THE WATER COMPONENT OF THE INDUSTRIAL LOCATION PROBLEM: BRITISH COLUMBIA'S PULP AND PAPER INDUSTRY

by

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ABSTRACT

A study in economic geography, this thesis attempts to determine the importance of water for process supply and effluent disposal in industrial location decisions. It is postulated that industry faces physical, institutional, and technologic-economic constraints when evaluating the water component in location problems. Each of these three constraints is analyzed and evaluated for British Columbia's pulp and paper industry, with a view to discovering its effect on the range of spatial choice enjoyed by firms.

A number of general conclusions emerge from the investigation. Although a theoretic location proof is not offered, the study raises a number of arguments which indicate water has been over-emphasized in industrial location decisions, and that industry exhibits greater spatial mobility regarding water requirements than is contended in the geographical and technical literature. Of the three constraints, it appears that those of a technologic-economic nature impose the severest limitations on spatial choice; physical, the least. Institutional regulations are found to provide industry with incorrect signals for decision making -- the suggestion is offered that effluent control programs based upon economic rather than biological criteria would remove this problem. The implications of the above conclusions for future geographic inquiry regarding water management and development is considered in the concluding section of the study.

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I would like to thank Dr. Chapman, my thesis advisor, for his guidance during conceptualization, analysis, and writing of this thesis. Dr. Gates and Dr. Farley of the University of British Columbia geography department provided many useful suggestions as well. I also thank the individuals of the British Columbia pulp and paper industry who made the collection of study data an interesting and pleasant task. Finally, the support of my wife, Joan, is gratefully recorded.

CHAPTER I

THE CONCEPTUAL FRAMEWORK

"An adequate supply of good quality water is one of the most important factors in selecting a site for a pulp and paper mill."[1] "... water supply can become an important locational consideration, certainly affecting the actual choice of district and site within a region that is otherwise satisfactory."[2] "Is it possible that in giving due weight to the necessity of water in industrial processes we have overemphasized its strategic importance in industrial location?"[3]

The above statements represent the conflicting opinions, different scales, and various terms of reference used in literature considering the importance of water for industrial location. With such literature for a departure point, this thesis attempts to determine the significance of water for process supply and effluent disposal in industrial site selection using data from British Columbia's pulp and paper industry.

When searching for a new site, firms encounter a number of constraints regarding water requirements. These constraints or limiting factors may be placed into three categories:

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1 J. B. Culkin and G. S. Witham, Modern Pulp and Paper Making, New York, Reinhold, 1957, p. 440.

2 R. C. Estall and R. O. Buchanan, Industrial Activity and Economic Geography, London, Hutchinson University Library, 1961, p. 150.

3 G. F. White, "Industrial Water Use: A Review", Geographical Review, Vol. 50, No. 3, July 1960, p. 422.

physical, institutional, or technologic-economic. Physical limitations are represented by the quantity, quality, accessibility, and reliability of available or potential water sources. Institutional constraints are defined by the customs, laws and beliefs in any social structure governing the use of water. A comment by Thomas illustrates the fact that the institutional aspect is not unimportant. In his words

> Water is not truly available for a man's use unless society acknowledges his right to use it, and the cultural constraints upon water use may be more formidable than the physical constraints. [4]

Bylund echoes these ideas by writing, "Many obstacles to more efficient use of water are human rather than physical."[5]

The third constraint mentioned, technologic-economic, is an aggregation of technology and economics. While recognizing the distinction between technical, economic, and financial feasability, it is assumed in this study that technology used by industry is a function of economic and financial conditions. As Thomas suggests, "Water will be used in those places and for those purposes that can best afford to bear the cost under prevailing conditions."[6] Within the framework of these three

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4 H. E. Thomas, "Water Problems", Water Resources Research, Vol. 1, No. 3, 1965, p. 439.

5 H. B. Bylund, "The Human Factor and Changes in Water Usage Patterns", Water Resources Research, Vol. 2, No. 3, 1966, p. 365.

6 H. E. Thomas, op. cit., p. 444.

constraints, the study attempts to establish the role of the water component for the general location problem.

THE RESEARCH DESIGN

To investigate the role of water in industrial site selection, British Columbia's pulp and paper industry was chosen for analysis. The reasons for its selection were twofold. First, the industry uses large quantities of water. Second, a high percentage of water used for processing is returned to the natural system from which it is withdrawn. This heavy water demand for process supply and effluent disposal contributes to a popular contention that the pulp and paper industry is highly dependent upon water for site selection.

Once the industry was chosen, the problem still remained regarding choice of individual mills. It was hypothesized that entrepreneurial skill, plant age, product, plant capacity, and relative location would be important variables affecting the significance of water for siting. A stratified sample using the above variables for selection criteria was thus used to chose the study mills. The selected mills are shown in Figure 1 and Table I on the following pages. More detailed information about the plants is found in Appendix I.

PERSPECTIVE and SCOPE

This inquiry stems from two areas of research which have attracted geographical attention for many years -- resource (water) research and industrial location study. In water

Figure 1

PULP AND PAPER MILLS IN BRITISH COLUMBIA

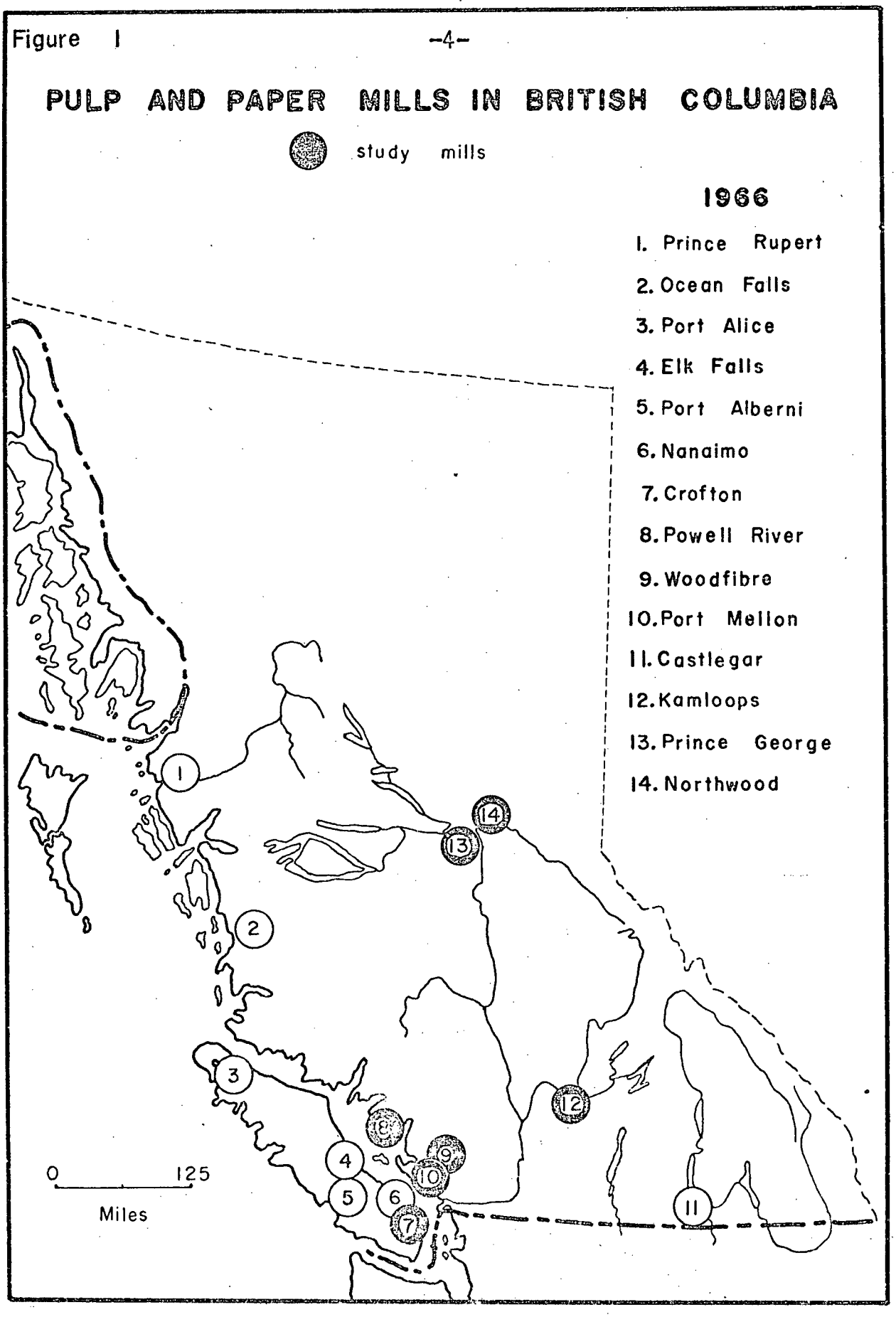

Table I

Study Mills:

British Columbia's Pulp and Paper Industry

Company	B.C. Forest Products	Canadian Forest Products Ltd.	Kamloops Pulp and Paper Ltd.	MacMillan Bloedel	Northwood Pulp Ltd.	Prince George Pulp and Paper Ltd.	Rayonier Canada (B.C.) Ltd.
Location	Crofton	Port Mellon	Kamloops	Powell River	Prince George	Prince George	Woodfibre
Plant Age	1958	1965*	1966	1965*	1966	1966	1961
Capacity (tons/day) and product	500 bleached kraft pulp	500 bleached kraft pulp	250 bleached kraft pulp	230 sulfite pulp 960 ground-wood pulp 1430 newsprint	625 bleached kraft pulp	300 bleached kraft pulp 375 kraft paper	250 bleached kraft pulp

*not date of initial production

resource research, interest has concentrated upon four themes: development and management,[7] perception,[8] environmental quality,[9]

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7 See, for example, G.F. White, "A Perspective of River Basin Development", Law and Contemporary Problems, Vol. 22, No. 3, 1957, pp. 150-162; W.R.D. Sewell, "The New York Water Crisis; an Opportunity for More Effective Management of Urban Water Supplies", Journal of Geography, Vol. 65, No. 11, November 1966, pp. 384-389; E. Hamming, "Water Legislation", Economic Geography, Vol. 34, No. 1, January 1958, pp. 42-46.

8 See, for example, R.W. Kates, Hazard and choice perception in flood plain management, Chicago, University of Chicago Press, Department of Geography, Research Paper No. 78, 1962; and Research Papers 29, 57, 75, 93, and 98.

9 See, for example, J.D. Chapman, "Water Pollution -- A Threat

and economic growth.[10] It is evident that while this investigation touches upon all four themes, the primary focus is development and management. In considering the role of the water component for industrial location, the study addresses itself to the problem of joint management and administration of water resources by government and industry. Nevertheless, it is also apparent that the concepts of perception, environmental quality, and economic growth will have to be recognized and considered if the study is to claim comprehensive analysis.

The concept of location has long held interest for the geographer.[11] Turning to industrial location studies, it is possible to recognize several approaches. One analyzes a particular industry with a view to determining its important locational factors.[12] A somewhat different approach is employed

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to the Quality of the British Columbia Environment", 1965 Conference on Water Pollution: Proceedings, edited by H.M. Rosenthal and G.A. Drew, Vancouver, B.C., University of British Columbia, Extension Department, 1966, pp. 60-65.

10 See, for example, G.F. White, "Industrial Water Use: A Review", Geographical Review, Vol. 50, No. 3, July 1960, pp. 412-430.

11 F. Lukermann, "The Concept of Location in Classical Geography", Annals of the Association of American Geographers, Vol. 51, No. 2, June 1961, pp. 194-210.

12 T.L.C. Griffin, "An example of Oil Refinery Location -- Port Stanvac", Australian Geographer, Vol 9, No. 5, March 1965, pp. 307-309; P.P. Karan, "Changes in Indian Industrial Location", Annals of the Association of American Geographers, Vol. 54, No. 3, September 1964, pp. 336-354; K.Warren, "Locational Problems of the Scottish Iron and Steel Industry Since 1760", Scottish Geographical Magazine, Vol. 81, No. 1, April 1965, pp. 18-37, Vol. 81, No. 2, September 1965, pp. 87-103.

by the school emphasizing the location factor -- either as isolated components[13] or as interacting variables[14] -- and relegating industry to a secondary position. A third method emphasizes neither industry nor location factors, but instead considers elements influencing both.[15] Within this range of approaches, it is possible to find studies ranging from description and explanation,[16] to prescription,[17] to abstraction.[18]

This study weds a number of these approaches. Water, as a

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13 M. Fulton and L. C. Hock, "Transportation Factors Affecting Locational Decisions", Economic Geography, Vol. 35, No. 1, January 1959, pp. 51-59; A. Rogers, "Coking Coal Supply: Its Role in the Expansion of the Soviet Steel Industry", Economic Geography, Vol. 40, No. 2, April 1964, pp. 113-149.

14 F.E.I. Hamilton, "Location Factors in the Yugoslav Iron and Steel Industry", Economic Geography, Vol. 40, No. 1, January 1964, pp. 46-64; T. McNight, "Industrial Location in South Australia", Australian Geographical Studies, Vol. 5, No. 1, April 1967, pp. 50-72.

15 E. M. Dinsdale, "Spatial Patterns of Technological Change; The Lumber Industry of Northern New York", Economic Geography, Vol. 41, No. 3, July 1965, pp. 252-274; G.J.R. Linge, "Governments and the Location of Secondary Industry in Australia", Economic Geography, Vol. 43, No. 1, January 1967, pp. 43-63.

16 F. Lukermann, "The Changing Pattern of Cement Mill Location in North America", Przeglad Geograficzny, Vol. 32, No. 4, 1960, pp. 537-559.

17 E. Casetti, "Optimal Location of Steel Mills Serving the Quebec and Southern Ontario Steel Market", The Canadian Geographer, Vol. 10, No. 1, 1966, pp. 27-39.

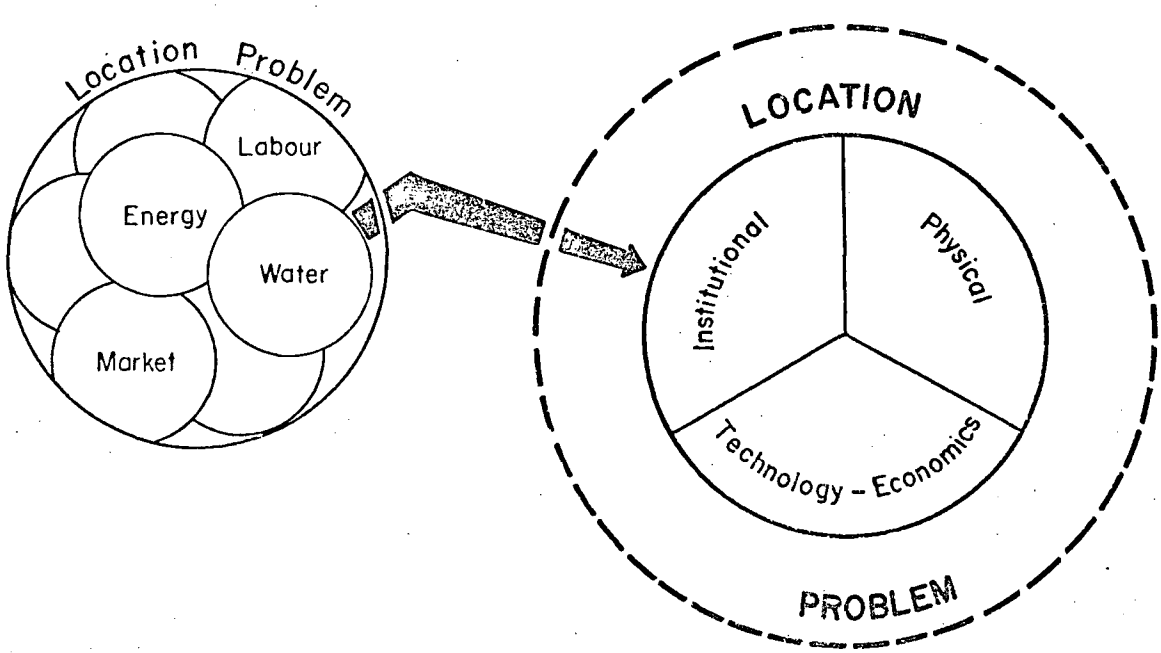
18 D.M.A. Smith, "A Theoretical Framework for Geographical Studies of Industrial Location", Economic Geography, Vol. 42, No. 2, April 1966, pp. 95-113.

component of the total location problem is emphasized; the British Columbia pulp and paper industry provides empirical data. While the study includes various characteristics of the water component -- physical, institutional, and technologic-economic -- which affect the location problem, the location focus provides the orientation point for the investigation. Regarding level of inquiry, the study is somewhere near the mid-point of a spectrum having description at one end and abstraction at the other.

To summarize, it is recognized that water is only one of many variables that industry must consider when evaluating a site. As a result, the present investigation covers only a portion of the total location problem. Diagrammatically this concept appears in the following manner.

Figure 2

THE WATER COMPONENT OF THE LOCATION PROBLEM



While the preceding framework does not allow complete analysis of the location problem, it permits coverage of the one variable chosen. That comprehensive coverage of water is required can be found in Mussey's statement

> Although many factors contribute to establishing the feasibility or even the limits of future industrial development, the one relating to available water supply is extremely important. A knowledge of the water requirements of various industries is valuable therefore in planning the logical development in any area where water is a critical factor. Thus far very little suitable information on the water requirements of our major industries is available for general planning. 19

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19 O. D. Mussey, Water Requirements of the Pulp and Paper Industry, United States, Department of the Interior Geological Survey, Water Supply Paper 1330-A, Washington, United States Government Printing Office, 1955, p. iii.

CHAPTER II

LITERATURE REVIEW

As explained in the first chapter, this thesis attempts to determine the role of water in industrial site selection. It was suggested that such evaluation would be possible by considering constraints -- physical, institutional, and technologic-economic -- which the characteristics of water impose upon industry. To discover the emphasis given to the three constraints, this chapter considers literature which has focused upon the water-industry-location milieu. The review, as a result, will act as a stepping stone for evaluation of data from the British Columbia pulp and paper industry.

PHYSICAL CONSTRAINTS

Within the scope of physical constraints, attention has been given to water quantity, quality, and reliability. Regarding quantity, there are varying schools of thought about the importance of this aspect for locational decisions. One group contends that adequate water quantity is critical for successful operation in many industries.[1] This argument is extended to state that because of abundant water supplies, British Columbia is attractive to water-using industries -- since the physical constraint of water quantity is insignificant. It is important

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1 Two proponents of this argument are: R. Haig-Brown, The Living Land, Toronto, Macmillan Co. of Canada Ltd., 1961, p. 45, and H.L. McDonald, British Columbia: Challenge in Abundance, Canadian Confederation Centennial Committee of British Columbia, 1966, p. 92.

to note that this argument is based on a regional scale. The validity of this stand will be one of the aspects considered in this study.

Another set of writers, referring specifically to the pulp and paper industry, suggest that high water demands impose important limitations on the spatial choice available to industry. DeBeck maintains that pulp mill water process supply needs prohibit construction of plants in many areas of the province, although those areas are not specified.[2] The National Council for Stream Improvement of the Pulp, Paper and Paperboard Industries, after conducting a water use survey of the industry, states that large quantities of water are required both for process supply and effluent disposal.[3] In fact, the Council concludes, the pulp and paper industry is probably more dependent upon water than any other major industry. It notes that the industry has increased water re-use and effluent treatment in an effort to reduce its dependency on water. Randall, a process engineer, explains that an adequate amount of process supply water is a major concern at his company's newsprint mill.[4] For

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2 H. D. DeBeck, Present Use of British Columbia's Water, prepared for the Seventeenth British Columbia Natural Resources Conference, Victoria, B.C., February 1967, manuscript, p. 14.

3 National Council for Stream Improvement of the Pulp, Paper and Paperboard Industries, "A Survey of Water use in the Pulp and Paper Industry", Pulp and Paper Magazine of Canada, Vol. 66, No. 8, August 1965, pp. 83-84.

4 D. J. Randall, "Reclamation of Process Water", Pulp and Paper Magazine of Canada, Convention Issue, 1964, Vol. 65, p. T134.

him, the two solutions to this onerous problem are increased re-use of water or improved storage capacity.

These three writers introduce several important concepts which are considered in this investigation. First, there is the notion of water being necessary for process supply and effluent disposal, with evident disagreement regarding the relative importance of these two aspects. Finding the weight given to water for process supply and waste discharge, and the consequent ramifications for location decisions, is an objective of this research. A second point raised here is the significance of water for a company facing expansion on an established site and a company searching for a new location. The role of water in these two cases is undoubtedly different, but the literature is not clear as to the degree or nature of the difference. It is hoped that some answers will emerge from analysis of the pulp and paper industry. Finally, the practice of water re-use is introduced along with suggestions about its possible contribution to spatial mobility. The significance of re-use techniques is included in this analysis.

Two other writers, Gibson and Speir, agree with the importance of water quantity requirements, but carry their studies further than the three mentioned previously. Gibson contends that adequate quantity supplies provide attraction for a site to the extent that firms will alter their product to accomodate capricious quality characteristics.[5] Regarding variations in

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5 J. R. Gibson, "The paper industry of North West England --

water requirements, he suggests that raw material, product, and extent of water re-use are as important as size of the firm. To test his assertion, these variables have been included in the set of elements hypothesized as effecting the water component.

Speir feels that water quantity is important enough in siting decisions to merit the classification of all siting factors as either water, direct, or indirect.[6] In discussing methods of site factor evaluation, Speir argues that only initial investment criteria reflect the significance of any factor for a site since investment requirements give all factors a common denominator. Arguments such as Speir's led to investment as well as physical data being used in this study.

Water quantity is not always considered in isolation. There are investigators who include it with, or place it secondary to, the notion of water quality. Estall and Buchanan fall into this school, suggesting that quantity and quality of available water are important for locational choice at several scales -- region, district, or site.[7] They continue, commenting that the costs associated with obtaining quantity and quality requirements will vary with relative location to the water source, the

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Part 2: Influence of water supply and effluent disposal upon location", The Paper-Maker and British Trade Journal, Vol. 136, No. 4, October 1958, pp. 64-66.

6 W. B. Speir, "Are You Sure You Picked the Right Site?" Southern Pulp and Paper Manufacturer, Vol. 27, No. 9, September 10, 1964, pp. 72-78.

7 R. C. Estall and R. O. Buchanan, Industrial Activity and Economic Geography, London, Hutchinson University Library, 1961, pp. 147-152.

need for purification and re-use, and the costs of pumping and storage. As many of these variables as possible have been included for analysis in this study along with the set derived from Gibson's work. Ronalds also considers quality and quantity to be inseparable variables, arguing that they have a definite effect upon siting decisions.[8] Quality is thus incorporated as one of the physical constraints deserving investigation.

The idea of reliability has received less attention than those of quantity and quality, but, nevertheless, some writers have given it consideration. Van Horn, for example, recognizes the importance of the reliability concept when writing that, "There is an absolute need for a uniform and continuous water supply in the expanding industrial community".[9] Gourdeau and Asselin echo this stand by stating that, "It is much more prejudicial for an industry to have water of a quality that changes frequently than to have at its disposal water of inferior but constant quality".[10] As reliability has been neglected relative to its other counterparts, it receives emphasis in this inquiry.

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8 A. F. Ronalds, "The Industrial Use of Water", Water Resources Use and Management, proceedings of a symposium held at Canberra by the Australian Academy of Science, Melbourne University Press, 1964, pp. 54-63.

9 W. M. Van Horn, "Water: Industry's Lifeline", Pulp and Paper, Vol. 34, No. 5, May 1960, p. 64.

10 J. P. Gourdeau and R. Asselin, Industrial Use of Waters, Background paper A4-1-6, from the Pollution and Environment Conference sponsored by the Canadian Council of Resource Ministers, October 31 to November 4, 1966, p. 24.

Not all authors agree that the physical attributes of water restrict industrial choice of location. Thurn concedes that the first pulp and paper mills were located adjacent to rivers due to the necessity of water needs.[11] Today, however, he feels that advances in technology have resulted in a situation where location of mills is keyed to product distribution -- which may be a long distance from a large river. The variability of water requirements in the iron and steel industry presented by C. Langdon White could also be taken as an argument against the influence of physical constraints.[12] White implicitly introduces the concept of factor trade-off in his study. In other words, when compensating factors are found to be particularly advantageous, industry can incur high water costs at a site and still operate profitably. On the basis of two investigations, Gilbert White concluded that industry is flexible regarding water requirements, since few concrete cases were available where industries changed prospective sites because of unfavorable water supply conditions.[13] It is apparent from these studies that

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11 A. Thurn, "Water and Water Reuse", Chapter 6 in Pulp and Paper Science and Technology, edited by C. Libby, New York, McGraw Hill, Vol. 2, 1962, pp. 144-162.

12 C.L. White, "Water -- A Neglected Factor in the Geographical Literature of Iron and Steel", Geographical Review, Vol. 47, No. 4, October 1957, pp. 463-484.

13 G.F. White, "Discussion", Water for Industry, edited by J. B. Graham and M. F. Burrill, Washington, D.C., Publication No. 45 of the American Association for the Advancement of Science 1956, pp. 121-124; and "Industrial Water Use: A Review", Geographical Review, Vol. 50, No. 3, July 1960, pp. 412-430.

literature regarding the significance of the physical attributes of water is far from clear -- clarification thus becomes a primary goal in this investigation.

To summarize, studies emphasizing physical constraints associated with water stress the importance of quantity and quality to the relative exclusion of reliability. Investigations concentrate on water for process supply, generally neglecting it as a factor for effluent disposal. Study scales range from the metropolitan area to subcontinental regions, and yet, despite this variety, or perhaps inspite of it, there is agreement that physical aspects of water impose real limitations upon spatial flexibility.

INSTITUTIONAL CONSTRAINTS

Although considerable attention is focused upon the aspect of social regulation in water development,[14] there are few statements available in the geographical literature specifically relating institutional controls to the industrial location problem. This omission is unfortunate since with increasing competition for available water supplies and growing demand for environmental quality, public management programs should be critically evaluated and reviewed. As Graham and Burrill note

> It, therefore, becomes necessary, on the one hand, to ascertain as precisely as possible the limitations of nature, and on the other hand to design for,

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14 See, for example, Canadian Press, "Ministers Agree on Pollution Group -- National Council Offered as Solution to Problem", Vancouver Sun, Saturday May 6, 1967, p. 3.

> develop, and use limited resources with maximum efficiency and equity. [15]

It is evident that Graham and Burrill recognize the physical or natural limitations associated with water, but they go further to acknowledge that available supplies must be used to maximize social benefits. In other words, to achieve multiple purpose water development programs, social controls are necessary for social benefit maximization. Surely consideration of regulations and controls is pertinent to the general location problem, where industry must compete for water.

Bylund indicates another aspect of the institutional constraint -- the human factor.[16] He stresses the persistence of people to resist change -- which can be seen today in public reluctance to accept the concept of "optimum" pollution levels in streams. This human attitude is pertinent to the current study, where any social regulations must achieve a balance between economic growth objectives and public demands for pollution standards. Geographical inquiries appear not to have touched upon this area of research, which becomes one of the avenues followed in this study.

While Bylund cited the human element as a factor to contend with, De Laet notes that jurisdictional and legislative problems

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15 J. B. Graham and H. F. Burrill, eds., "Preface", Water for Industry, Washington, D.C., Publication No. 45 of the American Association for the Advancement of Science, 1956, p. iii.

16 H. B. Bylund, "The Human Factor and Changes in Water Usage Patterns", Water Resources Research, Vol. 2, No. 3, 1966, pp. 365-369.

often pose greater difficulties for water quality management than technical solutions.[17] Government jurisdictional and legislative difficulties are thus analyzed along with the other institutional aspects discussed earlier.

As mentioned at the beginning of this section, literature considering institutional constraints related to the water-location problem is scarce. In the few investigations cited, however, it is obvious that there are some who feel that the institutional constraint may impose the greatest rigidity for industrial location. It must be noted that these opinions are not supported by empirical evidence, but instead have arisen from qualitative analysis. Consequently, one of the prime interests here is to consider and analyze the effect of regulations on the location problem. With increasing concern given to environmental quality, it appears that the present and future role of this limitation should be clarified.

TECHNOLOGIC-ECONOMIC CONSTRAINTS

These two factors -- technology and economics -- are considered together in the belief that they are closely interrelated, and, that consideration of one without the other would yield misleading rather than guiding results.

Gotaas illustrates the entwining relationship between the two variables when writing the following

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17 C. De Laet, "Pollution and Our Environment", Pulp and Paper Magazine of Canada, Vol. 66, No. 11, November 1965, pp. 132-133.

> Though technological tools are available to solve most wastewater problems, economic feasibility is often a barrier to their use. Future penetration of technologic frontiers will include a better understanding and more economical use of present methods and the acquiring of new knowledge which will permit more efficient wastewater management. [18]

Gotaas thus says that improved economic knowledge will allow more efficient waste water management. A similar thesis is put forward by Turner.[19] This point can be taken one step further, however. If advances in knowledge permit increased treatment efficiency, then at the same time there must be a concomitant increase in spatial choice given to industry. In other words, improved techniques would allow formerly unsuitable water supplies to be exploited. In looking at different pulp mills in British Columbia, built at different times, it is hoped that some insight will be gained into the role of technology as a catalyst for spatial mobility.

Despite problems related to the economics of the firm, there are a number of writers who have shown that industries have been able to reduce water requirements, thus providing greater locational

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18 H. B. Gotaas, B. W. Johnson, F. H. Doe, and A.E. Berry, "Frontiers in Wastewater Management: Technological, Administrative, Financial", Journal of the Water Pollution Control Federation, Vol. 38, No. 5, May 1966, pp. 745-773, see particularly pp. 745-754.

19 J. N. Turner, "Clear Water: A National Priority", Pulp and Paper Magazine of Canada, Vol. 66, No. 11, November 1965, pp. 130-132.

freedom. Empirical statements to this effect can be found from Fuller,[20] Wollage,[21] and Ross.[22] Wollage is enthusiastic about future reductions in water requirements through technological break throughs, but warns that reductions will likely be small in older mills. The two considerations of the location problem appear: a site must be found to satisfy present water demands and long range expansion requirements. The significance of these two aspects for new and established mills in British Columbia is analyzed later in this study. Ross explains that water conservation is necessary since it, "... usually decreases the cost per ton of paper and/or improves quality of paper". With such incentives, technology should continue to obtain reductions in total water needs for pulp mills. An attempt is made to see if the British Columbia pulp and paper industry follows this trend.

SUMMARY

From the review presented in this chapter, it is possible to make a number of generalizations. First, a large majority of studies conclude that the water component is extremely critical for the industrial location problem. Water is frequently

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20 R. R. Fuller, "Water Usage -- The All American Problem: Part 1: Water Works for Man", Southern Pulp and Paper Manufacturer, Vol. 27, No. 5, May 10, 1964, pp. 45-47.

21 J. C. Wollage, "Water Resources and the Pulp and Paper Industry", Tappi, Vol. 47, No. 7, July 1964, pp. 16A,22A.

22 E. N. Ross, "Water Conservation by Reuse -- Panel Discussion", Tappi, Vol. 47, No. 1, January 1964, pp. 180A-182A.

ranked as one of the most important site considerations for the firm seeking a new location, or expanding an old one. A second, and notable point, is that the degree of importance attached to water is maintained for varying scales and terms of reference. Whether the scale is topographic or national, the terms of reference process supply or effluent disposal, water is, in most cases, accorded a significant role in location decisions.

Third, studies recognize three constraints that can be associated with water, and which, in turn, effect the range of available location alternatives. Greatest attention has been given to physical constraints -- that is, the water quantity, quality, and variability that plants can tolerate and still remain operational. There is agreement that large water use requirements significantly restrict industry in its choice of sites.

The role of institutional constraints upon industrial location decisions regarding water has been largely neglected in the geographical literature. The reason for neglect may stem from the fact that physical variables are more easily measured than their intangible social counterparts. The overlooking of social measures is unfortunate, especially with increasing concern with environmental quality concepts.

The role of technology and economics as constraints or catalysts for spatial choice has been adequately covered in the literature, but less thoroughly than the physical aspects.

Agreement is reached that current technology is able to cope with process supply and waste disposal problems, but that many solutions as yet are not economically justifiable. With the ideas expressed in the literature serving as a background, the present study analyzes the British Columbia pulp and paper industry, with a view to clarifying the role of the above constraints in the industry.

CHAPTER III

WATER IN PULP AND PAPER PRODUCTION

In Appendix II, a detailed outline of pulp and paper-making is provided to illustrate where and how water enters the production process. In this chapter, water requirement data of the industry is presented in order to provide a perspective for information gathered from British Columbia mills. Figure 3, depicting water utilization during the various stages of pulp production, is included at this point to make the following water-use data more meaningful.

A few comments about the data are in order. Water-use surveys have concentrated upon the following requirements of industry: supply quantity, effluent discharge, and quality characteristics. Little, if any, attention has been given to institutional standards, capital investment, and operating costs. As a result, the following information covers the first set of attributes but does not include the second. An attempt is made to include all of the above variables for the British Columbia industry.

SUPPLY QUANTITY

The pulp and paper industry has traditionally required large quantities of water. The industry's needs have, however, dropped considerably since a 1914 report portraying many paper mills using almost 400,000 gallons of water per ton of product.[1]

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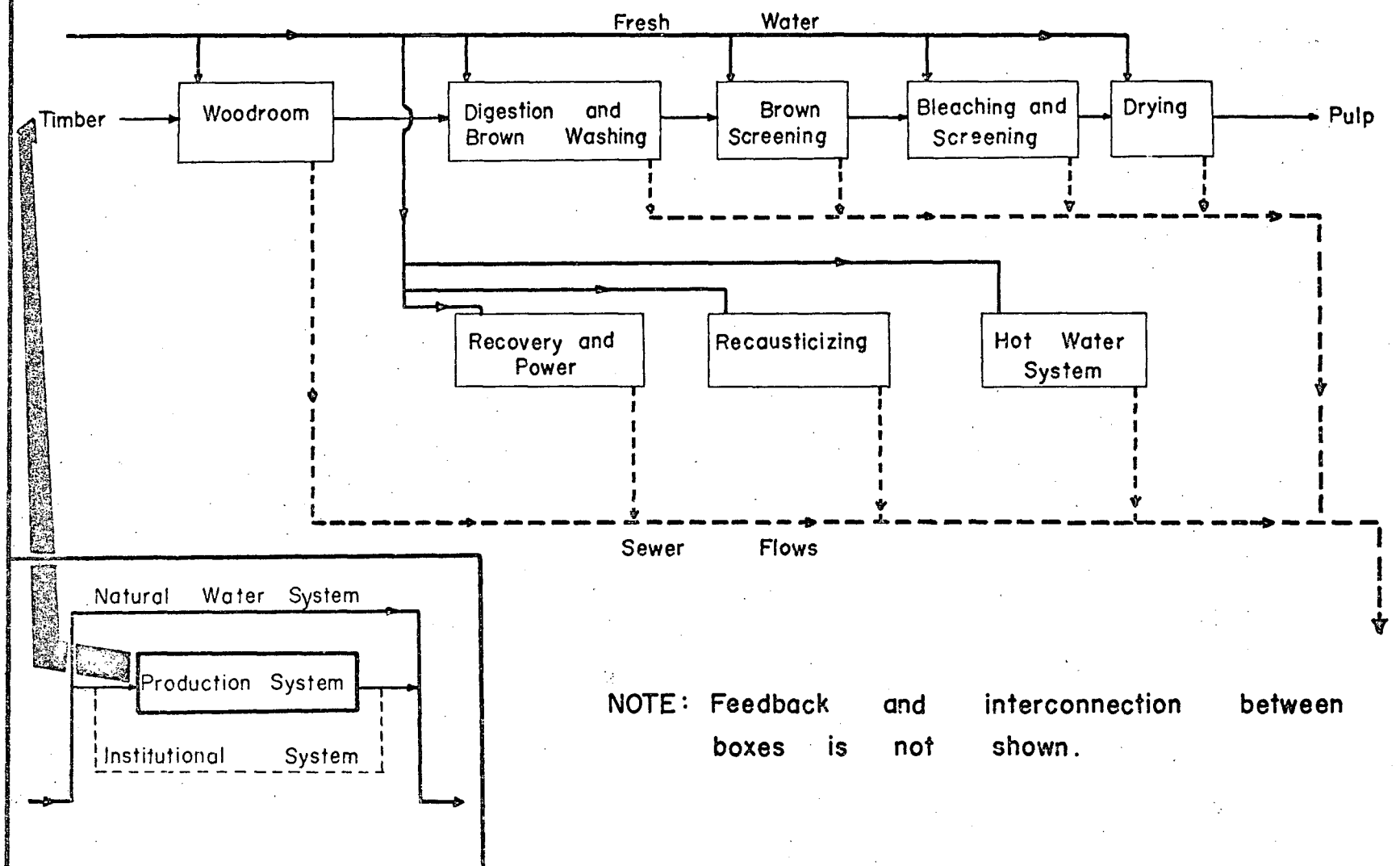
1 W. Van Winkle, Quality of the surface waters of Washington, United States Geological Survey Water Supply Paper No. 339, 1914, p. 23.

Figure 3

WATER IN PULP PRODUCTION



NOTE: Feedback and interconnection between boxes is not shown.

The following four tables are presented chronologically to facilitate evaluation of quantity requirement changes through time. A note of caution. It will be apparent that comparison is difficult, since the same mill classification has not been used in every survey. The important aspects to note, nevertheless are the large amounts, the high variability, and the general decrease of water requirements.

Table II

United States Pulp and Paper Industry

Water Intake per Unit of Production[2]

(1939 survey)

Product	Gallons of water per ton Maximum	Minimum	Average
(1) Paper pulp			
Groundwood-news	12,800	4,000	9,000
Groundwood-specialty	50,000	5,000	28,800
(2) Sulfite pulp			
Unbleached	62,000	40,000	51,000
Bleaching	92,000	50,000	75,700
Total bleached	133,000	70,000	92,000
(3) Sulfite (book, waxing, bond, catalog, hanging grades)			
Unbleached	60,000	30,000	39,300
Bleaching	41,600	39,000	40,200
Total bleached	83,100	70,000	75,100
(4) Kraft pulp			
Unbleached	57,000	11,000	34,600
Bleaching	67,000	5,000	36,000
Total bleached	93,000	91,600	92,300

2 Technical Association of the Pulp and Paper Industry, Industrial water for pulp, paper, and paperboard manufacture, Tappi Monograph Series, Number 1, 1942.

Table III

Compared Unit Water Requirements, in Gallons per Ton for Pulp and Paper Mills in Wisconsin[3]

(1949 survey)

Product	Number of sample mills	Total water requirements per ton of pulp		
		Maximum	Minimum	Average
(1) Groundwood pulp	4	12,300	1,050	4,070
(2) Sulfite pulp	15	115,000	16,300	65,800
(3) Kraft pulp	4	145,000	28,000	75,000

Table IV

United States Pulp and Paper Industry

Unit Water-Use Values for Pulp and Paper Manufacture[4]

(1951 survey)

Product	Number of sample mills	Gallons per Ton of Product		
		Maximum	Minimum	Average
(1) Groundwood pulp	2	16,000	7,350	12,000
(2) Sulfite pulp	4	80,000	38,000	53,250
(3) Kraft pulp	2	92,000	36,400	64,000

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3 O. D. Mussey, Water Requirements of the Pulp and Paper Industry, U.S. Geological Survey Water Supply Paper No. 1330-A, 1955, p. 28.

4 Ibid., p. 31.

Table V

United States Pulp and Paper Industry

Gross Water Intake in Gallons per Ton of A.D. Product[5]

(1952 survey)

Mill Type	Maximum	Minimum	Average
Integrated Mills			
(1) Kraft and groundwood pulp; paper	---	51,500	51,500
(2) Kraft and sulfite pulp	95,000	84,000	89,500
(3) Sulfite and groundwood pulp; newsprint paper	28,600	26,600	27,600
(4) Sulfite pulp; bleachery; paper	130,000	65,000	97,000
(5) Groundwood pulp; paper	108,200	4,210	40,530
Non-Integrated Mills			
(1) Groundwood pulp	---	---	10,000
(2) Sulfite pulp	---	---	86,750
(3) Kraft pulp	---	---	50,000

It is evident that magnitude, variability, and slight decreases mark the water quantity data shown in the previous tables. Reasons for these characteristics, and their implications for the location problem, will be discussed after the British Columbia information is presented in the next chapter.

EFFLUENT DISPOSAL

The pulp and paper industry not only needs large quantities of water for process supply, but also to dissipate effluent. If the next set of tables is compared with the first group, it will become clear that the industry usually returns 70 to 90 percent of its used water into the natural system from which it

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5 Technical Association of the Pulp and Paper Industry, Water Technology in the Pulp and Paper Industry, Tappi Monograph Series, No. 18, 1957, p. 16.

is withdrawn. The fact that mill effluent represents a high percentage of total water intake and thus a large physical volume of discharge makes it mandatory for mills to explore waste quality management practices if a wide range of sites is to remain available. Once more, the survey data is presented in chronological order.

Table VI

United States Pulp and Paper Industry

Waste Flows and Sewered Population Equivalents for Pulp and Paper Mills[6]

(1944 survey)

Product	Waste Gallons	Sewered population equivalent* (number of persons)	
		Biochemical oxygen demand	Suspended solids
	Per ton of product daily		
Pulp			
Groundwood	5,000	16	--
Sulfite	60,000	1,330	--
Sulfate	64,000	390	--
Miscellaneous paper			
No bleach	39,000	26	520
With bleach	47,000	40	220

*The calculated population which would normally contribute the same amount per day.

6 O. D. Mussey, op. cit., p. 20

Table VII

Compared Unit Water Effluent in Gallons per Ton for Pulp and Paper Mills in Wisconsin[7]

(1949 survey-compare with Table III)

Product	Maximum	Minimum	Average
(1) Groundwood pulp	9,293	598	2,927
(2) Sulfite pulp	88,466	12,330	50,304
(3) Kraft pulp	111,325	21,180	57,762

Table VIII

United States Pulp and Paper Industry

Pulp or Paper Mill Effluent

Gallons per Ton of A.D. Product[8]

(1952 survey-compare with Table V)

Mill Type	Maximum	Minimum	Average
Integrated Mills			
(1) Kraft and groundwood pulp; paper	--	--	43,450
(2) Kraft and sulfite pulp	72,000	41,000	58,207
(3) Sulfite and groundwood pulp; newsprint paper	27,000	25,000	26,000
(4) Sulfite pulp; bleachery, paper	130,000	62,500	85,900
(5) Groundwood pulp; paper	103,200	2,845	41,104
Non-Integrated Mills			
(1) Sulfite pulp	--	--	84,500
(2) Kraft pulp	--	--	25,000

The figures in Table IX perhaps best indicate the rough nature of the survey's data -- two surveys in the same year

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7 Ibid., p. 20

8 Technical Association of the Pulp and Paper Industry, Op. Cit., 1957, p. 29.

Table IX

United States Pulp and Paper Industry

Water Intake and Discharge in 1959[9]

(billion gallons/year)

Source	Year	Total Water Intake	Total Water Discharged	Intake Water Lost (%)
National Assoc. of Manufacturers	1959	1,640	1,570	4.3
U.S. Bureau of the Census	1959	1,937	1,824	5.8

yield distinctly different results. It would be unrealistic to expect identical outcomes from two independent studies, but differences registering in the millions of gallons emphasize the crudeness of this type of survey -- and also reflect the necessity for explicit terms of reference and definitions in any analysis. With this explanation for background, effluent discharge data will be shown in the next chapter with a view to determining its significance for location decisions.

QUALITY

The other aspect considered in surveys, that of water quality, has received less attention than quantity supplies and effluent discharge. A description of the various quality characteristics, and their recommended levels for pulp and paper

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9 National Council for Stream Improvement of the Pulp, Paper and Paperboard Industries, "A Survey of Water Use in the Pulp and Paper Industry", Pulp and Paper Magazine of Canada, Vol. 66, No. 8, August 1965, p. 84.

manufacture, can be found in Appendix II. The following table, on the other hand, shows the varying types of water quality contained in pulp and paper mills' water supply sources. Like quantity and waste discharge, it is apparent here that a considerable range in water quality is tolerated by plants. And, as with the other variables, the significance of variability and magnitude will be analyzed after presentation of data from British Columbia mills.

Table X

United States Pulp and Paper Industry

Characteristics of Untreated Water Used in Pulp and Paper Manufacture[10]

(in parts per million)

Constituent or Property	Number of Samples	Minimum	Median	Maximum
Turbidity	12	Trace	4	55
Total Hardness	56	0	55	475
Color	29	2	12	360
Iron	42	0	0.05	112
Silica	51	1.0	6	56
pH	49	4.6	7.2	9.4

An important point should be stated here. The data presented in the tables represents average measures. High and low extremes are not given. It is hoped by introducing the notion of reliability that this weakness will be removed from

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10 O. D. Mussey, Op. Cit., p. 46.

the present study. Furthermore, inclusion of capital and operating cost information should provide more comprehensive coverage of the water component than is found in current studies.

CHAPTER IV

THE WATER COMPONENT OF THE PULP AND PAPER INDUSTRY

To indicate the role that the water component has in the British Columbia pulp and paper industry, this chapter presents data associated with physical, institutional, and technologic-economic constraints of water for the industry. Before proceeding, however, it is appropriate to comment upon the information used in the investigation.

Except where noted, information related to a mill pertains to the situation when operations first began.[1] If this investigation were to be a study of water in the industrial location problem, it was decided that the best approach would be to obtain data from mills regarding their initial operational requirements. In this manner, focus would fall upon water problems encountered at the outset of production -- problems demanding consideration for site evaluation. To balance this approach, since water problems are not necessarily identical for a new mill and a mature mill, attention is given to future water component developments foreseen by companies. With this

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1 The exceptions are Woodfibre (1961), Powell River (1965) and Port Mellon (1965). It is recognized that the water component is considered not only in evaluating new sites, but also in expanding at old ones. As a result, the conclusion was reached that data should be included for at least one older mill, based on some period after initial production. The information for Powell River represents the situation immediately prior to a major expansion program; that at Port Mellon, just after expansion. The date at Woodfibre marks completion of a changeover from sulfite to sulfate production. More detailed accounts are available in Appendix I,

brief introduction, the study turns to the physical constraints associated with the water component -- quantity, quality, and reliability.

PHYSICAL CONSTRAINTS

QUANTITY

As documented in Chapter II, comments frequently appear regarding the large quantities of water required by pulp and paper mills for process supply. On the basis of these large demands, suggestions are made that the industry is sharply restricted in its choice of sites. As a first step towards determining the importance of quantity, mills were asked for their water requirements. Table XI summarizes the results of this survey.

Two features are apparent from the data. For both process supply and effluent discharge there is a wide range in water requirements -- by day and by ton of product. Total water supply requirements vary from 13 million gallons at Kamloops to 64 million at Powell River.[2] On the basis of product, the variation extends from Prince George's average of 44,000 gallons to Crofton's 70,000.[3] The large differences in total water requirements can be easily explained as functions of total mill capacity. In other words, Powell River's high total daily demand derives

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2 In this study, gallon refers to the United States measure as opposed to the Imperial gallon.

3 Usage per ton of product was not available from Powell River. Three products -- newsprint, groundwood pulp, and sulfite pulp -- are made by MacMillan Bloedel, but water requirements were specified in terms of total rather than individual production.

Table XI

Water Requirements for British Columbia

Pulp and Paper Mills

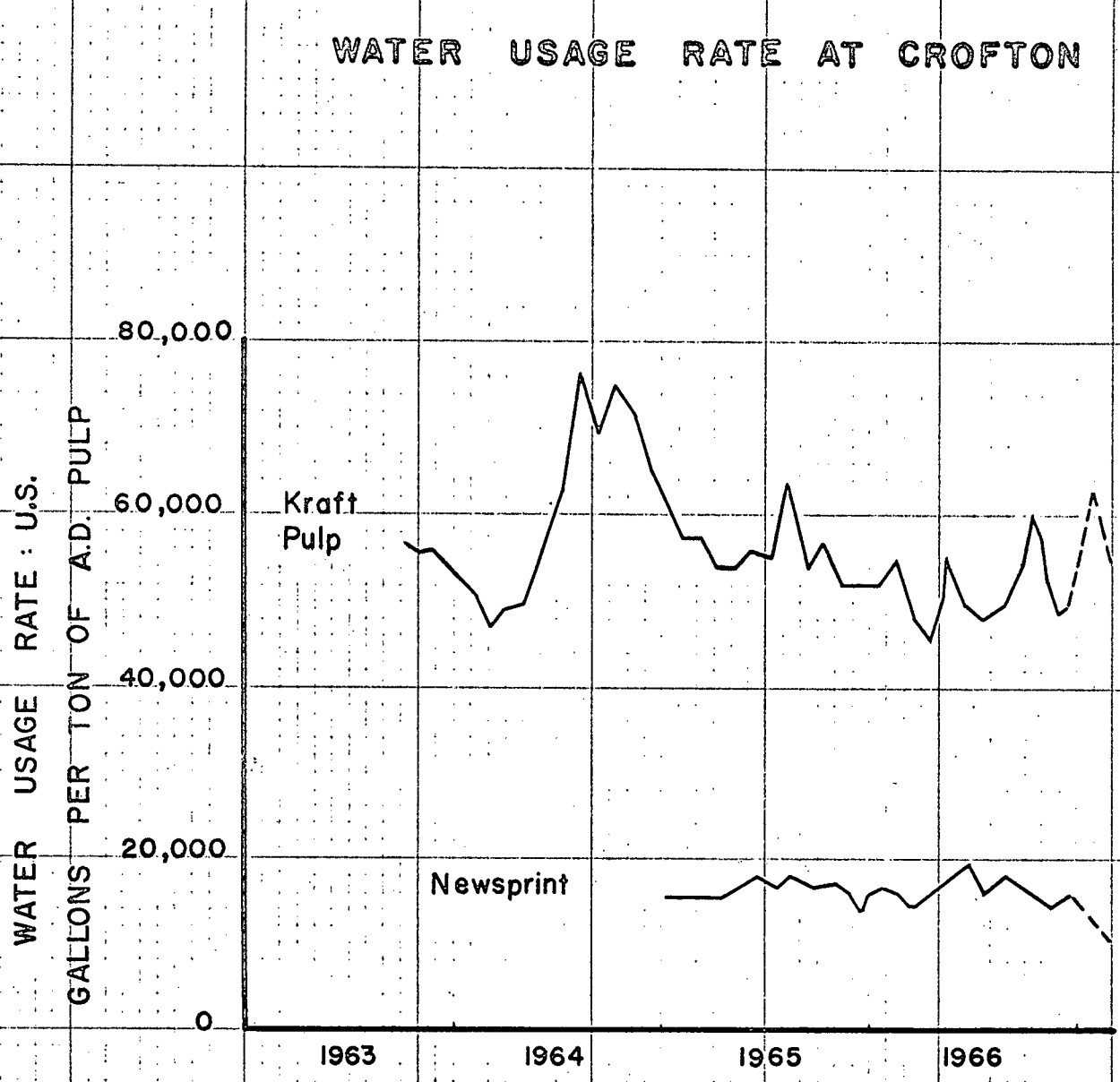
Mill and Year	Average Total Daily Water Requirements in Millions of U.S. Gals. Max.	Av.	Min.	Average U.S. Gals. per ton of Product Capacity	Average Daily Effluent Discharge in Millions of U.S. Gals.*	Effluent Discharge Total Water Requirements
Crofton 1958	37	35	30	70,000	33	95%
Port Mellon 1965	35	31	27	62,000	29	94%
Kamloops 1966	15	13	10	52,000	12	92%
Powell River 1965	68	64**	60	--	58	90%
Northwood 1966	38	35	32	44,000	26	75%
Prince George 1966	33	30	27	56,000	23	76%
Woodfibre 1961	18	15***	12	60,000	14	93%

* Plus or minus 10 per cent
** Two billion gallons more used daily in hydro-electricity generation
*** Eleven million gallons more used daily in hydro-electricity generation

from a capacity which approaches 3,000 tons of pulp and newsprint each day, while Kamloops' daily capacity is only 250 tons.

Variety in water required per ton of product is more complicated. That variation exists among mills is evident from Table XI. In Figure 4, however, it is apparent that there may be considerable variation even within a mill unit. Perhaps the best explanation for variation in per unit requirements between

Figure 4



Source: B.C. Forest Products Ltd.
Crofton, B.C.

mills is found in the age of plants. In Table XI, the mills showing the lowest per unit water needs are Northwood, Kamloops, and Prince George -- all of which started operations after 1965. The newer mills, especially those in the Prince George area, also show the lowest percentage of effluent discharge among the study mills. Conversely, it is the older mills which exhibit higher demands for process supply and effluent disposal water. Therefore, newer mills have significantly lower water quantity demands than their older counterparts, and, according to industry spokesmen, this is primarily a result of more recent and sophisticated production equipment needing smaller amounts of water. Older mills are not at an absolute disadvantage in this regard, however, as modifications to existing equipment allow reduction in quantity requirements. For example, while average per unit water requirements at Crofton were 70,000 gallons in 1958, B.C. Forest Products has been able to reduce this rate to 50,000 gallons by 1966.[4]

There are other reasons for variations between mills. A partial explanation is the variations in requirements for different products. Some mills are integrated while others are non-integrated. Another factor which enters is the relationship between the cost of reusing water and the cost of fresh water itself. In British Columbia, re-use appears to be becoming

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4 N. Rubboli, Kraft Mill Water Balance, B.C. Forest Products Ltd., Crofton Pulp and Paper Division, Technical Services Department, Study TDM67-44, February 16, 1967, manuscript p. 1.

more widely applied within the past few years than in former periods. An additional, and perhaps most important factor, must be included. Most mills have only at best inaccurate measurements of water used, and in particular, of water distributed throughout their plants.[5]

Specifically referring to variation within mills, such as shown in Figure 4, it is evident that the grade of product influences water quantity demands. An obvious example of decreasing requirements is a switch from bleached to unbleached grades of pulp for several days or weeks. Extra quantities of water will also be required when equipment is backwashed --- resulting in larger effluent discharge as well.

Having considered the water quantity requirements or demand by mills, it is appropriate to turn to the supply side. In Figure 5, the mean monthly discharge for the various mill water supply sources is shown. Since one cubic foot per second is equal to 646,360 gallons per minute, it is evident that mill water supply sources adequately meet mean and maximum average quantity requirements shown in Table XI. Even though there are marked differences between maximum and minimum seasonal discharges, the lowest average monthly flow of 88 cubic feet per second at Rainy River is equivalent to nearly 57 million

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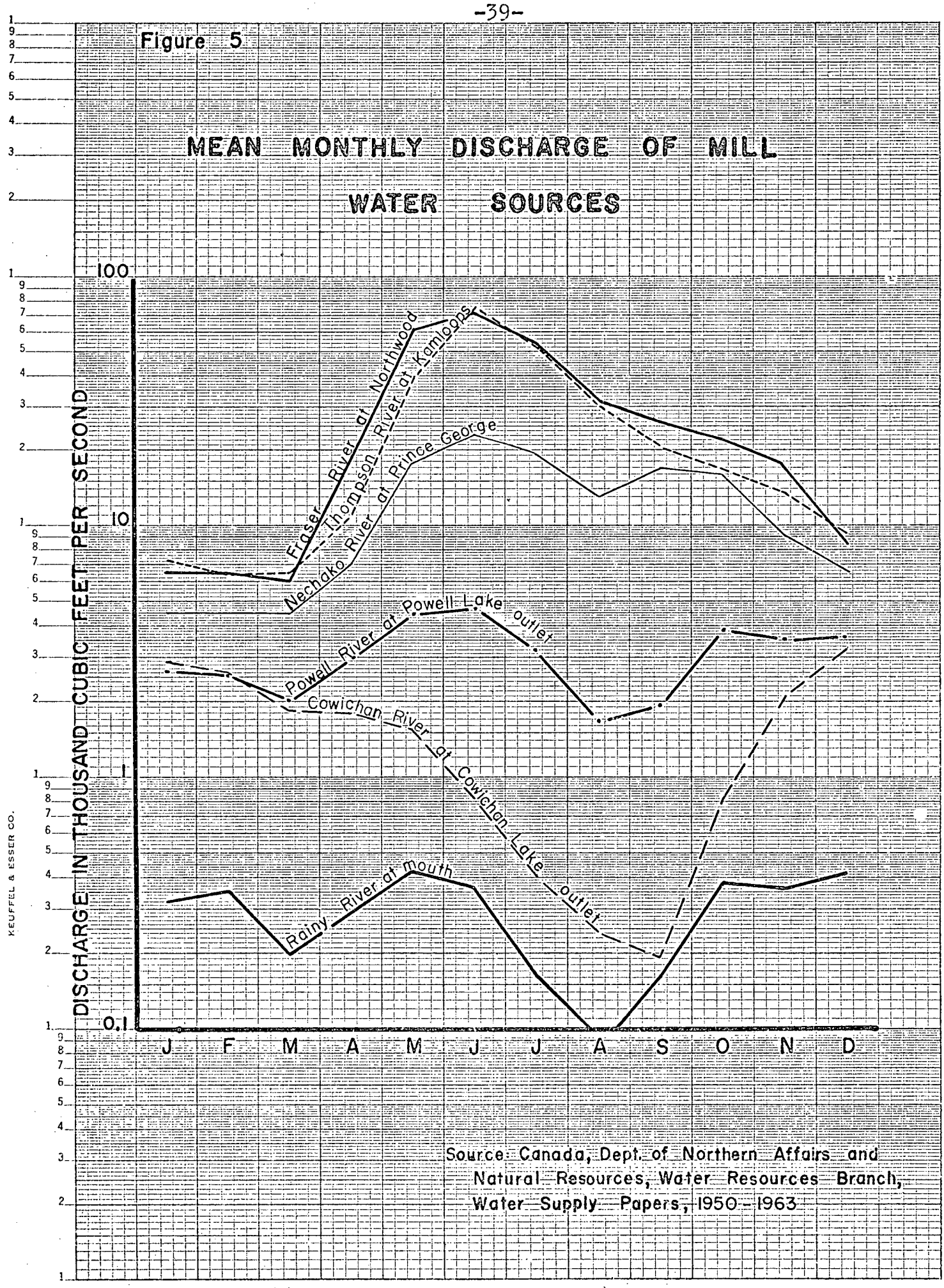
5 See, C. Libby, ed., Pulp and Paper Science and Technology, New York, McGraw Hill, 1962, Vol. 2, p. 147, and Technical Association of the Pulp and Paper Industry, Water Technology in the Pulp and Paper Industry, Tappi Monograph Series, No 18, 1957, p. 17.

Figure 5



Source: Canada, Dept. of Northern Affairs and Natural Resources, Water Resources Branch, Water Supply Papers, 1950 - 1963

gallons of water per day, well above Port Mellon' demands.

On the basis of data relating quantity requirements and available water supply, it appears that although British Columbia mills follow the general trend found in Chapter III of high (but gradually decreasing) quantity requirements, the present need for given amounts of water have been met to date. The abundance of untapped rivers with relatively low discharges such as the Rainy River in British Columbia relegates adequate quantities of process supply water to a minor role in site evaluation.

Consideration of five of the seven study mills bears out this claim. Port Mellon, Powell River, Kamloops, Prince George and Northwood are confident that their water supply sources are adequate for future requirements. The two anomalies are Woodfibre and Crofton. Regarding available water quantity, present and future, a Woodfibre scientist explained that

> This could be our most serious problem. Our storage area is relatively small and we are dependent upon normal weather patterns to maintain our storage. 6

The key work in this comment is "normal". As long as average conditions prevail, such sources of water as Port Mellon's Rainy River and Woodfibre's comparable Cedar and Mill Creeks are adequate. Once fluctuations enter, however, mill operations become seriously handicapped -- necessitating large capital expenditures to increase storage or to tap other sources. The

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6 Personal reply to a question by the writer on July 7, 1967.

notions of reliability and capital investment receive more intensive treatment later in the chapter. Nevertheless, from these preliminary comments, it is obvious that highly variable regiments on low volume rivers is a deterent for an industrial site.

Crofton's problem centers upon increased water demands stemming from an expansion program. In 1958 when the mill began producing bleached kraft pulp, total water requirements fell in the vicinity of 35 million gallons per day. In 1964 kraft pulp capacity was increased, and new groundwood pulp and newsprint plants were added. A second newsprint machine is being installed in 1967, and with a view to its beginning production, one of the research scientists associated with the mill has predicted that

> The present rate of water usage is about 50,000 USG/ADT kraft and 10,000 USG/ADT newprint which corresponds to a projected total consumption of 60 MGPD with two news mills plus two kraft mills, all operating at full production rate. Adding 2 MGPD for backwash and 10 % for winter sewage capacity the requirement becomes 68 MGPD.
>
> Existing pumping capacity with six big pumps is 67 MGPD. There will therefore be a serious need for water conservation when the second mill comes on line.
>
> Since pipeline capacity is estimated as 70 MGPD, capital outlay for any further expansion could include white water treatment and reuse in preference to a new pipeline. 7

From this statement it would seem that mills which elect a site requiring transportation of water over long distances (in

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7 E. C. Metherell, News Mill Heat and Water Balance, B.C. Forest Products Ltd., Crofton Pulp and Paper Division, Technical Services Department, Study TDM67-75, March 22, 1967, p. 2.

Crofton's case 9 miles) should give special consideration to possible future water requirements -- especially when the supply source is not large. The most recent mills have located adjacent to major rivers, where pumping and other transportation costs would allow further investment to augment an inadequate supply. For Crofton, on the other hand, either alternative to increase water supply involves a greater expenditure than new mills would encounter.

As a result of the situation at Woodfibre and Crofton, the statement that water quantity for process supply has not yet been a major locational constraint should be modified. Sites which rely on a small volume, highly variable supply source, or a source far removed from the mill, may find that although initial water demands can be accomodated, future increased demands may provide extremely difficult problems for production. As a result, any potential water component exhibiting one or both of the above characteristics is likely to prove unattractive, unless there are other compensating factors.

QUALITY

Quality characteristics of a water source deserve consideration since chemical constituents can effect final product quality to a considerable extent. Natural water quality determines, of course, the degree of pre-use treatment that is required before water is suitable for pulp production. It follows then that lower quality water will necessitate higher treatment investment, which will detract from a potential supply source --

and, in turn cause restrictions on choice of site.

Table XII shows the range of quality characteristics associated with the water sources of the study mills. In the

Table XII

Water Quality Characteristics in PPM

Recommended Standards*	Turbidity	Total Hardness	Calcium Hardness	Magnesium Hardness	Color	Iron	Manganese	Silica	pH
Bleached kraft pulp	40	100	--	--	25	0.2	0.1	50	6 to 8
Unbleached kraft pulp	100	200	--	--	100	1.0	0.5	100	6 to 8
Groundwood pulp	50	200	--	--	30	0.3	0.1	50	6 to 8
Mills									
Crofton	T to 700	25.0	8.0	0.8	T	0.8	0.8	1.8	7.1
Port Mellon	T	5	T	T	10	T	T	14	--
Kamloops	T to 15	45	35	12	17	T	T	5	7.6
Powell River	T	4	--	--	5	0.5	1.5	1.5	--
Northwood	10 to 100	62 to 106	60	23	50	1	3	5.0	7.4
Prince George	5 to 40	45	30	17	10 to 140	4.9	6	5.9	7.8
Woodfibre	1	3.5	2.0	1.5	4 to 7	0.20	T	2.5	6.7

T = Trace

* O. D. Mussey, Water Requirements of the Pulp and Paper Industry, United States, Department of the Interior, Geological Survey, Water Supply Paper No. 1330-A, 1955, p. 39.

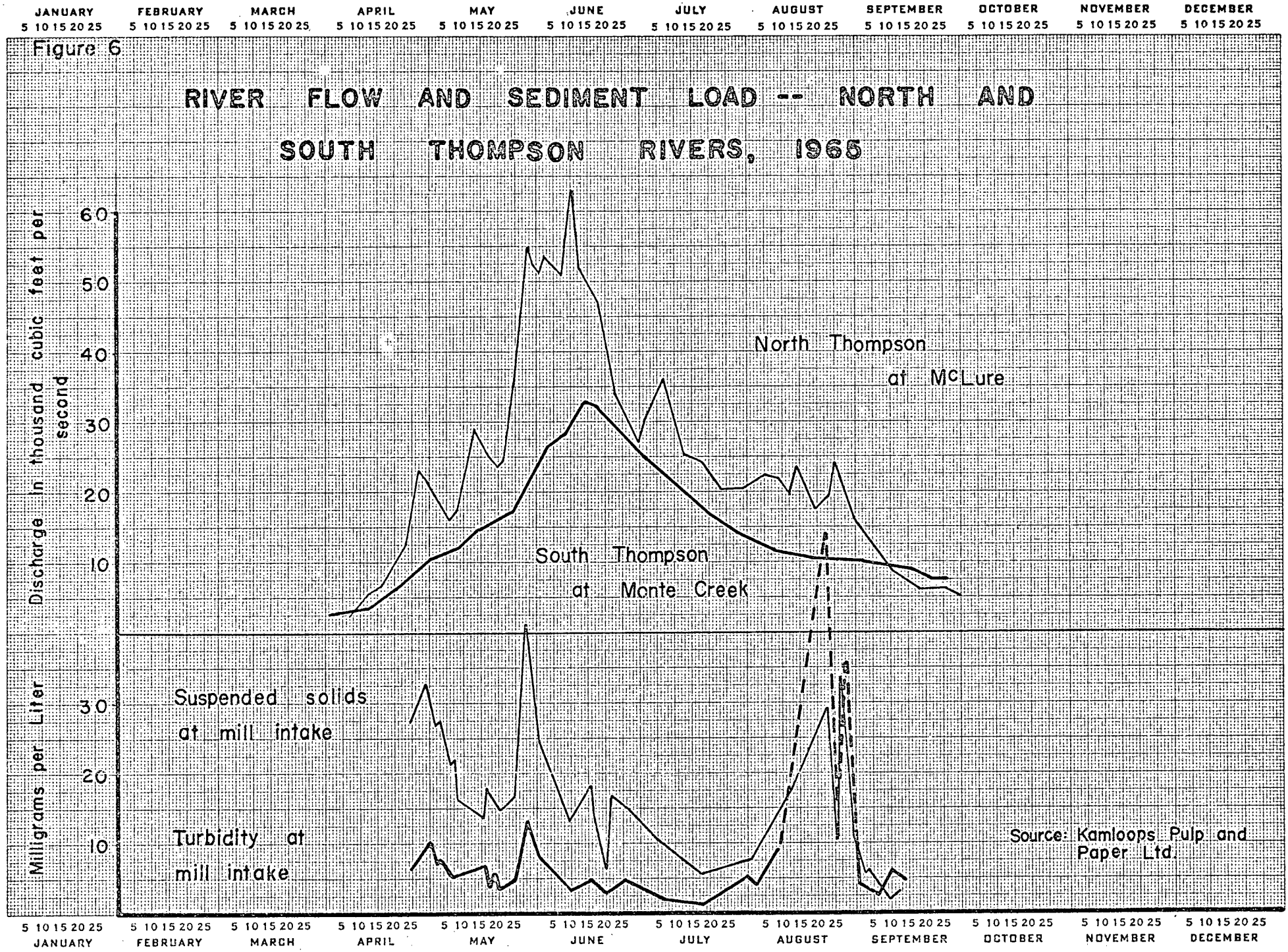
first three rows, recommended quality standards are included to allow comparison of the mills' water quality constituents. It is apparent from the table that the British Columbia mills enjoy water of high quality relative to the recommended standards. Port Mellon, Powell River and Woodfibre have the highest quality of water; the two Prince George mills, the lowest. Water quality problems in the Prince George area are reflected by extensive pre-use treatment, especially at Northwood.

On the basis of the data in Table XII, it appears that interior locations offer lower quality water than those on the coast. A further point should be made. A spokesman at Kamloops suggests that interior mills face a seasonal problem that does not affect coastal operations. Elaborating, he explained that the presence of deciduous rather than coniferous trees along interior river courses is much more prejudicial for production quality since the deciduous species annually "shed" their leaves. When leaves fall into a river, they are carried along on the water surface, susceptable to being drawn into a plant's production system. As a result, interior mills must include appropriate screening equipment to prevent such an occurence, yet such screens are rarely one hundred per cent effective. It is problems such as this one that is forcing Kamloops to consider expensive additions to their pre-use treatment equipment.

As with quantity requirements, mills must be able to accomodate variations in water quality. Figure 6 illustrates the relationship which exists between discharge and quality.

Figure 6

RIVER FLOW AND SEDIMENT LOAD -- NORTH AND SOUTH THOMPSON RIVERS, 1965



It is evident during freshet that water quality, as represented on the graph by suspended solids and turbidity, sharply deteriorates.

The graph pinpoints one of Kamloops major problems. Located just below the confluence of the North and South Thompson Rivers on the south bank of the Thompson River, the Kamloops mill receives its water supply for ten months of the year mainly from South Thompson River discharge which is stabilized by the Shuswap Lakes. During spring freshet, however, the North Thompson River, which is much more turbulent and boisterous than the South Thompson, forces its way across the channel of the Thompson River until it represents nearly 80 per cent of the flow, as opposed to a usual 55 to 65 per cent. When this situation occurs the Kamloops water supply intake pipe, which extends out into the Thompson River, draws its supply primarily from North Thompson River water. Consequently, while Kamloops enjoys fine water quality for ten of twelve months, the sharp quality deterioration in May and July poses operational problems.

It is essential to recognize that treatment equipment must be able to cope with wide ranges of quality, and in particular, be able to cope with water when its natural quality is poorest. Thus, while average quality conditions at the study mills do not impose severe constraints on the location problem, it is necessary to include the aspect of variability.

RELIABILITY

In Figure 5, it was shown that there is wide seasonal

variability for mean monthly discharge of mill water sources. That graph still did not hit at the core of the reliability problem, however, since it was portrayed in terms of mean data. Figure 6 came closer to showing how the notion of reliability integrates quantity and quality by using data for a single year. Figures 7, 8, and 9, and Table XIII, provide a clearer picture of the reliability concept. On the graphs, discharge -- monthly mean, maximum, and minimum -- is represented for the Rainy, Cowichan, and Fraser Rivers. From the sharp fluctuations shown on the graph and the long-run extremes indicated in Table XIII, it is obvious that mean data provide only a portion of the total picture. For instance, in August and September of 1961, minimum daily discharge on the Rainy River was recorded at less than one cubic foot per second, while mean monthly discharges were 40 and 95 cubic feet per second, respectively. Such extremely low discharges led to the construction of a $762,000 storage dam on the Rainy River in 1963 to provide some control over the river. Comparable structures are found on the water sources of Crofton and Woodfibre for the same reason.

Such sharp daily fluctuations around monthly mean discharges make the comment from a Northwood executive about the Fraser River that, "... water quality may change significantly within four hours"[8] easy to believe, especially when the relationship between quantity and quality shown in Figure 6 is recalled. While the Prince George water treatment plants operate continuously,

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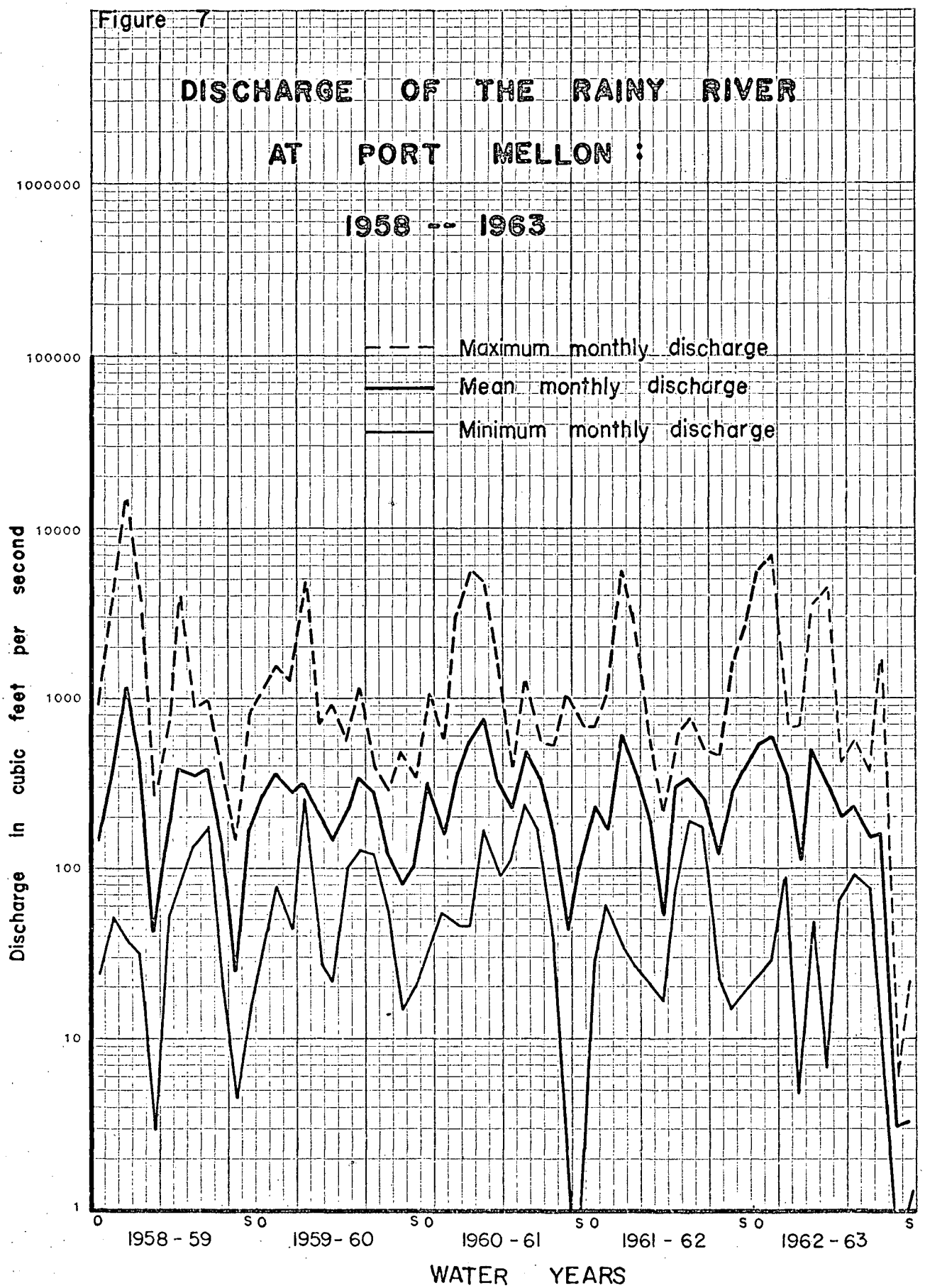
8 Personal reply to a question by the writer on June 20, 1967.

Figure 7



Source: Canada, Dept. of Northern Affairs and National

Figure 8

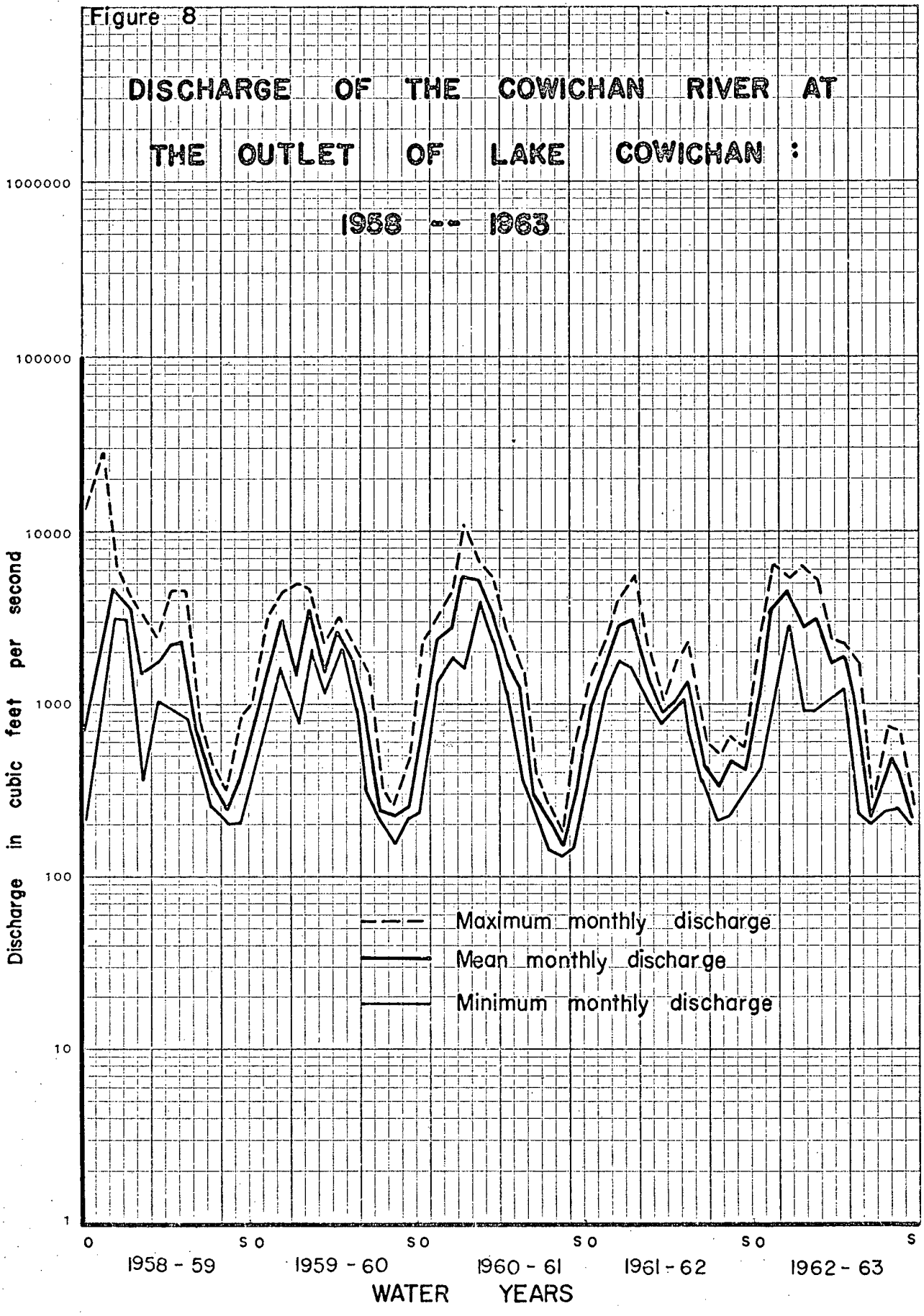

DISCHARGE OF THE COWICHAN RIVER AT THE OUTLET OF LAKE COWICHAN :
1958 -- 1963
1000000
100000
10000
1000
100
10
1
Discharge in cubic feet per second
Maximum monthly discharge
Mean monthly discharge
Minimum monthly discharge
O
S O
S O
S O
S O
S
1958 - 59
1959 - 60
1960 - 61
1961 - 62
1962 - 63
WATER YEARS

Figure 9

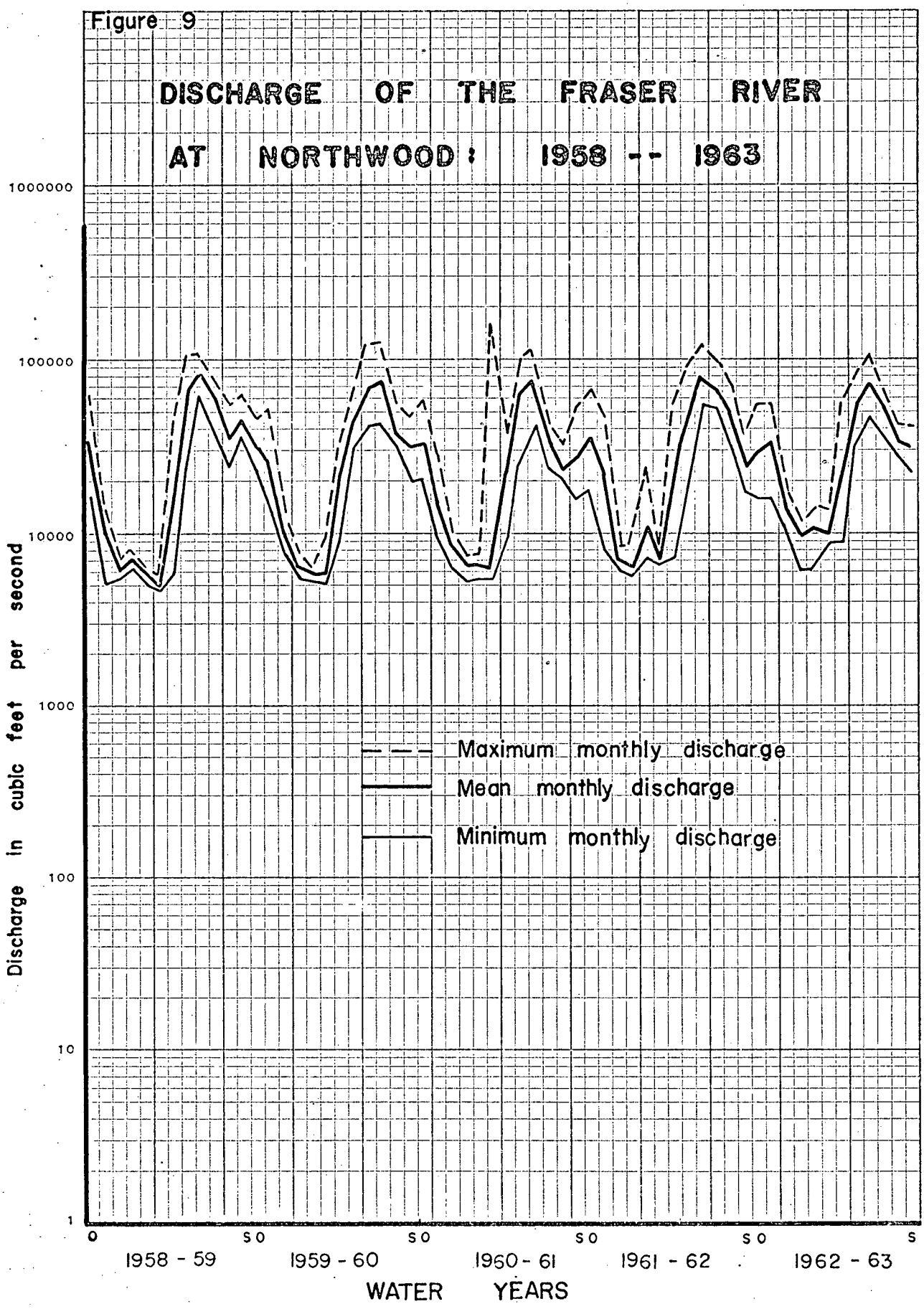

DISCHARGE OF THE FRASER RIVER
AT NORTHWOOD : 1958 -- 1963
1000000
100000
10000
1000
100
10
1
Discharge in cubic feet per second
Maximum monthly discharge
Mean monthly discharge
Minimum monthly discharge
O
S O
S O
S O
S O
S
1958 - 59
1959 - 60
1960 - 61
1961 - 62
1962 - 63
WATER YEARS

Table XIII

Stream Flow Variability

Rainy River

(at Port Mellon)

Mean Discharge (16 years); 295 cubic feet per second.

Extremes Recorded
Maximum daily discharge: 15,100 cfs on December 1, 1958.
Minimum daily discharge: 0.0 cfs on September 30, 1963.

Water Year	Max. Daily Discharge	Min. Daily Discharge	Mean Discharge
1962-63	6,080 cfs; Nov.19/62	0.0 cfs; Sept.30/63	--
1961-62	5,160 " Dec.29/61	9.4 " Sept.12/62	258 cfs
1960-61	5,260 " Jan.10/61	0.7 " several times in Sept.1961	307 "
1959-60	4,600 " Jan.29/60	15 " Aug.12/60	226 "
1958-59	15,100 " Dec.1/58	3.2 " Feb.13/59	298 "

Cowichan River

(at Cowichan Lake)

Mean Discharge (29 years): 1,570 cubic feet per second

Extremes Recorded
Maximum instantaneous discharge: 11,000 cfs at 2 a.m. January 16, 1961.
Minimum instantaneous discharge: 15 cfs on September 10 and 11, 1944.

Water Year	Max. Instantaneous Discharge	Min. Daily Discharge	Mean Discharge
1962-63	6,360 cfs; Jan.2/63	208 cfs; Sept.16/63	1790 cfs
1961-62	5,680 " Jan.3/62	210 " July 29/62	1340 "
1960-61	11,000 " Jan.16/61	133 " Aug.25/61	1970 "
1959-60	4,980 " Jan.31/60	183 " Aug.8/60	1530 "
1958-59	6,690 " Dec.3/58	182 " Sept.8/59	1700 "

continued on following page

Table XIII(continued)

Fraser River

(at Northwood)

Mean Discharge (13 years): 28,200 cubic feet per second.

Extremes Recorded

Maximum daily discharge: 131,000 cfs on June 17, 1950
Minimum daily discharge: 3,480 cfs on Dec. 9 and 10, 1952.

Water Year	Max. Instantaneous Discharge	Min. Daily Discharge	Mean Discharge
1962-63	106,000 cfs: June 13/63	6,500 cfs; Feb.2 and 3/63	31,900 cfs
1961-62	117,000 " July 28/62	5,540 " Jan.19/62	33,100 "
1960-61	114,000 " June 7/61	5,650 " Jan.30/61	27,000 "
1959-60	115,000 " July 1/60	5,150 " Mar.14-16 1960	31,200 "
1958-59	109,000 " June 5/59	5,550 " Mar.9/59	31900 "

seasonal variability has resulted in Crofton requiring a $1.25 million water treatment plant which only operates from November to April. It is thus apparent that both seasonal and daily variability require capital expenditures for equipment, and, as a result, introduce prejudice against a site offering a highly variable stream flow.

To summarize, of the three physical aspects of water -- quantity, quality, reliability -- the aspect of reliability creates the greatest operating problems for mill operations, and thus must stand out as the most important locational constraint associated with water in British Columbia -- even though the reliability concept is neglected in the general literature of industrial water use. That reliability is important can be found in a report from R. W. Thomas, vice-president and general manager of Kamloops

Pulp and Paper Ltd. With a depressed world market for pulp, several British Columbia mills stopped operating during the spring of 1967 in order to sell their year's output. Kamloops' closure, according to Thomas, was timed to coincide with the period of peak discharge on the Thompson River which has provided difficulty for product quality control.[9] Physical aspects are just one part of the water component, however. A second factor deserving consideration is the social controls affecting industrial water use.

INSTITUTIONAL CONSTRAINTS

Institutional controls are exercised upon industrial use of water for both process supply and effluent disposal in British Columbia. Regulatory power for process supply water falls under the jurisdiction of the Water Rights Branch in the provincial government's Water Resources Service. Effluent standards, on the other hand, are set by three agencies: the Pollution Control Board of the Water Resources Service in the British Columbia Department of Lands, Forests and Water Resources, Canada Department of Fisheries, and the Pacific Salmon Fisheries Commission. Government departments associated with health, recreation, conservation and other aspects have an interest in water regulation, but the four agencies noted above are the ones pertinent for this study. The powers and influences of these

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9 B. McMurray, "Pulp mills slowed by soft market', The Province, Saturday, May 20, 1967, p. 23.

regulatory bodies are considered below.

PROCESS SUPPLY WATER

As noted above, the quantity of water withdrawn from a natural system for industrial use must be approved by the Water Rights Branch of the Water Resources Service, British Columbia Department of Lands, Forests and Water Resources. Since British Columbia follows the doctrine of appropriation rather than riparian rights in water management, the objective of the Water Rights Branch is to assure that a new water user does not adversely affect activities of water users already established on a water system.

To date, pulp and paper mills have not had a water request rejected by the Branch. A mill receives a conditional licence which becomes permanent once all agreed developmental work has been completed. As one pulp mill executive explained, there have been no limits placed on the amount of water withdrawn for industrial use. The effective limitation to date, he explained, has been the level of pumping costs which mills can tolerate. Examples of quantities permitted on water licences are 90 cubic feet per second on Kamloops' conditional licence, 100 cubic feet per second on Crofton's conditional licence, and 100 cubic feet per second and 45 feet cubic feet per second on Powell River's final and conditional licences respectively.[10]

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10 Personal communication with the Water Rights Branch, March 16, 1967.

EFFLUENT CONTROL

Pollution Control Board

The Pollution Control Board was established in 1956 with the following powers and duties:[11]

(1) To prescribe standards regarding the quality and character of the effluent which may be discharged into any of the waters within the areas under the Board's jurisdiction.

(2) To determine what qualities and properties of water shall constitute a polluted condition.

(3) To conduct tests and surveys to determine the extent of pollution of any waters within the areas under the Board's jurisdiction.

(4) To examine into all existing or proposed means for the disposal of sewage or other waste materials, or both, and to approve the plans and specifications for such works as are deemed necessary to prevent pollution of the water of the area or areas.

(5) To notify all persons who discharge effluent into the said waters when the effluent fails to meet the prescribed standards.

(6) To order any person to increase the degree of treatment of the effluent or to alter the manner or point of discharge of the effluent being discharged by such person to bring the effluent up to the prescribed standards.

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11 British Columbia, Pollution-Control Act, R.S.B.C. 1960, Chapter 289, Section 4.

(7) To order any person who fails to comply with an order issued under clause (6) to cease discharging effluent into any water in the area as and from a day and time specified in the order.

The scope given to the Board is considerable. It may prescribe tolerable effluent standards, approve waste disposal systems, and have the power to order any party to increase effluent treatment. The overriding objective is to maintain water systems in a condition for the derivation of maximum social benefits. The implications of such regulatory power for the industrial location problem is evident. A pulp mill considering a site must satisfy the Pollution Control Board's criteria for effluent treatment and disposal before it can use a location.

When first established, however, the Board's jurisdiction did not extend over the entire province. Until April 1961 control only covered the area drained by the Fraser River and tributaries west of Hope. Thus, any pulp and paper mills built prior to April 1961 -- which include Powell River, Port Mellon, Woodfibre, and Crofton in this study -- did not have to meet Board requirements. On April 1, 1961, effective jurisdiction was increased to include the Canadian portion of the Columbia River watershed.[12] Less than two years later, control was further extended. In January 1963 all of the Fraser River Basin and most

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12 British Columbia, Pollution-Control Act, B.C., Reg. 78/64, Order in Council No. 643, Approved March 14, 1961, extending area to which act applies.

of the populated area along the east coast of Vancouver Island came under the Board's jurisdiction.[13] Consequently, when pulp mills were being built at Kamloops and in the Prince George area the companies had to satisfy Board requirements. The entire province fell under the Board's control in 1966, when the Pollution Control Act was amended in the legislature.[14] As a result, all new pulp mills, or any other industrial development, will have to consider the requirements of the Board in any future site evaluation.

In establishing criteria for the amount and type of effluent which may be discharged into water bodies, the Board appears to apply the philosophy voiced by the provincial Water Rights Comptroller that

> ... it is necessary to emphasize that the use of water for carrying away wastes is a use that we cannot do without, and it must therefore be numbered among the major uses of the water resource. [15]

Thus, the Board's general guideline is to recognize multiple-purpose use of water -- the disposal of wastes being one of many uses. However, to assure multiple-use of the water resource, the Board sets limits on both quantity and "quality"of disposable wastes.

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13 British Columbia, Pollution-Control Act, B.C., Reg. 79/64, Order in Council No. 2995, Approved December 6, 1962, as amended by Order in Council No. 3049/62, extending the area to which act applies.

14 British Columbia, Bill No. 62, An Act Respecting Pollution Control, Victoria, Queen's Printer, 1967.

15 H. D. DeBeck, Present Use of British Columbia's Water, prepared for the Seventeenth British Columbia Natural Resources Conference, Victoria, February 23,1967, p. 16.

Referring to the pulp and paper industry in particular, the Board follows a general policy which seeks to "maximize the social benefits of the water resource". Greater detail is provided in the following quotations, taken from two letters from the Pollution Control Board. Although somewhat lengthy, the extracts are included to illustrate the rationale used by the Board in its approach to pollution control. In addition, the ideas expressed in the comments suggest the impact that Board requirements should have upon future site decisions. In the Board' words

> Generally speaking in matters pertaining to waste disposal, there are no hard and fast rules which can be applied to all pulp mills. It is our practice to assess each mill individually, taking into account the capacity of the mill, nature of the product, quality and quantity of the receiving body of water, the uses made of the receiving water, public interest affected etc. The accepted quality of effluent discharged to the receiving water is mainly influenced by the dilution and assimilating capacity afforded by the receiving water to maintain a realistic margin of safety to the marine or freshwater environment from toxic conditions, as well as the protection of other present and future beneficial uses the receiving waters provide or may assume.
>
> Specifically, all of the mills built in British Columbia prior to 1964 (which includes Powell River, Port Mellon and Crofton,(and Castlegar)), utilize dilution and the natural biological forces of nature as their means of waste treatment. All these mills, with the exception of Celgar, are located on tidewater, and the dilution afforded at these sites has, in the past, been adequate to preclude any further treatment. Since 1964, the new kraft mills constructed on inland waters are exercising the ultimate in in-plant waste control and recovery, and in addition, are providing secondary treatment of the waste effluent, prior to and as supplement to, ultimate dilution and natural assimilation in the receiving stream, to

> protect the salmon stock therein. It is likely that this degree of treatment will be required of all new mills locating anywhere in British Columbia. 16

> ... each mill is required to provide pollution control measures to the extent, that the beneficial uses of the receiving waters are not impaired by the mills effluent discharge. The measures proposed by the mill are assessed by our technical staff to ascertain whether, or not, the discharge is likely to be injurious to other parties directly, or indirectly through injury to a resource. If injury is likely to occur, the applicant is required to provide further pollution abatement measures which protect the resources involved. 17

Turning to the individual mills in this study -- Crofton, Woodfibre, Powell River, Port Mellon, Kamloops, Prince George, and Northwood, it is possible to see what controls the Board has actually used. For the four plants located on the coast -- Crofton, Powell River, Port Mellon, and Woodfibre -- there have been no specific regulations established. After sampling the effluent in the receiving water, in this case, salt water, the Board has been satisfied that natural dilution provided by the ocean is sufficient to remove any threat to marine life. As a result, there have been no specific recommendations for post use treatment of coastal mill effluent.

It is important, however, to note the words in the preceding quotations which state secondary treatment will probably be required for all new mills in the province -- wherever they may locate. Industry recognizes this probability as well, with most coastal firms feeling that within five yars they will have

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16 Personal communication from the Pollution Control Branch, April 18, 1967.

17 Personal communication with the Pollution Control Branch, May 19, 1967.

to provide secondary treatment. If such a situation does develop, then the range of choice offered by coastal sites will be significantly restricted. Faced with increased investment for effluent treatment, mills are likely to conclude that otherwise satisfactory potential sites adjacent to large population centers or areas of public recreation are less favorable than locations removed from such possible sources of conflict over water use. It is therefore possible that a future trend will be location of new coastal mills in relatively isolated places where the problem of effluent disposal is minimized.

The interior mills, Kamloops, Prince George, and Northwood, face a different problem compared to their coastal counterparts regarding control. Since these three mills were built after 1963, they have been under the Pollution Board's jurisdiction since the design stage. Consequently, not only have limits been set as to quantities of effluent which may be disposed into water bodies, 12.5 million gallons per day at Kamloops and 33.25 million gallons per day at Prince George, but restrictions have also been established regarding quality of the waste. The most significant standards applying to all three mills are:

(1) That mill effluent, when diluted to a 65 per cent concentration in river water shall not cause any mortality to yearly sockeye, coho or chinook salmon in a period of 96 hours.

(2) That effluent shall average 60 ppm and shall never be more than 90 ppm of suspended solids. This is equivalent to 25 pounds per ton of air dried pulp and 37.5 pounds per ton of

air dried pulp respectively.[18]

The result of these regulations was that the three interior mills had to install extensive post-use treatment equipment in order to meet the standards. The significant aspect to note is that the quality standards are principally oriented toward protecting the river fishery. Consequently, while it would appear that any mills proposing an interior location would face severe pollution constraints, most of the limits are only applicable to salmon-carrying rivers. As a result, the Celgar mill, located on the Columbia River and having no conflict with a commercial fishery resource, does not have as many standards to meet. When evaluating the effect of these social controls on the range of sites available to industrial plants, it is thus not possible to state that interior mills face much more rigid control that those on tidewater, unless the statement is qualified to include interior mills located upon commercial fishery rivers.

Canada Department of Fisheries

Pacific Salmon Fisheries Commission

Although these are two separate agencies, they are considered together since their primary objective in water resource management is to maintain fisheries in any water body being used concomitantly by industry. It is necessary to note that fishery

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18 British Columbia Pollution Control Board, Permit No. 144, Addendum, 1965, p. 1.

interests are concerned with water for process supply as well as for effluent disposal. Consequently, in a 1961 interim report a listed requirement was that water intakes from a river must be screened in order that salmon fingerlings are not drawn into the mill. In addition, fishery personnel are concerned that enough water is present in a river at all times to allow passage of spawning salmon upstream. Thus, mills drawing water from a relatively small stream which may approach a dry state in the low-water season, such as Port Mellon or Woodfibre, must operate control structures to maintain a minimum acceptable flow for fish passage.

This problem is most important, of course, when the low water season coincides with the spawning period. At this time a mill is likely to be encountering insufficient amounts of process supply water, yet a specified amount must be left in the stream course. As a result, while a low-flow stream with high variability will not be attractive to a mill at the best of times, presence of a fish stock will be a further detraction. On the other hand, the storage structures built by plants often benefit the fishery stock immensely. Not only are extremely low flows removed, but conversely peak discharges, which may uncover eggs on a river bottom, are reduced. When a storage structure provides a mill with a stable water supply and increases fishery benefits at the same time, the concept of multiple-purpose use is approached -- to everyone's benefit.

A recent statement by the Chief of the Resource Development

Branch in the Department of Fisheries outlines the general policy followed by the agency regarding effluent disposal.

> The Department of Fisheries insists that all effluents entering rivers, streams and estuaries frequented by fish receive prior treatment to render them non-toxic or as nearly non-toxic as is economically feasible. As an added safety factor, rapid dilution through a diffuser is also required although this standard has been relaxed where there is assurance that effluents discharged directly into the sea will be rapidly diluted. As an example of this policy, new pulp mills established on important salmon rivers must provide biological treatment before discharging their wastes through diffusers of approved design; whereas pulp mills situated on the sea coast where effluent treatment is not judged to be necessary because of the large dilution factor may discharge their wastes directly into the ocean. 19

From the officer's comment it is apparent that the affect of the Department of Fishery regulations are not unlike those of the Pollution Control Board. Mills located on tidewater are not required to treat wastes but only to discharge them in such a way that the effluent will diffuse rapidly. The common method for waste dissipation is through long underwater pipelines containing numerous nozzles. Once being ejected through the nozzles waste is quicky diffused by currents.

Interior mills are subjected to more rigorous requirements. Following rumors in 1961 of a round of pulp expansion in the province, which would result in several mills locating in the Fraser River watershed, the Department of Fisheries in co-operation

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19 R. E. McLaren, "Water Pollution Control in Relation to the British Columbia Fishery", Conference on Water Pollution: Proceedings, edited by H. M. Rosenthal and G. A. Drew, Vancouver, B.C., Extension Department, 1966, p. 36.

with the Pacific Salmon Fisheries Commission undertook a survey of possible effects of new mills upon salmon using the river for spawning purposes.

The study focused upon types of pulp mill effluent, their effect upon fish, and possible treatment methods. On the basis of the investigation the Department of Fisheries arrived at a set of basic requirements which were considered necessary for protection of Fraser River salmon. The main criteria, published in an interim report were:[20]

(1) Sludge from raw water treatment, if any, involving the use of flocculating chemicals, to be disposed of on land where it cannot be washed into the river.

(2) Hydraulic barker effluent, if any, and Fourdrinier machine white water may be disposed of directly into the river after clarification, if necessary, to produce an effluent containing not more than 0.3 pounds of suspended solids per 1,000 U.S. gallons.

(3) Bleach plant and all effluent from the pulping operating excluding those not polluted with pulp mill chemicals, shall be passed through a retention basin for a period of not less than 5 days. The basin shall be equiped to remove 60 per

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20 From, Canada, Department of Fisheries, Interim report on proposed kraft pulp mills on the Fraser River near Prince George with recommendations for the treatment and disposal of wastes, September 1961; R.G. Ryan, "Effluent handling and treatment at Prince George Pulp and Paper Ltd.", Pulp and Paper Magazine of Canada, Vol. 68, No. 2, February 1967, pp. T59-T60.

cent of the biological oxygen demand (B.O.D.) and produce an effluent containing not more than 80 ppm of B.O.D.

(4) The effluent from the retention basin or from other mill process sewers which are not discharged into the basin shall not contain more than 0.1 ppm residual chlorines or 1 ppm of resin soaps and their salts or 0.1 ppm of sulphides and mercaptans.

(5) Final mill effluent shall have a pH of not less than 6.7 and not greater than 8.5.

The above standards, and others, were established to protect the fishery resource in the Fraser River drainage basin. Many of these requirements have been incorporated into the permit issued by the provincial Pollution Control Board. When these controls are considered in the light of their effect upon industrial location, it is obvious that any firm evaluating a site involving commercial fishery waters will have to anticipate significantly increased waste treatment costs. On the basis of pollution control requirements, it is possible to divide receiving water bodies into three types: (1) rivers containing commercial fisheries, (2) rivers not containing commercial fisheries, and (3) tidewater. The different social pollution controls associated with each of these types will make fish-bearing rivers most costly for industrial location.

Having considered the approach used by the provincial government for waste disposal management, it is now appropriate to look at the government objectives, criteria, and methods in order to analyze their ramifications for industrial location.

Briefly, the government seeks to achieve multiple-purpose use of British Columbia water resources, and, by so doing, maximize social benefits from the resource. Based on this philosophy, waste disposal is recognized as a legitimate water use. Such objectives fare well for industrial decision-makers evaluating sites, as the government, appreciating that industrial growth will be accompanied by industrial wastes, feels that an optimum pollution level compatible with economic goals and environmental quality demands should be sought.

Industrial location decisions are hindered, however, by the government criteria for achieving an optimum level of pollution. The sections outlining effluent standards which were noted previously are oriented toward preservation of fish life. The use of fishery mortality as an effluent index raises a central question -- how is the desired quality of water in streams to be determined? It is suggested here that standards based upon fishery mortality cause unnecessary over-investment in waste treatment equipment by industry. If this suggestion is accurate, then not only will otherwise acceptable sites be rejected by industry, but also society's resources will be misallocated. As a result, the goal of social benefit maximization cannot be realized under the present system.

What of fishery criteria? It is argued here that for efficient use of resources the benefits and costs associated with any act must be balanced at the margin and fall upon the responsible economic unit. Present use of fishery mortality

as a guide for social costs resulting from effluent disposal relates neither the costs nor the benefits to the waste discharger, or other potential users of a river course. As Kneese has noted in discussing water quality management in the Ruhr valley

> ... a procedure based upon physical results alone (ie., avoidance of fishery mortality) will, in principle, not allocate costs properly. For example a substance may be very destructive to fish but be relatively inexpensive to treat or to deal with by other methods. 21

Thus, although there are still difficult problems in the measurement of intangible values, such as recreation, aesthetics, and public health, associated with water use, it is argued here that research is needed to determine costs related to waste disposal if society is to receive maximum benefits from multiple-purpose water use, and if industry is to be given the correct locational signals by society.

There are several criteria which should be included in a water quality management program, at least two of which are pertinent to industrial location problems:

(1) The system should provide incentives to industrial waste dischargers to reduce their effluent load.

(2) The system should be able to take advantage of scale economies not available to individual operators.

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21 A. Kneese, "Water Quality Management by Regional Authorities in the Ruhr Area with Special Emphasis on the Role of Cost Assessment", Papers and Proceedings of the Regional Science Association, Vol. 11, 1963, p. 245.

The provincial government attempts to provide incentives through the use of effluent standards, with the consequent resource misallocation noted earlier. Scale economies refer to waste treatment technologies feasible at a co-operative level but prohibitive at individual scales. Looking to the future, it would seem that the government should provide apparatus in its pollution control program to encourage collective treatment of industrial waste.

The cluster of pulp and paper mills in the immediate vicinity of Prince George provides an example of where scale economies might be attained by industry. Surely comparison of costs from collective waste treatment by these mills against those of individual treatment should be attempted to determine what possible savings might be realized. If necessary, the government should be prepared to contribute to construction costs of such a treatment project, drawing funds from taxes imposed on those receiving benefits from such a program.

The objectives and criteria of the government effluent control program have been analyzed above. The last aspect to be studied is the method used to implement the program. As mentioned previously, objectives of maximum social benefits from multiple-purpose water use on the basis of fish mortality indices are sought through the imposition of effluent standards upon industrial wastes. The nature of these standards has already been considered. Despite the easily understandable nature of such regulations, it should be recognized that effluent standards do not

balance the costs and benefits associated with waste discharge, nor do they provide incentive to check disposal beyond a required level, even though this might be possible quite inexpensively.

The alternatives to standards are subsidies and/or charges. Subsidies have the advantage of centralized control, easing the administration burden. Nevertheless, funds must be raised for subsidies, and for a government agency these will be derived from tax revenues from all people in the province -- some of whom receive no benefits from the program. Further difficulties would arise with industry, as payments could encourage processes which yield high quantities of effluent just in order to collect larger subsidies. Industrial location decisions would be further distorted since industry would receive a subsidy even if a particular site would have been used with effluent disposal charges. Since social regulations should reflect society's wishes to industry, it would seem that a payments system would be less than ideal.

A system of charges or taxes, reflecting the costs related to varying levels of waste discharge through time and space, appears to be the best method of pollution control. First, charges seem to be more acceptable than subsidies to the public concept of justice and equity. In addition, a charge system would provide government with funds which could be used to support collective treatment programs taking advantage of scale economies. Finally, charges would enable the industrial firm to decide the level of treatment costs incurred, an aspect which has favor in

a market economy.

The main point of criticizing the government pollution control program and proposing alternative approaches has been to suggest that current practices cause over-investment for industrial waste treatment facilities. Such being the case, it is claimed that sites will be artificially prohibited to industry on irrational grounds in the future unless some institutional changes are made.

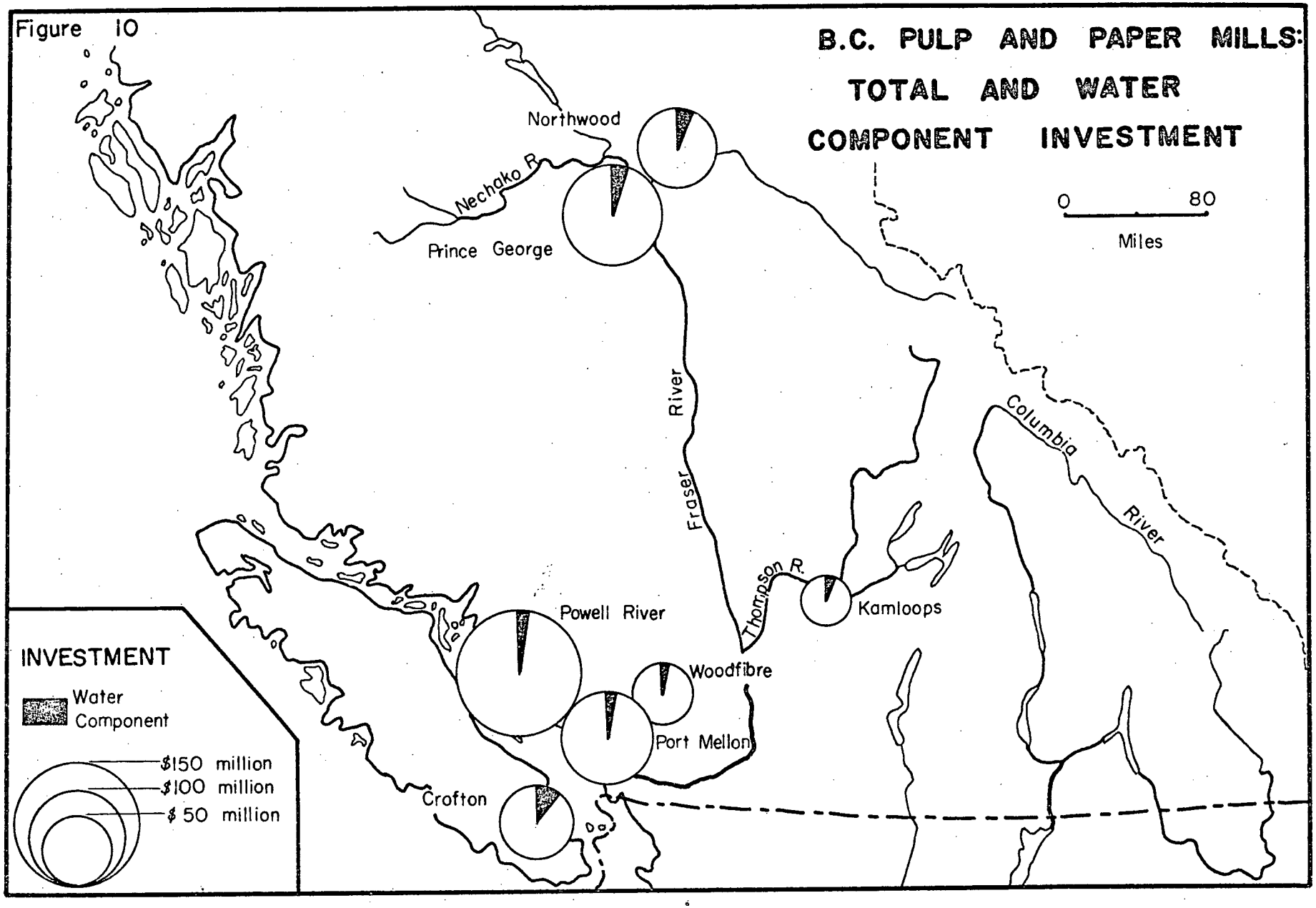
TECHNOLOGICAL-ECONOMIC CONSTRAINTS

Under this heading, analyses are given of the costs -- capital and operating -- associated with various aspects of the water component and the methods used by mills to handle water. The purpose of such an exercise is to determine the range of approaches, if any, that are applied to water by the pulp and paper industry.

TOTAL and WATER COMPONENT INVESTMENT

A study of Figure 10 reveals two significant facts. Compared to total investment, the capital cost associated with water is relatively small, in all cases being less than 15 per cent. Despite the limited nature of the water component investment, however, it is important to note that there is considerable range in magnitude of investment among the mills -- from slightly over 1 per cent at Powell River to nearly 11 per cent at Crofton. The average investment of the seven mills shown on the map is 5.5 per cent.

Figure 10


B.C. PULP AND PAPER MILLS:
TOTAL AND WATER
COMPONENT INVESTMENT
0
80
Miles
Northwood
Nechako R.
Prince George
Fraser River
Thompson R.
Kamloops
Columbia River
Powell River
Woodfibre
Port Mellon
Crofton
INVESTMENT
Water Component
$150 million
$100 million
$ 50 million

If the mills were to be divided on the basis of their expenditures on water three classes would evolve. The first class would include Powell River and Port Mellon, both having less that 2.5 per cent of their total investment devoted to water for process supply and effluent disposal. A second group would be formed by Woodfibre, Kamloops, Prince George, and Northwood -- the range of their water investment extending from 5.0 to 7.5 per cent. Crofton would be the lone member of the third class, allocating some 11 per cent of its funds to water purposes.

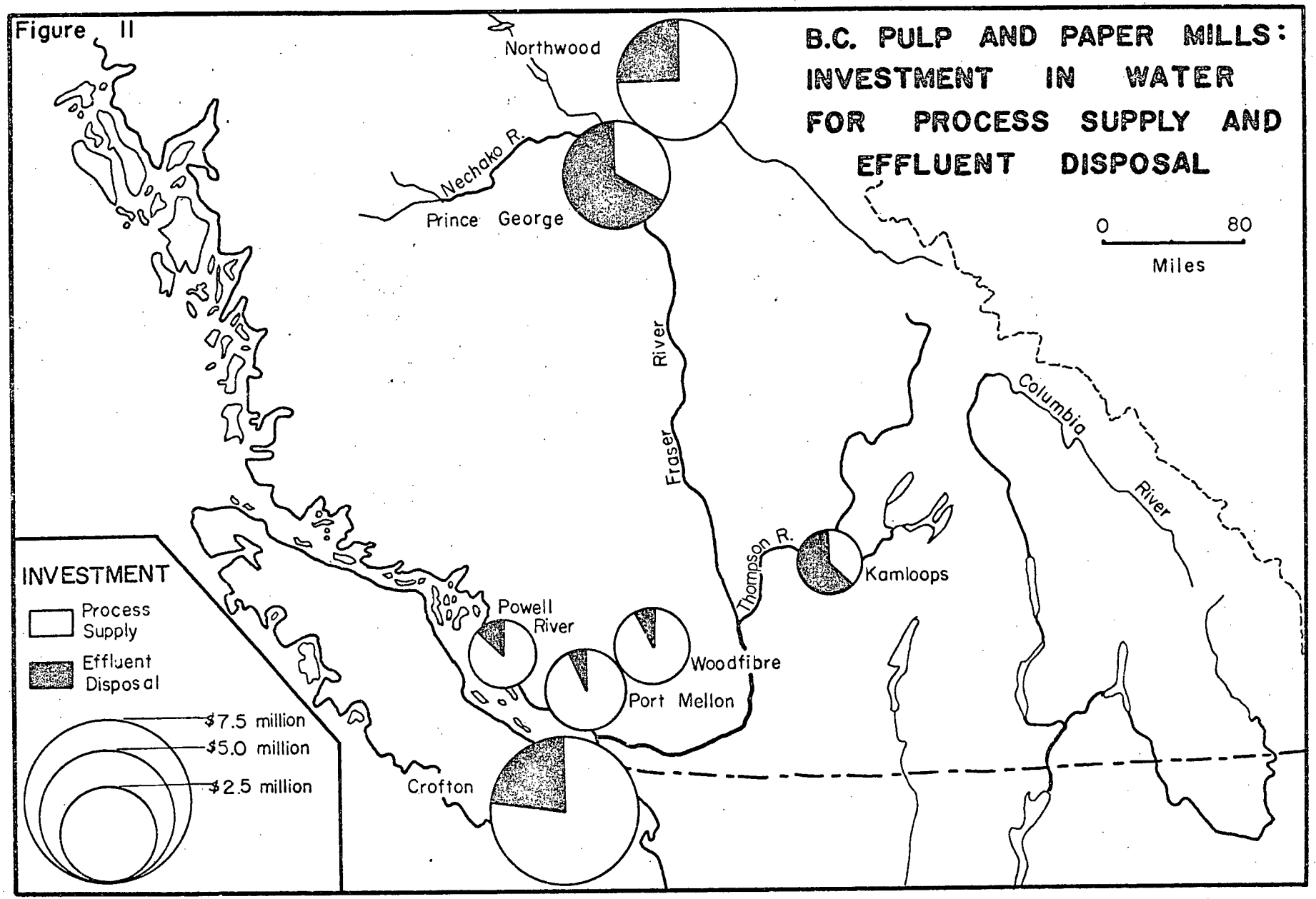
What do such generalized figures as capital investment suggest for locational choice? As a first measure, this data indicate that British Columbia mills have a wide range in which a suitable water source may be found. As the British Columbia industry exhibits a range of 10 per cent in water investment, initial analysis suggests the industry may have a greater range of choice for water than is contended in most of the literature.

INVESTMENT for PROCESS SUPPLY and EFFLUENT DISPOSAL

As indicated in Figure 11, variable emphasis is given to investment for process supply and effluent disposal among the study mills. It is apparent that the mills fall into three groups on the basis of investment for process supply water and waste treatment. Powell River, Port Mellon, and Woodfibre have each allocated less than 15 per cent of their investment to effluent disposal; Northwood and Crofton, approximately 25 per cent; Kamloops and Prince George, 65 per cent.

This pattern is interesting, as it would seem logical that

Figure 11


B.C. PULP AND PAPER MILLS: INVESTMENT IN WATER FOR PROCESS SUPPLY AND EFFLUENT DISPOSAL
Northwood
Nechako R.
Prince George
Fraser River
Thompson R.
Kamloops
Columbia River
Powell River
Woodfibre
Port Mellon
Crofton
0 80
Miles
INVESTMENT
Process Supply
Effluent Disposal
$7.5 million
$5.0 million
$2.5 million

there would be a distinct difference between coastal and interior sites due to the variation in pollution controls for plants discharging waste into the sea and those discharging into rivers. Yet, instead of a two-way grouping, a three-way one emerges. Kamloops and Prince George fit the picture of the interior mill allocating the greatest proportion of its water investment to waste treatment equipment. Powell River, Port Mellon, and Woodfibre, on the other hand, represent the image of a coastal mill -- relatively minor investment associated with pollution control and the greatest share for an adequate water supply.

Crofton and Northwood are the anomalies. While Crofton fits the coastal site image by transporting water some distance from source to mill site, its large waste treatment investment is explained by a two mile underwater diffusion pipeline. The other coastal mills use outfall sewers -- simple equipment which meets social performance requirements.

The situation at the Northwood mill offers the greatest hope for future spatial mobility. The three interior mills all collect their wastes by inplant sewer systems, and then transport the effluent to settling basins where sludge is deposited. From the settling basins the effluent is pumped to aeration ponds where the biological oxygen demand is reduced to required standards. Only after this secondary treatment is the waste pumped to a diffusion pipeline emptying into the receiving river water.

Prince George and Kamloops required over 50 per cent of their water component investment to provide adequate facilities. Northwood has been able to meet the same pollution standards with

under 25 per cent of its water investment. The fact that this plant is able to meet pollution criteria and is still able to keep the proportion of its waste treatment investment comparable to coastal mills suggests that social controls as a constraint may not play a major role in future location decisions. The practicality of installing efficient low-cost treatment equipment opens a wide range of spatial mobility.

From Figures 10 and 11 it is apparent that there is varying emphasis given to investment aspects -- regarding both amount and proportion. From this variability the impression is given that both the investment "pie" and the slices within it vary remarkably. It is suggested that such marked variability indicates that the pulp and paper industry is flexible regarding the technological and economic constraints imposed upon it by water characteristic components. It is further argued that such variability indicates the industry has a greater range of choice than the present literature suggests.

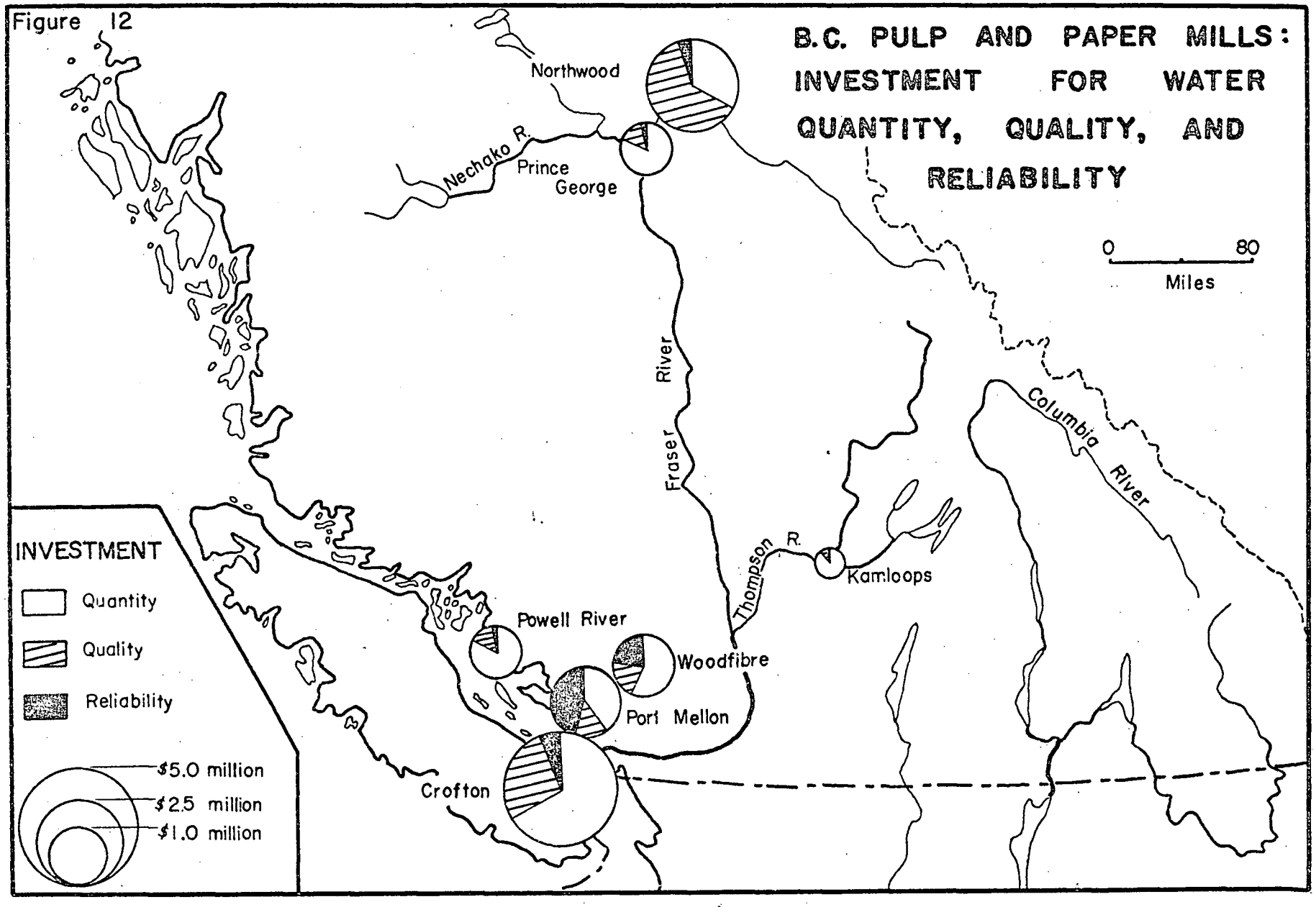
INVESTMENT for WATER QUANTITY, QUALITY, and RELIABILITY

As discussed in the section under physical constraints, the aspects of water quantity, quality, and reliability are vital to the industrial production process. In that section, it was shown that the raw water supply of mills exhibited differing characteristics. In Figure 12, some indication is given as to what investments are involved to make these varying characteristics satisfactory for mill requirements.

Quantity

Regarding water quantity, it was assumed that investment

Figure 12


B.C. PULP AND PAPER MILLS: INVESTMENT FOR WATER QUANTITY, QUALITY, AND RELIABILITY
0 80
Miles
Northwood
Nechako R.
Prince George
Fraser River
Thompson R.
Kamloops
Columbia River
Powell River
Woodfibre
Port Mellon
Crofton
INVESTMENT
Quantity
Quality
Reliability
$5.0 million
$2.5 million
$1.0 million

needed to bring required amounts of water to the mill site would reflect the importance given to this attribute. Consequently, the portion of the circles representing quantity investment is the aggregation of costs encountered in the construction of pumping and transportation facilities to carry water from source to mill site. From the map, it would appear that Kamloops has incurred the highest per unit investment for quantity in its process supply requirements. The main explanation for this fact, however, is that the investments for quality and reliability are unusually low at Kamloops -- resulting in the quantity investments taking on an inappropriate weight.

Turning to the other mills, however, the high costs associated with the quantity at Crofton, Powell River and Woodfibre represent the construction of pipelines to transport the water to the site.[22] Port Mellon has also built a pipeline from its water source, but it is relatively short compared to the others. The two Prince George mills are notable for their differences. Prince George Pulp and Paper has a large proportion of its investment related to quantity -- a combination of sophisticated pumping

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22 The cost of transporting water to Powell River is an estimate. MacMillan and Bloedel presently has three penstocks which carry 2.6 billion gallons of water daily to the mills. Of this total amount, about 2 billion gallons is used to drive the turbines which provide Powell River with its source of power. The 60 million gallons used for process supply is simply "siphoned" off of the penstocks. As a result, the cost shown on the map is an estimate of the investment required for a pipeline which would do nothing but carry process supply water to the mill site.

equipment and a relatively small concern with natural water quality. Northwood, on the other hand, has a much smaller percentage devoted to quantity. Thus, while the total amount for quantity is greater at Northwood than at Prince George Pulp and Paper, the Northwood percentage is smaller because of the sharp and frequent quality variations in the Fraser River -- and the consequent large investments required for pre-use quality equipment.

Quality

The cost of water treatment which would provide water to meet process requirements was assumed to represent the importance attached to quality by the industry. With this assumption in mind, Figure 12 suggests that the concern given to water quality varies from mill to mill. Kamloops has the smallest proportion devoted to quality treatment. The only treatment its water supply receives is retention in a settling pond so that suspended matter can settle out. It is interesting to note, however, that the Kamloops' technical staff is concerned enough with the effectiveness of this treatment that feasibility of a larger quality control plant is being considered. The construction of new facilities would require an investment of approximately $400,000, and, as a result, the Kamloops' personnel are waiting until a thorough evaluation can be made.

Powell River, Port Mellon, and Woodfibre enjoy relatively low quality treatment costs. Their equipment consists of little more than filters and screens which strain out suspended matter. Crofton has a fine quality source, except during the winter rainy

season. During this highwater period turbidity has risen as high as 700 ppm, necessitating installation of a $1.25 million water treatment station.

The reasons for quality investment at the Prince George mills has already been suggested. Prince George Pulp and Paper Ltd. has a small investment, consisting of 6 screens and clarifiers, because the Nechako River provides fine quality water, except during the spring-summer freshet period. The Fraser River is turbid all year around, requiring Northwood to have the highest proportional investment in pre-use quality treatment equipment among the mills studied. While Crofton does not operate its treatment plant from May to October, the Northwood facilities must function continuously. As with total and quantity water component investment, there is a wide range in the type and degree of quality control exercised by the study mills.

Reliability

The concern placed upon reliability was assumed to be a function of the investment directed at reducing discharge variability of the water source. For Prince George, Northwood, Kamloops and Powell River, this cost has been insignificant. Costs related to reliability are relegated to screening systems designed to remove debris accompanying the freshet season.

At Port Mellon, Woodfibre, and Crofton, reliability control has resulted in more extensive measures -- construction of $750,000, $340,000, and $214,000 dams respectively. The Port Mellon and Woodfibre controls are a necessity if salmon and industry are to jointly utilize the stream. Crofton's weir is located on the

outlet of the Cowichan Lake, with the objective being to maintain a minimum flow of 250 cubic feet per second at all times. It is noted that a dam exists at the outlet of Powell Lake, the source of water for MacMillan Bloedel's Powell River complex. However, the Engineering Department at Powell River feel that the dam is only there to meet the requirements for power generation. In their opinion, if Powell Lake were tapped only for process supply water, a dam would not be necessary since the minimum average flow is well above mill requirements, and turbidity is seldom a problem.

OPERATING COSTS

All previous reference to costs has been in the context of fixed capital investment for water component equipment. What about operating costs? Although pulp and paper mills were unable to provide empirical information in this respect for the study, company spokesmen were unanimous in the opinion that operating costs, as related to water supply and effluent control, were minor aspects for mill operation.[23]

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23 When asked about operating costs, mill respondents felt that an accurate breakdown would be difficult to give without considerable time for investigation. They stated that operating costs associated with chemicals and overhead could be determined relatively easily, but that maintenance and labor factors would be difficult to determine. An example of the problem: a person working in a technical department may spend part of his time related to testing of water quality, etc., but this would only be one of several responsibilities. But, when asked for generalizations, companies replied that water operating costs were not significant related to total operational expenditures.

The exceptions to lack of data were found at Kamloops and Crofton. On the basis of a recent study, Kamloops' officials stated that operating costs for effluent treatment had averaged $16,500 a month, and that total monthly water component operating costs would not be greater than $25,000.[24] Crofton has stated its costs associated with water in a different form. In 1961 a research technician for B.C. Forest Products stated that

> The actual cost of obtaining raw water is less than a tenth of a cent for one thousand pounds for raw filtered and seven tenths of a cent for cooled condensate. [25]

Transforming these figures in terms of gallons, the result is operating costs of approximately one cent per 20,000 gallons of process water. These two examples appear to support the industry's claim that operating costs for the water component are neither high nor restrictive.

From the cost data presented here, it is evident that the study mills exhibit a wide range in emphasis given to water component investment, process supply, effluent disposal, quantity, quality, and reliability. It is contended here that the wide range of investment which appears indicates the industry shows

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24 E.L. Bailey, "Effluent treatment - success or failure?", Pulp and Paper Magazine of Canada, Vol. 68, No. 3, March 1967, p. T130.

25 E.T. Guest, "Heat and Water Utilization in a Single Unit Bleach Kraft Mill", Canadian Pulp and Paper Industry, Vol. 14, No. 7, July 1961, p. 20.

considerable adaptability in balancing water requirements against available water supples -- and thus exhibits more spatial mobility than is suggested in the literature.

CHAPTER V

SUMMARY AND CONCLUSIONS

THE ROLE OF WATER IN THE INDUSTRIAL LOCATION PROBLEM

As mentioned in the second chapter, literature considering the role of water in the industrial location problem exhibited several characteristics. A majority of opinion stated that water can be important for industrial production, and furthermore, that the presence or absence of an adequate water source has had a dominant influence in siting decisions. The literature focused on three aspects of water -- physical, institutional, and technological-economic -- contending that of these attributes the technological-economic factor has been the most significant element.

On the basis of this investigation, which has studied the role of water in British Columbia's pulp and paper industry, it is agreed that water is indeed important and necessary for successful industrial operation. In the study, however, the pulp and paper industry showed itself to be adaptible and flexible to varying process water supply and effluent disposal conditions through both time and space. It is therefore argued that water, as a locational factor or constraint, has not yet been a major element in reducing the range of choice for sites available to pulp and paper mills in British Columbia.

From the capital investment information provided by the companies, it would appear that any new mill must allocate 5 to 8 per cent of its total investment to the water component. If

these limits are correct, then it is possible to establish three classes of investment related to water which indicate the attractiveness of a potential source. As already mentioned, mills must expect to spend 5 to 8 per cent of total investment for water. Consequently, any water sources falling within that range of investment should be satisfactory and suitable for mill location. It then follows that any site where investment for water is less than 5 per cent of the total will become extremely attractive. On the other hand, investments greater than 8 per cent for water are likely, in the future, to deter mills from locating at a given site.

The fact that the latest mills to begin operation have been able to keep their water investment under 8 per cent, despite having to meet rigorous pollution control standards, appears to substantiate the claim that water, as an element in British Columbia's pulp and paper industry raw material base, has not yet been a locational constraint. The 5 to 8 per cent range appears to hold, despite the possibilities for scale economies, different entrepreneurial approaches, varying relative locations, and potential factor trade-off.

While the different variables mentioned above do not appear to significantly affect water component requirements, with the possible exception of relative location, further inquiries into the industrial location problem should consider the impact of consulting engineer firms as a variable. Mills in this study depended in varying degrees on consultants, from MacMillan Bloedel which relies primarily on its own staff, to Kamloops which had

a "turnkey" arrangement with Phillips, Barratt-Hillier Ltd. of Vancouver and John Beaver of Portland. In a "turnkey" contract, the consulting engineers are responsible for the entire project, and thus in such a situation the attitudes of consultants could have an important influence upon water component decisions.

PHYSICAL, INSTITUTIONAL, AND TECHNOLOGICAL-ECONOMIC CONSTRAINTS

The aspects of technology and economics integrate physical and institutional demands related to industrial water use, and therefore must be rated the most important of the three constraints. Pulp and paper mills are capital intensive;[1] it would seem that without further technological breakthroughs, current economic limitations will not allow significant reduction in investment required for the water component.

Mills are, nevertheless, gradually introducing more sophisticated water re-use techniques into their production systems. These advances are not aimed specifically at reducing water quantity requirements, but instead at potential savings from chemical and heat reclamation. As a Crofton official explained

> Water waste and heat waste generally go hand in hand. Also, as chemical and fibres have an unpleasant habit of going along, any saving in water has extra benefits. [2]

A sidelight of water re-use practices, however, cannot help but

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1 Staff Report, "Compact mill only a beginning", Pulp and Paper Magazine of Canada, Vol. 67, No. 7, July 1966, p. 80, reports that capital cost per ton averages $80,000 for the industry.

2 E. T. Guest, "Heat and Water Utilization in a Single Unit bleach Kraft Mill", Canadian Pulp and Paper Industry, Vol. 14, No. 7, July 1961, p. 20.

be greater spatial mobility -- since re-use by definition will reduce the physical quantity constraints imposed by water requirements.

With growing public interest in "environmental quality", institutional constraints may become important for future site decisions -- they do not appear to be so now. Although the increased importance of social controls is indicated by pollution standards required of new mills, compared to regulations encountered by pre-1963 plants, the newer mills appear to have adapted to social criteria and still remained competitive in the industry.

Regarding social control standards, it is apparent that the provincial government follows the concept of multiple-purpose resource use, and recognizes that effluent disposal is a legitimate use of water. While this is a progressive approach, the application of pollution standards based on preservation of the fishery resource is open to question. If the government's objective is to maximize social benefits from a water resource through multiple-purpose use, pollution regulations should be established which balance at the margin costs incurred and benefits achieved from waste treatment. Only in this manner will social controls provide the right signals to industry for location decision-making. The current practice of establishing standards based on fishery protection does not balance social costs and benefits, and thus does not provide industry with society's goals. This study suggests that a pollution control program

based on a charge system rather than standards would be more equitable and eliminate over-investment in effluent treatment equipment.

In the initial location decision, physical aspects of water appear to have a secondary position relative to the other constraints. While the quantity of water required for production enters all decisions, in British Columbia this aspect does not seem to raise a significant obstacle. Stream reliability appears to create the greatest difficulties for mill operation, but this factor seems to be one that cannot be fully assessed until production actually commences.

STUDY EVALUATION

There are several weaknesses in the approach used in this study which should be recognized. These are: scope of the investigation, terms of reference, and data.

SCOPE of the INVESTIGATION

This research focused upon the role of water in industrial location decisions. It is evident that water is only one of many factors which must be considered in site evaluation. Becasue of the limited scope, it is not possible to suggest the relative importance of water for the location problem. However, the three investment categories suggested should aid in determining the water attractiveness of sites.

Related to the limitation of a single component approach is the notion of factor trade-off. In other words, few, if any,

sites provide industry with optimum conditions for all of the components required for operation. Consequently, choice of a site results from a search for the combination of components yielding the best alternative to the optimum solution. Such an approach will not result in individual components being optimized. Rather, advantages and disadvantages of various components will be "traded-off" against one another to achieve the best total result. Due to this practice of factor trade-off, it is conceivable that sites requiring water component investments greater than 8 per cent will be selected (Crofton being such an example). This exception does not invalidate the investment groups suggested, but does emphasize that they are generalizations, and must be used as such.

TERMS of REFERENCE

For this study the water component was defined in terms of water for process supply and effluent disposal. It is recognized that water may enter the location problem as an element of the power component, when it provides the input for hydro electricity generation. Powell River is an illustration, where only 3 to 5 per cent of water drawn from Powell Lake is used for production. All the rest is utilized to drive turbines, and, as one MacMillan Bloedel engineer explained, the potential for relatively inexpensive on-site power was one of the major attractions for the original mill site. Such an anomaly represents a further aspect which was recognized but given secondary priority in this investigation.

DATA

Several minor difficulties were encountered with capital cost information. In the newer mills, data was readily available, but in older plants years of modifications and alterations made it difficult to designate with great precision investment pertaining only to water. With older mills, the problem of discounting required consideration. It is felt that this was safely by-passed by using data representing the replacement value of the mills for the years specified in the text.

The semi-confidential nature of cost information posed difficulties at some mills, and was the reason for exclusion of several plants from the study. Nevertheless, companies were generally co-operative and interested in the research, and willing to supply any information which would not adversely affect their competitive position in the industry.

IMPLICATIONS FOR GEOGRAPHIC RESEARCH

At the outset it was explained that this thesis had its roots in the two research clusters of resource studies and industrial location investigations. By way of concluding, it should be emphasized that, although the evidence is inconclusive due to the single industry nature of the survey, the study raises several arguments suggesting current over-emphasis of water in location decisions.

The question mark raised regarding the real importance of water in industrial location opens many corridors within the water research themes -- development and management, perception,

environmental quality, and economic growth -- outlined at the beginning of the investigation. If for example, industry is indeed flexible regarding water requirements and through the notion of factor trade-off has a wide range of choice regarding water demands, there are numerous ramifications for water management programs. In future planning for water development, is the current institutional framework adequate, or is it causing misallocation of resources? If the present arrangement is inadequate, as indicated by the results of this inquiry, then the geographer appears to be in a position to integrate the varying physical, social, and economic aspects requiring consideration for the attainment of workable and acceptable programs.

Economic growth and environmental quality objectives often seem to be diametrically opposed. With the possibility that water has been over-emphasized as a siting factor by locational analysts, further consideration of objectives becomes necessary. Priorities must be established between the above two goals; the fact that industry may be more flexible regarding water needs than is generally accepted necessitates reassessment of present priorities and decision criteria. The geographer, with a grasp on resource and location problems, should be able to contribute to the adjustments which are required in water programs.

For those geographers inclined toward perception studies, the importance of water raised here opens numerous paths for inquiry. The ideas held by the general public toward the industry-water relationship will surely color attitudes toward demands for environmental quality and public control of water

resources. Similar patterns should be present in both government and industry outlooks to water management. Determination of the extent of misconception regarding the importance of water for industry could provide a valuable aid for planning intelligent water utilization and formulating educational programs which avoid current misunderstandings.

In the final analysis, although minor difficulties were encountered in conceptualization and data collection for the study, it is hoped that the investigation has gone some way to clarify the vagueness and confusion marking the literature which considers water and industrial location. While differences of opinion are generally a healthy sign of progressive inquiry, differences resulting from unclear terms of reference and ambivalent definitions provide little guidance. Consequently, although attempts at clarifying the scope and terms of reference of research generated problems, it is hoped that even if the conclusions do not create unanimous agreement, the organizational framework employed may provide a departure point for further inquiries.

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APPENDIX I

The purpose of this appendix is to elaborate upon information presented in Table I. As a result, in the following pages the study mills are presented one by one with detailed commentary regarding their expansion and development. It is hoped that this extra information will provide a two fold service: set each study mill in perspective and illustrate the rapid change within the industry -- thus allowing greater insight into water problems of the past, present, and future.[1]

B. C. FOREST PRODUCTS LTD: CROFTON

In 1958 production of bleached kraft pulp started at B.C. Forest Products mill at Crofton. Initial capacity of the $48 million plant was 500 tons per day, with daily water use averaging 35 million gallons. In 1964, a $34 million expansion program was finished, which resulted in kraft production capacity rising to 625 tons per day and a new groundwood pulp mill rated at 275 tons per day capacity being started. The third part of the program was construction of a $20 million, 350 tons per day newsprint machine.

Further expansion in 1965 increased kraft pulp capacity to

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1 Information for this appendix has been drawn primarily from three sources: interviews with company officials, and the following two reports: British Columbia Hydro and Power Authority, Industrial Development Department, The Pulp and Paper Industry of British Columbia, Vancouver, October 1966; and, British Columbia, Department of Industrial Development, Trade and Commerce, Bureau of Economics and Statistics, Regional Index of British Columbia, Victoria, January, 1966.

950 tons per day. A second newsprint machine is being installed during 1967 at an estimated cost of $22.5 million, which should double the newsprint capacity at the Crofton complex. When the second newsprint machine begins operation, peak water requirements will reach 68 million gallons per day, severely taxing current water supply facilities.

CANADIAN FOREST PRODUCTS LTD: PORT MELLON

Port Mellon is the site of one of British Columbia's oldest pulp mills. The plant's history is complicated and difficult to trace, but the following brief resumé of its growth should serve to illustrate the difficulty associated with trying to obtain accurate capital cost information for an older mill.

The mill was started in 1908 by the British Columbia Wood Pulp and Paper Company. Production was 20 tons per day of soda pulp and wrapping paper, but operations only lasted six months due to marketing problems. In 1912 the plant was re-organized as Colonial Lumber and Paper Mills but production was never started. The mill did not resume operations until after World War I, when the Rainy River Pulp and Paper Company bought the mill and converted it from soda to kraft production. This ownership went bankrupt in 1919 and the plant changed hands once more -- the new owners being the Western Canada Pulp and Paper Company. Although production was increased in 1925, Western Canada Pulp and Paper followed the fate of its predecessor. In the next three years the Howe Sound Pulp and Paper Company and the Vancouver Kraft Company unsuccessfully attempted to produce

kraft pulp at Port Mellon.

From 1928 to 1939 the mill was owned, but rarely operated, by Vancouver Kraft Mills Incorporated. An ambitious expansion program was undertaken by this company but the depression reared its head, keeping the mill shut down for seven years. In 1940 Vancouver Kraft Corporation Limited was able to re-start production at a rate of 60 tons per day. The following year, however, the Sorg Paper Company of Ohio purchased Port Mellon. A Canadian subsidary, the Sorg Pulp Company Ltd., operated the plant. Starting with a production rate of less than 100 tons of unbleached kraft pulp each day, Sorg increased production to 130-140 tons per day. For eight years the mill was kept in sustained operations for the first time in its life -- due to a captive United States market.

Market conditions in 1949 forced closure, the mill remaining closed until 1951 when Canadian Forest Products Ltd., present owner, purchased the plant. During 1951 and 1952 modernization and rebuilding occured, resulting in 200 tons per day capacity during operations in 1953. The next year a bleach plant was added. Water requirements at this period were approximately 12 million gallons daily. Several expansion programs have been completed since then, the last in 1965, so that current capacity is 520 tons per day of bleached kraft pulp. Present water requirements have also grown to over 30 million gallons per day.

As mentioned earlier, the Port Mellon operation suggests how capital cost information could be difficult to obtain for established mills. Port Mellon has had at least nine owners

before the present one, and many changes and modifications made over the years make discounting calculations hazardous estimates at best.

KAMLOOPS PULP AND PAPER COMPANY LIMITED: KAMLOOPS

Located some three miles below the confluence of the North and South Thompson Rivers, Kamloops Pulp and Paper Company Limited produced its first pulp in December 1965. The plant currently has a capacity of 250 tons per day of bleached kraft pulp, which is relatively small, but long range plans foresee a 1,250 ton per day complex.

This mill represents a partnership between a group of five interior British Columbia lumber firms and Weyerhaeuser Company of Tacoma (controlling 51 per cent). One of the striking aspects of the mill is the low capital cost per daily ton -- approximately $60,000, compared to about $80,000 normal current costs for the industry.

MACMILLAN BLOEDEL LIMITED: POWELL RIVER

The Powell River complex owned by MacMillan Bloedel has a long history, just like Port Mellon. The mill first began operations in 1911 under ownership of the Powell River Company Limited -- British Columbia's first manufacturer of newsprint. Construction of the plant started in 1909 and the first rolls of newsprint were turned out in April of 1912. Original capacity was 250 tons per day, but post World War I demand resulted in the addition of two more newsprint machines in the mid 1920's which raised capacity to 500 tons per day. Nine machines were

operating with a capacity of 1,500 tons daily by 1956.

It was in 1959 that the Powell River Company mill was purchased by MacMillan Bloedel interests, two names synonymous with the British Columbia forest industry. The H. R. MacMillan Export Company was established during 1919 to export timber from the province; Bloedel, Stewart and Welch was formed in 1911 as a logging company. These two companies merged in 1951 as MacMillan and Bloedel Limited. By 1959 when Powell River was included in its operations, MacMillan and Bloedel was already operating two other pulp mills at Nanaimo and Port Alberni.

The Powell River plant presently has a capacity of 1,200 tons per day of groundwood pulp and 300 tons of sulfite pulp, both used for newsprint production at a rate of 1,500 tons per day. A $109 million expansion and modernization program is currently under way which when completed in late 1967 will add 450 tons per day to newsprint capacity, a new 500 ton per day kraft pulp mill, and further groundwood capacity.

NORTHWOOD PULP LIMITED: PRINCE GEORGE

This mill, one of three in the Prince George area, is located seven miles north of Prince George on the bank of the Fraser River. Operations started in July 1966 at Northwood, with initial capacity rated at 625 tons per day of bleached kraft pulp. The Northwood mill represents an investment of $56 million, of which $4¼ million was required for the water supply and waste treatment disposal systems. Northwood is a joint operation of Noranda Mines and the Mead Corporation of Dayton,

Ohio, each having fifty per cent interest.

PRINCE GEORGE PULP AND PAPER LIMITED: PRINCE GEORGE

Prince George Pulp and Paper Limited is jointly owned by Canadian Forest Products Limited and the Reed Paper Group of the United Kingdom. It is located on a 440 acre site at the confluence of the Nechako and Fraser Rivers, about four miles outside of Prince George. The plant, which opened in 1966, has a capacity of 300 tons of bleached kraft pulp and 375 tons per day of kraft paper. An interesting aspect of its location is that process supply water is withdrawn from the Nechako River while effluent is discharged into the Fraser.

A further note of interest is that these two partners have joined with Feldmüle A. G. of Düsseldorf to form Intercontinental Pulp Company Limited. Intercontinental is presently constructing a 650 ton per day bleached kraft mill adjacent to the Prince George Pulp and Paper site which should be operational early in 1968. The management of Prince George Pulp and Paper will also be in charge of Intercontinental operations.

RAYONIER CANADA (B.C.) LIMITED: WOODFIBRE

Like Port Mellon and Powell River, Woodfibre has been upon the British Columbia forestry scene for many years. The mill first started in 1911, when the Whalen brothers of Fort William, Ontario established a 50 ton sulfite mill at Woodfibre. Shortly after the first world war the Whalen Pulp and Paper Company encountered financial difficulties and the company's bondholders took over Woodfibre, forming the B.C. Pulp and Paper Company to manage it. This company successfully operated the plant

until 1951, when Alask Pine Company, headed by Leon and Walter Koerner, and Abitibi Paper Limited purchased Woodfibre. Under this dual ownership the mill was renamed as Alaska Pine and Cellulose Ltd.

Abitibi did not remain in the partnership long, however, and in 1954 control was acquired by Rayonier Incorporated.

Rayonier operated Woodfibre as a sulfite pulp mill until 1961, at which time the plant was converted to bleached kraft pulp production -- at a cost of $12 million. This conversion resulted in a mill with a 250 ton per day capacity. This change was apparently successful, as Rayonier spent $24 million in 1965 to increase kraft capacity to 550 tons per day. An interesting sidelight of the expansion program is that after the 1961 transformation water requirements for both process supply and power generation were 26 million gallons per day. However, although capacity was doubled in 1965, water needs only increased to 34 million gallons daily -- a fact which may provide optimism for technology advocates.

APPENDIX II

Although there are numerous excellent descriptions of pulp and paper-making available,[1] this appendix briefly outlines the different types of pulp -- how they are produced, what their water requirements are, and what wastes are associated with them.

Pulp can be classified either on the basis of process or product. The two basic processes are mechanical and chemical; the product of the former being groundwood pulp, and those from the latter sulfate(kraft) or sulfite pulp. Paper products result from further treatment of one pulp or blends of different pulps. An example is newsprint, a mixture of 80 per cent groundwood and 20 per cent sulfate pulp.

MECHANICAL PROCESS

When logs first enter the mill, they are debarked either by jets of high pressure water, revolving drums, or cutting knives, and then are cut into appropriate lengths for grinding. Once

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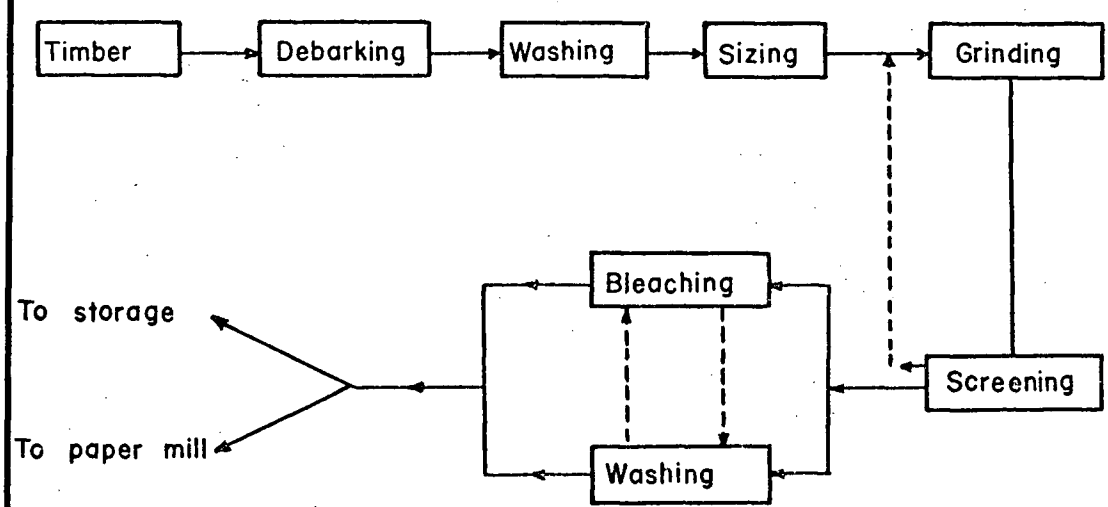
1 See, for example, (1) E.A. Ackerman and G.O.G. Löf, Technology in American Water Development, Baltimore, John Hopkins Press for Resources for the Future, 1959, pp. 175-181; (2) American Society for Testing and Materials, Committee D-19, Manual on Industrial Water and Industrial Waste Water, A.S.T.M. Special Technical Publication No. 148-G, 1965, pp. 1-11; (3) J. B. Calkin and G.S. Witham, Modern Pulp and Paper Making, New York, Reinhold, 1957; (4) N.S. Chamberlain, et. al., Water Technology in the Pulp and Paper Industry, Tappi Monograph Series, No. 18, 1957; (5) C.E. Libby, Pulp and Paper Science and Technology, New York, McGraw Hill, 1962, Vol. 1; (6) O.D. Mussey, Water Requirements of the Pulp and Paper Industry, United States Department of the Interior, Geological Survey, Water Supply Paper No. 1330-A. 1955.

cut, the logs are transported to a grindstone, where they are forced against the revolving abrasive stone in the presence of water. Pulp fiber is produced in this manner by tearing fibers as long as possible from the wood.

The mass of fibers resulting from the grinding process is passed over a screen which removes and discards foreign material. The remaining pulp continues over a series of finer screens. Any fiber unable to pass through the openings in these screens is returned to the grindstone for further treatment. The pulp passing through all the screens is then washed and/or bleached, depending upon the grade of groundwood desired. After those stages, the pulp is thickened and then mixed with a chemically made pulp in order to start paper production. The other alternative is to dewater the pulp and store it for future use. The

Figure 13

MECHANICAL PROCESS: GROUNDWOOD PULP



production process is shown schematically in Figure 13.

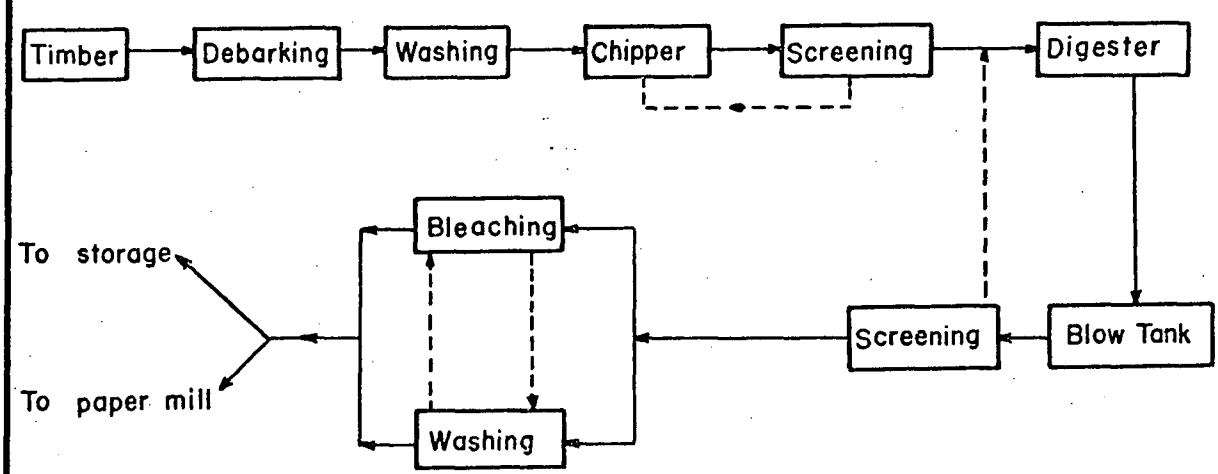
There is very little waste from groundwood production compared to the chemical pulps, since both the lignin and the cellulose from the wood are used in the process. In addition, the various chemicals so important for sulfate and sulfite production are absent in the mechanical process. The finished product is used for paper where high quality is not the principal criteria and low price is critical.

CHEMICAL PROCESSES

Sulfate pulp, produced by an alkaline process, and sulfite pulp, from an acid process, are the two principal products from chemical pulp-making processes. As shown in Figure 14, logs are first debarked and washed, just as for groundwood pulp. The logs

Figure 14

CHEMICAL PROCESSES: SULFITE AND SULFATE PULPS



are then chipped in multi-knife chippers, which slice the logs into small pieces of wood one-half to one inch long, one-sixteenth to one-eighth inches wide, and one-half to three-quarters inches thick. When wood is received in the form of sawmill chips, the chipping stage is bypassed. After chipping, the small pieces of wood are passed over screens, with oversize ones being returned for further chipping.

The chips are carried by conveyor belt from storage silos to the digester, where they are cooked under pressure in a liquor containing caustic soda and sodium sulfite for sulfate pulp -- or calcium, magnesium, or ammonia bisulfite for sulfite products. It is at this stage that the chemical processes yield a product different from their mechanical counterpart. While mechanical pulp is formed by tearing fibers from timber, chemical pulp is derived from cooking wood chips in a chemical solution under pressure. In the digester, cellulose fibers are left in the pulp, but lignin is dissolved.

Following cooking, the pulp and used chemicals (called black liquor) are blown into a tank where they are diluted with dilute black liquor from previous digester cookings. The two components are then pumped to knotters, where uncooked chips are segregated for further cooking. The pulp passing through the knotters then enters a preliminary or "brown stock" washing stage in which the residual liqours are washed away. Some dilute black liquor used in brown stock washing is returned to the digesters for further use. The remainder goes to the mill's recovery unit, where valuable chemicals are reclaimed.

The semi-washed pulp, called brown stock, is sent over screens as a mixture of pulp and water. After screening, the pulp undergoes further stages of washing, until the desired grade of pulp is attained. Once the proper brightness is reached the pulp either enters a series of rollers and then a drying machine to remove the water content from the product, or proceeds to the paper-making unit. If dried, the pulp will be stored in bundles for shipment to customers; if passed on to the paper-making unit it will be mixed with groundwood pulp to form the paper base.

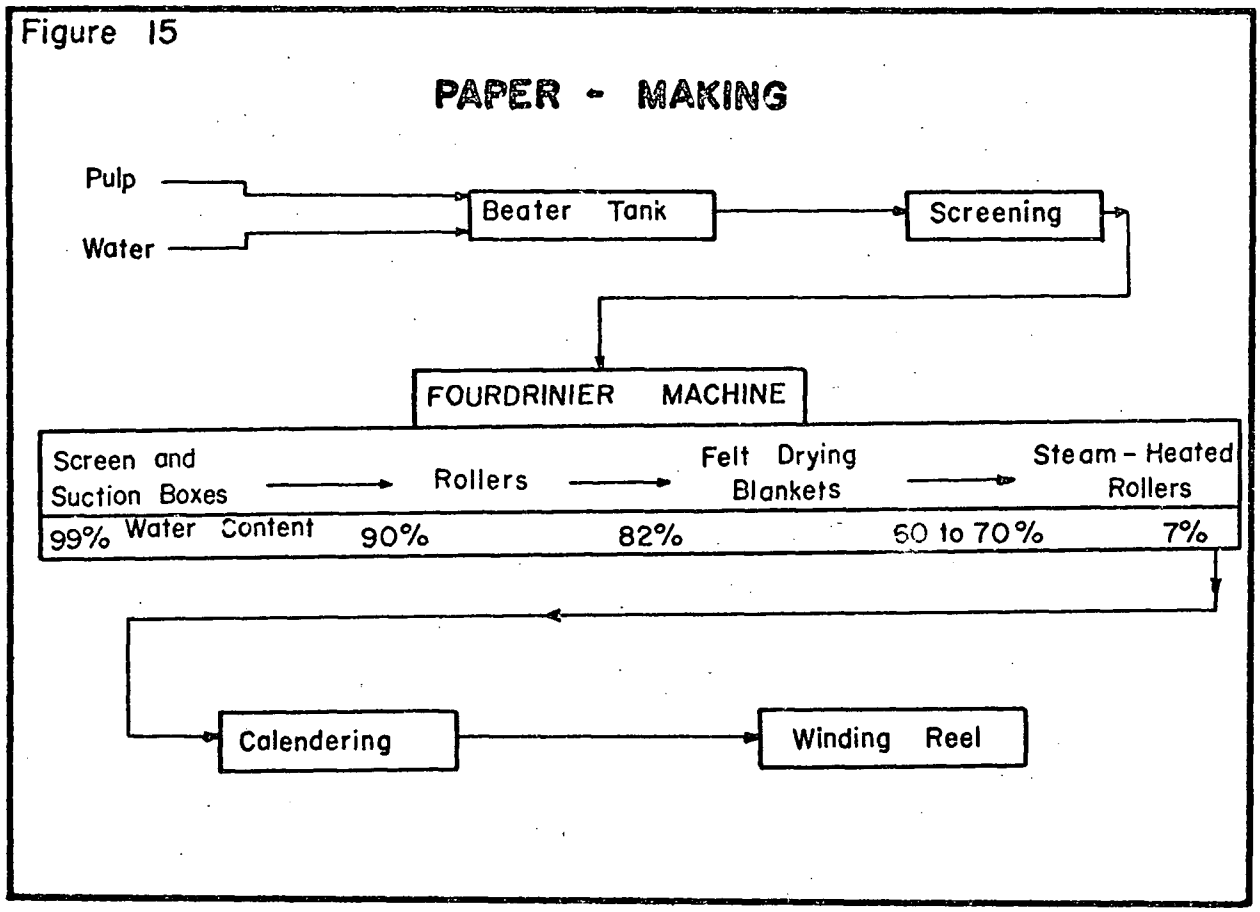
Water enters the above process in many ways. First,it is used as steam and process water in the digesters, in transporting cooked pulp, and in recovering chemicals from black liquor. In addition, water is employed in byproduct recovery plants, as well as for boiler and cooling water in the power plant. Finally, water is frequently used to prepare wood for cooking (i.e., debarking).

Effluent from the sulfate process is less than that from sulfite pulp since the sulfate wastes contain little lignin or cooking chemical, and, in addition, black liquor wastes can be burned to recover both chemicals and heat. Sulfite pulp production, on the other hand, causes bothersome problems because sulfite black liquor cannot be burned nor easily broken down. Bleaching, whenever used in a process, discharges wastes containing fibers and chemicals.

PAPER-MAKING

Paper products range from newsprint to high-grade writing stock. The process for the various basis products is similar. Depending upon the final paper product desired, a particular

Figure 15



blend of pulp types is made. As indicated in Figure 15, this mixture is then sent to a beater tank full of water, where the pulp fibers are separated and other ingredients such as synthetic and natural clays, dyes, and starches, are added. In the industry this step is known as "making" the paper. The clays are used to fill spaces between the fibers, yielding a smoother paper surface, increased whiteness, and greater ability to absorb ink. Dyes, of course, are used to color the paper; starches, to give

resistance to penetration by liquids.

After the "paper" is made (at this stage it is approximately 1 per cent fibers and 99 per cent water), it is fed into a Fourdrinier machine. This machine, through a series of steps, reduces the water content of the paper. The machine itself is an "endless" screen, over which the paper and water mixture travels. Vibration of the screen and suction boxes beneath it reduce the water content to 90 per cent. As well as removing moisture, the steady shaking motion of the screen orients the fibers giving greater strength to the sheets.

At the end of the wire screen are a series of rollers which reduce the water content to about 82 percent. The paper is then transferred onto a blanket of heavy wool or felt which travels through several rollers. This stage removes the water by a further 15 to 20 per cent. The remaining water cannot be removed by pressing due to limited crushing strength of paper, so the final step involves passing the paper sheet through a number of steam-heated rolls, decreasing the water content to 7 per cent. Calendering is the final step, a process where passage of the sheet over several steel rollers yields a smooth shiny surface for the paper. After calendering, the finished product is rolled onto large reels. For sale to customers, the paper on the large reels will be cut into smaller, more easily handled, rolls.

While there are fewer chemical residues in paper-making than in pulp production, there is still effluent. The major

wastes are from water containing fibers, filler, dyes, paper machine cuttings, and residues from the beaters, refiners, mixing boxes and screens.

WATER USE IN PULP AND PAPER MILLS

From the description of production processes, it is evident that water enters many phases of pulp and paper making. Some of the uses of water are for hydraulic debarking and washing, for solvents, for transporting pulp, for bleaching and washing, and for steam generation. To generalize, water for process supply includes that for actual pulp production, boiler-feed, cooling, and general mill requirements, while that for effluent disposal is the volume required to dissipate waste.

In the fourth chapter, data regarding quality characteristics for process supply water was given but little comment appeared about the nature of different chemical constituents. In the concluding part of this appendix the various water constituents mentioned in Chapter IV will be described in detail to indicate their significance for pulp production.

Turbidity: results from the presence of fine particles such as clay, silt, sand, or organic matter in the water. When present in a water source, turbidity reduces brightness and darkens the color of white pulp or paper.

Hardness: is caused by calcium and magnesium compounds. It is generally expressed as parts per million of calcium carbonate. Water containing less than 60 ppm $CaCO_3$ is considered soft; that with more than 120 ppm, hard. The effect of hard water is deposition of scale on screens and equipment because

calcium and magnesium carbonates precipitate easily when water becomes warm.

Color: arises from dissolved material in water. Natural organic material or industrial waste and sewage are the principle causes. As cellulose fibers absorb color, its presence may cause loss of brightness. Color caused by organic matter may contribute to slime formation on equipment as well.

Iron and Manganese: The presence of iron or manganese causes discoloration of pulp and paper products. Iron can be absorbed by cellulose, turning white products yellow. Manganese reacts to leave a pink color.

Silica: is undesirable in water since it adds to ash content in pulp. In sulfate mills, silica may react in black liquor, leaving a scale in the recovery evaporators and heaters.

Hydrogen concentration (pH): measuring the degree of acidity or alkalinity of water, the pH is an index of corrosive property of water. A pH of 7 indicates neutral water. Most natural water sources will have a pH within the range of 6 to 8 -- values above 7 indicate increasing alkalinity; below 7, increasing acidity.

For the production of pulp, calcium and magnesium compounds are kept low because of a tendency to form scales on equipment and precipitate on pulp. Turbidity, a measure of suspended material, must be low or else impurities will be included in the finished product. Nothing is more disconcering for a quality control technician than to see leaves imbedded in pulp or paper at the dry end of a Fourdrinier machine. High concentrations

of iron, manganese and color cannot be tolerated, due to the possibility of their absorption and the consequent dulling effect on a product.

Boiler-feed requirements are even more stringent than those for production purposes. Boiler capacity is essential in the industry since considerable steam is used to produce pulp, and heat is used extensively in paper production. However, since boiler-feed standards are so high, as evident in the following table, all mills must accept an investment charge for suitable treatment equipment despite the quality of a natural supply source. Treatment is aimed at protecting the boiler which, although it has no moving parts, is subject to corrosion, caustic embrittlement and scale formation. Cooling water quality does not impose a constraint, since mills need large production quantities, and quality suitable for production standards meets cooling water criteria.

Table XIV

Chemical and Physical Characteristics of an Ideal Boiler Water*

Characteristics	PPM
Hardness	0
Sodium chloride	0
Sodium sulfate	0
Silica	0
Sodium hydroxide	40
Suspended matter	0
pH	11

* Mussey, op. cit., p. 41.