUBLISHED WORKING
DOCUMENTS

FIGURE C13

ANNUAL OPERATION AND MAINTENANCE COSTS OF HYDROELECTRIC PLANTS



SOURCE: FEDERAL POWER COMMISSION
TECHNICAL MEMORANDUM No.1
JAN.1, 1962

FIGURE C14