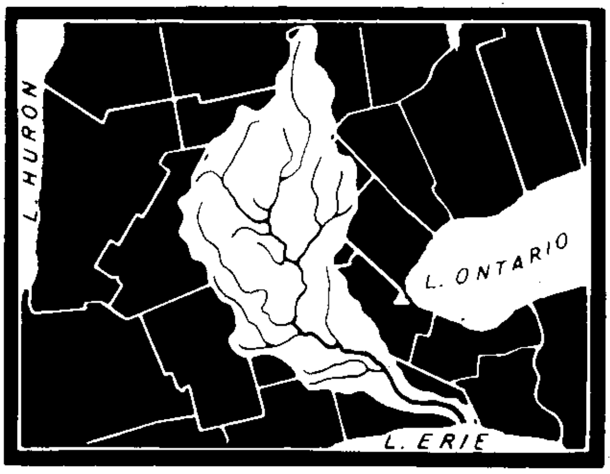
GRAND RIVER

• HYDRAULICS •



CONSERVATION REPORT

(WITHOUT PHOTOGRAPHS)

ONTARIO DEPARTMENT OF LANDS AND FORESTS

SECOND EDITION

DEPARTMENT OF LANDS AND FORESTS
Conservation Authorities Branch

HON. J. WILFRID SPOONER
Minister

F. A. Mac DOUGALL
Deputy Minister

A.S.L. BARNES
Acting Chief

GRAND RIVER CONSERVATION REPORT

HYDRAULICS

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TORONTO

SECOND EDITION, 1962

Fifty copies of the second edition
of this report have been prepared
of which this is
Number 48

Honourable J.W. Spooner,
Minister,
Department of Lands and Forests,
Parliament Buildings,
Toronto, Ontario.

Honourable Sir:

I take pleasure in transmitting herewith the first copy of the second edition of the Grand River Hydraulic Report.

Twenty copies of this report were bound in 1954 and fifty copies have been prepared for this second edition. Some aspects of the hydrology have been modified in this edition due to changing techniques and further studies on this phase of the work.

This report, covering the hydraulic phase of the conservation investigations for the whole of the Grand River, is one of four conservation reports prepared for the Grand Watershed.

Yours very truly,

A.S.L. Barnes
Acting Chief
Conservation Authorities Branch

May 1, 1962.

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AUTHORSHIP

The preparation of this report was under the direction of C. E. Bush assisted by J. W. Murray. The section on the history of floods was written by V. B. Blake and the chapter on pollution by Professor J. D. Lee, Queen's University.

First Edition 1954
Second Edition 1962

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NOTICE

The figures referred to in this report and listed on the following pages are not included in this copy of the report, but prints or photostats of the same may be obtained by applying to the Department of Lands and Forests, Conservation Authorities Branch. The Department will supply the names of reliable firms in Toronto who will prepare the prints and invoice the applicant for same.

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H-17	0.95	H-49	0.50
H-18	0.95	H-55	0.50

LIST OF FIGURES

(In Map Case accompanying Report)

The following Figures H-10 to H-18 inclusive show a contour plan of the Reservoir, the Township Lots, etc. Each figure also shows a Profile of the Tentative Damsite; Storage and Area Curves; Bridges Affected; the Damsite Reference Line and Bench Marks.

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INTRODUCTION

The problems arising from the extreme high and low flows of the Grand River and its tributaries are not new and have concerned the people living in these valleys for many years. In the past the problems were attacked on a local basis by the individual municipalities and little thought was given to an over-all plan for the control and development of the river to the benefit of all.

In the year 1912, due to increasing damage from floods, the municipalities of Brantford, Paris, Galt and Preston made representations to the Government of the Province of Ontario for relief and requested that a survey of the river be made. Shortly after gauging stations were established on the river and its principal tributaries by the Hydro-Electric Power Commission of Ontario and a preliminary report submitted. No action was taken at this time and the matter rested until the year 1929.

Following the disastrous 1929 spring flood the people along the Grand River again became active and began a campaign up and down the river for concerted action on the part of all the municipalities for a survey of the whole drainage area and an engineer's report with all the available data and recommendations for remedial measures. As a result of this campaign a group known as the Grand River Boards of Trade representing a number of municipalities along the river was formed in 1931 and the Government of the Province of Ontario was requested to investigate the flood and low flow problems and report on ways and means of flood control and water conservation within the valley. With the approval of the Minister of the Department of Lands and Forests and the Chairman of the Hydro-Electric Power Commission of Ontario the Hydro Commission carried out the surveys and a report was published in February, 1932.

This report was quite thorough and recommended the immediate construction of at least three storage reservoirs to retain peak flows and to augment low flows during low-water periods. Other recommendations in regard to reforestation, wildlife and the general improvement of the scenic features of the river valley were also included.

Later in 1934 the late Mr. L. V. Rorke, Surveyor-General and Deputy Minister, Department of Lands and Forests and Dr. T. H. Hogg of The Hydro-Electric Power Commission jointly reported further to The Honourable William Finlayson, Minister, Department of Lands and Forests, on the flood control and water conservation projects outlined in this report.

To carry out the projects recommended in this report, The Grand River Conservation Act was passed in 1938 and commissioners were appointed from eight municipalities to administer the work. The Commission immediately engaged the engineering firm of H. G. Acres & Company Limited, Niagara Falls, and work actually got under way in 1939. The Shand Dam was completed in 1942 and proved its worth during the spring floods of 1943, 1947 and 1948 and throughout the intervening periods of drought. In 1949 the Commission began to work on the Luther Project and at the same time was carrying out the necessary preliminary engineering investigations for the Glen Allan (Conestogo) Project.

In addition to these flow regulation works the Commission undertook to reforest the fringe areas and to landscape and develop the lands adjacent to the reservoirs for recreation purposes or as wildlife sanctuaries.

In 1944 the Department of Planning and Development was established, and the Conservation Branch was set up to promote conservation on a watershed basis with all the municipalities as partners. The Conservation Authorities Act was passed in 1946, and under the terms of this Act the

Grand Valley Conservation Authority was established by Order-in Council No. 376-48, dated February 26, 1948, following an organization meeting held at Galt on December 18, 1947.

Thus on the Grand Watershed there are now two groups carrying out conservation work - The Grand River Conservation Commission representing the eight urban municipalities of Brantford, Paris, Galt, Preston, Kitchener, Waterloo, Elora and Fergus; and The Grand Valley Conservation Authority representing all 70 municipalities of the Grand Watershed. In regard to the conservation work it was agreed that the Commission would look after the building of large dams and confine its other conservation activities to Commission lands and that the Authority would confine its work to reforestation, land use problems, wildlife, recreation and flood control measures other than large dams.

While it is the sole responsibility of the municipalities within a watershed to initiate and carry out conservation work through their Authority or Commission, the Conservation Branch usually undertakes to make the preliminary investigations as a service to these organizations. The conservation needs of the watershed are appraised by means of field surveys, and a detailed report is submitted outlining the conservation measures that should be followed.

Such a survey was started on the Grand Watershed in May, 1949, but owing to its size it was necessary to break the Grand Watershed down into its tributary areas and study each separately. However, this was not practical in the case of the hydraulic studies, and it was necessary to study the watershed area as a whole in order to arrive at a plan which would satisfy the widespread water problems which existed in the area.

The field surveys were carried out during the summers of 1949 and 1950, and the report was prepared in draft the following year.

Since the earlier reports were published, conditions within the valley have changed considerably. The spring floods of the 1940's were far greater than any previously known floods, and the population and industrial expansion have aggravated the water supply and pollution problems.

In view of the increasing flood hazard and the increased use of the rivers for domestic water supply, sewage and industrial waste disposal, and recreation, it was necessary to reconsider the water problems. Accordingly a system of reservoirs in conjunction with some local channel improvement is herein proposed which will, it is believed, provide adequate flood protection for the major trouble areas and satisfy the low-flow problem for the driest years.

The report is in three parts. Part I briefly outlines a description of the watershed, flood conditions, remedial measures and the estimated cost of the proposed plan. Part II includes the hydrology study of the watershed area, the method of determining the volume of storage required to satisfy the flood problem and a brief description of the field surveys. Part III deals with the pollution problem and the determination of the conservation storage required to satisfy the water needs of the valley and restore the river to a more or less sanitary condition.

The report is submitted herewith for the consideration of the Grand Valley Conservation Authority and the Grand River Conservation Commission.

ACKNOWLEDGEMENTS

While this Hydraulic Report was prepared by the Conservation Branch of the Department of Planning and Development, it could not have been readily accomplished without the valuable aid of the many people who so generously contributed information, maps, illustrations and advice on the past and existing flood and low flow problems. Early reports, newspapers and other relevant publications have been used freely and are herewith acknowledged.

The Conservation Branch is indebted to Mr. E. F. Roberts, Secretary-Treasurer of the Grand River Conservation Commission, for his information and advice and to Messrs. F. Midgeley of Galt and G. H. Richards of Brantford for the data supplied by them.

Thanks are also extended to the many municipal officials who supplied valuable data from their records and assisted in carrying out flow tests and flood observations on several occasions.

ABBREVIATIONS, EQUIVALENTS AND DEFINITIONS

Abbreviations

ac. ft.	is the abbreviation for acre foot which is equivalent to 43,560 cubic feet and is the quantity of water required to cover one acre to a depth of one foot.
c.s.m.	is the abbreviation for cubic feet per second per square mile and is the average number of cubic feet of water flowing per second from each square mile of drainage area.
c.f.s.	is the abbreviation for cubic feet per second and is the unit generally used to express discharge or the rate of flow.
M.P.N. or m.p.n.	most probable number
ML or ml.	millilitre
P.P.B. or p.p.b.	parts per billion
P.P.M. or p.p.m.	parts per million
PH or ph	value measure of acidity or alkalinity

Equivalents

1 c.f.s. = 6.25 imperial gallons per second

1 c.f.s. for 1 day = 1.98347 acre feet or approximately 2 acre feet

1 c.f.s. for 1 year = 724 acre feet

1 ac. ft. = 271,472 imperial gallons

1,000,000 imperial gallons per day = 1.86 c.f.s.

Definitions

BOOST STORAGE is the storage required to increase the head of water over the discharge tubes in order that they may be able to discharge the required flow.

CHANNEL CAPACITY or "IN-BANK" FLOW is the maximum flow which is contained within the river banks and does not overflow the adjacent low lands.

CHANNEL CAPACITY STORAGE is the volume of water that must be impounded in order that the stream flow will not exceed the channel capacity flow or stage.

CONSERVATION STORAGE is that volume of water remaining in a reservoir which may be used to augment the low flows and is equivalent to the maximum storage capacity of the reservoir less the dead storage, evaporation and ice losses and the space reserved for flash floods.

DAM is a structure in and across a river valley to impound, control and otherwise regulate the river flow.

DEAD STORAGE is the amount of water kept in a reservoir at all times for the purpose of protecting the artificial and natural water seals at the base of the dam.

DISCHARGE TUBE or CONDUIT is an opening through the base of the spillway to provide means for discharging water when the water level of the reservoir is below the spillway level.

FLOOD is an overflow or inundation coming from a river or other body of water.

FLOOD CONTROL is the prevention of flooding by controlling the high water stages by means of storage reservoirs, dikes, diversions or channel improvement such as widening, deepening and straightening.

FLOOD CONTROL STORAGE is the total volume of water that must be impounded during a given flood in order that the stream flow will not exceed the channel capacity flow or stage and is equal to the sum of the channel capacity, dead, boost and operational storages.

FLOOD CREST is the maximum height or stage that the flood waters reach during any one flood period.

FLOOD HYDROGRAPH - a hydrograph which covers only the flood period or time interval during which the river flow is above the flood stage.

FLOOD RATIO is the rate of peak flow to the average flow for the flood period.

FLOOD STAGE is an arbitrary flow stage which varies from place to place and from season to season and is that flow or water level at which the water threatens to do damage.

FREEBOARD is the vertical distance between the maximum permissible water level and the top of the dam or dikes.

HYDRAULICS as applied to conservation deals with the measurement and control of run-off from river drainage basins.

HYDROGRAPH is a plot of flow against time and is a correct expression of the detailed run-off of a stream resulting from all the varying physical conditions which have occurred on the drainage area above the gauging station previous to the time which it represents.

HYDROLOGY is the science which deals with the occurrence and distribution of water in its various forms over and within the earth's surface. As applied to conservation it deals more specifically with that portion of the hydrologic cycle from precipitation to re-evaporation or return of the water to the seas and embodies the meteorological phenomena which influence the behaviour of the waters during this phase of the cycle.

OPERATIONAL STORAGE is additional storage that is required to provide a safety factor to enable the controller to regulate the discharge from a dam so as not to exceed the channel capacity flow or stage.

RATE OF RUN-OFF is the rate at which water drains from an area. Usually expressed in cubic feet per second (c.f.s.).

RATE OF RUN-OFF PER SQUARE MILE is the average number of cubic feet per second of water flowing from each square mile of area drained. (c.f.s./sq.mi. or c.s.m.).

RESERVOIR is the body of water created by the construction of a dam.

RESERVOIR CAPACITY is the maximum amount of water that may be contained within the reservoir without exceeding the maximum permissible water level. Usually expressed in acre feet.

RUN-OFF is the amount of water which reaches the open stream channels and may be broadly defined as the excess of precipitation over evaporation, transpiration and deep-seepage.

RUN-OFF DEPTH IN INCHES is the depth to which the area would be covered if all the water flowing from it were conserved and uniformly distributed over the surface.

SPILLWAY is that part of a dam over which the excess water is discharged.

SPILLWAY CAPACITY is the maximum amount of water that may be discharged over the spillway without exceeding the maximum permissible water level in the reservoir.

STREAM GAUGE is a measuring device used to determine the elevation of the water surface at selected points. - usually a graduated rod fixed in an upright position and set to a known elevation from which the gauge readings are obtained by direct observation. Automatic type gauge is a mechanically operated recording instrument which gives a continuous record of water surface elevations.

WATER or CLIMATIC YEAR is a 12-month period from October 1 to September 30. The water year was found to be a more convenient form than the calendar year for the purpose of stream flow studies as it groups together those months in which the water losses due to evaporation and vegetation demands are at a minimum (October - March) and those during which the losses are high (April - September).

CHAPTER 1

GENERAL HYDRAULIC PROBLEMS

Hydraulics as applied to conservation deals with the measurement and control of run-off from river drainage basins. Measurement has to do with such factors as precipitation - both rain and snow - the topography and vegetative covering of the area and the daily gauging of the flow of the river at selected points. Control deals with the prevention of floods by the use of reservoirs and other structures, and the increase of summer flow.

Floods which are caused by the natural run-off from river basins have occurred from time to time in Southern Ontario ever since records were first kept. Evidence of these can be found in diaries going back well over 150 years and from newspaper records for at least 100 years. Most of this run-off occurs in the spring, with the result that there is too much water in our rivers at the time of the year when it is needed least and very little, if any, during midsummer, when it is required most. In addition to the flooding which is caused by spring run-off, occasionally floods also occur during the summer on watersheds which have little natural protection. These summer floods do serious damage to crops. Such floods are not confined to a few of our largest rivers, but records show that all rivers of any consequence have from time to time caused serious damage in this way.

When Ontario was mostly covered with forest and the natural reservoirs such as large swamps had not been interfered with, severe flooding probably was not as frequent as it is today because these two factors had an ameliorating effect on the flow of water. Land clearing and drainage were necessary to open up the country for agriculture, but in some respects these were carried beyond the point of necessity, thereby aggravating the flood situation. In order now to regain a more or less stable condition of the rivers and streams, certain conservation measures must be carried out. These include such measures as the reclaiming of large swamps and natural water-storage areas, the reforestation of marginal and submarginal land, and proper agricultural practices, which tend to reduce surface run-off and soil erosion. Such methods aim to control water where it falls on the land. If this could always be done it would be the ideal solution of the flood problem, but to minimize the required flood storage in a large watershed by a program of improved land use would need the co-operation of a great many individual farmers. This would take many years to accomplish, and more immediate measures are therefore necessary, especially where urban centres are frequently flooded.

One of the first problems facing the hydraulic engineer is to estimate or measure the run-off from a drainage basin which causes flooding farther down the valley. This includes a careful examination of rainfall over the years at different times of the year, which in turn presupposes that weather stations have been established in the area. Topography, types of soil, the amount of vegetative covering, particularly tree growth, on the area and the gradient of the river, which has a bearing on the rapidity with which the water travels to the river's mouth, must all be carefully studied. If no gauging stations have been established, then the run-off must be computed by taking the above factors into consideration and an approximate figure of flow determined by comparison with a neighbouring drainage basin which has gauge records, in order to decide how much protection by the use of reservoirs is required. If, on the other hand, gauges have been established by which a daily record is kept of the amount of water going down the channel at certain points, then a more accurate determination can be made of how much protection is needed. Fortunately there are hydrometric records dating from 1914 for Galt and other stations on the watershed, and although the years of records for some are short, these may be correlated with the long-term records and dependable run-off ratios established.

After the amount of run-off has been measured by whichever means are available to the engineer, it will give him a figure of flow which will indicate how much of this water will have to be held back in order to give the necessary protection where flooding is taking place. This means that a reconnaissance survey of the whole watershed must be made in order that suitable valleys may be selected where dams can be built for the storage of the required amount of water. When more than a sufficient number of such reservoir sites have been selected, each must be measured as to its capacity, and the required number chosen to hold back sufficient water to solve the flood problem. In addition, wherever a dam is to be built, some subsurface exploratory work must be done at the site to make certain that the dam will have a proper foundation. Only after this preliminary work has been carried out can the reservoirs be chosen, the actual designing of the dam structures undertaken, and the work carried through to completion.

While conservation reservoirs are usually built for the purpose of preventing floods, they are needed just as much in Southern Ontario for increasing summer flow. This has become increasingly important in recent years because rivers with extreme low flows and those which dry up entirely are a health menace to the communities through which they pass. Summer flow is necessary for flushing out the channel; to furnish water for industrial plants; for the practice of good agriculture; and is absolutely necessary for dilution where urban municipalities empty the effluent of their sewage disposal plants or raw sewage into the river.

The building of dams for the prevention of flooding and the increasing of summer flow is a comparatively new concept in engineering. It is only since the turn of the century that structures of this kind have been used for this purpose in North America. The older methods included such projects as straightening and widening the river channel and removing obstructions such as islands in the river, narrow bridges and other man-made works which might obstruct the flow or cause ice jams. Also, occasionally, for such work a river was diverted into another watershed, or dikes were built to hold it within its banks. Such practices are aimed at one thing only, namely to get rid of water as quickly as possible. They do not take into consideration the necessity of holding water at the headwaters for deep infiltration or retaining it for summer flow throughout the year. On some rivers in Ontario channel improvements, diversions and even dikes must be carried out and built, especially where dams and reservoirs are not economical and summer flow is not a major problem.

CHAPTER 2

GENERAL DESCRIPTION OF THE WATERSHED

1. Location, Municipalities and Overall Dimensions

The Grand River Watershed (Fig. H-1) occupies the central part of a peninsula in the south-west part of the Province bounded by Lake Erie, Lake Huron, Georgian Bay and the westerly end of Lake Ontario. It comprises practically the whole of the Counties of Waterloo, Wellington and Brant, and parts of Grey, Dufferin, Perth, Halton, Oxford, Wentworth, Norfolk and Haldimand; and contains the cities of Brantford, Galt, Guelph, Kitchener and Waterloo, six towns, eleven incorporated villages and several important hamlets. The urban centres have many varied and thriving industries and the farms and soils of the rural areas are among the best in the Province. The watershed is the most densely populated of any of similar size in Canada. It has an overall length of 118 miles, an average width of 22 miles and an area of 2,614 square miles.

2. Description by Zones

The watershed can be better described by dividing it into zones, namely the Northern or upper, the Central and Southern zones.

The Northern zone is triangular in shape, having a base of 18 miles along a line through the town of Arthur and a point 3 miles north of the village of Belwood, and tapering northerly 27 miles to an apex which is within 19 miles of Georgian Bay. This zone is part of a high tableland which is the headwaters of several rivers, namely the Nottawasaga, Beaver, Sydenham, Maitland and the North Branch of the Thames River, as well as the Grand and its tributaries. The greater part of this tableland was originally swamp land that has since been drained and most of which is now under cultivation. Owing to its high altitude it is subject to low temperatures and heavy snowfall during the winter months.

The total annual snowfall for this region ranges from 120 to 130 inches in depth with a high of 154 inches being recorded for one winter season.

This zone slopes heavily to the south. Further, the upper Grand and its tributaries have high gradients and the lateral slopes to the rivers are also quite steep. The soil is clay and there are extensive headwater swamps which are drained. It will be seen later that these physical features produce a high rate of run-off and in conjunction with adverse climatic conditions are basically the cause of flooding within this zone and at places downstream.

The central zone is much the largest of the three zones. Its length from north to south is about 64 miles and its width varies from 20 to 40 miles. It contains all of the cities and towns, except Dunnville, and most of the incorporated villages and it is in this zone that the greatest flood damage occurs. The physical features and climatic conditions of this zone are largely similar to those of the northern zone and further aggravate flooding.

The southerly zone is roughly triangular in shape, being 12 miles wide on a line running north-easterly through Caledonia and tapering off to ¼ of a mile where it empties into Lake Erie about 3½ miles south-east of Dunnville. It has an over-all length of 27 miles with an average width of 4 to 5 miles and contains the town of Dunnville and the villages of Caledonia and Cayuga. The flooding in this zone is confined to a narrow strip along the river.

3. Description of the Grand River and Principal Tributaries

(Figs. H-1 and H-2, Table H-1)

The watershed is drained by the Grand River and its tributaries. The most important tributaries are the Conestogo, Nith, Speed and Eramosa Rivers and Whiteman, Fairchild, McKenzie, Boston and Big Creeks. The flow in the creeks is comparatively moderate and consequently they have little

TABLE H - 1
GRAND WATERSHED - DRAINAGE AREAS (SQUARE MILES)

Tributaries		Places		Reservoirs		Gauges	
1. Conestogo River	317.45	Drayton	125.23	Drayton	122.11	Drayton	125.23
		Hawkesville	256.07	Glen Allan	219.47	Conestogo	316.97
		Conestogo	317.45	Wallenstein	243.60		
				St. Jacobs	295.83		
2. Eramosa River	115.37	Guelph)	115.37	Everton	42.45		
		) 218.60)		Arkell	103.22		
3. Speed River	187.27	Guelph	103.23	Barrie Hill	62.43	Oustic	21.0
		Hespeler	274.04	Guelph	102.95	Guelph (above)	104.0
		Preston	301.19	Hespeler	250.90	Guelph (below)	229.15
						*Hespeler	274.86
4. Galt Creek	34.5	Galt	34.5			*Galt Cr.	33.96
5. Grand River (above Galt)	1,357.86	Fergus	314.51	Luther	21.10	Waldemar	259.60
		Elora	403.64	Shand	308.49	*Belwood	299.40
		Conestogo	555.47	Montrose	450.80	Shand	309.24
		Bridgeport	884.60	Freeport	960.54	Galt	1,357.86
		Galt	1,357.86				
6. Nith River	432.2	New Hamburg	209.14	Nithburg	125.10	New Hamburg	209.14
		Plattsville	243.37				
		Ayr	357.80	Ayr	329.80	Canning	398.40
		Paris	432.2				
7. Whiteman's Creek	146.81	Burford	145.8			Princeton	62.0
8. Grand River		Paris	1,406.29				
		Brantford	2,006.68			Brantford	2,008.60
		Dunnville	2,588.00				
		Port Maitland	2,613.91				

* Discontinued

influence on the flood problems. No further reference will be made to them, therefore, except to say that Whiteman Creek and others have a lively flow of fresh spring water and so have future recreational possibilities.

The Grand River rises about five miles north-east of Dundalk. Its course is southerly as far as Paris where it swings south-easterly and empties into Lake Erie at Port Maitland. Its length is about 180 miles, its drop from headwaters about 1,165 feet and it has an average grade of approximately 6.4 feet to the mile. Excluding the above tributaries, the remaining drainage area of the Grand River has a length of 118 miles and an average width of 9 miles. The width varies from 2 miles at Paris, 5 miles at Galt to 15 miles at Kitchener and Elora. The drainage area is 1,049 square miles. Within this drainage area are the cities of Kitchener and Waterloo, and located on the river about midway between the headwaters and Lake Erie is the city of Galt and 24 miles farther downstream the city of Brantford. Also located on the river are the towns of Paris, Dunnville and Fergus and the villages of Dundalk, Grand Valley, Elora, Caledonia, Cayuga and Port Maitland.

The Conestogo River has two branches at its headwaters. One branch rises about 10 miles north, and the other branch 10 miles north-west of Arthur. It flows south-westerly for half of its course and thence south-easterly, joining the Grand River near the village of Conestogo or 25 miles north of Galt. Its length is about 51 miles, its fall from headwaters about 550 feet and it has an average grade of 10.8 feet to the mile. The drainage area is 38 miles long, varies from 4 to 13 miles in width and measures 317.5 square miles. The villages of Arthur and Drayton are located on the Conestogo.

The Nith River rises about 5 miles south-east of the town of Listowel, has a long meandering course of 98 miles in a general south-easterly direction and joins the Grand River at the town of Paris 10 miles above Brantford. The total fall from headwaters is about 650 feet and the average grade is 6.6 feet per mile. The drainage area lies in a south-easterly direction and has an area of 432.1 square miles. It measures 45 miles in length and has an average width of about 10 miles. It may be noted that the length of the river is more than double the length of its drainage area. The villages of Ayr, Plattsville and New Hamburg are located on the Nith and the town of Paris is astride its confluence with the Grand.

The Speed River rises 18 miles north of Guelph, flows southerly and joins the Grand about 3½ miles above Galt. Its length is 37 miles and it has a fall of about 570 feet and a grade of 15.4 feet to the mile. The towns of Preston and Hespeler are located on the Speed, the former being one mile and the latter 5 miles above its confluence with the Grand.

The drainage area of the Speed lies almost due north and south and has an area of 187.3 square miles. Its length is 30 miles, with a minimum width of 4 miles at Guelph and a maximum width of 11 miles just below Guelph. Guelph is located at the confluence of the Speed and Eramosa Rivers, and is about 15 miles above the confluence of the Speed and the Grand Rivers.

The Eramosa River rises 25 miles above Guelph, flows southerly throughout most of its course and then turns westerly as it approaches the confluence at Guelph. It has a total fall of 410 feet and an average grade of 16.4 feet to the mile.

The Eramosa drainage area is 115.3 square miles. It lies east of, and parallel to, the Speed and has a length of 23 miles with an average width of 5 miles.

Drainage areas for the Grand River and its main tributaries are shown on Table H-1.

4. Description of the River Valleys and Bed

The river valleys of the Grand River and the tributaries described above are, with few exceptions, U-shaped and there is no flaring out into extensive flats which would reduce flood flows or provide large economical reservoir sites. The banks average from 50 to 75 feet in height with extremes of less than 40 feet to 125 feet or more. The width between the bank crests varies from 1,500 to 3,000 feet.

The Hydro report shows that on the Grand, Speed and Eramosa Rivers, solid rock appears in the bed of the river along several stretches but not in any of the other rivers. These rock outcroppings are shown on Fig. H-1.

On the Grand the river bed is of solid rock for a distance of about 2 miles above Paris, 3 miles at Glen Morris, from about 1½ miles below Galt to Preston, from 3 miles below Elora to the Shand Dam and about 7 miles above and below Grand Valley. On the Speed the bed of the river is nearly all solid rock from Preston to Guelph and this continues up the Eramosa for 8 miles except for a mile at Guelph.

It will be shown later in the case of the other tributaries (the Nith in particular) that ledge rock is some distance below the bed of the rivers. The bed of the Conestogo River consists of embedded boulders for much of its length, with the known depth of overburden varying from 9 feet in the river bed near Glen Allan to 125 feet at St. Jacobs.

CHAPTER 3

FLOODS ON THE GRAND

1. History

(a) Up to 1790

Floods are a natural phenomenon that may occur on any river system. However well forested the area through which the river flows, a point may be reached when the ground has absorbed all the moisture it can hold. When this is the case, rain or melting snow must find its way directly into the streams. If the volume is too great some degree of flooding will result and at intervals this will be sufficient to cover the whole flood plain of the river to a considerable depth. This must have happened many times without being recorded, both before and after the white men first entered the Grand Watershed. It is not impossible that floods followed the melting of the unusually heavy snows that fell in the winter of 1640-41. But the first definite record of flooding in Upper Canada yet found was in April 1680. It was on a journey overland from the Detroit to the Niagara River, which must have taken the party across the Grand, that two companions of La Salle "succumbed to the toil of walking continually in water, the constant rain and great thaw having flooded all the woods". This, however, probably happened at some point well to the west, and the freshet was probably over before La Salle reached the Grand.

A careful search of the records might establish a few more dates between the time of La Salle's journey and the arrival of the Loyalists in Upper Canada, a little more than a century later. But these would probably be too few to establish the two main points of interest - whether high floods occurred as frequently then as in later centuries and whether these reached comparable heights. In any case it is unlikely that they would refer to the Grand River.

That the river overflowed frequently cannot be doubted, for it was the alluvial flats, formed and kept comparatively clear of trees by high floods, that made the valley of the Grand a centre of Indian settlement. It was the presence of such flats, quite as much as the advantages of river travel, that determined the siting of the Neutral villages and it had even more weight with Joseph Brant when he selected the valley as a home for his people in 1783.

The white settlers of that period were quite as aware of the advantage of securing a proportion of "cleared flats" as part of their holdings. Such meadows could be cultivated at once and had their fertility regularly renewed by flood silt. The settlers derived another important advantage from ordinary freshets, for the high water allowed them to bring timber and produce from much farther inland than was possible with normal flow. Both these advantages are often mentioned in early accounts of the Province.

The first reference yet found for Upper Canada after 1783 is for 1790, where "an extraordinary freshet or flood" wrecked the Government Mill on Four Mile Creek near Niagara, but it contains an implication that such damage had occurred before 1785. Some disastrous floods are recorded in the Eastern States between 1750 and 1785 and it is likely that the rivers of Canada had also risen during that period. But there is some reason to think that the late 1780's formed one of the brief periods free from floods that sometimes occur in Ontario.

(b) <u>1790 - 1799</u>

During the 1790's, however, a year without a flood is the exception and several on the Thames were as severe as all but a few that have happened since. There are several references for the Grand, but they are not so detailed as the record for the Thames and taken alone would imply only sharp freshets or heavy floods. Where, however, they coincide with severe floods at Moraviantown, it is safe to assume a fairly severe flood on the tributaries concerned, if not on the Grand itself. The first references again involve a distinguished traveller returning from Detroit, for they are found in two accounts of Lieutenant-Governor Simcoe's journey of 1793. The best known account, a diary kept by Lieutenant Littlehales, Simcoe's Military Secretary, merely mentions the difficulty of crossing swollen creeks between the Upper Forks of the Thames (Woodstock) and Daniel Springer's trading post west of the Grand.* Lieutenant David William Smith (later Deputy Surveyor-General) is more precise. From him we learn that Whiteman's Creek and certain neighbouring streams were "much swollen" on March 5-6, but he is silent as to the condition of the Grand itself.†

(1) October 1795

The first reference to flood damage is contained in the accounts of the building of Thomas Horner's sawmill at Princeton on Horner's Creek. This mill was being built in July and August, 1795. It is said to have been in "working order" by autumn of that year, but the dam was broken almost at once and sawing did not begin until early in 1797. There was a very severe flood on the Thames in October 1795 and no freshet of importance in 1796. So it seems probable that Horner's dam was broken by an October flood in 1795, caused by prolonged rains, and rebuilt after harvest the following year so as to be ready for use by January 1797. The primitive dams used by the first settlers were capable of withstanding ordinary freshets, for the water flowed through as well as over the brush and boulders of which they were chiefly composed. A high

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* Littlehales does not name this post, but Smith and Augustus Jones identify it as Springer's and fix its position.

† Brant had sent on horses for Simcoe and part of his staff. The others remained at Springer's overnight and may have crossed in canoes.

flood, however, might cut away the bank or destroy the mill race, and this freshet on Horner's Creek was probably as high as that on the Thames.

High water on Whiteman's Creek and the adjoining streams interfered with a survey which Augustus Jones was trying to make in Burford and Oxford Townships about April 9, 1798. George Lawe was also forced to stop the survey he was making in Blandford Township, because the water was too high in the swamps and Horner's Creek. On May 3, 1799, William Hambly, taking a survey party to the Thames, found at Brant's Ford, the "river all too high for crossing a team and no canoe or boat". This may have been a minor freshet, or the end of a late and prolonged spring flood.

(c) <u>1800 - 1815</u>

After 1800 the Surveyor's diaries are not available as a source, for the unreserved townships had been sufficiently surveyed for the time. The surveys in Waterloo Township were carried out for private owners and if the surveyors kept diaries these have probably been lost. Travellers across the area are said often to have had to wait some time at a house just west of Brant's Ford before the water was low enough to cross, but those who have left accounts of their trips seem to have managed to get to the Grand in times of low water. We do not know whether the Grand rose like the other rivers in 1801, 1804, and 1808. In 1812 dams were burst or bridges washed away in various parts of the Province; but the only hint of this kind of damage on the Grand is the collapse of the first bridge built at Brantford soon after it was finished, and this is attributed to poor construction. In November 1814, however, "an unexpected freshet" saved the settlers east of the Grand from the American raiders, who had plundered and burned from Delaware to near Brantford. The river was too high for fording, although most of the force was mounted. The boats had all been removed, and General McArthur hesitated to swim the horses through the river, in the face of a force of Militia gathered on the east bank.

(d) 1816 - 1849

When settlement began to increase after 1816, more bridges and mills were built and references to floods and flood damage occur in the history of most settlements. Except in one or two cases, like the destruction of the first mill dam near Elora about 1822 or the flooding of the Brantford Flats in 1833, it is not possible to attach these references to any particular year. We are told that the Lower Village at Paris was often under water in the years after it was founded in 1828, and the various anecdotes indicate that both bridges were broken more than once.

In the case of the very severe flood of 1833, some definite information is available, though this must be pieced together from casual references. No one of these states definitely that a flood took place, much less gives any details of its height or duration. The freshet evidently occurred after the middle of March. On March 21, 1833, the Reverend James Proudfoot of London, travelling to Brantford from Mount Pleasant, found that "the flat on the side of the Grand River was all overflowed with water. We had to walk on the fences, there was no other way for about 100 yards". The flood had evidently subsided by that time, for there is no mention of difficulty in crossing the river to Brantford, although the bridge had almost certainly been wrecked. A new bridge was built in 1834 and in describing it a writer in the Christian Guardian (July 16, 1834) expresses the pious hope that it would last for "a series of years" - a hint that its predecessors had not been so fortunate.

The flood of 1833 was long remembered on the Grand The disastrous freshet of 1852 was said to be the highest at Brantford "in eighteen years" and at Paris, "the highest since 1833". The wording implies that the later flood did not quite equal that of 1833, so that the earlier freshet must have risen appreciably above 15 feet at Paris, the point reached by the flood of 1852 a little before it was at its height. The flood of 1833 thus ranks with the four or five worst floods of that century.

Although this is the only year between 1825 and 1850 in which there is definite evidence of a flood on the Grand, the indications that others occurred in this period are fairly conclusive. Besides the general references to flooding already mentioned and the records of floods on adjoining watersheds, much larger sums were spent by the Provincial Government on the various bridges carrying the main roads over the Grand, than were needed to keep these bridges in repair under ordinary circumstances and to replace them when obsolete. The bridge built at Brantford in 1834 was 240 feet long, in two 110-foot spans, and 24 feet wide. It was an expensive structure for the time; but similar bridges were built ten years later for less than £600 Currency or $2,400. The Paris bridge was probably about the same size. The earlier bridges at both places would be of a more primitive type and may have been no more expensive than the one at Seneca which cost "nearly £250" about 1850. Yet up to 1841 the Government had spent £1,500 Currency or $6,000 on each of these bridges, most of it after 1833. There must have been at least heavy repairs during this period and probably one or two rebuildings besides one in 1833-4.

It is therefore not unreasonable to assume that there was serious flooding in 1830, and again in 1836, both of them years when severe floods took place on neighbouring watersheds. For the eight years following 1841 the story is very much the same as for the previous decade. The records of the Thames and other rivers indicate 1843, 1846 and 1847 as years of severe floods. No definite records of floods on the Grand have been found for those years, but again the sums known to have been spent by Government on the bridges during this short period were in most cases far beyond what was required for one rebuilding and ordinary maintenance.

A loan from the British Government in 1841 enabled the Provincial authorities to complete and greatly extend the program of road improvement begun in 1833.* A plank - and - macadam highway was finished from Hamilton to London in 1843, following the line of the present Highway No. 53 by Woodstock. This involved the rebuilding of the bridge at Brantford as a covered bridge (possibly in one long span) connected by an embankment or "causeway" with the "Little Bridge" across a back channel behind an island. The Hamilton--Port Dover plank road was carried over the Grand at Caledonia on a long bridge of six sections (one of them a swing bridge over the canal) which was finished in 1845-6.

During the eight years ending in December 1849, $11,300 was spent on the Brantford Bridge and $13,295 on the one at Caledonia, over and above the ordinary expenses of operation and maintenance which were met from the tolls collected. The bridge over the Thames at Delaware, built at about the same time and considered the finest in Upper Canada in 1846, cost the Government only $6,804, although it appears to have been a free bridge with no annual revenue from tolls. This bridge was 900 feet long and can hardly have cost less than the Grand River bridges, even if these were extravagantly expensive. A large margin remains for flood damage. That no tolls were collected at Brantford or Caledonia in 1847 may be another indication that there was heavy damage in that year, and that traffic was interrupted while the bridges were repaired.

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* Grants for roads had been passed by the Provincial Legislature in 1806, 1814, and 1833. In 1836 trustees empowered to collect tolls were appointed for certain highroads and bridges. This system was extended up to about 1845, when the government again took the highroads into its own hands and for a time ceased to lease the tolls. After 1850 many highroads and county roads were sold or leased to road companies. By the 1860's Counties were beginning to buy out these companies, but in most cases continued to collect tolls.

The Dunnville Bridge* was also rebuilt during this period, but the amount spent on it ($5,328) was much less than on the two just discussed*. It was, however, large enough to allow for some heavy repairs, and this was true also of the government bridge at Paris. This had become less important since the building of the plank road and does not seem to have been completely rebuilt until it became the property of a road company chartered under the ct of 1849.

The inhabitants of the Grand Watershed were evidently accustomed before 1850 to the interruption of traffic caused by the destruction of their principal bridges and the flooding of roads. How much they suffered from the flooding of buildings, the bursting of mill dams, etc., can only be conjectured. The quantity and value of property exposed to flooding was growing very rapidly in the 1840's. Not only was settlement taking place faster than at any other period, the development of the export trade in lumber and flour was stimulating mill-building far beyond local needs. By 1846 there were about ten dams across the Grand between Fergus and Port Maitland and the total of mill dams in the watershed must have been well over a hundred. New bridges were also being built every year or two, for until after 1852 all the wheat, flour and other freight had to go by road to Brantford or the Head of the Lake. The growing number of dams and bridges was not without effect on the character of the floods. Both bridges and dams tended to impede the ice in spring freshets. In flash floods the crest often struck when the ponds were full and before the millers had time to open the floodgates. With sufficient warning and proper management the many ponds could have been used for a measure of flood control. But the millers were not conservationists and the water

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* The road ran along the dam at Dunnville as it does now, so that this bridge was shorter than those upstream at Caledonia and Cayuga. The Cayuga Bridge was built (or rebuilt) in 1836, but was not paid for directly by the Provincial Government.

stored for power often went to swell the volume of the freshet. Certainly the increasing value of these and other types of property in situations liable to flood damage is partly responsible for the fuller reporting of freshets which begins in Upper Canada in 1850.*

(e) <u>1850 - 1859</u>

From 1850 the records of floods on the Grand are much more detailed and more nearly complete. Indeed, the Galt Reformer, after the disaster of 1857, began to keep a "Flood List" which gives a date for every year except 1863, with the addition of a few severe floods which did not accompany the final spring break-up. The fact that this list began with 1858 gave rise, towards the end of the century, to the idea that there were no flood records before that year. Actually five flood years before 1858 are on record, some of them reported by the Reformer. They include at least two floods of exceptional severity. The date of the break-up of 1863 is also known from other sources. In some of the years listed there was no more than the usual spring freshet, but the "usual freshet" could sometimes do a good deal of damage. A fairly heavy spring flood was in fact normal on the Grand; it was an exceptional year that passed without flood damage somewhere in the watershed. Nor did the freshets all coincide with the final break-up of the ice. In many more seasons than the Galt list would indicate, there was a series of "break-ups" between December and April, and often more than one of these produced serious flooding. Some of the worst floods also occurred when there was neither ice nor snow.

In the following discussion of various floods, the ordinary spring freshets, even when quite heavy, are not

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* Other factors were a larger reading public, more interested in Canadian news; reduced costs of printing and paper; and, consequently, an increase in the size and number of newspapers and more frequent issues. Bi-weekly papers replaced weeklies and were increasingly replaced by dailies.

discussed in detail unless they present some unusual features. The two or three really severe floods that occur in each ten years are given more space, and so are less serious ones that occurred in summer or autumn. Because the same details occur again and again, the earliest floods have been discussed more fully than some later and better known ones of the same severity.

Though two or three really bad floods are found in each decade, exceptionally high freshets occur at longer intervals. These may be found in periods when severe floods have been less numerous and they do not always cause the greatest damage. It is difficult to make any exact comparison between the floods that took place before flow gauges were established in 1913 and those of the previous years. It seems probable that some of the highest floods have occurred since 1930, but if these exceptional floods are excluded, it would appear that the average severity was not much less before 1900 than it has been since. The details of the areas flooded, the depth of water at particular points, and the extent of damage, make it seem likely that the worst floods of the fifties and sixties would still be disastrous if they took place today and that the number of severe floods in each decade has been fairly constant.

(1) <u>1850</u>

In 1850 the ice appears to have broken up in February and again in March and to have gone out without causing serious damage. The snow which had fallen since the first thaw was not yet melted to any extent by April 1. Then heavy rains began and continued for three days. On April 4 and 5 the rivers all over the Province rose to great heights. The floods seem to have taken the millers by surprise, with their floodgates down and their ponds full. On the Grand and its tributaries dams began to give way "in all directions".

Reports from Guelph, Galt and Brantford speak of mill dams and bridges being destroyed on the Speed, Nith and

Doon Creek. The damage to the dam at Guelph was less serious than at New Hope (Hespeler), Doon Mills and New Aberdeen. A great deal of timber passed Galt and threatened the bridges, but the damage here was chiefly to Dickson's Dam, and to the "river walls". Some workshops along the river were badly flooded. At Brantford the danger to the bridges was more serious and the Little Bridge was only saved by the exertions of the mayor and citizens "in the construction of breakwaters, &c". The flooding of the flats did less harm than in later floods, when more buildings had been built on low ground.* The chief damage there was a break in the canal bank. Because there was no ice in the river the bridges over the Grand escaped injury, but the incomplete reports show that the water was very high and the loss greater than was usual.

(2) <u>1852</u>

The freshet of March 14, 1852, is the first very severe flood on the Grand of which we have many details. The reports are mostly from the watershed below Bridgeport. This may be due to the fact that the weather turned cold after the 16th, while the flood was still going on. When the ice went out on the upper streams, the river had fallen and was clear of the ice below Galt; so that the damage was less than it might have been if the thaw had continued.

The thaw began on March 11 and was accompanied by heavy rains through the 12th and 13th. By the night of Saturday, March 13, most of the tributaries were in flood. The crests on the Nith, Speed and Grand reached Paris about 3 p.m.

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* Lewis Burwell's plan of Brantford in 1852 shows a small suburb west of the bridge, around Farrell's Inn, which probably dated from the late 1830's. This grew considerably during the railway boom of 1856-7. Holmedale and the northern flats had been subdivided by 1859. There was some industrial development near the City Dam. A straggling suburb had grown up between this and the Cockshutt Bridge by the 1870's, but the view of Lorne Bridge in 1886 shows that the main developments on the southern flats took place after 1890.

on Saturday and the river there rose 15 feet "above its usual height". With the flood came the ice from below Galt where a large jam was forming. The Lower Village at Paris was entirely flooded and also the surrounding flats. About 4.30 p.m. the ice on the Grand appears to have broken and taken out "Phillips' Bridge",* three miles above Paris. This bridge struck the supports of the Lower-Village Bridge, carrying them away so that two sections (about 160 feet) fell and floating down the flood destroyed the western section of the Dundas Street or Upper-Village Bridge. The ice on the Grand had already destroyed the eastern section, so that this bridge, between 300 and 400 feet long, was a total loss. The Glenmorris Bridge had already been damaged and was expected to fall. Above Galt all the flats were flooded and buildings were "sailing gallantly down the stream" past Galt from around Preston. The rise was so sudden that Mr. Thompson of Cruikston Park, below Blair, had his buildings flooded and lost his stock and orchard in a few minutes. Tons of ice and debris were jammed in the river from Doon to Dickson's Dam on the 14th and Galt was anxiously expecting the damage that would happen when the jam broke.

It was evident that some bridges had gone farther up the river; but the mill dams in Waterloo Township were reported to be holding although damaged. The mill dams around St. George had been destroyed and Ayr was threatened by a jam of saw logs. The ice and wrecked bridges from Paris appear to have jammed somewhere above Brantford, but the flood there was already higher on March 17 than any in eighteen years. Houses were flooded in West Brantford; the water was pouring across the road by Farrell's Inn on Oxford Street, cutting away the road-bed and threatening other streets and houses. The bridges were still standing, but it was feared that they would go when

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* The bridge is not mentioned after 1852 and is not shown on the map of 1859. It was practically on the site of the abandoned railway bridge.

the wrecks of the Paris bridges struck them. The "new" bridge at Mohawk had already gone, there had been flooding at Cayuga,* and the damage down the river was believed to be heavy.

The weather had already turned colder, and the ice passed Brantford without seriously injuring the larger bridge, but the Little Bridge was so shaken that it had to be rebuilt. The water had fallen before the 24th. However, Dunnville reported on that day that "the state of the Village, and all along the line of the Grand River is awful - being completely inundated and the water flowing into the houses - all the Bridges have been carried away and the River filled with floating timbers of Houses, Barns, Bridges and Mills ...".

The snow on the lower part of the watershed had been unusually deep and the rains melted it rapidly. The smaller streams rose and overflowed the roads so that "it was utterly impossible for a horse to travel". All the bridges over Boston Creek were destroyed and with one of them went Judge Foley's† carpet bag with "all the records of the county courts since his assumption of office". The Dunnville Bridge was broken with the rest and "all the scows, boats etc." carried away, so that the Grand could not be crossed below Brantford for some time. A special scow was begun at once to replace the Lower-Village bridge at Paris, which it was expected would not be completed before May. Altogether the loss must have been very great.

To the $5,250 estimated as the replacement cost of the three Paris bridges** must be added the cost of an unknown number of bridges in Waterloo County, on the Nith and

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* The later report from Dunnville implies that the Cayuga Bridge was broken though it is not specifically mentioned in any report.

† Bernard Foley, Judge of the County and Surrogate Court of Haldimand County. The bridge may actually have been over the lower part of McKenzie Creek.

** A footbridge across the Nith near the lower dam collapsed on March 14.

Speed and on the tributaries below Paris. On the Grand itself the costly bridges at Caledonia and Dunnville, the smaller ones at "Mohawk", Seneca and Indiana were all lost. The loss of bridges alone must have cost between $20,000 and $30,000, the equivalent of at least $100,000-$150,000 in modern values.

The freshet of 1853 did little or no damage but the flood of March 16, 1854, partly wrecked the Upper Bridge at Galt and destroyed the Main Street Bridge, doing a total of $3,000 damage including private property. The Toll Bridge at Brantford was evidently injured also, for it collapsed on July 1. Otherwise this flood does not appear to have been remarkable. The damage was due to ice and the water at Brantford seems to have been lower than in 1852.

(3) 1857

Both ice and water combined to make the flood of February 1857 one of the worst in the history of the Grand Watershed. At Galt it was thought to be the worst since the village was founded in 1816. The water was at first reported to be 6 feet above any flood in that time, but this estimate was later reduced to "four or five feet". Some of this extraordinary height can be attributed to ice jams and to the narrowing of the river bed by retaining walls. This had already begun before 1850 and had been extended considerably by new walls built in the preceding summer. The town had been growing rapidly and both here and at most other places in the watershed the amount of property exposed to flooding was much greater than in 1850 or 1852.

There had been heavy snow and hard frosts in the early winter. A severe flood was expected at the break-up, but the early thaw took people by surprise. Two or three mild, spring-like days were followed on Saturday, February 14, by heavy rain and on Sunday, under a thick fog, the river rose and swept away most of the bridges above Galt and others on the tributaries. At Bridgeport there was six feet of water over the road, but the bridge stood, possibly the only one to do so between Fergus and Galt. At about the same time the ice below Indiana suddenly broke up and carried away a pier of the Cayuga Bridge. On Dickson's Dam at Galt the ice and debris gave way suddenly at midnight on Sunday the 14th. The mass of ice and timber carried away Dickson's Bridge and swept down through the town, overtopping the banks and crashing against the buildings. At the Main Street Bridge it piled up so high that the woodwork above the roadway was swept away, but the bridge itself resisted the pressure.

The flood took out the recently rebuilt footbridge three miles downstream, left hardly a trace of the Glenmorris Bridge and broke the first bridge at Paris. It reached Brantford in less than 28 hours, after destroying a mill dam and a bridge at Holmesdale. Before long most of the flats were under water and about 4 a.m. on Tuesday the bells rang an alarm to bring the people to the rescue of the families in the houses in West Brantford. The water was six or seven feet deep in many places; boats had to be used and the fog made the work more difficult. The flood fell quickly; by 7 a.m. the flats were free of water, but still strewn with ice and wreckage. The damage was chiefly to private property. Some houses were washed away bodily and both parts of the Toll Bridge were broken. The Free Bridge was barely saved by filling the cribs with stone and brush, but it was badly shaken and like the surviving one at Galt could not be used by vehicles. The Cockshutt Bridge was less seriously injured.

Farther down the river, the damage was nearly as severe as above Brantford. All the bridges from Mohawk to Dunnville were impassable for vehicles and three were destroyed. In all, about ten major bridges were broken so as to be useless and at least five others were so damaged as to be unsafe for a time. Until these were repaired or ferries organized, wheeled traffic could cross only at Bridgeport, Paris, Mohawk, and

Dunnville and foot passengers at Galt, Brantford, Caledonia and Indiana. The situation was less serious than it would have been a few years earlier, for the railway bridges were unharmed.

The replacement cost of these bridges may be reckoned at $25,000 to $35,000, but damage to bridges on the tributaries is reported only in general terms. The indications are that the Conestogo (and possibly the Speed) flooded heavily; but that the flood on the Nith was less serious. The damage to private property can only be guessed at, except at Galt and Brantford where it was especially heavy. If the water was as deep in other places as at Bridgeport and Brantford, many houses and other buildings must have been flooded and some shanties were certainly washed bodily away above Galt.

A detailed survey of the damage from Dickson's Mills to below Main Street in Galt, made on February 17, lists one mill, four factories, a foundry, four houses and a store as badly damaged by ice and others flooded more or less; a house and three stables washed away, besides a number of smaller buildings including a log woodshed and the hogpens at Flemming & Robinson's distillery. In the latter sixty hogs were drowned, and a horse, buggy and harness went with one of the stables. The ends of two stone stables were also destroyed, with stone walls and fences in the case of five houses and the soap factory. Here and in many other buildings besides those mentioned there was much damage to grain, goods and furniture from water. The loss in Brantford was perhaps less, and was chiefly to the contents of houses, to roads, gardens and fences. Here also there was some destruction and damage to buildings by ice.

(4) 1858

Dickson's Dam was also injured in this flood. The bridge near it was rebuilt strongly enough to resist the ice which on March 18, 1858, carried out the weakened Main Street Bridge. A number of "prominent citizens" just managed to get off the bridge in time, but two were carried some distance downstream on the section before it grounded and allowed them to climb into a tree from which they were rescued by a boat.

(f) 1860 - 1869

(1) 1860

The floods of the 1860's were more numerous, but not more severe than those of the previous decade. Their details are very similar, though some new features appear. In 1860 a not especially severe flood was complicated by ice jams at Brantford and Galt. These formed at about the same time on March 4. The ice at Kerby Island, near the mouth of D'Aubigne's Creek, above Brantford, deflected the river across the flats, flooding houses, washing out Oxford Street and damaging the large canal. The jam at Dickson's Dam at Galt was unusually large. For the first time attempts were made to blast the ice. "Enough powder to blow the river from its bed, had it been properly used, was applied, but it wasn't and the experiment was attended with but small success." However, perhaps because the river had cleared lower down, the jam eventually went out without doing much damage in Galt, though there must have been some flooding above the jam. The ice damaged the Caledonia Bridge to the extent of $1,000.

(2) 1861

Almost exactly a year later, on March 3, 1861, the ice again jammed at Kerby's Island and again flooded the flats. The water seems to have been deeper in 1861, the danger to the bridges greater and the houses and streets more severely damaged. This flood was checked by a spell of cold weather. It was most severe on the lower river. The Indiana ice had already destroyed part of the "splendid new bridge" at Cayuga on March 2, before the jam passed Brantford early on the 4th. The crest of this second flood reached Caledonia at 4.30 p.m. the same day. The water there had been rising steadily since the 2nd and was now about two feet higher than it had been in many years. The mass of "ice, timber, flood-trash (including a scow) etc." swept over the upper dam and struck the two sawmills, piling up as high as the roof of McKinnon's mill. The building was moved four or five feet and completely filled with ice. The machinery was ruined and the damage placed at $12,000-$15,000.* Scott's sawmill escaped with only $500-$600 damage.

The ice then struck the repaired bridge and carried away three sections. These in turn destroyed the centre "bent" of the bridge at Seneca, leaving it impassable. There were now only two usable bridges above Dunnville in Haldimand County. There was flooding and further damage to buildings in Caledonia. The Seneca Creek flooded the whole of that village below the grist mill and floated off the bridge on the Dunnville Road. It was only with difficulty that the bridge was secured and anchored in the creek before it floated into the river.

The damage at other points on the river was less serious. A mill dam was destroyed at Paris and there was the usual loss of loose property, small buildings and the contents of cellars.

(3) 1862

In 1862 the main flood took place after the ice had gone out, probably from Bridgeport down. The ice on the Conestogo carried away the bridge at St. Jacobs about April 16. There had been heavy snow which had not yet entirely melted, and now rains brought the Grand, Conestogo, Speed, Eramosa and Nith to unusual heights. The Speed at Guelph was "very large" on the 18th and 19th, and on the 20th a cut was made around the sawmill at the People's Mills to save the dam.

A bridge was carried away at the Union Mills eight miles up the Eramosa from Guelph and a jam of timbers

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* McKinnon's sawmill was renting for $1,200 a year in 1851, so that the estimates are not too high for what amounted to almost complete destruction ten years later.

formed at the Eramosa bridge in the town. At Brantford the flats were flooded and people forced out of the smaller buildings. The water was higher on the 27th than in nine years "except on two occasions when it was dammed by ice" - "if the melting of the ice and snow had co-incided an immense amount of damage would have been done". As it was the damage was limited to the breaking of gates on the canal and to water spoliage. When the river began to go down on the 24th, the major bridges were all safe.

(4) <u>1865</u>

In 1865 the river again rose to great heights. The ice, however, went out in sections or the damage might have been even worse than it was. The ice from Brantford down took out the Caledonia and Indiana bridges. The water was already high at Brantford, but no damage had been done by the 18th. The water continued to rise on the 19th and 20th. The ice was collecting on Dickson's Dam at Galt and had already taken out the bridge at Freeport and the covered bridge above Doon.* The Galt ice jam broke at 1 p.m. on the 21st, taking the Paris bridges with it. The bridge over the Nith at Paris went at about the same time and there was "great excitement at Brantford and for miles around" when the communications with Paris were cut in this way. The "great rush of ice from the up country" reached Galt after the "dam"† had broken and the damage there was less than had been expected. This ice had carried away the bridges at Bridgeport and injured the Carlisle (Blair) Bridge. A new mill dam at St. Jacobs was probably broken at about this time, though not reported at Berlin until about ten days later. Brantford seems also to have come off better than was feared; but there was a "great flood" at Dunnville about the 25th and 26th.

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* This is not mentioned in the reports, but is known to have been destroyed and not rebuilt in 1865. It may have gone with the second ice shove.

† It is not clear whether this means the actual mill dam or simply the ice jam.

The next three freshets were less severe, though there were ice jams at Galt and some damage at Paris in both 1866 and 1867. Boats had again to be used on the flats at Brantford in 1868, but, though this was a bad year for floods all over Ontario, on the Grand it was far less destructive than the break-up of 1869.

(5) 1869

This year was long remembered on the river above Galt. At Guelph it was certainly the most destructive ever reported and was believed to be the highest yet known. The first reports came from Waterloo and Guelph on April 19, when the flood had been raging for some time. Armstrong's and Mickle's dams in Guelph Township, and Allan's and Presant's in the town had given way. Armstrong's bridge was gone and "a vast amount of bridges and culverts" had been destroyed on the roads "leading north and west". The loss of Eby's mill dam at Salem is also reported. A later report mentions six broken bridges over the Irvine in Garafraxa Township; great damage to roads, and small bridges; culverts torn up in every direction in Pilkington, Nichol and Peel Townships. Waterloo reports dams burst at Hollin, St. Jacobs, Bridgeport, Breslau and Waterloo itself and others expected to go soon. In Waterloo two bridges, a house, sidewalks and fences were washed away. A dam owner at Hollin, trying to save his dam, was carried away with the floodgates and drowned.

The dam at Doon gave way and the rush of water destroyed the road and carried away two houses and the end of a stone distillery. The loss was placed at $1,000. The same figure was given for the loss to Erb's Mills, at Preston. There the whole west end of the village was completely flooded all week. No vehicles could pass and boats were used to take the mails to the east end of the bridge.

At Galt the Grand rose so high that it flooded part of Water Street and most of the factories along both banks.

"Mill Creek poured forth a tremendous volume of water." The water began to fall at 4 p.m. on the 19th, but at 3 p.m. on the 20th it was still nine feet "above the ordinary level". In Galt the heaviest loss fell on the owners of Dickson's Mills (J.& R. Blain), whose floodgates, flume and buildings were injured to the extent of $2,000. The lessee of their sawmill lost $500 in lumber and sawlogs, besides being put temporarily out of business. All the woollen mills had dye-stuffs spoiled by water and some lost cloth or machinery or had their buildings damaged. A soap factory had $300 worth of ashes spoiled by the flood. Houses, a hotel, workshops, etc., were flooded and their contents spoiled or washed away. As in 1857, there was heavy damage to stone walls and fences.

The two bridges between Galt and Paris were not damaged. There are few details of the flood on the Nith. However it is quite possible that the damage at Hayesville, shown in the sketch, was caused by this flood rather than those of 1862 or 1865.

At Brantford the flood began on the 19th and lasted for 24 hours at least. The flats were flooded, the Canal bank broken near the woollen mills and a large section of the road washed away. For the fourth or fifth time, the mayor and councillors exerted themselves successfully to save the wooden bridge, but the damage to private property was heavy.

At Caledonia the damage to the lock and dam, to mill flumes and races was estimated at about $2,000 in all. McKinnon's mill accounted for about $600 of this. The mills and factories had to close down for some time. Farther down the river a break in the embankment stopped the plaster mills near York. Dunnville was already completely flooded on the 20th, with the water rising two inches an hour. Even after it began to fall at noon on the 21st, it was still "five to ten feet" deep on the town. The streets were full of flood wood and some entirely blocked by it. There had been great damage to grain stocks, to merchants' goods and the contents of houses.

One man had been drowned at Dunnville and a third fatality on the 23rd may be blamed on the flood. A man named Kaufmann drove into Mill Creek at Waterloo where the bridge had been washed away and died of the effects of the fall after being rescued from the water.*

Forty-four years later, in 1913, evidence was brought in a law-suit at Guelph that the water in the Speed was higher in 1869 than it had been for about nine or ten years and that it did not reach this height again until 1912. The exceptional high water in 1869 was attributed to the bursting of the dam higher up the river and lasted only a short time. It was stated (not in evidence) that, while the Speed frequently overflowed its banks below the sundial used as a flood mark, the ordinary flood heights were fairly constant. But the evidence indicated that they varied considerably and that some had almost reached the sundial. The flood of 1869 reached record heights in many other parts of the watershed, so that the breaking of the mill dam may have had less effect than was supposed in 1913.

One of the special points to be noted about this flood is the fact that, like the flood of 1850, it was really a flash flood, although occurring soon after the break-up. The ice had gone out some time before. There was no snow, for the winter had been unusually mild and open. From the first thaw on January 8, to February 15, there had been no sleighing near Toronto and much mild, spring-like weather. There were snow storms in February and March, but in each case thaws followed before long. Conditions on the Grand may have been somewhat different, but these thaws probably caused minor freshets on the river. It was remarked at Galt that "had the ice remained until

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* The Coroner's jury took a severe view of this case. Their verdict was "that the deceased was killed by driving into Mill Creek while intoxicated and that according to the evidence no blame can be attached to any person but himself"

the inundation took place, the loss of property and we have no doubt of life would have been frightful". The flood was caused by heavy rains which began with a thunderstorm on April 18. All the damage was due to water.

Other features were the heavy rise on the tributaries, including small creeks; the rapid advance of the flood; the long duration of the high water - several days at Preston, more than 24 hours at Brantford and Dunnville - and the depth of the flooding.

Even without ice the loss was heavy. The total estimates for Galt ($3,500) Caledonia ($2,000) and Doon ($1,000) may be taken as typical, since they include a town, a large village, and a small mill village. On the basis of these and of the estimate of $1,000 damage at Preston to Erb's mills alone, it may be calculated that the total for the fifteen places from which some details of loss are available, amounted to about $28,000 or more. This takes no account of damage at intervening mills and villages on these streams, of damage on the Nith or the loss of smaller bridges, culverts and farm property over the whole watershed. Probably $50,000 or $60,000 would be a very moderate estimate. Because of the absence of ice the major bridges mostly escaped injury though the bridge at Freeport was rebuilt in 1869.

(g) 1870 - 1879

(1) 1870

This estimate seems reasonable when the account of the freshet of April 7, 1870, is considered. This is said to have been "not so great as usual" because of "the absence of heavy rains" and to have caused "less destruction than was expected." Nevertheless ice jams caused the destruction of a bridge and the foundations of a woollen factory at Bridgeport "and flooded many houses to their second story". The ice took out the new bridge at Freeport, which had cost $10,000 the year before. There was slight damage at Galt, Caledonia and other points. At Dunnville the inhabitants checked the rise by cutting the Government dam near the waste weirs.

(2) 1873 (April)

The spring flood of 1873 had some points of resemblance to that of 1869, but the damage was probably less than in 1870. A slow rise in the river began at Galt on Saturday, April 5. There was little ice and no freshet was expected. However, a severe storm that night brought the river up eleven feet by Monday and part of the town was flooded. At about the same time it was reported that the bridges over Whiteman's Creek, between Paris and Burford, were impassable. Brantford reported a boy drowned, the water higher than in several years and four bridges swept away south-east of the town. Higher up the river the ice had not gone out. It broke up suddenly on the Speed about a week later and carried away Goldie's Dam as well as the dam and bridge at Presant's Mills. Most of the damage on the Grand, however, seems to have been due to water rather than ice.

(3) 1873 (December)

There was already good sleighing by the fourth week of November 1873 and the mill ponds on the Grand were frozen over. A thaw at the end of the month had melted most of the snow before heavy rains began December 1, and continued until Wednesday the 3rd. On Thursday the 4th a "tornado" accompanied by more rain, swept across much of Southern Ontario, blowing down trees and buildings and increasing the flood which had already begun on some streams, among them the upper tributaries of the Grand. By the 5th, the Nith, Conestogo and Canagaigue were in full flood. New Hamburg reported $5,000 damage; the dams at Hollin and Glenallan were swept away, bridges damaged, and buildings, fences, sidewalks and vehicles carried off. St. Jacobs reported the water a foot higher than it had been in the spring and considerable wind damage as well as loss by flood. Small bridges were destroyed near Elmira, the main roads impassable and in some places under two feet of water. The reports from Paris say that the Grand rose four feet in a few hours on the morning of Thursday, December 4, and seven feet during the day, with a heavy run of ice. The Nith rose "in like manner"; there was some flooding of the Lower Town, for factories were forced to close down on the 5th and 6th. They had re-opened by the 9th and the damage was not serious. At Galt and Brantford the chief damage was from wind; little or nothing is said about flooding though the rise in the river must have been notable.

(4) 1874 (January and March)

This series of floods continued into 1874. A thaw on January 23 caused "another large freshet at New Hamburg" that flooded part of the village and interfered with the repair of the mill dam. The damage, however, was less than the previous December. At Brantford the bridge to West Brantford was damaged by the water washing around each end. Strenuous efforts were being made to save it. In the meantime one span of the Caledonia bridge was carried away.

This freshet was checked by cold weather, but the Brantford bridge must have collapsed before long, possibly as a result of another freshet early in March, for on March 16 a scow was rigged to take its place. The real break-up, recorded at Galt on March 19, carried away the rest of the Caledonia bridge on the 20th.

During the next four years the spring freshets came early in April and do not appear to have been unusually severe. An ordinary flood could, as we have seen, do a good deal of damage, and it is just at this period, 1872-1877, that we are told that the valley at Conestogo was often filled "from brim to brim" and the loss to the inhabitants sometimes heavy.

The year 1878 was one of many freshets and summer storms. The Grand appears to have done little damage in

February, when rivers in Central Ontario flooded badly, but there was some degree of flooding about March 3, at the break-up on April 7-8 and again about April 22.

(5) 1878 (September)

A series of thunderstorms in August may have caused a freshet at Brantford, though this is doubtful.* But the flash flood of September 13, 1878, (often called the "Mowat" Flood) was long remembered as one of the worst on the Grand. The storm that produced these floods originated in the Gulf of Mexico on September 6; after taking a circular course over Florida, Cuba and South Carolina, it started northward on the 10th and reached the west end of Lake Ontario early on the morning of Friday 13th. There had been heavy rain in many areas for more than two days before, including the northern part of the Grand Watershed, and the streams were already swollen. The centre of the storm seems to have circled around the west end of Lake Ontario, then travelled north-east and east along the Morainic Upland. Almost the whole of the Grand Watershed was affected. Broken or damaged mill dams were reported at practically the same time on Friday from Scotland, Hollin, Elora and Fergus. The flood on the Conestogo at Hollin was considered the "highest since 1872"; at Fergus, Elora and Bridgeport the "highest ever" - a stock exaggeration. At Bridgeport the water was still rising on the 13th. A few miles above Galt the Grand was "a quarter of a mile wide", on the 14th. At Galt the flood was "almost as high as in 1869" and at Brantford "higher than for years". A child was drowned at Galt and two men at Brantford. Houses were washed away at Fergus and flooded at Elora, Bridgeport, Galt, Brantford and elsewhere. At Mount Healey, 200 feet of embankment on the dam was washed away and there was great damage to crops and fences on the lower river.

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* A reference in an account of floods in 1898 to a bad one in "August" 1879 is probably a misprint or mistake for "September" or a confusion with the flood of August 1883.

Brantford appears to have suffered the most. There was four feet of water in houses on the eastern flats and 2-3 feet through much of west Brantford. The iron bridge was carried away and 40 feet of track washed out. Apart from this bridge and those at Bridgeport, which were damaged so as to be impassable, the bridges on the main river suffered little. But many were destroyed on the tributaries, and here as elsewhere the Provincial Election that gave the flood its name had to be postponed until voters could get to the polls.

This is the first severe "summer" flood on the Grand of which we have detailed reports. Such floods had been fairly numerous in other parts of the Province. They tend to occur in groups, often in a period when heavy flooding was usual in spring. There had been several between 1790 and 1812, a few in the 1830's and occasional examples in the 1850's and 1860's. When really severe they cause more loss to farmers than the spring freshets, but usually do less damage in towns and villages and to bridges. For this reason they sometimes pass without comment from the press and may be more common than the records indicate. A really severe flash flood, however, attracts a good press and is remembered for generations. This is especially true when several rivers flood as in this case and in June, 1890, or when several local disasters occur in a decade as was the case in the 1880's.

(h) <u>1880 - 1889</u>

The first years of the 1880's produced little flooding, but in 1883 there were two spring freshets, one of them severe, two summer freshets and a disastrous flood in August.

(1) <u>1883 (April)</u>

The first freshet early in March was of little importance, but may have cleared some ice from the river. The real break-up in April was more serious and would probably have been worse if the thaw on the headwaters had coincided with the break-up on the river below Bridgeport. The ice passed Galt on April 9. On the 15th the river had risen eight feet at Brantford and the flats were flooded. The next day Dunnville reported the river up four feet and still rising. This rise, however, represented only the freshet from the southern two-thirds of the watershed. The break-up on the headwaters burst the mill dam at Fergus on the 14th and sent $1,000 worth of saw-logs against the booms at Elora. One of these broke and the logs rushed over the falls. The other boom was saved by yanking logs out of the water by steam power. The river higher up was full of logs cut in Luther Township. These jammed against the piers of the Fergus bridge and formed another jam a mile long above Douglas.

The water at Elora reached a height that had only once been equalled since 1858. At about the same time a sudden freshet on the Conestogo in Maryborough Township broke two bridges and a mill dam, while cellars were flooded in the stores in Drayton.

(2) <u>1883 (May to July)</u>

There were two fairly heavy freshets on the Nith at Ayr between May 18 and August 18. These are referred to in an account of the severe flood of August 19. One of these probably took place on July 12 or 13 when thunderstorms and heavy rains south of Listowel raised the North Branch of the Thames and caused flooding in Logan and Fullarton Townships. There were flash freshets in many parts of Ontario at the same time and another group of freshets had taken place between July 1 and July 10. The rains that produced these were general over the whole province, but the storm that caused the disaster in London on July 11, 1883, seems to have been too local to affect the Nith. The words "the third time in three months" seem to indicate a freshet in May or early June of which nothing is known.

(3) 1883 (August)

In any case this exceptional series of rains had soaked the ground and filled the swamps and streams. The various freshets and the disaster at London on July 11 had made people alert to the threat of flooding, but the rise of August 18-19 passed all expectation. There had been rain at Listowel all day on Saturday, August 18, but the severe thunderstorm that was the direct cause of the flood broke in that region at about 10 p.m. Its centre was a little to the south and it had travelled south-east from Wingham, where it had begun early on Saturday morning. Rain began in New Hamburg towards evening and lasted twelve hours. Buildings were struck by lightning in Heidelberg, above Elmira, in St. Jacobs at 6 a.m. on Sunday, and in Berlin, Waterloo, and Hamilton.

The Nith, Conestogo and their tributaries received the greatest run-off. By the time the storm reached the Grand at Bridgeport its force was partly spent. The Nith flooded in North Easthope and in Mornington, where 11 bridges were washed out, most of them on the Nith. Reports of damage came from Milverton, Poole and Burns. The villages in Wilmot Township suffered heavily. The accumulated wreckage struck Christner's Bridge on Snyder's Road, above New Hamburg, which was carried away and, reinforced by the wrecks of Helmer's Bridge in the village and of a large livery stable, destroyed the new iron bridge at East-and-West Street and Rau's Bridge* below it. It then swept on through Hayesville, where the centre of the village was largely destroyed, and had reached Plattsville after 11 p.m. on Sunday the 19th. A warning was carried to Ayr from Plattsville by buggy and from that village to Paris, for in both cases the distance by road is about half that by the windings of the river. The Nith had been high in Ayr that morning, but had fallen by 8 p.m. and did not begin

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* On Bleam's Road.

to rise until about midnight. Bells rang the alarm at 1 a.m. and the villagers turned out to find the water already in the streets. The river rose faster than in any flood that was then remembered and reached fifteen feet above its ordinary level. It was still at its height between 6 and 7 a.m. on Monday and had not gone down completely until Tuesday morning. The crest on the Nith reached Paris on Monday afternoon.

The Conestogo flooded about the same time. There are few reports of damage on the upper part of that river, but at St. Jacobs on Sunday the river rose six inches an hour "until it reached the highest point ever known". The dam and bridge were saved with difficulty. At Bridgeport on Sunday afternoon the flats were all flooded and the water "higher than ever in the spring freshets, unless blocked by ice".

The Waterloo Creek flooded Bucker's foundry several feet deep and covered the site of Shantz's old mill pond with "more water than when the pond was in existence". Some flooding was reported at Galt, but the flood on the Grand was not so heavy as on the Nith and had time to spread out before reaching Paris. The flooding there was due almost entirely to the Nith and farther down the river the rise was less remarkable.

The flood throughout the Nith Valley was probably the highest ever recorded. The tendency to forget floods after twenty or thirty years is so general that this cannot be certain. It was certainly not equalled for about thirty years more. The damage was far greater than in any flood up to that time. Detailed estimates are available for damage at Paris and Ayr and figures are given that permit a rough calculation of the loss at New Hamburg and the cost of the seven large bridges destroyed in Wilmot Township. All were about 100 feet long; two (at New Hamburg and Hayesville) were of iron. The values ranged from $1,000 to $3,000 each. In at least three cases the stone abutments were also destroyed. The total cost of replacement may be placed at about $10,000. The loss of private property in

New Hamburg may be placed at about $6,000 or $7,000, including the complete destruction of a livery stable, a cooperage, a barn and an "oil house"; damage ranging from $50-$500 to stores and factories; and water damage in flooded houses. Probably another thousand might be added for loss of road surface, sidewalks and telephone poles.

The editor of the Ayr Recorder made a partial survey of the damage in the centre of the village on Tuesday morning, before the flood had entirely subsided. In this he collected estimates from seven sufferers, including householders, merchants and a cooper who had lost his workshop and all its contents. Three thousand dollars' damage was reported by the owner of the mills at "Nithvale" immediately below Ayr and between $5,000 and $6,000 from Goldie's Mills at Greenfield farther up the Nith. This made a total of $11,250 for Ayr and the vicinity, but this did not include the heavy damage in the Watson Implement Works; in several other houses near Knox Church and on Swan Street; the loss of one abutment of the Nithvale bridge; of 15 to 20 feet of fill at one end of the railway bridge; of sidewalks and roadways or of the temporary foot-bridge that had replaced the Piper Street bridge while it was being rebuilt. Three houses and a stable at Nithvale were also badly wrecked and much of their contents destroyed or damaged.

An attempt had been made at Ayr to shift goods above flood level, but there had been too little time and the flood had risen higher than ever before. At Paris the warning had come much sooner, but even so the total damage was set at $25,500. Ahren's Pottery had been completely destroyed and accounted for $7,500 of this; the loss of Whitelaw, Baird & Co's dam and headgates for $3,000 and damage to Schiler's Pottery for $500. The remaining $14,500 of unspecified damage must have occurred to factories, stores and houses in "the southwest side of the Lower Town". The bridges were not seriously injured.

These estimates for three localities total $53,750. When the unspecified loss at Ayr, in Mornington, Wellesley, and Blenheim Townships and their various villages is added, the figure for the Nith alone may well have totalled from $75,000 to $80,000. The less serious loss on the Conestogo at Waterloo and Bridgeport, and on some smaller tributaries may have brought the whole cost of this summer flood to between $90,000 and $100,000. This should perhaps be multiplied two or even three times to bring it to modern values.

The extent and height of the flood may be judged by the details given at Ayr, where exact measurements were taken in several buildings. The flooded area extended from beyond Knox Church (which then stood in the west part of the village a little east of the new Arena)* to "the lower part of Swan Street" beyond the Watson Works to the east. The flood at its height must have covered the site of the present War Memorial to a considerable depth. It flowed in the lower windows of Watson's "large new building" and left a watermark 2 feet 7 inches above the lower floor, covering such of the contents as had not been removed, with a thick coating of mud. In the bakery, which can be seen opposite Watson's to the right of the photograph, the water was 5 feet 6 inches deep in the "cellar kitchen, bake-house, and other buildings". These were above ground but below the road level, so that this was the depth above the river-bank at that point. The flood brought down a great quantity of silt and left a coating of mud wherever the water reached. It was fortunate for the inhabitants north of Piper Street that there was no flood on Cedar Creek; for had the two mill dams on that stream burst, the disaster would have been even greater. The flood of August 1883 was not equalled

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* This church, with its churchyard, the "Town Hall" and houses between it and the bridge have disappeared so completely that it is necessary to look closely to find any trace of them. Some photographs in the archives at Ottawa show them standing in the early part of this century.

at New Hamburg for thirty years. Here, as at Nithvale, the water was up to the second storey of some houses. The damage at Hayesville was disastrous. The village was already declining in prosperity and the area devastated in 1883 was gradually abandoned. What is left of the village is now on higher ground and the flats are vacant.

The remaining years of the 1880's produced only minor winter freshets, and spring floods of varying severity. None of the latter are of particular interest, though, as has been pointed out, an "ordinary" flood could be costly and local conditions might make it more serious at a particular point than on the whole watershed. Some degree of flooding was accepted as a natural feature of the spring thaw, but since the running of logs down the river had largely ceased below Elora and was soon to become less important on the upper waters, there was no compensating advantage to offset the nuisance of the freshets.

Since 1878 or even earlier the opinion had been increasingly held that floods were growing worse than they had been in the past. Clear-cutting was making more evident inroads on the woodlands than the highly selective cutting of the period before 1867. The change for the worse in the freshets was blamed on the disappearance of the forests, largely on a "<u>post hoc propter hoc</u>" basis, and after the August flood of 1883, the Ayr Recorder demanded that "the Government do something about it".

Before discussing this notion it will be as well to describe some of the worst floods of the 1890's, for though these were of a less extraordinary nature than the summer spates of 1878 and 1883, they were among the worst of the nineteenth century, especially at Brantford. Coming as they did during a period of prosperity and industrial expansion, when the cities were extending their limits more rapidly than they had in forty years, the loss from these floods was much more costly and widely distributed than in any previous freshets and they attracted far greater attention throughout the country. They were responsible for the first definite measures of flood control and hardened the attitude towards floods that had begun in the 1880's.

The Grand Watershed seems to have escaped serious consequences from the great storm of May 31 to June 1, 1889. This storm destroyed the city of Johnstown in Pennsylvania and swept north-east across Lake Ontario to burst over Cobourg, causing extraordinary spates on the streams and unheard-of erosion on the hills behind the town. The storm itself affected only a limited area, but the rains which accompanied it started heavy floods as far west as the Humber and probably caused a marked rise in the Grand similar to that on the Thames, though no flood reports have been found.

(i) <u>1890 - 1900</u>

(1) <u>1890 (June)</u>

The storm of June 4-5, 1890, touched off a series of flash floods across the Province, which again interfered with the polling of a provincial election. This storm followed the usual south-west-north-east course, entering Ontario by the Lake Erie shore, a little east of Port Stanley, and the Grand Watershed in Oakland Township. The storm seems then to have moved in a slightly more northerly course, a little east of the valley of the Grand, raising streams between Orangeville and Mount Forest. It appears to have missed the headwaters of the Nith and to have had little effect on the Conestogo or Speed so that the flood on the main river was not serious and few flood reports have been found.

McKenzie Creek destroyed the mill dam at Oakland and a bridge and seven rods of approach on the Waterford Road. This appears to have been the most serious flood damage, though storm damage was reported from Bright, flooding was reported from Elora and there were railway washouts in Melanchthon Township near Carleton.

(2) 1893 (December)

The next three spring floods were not remarkable. There was flooding at Elora in 1891, and in March 1893 the flood broke the City Dam at Brantford but seems to have done little other damage. Winter set in early that year and by the middle of December there was a considerable quantity of snow and ice. A thaw with rain began on December 15-16 which melted the snow and raised the river sufficiently to bring down the ice. The river was rising steadily at Brantford on the 18th. By evening a good part of the Eagle Place Flats were under water. This area was much more built up than it had been seven years before. The railway line had attracted more industry to the vicinity of the canal, which continued to be used for waterpower after the barge navigation had dwindled. Houses had been built there as well as factories and some families were now forced out of their homes. Erie Avenue was blocked by the water and the Harris Plant cut off.

The next day a jam of "slushy ice" formed above Lorne Bridge and it was the turn of West Brantford to be flooded. The fair-ground was under water; one-storeyed houses had to be abandoned and other families had to move to upper floors. Some houses had four or five feet of water in the ground floors. The flood fell on the 21st, but rose again on the morning of December 23 and flooded the flats, the fair-ground and West Brantford. The water was not so deep as before, but now sidewalks began to float away and telephone poles to fall. The ice moved out on Christmas Eve. The water began to fall once, but on December 26 the flood was still serious and was threatening to wash away the embankment near the headgates of the canal. If this had not been prevented by using sandbags, the damage in Eagle Place would have been much more serious. As it was, the loss in Brantford was estimated at $15,000 but this probably did not include all the damage in private houses.

(3) <u>1894 (March)</u>

The flood left what was described as an "ice gorge" near the Mohawk Church. This remained through January and February and was still firm when the ice broke up at the beginning of March. The flood on the 6th of March was a fairly high one in any case, but this "gorge" blocked the ice from below Galt and turned a heavy flood at Brantford into a very severe one. Both West Brantford and Eagle Place were again flooded though perhaps not to so great a depth as in 1893. The floating ice, however, increased the loss, wrecking some houses and barns and even injuring some more solid buildings. The area flooded must have been greater for the water backed up from the south instead of overflowing from the north. The headgates were still in danger on March 7, though the water was beginning to fall. If they had gone the loss in Eagle Place would have been more serious. The Massey-Harris Plant had already suffered $8,000 loss on the 7th and the Cockshutt Company $1,000. The City's costs in repairs to streets and sidewalks was then reckoned at $1,000. These three items alone thus account for $10,000, but this was not the total of damage to this type of property and the loss to houseowners must have been far higher.

A report written eight or ten days after the flood was over says that the depreciation of house property in the flood areas, including a fall in sales value, could "only be measured in tens of thousands". This article contains some interesting and even amusing remarks on the two floods and on the flood problem in general as it was regarded at that time. After referring to "vigorous protests in times past and gone, on the part of the Grand River against being restrained within the narrow channel which nature marked out...", the writer comments on the recent floods and their effects. Apparently he was unaware that the flooded areas at Brantford were part of the <u>natural</u> flood plain of the river which had in fact been created by floods in the remote past. He then "turns to the records of the past to ascertain whether in reality this is 'the greatest flood ever known here' as is constantly asserted". This effort to check the truth of the stock phrase led to the discovery that there had been a bad flood in "August, 1879" in which the first iron bridge had been destroyed. This seems to be a telescoping of two or more summer floods, rather than a simple error in date, but whether the August flood which is confused with the one in September, 1878 (which actually destroyed the bridge) occurred in 1878, 1879 or was the disastrous one in 1883, cannot now be determined.

The article ends: "But the stern fact remains that the clearing away of the forests and swamps in the northern counties where the Grand finds its water supply, has created a new danger that must be faced ... One says: 'Operations must begin at the Goodfellows Farm and jetties constructed for two or more miles to keep the water on check.' Another says: 'The railway bridges must be extended another span ... ' Still another urges that dynamite should have been used ... but all agree that the opinion of a competent engineer should be obtained and some means adopted to prevent if possible the recurrence" of disastrous floods.

The danger of flooding was hardly new, for the same areas had been frequently flooded ever since the town was laid out, though the extent and depth of flooding had varied. What was new was the extension of building onto the low ground, gradual from 1855 in West Brantford and near the east end of the bridge, much more rapid both there and in Eagle Place since 1885. This had long since gone too far for the people of Brantford to adopt the expedient of their forerunners and abandon the flats to the river. The engineers were evidently consulted and the result was the building of a flood dike to protect West Brantford, which served its purpose well enough during the next four years. The scheme of "jetties" was wisely discarded, since it would have been likely to increase the danger of ice jams.

Some of the other suggestions were to be carried out later when a fresh series of floods had proved the dike insufficient.

(4) 1898 (March)

The first of these floods came in March, 1898, a particularly disastrous year not only for Ontario but also for North America, Europe and even Asia.*

Thawing began about March 9-10 and at Guelph was so gradual that no flood was feared. The same opinion was held at Galt until Saturday the 12th, although ice had begun to collect at Blair, for throughout the day the river there was hardly above normal "at this time of year". Heavy rain began higher up the river on Saturday afternoon and continued into the night. The Grand rose steadily at Bridgeport for twelve hours and the ice jam at Blair had become "immense" before morning. A second jam was evidently forming above Bridgeport, for that village was partly flooded by Sunday morning. The Blair ice went out at about 7.30 a.m. and "came rushing down through Galt at frightful speed". This "shove" was probably started by the discharge of the Speed, which had risen to unusual height at Guelph during the night. The ice and debris did great damage as it passed and carried away or damaged at least five bridges between Breslau and Glenmorris. Warnings were telegraphed to Glenmorris, Paris and Brantford, where they may have allowed some time for preparation, though the crest moved so quickly that this cannot have been long.

At Paris in fact the warning seems to have come too late. By about 9 a.m. the river had risen "between fifteen and twenty feet above low-water mark". Stores and cellars had been flooded, "strong men" were carrying out the occupants of

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* It was the flood on the Tiber in 1898 that caused the Italian Government to imitate the ancients and protect Rome by immense embankments. Similar but smaller embankments had already been built at Paris and London. Like the Roman dikes all these have proved effective ever since in covering the areas they were designed to serve. It is not possible to say as much of the works at Brantford or at London and Paris, Ontario.

some houses. The crest passed Brantford not long after and had carried away 25 feet of the Cockshutt Bridge before noon. The first report from Brantford mentioned a rise of 15 feet and the water blocking the road at Newport, but later on Sunday 18 feet was reported, the flats flooded, large masses of ice and debris, and many houses surrounded by water on both sides of the river, although the dikes were still limiting the flooding in West Brantford. The life-boat recently installed by the City had been called into action and the Corporation staff was busy strengthening the threatened dikes.

The water fell at Galt, Paris and Brantford on Sunday afternoon, almost as quickly as it had risen. But the break-up was not over on the upper waters. About noon on Sunday Bridgeport was almost overwhelmed by a sudden rush of water and ice from above, probably caused not only by the outpouring of the Conestogo, but also the breaking of a jam or jams higher up the Grand. After the first rush the water rose "slowly but surely" until it submerged a row of cottages along the Main Street, forcing the families to climb onto the roofs and wait there until one of the men procured a boat and rescued his family and neighbours. At Breslau the water rose to within four feet of the "big driving bridge", backed up over the fields to the mill and by 5 p.m. had covered the Berlin road on either side of it. A small bridge across the creek was damaged after the roadway on either side had been washed out. "People who drove from their homes on the Berlin road to Sunday School had to return home by way of Galt".

This second crest did not reach Galt till night, so that two of the bridges could still be used. The river was at its height between twelve and one o'clock on Monday morning - sixteen feet above normal. By morning two spans of the Queen Street Bridge were gone and more planking had been torn off the bridge at Main Street. A frame storehouse and one wall of a brick dye-house were swept away. The flood spread over a much wider area and greatly increased the number of flooded buildings. More families had to leave their houses and for a time some were in a position of some danger. Stores on Main Street 50 yards from the river had their cellars flooded. The watermain on the Queen Street Bridge had burst and the flood had backed up the drains. The river fell five feet on Monday, but the flats around Blair were still under water and it was not possible to take stock of losses until the Grand went down another seven feet by Tuesday.

The flood crest did not take long to reach Paris and in the early hours of Monday the Grand is said to have been two feet higher than on Sunday morning. "Nearly every merchant on the east side of River Street suffered loss." The two floods had undermined the west abutments of the Grand Trunk bridge three miles above Paris. At 7.45 a.m. on Monday it settled two feet and became unsafe, less than half an hour after a heavy freight had crossed. Railway bridges over the Grand had from the first been built high above the river and were usually strongly constructed of iron and masonry. They had withstood the floods much better than the road bridges, but the scouring of many freshets was now beginning to have some effect.

By 5 a.m. on Monday, West Brantford was under five feet of water. "The dyke did well, but the Grand River went it one better very easily." The other flats were flooded more or less and the damage was more widespread and serious than in the earlier flood. The river fell only slightly on Monday, and the city was kept on the alert for nearly twenty-four hours.

Below Brantford the flood was not so well reported. There had been time for warnings to be sent from higher up and much of the ice had stranded upstream. Still there must have been widespread flooding and some considerable loss.

The only detailed reports of losses come from Galt and are strikingly parallel to those reported in 1857. The same areas were affected and the damage to the two upper bridges was very similar. There had been changes in the condition of the riverbed during the thirty-one years between the floods that must have affected the character of the flooding. The flood of 1857 seems to have risen at least 13-14 feet, as compared to the 16 feet recorded in 1898, but before it reached this height the water would be over the unprotected banks between the new retaining walls, and flooded a wider area beyond North Water Street. Many more buildings were shattered or swept away in 1857, for after 1880 a number of large and substantial buildings had been put up between North Water Street and the river, some of them directly on the retaining walls. These mills and factories suffered heavy water damage in 1898, but they tended to shield the area east of them. Most of the ice and water that flowed down Water Street in 1898 probably came directly from Dickson's Pond or from the backing-up of drains which has been a feature of floods at Galt since about 1890. These led the water directly into the cellars and extended the loss farther up Main Street.

The destructiveness of the ice shove in 1857 probably brought the value of the property lost up to or beyond the final estimate for 1898. This was placed at $10,000 in stores and factories and between $5,000 and $7,000 to the Municipality. To this $16,000 must be added the damage in private houses, so that the total would be around $20,000 for Galt alone. A total of $150,000 might not be excessive for the whole watershed, considering the large area affected, the loss of seven or eight large bridges and the loss of time from the closing of factories and from the interruption of road and rail traffic.

(5) 1899 (March)

The next series of floods began almost exactly a year later, when the ice broke up on the Speed, causing a "mild flood" at Guelph and a heavy one at Hespeler. Brodie's dam in that village suffered a partial break. The low ground was overflowed and traffic on the electric railway interrupted for some time. At about the same time the ice above Galt went out and caused just enough flooding to make people think that they were safe for another year. A serious ice jam below Brantford turned this comparatively harmless freshet into a severe flood. By the night of March 16 the water had backed up over Eagle Place so that it was several feet deep in the waiting rooms of the Toronto, Hamilton and Buffalo Railway station. No trains could run; the life-boat from the firehall was busy taking people from their houses, and at the Massey-Harris and Waterous Engine Works on Market Street gangs of men were occupied with sandbags trying to keep the flood out of the cellars. Already more than a thousand reapers and mowers had been moved at the Massey-Harris plant. West Brantford was not flooded, although people there were alerted and horse-buses, cabs and wagons held ready to evacuate them.

(6) 1899 (April)

The false security inspired by this freshet was rudely disturbed just a month later. This time the flood was much more serious. In the interval more ice had formed in the lower river, while above Bridgeport it appears to have been still unbroken. On Tuesday, April 11, a thunderstorm in the afternoon started the break-up on the Irvine and on the Grand above Fergus and was felt as far south as Guelph. Bridges were washed away at Wilson's mill in Fergus and in Garafraxa Township. Ice jams soon formed at the second dam in Salem and at the Glen Lammond sawmills three miles above Fergus.* The Salem

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* This is the ice jam shown in the illustration.

jam backed the water up "fifteen feet deep"; but at the time seemed to have done little harm. When the jam went out at Glen Lammond it took the mill dam with it and did a good deal of damage to flumes in Fergus and below the village.

At about the same time the Speed rose to a greater height than at any time since 1869. Three bridges in Guelph Township were swept away above the city. All the low ground around Guelph was under water and some cellars were flooded. The flood was rather worse at Hespeler, where it produced very much the same situation as the earlier freshet with a more urgent threat to Brodie's dam.

As the combined floods reached Galt, jams were forming at Freeport and a mile below the town. The water began to rise alarmingly by 8 a.m. on Wednesday and within an hour it had almost reached the level of the March flood. Before midnight it was well above that record, for the breaking of the Glen Lammond jam sent another crest down the Grand. Fortunately most of the ice had lodged between Fergus and Elora where it held back part of the flood. For two days exaggerated rumours of the size of this ice jam, and that it was coming down river with the wreck of the Elora bridge, kept the people of Galt and Brantford in a state of alarm.

Actually the ice jams appear to have been breaking up piecemeal, for floes of moderate size were passing Galt on Wednesday in considerable numbers. During the night another wave of water was released by the partial failure of the dam at Hespeler. The river again rose sharply at 2 a.m. on Thursday and started a new danger by making a small break in the Galt dam. It seemed that this dam must go, but at the critical moment the flood began to subside and in half an hour had dropped two feet. This was enough to save the dam. The flood at its highest had been only a foot or two below the bridges, but because there was still no ice they too were safe. The water rose once more on Thursday night and did not really go down until the next day (April 14).

At Brantford the bridges did not come off so lightly as at Galt. To widen the channel a new hundred-foot span was being added to the Lorne Bridge. The first crest swept away the temporary bridge, cutting off West Brantford. The Cockshutt bridge was also damaged and the only way of crossing was to walk over the railway bridge. On April 12 the dikes had kept the water out of West Brantford. When the river rose again on the following afternoon the widened channel may have helped to keep the water below the top of the dike. Part of the suburb was thus protected, but about 50-60 feet of dike collapsed. The flood rushed across the fair-ground and back to the river below the power plant. The plant was flooded so that the city was in darkness and the lifeboat had to be used a second time to rescue isolated families.

Water damage was heavy both in Galt and Brantford. It was rather less in Paris, for the Nith had cleared in March, and in April flooded less severely than the Grand. The interruption of work was particularly costly at this time, for the foundries were working "night and day". The only estimate of damage found is for repairs to the flour mill at Salem. One corner, a hundred feet high, had been undermined and collapsed after the flood, taking some machinery with it. Repairs were set at $1,000, but there is reason to think that this estimate was too low and that the damage was never made good.*

(7) 1900 (February and April)

A sudden thaw on February 8-9, 1900, brought the Grand so high at Galt that the ice was pressed against the bridges and tore some planks from the Main Street Bridge. For more than an hour the situation appeared serious and warnings were telegraphed to Paris and Brantford. When the water fell as quickly as it had risen some damage had been done at Galt

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* The ruins seen in the illustration show the damaged corner as broken in 1899. Any repair that may have been made did not prove lasting.

in the basements of factories along the river. No ice jams had formed lower down the river and damage at Paris and Brantford was slight.

The dikes at Brantford had been repaired and extended to protect Eagle Place. These precautions did not suffice when the final break-up began at the end of March 1900. The floods on the upper river, though heavy, were less serious than others in this group, but a large jam above Brantford combined with the freshet on the Nith to cause severe flooding at Paris. The ice moved out on April 1 and jammed at the railway bridge in Brantford and at the Cockshutt Bridge. The water backed up by April 2 "finding the lowest spot in the dyke directly at the end of Market Street south, worked its way through there". At 10 a.m. another break was made beside the T.H. & B. tracks behind the Massey-Harris Works. The flows united to cover the railway yards, doing a great deal of damage. At almost the same time the water rose over the dike near the Erie Avenue headgates. Efforts to close the breaks failed, and by 11 o'clock workers had to be removed from the Massey-Harris and Waterous plants and families from the houses.

On the morning of April 2 the water was 18 feet above normal at the headgates. It rose and fell all that day. Then the ice moved out and, since the river was clear at Newport, there was no more flooding. West Brantford had escaped; but the damage on the whole was little less than in 1898 and the water probably higher.

(j) <u>1901 - 1913</u>

During the first six years of the new century there was a heavy freshet on the Grand River every spring. Each of these did some damage in one part or another of the watershed, but on the whole these freshets were not nearly so severe as the last three of the previous century. In 1902 and again in 1903 there were heavy floods with ice jams in the area above Elora. Both caused some damage there and at Fergus. The flood of March 1904 was more serious.

The ice had jammed above Galt and on March 26 it jammed again below the dam. This brought the water up six feet in a short time and the town suffered a good deal of inconvenience and loss from the flooding of many cellars, the interruption of traffic over the lower bridges and the breaking of water mains carried across them. The bridges themselves were only slightly damaged, but the ice took out the Glenmorris bridge and the "footbridge" (now a road bridge) between Glenmorris and Galt. It was estimated that the latter bridge would cost $10,000 to replace.

In spite of the masses of ice coming down from Galt, the flood at Paris later in the day was three feet below that of 1900. The ice did not jam until it was well below Brantford and though the water there was very high, the dikes prevented serious flooding. However, the height of the flood and the damage at Galt and elsewhere may perhaps place this among the severe floods.

In March 1905 a jam below Fergus flooded the power house on the 24th and did $2,000 damage to the Broomfield Mills. The Speed had been blocked in the same way at Idylwild Park on the 23rd. This caused flooding near Hespeler and there was further damage in that village on the 27th. On that day also the Conestogo broke Snider's mill dam at St. Jacobs. In most other parts of the watershed the thaw and break-up were gradual and the flood was heavy but not destructive.

(l) 1906 (January, February and March)

The first of these three freshets may be reckoned as a severe flood at Galt and Brantford. A thaw in the middle of January brought the Belwood ice down to Fergus on the 29th, causing a brief stoppage at the power plant. The next day the "Grand Valley jam" passed Fergus without damage, but the river was very high and rain brought it still higher on the 23rd. The Speed at Guelph was higher than in fifteen years, flooding buildings at Goldie's Mills and covering the flats below the city. At Galt the water rose fifteen feet in two days, enough to cause serious flooding, and the flood was reckoned "the earliest and worst in fifty years". The ice seems to have done comparatively little damage in passing down the river and the dikes prevented serious flooding in Brantford, though the flood was "one of the worst on record". The chief difficulty there was the backing up of the river at the power plant. This not only left the city in darkness for two nights, but also caused a stoppage at the malleable iron works that deprived 100 men of at least two days' work.

A similar stoppage must have occurred a month later when the Grand broke up for the second time and again flooded the Brantford power plant. The final freshet on March 27-28 seems to have been the mildest of the three, though an ice jam below Preston caused flooding around the hotels at Preston Springs and interrupted traffic on the Grand Trunk Railway between Galt and Blair.

The inhabitants of the watershed were now thoroughly alert to the danger of floods. Warnings were often sent ahead of the freshet and precautions taken in time to reduce the loss. This may be partly responsible for the comparative rarity of flood reports between 1906 and 1912, but it seems likely that the Grand was fairly well-behaved during these years. There were few floods in Ontario in 1907 and 1908. The severe floods on some rivers in 1909 and 1910 were aggravated by special local conditions - the breaking of dams or the formation of ice jams at the river's mouth. There were some high freshets on the Grand in these years. In 1909 a farmer was drowned with his team when he tried to cross a quarter of a mile of flooded road near Hagersville, but there is little record of damage in the towns.

(2) <u>1912 (April)</u>

The quiet break-up of the ice above Bridgeport on Sunday, March 31, 1912, led to the belief that there would again be no flood that year. But by the time all the ice had passed Galt on the following Saturday great quantities of melting snow had raised the river at both Brantford and Dunnville. Heavy rain on Saturday evening and night brought the Speed at Guelph to its greatest height since 1869. By 4.30 on Sunday morning the river was rising noticeably at Galt. A flood had begun on the Grand above Belwood that was destroying bridges and threatening dams. When this crest reached Bridgeport, it flooded streets and houses on the east bank two or three feet deep.

At 8 a.m. the water at Galt was high enough to cause alarm. Some people on Water Street South were wise enough to leave their homes at once. When the others had to be removed during the afternoon, firemen had to wade through water up to their waists to carry them to "rigs" waiting to take them to higher ground. Water Street was under water for three-quarters of a mile; adjoining streets were flooded and drains carried the water into cellars a block and a half from the river. The west bank below Main Street was overflowed to nearly the same extent. For about two miles below Galt the east river road was under several feet of water and in this neighbourhood two canoes were taking people from flooded houses. All three bridges were closed and the one at Main Street damaged.

On Sunday evening there was four feet of water in the Penman mills at Paris and in some houses on the flats. The water was within a foot of the top of the West Brantford dike. It had risen so high at the Cockshutt Bridge that the gas main was washed away and the flats towards the city flooded. Lower down, at Newport, the river spread out "like a lake, submerging farmlands on each side". This must have been the case at many points between Newport and Dunnville. There the Grand had been rising for three days and overflowing banks raised to protect the town. The water was "fifty-six inches above standard level - the highest it has ever been known to be", and it was still rising on Monday. The citizens had worked all night building temporary dikes; but there was already three feet of water in the Erie Woollen Mills and it seemed likely that all this work would prove useless.

The flood had already begun to abate. Sunday had been cold and windy and the thaw was checked. When Dunnville was still expecting a further rise, Guelph and Galt were reporting falls of six feet on the Speed and Grand, while, on Monday also, the river fell three feet at Brantford. The extreme high water had lasted a comparatively short time, but it had done an extraordinary amount of damage. Except for some injury to the Long Bridge at Dunnville early in the freshet, ice is hardly mentioned in the reports. The freshet of the previous week had cleared most of the river. Damage to mill dams was comparatively light and the bridges destroyed were almost all above Elora.

There are no estimates of damage in Bridgeport, Paris, Dunnville and other towns and villages in the part of the watershed chiefly affected. In Rockwood one family had to be rescued by boat and buildings were flooded in Hespeler and Preston. Although the storms of rain were more severe in the north-east section, the damage at Paris from the flood on the Grand was "particularly heavy" and this was probably so in the other places on both the Speed and Grand. By keeping gangs of men working all day on Saturday and on into the night the Brantford Corporation had preserved the dikes, West Brantford escaped flooding and the damage in the city was light. But 200 to 300 people had been affected by the flooding of houses near the Cockshutt Bridge and on Monday "large areas south of Parkdale" were still under water. It had not yet been possible to mend the break in the gas main, and Paris and Galt, as well as Brantford, were still without gas in consequence.

The loss at Galt had finally been set at a minimum of $100,000 - all of it caused by water only and most of it to private property. There had been no time to shift goods, machinery or furniture from the ground floors. All the foundries and factories along the river were closed for two or three days. The dam of the Galt Light Company had been injured by "a wooden bridge from Elora" which had lodged against one end. If the dam had broken the damage would have been even greater than it was.

It was, however, the severity of the damage at Guelph that distinguishes the flood of 1912 from most others that had so far occurred on the Grand River. An estimate of $76,000 loss was considered conservative and possibly did not include certain items, such as several hundred dollars damage to the sewage disposal plant. The worst damage was suffered by factories near the bridge on Neeve Street. This had recently been rebuilt in concrete and it was believed that most of the flooding in this area was due to the arches having been made too narrow. That this was actually the case to a considerable extent was determined by the damage case against the City already referred to. Judgment in this case was not given until after the flood of 1913 and the details will be discussed in connection with that freshet. It is, however, necessary to point out that the flood was already exceptionally high before it reached the Neeve Street Bridge. It had overflowed the banks at Riverside Park and threatened to break the dam there. Goldie's Dam was only saved with difficulty by strengthening it with bags of earth. At Allan's Dam the flood burst up the race and returned to the river by a roadway. The block which formed at the Neeve Street Bridge was formed largely of timbers from a footbridge at the Homewood Sanatarium and one connecting Goldie's flour mill with its cooper's shop, washed away from far up the river. There was other debris from small buildings within the city, but the amount of property within reach of floods on the Speed above Neeve Street is not very great.

The bridge at Husskison Street (also fairly new) and Gow's Dam farther down the Speed also backed up the water so that all the low ground was flooded. All access to the Agricultural College and all that side of the river was cut off until Sunday night. The flood here must have been increased by that on the Eramosa which reached Guelph before the Speed had subsided entirely. Not all the damage was due to the two rivers; small creeks also overflowed and covered the Collegiate Institute campus with two or three feet of water. This flooding also did damage in a motor works and caused loss of $4,000 to a shoe company. The sewage disposal plant was completely covered.

The Guelph Carpet Mills Company was at the time considered to be the heaviest sufferer. However, in the end the Guelph Worsted Spinning Company was awarded $15,000 damages against the City for the flood of 1912 and the Carpet Company $5,500. The Taylor-Forbes Company also suffered considerable loss and several other plants had their boiler rooms flooded so that they had to remain closed for some time. About a hundred houses were completely surrounded by water so that people were rescued from some in boats. Many others had their cellars or yards partly overflowed.

Altogether the flood at Guelph in 1912 was unique in the history of the city, though it seems to have been agreed that the water had been as high in 1869 and the damage as serious in proportion to the development of the town at that time. If any dam had broken in 1912 or if the flood on the Eramosa had come a few hours earlier, the flood would probably have reached the steps of Colonel Davidson's house without any assistance from the bridges. In that case the damage caused by narrowing the spans would have been even heavier.

(3) <u>1913 (March)</u>

As had happened in 1898 and 1899, the flood of 1912 was followed by one nearly as severe in March 1913. Galt reported three overflowings of the Grand River during that month. It was the floods following the spring break-up on March 12-14 and those caused by rain less than two weeks later that equalled, and in some places surpassed, the flood of 1912. The ice on the river below Breslau began to move late on Wednesday, March 12. The ice was unusually thin; for a thaw in January had cleared much of the river and the rest of the winter had been comparatively mild, the snow melting almost as soon as it had fallen. The situation was not considered threatening on the 13th, although a "tremendous ice jam" had formed near Freeport and ice was collecting on the City Dam at Brantford. By evening, however, the Grand was "blocked" from Newport to Galt and at Guelph the Speed was rising rapidly.

The next day the Speed, Upper Grand and Nith were all in full flood. At Guelph the Speed was "about on the level that usually results in flooding the carpet mills". There was still eight inches clearance at the Neeve Street bridge; but the Taylor-Forbes plant had been partly flooded. A sudden break-up of ice on the ponds was likely to be disastrous. The Corporation, with writs out against the City for 1912 damage, were watching the flood anxiously, but rather helplessly, for there was little that anyone could do.

A little before three o'clock on Friday afternoon the Grand broke part of McGowan's Dam, half a mile above Elora, and the sudden rush of water destroyed the flume and one turbine at Mundell's Furniture Factory. The river rose five feet in less than fifteen minutes, damaging other buildings, including another factory and a foundry. The news that the flood at Elora was the worst "in the experience of that town" naturally caused great alarm at Galt. Hasty preparations were made for a record flood and before night people were warned to be ready to leave houses along the banks. Paris was also threatened by the flood on the Nith, which at midnight on Friday overflowed at New Hamburg. For two hours the stream ran across the main street and down Union Street past St. Peter's Lutheran Church. The water for a short time was above the marks of the great flood of August 1883. There had been a great ice jam above Stuart's mill and as it moved out, the poles of the Hydro line between the Grand Trunk Railway and the town were broken.

Fortunately the ice, piled up eleven or twelve feet high on the dam at Brantford, had given way just after 11 p.m. on Thursday and the rush of pent-up water had sufficed to clear the Grand "from Newport to Paris". The flow of the Speed must have completed the work of clearance before the floods could reach Galt and Paris from Elora and New Hamburg. Consequently "the most serious result of the rampage of the Grand River" at Brantford, Paris and Galt was the breaking of the gas main on the Cockshutt Bridge. This caused loss of time in factories and newspaper offices, and forced "many citizens to be satisfied with cold lunches instead of hot dinners", eaten in some cases by lamplight.

The ice moved fairly rapidly down the river until it jammed behind the dam at Dunnville on the afternoon of the 15th. The sudden rise sent the water flooding through Main, Lock and Broad Streets. The water was higher than "for at least fifty years". An attempt to blast the jam at midnight on Saturday had little effect. Streets and houses remained flooded until Sunday evening. The river had already fallen ten feet at Galt; the Speed had not risen further; the dikes at Brantford had controlled the flood and the first freshet of 1913 was over by March 17 with little damage in the cities. The loss at Dunnville was probably greater than at Elora and New Hamburg which estimated $5,000 apiece.

The second flood took place on the Grand a few days later, probably on March 21 when a "hurricane" raged at Guelph and other parts of the watershed. This was followed on the night of the 23rd by a heavy rain lasting into the next morning. This brought on a second flood on the Speed and a third on the Grand, both more severe than the first. The flow of the Speed at the Neeve Street Bridge in 1912 was calculated to be 4,400 cubic feet per second, the flow at "the normal high water mark for floods" being given as 2,350 c.f.s. The river overflowed considerably near the Eramosa Bridge, reaching the doorsteps of the houses and entering the cellars. Some part of Allan's Dam was carried away without breaking the dam itself. This section was

> "deposited against the side of the railway bridge, causing a much greater fall, succeeded by a higher rising of the boiling stream, as it plunges on to Neeve Street bridge, where the water is higher than the arches and great logs are jammed against the structure. The City Engineer, with a gang of men, used pike poles, ropes, and blocks and tackle to remove these obstructions."

At the time this was written rain was still falling and the river rising. The carpet mill was surrounded by water but not yet actually flooded. At Husskison Street the water backed up by the bridge was spreading over the sidewalks. The dye room of the Canadian Textile and Weaving Company, the basement of the spinning mill and part of the Taylor-Forbes plant were also already flooded. By evening there was eighteen inches of water in the latter and some had entered the carpet factory. This must have been near the crest of the flood, for on the whole the damage was less than in 1912 and the area flooded not so large. There is no reference to damage from flooded creeks. The Guelph Worsted Spinning Company brought a second suit against the City and eventually received $5,500 damages for 1913. Taylor-Forbes' loss was estimated at $1,000 or more.

The Grand River seems to have begun rising at Galt somewhat sooner than the Speed at Guelph. By afternoon it was overflowing the retaining walls, backing up drains and spreading over low ground. The area affected was much the same as in 1912. As the river began to fall on the 25th the retaining wall of the Central Presbyterian Church collapsed, endangering the west abutment of Main Street Bridge. The danger was almost past by evening, for the water had gone down two feet in as many hours. The damage was heavy; several plants were closed down and it was said that "never before have riverside manufacturers suffered so much from high water as this year".

This was not the case at Brantford, where the three floods did little harm. The water on the 25th was eight feet six inches over the city dam - six inches lower than in the first freshet which had been "about equal" to the flood of 1912. The high water on March 16 had been partly due to ice jams, so the volume of water in the river on the 25th was evidently greater.

This series of very severe floods strengthened the feeling which had been growing for thirty years that "something must be done about it". However, the idea still prevailed that such flooding was unnatural and would not occur if the river bed were cleared of artifical obstacles and possibly straightened in a few places. At a meeting held in Guelph before the 1913 flood was over, several property owners suggested "doing away with some of the dams in the river, claiming that they hold back the water during the spring thaws and rains, and that if these were done away with the trouble would cease". The Neeve Street Bridge was indicted as a nuisance in the cases against the City; but had already been altered to allow a greater flow, when the judgment sustaining this indictment was finally given in January 1914. The inhabitants of Brantford put down part of their immunity in 1913 to the fact that an additional hundred-foot span had been added to the Grand Trunk Railway bridge.

The most important consequence of these floods was the establishment in the summer of 1913 of a number of flow-gauging stations on the Grand and some of the larger tributaries. These were for several purposes, for proposals to develop the

Grand for the production of electricity, and possibly to revive the navigation, were just then being given serious consideration. A careful study of the fluctuations of flow in the river was essential before any decision could be made with regard to these plans. The data collected were, and are, very useful for the study of floods on the Grand, but they revealed also the extreme low flows common in summer. The hydro-electric schemes were given up as impracticable and some stations were abandoned, while at others readings were discontinued for a time. As a result a continuous record is available only at Galt.

The records of these stations are given in the hydrographs which are included in Chapter 8. They indicate some of the years of extreme run-off, but do not give the full picture. The figures on which they were based represent the mean between two daily readings separated by an interval of several hours. In many winters, conditions prevented regular daily reading of the gauges and the mean was struck for a period of weeks or months. It was often within these periods (which show as blanks on the hydrographs) that the peak floods occurred. Some of the most serious are not indicated at all on the charts. In other cases the flood appears to have risen quickly to extreme height from a comparatively low level and to have begun to fall rapidly before the second reading was made. The mean for the day when the flood reached its highest reported point may show lower on the chart than that for a day or two later when the already swollen stream rose to a somewhat lower peak and fell more slowly.

(k) <u>1914 - 1934</u>

Nevertheless, 1913 marks the beginning of serious study of flow conditions on the Grand and a definite attempt to co-ordinate the efforts at flood protection. It was to be more than twenty years before this attempt produced concrete results. But allowance must be made for the outbreak of war in 1914 and for the natural tendency for public concern over flooding to wane during periods of comparatively light run-off. As the hydrographs indicate, such a brief period of moderate flow followed closely on the floods of 1912-13.

The more normal break-up of 1914 was preceded by an unusually heavy formation of ice in the river. It was anxiously watched at Galt, Paris and Brantford. Precautions were taken and officials were alert for the first sign of danger. But no very bad ice jams were formed and, though cellars were flooded at Galt and some flats overflowed near Brantford, the damage was on the whole slight. The next year may be regarded as free from floods, but in 1916 the river rose higher than it had for three years. Timely precautions again prevented serious loss at Galt and Brantford. Flooding of flats at Preston and around Blair interrupted traffic on roads and railways. A threat to the Husskison Street Bridge at Guelph forced the dynamiting of part of Presant's Dam and resulted in a serious accident to the mayor, whose leg was broken by a piece of flying concrete from the dam. There was no flooding to speak of in 1917, though the mean flow of the river was somewhat higher at the break-up in March than in the previous year and sharp rises occurred in June and July.

(1) <u>1918 (February and March)</u>

A sudden thaw on February 20, 1918, took the merchants of Galt by surprise and did some thousands of dollars damage to goods stored in cellars. The water rose high enough to pile thick blocks of ice against the Main and Concession Street Bridges, breaking the gas mains below the roadway, causing leaks in the watermains above and damaging the roadways themselves so that traffic was interrupted for some time. At Brantford an ice jam brought the water "three feet over the highwater mark of six years ago". But the water was still well below the top of the heightened dikes at Eagle Place and the timely breaking of the jam prevented serious damage. At Guelph a sudden return to cold weather was credited with saving the city from a flood as bad as in 1912. As it was, some factories and cellars were flooded, although the water was successfully kept out of the carpet works. A considerable area of low ground was covered with water.

There had been no January thaw in 1918 to clear some of the ice out of the river. This had increased the danger in February, but when the final break-up came, exactly one month later, much of the river was clear. There was little damage from Paris up. At Brantford on March 20 the river was at danger height and still rising. The Eagle Place dike had been breached near the City Limits and some acres were flooded. The following morning the ice took out the bridge at Dunnville without much other damage, and the serious situation expected at Brantford did not develop.

(2) 1922 (March)

It was not till 1922 that another really severe flood took place on the Grand although the mean flows were high in March 1919 and there was some damage at Paris in 1920. The flood at Galt on March 7, 1922, was considered to be "nearly equal to that of 1912". Ice blocks again floated down Water Street and "for two blocks on Water Street South there was two to three feet of water in the houses......". The bridges again took a pounding from the ice. Traffic was stopped on Main and Concession Streets and on the Grand River Railway bridge. Although the flood (partly due to a jam upstream) lasted only from 4.30 p.m. until about six o'clock, the damage was believed to be "thousands of dollars".

There was some flooding of roads below Brantford in 1923 and of buildings at Guelph, Waterloo and Kitchener in 1925. The pattern of 1928 and 1929, however, almost reproduced that of 1912 and 1913, though in this case the second flood was the more serious.

(3) 1928 (March)

The Grand at Galt and Paris was as high on Sunday, March 25, 1928, as it had been on Easter Sunday, 1912.

The damage at Galt was considered to be less because of the absence of ice. A jam had formed above Blair on the Friday night, but warm weather the next day allowed most of the ice to pass Galt quietly. Rain began towards evening on Saturday and lasted into Sunday morning. The river rose rapidly until the millrace overflowed and flooded North Water Street, while the river overflowed retaining walls and backed up storm drains to flood cellars of stores a block from the river. Some inhabitants of South Water Street showed the usual reluctance to leave their homes when first warned by the firemen. At least a dozen families were "marooned", and had to be brought through a considerable depth of water. The flood began to go down about 3 p.m., nearly nine hours after the rise had begun. Blair had been isolated on the 24th when the river overflowed the roads. There was similar flooding on the Preston flats which cut off at least one house and covered the C.N.R. tracks with two feet of water.

Serious flooding at Paris resulted in heavy loss and led to the building of a dike to protect the Elm Street area, completed during the following summer. The flood at Brantford was alarming, but seems to have caused little damage. A second rise occurred on the 27th and was checked by cooler weather.

(4) 1929 (March)

The heavy rain on January 19, 1929, which did so much damage in other parts of Ontario, caused comparatively little trouble on the Grand. The ice went out on much of the river (causing some people to suppose that this was the break-up) and the water overflowed to some extent at certain points. More ice formed before the beginning of March and when the real break-up occurred on the 14th, after 24 hours of rain, the condition was really serious. In most of the floods of the 1920's the reports have little to say of conditions on the upper river and tributaries. There must, however, have been some flooding and there had been ice jams below Bissell's dam at Elora in several springs before 1929. The fact that no jam formed there on March 14 led to the belief that the flood would not be severe, although later in the day a rush of ice, trees and timber from higher up broke the windows and flooded the cellars of buildings along the river. More ice and the debris of wrecked barns followed on the 15th, indicating widespread flooding upstream, and three factories had to close down because their ground floors were under water - four feet deep in one mill. The waters of the Grand began to fall by Sunday the 17th but in the meantime the Irvine had swept away the bridge on the Bonacord Road, cutting off a considerable stretch of country. The ice on that river had jammed at Jamieson's Mill, backing the water over the banks for several miles. It looked as though there might be more trouble when this jam broke, but a change in the weather allowed the river to fall before this happened.

The flood on the Conestogo was equally formidable. Two spans of the Schiefl bridge were broken by the ice, causing $20,000 damage; cellars were flooded in St. Jacob's and there was three feet of water on parts of the Lexington and Waterloo Roads. The combined floods did little damage at Bridgeport, but at Freeport, where the ice began to jam, the river "so increased that the water entered the stables, a condition never before experienced". In the early hours of the 15th, one of the piers of the Grand River Railway Bridge at Freeport was undermined so as to displace two of the heavy iron spans and one of these later slipped into the river.

The rush of water from Freeport and above backed far enough up the mouth of the Speed to flood some cellars in Preston and spread over the flats there and at Blair, blocking roads and railways. At Galt this first peak was considered to be nearly equal in height to the flood of 1912 and definitely the worst in seventeen years. About a mile of Water Street was flooded to such a depth that the firemen used boats in their rescue work in some places. Two bridges were damaged by ice and the next day a conservative estimate placed the loss at $15,000, not counting the loss of time and wages from the closing of plants along the river. The second peak on Saturday afternoon was believed to set a record. It was certainly higher than 1912, but possibly not above those of more remote freshets. The water again flowed over the walls, but the high water was over in a few hours and as there was no ice the loss was much less than it might have been.

The Speed had already reached flood levels at Guelph on the 14th. The situation there continued to be dangerous till the 17th. But when the river began to fall there had still been comparatively little damage.

At Paris on March 14 the Grand was within a foot of the highwatermark of 1912 (a little higher than in 1928) and the Nith had already risen sufficiently to cut off several houses on Coney Island, about 150 yards above the confluence. The new dike protected the Elm Street area, but the Penmans plants were partly flooded and employees in one section had to climb down a fire escape into a truck. The Grand fell considerably during the night, "but the Nith ...... put on a real demonstration at six this evening (March 15), overflowing its banks and leaving chunks of ice weighing a ton or more all over Coney Island". Several houses were badly flooded and one was "demolished, half of it going downstream .... it was the most destructive the Nith has staged in years". The second rise on the Grand on the 16th did not improve matters. It was not till Sunday morning (March 17) that many people were able, for the first time in twenty-four hours, to leave their houses without rubber boots.

Until Thursday night the break-up at Brantford was still expected to be "the quietest in years". However, during the night the river rose to nine feet ten inches above normal - "the highest level recorded since the twelve-foot flood of 1912". The Grand left its bed above the city and rushed across the northern flats, scattering huge floes through the suburbs. There was serious flooding and ice damage at the waterworks and the canal overflowed, washed out fill, flooded car tracks and threatened factories. The river continued to rise until Saturday afternoon, the final level being about ten feet six inches.

On the lower river the worst flooding was at Cayuga and immediately above it. An ice jam formed south of the village on Friday morning and soon had brought the water ten to twelve feet above normal. Houses 200 yards from the river had their first floors flooded. Others had their cellars full of water and part of the village was isolated. Farmers lost heavily from the spoiling of potatoes, roots and apples stored in cellars and root houses. There was less serious flooding at Caledonia and at York, while the river road between them was under water in several places. Dunnville had been expecting flooding when the dam broke, but it appears to have gone out gradually on Friday afternoon, after about eight hours, and the water at Cayuga fell quickly. A similar jam below Dunnville that had caused alarm at Port Maitland on Friday night also went out without doing much damage.

(5) 1929 (April)

The loss in this March flood must have run to many thousands, but it is obvious that it was reduced to some extent by the fact that a flood was expected and some precautions had been taken in advance. The floods which struck almost three weeks later were completely unexpected. The snow and ice were largely gone, most of the frost was out of the ground and suckers were already running in the Grand. The flood therefore belongs rather with the flash floods of summer than with the ordinary spring freshets, though the fact that the river was still above normal height would increase the extent of flooding.

The severe thunderstorm which began the freshet struck the upper part of the Grand Watershed in the early morning of April 5, moving from the north-west. By afternoon the Grand at Elora and the Speed at Guelph had both reached flood height. The next day factories in Elora had to close down because their ground floors were flooded. There was serious flooding at Waterloo, Bridgeport and Breslau and other points; roads were under water and railways washed out in several places. Both the Irvine and the Grand were considered at Elora to have reached "the highest point on record", but at Bridgeport, although the river rose about ten feet until it was nearly level with the bridge, the water in the houses and streets was not so deep as in several former floods.

It was the flood on the Speed at Guelph that really broke all records, surpassing that of 1912 and possibly also the flood of 1869. The rain had continued after the thunderstorm through Friday night and on Saturday morning (April 6) was becoming "torrential". The Speed and its tributaries were already swollen to flood height. The breaking of the dam at the Jesuit Novitiate north of the city sent the contents of this pond down the creek into the Speed. The rush of water damaged the sluice at the Speedvale Mills and carried away part of Goldie's Dam. The crest formed by the contents of both ponds, combined with exceptionally high flow, was possibly the greatest so far recorded at Guelph. Allan's dam fortunately held and this prevented a really serious catastrophe. But it did not prevent unusually heavy damage to both factories and homes along the banks of the Speed right through the city. At the same time the Eramosa spread out "like a lake" over the grounds of the Reformatory and adjoining streets. Traffic on the C.P.R. was interrupted by a washout and on the Electric Railway and some highways by flooding. The loss in the plants flooded was reasonably believed to amount to "hundreds of thousands of dollars", without taking account of the damage in the houses.

Galt got the brunt of the floods on both the Grand and Speed, but the two crests did not reach the town at exactly the same time.

> "The remarkable feature of the flood was...the suddenness with which the river rose, victims of the high water having no time to save anything. At 5.45 o'clock (a.m.) water started bubbling out of manholes, and an hour later it broke out upon Water Street, which by 8 o'clock had been converted into a river. The flood reached its maximum point about 1 p.m., remained stationary for three hours and showed the first signs of abating at 4 p.m."

The dams at Guelph are reported to have broken just after 6 a.m. on Saturday, so that, if the times given at Galt are accurate, the Grand must already have been flooding Water Street when the Speed crest reached Galt. It was certainly the flood from the Speed that kept the level stationary for so long. Most of the incidents of 1912 and 1913 were repeated, but the water was definitely higher and the areas flooded larger. "The east side of the river, a block back from Water Street to Ainslie Street, was inundated from Simcoe to the southern limits." The water was from three to four feet deep on Water, Ainslie and Dickson Streets and eight feet was reported in a lane north of Main Street.

The damage was proportionately high - "Not an industrial plant on the east riverbank escaped". Two days after the flood, an estimate of $250,000 was considered conservative. Fifty-seven victims had reported losses totalling $120,000 and many manufacturers and merchants were still unable to give an estimate. In addition there was the loss of working time to hundreds of hands, from flooding of plants and the failure of electric power, and the further cost of cleaning up and pumping out cellars.

This was all water damage; if there had been ice in the river it would have been much greater. As the rain had stopped soon after the flood began and the day was sunny, the unusual features at Galt included canoeing on the streets, boys swimming on Dickson Street and the taking of suckers in streets and cellars. The absence of ice was responsible for the fact that there was little damage at Brantford beyond the brief flooding of some roads and bridge approaches. The level was a little higher than it had been in the March flood, but not high enough to go over the dikes.

The floods of 1929 made the inhabitants of the watershed more determined than ever that something must be done to control the river. It was now plain that the problem could not be solved simply by works designed to protect a particular area and carried out independently by municipalities or property owners. Co-operation between the cities and towns exposed to flooding was now much closer and a definite plan was beginning to take shape. However, several years of discussion, investigation and negotiation were required before the necessary legislation was passed and the first control works begun.

In the intervening years the character of the freshets was influenced by unusual weather conditions. The winters of the early 1930's were, on the whole, remarkably mild and open. Although periods of low temperature occurred and there were some heavy falls of snow, these alternated with longer spells of mild weather, sometimes almost approaching summer temperatures. As a result the rivers broke up several times in most winters. When these thaws were accompanied by rain there was flooding of varying degrees of severity.

The break-up of January 8, 1930, was regarded as the earliest in seventy-two years, though this took no account of December floods, such as the very severe one in 1893. This January freshet was followed by one on February 21-22, while the Galt hydrograph records a third rise (probably the lowest) early in April. None of these did any damage to speak of, nor were the spring freshets of 1931 of much account. On Christmas Day, 1931, however, a freshet broke up the ice at Elora and at Paris and made a sufficient impression to be remembered and counted as one of the four floods of the winter of 1931-2.

(6) 1932 (January, February and December)

The second of these, on January 8, 1932, was remarkable chiefly because it followed a record drop in temperature; the third, six days later, flooded low ground between Birkett's Lane and the Cockshutt Bridge below Brantford. This freshet was caused by heavy rains, as was also the fourth flood on February 11-12, the most severe of the four and general over almost all the watershed. The flood on the Conestogo was thought to be "the highest since 1904"; at Bridgeport, the highest in five years; and at Guelph, the highest since 1929. Although there was some ice in the rivers, no jams seem to have formed and the damage was less than might have been expected from the "enormous volume of water". Cellars and basements were flooded at New Hamburg, Waterloo (by Laurel Creek), Conestogo, Paris and Preston. At Galt there was eighteen inches of water on Water Street South; houses were isolated and some cellars flooded farther back from the river. Families were also cut off at Bridgeport and Blair, where motor and railway traffic was stopped for some time. The water was several feet deep on the highway at Bridgeport and two feet deep in places between Caledonia and Cayuga. At Brantford and Paris, however, this February flood was not considered to have reached the height of one of the earlier floods, presumably that of January 14.

Four floods might be thought enough for one twelve-month period and, in fact, the spring, summer and autumn mean flows of 1932 were moderate, though always a little above normal. But the winter of 1932-3 seemed likely to repeat the pattern of the previous year. There was a freshet early in December that caused some flooding around Elora. This was followed by cold weather and a blizzard. When higher temperatures and heavy rain began on December 23, the ice above Bridgeport went out on Christmas Day for the second year in succession. The ice passed Galt about 3.30 p.m. and reached Paris in about two and a half hours. The Nith was also in flood and when it broke up the following day the ice carried away the centring under the arches of the new Nith Bridge and destroyed the temporary footbridge. Fortunately the first crest on the Grand had already passed Paris. A second crest, caused by the break-up of ice above Elora, about noon on the 26th, had not yet reached the town. The damage here and at Brantford was not serious and little is reported higher up.

(7) 1934 (March and April)

The winter of 1933-34 was more severe. There was a good deal of snow and when the first thaw came at the beginning of March the rivers and streams were full of ice. By March 3 serious ice jams had formed below Belwood, above Bridgeport, Galt and Brantford, and below Caledonia. There was serious alarm all down the valley, but cold weather checked the run-off before much flooding had occurred. Two weeks later very similar conditions produced another series of ice jams. Some of these were of great size. The jam at Belwood was thought to be the largest known and that at Galt was three miles long. The weather turned colder on March 17, but this only served to fix the ice more firmly. Before the cold weather had checked the freshet the water had backed up sufficiently to flood some highways and much farm land.

Some stretches of the river were reported clear of ice after this freshet, but the greater part was still in the river when the final thaw began on April 2. Attempts to move the jams by dynamiting had been unsuccessful. There was much excitement and alarm as the ice moved down on April 4 and 5. Some cellars had been flooded by the backing up of the Speed at Preston and of the Grand at Elora. A bridge at Grand Valley was swept away and others were damaged by the Grand or Speed. Fields were flooded and strewn with ice; fences were destroyed; but the larger towns escaped damage and very little was reported from the rest of the area.

In 1935 and 1936 the Grand River cleared in the middle of March with some flooding of highways and farmlands, but with little damage in the towns beyond a few flooded cellars. There was a sharp freshet in June 1935 and a second and higher crest on March 25-26, 1936, when warm weather followed heavy snowfalls. This flooded some basements in Elora and covered "hundreds of acres of farmland in Pilkington Township". The heavy rains in April 1936, that brought catastrophe to London, Ontario, only caused a slight rise in the Grand at Galt, and it was not until late in December that there was trouble from the river.

(1) <u>1937 (January, February and April)</u>

Between December 25, 1936, and February 9, 1937, the Grand broke up and froze over again five times below Bridgeport and four times at Fergus. Each of these freshets was accompanied by some overflow and three at least were regarded as floods. Galt reported floods on January 1, 9 and 14. The last was apparently the highest of the three; at Brantford on January 15 the Grand was higher than it had been in 1936. None of these floods did much damage in the towns, but there was a good deal of overflowing of low ground, and fields near Preston and elsewhere were strewn with blocks of ice.

The fifth freshet of the winter, and the fourth in 1937, rose to 12 feet above normal at Galt on February 9 and at Fergus was considered the highest "in twenty years". There was some heavy flooding on the Nith at New Hamburg; the Speed was at flood height at Guelph but did no damage there. Smaller tributaries were also in spate, Cedar Creek threatening serious flooding at Ayr and Laurel Creek flooding parts of Waterloo. Ice jams formed at several places in the river and these increased the damage when a storm on February 22 brought on another freshet.

This flood was considered to be the highest seen at Fergus in "fifty-five years". The Grand rose 12 feet in less than an hour and flooded houses and factories, while gardens and roadways were overflowed by a small creek on Garafraxa Street. The Grand also flooded part of Elora and the Canagagigue practically isolated Elmira, overflowing streets and highways, in some cases four feet deep. There had been bad ice jams near Fergus, and at Guelph the ice on the Speed carried away a footbridge, but this flood cleared most of the river. When rains brought a high rise early in April and another on April 26, these sixth and seventh freshets of 1937 were regarded only as threats of flood.

In the same way the flood of February 6, 1938, which broke the Shantz Dam at Preston and flooded the highway to Kitchener, cleared the river so that higher flows in March did little damage. In 1939 the ice was exceptionally thick on the upper river and the snow very deep. There were no early thaws and when one began in the last week of March trouble was expected. A rather high rise on the 26th cleared much of the lower river without doing more than flood some flats. The ice above Fergus did not break up until some days later and a jam at Grand Valley was dynamited on the 29th. This ice also went out slowly without serious flooding. The much greater rise on April 19 was caused by rain. The Nith and Speed rose at about the same time as the Grand, causing alarm at Paris and Preston. Highways were flooded at Grand Valley and near Caledonia and all along the rivers low ground was under water. Only the fact that the Grand was clear of ice prevented more serious damage in the towns.

No single flood in this decade was as destructive as the great freshets of the past, but such a succession of threatening high water naturally increased the demand for action on flood control. In 1932 a survey of the valley had been carried out, sponsored by the Chambers of Commerce of the principal cities and towns. The Grand River Conservation Commission was established by letters patent in 1938 and

Commissioners appointed from eight urban municipalities. In the same year The Grand River Conservation Act was passed to provide Government help for the projects. Four units - one on each of the Grand, Conestogo and Nith Rivers, and one at the Luther Marsh - were decided upon. In the summer of 1939 work began on the first, the Shand Dam, between Fergus and the village of Belwood. The Governments of Canada and of Ontario undertook to bear seventy-five per cent of the cost in equal shares, the rest being divided between the municipalities of Brantford, Kitchener, Galt, Waterloo, Preston, Paris, Fergus and Elora, partly on the basis of size and partly on that of exposure to flooding.

(m) 1940 - 1954

The work on the Shand Dam was not interrupted by the outbreak of war, although this was to make it necessary to postpone the other units planned to control the tributaries. Low flows through most of 1939 and the beginning of 1940 reduced the spring freshets on the Grand. The Nith was high enough at the end of March to cause a serious railway washout near Baden; but when the ice on the Upper Grand went out on April 8 the water in the gorge at Fergus was reported to be about 15 feet lower than was usual at the break-up. The effect of this was felt at least as far down as Galt, but farmlands were flooded in Pilkington Township and highways near Brantford and Caledonia.

The river was as high in the last days of December 1940 as it had been in April, but the next serious flooding on the Grand was on March 10, 1942, when New Hamburg was heavily flooded by the Nith, blocked by three ice jams near the village. There was heavy flooding on the Grand at this time, but the river reached a much greater height a week later. On this occasion there were floods on the Canagagigue and Conestogo; Galt reported the "worst flood since 1929"; the Nith broke up a second time, flooded New Hamburg and caused flooding at Paris and flats were overflowed at several places on the lower river.

Continued rain in May 1942 caused a summer freshet that did some damage on the Upper Conestogo at Drayton and on May 31 at Shelburne on the upper waters of the Grand. This flood rose 15 feet above normal at Galt, high enough to cause some flooding. The overflowing of flats along the river at this season is a much greater threat to crops and cattle than in the early spring break-up. In August the Shand Dam was completed, so that in all subsequent floods there was some measure of control of the waters of the Grand River.

(1) <u>1943 (March - April)</u>

It was not long before the new reservoir was tested by a very severe flood. The first freshet of 1943, on March 17, was not remarkable, but with the melting of accumulated snow in the last week of March a flood developed on the Upper Grand that filled the new Belwood Lake nearly to capacity by the night of April 1. It is reported that "on the upper river run-off was 63% in excess of any known record". The flood on the various tributaries was similarly high and by holding back somewhat more than 40,000 acre feet of water in the reservoir until the crest on the tributaries had passed, the Shand Dam probably prevented a record flood. As it was this flood was sufficiently severe. A bridge was swept away in Nichol Township, houses were isolated, and highways blocked in several places. At Galt the river reached 13.5 feet on the evening of March 31, having risen 3.7 feet in less than twelve hours. This was not the peak for there was flooding below Galt the next day, but the peak at Brantford was 1.7 feet below that of 1929. It was plain that the $2,056,487 spent on the project had been entirely justified, but it was equally plain that this single dam could not give full protection to the watershed. This flood was followed by a higher one on May 12, 1943. This time the water was 14 feet 3 inches at Galt and parts of Water Street were under water, whereas in March only cellars were flooded. Once more the dam probably prevented more serious loss, especially to farmers, some of whom had difficulty in saving their stock. More than fifty cattle and horses were marooned on one piece of high ground below Brantford. Another May flood in 1945 did some damage at Preston and other points. There was a fairly heavy flood in March of that year and some damage from ice in March, 1946, but so far the 1940's had not produced a record flood. This was to come in the following April, followed by two more summer floods in June and July, 1947.

(2) 1947 (April)

The spring freshet of 1947 began on the lower river with the breaking up of the ice on March 23. Two weeks of "semi-flood conditions" followed at Brantford. The Shand Dam was restricting the flow on the Grand, and even after twenty-four hours of steady rain on April 4 and the break-up of the Nith, Conestogo and Speed on the 6th, the dam continued to give a large measure of protection to the towns along the Grand River. The river was, nevertheless, very high and New Hamburg and other places had suffered severe flooding by April 7. The flood at New Hamburg was called the worst "in over 32 years" and at Brantford the Grand was considered to be at nearly record height on April 6. There had been comparatively little damage on the main river, and when the water began to fall for a time, rather too optimistic hopes were held out that the loss would be trifling compared to past floods.

The rain continued on the upper watershed. By April 10 it was obvious that Belwood Lake could not contain the whole run-off. Warnings were issued, and on April 11 the gates had to be opened and a huge volume of water released. The river had risen 11 feet at Grand Valley and this discharge from the dam changed the already severe flood downstream into one of the worst on record. All down the river - at West Montrose, Conestogo, Bridgeport, Blair, Galt and Glenmorris - houses and roads were flooded and families evacuated. At one point between Galt and Brantford on Highway No. 24 there was six feet of water over the road. At Brantford the height of water (7 feet 8 inches) was less than earlier in the week, but several families had to be moved for the second time. Lower down, near Caledonia and elsewhere, flats were again flooded and highways closed. As the hydrograph indicates,the crest at Galt was much higher than in any flood since 1913.

In so recent a flood it is not necessary to give full details of the flooding, but some items of damage (reported in 1950) are of interest. In the earlier flood on the Nith and Conestogo, a bridge over the Conestogo cost Wellington County $8,000. Two items from Ayr totalled $1,800. Damage at Plattsville was placed at about $500. No estimate of the much heavier loss at New Hamburg was given and there were several other losses reported without estimates. In the later flood of April 11-12, a survey of 19 sufferers made at Galt, just after the flood, gave a total of $20,300. Paris reported $2,239 for repairs to dikes on the east side of the river and $1,857.60 for "cleaning the river" in 1947 - a cost of over $4,000 to the municipality. The Galt estimate is certainly incomplete and the private loss at other points on the river can only be guessed at. It would have been heavier if there had been less warning before the crests struck.

(3) <u>1948 (March)</u>

The need for a full program of flood control had been amply demonstrated and the dwellers on the Grand were given little chance to forget it. Apart from the two summer floods already noted, in which the Belwood Reservoir was functioning at full efficiency, the spring flood of 1948 was much worse than that of the previous April. The flood began on March 16, when the unusually thick ice began to heave on the Nith and Conestogo and on the Grand River below Bridgeport. The water was already above normal, but Belwood Lake was not full and the ice from Fergus to Bridgeport was still firm. The next day the ice, after jamming briefly above Galt, passed down river below Brantford without doing any serious damage, although the Grand reached 6 feet 6 inches above normal in that city. Highway No. 54 below Caledonia was blocked by ice cakes and the ice was jamming above York, but still it was hoped that no serious damage would occur.

Unfortunately another jam formed above Caledonia and, after the Speed had broken up, threatening Preston with heavy flooding, the outpourings of the Speed and Conestogo broke this jam, forcing tons of ice into the streets of the town. The great mass of the ice moved down the river to pile up behind the dam at Dunnville. Here it hung until 9.25 p.m. on March 18, when it went out with a roar after flooding had already begun in the town. The ice on Lake Erie was still firm, so the river ice soon filled the five-mile reach between Dunnville and Port Maitland. On March 19 this jam broke explosively, wiping out a pier and buildings and tossing fishing boats like corks, fortunately without damaging them seriously.

This first flood cleared the ice from the lower river, but meanwhile milder weather and rain had been completing the break-up above Bridgeport. The ice went out above Grand Valley early in the afternoon of March 19 and the river rose at once and flooded most of the village. There was still storage space in Belwood Lake. It was not found necessary to open the valves; but the rain was growing heavier and exceptional floods were developing on all the tributaries. By morning on the 20th the Grand at Galt had reached a height of 17.6 feet, said to be the highest on record. Record floods were reported on the Nith, Conestogo and Speed and as the crests swept down the rivers the flats were overflowed, dams and bridges injured or destroyed and traffic on roads and railways blocked by flooding or washouts. Some smaller creeks also took their toll and from above Bridgeport to Cayuga the low-lying streets and buildings in towns and villages were flooded to an extent unknown for years. No such flood had been seen on the Nith at New Hamburg since 1883, and a similar account was given of the flood wave at Hawkesville on the Conestogo.

The damage was mostly from water, for the ice passed down before the crest was reached. The river was definitely falling by March 22, but it was not until two days later that the flood could be said to be over. Even then the water was above normal and on March 31 it rose sufficiently to wash out the C.N.R. line near Brantford more seriously than during the main flood.

The winter and spring freshets of 1949 were less remarkable, though the rise in March was high enough to cause flooding in various places. These three freshets would have been more serious without the protection afforded by the Shand Dam, and this was still more the case with the high water of December 22, 1949. This freshet caused a twelve-foot rise at Grand Valley which flooded the streets and highways. There was heavy flooding on the Nith at about the same time; but the crests at Galt and Brantford were much lower and, though flooding was reported from several places, the damage was not serious and items reported for 1949 are small compared to those for 1948 or 1950.

(4) <u>1950 (March and April)</u>

In 1949 the dikes at Brantford were raised and extended, costing the city, with some other items of river clearance, $13,500. This money was well spent; for in the spring flood of 1950 the water again rose close to the top of the dikes. A small additional rise would have overtopped the dikes and loss would have been extremely heavy.

This flood had two separate peaks. The first, on March 28, was very severe, especially on the Speed. It was recognized at the time that this flood was "coming from the Conestogo, the Irvine, the Speed, and all the little rivers and creeks". The rivers rose rapidly, the Grand reaching its peak at Galt and Brantford on the morning of the 29th and falling as rapidly on the morning of the 30th. They were, however, still much above normal on April 4 when heavy rain started a second flood. This time the peak at Galt on the 5th was 15 feet, .9 feet higher than in the previous week and only about 2½ feet lower than in 1948. The same places were flooded for the second time in six days, Hespeler, Preston and Guelph again suffering heavy damage.

All this time the Shand Dam had remained closed. It was not till April 6, when the second flood was almost over, that a moderate amount of water was let out of the reservoir. As a result there was little flow in the Grand below the dam, though there was flooding above it, and the heavy run-off from the Irvine did comparatively little damage above Bridgeport. It was this limiting factor, as well as the precautions taken as a result of timely warnings, that reduced the loss at Galt and Paris, and it probably saved West Brantford and the Eagle Place area from disastrous flooding. As it was, the damage to private property at Brantford in the areas affected by this flood and by the two other very severe floods of the decade was estimated to be "not less than $100,000" in each case. Elsewhere the degree of loss varied. In Guelph, Preston, Hespeler and Waterloo it was considered to be far above 1948 and at New Hamburg to be very little less. Some rural municipalities also reported large items for replacement of bridges and repair of roads. On the other hand the estimates received from several towns and villages were considerably lower than two years before. Hespeler was probably the heaviest sufferer. A list of losses produced at a council meeting on May 8, 1950, includes the Town of Hespeler, the Canadian National Railways and eight business establishments and totals $140,526.

During the last four years there have been at least two major floods on the Grand and a number of freshets high enough to cause flooding. The flooding in 1951 was comparatively unimportant and the same might be said of the freshet of March - April, 1952, in most parts of the watershed, but there was heavy flooding at Drayton on the upper Conestogo due to ice jams, and Grand Valley also suffered to some extent. The floods of February 21 and March 4, 1953, must be classed as severe, particularly on the Conestogo and Speed and on the Grand below the confluences of these rivers. Although not disastrous, these floods caused a considerable amount of loss and inconvenience.

This is also true of the freshets produced by prolonged rains in May 1953. In this case the damage was very largely due to smaller tributaries, such as the Canagagigue at Elmira, Laurel Creek at Waterloo, Hopewell Creek at Breslau, Mill Creek at Galt and tributaries of the Speed near Hespeler. However, the Nith caused flooding at Milverton and Wellesley Village and some flooding at Galt on May 26 was attributed to the Grand itself.

(5) 1953 (June)

It was, however, the flash flood of June 17 that made 1953 remarkable as a flood year. This flood closely resembled the great flood of almost seventy years earlier and was thought to be "nearly as bad". Like the flood of August 1883 it was most severe on the Nith, but this time the "torrential downpours" that raised the rivers covered a wider area. The storm centred between Stratford and Kitchener and there was heavy flooding from Laurel Creek at Waterloo as well as on the Nith and its tributaries. The loss was heavy, much of it to gardens, crops and stock. If fewer buildings were damaged than in 1883, it was because at some places, as at Hayesville and Ayr, dams, mills, houses and so forth had disappeared from the flood plain in the seventy years that separated the two floods.

The flood of February 16 and 17, 1954, must be ranked as very severe. It was described on the 16th as a flash flood, but the crest actually came on the following day. This peak at Galt (14.7 feet) was lower than the April flood of 1950. It came mostly from the Conestogo, but the peak on the Nith at New Hamburg was very close to the "all time record of August, 1883". A second flood on March 1 - 2 reached 14.9 feet at Galt. This time there was flooding on the Speed as well as the Conestogo. In none of these floods was it necessary to let any appreciable amount of water out of the Belwood Reservoir. From the spring of 1952 the Luther Dam has provided additional flood storage. It may be hoped that before another major flood occurs the Glen Allan Dam will control the lower part of the Conestogo. This should afford a larger measure of protection to Galt, Brantford and Paris, but other measures will be needed before full control of the Grand River floods can be established.

2. The Cause of Floods

As indicated in Chapter 2, the conditions which cause floods may be grouped in two general classifications:

(a) Geophysical, which are permanent.

(b) Climatic, which are variable.

(a) Geophysical

The lateral slopes to the rivers are extremely high over the whole watershed, and the grades, particularly on the upper zone, are as high as 75 feet to the mile over some areas. With such surface slopes the snow melt or rain is delivered rapidly to the rivers via ditches, rivulets and streams, and reaches the rivers in such volume that it cannot be contained within the river banks in the low-lying land or flats. These physical features and the impervious clay soils, in conjunction with adverse climatic conditions, are fundamentally the cause of floods and subsequent low flows, the flood magnitude being chiefly dependent upon the climatic conditions. Once the run-off reaches the rivers it is carried away by channels which have average grades (Fig. H-2) of 6.4, 10.8, 6.6 and 16.4 feet per mile for the Grand, Conestogo, Nith, and Speed Rivers respectively. These are average grades, however, and in general the grades are much greater at the headwater zones and less downstream. Any decrease in grade will increase flood stages unless there is a corresponding increase in the width or cross-section area of the channel. The overall course of the Grand River is a good example. It has an average grade of 8.4 feet per mile at the headwater section, changes abruptly to about 4 feet per mile between Paris and Brantford, and from a point just below Brantford to Lake Erie flattens out to an average of 1.2 feet per mile. The latter is a low gradient and a contributing factor to the flooding at Brantford.

The watershed lacks those features such as adequate forest cover, lakes, swamps and broad flats, which provide temporary storage to delay the run-off and reduce peak flows. The flats which do exist are of no consequence and are often occupied by cities and towns. There are no effective swamps left to store water and delay the run-off.

The Grand Watershed has extensive systems of both tile and open drains or ditches. Legitimate drainage is a necessity for good husbandry and the effect of tile drainage on run-off may be questioned, but there is little doubt that open drainage together with the thousands of miles of road ditches which criss-cross the watershed aggravate the existing flood problem.

Drainage lowers the ground-water table and the increase in depth of dry soil provides temporary storage for precipitation. Some authorities hold that this potential ground storage delays run-off and has a tendency to reduce flood crests, whereas others contend that they are increased. One authority*

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* George W. Pickles, Professor of Drainage Engineering, University of Illinois. Drainage and Flood Control Engineering.

summarizes a logical argument by saying: "It may be said that up to the point of soil saturation the effect of artificial drainage is to decrease flood flows, while beyond this point it is to increase it".

It is the unusual and extreme conditions which are the concern of the flood problem. Ditches and drains are dug to get rid of water in order to make the land fit for earlier seeding and subsequent growth. At the time of the spring break-up the ground may be saturated, frozen, or covered with ice and the snow melt and rain, instead of lying in depressions on the flat or uneven ground for a time and thence following a devious course to the natural channels, drains directly to the open ditches and graded stream channels in an uninterrupted flow to the river. In the spring, very little, if any, of the water is held back for infiltration.

It seems apparent therefore that open ditches, drains, and highway ditches discharge more water in less time into the rivers and that this extra load raises flood crests to a higher level.

A description of the effect of drainage in the upper zone of the watershed appears in the Hydro report, and is quoted as follows:

> Fig. H-1 "shows that there are two somewhat distinctive soil areas. To the east is a sandy loam, known as the Guelph soil area, which is underlain by gravels and which permits ready percolation and deep seepage. To the west and north is a clayey loam underlain by gravelly silts high in clay, and known as the London soil area. This London area generally has to be underdrained and frequently open-drained, in order to make it commercially workable. The Townships of Arthur and West Luther in the County of Wellington, East Luther, Amaranth and Melancthon in the County of Dufferin, and parts of Proton in the County of Grey, lie in this belt, and are largely drained by sub-surface drains, open drains and improved natural drainage channels.
>
> "The Luther, Amaranth and Garafraxa Marshes are included in this area, which embraces some 360 square miles, contains 150 miles of open ditches of various dimensions and 62 miles of improved natural drainage channels or streams. This amounts to 0.59 mile of drainage channels per square mile of area, which is very high, and it is doubtful whether it can be exceeded outside an artificially irrigated area. This does not include a large mileage of

lateral or feeder drains of small section. In quoting opinions of authorities on drainage, this important fact of the percentage of ditching per square mile must be borne in mind. In the usual cases quoted, the percentage of land drains is comparatively small. On the other hand, the total area of the basin of the Grand River thus drained is about 500 square miles, or equal to 35 per cent of the watershed area at Galt.

"This report does not question the policy of the establishment of the majority of these drains, for unquestionably the profitably workable area has been very largely increased thereby. An excessive amount of low marshy areas, which undoubtedly existed in this territory in its virgin condition or in the early days of settlement, surrounded with close cedar and tamarac growths, reduced the potential growing period considerably. During the early spring and late fall, when the high temperatures of the day caused the evaporation of large masses of these waters, the moisture of which was converted into low-lying fogs by the early night frosts, the surrounding country area was generally affected detrimentally. Extant history of early settlers is replete with records of the miasmic fevers of malarial character against which these pioneers struggled. There is, therefore, no question that over a large part of the area under consideration, ditching is the advisable policy.

"There are areas, however, that have been drained and have since been abandoned through the course of economic events, and it appears as if still other areas are likely to be drained from which no large agricultural benefits will accrue. Areas of this character have largely been converted into pasture lands for stock raising, but the ditches have been permitted to lapse in that they are now lined with strong herbaceous growth which, to a certain extent, defeats the object for which the ditches were established.

"Van Ornam states that ditching reduces the retarding effect of ground storage, but this is largely neutralized and even exceeded by the effect of preventing the saturation of the upper layers, thus permitting rain to penetrate instead of running off the surface. The amount of land so affected is usually small in proportion to the total storage capacity of the soil, so that, all things considered, the modifying effect of drainage averages a comparatively small amount, although sometimes it is locally quite considerable.

"Meyers states that both open and tile drains facilitate and hence increase surface run-off, but on the whole have an equalizing tendency. In so far as tile drains intercept water which has already passed beneath the surface and bring it into open channels again, they must inevitably increase the total surface run-off and reduce the seepage flow. During heavy rains or rapid melting snows, the rate of absorption of water by even the best drained heavy clay soils (such as the London clays) is altogether too slow to prevent excessive surface run-off. Open ditching under such circumstances facilitates rapid surface run-off, and increases flood flows.

"The question of the drainage of the swamp areas, such as above mentioned, has frequently been discussed. Meyer's opinion regarding this matter is quoted in full,

> as it is the generally accepted one. 'The drainage of swamps and bogs, and particularly those having a heavy covering of peat vegetation and the water table near the surface of the ground, usually has an equalizing effect upon the flow of streams. Peat vegetation quickly absorbs large quantities of precipitation, and, as the porous spaces are large, such soil rather readily delivers up its burden of gravity water to the drains below. The temporary storage capacity of such vegetable soils is greatly increased by drainage. Drainage of swamps and bogs with peaty soils thus usually reduces the ordinary flood run-off, increases the total run-off and does not materially decrease seepage flow. In short, the drainage of such soils tends to equalize stream flow'.
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> "Hazen more or less supports the above view that drainage takes the water out of the swamp soil and creates a storage space where none had existed. The effect of soil storage is greatest in taking care of run-off from summer or early autumn storms after the soil has been thoroughly dried out, but it may be much less with respect to late winter or early spring flood flows.
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> "While no measurements of the discharge of the drainage ditches in the area of the Grand River basin under review have been made, a series of excellent photographs were taken during the spring of 1929 depicting these drains running full. These appeared to be functioning like ordinary drainage streams, carrying away the flood waters in a rapid manner and depositing them in the main natural drainage channels, some of which are improved, thus expediting the removal of the freshet waters in as efficiently a manner as possible. It is evident to anyone who has examined the drainage system of this area that it must add substantially to the flood discharge of the main stream, both in volume and peak. The ground water table is generally above the level of the bottom of the ditches during the open months of the year, and these ditches then provide a means of carrying ground water from a lower level than otherwise. This somewhat compensates in low flow for the reduction in ground water level, due to the action of these ditches during the freshet season".

(b) Climatic

The geophysical factors are constant and are such as tend to produce a high rate of run-off. The climatic factors, on the other hand, are extremely complex and variable, and the magnitude of the spring run-off depends largely upon the climatic conditions at the time of the break-up. The climatic factors which affect run-off are: amount of snow cover; temperature, whether moderate or unseasonably high; the extent and duration of periods of freezing temperatures; amount of rainfall; and the direction and velocity of the wind. Fig. H-3 shows the average annual amount of snow and rain which falls on the watershed and Fig. H-4 illustrates graphically the influence of precipitation and temperature on spring run-off for the years 1942, 1947 and 1948. A study of the latter figure is of interest and is self-explanatory.

During an average winter 90 inches of snow falls on the headwater zone, and with an average winter temperature of 21 degrees (Fahrenheit) most of it may remain on the ground or be contained in the upper soil until the spring break-up. During the winter months preceding the great spring flood of 1947, 130 inches of snow fell over the area north of Elora, and most of it was on the ground at the break-up. At the Shand Dam that year 105 inches of snow fell during the winter, of which 72 inches was on the ground at the end of March. The weight, or water content, of the snow was not recorded.

High unseasonable temperatures are the chief cause of many spring floods, and with high temperatures rain can be expected at the time or to follow shortly. On March 31, 1943, at the Shand Dam the temperature reached a high of 67 degrees, and the average high for that day over the watershed was 68.5 degrees. There had been thaws previously during the months of February and March, and little or no snow was left on the ground at this time. This high temperature, together with recent thaws, soon defrosted the ground. The saturated condition of the ground, together with an average of 1.33 inches of rain over the watershed, during the period March 29 to 31, resulted in a high rate of run-off which would have caused more serious flooding had not the Shand Dam been in operation at that time. On April 11, 1947, the temperature at the Shand Dam reached a high of 60 degrees and the average high for that day over the watershed was 62 degrees. This high temperature was accompanied by rain. Also 1.19 inches of rain was recorded between the first and sixth day of April at the Shand Dam with an average for the whole watershed between the first and the fourth of 1.71 inches. There was heavy snow cover at this time, and a study of the hydrometric and meteorological records show that there was an equivalent of approximately 11.2 inches of water in and on the ground at the end of March. This combination of climatic conditions resulted in the greatest known flood (greatest by total volume of run-off).

Ice jams are a hazard and if they are not prevented from forming, or broken at an early stage, they may hold back water of such volume that when the jam breaks the water will surge down and boost already damaging flood peaks. The failure or the untimely regulation of private dams has the same effect; and unfortunately usually coincide with the flood crisis.

The worst combination of conditions for a spring flood is frozen ground covered with ice and a heavy snow mantle in conjunction with abnormally high temperatures with no freezing intervals, warm winds and rain.

(c) Encroachments

In addition to the above conditions which cause flooding there is a third factor which must be taken into consideration, and that is the encroachment on the flood channels. Encroachments include any works of man which are built in the natural flood channel of a river. These flood channels may not be used by the river for several years, but at certain intervals, due to excessive precipitation and other factors, this supplementary channel which it has created for itself will most certainly be flooded, because flooding is a natural phenomenon of rivers. As early as 1541, when De Soto came up the Mississippi, he recorded "floods to the height of the treetops for miles back from the river".

Encroachments on the flood plains of the Grand River and its tributaries are numerous. In Ontario the early settlements generally sprang up near a mill or around an inn, since in many cases the millers and inn-keepers were also merchants. The inns frequently housed post offices and relay stations for post horses, which attracted blacksmiths, wheelwrights, saddlers and harness makers. Thus the inn with its post office, smithy and wheelwright shop would become the centre of a hamlet or village.

The inns were usually located in strategic positions with regard to the roads, and where an important crossroads happened to be away from the river, the settlement was beyond the reach of floods. Such is the case at Kitchener and Waterloo. However, land surveying and convenient river crossings often placed these intersections in the valley bottoms, and sections of the settlements which grew up around these points were apt to be in the flood plain, as is the case at Brantford and Galt.

Where a mill with its store and post office formed the nucleus of an early settlement, the occupied area was invariably in the flood plain. Then, as the settlement expanded, the river was confined or obstructed by buildings and narrow bridges and the flooding thereby aggravated. Further, as the property increased in value the flooding became more serious. This type of development is amply illustrated at Paris, Preston, Hespeler and numerous other places on the watershed.

Moreover, as such encroachments were in progress, and particularly if the river did not flood severely for fifteen or twenty years, people began to think that severe floods would not occur again. This, of course, is an example of foolish wishful thinking, because records show that rivers of Southern Ontario do flood systematically, and of late years these floods have become more severe; both from the standpoint of high water, and damage to structures which have been built in the flood channel.

The presence of encroachments such as narrow bridges with abutments projecting out into the river valley, factories, buildings and so forth, not only aggravate the situation from the standpoint of preventing the free passage of water but also by piling up large cakes of ice which naturally float on the crest of the stream in the spring. The ice blocks accumulate behind these structures and build up a dangerous dam which may break suddenly when the pressure becomes too great or the temperature modifies and sends a flood wave down the valley. These encroachments, together with the gradual denudation of the forest, especially at the headwaters of the rivers, have aggravated the flood situation on most of our streams in Southern Ontario, and it is largely due to these causes that some major works must be undertaken, chiefly in the building of dams, in order to protect towns and cities which occupy the river channel in whole or in part at certain points on its course.

The problem of encroachments has been pertinently summed up by a U.S. Army Engineer as follows: "When we are honest with ourselves and get down to the bottom of the flood problem, about 90% of perennial flood damage is a result of man's damn foolishness in building his roads, railroads, factories, houses, farms and whatnot on land that plainly belonged to the river. When he built there, the evidence that the river had used that land for flood purposes was plainly visible, and when that evidence is there you can be darn sure the river will again flood that land. It would be much simpler and more economical to retire from human occupancy than use these perennially flooded river bottoms, and give them back to the river for flood purposes".

This is an arresting statement, but of course impracticable where settlement has advanced to the extent of millions of dollars in real estate. It does, however, set forth clearly the relationship between flooding and encroachments.

The number of bridges required when a town straddles a river always increases the likelihood of ice jams and consequently exposes larger areas to serious flooding. These blocks sometimes form behind road bridges, damaging the bridges themselves, flooding roads and causing a dangerous rush of water when they finally do give way. Ice jams also frequently form behind natural obstacles such as bends in the channel, piles of debris, shoals and sandbars.

3. Remedial Measures for Flood Control and Low Flows

(a) Conservation Measures

The conservation measures employed to control floods and to increase low flows are the same and are complementary, namely:

(1) Proper land use practices
(2) Reforestation
(3) Farm ponds
(4) Reservoir storage

(1) Proper Land Use Practices

With regard to conservation, proper land use practices have to do with such farming methods as tend to reduce surface run-off and soil erosion. Important among these are contour tillage, restricted crop rotation, winter cover crops, long-term pasture, diversion terraces, grassed waterways, etc. Contour tillage is ploughing furrows along contour lines or through points of equal elevation. With this method each furrow serves as a miniature dam, delaying the surface run-off and promoting infiltration which increases the soil moisture and raises the ground water table. Contour tillage also reduces the loss of vital topsoil by erosion and the subsequent silting of the stream channels. This method is generally satisfactory for the smooth regular slopes, but with the more irregular and steeper slopes it may be necessary to employ one or more of the other methods mentioned above to retard the run-off and hold the topsoil in place.

The Report of the Select Committee of the Province of Ontario on Conservation, which was submitted to the Legislative Assembly on March 15, 1950, stated:

> "Water control must begin with a program of proper land use. Such a program requires the co-operation of a great many individuals over a period of years. This is a program which cannot succeed overnight. The first essential is to persuade every landholder that both his individual advantage and the public good, call for such a program. It is a fundamental recommendation of this Committee that:
>
>> 'To reduce excessive water run-off, which increases the flooding of river valleys, land use practices tending to soil wastage, soil depletion and soil erosion must be discouraged and discontinued, and the farm-planning program set out in the chapter on soils in this report must be adopted and implemented.'"

(2) <u>Reforestation</u>

The reforestation of marginal and submarginal land has an ameliorating effect on run-off. It retards run-off, checks erosion on all types of slopes, steep as well as moderate, increases low summer flow, and reduces silting.

The delay in snow melt due to a preponderance of forest cover, until a time when high temperatures and rain arrive, could intensify floods. However, there is no known record for any flood in Southern Ontario that might be attributed to this adverse effect of forest cover. The Grand Watershed has less than ten per cent of forest cover and any increase would benefit the flood problem in that, in relation to the cleared land, there would be a lag of a few days in the snow melt contribution.

A paper on the influence of forest cover on water conservation, which was published in the Transactions of the American Society of Civil Engineers for the year 1929,* is of interest and is quoted as follows:

> "In an address before the Mississippi Flood Control Conference at Chicago, Ill., early in June 1927, United States Forester W.B. Greeley took the position that, while the main reliance for handling large flood discharges must be placed upon engineering structures, forests have a definite part in flood control, together with other forms of land

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* Paper by E.F. McCarthy, Esq., Director Central States Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Columbus, Ohio.

> use which check erosion and favourably influence natural storage conditions. This attitude is the rational one, and engineers facing the problem of flood control in the Mississippi will doubtless feel that any agency which will assist in lowering the flood crests and in retaining the flood water within predetermined bounds should be used if economically feasible. ... The Forestry Committee on the Relation of Forests and Waters submitted the following statement to the Fifth National Conservation Congress.*
>
>> 'In the mountains, the forests break the violence of rain, retard the melting of snow, increase the absorptive capacity of the soil cover, prevent erosion, and check surface run-off in general, thus increasing the underground seepage and so tend to maintain a steady flow of water in streams'.
>
> "Zon** has summarized the effect of forests on stream flow, as follows:
>
>> 'Among the factors, such as climate and character of the soil, which affect the storage capacity of a water-shed, and therefore the regularity of stream flow, the forest plays an important part, especially on impermeable soils. The mean low stages as well as the moderately high stages in the rivers depend upon the extent of forest cover on the water-sheds. The forest tends to equalize the flow throughout the year by making the low stages higher and the high stages lower.
>>
>> 'Floods which are produced by exceptional meteorological conditions cannot be prevented by forests, but without their mitigating influence the floods are more severe and destructive.'"

(3) Farm Ponds

Farm ponds serve many purposes and are an asset on any farm. They provide water for farm stock, fire protection if located near the buildings, and a means of recreation for the family. Adults as well as children may enjoy the fishing, swimming, skating and boating. With landscaping, farm ponds can transform the appearance of the property.

A permanent stream, although desirable, is not necessary for a farm pond. They may be fed by a spring or by

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* (Raphael Zon et al) The Relation of Forests and Water. Sub-Committee on Forest Investigations.

** (Raphael Zon) Forest and Water in the Light of Scientific Investigation, Final Rpt., National Waterways Comm., Appendix V.

surface run-off alone, by using or enlarging a depression in the ground.

An informative booklet entitled "Farm Ponds for the Grand Valley Conservation Authority" has been published and is available to any owner who may be interested. It shows various types of ponds, none of which is expensive to construct and particularly if all or part of the work is done by the farmer. If ponds were in sufficient number, they could materially increase the summer flow. If the dams in small streams were substantially built, so as to withstand any spring flood, and were emptied prior to the freshet and properly regulated until the spring run-off was complete, they would decrease flood flows to some extent. However, should the dams fail, they would have the opposite effect.

(4) Reservoir Storage

The foregoing water conservation measures provide substantial and necessary aid in reducing flood crests and increasing low flows, and are an integral part of the plan to remedy the problem. They require time and the co-operation of all landowners, however, and alone would never be sufficient. Storage reservoirs are therefore necessary to satisfy both problems. The amount of storage required, the location, capacity and cost of the reservoirs is the chief concern of the hydraulic report. With adequate storage provided in a system of regulated reservoirs, a sufficient volume of the flood run-off may be impounded and controlled to the extent that flood crests may be lowered to a safe stage. In conjunction with some local improvement, the excess flood run-off can then be confined within the river channel at places subject to floods. Conversely, with the reservoirs full at the end of the flood period, the water may be released and low flows thereby increased to a reliable sustained rate, which will assure adequate dilution of sewage effluent and industrial waste, and also a dependable supply for any industries that may use the river for the development of power. There are also other benefits. Lakes will be created for recreation, and the ground-water table raised in the vicinity, and to some extent downstream as well. The increased flow will restore fish life, and the waters will be safer for domestic use and recreation.

Agriculture on the Grand Watershed is already highly productive, but these conservation measures, when implemented, will further increase the well-being directly or indirectly of all the residents of the watershed and will restore the rivers to a sanitary condition. The above measures are not a new concept, but have been practised in Europe for generations though only in recent years on this continent. Many conservation authorities have been set up in the United States and their methods have increased production to such a degree that it is obviously in the interests of our own landowners to adopt these well proven measures.

(b) Expedients

(1) Channel improvement
(2) Dikes
(3) Diversions

Channel improvement, dikes and diversions are classified as expedients and are not recommended when other conservation methods are possible and practical. Their only objective is to get rid of the water by providing an adequate channel through or around the trouble area. The benefits of such measures are only local and as they tend to increase the velocity of the flood waters they often aggravate the flood conditions at other trouble areas downstream. For reasons of economy, however, these expedients are sometimes used in conjunction with reservoirs as in the case of New Hamburg, Paris, Brantford, etc., or to provide the necessary flood relief at those places which are located above or too far below the proposed reservoirs for effective relief by flood storage. The village of Drayton and the town of Dunnville are examples of these latter conditions.

(1) Channel Improvement

Channel improvement may require the widening, straightening, deepening and regrading the river channel through, and often for some distance below, the trouble area. It is sometimes necessary to protect the banks from erosion by rip-rap or other means.

(2) Dikes

Dikes are earth embankments with an impervious clay core located at or near the river, and built high enough to seal off the flooded area and confine the flood waters to the river channel. If the velocity is low and there is no danger of ice scouring, they may be protected against erosion by turf, otherwise it is often necessary to face the river slopes with stone or concrete. Pumping installations may be necessary to pump out the run-off trapped behind the dikes.

Dikes should be provided with ample freeboard, be substantially built and maintained in good condition, for should they be topped or burst the damage could be greater than if they had not been there.

(3) Diversions

If reservoirs, channel improvement or diking are impracticable or ineffective, it is sometimes possible to detour the stream, or part of it, around the flooded area; or in some cases divert it to another watershed if the topography is favourable.

CHAPTER 4

RESERVOIR STORAGE

1. The Degree of Flood Protection

The cost of providing absolute flood protection by means of storage against any freak flood which might occur in the future would be prohibitive, particularly so for the Grand and other watersheds in Southern Ontario due to the steep gradients of the rivers. However, sufficient storage must be provided to give reasonable protection against the flood hazard and to ensure that the minimum permissible flows are sustained throughout the year in order that the river may be safe for domestic or recreational use.

The hydrometric records for Galt dating from 1914 show that the greatest floods occurred in the springs of 1947 and 1948, the former being the greatest in run-off volume, but the latter reaching the higher peak. From this it can be seen that both the peak flow and the volume of run-off must be considered in determining a design flood.

The 1947 and 1948 floods were extraordinary but well within the flood potential of the river. The volume of run-off for the same number of days for the 1947 flood was 40 per cent greater than that of 1929, 42 per cent greater than 1943, but only 5 per cent greater than 1948. Of these maximum floods of record, three occurred within six years and the great flood of 1947 was followed the next year by one almost as large. It is, therefore, necessary in calculating the "design" or "hypothetical spring flood" for a construction program which will provide adequate flood protection for future generations, that consideration be given to all variations in climatic elements such as snow cover, temperature and rain along with detailed information on streamflow characteristics in order to arrive at a flood design which is sufficiently high but within the potential of the basin.

2. Storage Required

One method of computing the storage required for flood control is by statistical analysis. In this method a frequency curve is plotted using the hydrometric records covering a period of years. This plot indicates the frequency of occurrence of any particular maximum flow in relation to the maximum flows of record. It is also common practice to extend this frequency curve beyond the period of record and by this means extrapolate flow data for high floods of low probability of occurrence. Considerable care must be taken in using this method of extrapolating data as serious errors can develop.

In this regard it is interesting to note the effect of using two different periods of record from the gauge data at Galt. In Figure H-5, the solid line was prepared by using the record for 1914 to 1942 inclusive or up to the time when Shand Dam came into operation. The broken line on this chart was prepared for the years 1914 to 1948 inclusive and thus includes the great floods of the forties. Adjustment was made for this latter period to compensate for the influence of the Shand Dam. On the basis of the first curve the maximum mean daily flow of 36,700 c.f.s. might be expected to occur only once in 100 years whereas actually it was exceeded twice in two succeeding years, 1947 and 1948. From a second curve which includes the longer period of record, the estimate of the once in 100 year flood becomes 44,300 c.f.s. This chart indicates the limitations imposed on extrapolating a frequency graph much beyond the period of record.

The plan for the Miami Watershed in the State of Ohio provided for a flood 1.33 times that of March 1913, their greatest flood on record. The plan for the Muskingum Watershed, also in the State of Ohio, was based on a 10-inch 5-day rainfall with a 90 per cent run-off factor. This rainfall is 36 per cent greater than the March 1913 storm, which was the greatest recorded for this area, and the maximum discharge of the resultant flood at

Zanesville would be 22 per cent greater than the maximum discharge for the March 1913 flood. Zanesville is the key point on the Muskingum Watershed such as Galt is on the Grand.

These experiences in flood control methods in a region close to Ontario were used to arrive at a design figure for planning the program of flood control and the "hypothetical spring flood" was placed at one and one-third times the 1947 flood. On this basis it is shown later in the chapters on hydrology and storage that the total storage required for a flood of the hypothetical magnitude is 211,780 acre feet of which 169,380 acre feet is above Galt and 42,400 acre feet on the Nith River above Brantford. This method of choosing a fixed value for the hypothetical flood above the highest flood of record, has many of the limitations of the frequency analysis curve. However, it is considered to give a sufficiently high value for planning purposes. For spillway design it will be necessary to review these values on the basis of more detailed hydrologic studies.

It is shown in Part 3 of this report that sustained flows throughout the year of not less than 350 c.f.s. at Galt and 500 c.f.s. at Brantford are necessary to satisfy the low flow problem and that this storage is more than enough for that purpose.

3. Types of Dams and Reservoirs Proposed

(a) Dams

(1) Gravity Type - gravity dams depend upon their own weight for stability and because of their great weight must have a ledge rock foundation. This is the cheapest type of structure and is the one most commonly used when the foundation conditions are favourable. They may be all concrete, or earth or rock fill with impervious clay cores and a central concrete spillway section. The concrete section may have a free overflow spillway, or it may be provided with gates, such as for the

Shand Dam on the Upper Grand and the Fanshawe Dam on the Thames above London. Regulating valves of sufficient size and number would be installed at the base of the dams to enable them to discharge their proportion of the channel capacity flows under a minimum head.

The choice of either a free overflow or a gated spillway for a dam, depends on a large number of factors such as operation and control procedures, type of structure, location of damsite, size of reservoir in relation to drainage basin to mention only a few. In all cases where life or property may be endangered the spillway must be designed to pass the largest possible flood so that the structure will not be overtopped and washed out. Emergency by-pass channels are frequently used as a means of protecting a dam from very high flows where it has been found necessary to limit the discharge capacity of the spillway.

The overflow spillway is usually more costly than the gated spillway but does not have the maintenance and operation problems presented by the gates. In a region such as Southern Ontario, reservoir capacity is seldom large enough to contain the total run-off from a basin. The gated spillway has much greater flexibility for use in flood control and water management. For this reason gates are being used on the larger control dams with overflow spillways being restricted to small storage reservoirs. The possibility of mechanical breakdown is an ever-present danger to a dam with a gated spillway and must be given serious attention in both design and operation.

(2) Buttress Dams

The overburden at five of the damsites for the reservoir schemes shown in Table R-4 is of such depth that the cost of building the structures on ledge rock is probibitive. Wallenstein, St. Jacob's and Freeport of the Freeport grouping have overburden ranging from 63 to 73 feet: at Ayr and Upper Nithburg, the overburden is approximately 47 and 183 feet respectively. With the possible exception of Ayr, it will be necessary to build these structures on continuous reinforced concrete foundation slabs or mats. These will probably be one of the buttress types of dams, since this type of structure is considerably lighter than the gravity type, and also as their articulated method of construction makes them more suitable for areas where the foundation conditions are poor. However, further investigations of these areas and comparative cost estimates for suitable types of dams will be required before any definite selection can be made.

(3) Spillway Capacity

The calculations, tables and graphs which appear in this report concerning the storage capacity necessary to control floods, have been based on a hypothetical flood with a magnitude one and one-third times the 1947 flood, see Figure H-37. The spillway discharge capacity of a dam where it is necessary to ensure utmost safety, must be such as to pass the highest peak flow which can possibly develop on the river at the damsite. The present procedure for calculating this value is to route down the river the maximum probable storm in conjunction with the most adverse conditions of soil moisture and infiltration. The peak flow resulting from this is considered to be the required spillway capacity. This will provide for the contingency where the reservoir might be prematurely filled and the dams are required to pass the peak flood flows.

(b) Reservoirs

Dams create artificial lakes of different types according to the purpose for which they are used; whether for recreation only, a combination of flood control and recreation or those which are used for the dual purpose of flood control and increasing subsequent low flows. In order that the purpose of these three types of reservoirs or artificial lakes may be understood when referred to, they will be called "permanent","retention" and "conservation" reservoirs respectively, and definitions concerning their use, effect and economy follow.

TABLE H-1a

SPILLWAY CAPACITY FOR GRAND RESERVOIRS

Reservoir	Drainage Area	Flow Ratio Relative to Galt*	Twice Hypothetical Flood by Fuller's Formula: Peak		Discharge Capacity Not Less than:
	Sq. Mi.		C.f.s.	C.s.m.	C.f.s.
Luther	21.11	0.01683	3,446	163.3	3,500
Shand	308.5	0.24601	37,983	123.1	38,000
Montrose	450.8	0.34544	51,819	114.9	51,900
Freeport	960.5	0.84067	119,902	124.8	119,900
Glen Allan	219.5	0.35954	57,084	260.1	57,100
Wallenstein	243.6	0.37642	59,242	243.2	59,300
St. Jacob's	295.8	0.39923	61,841	209.1	61,900
Guelph	102.9	0.06614	11,263	109.4	11,300
Hespeler	250.9	0.11402	17,900	71.3	17,900
Everton	42.4	0.01446	2,714	64.0	2,800
Arkell	103.2	0.03520	5,993	58.1	6,000
Nithburg	125.1	0.05137†	10,481	83.8	10,500
Ayr	329.8	0.13542†	25,396	77.0	25,400

* Flow ratios determined for the max. mean daily flows for spring freshet periods from recorded discharges at the gauges nearest the damsites and further corrected to the actual damsite by areal proportion.

† Flow ratios relative to Brantford.

(1) A permanent lake or reservoir is one in which the water level remains more or less constant throughout the year and may be held at a determined level by regulation from another upstream reservoir. If there is no upstream reservoir, it may be defined as a lake which would fluctuate a **few** feet with precipitation and drought. This type is ideal for recreation, but serves that purpose only, there being no reservoir space for flood control or storage available for increasing low flows. They are not subject to severe flooding or receding beaches, and cottages and boathouses may be built near or at the water's edge. Large bodies of water of this type would be an expensive undertaking, and none are included in the system of reservoirs for the Grand Watershed.

These favourable conditions can be attained at a comparatively low cost, however, with small lakes or ponds used for the summer and fall seasons only, by constructing removable timber structures up to 10 feet in height with a small concrete stop log section at one end large enough to pass summer and fall flows. The timber section would be taken down in the fall. During a heavy summer storm, they could be quickly removed if the spillway opening was too small for the approaching flood flows.

(2) Retention reservoirs or lakes combine flood control with recreation. These reservoirs would be filled, or nearly so, during the spring run-off, and thereafter dumped as soon as possible down to a determined lake level in order that vegetation would not be killed. They would remain approximately at that level until late fall, or throughout the winter, and then lowered to the dead storage level before the spring break-up. With this type the full capacity of the reservoir is available for flood control but the impounded water is wasted, none being used for increasing low flows. The water level of the lake would be fairly constant and similar to that for permanent lakes. Cottages

would have to be above the maximum possible water level and any boathouses or wharfs either floating or portable.

The Fanshawe Reservoir, on the North Branch of the Thames, is of this type. Part III and Fig. H-55 show a surplus of conservation storage after the low flow problem has been satisfied sufficient to make the Guelph site a retention reservoir, and possibly Ayr or one of the other sites as well. Apart from the surplus storage in the systems, it is expected that there will also be considerable ground water returned to the reservoirs which will provide a further increase during the low flow period.

(3) Conservation reservoirs

Conservation reservoirs serve the double purpose of flood control by impounding the flood waters, nearly all of which are retained and subsequently released to augment the low flows. The ever changing water level kills vegetation within the reservoir and, as it is lowered, leaves trash and a poor beach. Owing to these conditions their recreational value is greatly impaired. Even so, however, except for the upper level of the reservoirs, there are possibilities for recreation.

Lake Belwood is a conservation reservoir. All the reservoirs proposed for the Grand System are of this type except as stated above.

4. Selection of Reservoir Sites

(a) Strategic and Economical Considerations

The ideal conditions in choosing the reservoir sites are as follows:

(1) That the allocation of the total storage in the Grand River and the main tributaries should be as near as possible in direct proportion to their run-off ratios;

(2) That the controlled drainage area above the dams, if practicable, should not be less than 65 per cent of the drainage area above the trouble areas;*

(3) That in order to satisfy both the flood and low flow problems, each tributary, if practicable, should have two reservoirs, one well upstream and the other downstream nearer the trouble area;

(4) That the bed of the stream at the damsite is faultless ledge rock;

(5) That overburden, if possible, be impervious and economical in depth for construction;

(6) That the capacity of the reservoir is great relative to height and length of the dam, and that the cost of property damage at the site is not too high.

(b) Reasons why Reservoirs should be Developed to their Maximum Capacity

Since a dam once built cannot be increased in height, reservoirs (consistent with property damage) should be developed to their maximum capacity at the beginning. If, however, the extra storage definitely will never be needed or the reservoir is so far upstream that its drainage area is not sufficient to fill same, then the above policy obviously would not apply.

Following this principle in the selection of reservoir sites, it would be a coincidence if the storage should equal that determined for the hypothetical flood. In fact, the storage substantially exceeds this amount. There are several reasons and usages for this extra storage as follows:

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* In the Muskingum system 50 per cent of the drainage area was above reservoirs, and 65 per cent of the area above the principal flood-damage centre at Zanesville was controlled.
Davis. Handbook of Applied Hydraulics, p.123.

(1) Good reservoirs and damsites are at a premium.

(2) It provides additional flood protection and a further increase in low flows.

(3) It provides greater freeboard at Galt; in the operation of the reservoirs, the one foot provided may not be enough.*

(4) It provides a reserve of storage space against unexpected and unpredictable high run-off, due to high temperatures and rain toward the end of the spring flood period.

(5) Or conversely provides a reserve of storage in the event of a low spring run-off, followed by a dry summer and fall.

(6) Surplus storage may be used for a recreational lake.

(7) Compensates for loss of storage by silting. †

(8) Should the dams be designed for free spillway overflow instead of gates, the storage shown would be reduced by at least 10 per cent.

(9) The hydrometric records, by which the storage has been determined, are subject to error either way. No allowance has been made in this respect.

Three of the chosen reservoir sites, viz. Montrose, Nithburg and Everton, each have available capacities which, in conjunction with the other reservoirs, would exceed the total storage required.

Montrose, owing to its strategic location and rock foundation, should be developed to its full capacity. Both Nithburg and Everton, however, are exceptions. The drainage area of Nithburg is only 125.1 square miles, or 29 per cent

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* See Section 1(c), Chapter 8, also Fig. H-39 (Hypothetical Hydrograph at Galt showing gauge heights).

† See Sec. 6 below.

of the Nith drainage area. The run-off for the Nith Watershed is much less than that of either the Conestogo or Upper Grand Rivers. Therefore storage greater than 18,700 acre feet would have but little flood benefit downstream and would not warrant the additional cost of approximately $550,000. The Everton site, which is located above Guelph near the headwaters of the Eramosa River, has a maximum capacity of 27,700 acre feet, but a drainage area of only 42.45 square miles, which is only 36.8 per cent of the Eramosa drainage area. This reservoir, if developed to maximum capacity, would probably fill during the spring hypothetical flood period, but it would not have filled during any flood on record. Any storage, therefore, in excess of 10,000 acre feet would provide little added flood benefit below except for the city of Guelph when, during a major flood, the discharge valves could be closed until the floods from the Speed were over. The cost of a dam at this rock foundation site is comparatively low and the extra storage by accumulation could be used as a reserve pool. And, as a reserve pool may be required at this point to stabilize the water level of a future recreational lake downstream or for the purpose of further supplementing low flows, not less than 15,000 acre feet should be provided in this site.

(c) Reservoir Sites Surveyed and Selective Grouping

Figure H-1 shows the location and outline of 24 reservoir sites of which contour surveys have been made and Table H-1b the relative distances of 11 of the damsites to Galt and Brantford respectively. According to the data available at the present time it would appear that the nine sites coloured red are the best. The four sites shown in red hatching are alternative sites which may be used if further investigations and sub-surface exploratory work at the various damsites indicate a more economical grouping. The sites coloured black are those which have been eliminated. Figures H-6 to H-18 show

TABLE H-1b

RELATIVE DISTANCES OF HYDROMETRIC GAUGES AND RESERVOIRS TO THE GALT AND BRANTFORD GAUGES

Gauge	Reservoir	Distance in Miles to:	
		Galt	Brantford
Burford			8
(Whiteman's Creek)	Mount Vernon		12
	Princeton		23
	Blandford		29
Canning			21
(Nith River)	Canning		15
	Drumbo		27
	Ayr		41
	Lisbon		84
	Nithburg (lower)		92
	Nithburg (upper)		93
Galt			27
(Grand River)	Freeport	12	39
Hespeler		9	36
(Speed River)	Guelph	22	49
	Barriel Hill	30	57
	Hespeler	10	37
	Arkell	22	49
	Everton	34	61
Conestogo		30	57
(Conestogo River)	St. Jacob	36	63
	Wallenstein	45	72
	Glen Allan	53	80
	Drayton	64	91
Salem		45	72
(Irvine Creek)	Elora	48	75
	Dracon	58	85
Conestogo		29	56
(Grand River)	Montrose	36	63
	Shand	52	79
Belwood		56	83
(Grand River)	Luther	77	104

the contour plan, damsite profile, storage and area curves, and other data for each of the selected reservoir sites. For the purpose of comparison Fig. H-19 shows storage curves for all the reservoir sites, which have been surveyed.

In order that a comparison may be made by substituting the alternative sites, Table H-2 shows five groupings or reservoir systems tentatively in order of merit. It shows for each system or reservoir plan the height of the dams, the reservoir capacities, the estimated cost and the percentage of the drainage area controlled by each system with respect to the principal trouble areas. Table H-3 also shows these percentages in a more comprehensive form.

(d) Reasons for Eliminating Some of the Surveyed Reservoir Sites

Before considering the merits of the five systems, the reasons for the rejected sites will be briefly explained.

The Elora site alone has not enough storage, but would have certain advantages if combined with that of Drayton on the Conestogo and substituting them for Montrose. The total storage would be about the same as in System 1, but the cost would be $800,000 more. Channel improvement at Drayton, however, would not be necessary then and would in part offset this increase in cost. Also the Elora site would control the Irvine Creek which is a turbulent stream. However, there are several objections to this plan which outweigh the advantages. Firstly, with two reservoirs, the Glen Allan and Drayton on the Upper Conestogo, there would be too much storage concentrated in this area. Secondly, by eliminating the Montrose site, the controlled area would be reduced by 24.2 square miles, or the total controlled area relative to Galt would be reduced from 68.2 to 62.8 per cent. And thirdly, there would be two dams in the place of one which would substantially increase the operational and maintenance costs. Therefore the Elora and Drayton sites have been abandoned.

TABLE H-2

Comparison and Selection of Reservoirs
and Estimated Costs

Total Storage Required above GALT: 169,383 Acre Feet

Storage in the Grand R. & Tributaries According to Run-off Ratios Acre Feet	Reservoir	Holding Storage 6 Ft. Below Top of Dam Acre Feet	Dam: Feet			Dam and Reservoir		Reservoir Systems									
			Above bed of stream	Depth to rock	Above ledge rock	Approx. Estimated Cost $	Approx. Unit Cost $	No. 1		No. 2		No. 3		No. 4		No. 5	
								Storage Acre Feet	Approximate Cost $	Storage Acre Feet	Approximate Cost $	Storage Acre Feet	Approximate Cost $	Storage Acre Feet	Approximate Cost $	Storage Acre Feet	Approximate Cost $
Grand River Ratio 46.7732%	Luther††	10,000±	19.5			233,806	23	10,000	233,806	10,000	233,806	10,000	233,806	10,000	233,806	10,000	233,806
	Belwood†† (Shand Dam)	49,600	74.0	0.0	74.0	2,056,487	41	49,600	2,056,487	49,600	2,056,487	49,600	2,056,487	49,600	2,056,487	49,600	2,056,487
	Montrose	37,000	76.0	27.0	103.0	5,870,000	159									37,000	5,870,000
	"	53,480	88.0	27.0	115.0	7,010,000	131	53,480	7,010,000	53,480	7,010,000						
	Freeport*	11,880	44.0	71.0±	*	1,840,000	155					11,880	1,840,000	11,880	1,840,000		
79,225	Sub total							113,080	9,300,293	113,080	9,300,293	71,480	4,130,293	71,480	4,130,293	96,600	8,160,293
Conestogo R. Ratio 36.8761%	Glen Allan	45,060	79.0	11.0	90.0	5,400,000	100	45,060	5,400,000	45,060	5,400,000	45,060	5,400,000	45,060	5,400,000	45,060	5,400,000
	Wallenstein*	16,600	58.0	63.0±	*	3,030,000	183					16,600	3,030,000	16,600	3,030,000		
	St. Jacob's*	13,250	54.2	73.0±	*	2,700,000	204					13,250	2,700,000	13,250	2,700,000		
62,462	Sub total							45,060	5,400,000	45,060	5,400,000	74,910	11,130,000	74,910	11,130,000	45,060	5,400,000
Speed River and Eramosa River Ratio Combined 16.3508%	Guelph	11,575	47.4	8.0±	55.4±	1,620,000	140	11,575	1,620,000	11,575	1,620,000	11,575	1,620,000	11,575	1,620,000	11,575	1,620,000
	Hespeler	9,670	39.0	3.0±	42.0±	980,000	101	9,670	980,000			9,670	980,000			9,670	980,000
	Everton	7,000	30.0	10.0	40.0	870,000	124									7,000	870,000
	"	10,000	34.0	10.0	44.0	1,080,000	108										
	"	15,000	39.0	10.0	49.0	1,300,000	87	15,000	1,300,000	15,000	1,300,000	15,000	1,300,000	15,000	1,300,000		
	"	27,700	47.8	10.0	57.8	1,820,000	66										
	Arkell	11,900	48.0	8.0±	56.0±	1,710,000	144			11,900	1,710,000			11,900	1,710,000		
27,696	Sub total							36,245	3,900,000	38,475	4,630,000	36,245	3,900,000	38,475	4,630,000	28,245	3,470,000
169,383	Total							194,385	18,600,293	196,615	19,330,293	182,635	19,160,293	184,865	19,890,293	169,905	17,030,293
Additional Storage Required above BRANTFORD: 42,400 Acre Feet																	
Nith River Ratio	U. Nithburg*	18,700	55.7	183.0±	*	3,300,000	176	18,700	3,300,000	18,700	3,300,000	18,700	3,300,000	18,700	3,300,000	18,700	3,300,000
	Ayr*	23,700	47.0	118.0±	*	2,500,000	105	23,700	2,500,000	23,700	2,500,000	23,700	2,500,000	23,700	2,500,000	23,700	2,500,000
42,400	Sub total							42,400	5,800,000	42,400	5,800,000	42,400	5,800,000	42,400	5,800,000	42,400	5,800,000
211,783	Total for Watershed							236,785	24,400,293	239,015	25,130,293	225,035	24,960,293	227,265	25,690,293	212,305	22,830,293
Percentage of the drainage area controlled by the various systems above the following places:						Galt		68.2%		64.6%		89.5%		86.0%		68.2%	
						Brantford		62.5%		60.1%		77.0%		74.5%		62.5%	
						Paris		68.3%		65.7%		84.1%		81.4%		68.3%	
						Guelph		66.5%		94.8%		66.5%		94.8%		66.5%	
						Hespeler		93.2%		75.6%		93.2%		75.6%		93.2%	
						Dunnville		48.5%		46.6%		59.7%		57.9%		48.5%	

† Does not include depth of excavation into bed rock.
†† Cost shown is for completed project.

* These would probably be built on concrete mats.
The costs shown are questionable.

TABLE H-2

TABLE H-3

COMPARISON OF DRAINAGE AREAS CONTROLLED BY VARIOUS GROUPING OF THE RESERVOIRS

SYSTEMS	GROUPING OF RESERVOIRS		CONTROLLED AREAS		PERCENTAGE OF CONTROLLED DRAINAGE AREAS ABOVE:					
	RESERVOIR	TRIBUTARY	SQUARE MILES		GALT DRAINAGE AREA 1357·9	BRANTFORD DRAINAGE AREA 2008·6	PARIS DRAINAGE AREA 1838·5	GUELPH DRAINAGE AREA 218·6	HESPELER DRAINAGE AREA 274·0	DUNNVILLE DRAINAGE AREA 2588·0
1 & 5	LUTHER SHAND MONTROSE	GRAND	450·8	1255·4	68·2	62·5	68·3	66·5	93·2	48·5
	GLEN ALLAN	CONESTOGO	219·5							
	EVERTON GUELPH HESPELER	SPEED	255·3							
	NITHBURG AYR	NITH	329·8							
2	LUTHER SHAND MONTROSE	GRAND	450·8	1207·3	64·6	60·1	65·7	94·8	75·6	46·6
	GLEN ALLAN	CONESTOGO	219·5							
	EVERTON GUELPH ARKELL	SPEED	207·2							
	NITHBURG AYR	NITH	329·8							
3	LUTHER SHAND FREEPORT	GRAND	960·5	1841·4	89·5	77·0	84·1	66·5	92·2	59·7
	GLEN ALLAN WALLENSTEIN ST. JACOBS	CONESTOGO	295·8							
	GUELPH EVERTON HESPELER	SPEED	255·3							
	NITHBURG AYR	NITH	329·8							
4	LUTHER SHAND FREEPORT	GRAND	960·5	1793·3	86·0	74·5	81·4	94·8	75·6	57·9
	GLEN ALLAN WALLENSTEIN ST. JACOBS	CONESTOGO	295·8							
	GUELPH EVERTON ARKELL	SPEED	207·2							
	NITHBURG AYR	NITH	329·8							

Lake Belwood and Luther Reservoirs have sufficient storage for the upper zone of the Grand River, and therefore eliminate the Dracon site.

The Barrie Hill site has a good strategical location in the upper zone of the Speed River but the storage is low and the cost too high.

With the exception of the Nith River, there are no serious flood problems on any of the tributaries below Galt, and since the proposed Nith reservoirs have sufficient storage capacity and are better located relative to the major trouble areas below Galt, the Blandford, Princeton and Mt. Vernon sites are therefore eliminated.

The Lisbon site, together with Nithburg, leaves too great an uncontrolled area, and would not provide sufficient flood protection for either Ayr or Paris. The Ayr reservoir has a good strategic location, has 10,286 acre feet more storage, and the cost is $480,000 less than Lisbon. The combined storage of Nithburg and Ayr satisfies the storage required for Brantford, Paris, and Ayr, therefore the Lisbon, Drumbo and Canning sites may be eliminated.

(e) The Preferred System of Reservoirs and a Comparison with Four Alternative Systems

The five reservoir systems shown in Table H-2 are basically in two groups. Systems 1 and 2 and 5 comprise the Montrose group and Systems 3 and 4 the Freeport group. In the Montrose group all the damsites above Galt have ledge rock foundations. The Montrose reservoir site has the largest capacity of any on the watershed, and the drainage area controlled by this group is believed sufficient. The alternative Freeport group brings an additional 290 square miles under control and is closer to Galt. However, the Freeport damsite on the Grand, the Wallenstein and St. Jacob's damsites on the Conestogo, which are substituted for Montrose, would not have ledge rock foundations. The over-burden is over 75 feet deep and the cost of carrying the foundations to rock would be prohibitive. The dams would probably be of the buttress type supported on reinforced concrete mats and sealed with sheet piling, instead of the usual gravity type. Nothing is known, however, of the soil classification at these damsites except that Freeport and St. Jacob's are in light soil, and that Wallenstein may be heavy soil. Sub-surface exploration will, therefore, be necessary, and, if found feasible, followed up by a preliminary design of the dams in order to determine the cost. For this reason, therefore, the costs shown in Table H-2 for these dams and also for Nithburg and Ayr are not reliable, and before any definite selection of reservoir sites may be made and firm costs estimated, a comprehensive drilling program and a preliminary design of the dams will be necessary. This should be done at an early date.

Four holes were drilled at the Montrose* damsite in 1939 at the time when surveys were made for the Shand Dam. The depth to ledge rock at this site is about 27 feet, and this dam could, therefore, be built on ledge rock. Substituting Montrose for the two, and possibly three, sites in the Freeport Group, there would be a substantial decrease in the cost of maintenance alone. For this reason and also owing to the above uncertainties System 1 is tentatively preferred.

Systems 2 and 4 are the concern of the City of Guelph.

Systems 1 and 2 are similar, except that Arkell, which is located on the Eramosa immediately above Guelph, has been substituted for the Hespeler site above the town of Hespeler. The same substitution is made in Systems 3 and 4 of the Freeport Group.

The Everton site has a drainage area of 42.4 square miles and controls only 36.8 per cent of the Eramosa

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* Called Pilkington in the Acres report.

drainage area, but in conjunction with the Guelph site would control 66.5 per cent of the drainage above the confluence of the Speed and Eramosa Rivers at Guelph.

Both Arkell and Hespeler are good damsites, the overburden being only a few feet at each site. The capacity of the Hespeler site is 2,230 acre feet less than Arkell, but even so, it is more than is required for flood control at this point. The Hespeler reservoir controls a larger drainage area and the cost is $730,000 less than Arkell.

The city of Guelph would benefit greatly by the choice of the Arkell site, and these benefits should be given consideration. The Arkell and Guelph sites would control 94.8 per cent of the Guelph drainage area, and Arkell, fed by the discharge from Everton together with the upstream springs, would assure the city of a domestic supply of water at their back door for all time. Guelph is supplied at present by wells at the upper end of the Arkell site, conveyed to the city by a recently renewed pipe line.

Owing to the proximity of the Guelph and Arkell sites to the city, both of these reservoirs would have to be of the retention type, which would leave only the 15,000 acre feet of storage in the Everton reservoir for increased flow. Whereas, proportionately, the conservation storage from the Speed and Eramosa should be approximately 28,000 acre feet. With a retention reservoir at Arkell instead of a conservation reservoir at the Hespeler site, the provision for the increase in summer flow through the towns of Hespeler and Preston would be reduced by about one-half. However, such would not be the case at Galt or places below, since the surplus conservation storage in the Grand and the other tributaries is much greater than this deficiency.

In System 5 the storage in the Montrose, Everton and Nithburg sites has been reduced to conform with the storage determined for the hypothetical flood. For reasons already explained it is not intended that System 5 should be given serious consideration, but it has been shown in order to compare the storage and cost with the other systems. A comparison of Systems 5 and 1 shows that System 1 has approximately 24,480 acre feet extra storage, the additional cost of which is $1,570,000 or $64 per acre foot.

Various worth-while uses may be made of the 24,480 acre feet extra storage. Probably the best purpose would be to use it to offset silting loss and in the meantime reserve the space in one or two of the reservoirs during the spring flood periods as a safety measure against unpredictable climatic conditions. This amount of space reserved in the downstream reservoirs of Ayr and Montrose or the Freeport alternative would allow the controller of the dams greater freedom in the filling of the other reservoirs to the required conservation level. It would also increase the flood protection at Galt and Brantford from 1.33 to 1.41 times the magnitude of the 1947 spring flood.

Other useful purposes of the extra storage are:

(1) The one foot of freeboard at Galt for the operation of the dams during flood periods, if found not to be enough, could be increased to as much as 1.53 feet.

(2) Provision has been made for sustained flows of 350 c.f.s. and 500 c.f.s. at Galt and Brantford respectively. These sustained flows could be increased substantially should the need arise.

(3) One or more of the reservoirs could be of the retention type.

(f) Comparative Storages and Costs for System 1 (Montrose Group) and System 3 (Freeport Group)

One foot of freeboard has been allowed at Galt for the operation of the reservoirs during flood periods (Section 1, Subsection (c)(3), Chapter 8). Obviously the nearer a dam is to Galt the less would be the freeboard required. The Freeport damsite is only 12 miles above Galt, whereas the Montrose damsite is 23 miles farther upstream. In the operation of the reservoirs, if the freeboard at Galt could be reduced 4½ inches, which would leave only 7½ inches below the channel capacity stage, the Wallenstein site could be eliminated and the Freeport and St. Jacob's sites would satisfy the problem for this group. Time and experience may show whether or not this is possible, but at the present time it would appear that it is cutting the freeboard at Galt too fine.

The data below show a comparison of storages and costs between Montrose and Freeport groups, including the Wallenstein site in the latter group.

System	Storage Ac. Ft.	Cost $
1(Montrose Group)	236,785	24,400,293
3(Freeport Group)	225,035	24,960,293
Difference	11,750	560,000

System 3, therefore, including Wallenstein, has 11,750 acre feet less storage and costs $560,000 more than System 1. If it were possible to eliminate Wallenstein, System 3 would have 28,350 acre feet less storage but would cost $2,470,000 less than System 1.

5. General Description of the Selected Dam and Reservoir Sites: Tables H-4 and H-5

The dams recommended for the reservoirs described below are in general of two types, depending upon the depth of overburden, viz. those which will be built upon ledge rock foundations and those which, owing to the great depth of overburden, will be built on concrete mats. As

TABLE H-4

DATA FOR CONSERVATION DAMS

Dam Site	Drainage Area	Length of Dam	Elevation G.S.C.			Height above Stream Bed	Depth to Bed Rock	Height above Bed Rock
			Bed of Stream	Top of Spillway	Top of Dam			
	Sq. Mi.	Feet	Feet	Feet	Feet	Feet	Feet	Feet
Luther	21.1	930	1,562	1,580	1,584	19	2	21
Shand	308.5	2,090	1,327	1,394	1,400	73	0	73
Montrose	450.8	2,275	1,068	1,150	1,156	88	28	116
Freeport	960.5	1,350	931	975	981	50	80	130
Glen Allan	219.5	1,800	1,216	1,290	1,296	80	10	90
Wallenstein	243.6	1,200	1,158	1,210	1,216	58	70	129
St. Jacob's	295.8	1,600	1,077	1,125	1,131	54	125	179
Guelph	102.9	2,400	1,069.5	1,109	1,115	46	15±	61±
Hespeler	250.9	1,950	960	993	999	39	0	39
Everton	42.4	1,860	1,218.8	1,252.9	1,258.9	40	10	50
Arkell	103.2	1,780	1,018	1,060	1,066	48	0	48
Nithburg	125.1	1,080	1,145.3	1,195	1,201	56	180±	236±
Ayr	329.8	2,700	930	971	977	47	100±	147

TABLE H-5

DATA FOR FLOOD CONTROL RESERVOIRS

Reservoir	Length		Average Width		Surface Area Spillway Level		Holding Storage Spillway Level	Cost of Dam & Reservoir	
	Feet	Miles	Feet	Miles	Acres	Square Miles	Acre Feet	Total $	Per Acre Foot
Luther	20,000	3.79	13,000	2.46	4,500	7.02	10,000	254,623	25.46
Shand	39,000	7.39	2,043	0.38	1,829	2.85	49,600	2,056,487	41.46
Montrose	33,000	6.25	2,400	0.45	1,455	2.27	53,480	7,010,000	131.08
Freeport	39,000	7.39	860	0.28	771	1.20	11,880	1,840,000	154.88
Glen Allan	30,000	5.68	1,800	0.34	1,816	2.83	45,060	5,009,500	111.17
Wallenstein	34,000	6.50	1,100	0.25	872	1.36	16,600	3,030,000	182.72
St. Jacobs	25,000	4.73	1,300	0.30	728	1.14	13,250	2,700,000	203.70
Guelph	19,000	3.60	1,100	0.21	1,011	1.58	11,575	1,620,000	139.96
Hespeler	24,000	4.54	1,300	0.25	709	1.11	9,670	980,000	101.39
Everton	23,000	4.35	2,240	0.42	1,180	1.84	15,000	1,300,000	86.67
Arkell	20,000	3.79	1,500	0.28	771	1.20	11,900	1,710,000	143.54
Nithburg	25,000	10.0	950	0.25	1,120	1.75	18,700	2,700,000	143.62
Ayr	38,000	7.2	2,500	0.47	2,197	3.44	23,700	2,060,000	86.90

already stated, the cost of building the latter on ledge rock would be prohibitive. The types of dams for these conditions have been described but at this time it may be said that the dams which have ledge rock foundations would be gravity earth fill dams with a concrete spillway section, while those not having a ledge rock foundation would be one of the ambursen types of dams, supported on a continuous reinforced concrete slab. In the following descriptions they will be called gravity dams or buttress dams for brevity.

(a) Luther Reservoir (Fig.H-6)

This reservoir was surveyed and the dam designed by H. G. Acres and Company for the Grand River Conservation Commission. Construction of the control works, comprising an earth dam 930 feet long and approximately 19 feet high, with provision for controlled discharge of the stored water, was completed early in 1953 at a cost of $233,806.

The damsite is located in Lot 21, Con. IX, Township of East Luther, and the flowage covers all or part of Lots 13-21, Cons. VII, VIII and IX; Lots 14-21, Con. VI; and Lots 17-20, Con. V, Townships of East and West Luther.

The flooded area of the reservoir covers some 4,500 acres of a former peat bog which had been partially and unsuccessfully reclaimed for agriculture. Total storage is given as 10,000 acre feet which is sufficient to provide, after allowance for losses, a flow of 50 c.f.s. for the months of July, August and September.

(b) Shand Dam and Lake Belwood (Fig.H-7)

Located in Lot 6, Con. III, Township of Garafraxa West, across the Grand River, 3 miles above the village of Fergus, the Shand Dam, designed by H. G. Acres and Company, was completed under their supervision in 1942 for the Grand River Conservation Commission. Total cost of this unit was $2,056,490. The dam is an earth fill structure with a concrete control section having 4 vertical control gates each with an opening 30 feet wide and 30.6 feet high to top of gates. It also contains 2 discharge tubes fitted with regulating valves; one being 66 inches in diameter at the bed of the river and the other 48 inches in diameter, the invert of which is 13½ feet above the bed of the river. The dam is 2,090 feet long, has a maximum water depth of 68.6 feet and impounds 49,600 acre feet of water.

The area flooded is 1,829 acres with a length of 6½ miles and average width of 2,300 feet. It covers all or parts of Lot 6, Con. III; Lots 5-9, Con. IV; Lots 7-10, Con. V; Lots 9 and 10, Con. VI; Lots 10-11, Con. VII; and Lots 10 and 11, Con. VIII, Township of Garafraxa West.

(c) Montrose Dam and Reservoir - Grand River (Fig. H-8)

Some preliminary investigations were carried out by H. G. Acres and Company in 1939, but were discontinued when the Shand site proved more suitable for the limited scheme then proposed.

The damsite area lies in Lot 7, Con. A, and Lot 65, west of Grand River, Woolwich Township, and the reservoir includes parts of Lots 60-64 W. G. River, Woolwich; and in Pilkington Township, Lots 2-5, Con. A; Lot 1, Con. II; Lots 6-9 and 12, Con. B; Lots 1-4 and 7-8, Con. A; Lots 5-6, Con. IV and V; and Lots 1-5, Con. III. This site has a drainage area of 450.80 square miles.

Ledge rock at a depth of 28 feet below the river bed permits construction of a gravity dam, with concrete spillway section, 88 feet high and 2,275 feet long. The reservoir would have a storage capacity of 53,480 acre feet with length of 6.25 miles, average width of 2,400 feet and cover an area of 1,455 acres. Of this flooded area, a large part (approximately 40 per cent) is cultivated, the balance being about evenly divided between pasture and woodland. Ten groups of farm buildings and two road crossings would be affected, as well as about 2 miles of gravel roads.

(d) Glen Allan Dam and Reservoir-Conestogo River (Fig.H-9)

The damsite lies in Lots 2 and 3, Cons. III and IV, Township of Peel, and the reservoir covers part of Lots 1 and 2, Cons. III, IV, V; Lot 1, Cons. VI, VII and VIII, Township of Peel; and Lots 14-19, Cons. III and IV; Lot 13, Cons. IV and V; Lots 6-12, Con. V; Lots 18-19, Cons. V-X; and Lots 13-17, Cons. VIII and IX, Township of Maryborough.

This site was recommended by H. G. Acres and Company, Consulting Engineers to the Grand River Conservation Commission, as the best site on the river for a large storage reservoir. They have submitted plans for a dam, 1,800 feet long and 80 feet high (above the bed of stream), to impound 45,060 acre feet and to be operated as a "conservation" reservoir for both flood control and summer flow.

The surveys made by Acres show that acquisition of 3,253 acres of land would be necessary to cover the area required for flowage and construction. In addition 2.7 miles of road, 14 bridges, a school, church, and high-tension Hydro line would be affected.

This project has been approved of by both the Government of Canada and the Government of Ontario. Land for the reservoir is now being purchased and work on the dam is expected to commence this year. The estimated cost of the dam and reservoir is $5,400,000.

(e) Guelph Dam and Reservoir - Speed River (Fig.H-10)

Situated just above the city of Guelph, the damsite provides for a long low dam 2,400 feet long and 47.4 feet above the bed of the river. Geophysical surveys indicate that bedrock lies between 10 and 20 feet deep, which is shallow enough to permit construction of a gravity type dam with concrete spillway section. The drainage area is 102.95 square miles and, being adjacent to the city, the retention type reservoir is recommended for this site.

At full capacity the reservoir covers approximately 1,011 acres, including 2,500 feet of No. 6 Highway, 1,000 feet of No. 24 Highway and 3,500 feet of two township roads, four groups of farm buildings and about 250 acres of cultivated land. The balance is largely willow scrub swamp, river bottoms and rough pasture. The reservoir would have a length on the river of 3.6 miles and on the two tributary branches a length of 3.9 miles, with an average width of 1,100 feet and a total storage of 11,575 acre feet.

The damsite is in Lots 1 and 2, Con. II, and Lot F, Division F; and the reservoir extends into Lots 8-14, Con. III; Lots 1-11, Con. II; Lots 7-10, Con. I; Lots 1-5, Con. VIII; Lots 1-6, Con. VII; Lots 3-6, Con. VI; Lots 6-8, Con. V; and Lots F,G,H, in Division F; all of Guelph Township.

(f) Hespeler Reservoir and Dam, Speed River (Fig.H-11)

The damsite is in Lots 13 and 14, south of Waterloo Road, Guelph Township, and Lot 4, Con. V, Puslinch Township, and the reservoir includes parts of Lots 6-14, south of Waterloo Road; Lots 1-9, Con. V, Division G and Lots D,E,G and H, Township of Guelph; and Lots 4-13, Con. V, and 12-13, Con. VI, Township of Puslinch.

Bedrock lying at or close to, the surface across the whole valley provides good foundation conditions for a gravity dam 1,950 feet long and 30 feet above bed of river. The site permits a higher dam, but higher water levels would encroach on the Guelph Sewage Disposal Plant at the head of the reservoir. The damsite has a drainage area of 250.9 square miles and the storage is 9,670 acre feet.

Practically the whole of the flooded area of 709 acres lies in the undeveloped valley, extending 4.5 miles with an average width of 1,300 feet. Most of the area is covered with second-growth cedar and swamp hardwoods in stands of various density, usually pastured and of little commercial significance.

Three roads cross the reservoir and would be submerged for a total length of 5,000 feet.

(g) Everton Dam and Reservoir - Eramosa River (Fig. H-12)

The damsite lies just above the townline road between Eramosa and Erin Townships in Lots 10 and 11, Con. I, Erin. Rock outcrops over most of the profile, except in the central section where geophysical surveys indicate its depth as less than 10 feet. This reservoir site has a capacity of 27,700 acre feet. As previously explained, it has a drainage area of only 42.45 square miles, hence it is believed that 15,000 acre feet is the limit for effective storage. A gravity dam impounding 15,000 acre feet of storage would be 1,860 feet long and 40 feet above the stream bed.

The reservoir includes parts of Lots 7-13, Cons.I and II; Lots 8-17, Con. III; Lots 9-13 and 16-18, Con. IV; and Lot 16, Con. V; all in Erin Township. It would have a length along the river of 4.35 miles and an average width of 2,240 feet, with a flooded area of 1,180 acres. Some 10 per cent of this area is cultivated and includes two farmsteads. The balance is largely second-growth cedar and alder bottomland swamp; a total of three miles of township roads, with 1,500 feet on No. 24 Highway; and three bridges would be affected.

(h) Nithburg Dam and Reservoir - Nith River (Upper Damsite) (Fig. H-13)

An alternative damsite about half a mile downstream was investigated but the upstream site with a drainage area of 125.1 square miles was considered the better site.

Due to the depth of overburden of 150 to 180 feet, the dam would probably be of the buttress type. It would have an overall length of 1,080 feet and height above the stream bed of 55.7 feet.

This reservoir is fairly well located for the purpose of flood control and, having sufficient storage capacity, will conserve water from periods of excessive flow for release during times of drought.

The reservoir would have a flooded area of 1,120 acres, divided approximately into 60 per cent pasture, 20 per cent cultivated, 10 per cent wooded, and 10 per cent in streambeds and roads; a length of 10 miles including branches, and average width of 950 feet. There would be five groups of farm buildings and six road crossings affected by the flowage. Two of the bridges could be raised above high water level, but the remainder would require reconstruction or re-routing of the roads. A total of about 2.6 miles of gravelled sideroads lie in the flooded area.

The upper damsite is in Lots 5 and 6, Con. I, Wellesley Township, and the reservoir includes parts of Lots 1-4, Cons. I-IV, Wellesley Township; Lots 10-18, Con. III; Lots 17-18, Con. IV; Lots 12,13,15,17,18, Con. II; Lot 13, Con. I, Township of Mornington. At the upper damsite the reservoir has an available capacity of 32,720 acre feet but, as already explained, 18,700 acre feet is the limit of effective storage for this site.

(i) <u>Ayr Dam and Reservoir - Nith River (Fig. H-14)</u>

The proposed damline lies along the road allowance between Waterloo and Oxford Counties at Con. X, Blenheim Township. The dam would have a total length of 2,700 feet and height above the streambed of 47 feet. Geophysical surveys indicate a depth to bedrock of over 100 feet, thus a buttress dam on a concrete mat would be required at this site. The drainage area is 329.8 square miles.

The reservoir includes parts of Lots 11-13, Con. IX; Lots 10-14 and 1-2, Con. X; Lots 1-5 and 8-14, Con. XI; and Lots 1-10, Con. XII; all in Blenheim Township.

The reservoir has a maximum flooded area of 2,197 acres and storage of 23,700 acre feet, a length of 7.2 miles and average width of 2,500 feet. The land flooded is largely (50 per cent) pasture, 25 per cent swamp or wooded, 15 per cent cultivated, and 10 per cent in streambeds, etc.

3.75 miles of gravel sideroads and three groups of farm buildings would be affected; four road crossings would need relocation, with some further road regrading.

(j) Freeport Dam and Reservoir - Grand River (Fig. H-15)

The damsite is situated about half a mile above the No. 8 Highway bridge, in Lots 53 and 16. The reservoir extends over parts of Lots 112-116 and Lot 1 on the east side, and Lots 117-124 on the west side, of the Grand River, all in Waterloo Township. Geophysical surveys indicate that bedrock at the damsite is at a depth of more than 80 feet. High flows may be expected from the drainage area of 960.5 sq. miles, and the discharge capacity of the dam would have to be quite large. Owing to the depth of overburden, a buttress dam on a concrete mat is recommended. The dam would be 1,350 feet long and 50 feet in height above the streambed.

The reservoir would have a length of 7.4 miles and an average width of 860 feet with a flooded area of 771 acres and storage of 11,880 acre feet. The only bridges crossing the reservoir are the C.N.R. and No. 7 Highway at Breslau, both of which are above the proposed flood level. A Bell Telephone long-distance cable crosses the reservoir just above the damsite, but could easily be re-routed along the dam. A considerable portion (about 30 per cent) of the land flooded is under cultivation, and several buildings would be affected.

(k) Wallenstein Dam and Reservoir - Conestogo River (Fig. H-16)

The proposed damsite lies ½ mile above the road between Waterloo and Wellington Counties, Lots 16 and 17, Con. I, and the reservoir includes parts of Lots 11-13 and 15-17, Con. I; Lots 6-16, Con. II; and Lots 4-6, 9-11 and 13-14, Con. III; all in Peel Township.

Geophysical surveys indicate a minimum depth to bedrock of 70 feet. This dam would therefore be of the buttress type on a concrete mat. The dam has a length of 1,200 feet, a height above the stream bed of 58 feet and would control the run-off from a drainage area of 243.6 square miles.

The reservoir would have a storage capacity of 16,600 acre feet, a length of 6.5 miles, average width of 1,100 feet, and flooded area of 872 acres. Due to the steep banks, only about 5 per cent of the area to be flooded is cultivated, the broad flood plain being generally pastured, with a few small woodlots. Three-quarters of a mile of roads, four bridges, but only two groups of farm buildings would be affected. The reservoir area is also crossed by a high-tension hydro line.

(1) St. Jacob's Dam and Reservoir - Conestogo River (Fig. H-17)

The damsite is located one mile above the village of St. Jacob's, Lots 11 and 40, Township of Woolwich, and the reservoir includes parts of Lots 11-17, 38-40, and 48-50, W. of Grand River, Woolwich Township, and Lots 19-20, Con. A, and Lots 1, Con. XII, Township of Wellesley. Because of the depth of 125 feet of overburden the dam would be of the buttress type on a concrete mat. The dam would be 1,600 feet long and 54.2 feet above the bed of stream. The drainage area, at this point, is 295.8 square miles.

The reservoir would have a storage capacity of 13,250 acre feet, a length of 4.7 miles, and average width of 1,390 feet, with a flooded area of 728 acres. Twenty-five per cent of this is cultivated (including almost all of one very good farm), 35 per cent wooded, with the balance in pasture or streambed.

This reservoir, if constructed, would be of the "conservation" type, which would be used to increase the stream-flow during periods of deficiency.

Only one sideroad crosses the reservoir, and another road would be flooded over a length of $\frac{3}{4}$ of a mile. The farm mentioned above is the only one on which buildings would be affected.

(m) Arkell Dam and Reservoir - Eramosa River (Fig. H-18)

The damsite for this reservoir is located about 1 mile above the city of Guelph in Lots 1 and 2, Con. IX. The reservoir area includes parts of Lots 1-5, Con. IX, and Lots 1-4, Con. X, Puslinch Township; Lot 1, Con. I and II, Eramosa Township; Lot 32, Con. I, Lots 30-32, Con. II and Lots 29-30, Con. III, Township of Nassagaweya. This is an ideal damsite as sound ledge rock outcrops or is only lightly covered along the whole length of the proposed site. A 48-foot dam (above bed of stream) 1,780 feet long would provide 11,900 acre feet of storage. A dam at this site would control a drainage area of 103.2 square miles.

At full capacity, the reservoir would have a water surface area of 771 acres, and would extend back from the dam for a distance of 3.79 miles, with an average width of 1,500 feet. The flooded area is almost entirely wooded and unoccupied, except for a few small summer cottages. Two township roads would be flooded out.

A serious objection to this reservoir is that the springs from which the city of Guelph obtain their water lie within this reservoir area. They have an elaborate collection gallery on the south bank of the valley on Con. X, Puslinch Township, and the main which carries the water to the city is located in the valley. Construction of this dam would probably flood out their springs, but Guelph could use the reservoir for their water supply. In time it may be necessary for the City to use this reservoir site for water supply, and every precaution should be taken to safeguard the river above Guelph against pollution.

A second site located a short distance downstream at the quarry in the Ontario Reformatory property was also investigated. This site would permit a much shorter dam (980 feet long), but it would require relocating ½ mile of railway line and a concession road, as well as the construction of two small side dams to close low points across the Reformatory grounds.

6. Loss of Reservoir Storage by Sedimentation

Sediment which is carried downstream and deposited in reservoirs causes a permanent loss of storage space and all reservoirs are subject to this loss, to some extent. The loss is variable, depending upon the topographical and geological conditions upstream and the size of the reservoir. According to statistics of the United States Soil Conservation Service, it may be from a negligible fraction of 1 per cent to more than 3 per cent annually. Sedimentation has also adverse effects on fish and wildlife.

The extent of what the storage loss would be for the Grand System of reservoirs is not known, but it can be assumed that it would be substantial. If as high as ¼ of 1 per cent, it would mean a loss of 600 acre feet annually or, at $90 an acre foot, $54,000. As there has been considerable surplus storage provided in the reservoir system, no allowance has been made for sedimentation loss. If measures were not taken to minimize sedimentation, at the above assumed rate of ¼ of 1 per cent per annum, the 25,000 acre feet of surplus storage would soon be lost by sedimentation. In one hundred years the loss would amount to 60,000 acre feet, a poor legacy for posterity, if not materially reduced.

The loss cannot be entirely eliminated, but it can be reduced to a tolerable extent, the first approach being through the land use and reforestation practices recommended in the various conservation reports.

Extracts are quoted below from an informative paper entitled "Sediment Steals Water" -

Sources of Sediment

"Substantial reduction of storage loss in large reservoirs can be achieved only by the reduction of sediment production in reservoir watersheds. What needs to be done and what it will cost depends largely on where and how the sediment originates.

"The five principal sources of sediment in the Missouri Basin, (1) sheet erosion, (2) gully erosion, (3) badland and related geological erosion, (4) alluvial valley trenching and (5) stream bank erosion require markedly different kinds of control measures. Geologically, there has always been some sheet and gully erosion, locally severe badland erosion, and extensive stream bank erosion. The Missouri River has been known as the "Big Muddy" since the days of the earliest explorers. There is considerable reason to believe, however, that its sediment load today may exceed that of 100 years ago by an appreciable margin. But more important is the evidence that indicates its sediment load could be reduced over the next 30 years, not just to its "geologic norm", but substantially below that norm by a combination of proper land use and treatment plus extensive channel stabilization and sediment detention measures".

Requirements for Sediment Control

"Insofar as reducing sedimentation is concerned, the principal deficiency in current soil and water conservation programs is the lack of adequate gully and channel stabilization. Wherever gullies and valley trenches exist, their control is a key to the reduction of sediment reaching downstream reservoirs. This is true in many cases not primarily because of the sediment they yield directly but because they provide the flumes through which sheet-eroded soil material is delivered to main stream channels and because their headward growth and enlargement, if unchecked make it impossible to permanently maintain the conservation practices applied on the land".

Need for Watershed Planning

"Watershed planning is the key to translating this concept of sediment control into reality with the greatest effectiveness in the shortest time at the least cost. The elements of this process are as follows:

"First, the major hydrological controls of the drainage basin should be recognized. For example, the watershed above each reservoir of the Missouri Basin is a natural control unit because each reservoir will eliminate practically all physical effects of its watershed on the area below the dam.

"Secondly, these major hydrologic control units should be divided into subwatershed planning units. This subdivision should be based on a watershed study of sources of excess runoff and sediment production in relation to the downstream problems which they cause. This is essential to determining the priority of treatment needs. Such a study above Boysen Reservoir has already shown that Five Mile Creek, a subwatershed containing 5 per cent of the total area, causes 40 per cent of the reservoir damage and the channel alone 36 per cent. It should obviously have No. 1 priority for treatment in this hydrologic unit.

"Third, a plan of treatment should be prepared. The kinds of treatment required should be determined for the subwatershed unit. In relatively small watersheds, a single plan may be made for the whole area. However, if subwatersheds are large and costs indicate that treatment would extend over a period of years, or if planning with local landowners and operators would be facilitated, the subwatershed may be broken down into minor watersheds. The plan for the subwatershed, or minor watershed, should include determination of the types, locations, costs and benefits for those water and sediment control measures that are not ordinarily included in conservation farming, range or woodland management. The subwatershed plan should be based on the assumption that all farm, ranch and woodland treatment measures will be applied through going soil and water conservation programs, primarily those of the 2,275 organized soil conservation districts which now include more than 80 per cent of the farmland of the nation. Subwatershed planning would be concerned mainly, therefore, with the additional measures needed, such as major gully control, stream bank stabilization, and others of the type recommended under stabilization of small watercourses in the Missouri Basin Agricultural Plan.

"Fourth, farm, ranch, and forest land planning and treatment should be carried out within the framework of subwatershed plans by accelerating the going soil and water conservation programs that are based on the principles that every acre should be used within its capability and treated according to its need as determined by scientific surveys of each farm, ranch or other ownership unit.

"Obviously this approach is more complex and will require greater effort than present procedures in farm planning, in education, and in developing co-operation between individual landowners and operators. But it is the kind of approach that will, in the long run, result in the most effective total soil and water conservation per unit of cost and time. The outstanding nation-wide accomplishments in soil conservation to date have, perhaps, been due primarily to two factors: (1) the developing more of an informed citizenry which has led, among other things, to the organization by landowners and operators of locally-controlled soil conservation districts as a means of accomplishing a job and (2) the availability of technical skill that has provided the landowner with a scientifically-designed plan for his whole farm or ranch and assistance in carrying it out. But the current soil and water conservation programs, for all their rapid strides, still have their weaknesses. They tend to deal too exclusively with individual landowners, too lightly with community groups, urban people, and industries. They are rooted too firmly to property and political boundaries, too loosely if at all, to the only land boundaries nature knows - namely, watershed boundaries. The remarkable accomplishments to date have been more in the direction of keeping the good agricultural land good than on controlling erosion and excess runoff wherever they occur within the watersheds of the nation. The best agricultural land is not the principal source of downstream problems in many large areas, including much of the Missouri River Basin. Rather it is the submarginal cropland and depleted range, the cutover and burned forest, the lands already gullied, the semi-arid sections and a few areas of rapid geologic erosion.

"Watershed planning and treatment have already been accomplished in enough areas to have demonstrated that river basin developments can be safeguarded. In the watershed approach the treatment needs of each farm and ranch can be determined in the light of total community needs. Individual farm and ranch plans can be made within the framework of sound technical watershed plans. Land use and treatment needs can be related not only to the best interests of the individual landowner but also of his neighbours, whether they live in the next section, in the valley below, or many miles downstream. Operations in the eleven watersheds authorized for flood control work by the Department of Agriculture and a few other watersheds where local interests have acted for self-protection are already providing the pilot plants and testing grounds for watershed treatment. The results are highly encouraging. They are giving many conservationists greater faith than ever before that the water resources of our river basins can be maintained in addition to keeping the good land good".

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* Paper presented by Mr. Carl B. Brown, Sedimentation Specialist, Soil Conservation Service, at the meeting of the Soil Conservation Society of America, Detroit, Michigan, October 28, 1950.

CHAPTER 5

EXPEDIENTS

1. Galt (Fig. H-20)

The area under consideration here is the stretch of the Grand River channel through the city of Galt and the adjacent areas on either side of the channel which are subject to flooding.

The area was surveyed by the stadia-traverse (mean height of instrument) method with levelled control points established at the upper and lower ends - Queen Street and the Galt pumping station respectively. The channel from the pumping station, which is located 2,700 feet south of Concession Street, to the Galt dam was surveyed in detail. The river was sounded throughout and the water levels, top of banks, top of walls and bridge seat elevations as well as the elevations and measurements of the Galt dam were all noted. In addition a reconnaissance traverse line was run from the pumping station downstream for a distance of about 4,300 feet. In this section, river bed soundings were taken at approximately 100-foot intervals and the river channel was cross-sectioned at several points.

High water marks and bedrock outcrops were noted throughout both sections and ties were made at several points with city lot surveys so that the river survey could be plotted relative to the plan of Galt.

Flooding is a major problem at this point and the immediate objective is the control of the flood water. It is known that the present channel through Galt can safely discharge a maximum peak flow of 30,464 c.f.s. (peak flow of the 1949 spring freshet). However, even during this comparatively low flow, basements bordering the channel were flooded due to seepage and water backing up the drains. The 1948 spring freshet had the greatest flow on record, with a maximum mean daily flow of 37,700 c.f.s. and a recorded peak flow of 46,280 c.f.s. (It has been estimated that this peak flow would have been approximately 52,000 c.f.s. if the Shand Dam had not been in operation.)

At the channel capacity flow of 30,464 c.f.s. the water is up to the top of the east abutment of the Galt Dam and to the top of the river banks at the south side of Galt, but as the water rises it overflows the east abutment, floods the mill-race and flows out onto Queen and Water Streets. The flood waters continue down Water Street flooding factories, stores and residences on both sides of the street. Similarly, at times of high flows property along the west side of the channel below Queen Street is also flooded, but in general this side is higher and the flooding is not so severe.

While the flooded area is comparatively small, it is largely an industrial and commercial area and the resultant losses are high. Also, there are many homes within the area and a number of persons are inconvenienced and exposed to major losses and danger by the flood waters.

Records show that Galt has suffered heavy damage almost annually in the past. The flooding has apparently been gradually increasing in magnitude and there is no assurance that it will not become even greater in the future.

Flooding here, as at other municipalities along the Grand River and its tributaries, is due to the fact that the river has been confined to its low-water channel by buildings and retaining walls built along its banks. The channel width varies greatly through the city, the widths at the main points being:

Location	Clear Channel width - feet	Clear Water Area opening - sq. feet
Galt dam (spillway)	282	
Queen Street Bridge	250	4,220
Main Street Bridge	183	3,946
Grand River Rwy. Bridge	230	4,650
Concession St. Bridge	211	3,950

The channel has been further restricted by the structures listed above, by several large shoals which have been built up in the river from debris carried down by the flood waters and by fill, factory refuse and other rubbish being dumped along the river banks. The normal passage of water under the Queen Street bridge is restricted by large shoals at the easterly end, and the opening of the Grand River Railway bridge is similarly restricted by shoals at the westerly end plus the encroachment of the fill being dumped along the west bank immediately above the bridge.

The river through Galt and for some distance below flows for the most part over an irregular, flat-lying bedrock surface. This rock is of the hard Guelph dolomite series, and the joint planes are roughly horizontal and vertical. The rock breaks away in blocks, leaving an irregular surface rather than a smooth one as might be expected in a river bed. In many cases shelves of this rock extend out into the river and at times of low flow may only have an inch or two of water flowing over them, and it is on these shallows that the shoals usually form. The shoals consist chiefly of broken dolomite which has been picked up off the river bottom and from along the sides during the high flows and moved along by the water until it is lodged against some obstruction in the bed or is deposited due to a change in the flow pattern.

It has been estimated that there are about 11,000 cubic yards of loose material in the channel proper. The removal of this would improve the condition of the channel considerably during periods of low flow, but it would have little effect upon the high spring flows. And in all probability, the shoals would be rebuilt in a few years' time unless some measures were taken to moderate the spring flows.

While the quantity of loose material to be removed is not excessive, the cost of this work alone would be high due to the fact that the material is not readily accessible and that it could not be conveniently disposed of nearby. This work must ultimately be done if the channel is to be improved for normal flows and it could be done to advantage at this time.

Estimated cost for such a clean-up scheme is $55,000.00.

To increase the channel capacity through Galt to the point where it could contain such flows as have been experienced in the past does not appear to be feasible. (The peak flows for the 1947 and 1948 spring freshets were 46,000 c.f.s. and 46,280 c.f.s. respectively.) The channel could only be increased by widening, deepening or both. Any scheme to widen the present channel would be exceedingly costly due to the amount of building along the sides of the channel. Deepening the channel would be equally costly in view of the solid rock in the river bed and the number of bridge and building foundations which would have to be reinforced. Also, if the channel capacity were to be increased by deepening, it would be necessary to extend the excavation for about two miles below the city in order to be effective. Further, to confine a flow of the magnitude of the 1948 spring freshet to the present spillway section of the Galt dam it would require raising the head-gate wall and dam abutments about eight feet and further diking around the millpond to provide a margin of safety. Or, as an alternative, the dam might be fitted with gates which would provide the additional discharge capacity at a lower head. Either method would be an expensive undertaking.

The maximum permissible stream flow velocity for stratified rock such as that at Galt is 8.0 feet per second, but a mean velocity of 10 feet per second might be maintained for short periods without undue damage. Thus for the 1948 spring flow a cross-section area of $\frac{46,280}{10} = 4,628$ square feet would be required. The present opening of the Main Street bridge is 183 feet wide with a cross-section area of 3,946 square feet. The required increase in cross-section would be 4,628 - 3,946 = 682 square feet or the channel would have to be excavated to a depth of 3.7 feet below its present level. On this basis it would be necessary to excavate approximately 350,000 cubic yards, 90 per cent of which would be rock excavation. The cost of the excavation alone would approach one million dollars.

A study of a series of 1947 and 1948 pictures covering the Grand River from Blair down past Brantford indicates that the high-water stage has a fairly uniform gradient throughout this length and at no point is there an appreciable sudden drop in the water level such as would indicate a serious obstruction. Thus it becomes evident that any scheme to control flooding by channel improvement alone could not be successfully carried out locally, but that it would have to be extended for some distance in order to show any appreciable drop in water level through the distressed area.

The channel improvement, even if practicable, would only benefit Galt, would aggravate conditions farther downstream and would be a waste of water which could be used to good advantage during periods of low flow.

The survey of the river channel through Galt was made with the thought of providing an expedient to give some immediate relief to the city until such time as the overall flood control program could be developed to the stage where the flooding at Galt would be eliminated. Since the survey was made, subsequent investigations and studies have shown that such an expedient cannot be provided at a reasonable cost and therefore the money would be better spent towards the development of the final plan.

2. Brantford (Fig. H-21)

The city of Brantford is situated on the banks of the Grand River about 62 miles up stream from Port Maitland where the river empties into Lake Erie and approximately 120 miles below the headwaters in Dufferin County. Brantford is the largest municipality actually located on the river and like many others suffers flood damage to some degree each spring. The river at this point has a drainage area of 2,006.7 square miles or about 77 per cent of the total watershed area. The area above Brantford is chiefly agricultural land, much of which has extensive drainage systems. Several thousand miles of roadways with their accompanying ditches criss-cross the area, all of which help to rush the water from rains and melting snows quickly to the river. The river above Brantford has a gradient of from 6.2 to 23.0 feet per mile while that portion from Brantford to Lake Erie has only 1.2 feet per mile. All of these factors, together with the fact that the river has been confined to its low water channel through the city, contribute to the flooding at this point, although the encroachment at Brantford is not as extensive as at many municipalities located on rivers in Southern Ontario. The extremely low river gradient below Brantford appears to be the chief contributing factor to the flooding at this point.

In the past, Brantford has spent several hundred thousand dollars on flood prevention works. They have endeavoured more or less successfully by the construction of dikes and river walls to confine the river to its natural channel. In other instances they have tried to achieve some measure of relief by other channel improvement work such as cleaning, widening and diversions, often going beyond their corporation limits to accomplish this.

*"The history of this work undertaken by the city of Brantford dates from the year 1887, when the late Samuel Kiefer, C.E., M.Can. Soc. C.E., was called in to investigate and report on measures which should be adopted to minimize the effects of the floods. He said in opening his report to the city authorities:

'I have now procured all the information necessary to enable me to form an opinion on the semi-annual floods from which West Brantford for years past, has suffered and to suggest the proper means for the protection of that portion of the city from inundation.'

"This would suggest that even at that early date floods in the Grand River were of common occurrence and had been for many previous years. He recommended that a system of earthen dykes be constructed along the southerly bank of the river, and marked out the location and form of these works. The earthen dykes were to be raised to a level 3 feet above high water, were to be 6 feet wide on top with both slopes at 1½ to 1. The area enclosed, he said, might need to be provided with a pump to pump out accumulated surface water. This latter recommendation was never carried out, nor was it found to be necessary, as floods were of such short duration that surface water did not prove to be of consequence.

"These dykes, however, were breached by a flood which occurred in 1894, and under the direction of the City Engineer, the late Mr. T. Harry Jones, were then raised and strengthened by timber cribs extending a short distance into the stream; also at that time a system of similar dykes was constructed along the north bank of the river to protect Eagle Place, another low lying section of the city which had suffered from floods. Later on the river channel was widened at Lorne bridge by adding to the existing structure an additional span 100 feet in length.

"One of the measures recommended and carried out at about this time was the digging of an artificial channel, Two Fish Island Channel, for the river below the city limits in an endeavour to improve a sharp bend in its course. This work did not prove effective, the channel silted up, and the river resumed its original course. In later years the dyking system has been extended, raised and strengthened; railway and highway bridges have been lengthened. No subsequent floods have broken through these defences.

"The present dykes have a minimum width of 8 feet on top with slopes of 2 to 1 on the river side and 1½ to 1 on the land side. The river faces where necessary are paved with reinforced concrete 6 inches in thickness, resting in low concrete walls or footings. The concrete facings extend to normal high water levels and are provided with expansion joints and are constructed in the same way as pavements of this type are built. Stone blocks were at first used for this purpose but it was found that the action of ice and river currents displaced them, necessitating frequent repairs."

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* Extract from "The Engineering Journal" Vol.XXI, No. 2, February 1938.

This dike system provided flood protection with a fair margin of safety for many years. However, during 1947 and 1948 spring freshets the flood crests came within a few feet of the tops of the dikes throughout most of their length and within inches at certain low points. Also, there are no protective works of any kind, at present, along the southerly city limits and the flooding is becoming more and more serious in this area as the city expands southward.

It has been suggested from time to time that a diversion canal might be constructed across the narrow neck of land at the Cockshutt Bridge to carry off the excess water during times of high flow. A canal at this point would be approximately 2,000 feet in length, whereas the present waterway distance around the loop is about 46,500 feet. At first glance this method appears to be quite practical, but subsequent investigations have shown that such is not the case. A detailed survey and study of the Cockshutt Bridge area was made a number of years ago and the cost of such a diversion with its subsidiary structures - control gates, road bridges, weirs or other equivalent works to control the velocity of flow through the cut - would be about one million dollars, and its effectiveness is doubtful. It would be helpful during the early stages of high flow, but as these flows began to exceed the capacity flow of the channel below, the water would be backed up and the discharge capacity of the cut would be progressively lowered and might even be reduced to the point where it would be of little use.

Also any attempt to remedy the flood situation in this area by channel excavation would be equally costly since the work would have to extend for some distance down stream in order to be effective.

Similarly Brantford recognizes the fact that diking is an expensive and never-ending process, but as an emergency measure they have recently investigated* the possibilities of raising and extending their present dike system. During the summer of 1948 a survey of the existing dikes and the area south of the city which they propose to dike was made. The low points in the existing dikes have since been raised and a limited amount of channel cleaning has been done. If the dikes were extended across the flats south of the city, as they propose, the improved channel would have a capacity flow equal to the peak flow of the 1948 spring flood with a minimum freeboard of three feet. The peak flow of the 1948 spring flood was 57,210 c.f.s.

Later in this report (Chapter 8) it will be shown that the present channel capacity at Brantford is comparatively low and that some channel improvement work together with the storage reservoirs would provide a more economical solution to their flood problem. Thus, in view of the fact that the proposed reservoir system is to be a long-term program and that some channel improvement should be done in any case, it is recommended that the work proposed by the City be carried out now. This work alone would provide protection against floods up to the magnitude of the 1948 flood.

Some of the work outlined in the original scheme has already been done. The islands above the Municipal Dam have been cleared, the existing dikes have been raised and strengthened at certain low points, and a short stretch of the channel below the L.E. & N. Bridge has been cleaned out and straightened.

Total cost of this work was approximately $16,000.00.

The remaining work consists of further channel cleaning - removing islands and shoals where ice jams might tend to form - and constructing a dike across the flats south

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* Report by G. H. Richards, City Engineer, Brantford, October 18, 1948.

of the city. This dike (which would be in two sections) follows, for the most part, along the bank of a former river channel. The ground surface immediately beyond this line drops sharply and to move the dike any farther south to include more area would increase the costs considerably. The first section would extend from the end of the present dike on River Road south to a point 550 feet below Birkett's Lane, thence east parallel to Birkett's Lane to the Cockshutt Road, a total distance of 5,750 feet. The top of the dike would have a uniform slope throughout its length, starting at elevation 657.5 feet at the River Road and sloping down to elevation 654.5 feet at the easterly end. Approximately 36,500 cubic yards of fill would be required for this stretch of dike. The second section, commencing at the Cockshutt Road, continues eastward, roughly parallel to Birkett's Lane, and ties in to the high ground at the rear of the Mohawk Church on Mohawk Street. This section of dike would be 5,200 feet long and would require 33,100 cubic yards of fill. The dike, which would be constructed of earth fill with an impervious clay core, would have a minimum top width of 10 feet with side slopes of 2:1 and 1½:1 on the river and inland slopes respectively. Where the proposed dike would cross the Cockshutt Road it would be necessary to sand-bag the road and its side ditches to a level with the top of the dikes for the duration of the high water. Also some pumping installations would be required to take care of the water from the area within the dikes and any seepage that might occur through or under the dikes. This would not be a serious problem for floods of short duration, but for those during which the water remains at high level for several days the amount of accumulated waters within the area could be considerable and would have to be taken into account.

In addition to the diking there are several shoals and points of constriction in the channel through

Brantford and immediately below the city which should be removed to permit the free passage of the high spring flows and to prevent as far as possible the formation of ice jams in this stretch of channel during the break-up period.

The estimated cost of removing this loose material and debris from the river is $8,000.00.

Total estimated cost of the channel improvement work at Brantford is:

Diking and subsidiary work	-	$92,110
Cleaning Channel	-	8,000
Total Cost		$100,110

3. Paris Channel Improvement (Fig. H-22)

The town of Paris is situated on the Grand River at the confluence of the Nith River about six miles northwest of Brantford. The total drainage area above this point is 1,838 square miles consisting of 1,406 square miles and 432 square miles for the Grand and Nith Rivers respectively. Each spring Paris has experienced varying degrees of flooding and damage due to heavy run-off from this area. Flash floods have also occurred in the late spring and during the summer months, but these are not so severe and usually only last for a few hours. Much of Paris, including the business section, is located in the low-lying U-shaped area bounded by the two rivers and almost annually a large part of this area is inundated. The residential and industrial area along the east bank of the Grand River between the dam and the old steel bridge and east to Willow Street is similarly flooded. The flooding in these areas is chiefly due to the Grand waters but is further aggravated by the waters of the Nith. If the Grand were at a low flow stage, it is not likely that the Nith alone would cause any serious trouble at this point. However, the two rivers usually peak within a short time of one another and the channels do not have sufficient capacity to contain the high discharges.

The 1948 spring flood which is the greatest on record for Paris had an estimated maximum mean daily flow of 48,650 c.f.s. on March 20 with a momentary peak flow on that date of approximately 56,200 c.f.s. These flows are the combined figures for the Grand and Nith and were estimated from the recorded flows at the Galt and Canning gauges with adjustments being made for the additional drainage area and the elapsed time of travel from these gauges to Paris.

As a matter of interest it might be pointed out here that the Grand River reached its peak flow of 47,950 c.f.s. at Paris at about 1 p.m. on March 20 when the flow from the Nith was only 8,250 c.f.s. The Nith River reached its peak flow of 16,150 c.f.s. at 6 a.m. on March 21, some 17 hours later. Had these rivers peaked together the resultant flood might have been substantially greater. Further it was noted that the Nith River peaked about 17 hours later than the Grand during the 1949 spring freshet. Fig. H-22a illustrates this flood period.

Above and below Paris the rivers have wide flats over which they can spread and flow with little or no damage resulting, but through the town these flats are occupied. Buildings and dikes line both sides of the rivers, creating irregular channels which vary greatly in width. The approximate channel widths at the following points are:-

Grand River		Nith River	
Penman's Dam	350 feet	Wincey Dam	250 feet
William St. Bridge	341 "	Footbridge	100 "
Confluence	400 "	River Bend	150 "
Below confluence	260 "	Nith R. Bridge	104 "
Old steel Bridge	350 "		

The channel capacities have been further restricted by bridge piers, shoals and the adverse angle of entry of the Nith flow to that of the Grand. The Nith enters almost at right angles to the Grand flow and the rushing waters meeting head-on in this manner are seriously impeded, resulting in higher flood stages. In addition the channel immediately below the confluence which must take the combined flows of the two rivers narrows down to a width of 260 feet, the narrowest section through Paris. The building up of the flats and restriction of the channels are the cause of the flood conditions at this point.

The river channels through Paris have good gradients. The Grand River has a fall of 10.5 feet in 4,200 feet and the Nith River has a fall of 6.5 feet in 2,100 feet. The Grand at this point flows for the most part over an irregular bedrock surface. Bedrock is also visible at the mouth of the Nith and farther upstream in the vicinity of Lion's Park.

Any attempt to provide complete flood protection by increased flow capacity through Paris by channel improvements would be costly. Such work would be in the nature of deepening, widening, constructing flood walls, diking the present channels or a combination of two or more of these methods. Deepening would entail rock excavation and would have to be extended for some distance downstream. Improvement by widening is limited by the buildings and bridges along the channels and, as in the case of Galt, with deepening the work would have to be carried some distance downstream to be effective. Some measure of relief could be obtained by raising and extending the present dikes, but this in turn is limited by the lack of space on which to build the dikes. Dikes to be substantial must have a good top width and sides with a low slope ratio, particularly on the water side. Further, diking confines the flood flows and produces higher flow stages which would probably increase the distress at other points.

It would be difficult to protect the buildings along Grand River Street which back on the river by diking since it would reduce the channel cross-section area and defeat the purpose of the improvement. A properly constructed flood wall would provide the required protection but at a considerably higher cost. A wall about 700 feet long and at least 21 feet high would be required.

The problem of low summer flows at Paris is as serious as the flood problem. During many summers the flow at Paris has fallen to a negligible value for a river of this size and there is not sufficient flow to properly dilute and flush away the domestic sewage and industrial waste being dumped into the river. Therefore, any project which does not take into account both phases of the hydraulic problem is not complete. All local projects such as channel improvements by straightening, widening, deepening, diking and diversions aim at one thing only, namely to get rid of the water as quickly as possible. Such schemes do not permit any low-water flow improvement, improvement of the sanitary conditions of the river or further development of the water resources of the region. In short, the water which will be badly needed later on during the summer months is lost. In addition, local works only benefit those in the immediate vicinity, and often aggravate conditions at other points downstream.

The channel capacity flow at Paris has been determined as 36,887 c.f.s. This was the peak flow of the 1949 spring freshet and from enquiries at Paris it was learned that at the time of this flow the water just reached the top of the banks at the low points but did not overflow and therefore might be taken as the maximum permissible flow for this section. This was the estimated combined flow of the two rivers and consisted of 31,551 c.f.s for the Grand and 5,336 c.f.s. for the Nith. The peak flow of 10,675 c.f.s. occurred in the Nith River approximately 17 hours after the peak flow of the Grand River had passed. The flows from each of the rivers may vary within limits from the above flows, but as long as the combined flow, barring ice jams, does not exceed a flow of 36,900 c.f.s. there should not be any flooding. During the 1950 spring freshets the peak flows in the Grand at Paris for each of the two runs were 31,600 c.f.s. and 31,900 c.f.s. and were within reasonable limits of the 1949 spring flow of the Grand. However, the flows on the Nith at these times were considerably higher, 13,675 c.f.s. - the highest on record for the Nith - and 10,857 c.f.s. respectively, and there was some flooding on each occasion.

When the whole system of conservation reservoirs is in operation, sufficient storage will be available to reduce any flood flow up to the magnitude of the hypothetical flood to the level of the 1949 maximum spring flow at Paris. The Glen Allan (Conestogo) Dam and Reservoir, which is the next in line for construction, will, it is estimated, reduce all flows up to the magnitude of the 1948 spring flood to the level of the maximum flow for the 1949 spring freshet. This would protect Paris on the Grand side for many of the years. The Ayr Dam and Reservoir would provide an even greater degree of protection on the Nith side. The Glen Allan project has been approved and will be under construction shortly. With this prospect in view and the present dike system on the Grand Channel, no further work is recommended here.

The proposed dams and reservoirs for the Nith Watershed would provide an even greater degree of flood protection on this side of Paris, but as these projects are of lesser priority and will not be undertaken immediately, other local works are recommended. This work which would provide relief from floods up to the magnitude of the 1948 spring flood, would consist of:-

(a) Raising and reinforcing Lion's Park dike	$ 500.00
(b) Retaining wall from Wincey Mill Dam to Mechanic Street	58,200.00

(c)	Raising, reinforcing and extending dike along left bank from Mechanic Street to Nith River bridge	$ 4,250.00
(d)	Installing outlet structures at Wincey Mill tailraces	1,000.00
(e)	Cleaning river bed from Wincey Dam to mouth and widening where necessary	1,200.00
	Total estimated cost	$64,650.00

In addition to the above work, a retaining wall should be constructed along the foot of the steep cut-bank just below Lion's Park. The severe erosion at this point is endangering the highway and buildings along the top of the bank and adds tons of silt and other debris to the river channel below each year. A retaining wall 600 feet long and 17 feet high costing approximately $81,000 would be required to stabilize this bank.

Total estimated cost of the proposed work at Paris is ....$145,650.00.

4. New Hamburg (Fig. H-23)

The village of New Hamburg is located on the Nith River approximately 11 miles south-west of the city of Kitchener. At this point the Nith River forms a large loop which almost completely encircles the village. The left bank or outside of the loop is for the most part quite high and above the flood level. The land within the loop, which contains approximately 60 per cent of the village proper, including the business section, is low and is subject to flooding practically every spring. Also some lesser flooding has occurred during the late spring and during the summer months following heavy rainfalls.

The chief cause of flooding here is simply that the channel is not large enough to contain the high flows which are to be expected at this point on the river. At times ice jams have formed in the river below New Hamburg and backed the water up over the flats into the village; thus flooding under these conditions could occur at comparatively low flows.

The river channel through New Hamburg has become deeply silted and in many places almost closed off by a heavy growth of underbrush along the banks and in what even might be considered to be the river bed itself. Refuse dumps along the river banks are edging out into the channel, causing further restrictions. The dam across the river 600 feet above the East-West Street crossing raises the water at that point 10 feet above the normal level, reducing the freeboard along the banks above the dam to six feet or less, but does not aggravate the flooding to any great extent. The channel immediately below the dam contains a series of large shoals. These shoals have a dense growth of scrub-willow which tend to consolidate the shoals and retard the river flows. The East-West Street bridge has a present water opening of 2,200 square feet which is not adequate for flows as high as those experienced in the 1948 spring freshet. The channel from the above bridge around the loop to Bleam's Road bridge has an average cross-section area of 1,190 square feet with an average gradient of 0.07 feet per 100 feet. The Bleam's Road bridge has only 2,200 square feet of water opening which is also insufficient for such flows as those recorded for the 1948 spring freshet. A new bridge is being built about 300 feet downstream from this bridge and in all probability the Bleam's Road bridge will be discontinued when this new bridge is opened.

Most of the flooded area lies within the loop. In all about 135 acres of land, 23 of which are business and/or residential property, are inundated. The critical point is along the rear of East-West Street opposite Union Street. At elevation about 1085 the river overflows East-West street, flows down Union Street and mingles with the flood waters spreading across the open flats from the river channel below the East-West Street crossing. Properties on both sides of East-West Street from the bridge to a point about 370 feet east and that on Union and Burns Streets are flooded. From here the water flows eastward through the north end of the village and then southward, flooding the property on the east side of Asmus Street. South of Boulee Street the water cuts across the fair grounds and floods the south end of Jacob Street.

Along the east side of the mill-pond the river overflows the bank and floods the north end of Wilmot Street, the lower end of North-South Street, and comes within 150 feet of the main intersection.

It was not possible to get an accurate estimate of the flood damage done here each year, but judging from the amount of business and residential area that is flooded it would be considerable.

Due to the large uncontrolled area between the Nithburg damsite and New Hamburg and to the fact that this unit will probably not be built for some time to come, other works which will supplement the Nithburg storage reservoir and provide more immediate relief are necessary. The Nithburg site is the first natural site above New Hamburg where the required storage may be found, but there are 84.04 square miles of drainage area between this site and New Hamburg and even with the dam in place the run-off from this area alone could be sufficient to cause flooding at New Hamburg.

By improving the channel through New Hamburg its capacity may be increased so that it will contain a flow of 4,740 c.f.s. without flooding. Any further increase in capacity by channel improvement is limited by the capacity of the channel immediately below New Hamburg. This improvement alone would contain the flood flows of many years, but would not contain peak flood flows of the magnitude of the 1948 spring flood which was estimated at 7,730 c.f.s. Nor would it contain the flow from the uncontrolled area below the proposed Nithburg site during a flood of the magnitude of the hypothetical flood for which all the flood control works for the whole Grand Watershed will be designed.

Further protection may be provided by raising and extending the present dikes to supplement the above channel improvement work. By this means the channel capacity would be raised to 9,400 c.f.s. which is the maximum discharge capacity of the East-West Street bridge. This combined work would provide for protection against such floods as have occurred in the past, and as supplementary works to the Nithburg project it would provide the necessary protection to the extent of the hypothetical flood.

The channel improvement provides for an excavated channel about 7,900 feet with a bottom width of 100 feet and graded to a uniform slope throughout. The improved channel would follow the general course of the river channel except for a short cut-off channel which leaves the present channel at a point about 200 feet below the East-West Street bridge and connects to it again about 1,600 feet down stream. This cut-off eliminates the sharp bend at that point and shortens the channel by about 300 feet. The concave side of the cut-off channel would be rip-rapped to prevent the river from returning to its former course.

The diking would parallel the right bank of the river and the new channel. Commencing at a point 470 feet north of the Church and Wilmot Street intersection, it would extend to the existing dike at the fairgrounds which would be raised and lengthened to prevent the flood waters from backing up into the village proper. The new dike would have a top width of 8 feet and would include control gates at the head and tail of the mill-race.

Plans showing the location and extent of this scheme have been submitted by R. K. Kilborn and Associates Ltd. of Toronto and their estimated cost as of January, 1952, is

(a) River channel improvement	$ 54,700
(b) Raising and extending dikes	35,300
Combined total cost	$ 90,000

In view of the serious flooding at New Hamburg and the fact that further work would be required here to supplement the proposed storage above New Hamburg, it is recommended that the combined scheme of channel improvement and diking to increase the channel capacity to 9,400 c.f.s. be implemented.

5. Plattsville (Fig. H-24)

Some local damage has been caused by floods in the village of Plattsville, Township of Blenheim, County of Oxford. The damage is confined to the flooding of cellars in the centre of the village and the maximum depth of water has been two feet on the village streets. It would appear that the flooding at this point is due to the mill dam across the Nith River one-quarter of a mile above the village.

The dam is a concrete overflow structure across the river channel, 270 feet long and 6 feet high (with earth embankments 6 feet above the spillway crest, crossing the flats). At the time of the survey (Sept. 1949) it was in poor repair, the downstream apron being badly undermined. Water flows to the mill from the mill-pond through a mill-race 2,000 feet long, controlled by a headgate at the pond and a gate at the mill.

During flood flows in the river, the water backs up behind the dam, due to the inadequate spillway capacity. At an elevation 4 feet above the spillway crest the water overflows the township road in Lot 18, Con. XIII, and flows south into the village, filling the comparatively low-lying central portion before overflowing the road between Cons. XII/XIII and making its way back to the river. This condition recurs with all periods of high flow and continues until the flow subsides, or part of the earth embankment between the mill-race and east end of the concrete dam washes out.

A similar condition on a smaller scale has been caused during periods of normal operation when the headgate at the mill-pond has inadvertently been left open overnight, and the gate at the mill closed. Water overflowed from the mill-race into the same low section of the village, although not in the same quantity.

In order to prevent flooding at Plattsville it would be necessary to either reduce spring flows to the present channel capacity or increase the channel capacity to contain the high flows. The Nithburg Reservoir will reduce the spring flows by about 45 per cent which would prevent flooding for most years. There would be 118.27 square miles of uncontrolled drainage area above Plattsville, and for years of extremely high flows such as 1947 and 1948 the run-off from this area alone would be sufficient to cause some flooding. Thus, as in the case of New Hamburg, some local work is necessary to provide further protection.

This additional protection may be had most easily by raising a short section of the forced road through Lot 18, Con. XIII, north of Plattsville. This would require a 700-foot length of the road being raised a maximum of 3 feet.

Estimated cost for grading and resurfacing this stretch of road with gravel is $3,500.

The fundamental cause of the trouble at this point, however, appears to be the inadequate spillway capacity of the mill dam. Measures to increase this capacity by adding stop-log sections to the dam would provide a more satisfactory solution but at a much higher cost.

6. Drayton

Severe floods occur at Drayton at almost every spring break-up, and occasionally during the summer. In fact one of their worst floods was due to a rainstorm in May 1942. According to the records of the Shand Meteorological Station, 2.89 inches of rain fell during May 29, 30 and 31, of which 2.05 inches fell on the last day. The village is only fourteen miles from the headwaters and the drainage area has a very high rate of run-off. For these reasons, the warning is short as it takes only four hours for the flood waters to reach Drayton. The summer flood period is usually only two days, but the damage is the same as for the longer spring flood periods. Figures H-25a and H-25b show approximately the area inundated but many cellars are also flooded with two or three feet of water outside this area due to water backing up in the drains.

The records of the Drayton gauge date from May 1950; thus records are available for spring floods for 1951 only. Using the flows for this year and by ratios related to the Conestogo gauge, the flows through Drayton for the 1948 spring flood and the hypothetical flood would be as follows:

	Flow c.f.s.	Rate per Sq. Mile
1948 Maximum Mean Daily	9613	76.8
1948 Calculated Peak	14127	112.8
Hypothetical Flood Maximum Mean Daily	11687	93.3
" " Calculated Peak	17175	137.1

Records for one year are not sufficient to establish a satisfactory ratio, but the rates shown above are believed none too high.

During the summer, the flow is reduced to a mere trickle. The records show flows as low as 2 c.f.s. during August 1951, which was not a dry but an average year. The flows may also be this low at times during the winter and for this reason the river often freezes solid and with subsequent thawing and freezing the ice may become quite thick. The river froze solid below Main Street in 1952 and about $400 was spent by the village in an effort to blast a channel through the ice jam which formed at this point.

With both high and low flow extremes, the best solution would have been a dual-purpose reservoir above Drayton. There is a good site two miles above Drayton, which would satisfy the Drayton problem. It only controls 38.5 per cent of the Conestogo drainage area, however, which is not sufficient for the protection of other places down stream. This site has a capacity of 32,000 acre feet. On the other hand, the Glen Allan site below Drayton has a capacity of 45,060 acre feet and controls 69.1 per cent of the Conestogo drainage area. The Glen Allan reservoir has sufficient capacity, is better located and a reservoir above Drayton would, therefore, have to be an addition to the reservoir system.

Channel improvement will satisfy the flood problem, provided an adequate channel is kept open through ice formations at the time of high winter and spring flows. Ice conditions are a major problem here and ice channelling or the loosening of ice jams by means of explosives are the only methods of overcoming this hazard.

The main channel through Drayton varies in width from about 50 to 100 feet. It splits into two channels 400 feet north of Main Street and rejoins 500 feet below, forming an oval-shaped island about 290 feet wide at the widest part. Sketches of the bridges are shown on Figure H-25a. The Wellington Street crossing of the main channel is by an old three-span steel bridge. The openings total only 2,260 square feet on the skew with an effective water area opening normal to the centre line of the river of 1,540 square feet. This opening is not sufficient and is largely responsible for ice jams forming at this point. The bridge is an old one and should be replaced.

The width of the east channel varies from 40 to 90 feet and is crossed at Main Street by a new steel bridge 117 feet wide between abutments with a clearance of approximately 12 feet from the bottom of steel to the bed of the river. The westerly channel is partially filled in and is choked with growth. It is dry most of the year, functioning only as an overflow channel during flood periods. It is crossed at Main Street by a concrete bridge which, although old, is in fair condition and will probably last for many years. The width between the abutments is 80.5 feet and the clearance from the bottom of the concrete beams to the present bed of the river averages about 10.5 feet. It will be noted later that, in regrading the west channel, there will be a cut of nearly 6 feet under the bridge, which will increase the depth opening to 15.7 feet. The openings of these Main Street bridges determine the proposed grading of the bed, the widening of the main river and the east and west channels.

Two schemes, viz. A and B, are submitted. In Scheme A the present east and west channels are maintained and widened. In Scheme B the east channel is filled in, the whole flow being through the west channel, and the steel bridge moved to the concrete bridge to form a two-span structure.

Scheme A (Fig. H-25a)

It is proposed to regrade the river via the east channel, a distance of 4,100 feet on a uniform grade of 0.134 per cent. The length of the west channel is about 50 feet less than the east channel, and its grade is, therefore, 0.138 per cent. The proposed bottom width of the main channel is 145 feet; the east channel 93 feet and the west channel 58 feet, with 2:1* side slopes throughout.

With this channel improvement,

the easterly bridge will pass	9,100	c.f.s. and
the westerly " " "	6,100	c.f.s.
or a total of	15,200	c.f.s. with a water

depth of 11.12 feet. This allows only a little over a foot for ice clearance at the easterly bridge but about 4½ feet for the westerly bridge.

This flow is (15,200 - 14,127) = 1,073 c.f.s. greater than the calculated 1948 peak, but is (17,175 - 15,200) = 1,975 c.f.s. less than the calculated peak for the hypothetical flood.

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* 2 feet horizontal for 1 foot vertical.

The total excavation for this scheme is estimated to be 75,200 cubic yards. Most of the work is widening, there being only a few light cuts in the bed of the river, none of which, except for the west channel, exceed 1½ feet. The banks of the river show clay, gravel and some boulders with no evidence of shale or solid rock. It is believed to be all "common" excavation, but an allowance of 500 cubic yards has been made in the estimate for rock. All of the excavated material can be disposed of nearby or used to build dikes or embankments.

There is no evidence of serious erosion along the banks at Drayton and, since the proposed overall grade of the bed of the river is unchanged and the channel much wider, it is not expected that there will be any serious erosion with the new channel. Consequently, except at the upstream end of the island where the channel splits, there is no provision for rip-rapping the bank slopes. All excavated stone, however, should be stockpiled in case rip-rapping should be necessary later.

Warped reinforced concrete approaches are necessary for both of the Main Street bridges in order that the flood flows from the trapezoidal channels may be streamlined into the rectangular sections at the bridges. With these a greater volume of flow may be funnelled through the bridge openings.

In addition the present retaining walls on the left bank above and below Main Street, except for a short length above Main Street, are in poor condition and should be replaced. Reinforced concrete walls 12.1 feet high above the river bed are proposed for these areas.

With the proposed regrading of the west channel there will be a cut of nearly 6 feet under the bridge. Unless the foundations of the abutments are on ledge rock it will be necessary to support the footings by concrete walls. The cost of these supporting walls, if necessary, is estimated to be $4,000.00.

For a flow of 15,200 c.f.s. and a water depth of 11.12 feet, the calculated normal clear opening for a bridge is 165 feet. Allowing 5 feet for each of the piers and 1.5 feet for the bridge seats, the length of a bridge at right angles to the river would be 178 feet. The bridge, however, is on an angle of 42° 45' with the centre line of the river, and, accordingly, the length of the bridge would be 262.2 feet. The cost of a three-span steel bridge of this length with a 30-foot roadway and one sidewalk including abutments, and piers parallel to the centre line of the main channel, is estimated at $142,000.00.

The estimated cost of regrading and resurfacing the approaches to the bridge with 3 inches of hot mix is $1,300. Concrete warped approaches will not be necessary for this bridge if the width of the bed at the approaches (upstream and downstream) is increased from 145 to 175.

Further flood protection may be had at a relatively small cost by using the excavated material to build dikes. With floods of only two days' duration, a dike, if made sufficiently wide, would not require a clay core, and the common excavation could be used to build the dikes. The haul would be closer than to the disposal area and the extra cost of building, consolidating and trimming the dike should not exceed 20 cents a cubic yard.

Since the floods emerge from the depression along the river and creek north of the village, this area could be diked off to advantage (Dike 1A) from Wellington Street bridge to and along the south-westerly bank of the creek crossing Elm Street and thence continuing south-easterly to higher ground near Wood Street to seal off this area.

The proposed dike would be approximately 1,300 feet long, have an 8-foot top with 2:1 slope on the outer face and a $1\frac{1}{2}$:1 slope on the inner. The proposed elevation of the top is 1,316.45 which provides freeboard of 3 feet. The embankment would average 5.6 feet above the ground surface for most of its length and 3.2 feet above the crossing at Elm Street. Allowing 15 per cent for skrinkage and consolidation, it would require 5,600 cubic yards of material.

The cost of the excavation is already accounted for and the estimated additional cost for the dike is $3,300.

The low flow trickle of 2 c.f.s., or less, should be kept in one channel, preferably the easterly one. A low weir, one foot above the bed across the west channel just below the entrance, would be sufficient. A weir of this height 300 feet from the concrete bridge would have little effect on flood flows through the bridge. With stone stock-piled from the excavation available, it is estimated that a stone weir with a 4-foot grouted top and extended up the bank slopes with grouted rip-rap would cost $500 or, if stone is not available locally, a concrete weir, with a downstream stone apron, $700.

The total estimated cost for Scheme A is $251,792.

Scheme B (Fig. H-25b)

Scheme A with Dike 1A will give protection for flood flows up to 15,200 c.f.s., which, as previously stated, is greater than the 1948 flood but less than the hypothetical flood. According to the calculated depth of 11.12 feet of water for a flow of 15,200 c.f.s., the rear of the buildings fronting on the west side of Wellington Street, between Main Street and the bridge, would be only a few inches above this flood stage and their outbuildings would all be flooded. The calculated depth of water for the hypothetical flood is 12 feet. This stage would not go over the road, but it would flood some of these buildings. There is not room for a dike along this stretch (particularly back of the creamery) and a wall extending from Main Street to Wellington Street would cost an extra $65,000.00. It is this unsatisfactory condition which prompted the following alternative Scheme B.

The natural alignment of the river below Wellington Street is via the present west channel. In Scheme B

SUMMARY OF COSTS

SCHEME A

1.	74,700 C. Y. of common excavation at 50¢ C.Y.	$ 37,350
2.	500 C. Y. of rock " at $4.00 C.Y.	2,000
3.	Rip-rap at the nose or split in the river consisting of an arc 170 feet long of heavy rip-rap hand-placed and grouted	3,000
4.	Retaining wall - 12.1 feet high x 125 feet long along the east channel, left bank, from the steel bridge downstream	12,500
5.	Retaining wall 12.1 feet high, 11 feet long along the east channel, replacing a portion of the old wall along the left bank north of the steel bridge	1,100
6.	East channel, left bank, a warped reinforced concrete approach 73 feet long connecting the 2:1 bank slope with the vertical retaining wall	4,700
7.	Warped reinforced concrete approaches from the 2:1 bank slopes to the face of the west abutment of the steel bridge and to the face of both abutments of the concrete bridge, each $2,400 and 50 feet long	7,200
8.	Possible concrete wall support to the footings of the concrete bridge due to excavation	4,000
9.	A steel bridge at the Wellington Street crossing 262.2 feet long (3 spans), 30 feet roadway with one sidewalk	142,000
10.	Grading and surfacing the Wellington Street approaches to the bridge with 3 inches of hot mix	1,300
11.	A dike north of the village 1,300 feet long at Elevation 1,316.45 (3 feet of freeboard) seeded	
12.	Weir - to confine low flows to one channel	500
13.	15 per cent for engineering and contingencies - 15% of 218,950	32,842
	Total Cost Scheme A	$251,792

the 145-foot bottom width is the same as Scheme A but is carried through the west channel and the east channel is filled in. The Main Street steel bridge would be moved to join the concrete bridge seated on a new pier and abutment, making a continuous two-span bridge.

This scheme has several advantages over Scheme A.

(i) The alignment is better.

(ii) With the floor of the steel bridge level with that of the concrete bridge, provision is made for a hypothetical flow of 17175 c.f.s., a depth of 12 feet of water and approximately 3 feet clearance for ice.

(iii) It provides room and material to seal the village off by a dike 4 feet above the hypothetical water level, a level which could be exceeded by lesser flows under certain ice conditions already referred to. Precautionary measures against ice jams would be necessary in any case, but with these precautions and the added protection of a dike the village should be immune from any conceivable flood.

(iv) The warped concrete approaches to the bridges and the retaining walls will not be necessary. The top of existing walls may be cut off and the bottom parts buried in the fill.

(v) It makes possible a good recreational or park area fronting on the river. The area could be made particularly attractive in conjunction with a removable dam and pond. A dam and pond is not feasible for Scheme A, since a heavy summer storm, with the dam in place and no dike along the east channel, might flood the village.

There is a difference in the width of the roadway of the Main Street bridges which would have to be overcome. The steel bridge (Fig. H-25b) has a 24-foot roadway and an overhanging sidewalk 5.2 feet wide. The concrete bridge is

25.1 feet wide with a 20.1-foot roadway, a curb and a 5-foot concrete sidewalk within the bridge. To continue the 24-foot roadway over the concrete bridge, the roadway could be paved to the level of the curb (if the bridge can withstand the extra load) or the sidewalk could be removed, which in either case would be replaced by an overhanging sidewalk similar to the steel bridge.

If practicable, the paving of the concrete bridge flush with the sidewalk would be preferable. With the floor of the steel bridge at the higher level, the clearance for ice under the steel bridge would be a little over 3 feet, whereas, by removing the sidewalk, it would be only 2.57 feet. To move the steel bridge, remove the easterly abutment of the concrete bridge and construct a new pier and abutment, provide an overhanging sidewalk on the concrete bridge and raise the floor to the level of the sidewalk, the cost is estimated to be $25,000.00.

By widening the bed of the channel at the approaches to the bridge from 145 to 154.5, warped concrete approaches will not be necessary.

In Scheme B, the centre line of the channel was swung northward pivoting on the point of intersection of the upstream curve in order that the proposed Dike 1B would be clear of buildings. In Scheme A, the bridge made an angle of 42° 45' with the centre line of the proposed channel. In Scheme B, it is 46° 00' and the length of the bridge 251.6 feet as compared with 262.2 feet for Scheme A. On the other hand, since this scheme provides for 12 feet of water instead of 11.12 feet, the bridge floor would be raised 2 feet.

The extent to which the grade of the approach may be raised from Wood Street to the bridge is limited owing to buildings fronting on the street. However, it is possible to construct an approach that would not affect these buildings and which would permit a visibility of 600 feet for motor cars approaching the bridge from opposite directions at a height 4.5 feet above the road surface.

The cost of a three-span steel bridge 251.6 feet long with a 30-foot paved roadway and a 5-foot overhanging sidewalk is estimated at $136,000.
The cost of grading and surfacing the approaches to the bridge is $1,300.

If the width of the river bed at its approaches to the bridge is increased from 145 to 178 feet, warped concrete approaches will not be necessary at this bridge either.

In Scheme B, there is the same flood risk as in Scheme A for the buildings fronting on Wellington Street. In this scheme, however, there is room for a dike which will seal off the village and protect it against any conceivable flood barring ice jams.

The top of the proposed Dike No. 1B (Fig. H-25b) is 16 feet above the bed of the river, has a top 8 feet wide with a 2:1 outside slope and a 1½:1 inside slope. It is approximately 3,200 feet long and would take 37,100* cubic yards of the consolidated excavation. For a flow of 17,175 c.f.s., there would be 12 feet of water, which gives 4 feet of freeboard. The average height of the dike above the ground surface is about 8 feet. It is also about 4 feet above the 1948 high water mark.

The estimated cost of Dike 1B is $10,810, the various items and their cost being shown in the Summary of Costs for Scheme B.

If the east channel is filled in, as proposed in this scheme, the storm sewer which, at present, empties into this channel at the Main Street bridge would have to be extended to the new channel. It is believed that the most economical location would be across the low ground just south

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* 15% has been allowed for shrinkage.

of the garages and club house, a distance of approximately 350 feet, with the outlet about 140 feet down stream from the bridge. The cost would be about $2,000.00.

The stretch of the east channel below the bridge could be left open and this expenditure avoided, but it would be an eyesore and encourage its use for a dump.

The total estimated cost for Scheme B is $267,444.00.

It is unfortunate that the construction of the steel bridge was completed only a few months before this field survey began. Otherwise, according to the above estimate, the cost of Scheme B would have been less than Scheme A. Both schemes are a crushing expenditure for a village of 500. If it can be financed, Scheme B is strongly recommended.

7. Guelph (Fig. H-26)

The city of Guelph is located on the Speed River at the confluence of the Eramosa River. The Speed River, flowing in a south-easterly direction, passes through the city while the Eramosa and the Speed below the confluence flow in a south-westerly direction and roughly follow the south-easterly boundary of the city. The total drainage area of these two streams above Guelph is 218.6 square miles, comprised of 103.2 and 115.4 square miles for the Speed and Eramosa Rivers respectively. This area is quite rugged, with the relief ranging up to 150 feet in many places. The overburden is, for the most part, comparatively shallow and there are numerous outcrops of bedrock. These topographic features together with the steep stream gradients, 19 feet per mile for the Speed and 16 feet per mile for the Eramosa, all tend to produce a rapid run-off from the area. On the other hand, the absorptive capacity of the glacial drift, the many swamps and the wooded nature of this area tend to offset the adverse factors and

SUMMARY OF COSTS

SCHEME B

1.	101,500 C.Y. common excavation at 50¢ C.Y.	$ 50,750
2.	500 C.Y. rock " at $4.00 C.Y.	2,000
3.	Removing east abutment of concrete bridge Constructing pier to seat both Main St. bridges Constructing new abutment for steel bridge Moving steel bridge to new location overhanging sidewalk on concrete bridges	25,000
4.	Removal of upper parts of retaining wall and the top of the old abutments of the steel bridge	200
5.	Filling and surfacing (3"hot mix) old location of steel bridge and the approach of its new location	800
6.	Probable concrete wall support to the footings of the west abutment of concrete bridge	2,000
7.	Steel bridge at Wellington St. crossing 251,6 long (3 spans), 30-foot roadway and one sidewalk	136,000
8.	Grading and surfacing approaches to Wellington bridge (3" hot mix)	1,300
9.	Building, consolidating and trimming Dike No. 1B 37,100 C.Y. at 20¢ C.Y.	7,420
10.	Turfing Dike No. 1B Peg sodding outer slope 15 feet from the top of dike between Wellington and Main Sts. and seeding the top and both slopes of the remainder	950
11.	Raising grade of Elm Street over dike: Gravel surfacing; 2-12" side culverts 36' long with flap gates	1,440
12.	Sump hole and pump	1,000
13.	Extending storm sewer to new channel	2,000
14.	Seeding the east channel fill	200
15.	Moving buildings on the island north of Main Street	1,500
16.	15% for engineering & contingencies (15% of 232,560)	34,884
	Total cost Scheme B	$267,444

moderate the stream flows. So far as the regime of this stream is concerned it is worthy to note that its seasonal fluctuations are less radical than most of the other Grand tributaries or the Grand itself. The Speed drainage area is about 22 per cent of the total above Galt but this river normally adds less than one-fifth of the total flow at Galt during the spring flood period and has contributed as much as one-half of the flow at Galt during dry seasons.

Guelph, for the most part, occupies comparatively high ground and this fact, along with the fact that most of the low lands bordering the stream channels have been retained for park areas or have been left vacant, and the more or less favourable behaviour of the rivers, have eased the flooding to a large degree. However, in spite of this Guelph has suffered severe flood damage from time to time and there is always the threat of even greater danger since the past floods have not been occasioned by the optimum conditions for a maximum flood. Also, as the city expands, the vacant lands along the river become more and more valuable and there is the possibility that these lands will become built-up and then even greater damage could result from floods of lesser magnitude.

In the past Guelph has carried out a considerable amount of channel improvement work and has recently cleaned, widened and diked the Speed channel from above the Neeve Street crossing to Edinburgh Road. It is believed that this work will protect this area from floods up to the magnitude of that experienced in April 1950, which is their greatest on record. In order to provide an equivalent amount of protection for the Webster Street area and the flats immediately below, which the city hope to develop as industrial sites, this work would have to be continued for at least one mile down stream. This area is very low and barely has any freeboard even during times of normal flow. Also there is a low weir and a narrow railway bridge across the river near the westerly city boundary which raise the water and tend to aggravate the flooding. But the removal of these obstructions alone would not eliminate all the trouble since the valley below is also flooded to practically the same extent.

No survey was made of this area and therefore it is not possible to outline any definite scheme to provide the necessary protection at this time. However, from a visual inspection of the area and a study of the stream flows and high water marks it would appear that any attempt to solve the problem locally would be exceedingly costly.

There are several good reservoir sites above Guelph and two of these are being recommended as part of the widespread reservoir system for the overall flood control and water conservation scheme for the Grand Watershed. These reservoirs would protect Guelph from floods up to the magnitude of the hypothetical flood or a flood one and one-third times greater than the 1947 flood, which would be substantially greater than any flood on record. Further, these reservoirs would help to protect all the other municipalities down stream and would provide for the further use and development of the water resources of the area.

It is estimated that it would cost approximately $65,000 to finish the work on hand at Guelph, which would give protection to the extent of the April 1950 flood. This work would include cleaning out the river channel below Edinburgh Road, reinforcing and extending their present dike system, removing the weir mentioned above and adding another span to the railway bridge at the Canada Gypsum Company plant.

It is recommended that this amount of work be carried out now to provide immediate relief and that the reservoirs be developed as soon as possible to give more complete protection from flooding and to provide for the further use of the water resources of the region.

8. Hespeler (Fig. H-27)

The Speed River rises approximately twenty-four miles north of the town of Hespeler near the village of Orton. From this point it flows in a southerly direction to its confluence with the Grand River near the town of Preston.

Approximately eight miles north of Hespeler the river passes through the city of Guelph, where it is joined by its main tributary, the Eramosa River, the whole comprising a drainage area of 274 square miles above the town of Hespeler. The topography of the lands constituting the drainage basins of both these streams is comparatively rugged, which feature tends to accentuate the rapidity of the run-off, although due to the wooded nature of most of the valleys this tendency is equalized to some extent.

The cause of flooding is due to the low carrying capacity of the channel through Hespeler, in relation to the excessive run-off experienced frequently in the past, with particular emphasis on the years 1947, '48, '50 and '51. The year 1950 produced the greatest recorded flood flow at Hespeler gauge,* as supplied by the Water Resources Division of the Department of Resources and Development,† the peak flow being 8,060 c.f.s. on April 5. A run-off graph developed for the gauge at Galt on the Grand River and related to Hespeler by ratio of flow, indicates a maximum mean daily flow for a hypothetical flood of 7,097 c.f.s., and applying Fuller's formula a peak flow of 9,732 c.f.s. With excessive conditions occurring simultaneously such as heavy rain, melting snow, and frozen ground, etc., the resulting flow may possibly exceed the 1950 flood, causing correspondingly greater damage than previously experienced.

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* Hespeler gauge has been discontinued since January 1949, owing to weed growth and stream bed changes during flood periods affecting control section.

† Now Department of Northern Affairs and National Resources.

The problem therefore, is to determine an immediate and economical method of confining the flood flows of the Speed River to a proper channel capable of carrying approximately 9,700 c.f.s. through Hespeler, so that property damage due to flooding can be eliminated. A problem of this nature can be solved in any one of several ways or a combination of these ways.

R.K. Kilborn & Associates Ltd., Toronto, have investigated this problem extensively and submitted a report outlining the various methods of solution as follows:

(a) Storage - Construction of storage reservoirs which will impound the flood waters.

(b) Englarging river channel - widen and deepen the main stream bed until it will contain the flood waters.

(c) Dikes - Construction of dikes along the river banks.

(d) Diversion canal - A diversion canal which will by-pass the surplus water.

(e) River Channel Improvement - Removal of either or both artificial or natural obstructions existing in the river channel.

Scheme (a) Storages - have been investigated and are considered in the overall conservation scheme for the Grand River and its tributaries. However, any or all of this overall plan is a long-term affair and does not wholly subscribe to the immediate local need as is evident in the area under consideration.

Of the other schemes, all are of a like nature, in that they tend to solve the problem in the immediate vicinity where the problem exists, viz. the river channel through Hespeler. Of those schemes, the one (e) river channel improvement, is preferred, in that it will suffice to meet the immediate need and economic factor. The following is the scheme as outlined in detail from the report as submitted by R.K. Kilborn & Associates.

(e) River Channel Improvements

There is a considerable quantity of rubble, logs, vegetation, and natural obstructions existing in the river bed.

The removal of these obstructions will assist considerably in the problem of flood prevention, but this will not of itself improve the river channel sufficiently to materially reduce flooding. However, in all of the schemes, the removal of these obstructions from the upper dam down to the Beaverdale Road must be undertaken and the cost of this work is included in the estimates.

In addition to these natural obstructions, the highway bridge and to some extent the dam owned by the Dominion Woollen Mills obstruct the flood flows. By removing the latter and increasing the size of the clear openings under the bridge, the river channel proper will carry, with the addition of some diking and channel widening, 9,000 c.f.s. of flood water.

It is realized that the impounded waters of the dam are used by Dominion Woollen Mills Limited for process purposes; however, the loss of this water pondage can be overcome by the installation of a pipe from the forebay of the Stamped Enamel Ware Company's dam to the Dominion Woollen Mills Limited. An 18-inch pipe in this instance would carry between 3 and 4 million gallons per day or 1 to 1 1/3 million gallons per eight hours.

The highway bridge should be raised 3 feet and a fourth span of 30 feet constructed on the north end.

In addition to the above, the track of the electric railway should be raised above high water level, and a concrete wall constructed on the north bank of the river from the highway bridge to the upper dam, and a low dike built along the river frontage of the Hespeler Furniture Company to the Hydro building and a concrete wall from that point to the highway.

The estimated cost of this scheme as of 1952 is $142,500.00.

The channel improvement shown in the Kilborn report is an expedient which will not be necessary if funds are available for the reservoirs above Hespeler, as recommended in the overall plan of this report.

9. Dunnville and Port Maitland (Fig. H-28)

Dunnville is situated on the north bank of the Grand River, five miles upstream from where the river empties into Lake Erie. This town owes its founding to the construction of a dam here by the Welland Canal Company to supply water to the summit of its canal, which was about 6½ feet above Lake Erie. This dam was completed in 1829, and the town plot was laid out the same year by Oliver Phelps of St. Catharines, and the erection of buildings followed shortly.

Dunnville is fairly well situated as far as the water problems attendant upon a river subject to seasonal flow fluctuations, such as the Grand River, are concerned. The town, for the most part, is located on comparatively high ground, since the building of the dam prevented any development of the flats for building sites. Being located well downstream, the flood peaks, by the time they reach this point, have been lessened to a large extent by the temporary storage of large volumes of flood water due to the flooding of the broad flats all along the river. This storage, called "valley storage", would be considerable in a valley the size of the Grand. There is not sufficient data available to determine just what this storage would amount to for any of the great floods in the past nor to be able to state by how much it reduced the flood stages at Dunnville, but there is no doubt that it did provide a good measure of relief and probably has prevented flooding in the town altogether on many occasions. This latter is probably true for both the 1948 and 1950 spring floods when, in each case, the water was lapping the crown of Main Street, which was built up to form a low dike, within inches of overflowing into the town.

In the lower part of the watershed, the river provided a wide flood channel for itself, but unfortunately the construction of the dam mentioned above forms an effective barrier across this channel and reduces the waterway opening to a fraction of its former size. Prior to 1829, the river at normal flow was a deep, narrow stream, being approximately 500 feet wide and varying in depth up to 30 feet, and for higher stages it had this broad floodway about one half mile wide over which it could spread and flow. Under these conditions the discharge capacity of the channel could be greatly increased, with very little increase in water stage or in the velocity of the stream, and the flood waters would pass with little or no damage being done.

During periods of drought, the river is often reduced to a negligible flow at some points, and at others it may dry up completely, but Dunnville, with such a large area to draw from, may be certain of fairly good stream flows even during the driest periods. Further, Lake Erie backs the water up to the foot of the present dam, and therefore the town is always assured of a bountiful water supply even if its quality is questionable. Also, as the proposed widespread system of conservation reservoirs is developed on the watershed, the summer flows at Dunnville will be increased accordingly and the general appearance of the river will be greatly improved.

In spite of its more or less favourable position, Dunnville is threatened by flood waters almost annually and has suffered serious flood damage on many occasions. However, the flooding here is due chiefly to ice conditions rather than just high flows alone, and as far as is known, each of the past floods has been accompanied by ice jams in the river. These ice jams do not occur at any one particular point but may form anywhere in the river from the mill-pond down to the outlet at Port Maitland, depending upon conditions at the time of the break-up. On the basis of these conditions, the ice jams may be separated into three general groups as follows:

(a) Those that form at the dam when the ice is caught in the spillways,

(b) Those that form on the heavy ice sheets which form in the slack-water reaches above the dam and between the dam and Lake Erie,

(c) Those that are formed at the mouth of the river by strong south-east winds piling the ice up at the outlet.

Of these three, the first is most common and the one which may be most readily remedied. This dam hasn't served any useful purpose since 1926, except to provide a bridge crossing, and therefore is more of a liability rather than an asset and should be removed. The roadway over the dam is inadequate for present-day traffic, and if the dam were removed, a modern bridge could be constructed in its place. Besides removing a serious flood hazard, the removal of this dam would eliminate the costly upkeep of the old structure and would reclaim several hundred acres of land in the immediate vicinity which could be developed for park sites. Further, removing this dam would lower the water level along the southerly boundary of the town, providing an additional 4.7 feet of freeboard at the mean lake level of 572.34 feet. Even at the highest lake level on record, 575.11 (July 1862), there would be an additional freeboard of 2 feet which would permit, barring ice jams, the safe passage of flood flows substantially greater than any on record. The main objection to removing this dam is the fact that Dunnville has their water intake above the dam and their sewage outlet below, and the dam prevents any of the sewage effluent from being carried back upstream to the intake. This difficulty could be easily overcome, however, by moving the intake upstream. Also, there is a proposal on hand to go to Lake Erie for their domestic water supply, and should this scheme be carried out, the difficulty would automatically be eliminated.

Further, river soundings showed that the river varied in depth from 6 feet at Cayuga to over 21 feet at a point 5 miles above the dam and then gradually decreased in depth until there was only 5 feet of water at the dam. The river below the dam is quite deep, and it is apparent that should the dam be removed the river would soon cut a deep channel back through the silt which has accumulated behind the dam. Confining the flow to a smaller channel would tend to increase the velocity, and under these conditions it is very doubtful if any of the sewage effluent would ever be carried back upstream against this current. In fact, with a deeper channel, the intake could be lowered to obtain a cooler and probably much better water than can be obtained from the present shallow and sluggish pond above the dam. The waste weirs should be left open to provide as much floodway capacity as possible, but the sills could be raised and permanently set at the same elevation as the exposed flats to prevent the flood waters from cutting channels across these flats during the spring freshets.

If this scheme is to be carried out and the dam removed, it would be worth while to consider the possibility of dredging the channel above the dam and using the material to raise the level of the flats along the southerly portion of the present pond area which would be exposed. Records show that the silt deposit behind the dam, which consists, for the most part, of good topsoil that has been eroded from the fields upstream, varies in depth up to 25 or 30 feet, and it does not seem reasonable that this valuable material should simply be flushed on out into Lake Erie, where it would be lost to all useful purpose.

Ice jams of the second group present a more serious problem. Removing the dam would eliminate the upper ice sheet which forms in the pond behind the dam, but at the same time it would increase the lower sheet to some extent by allowing the slack-water area maintained by the lake to extend farther upstream. However, the total volume of ice would be substantially less, and removing the dam would improve the situation. This type of ice jam is more or less restricted to the break-ups following extremely severe winters when the frazil ice problem is at its worst and the ice sheet is thickest. Frazil ice is formed in open water exposed to air at temperatures below freezing under conditions that provide sufficient turbulence in the water to carry the ice crystals away as quickly as they are formed. In this way an ice sheet is prevented from forming, and the frazil ice collects elsewhere. This usually occurs below rapids, where the frazil ice is carried under the sheet ice formed in the quieter stretches of the river to form inverted or hanging dams which considerably restrict the river channel. Ice may be formed to great depths in this manner and with long periods of intense cold weather might fill the channel right to the bottom. As pointed out above, this condition arises during a severe cold spell, and when it is known that such climatic conditions have existed, it would be well to check the thickness of the ice sheet and, if possible, cut a channel through to the lake or at least shatter the heavier sections of the sheet by blasting prior to the general break-up of the river. This is about all that can be done to alleviate this condition, but it could prevent a serious ice jam from forming and avert heavy damage from ice shoves and flood waters.

It is understood that "ice channelling" has been carried out here in the past, and it is strongly recommended that it should be continued as required. Also, it would be worth while to engage residents at strategic points up the river to act as "river watchers" and paid a per diem rate for services performed, who could be in close touch with the Town Engineer or a member of the Authority at Dunnville to report on conditions of the river above the town so that the control measures could be implemented when necessary.

Ice jams of the last group are, fortunately, less common than either of the other two, as they are dependent upon the coincidence of strong south-east winds at the precise moment of the breaking up of the river ice. Under these conditions, the ice is prevented from passing out into the lake and piles up in the mouth of the river. Once a blockage does occur, it is quickly intensified by the subsequent floes, and the river may become completely choked with chunk ice piled to a considerable height and extending upstream for several miles. This presents a formidable problem and one about which little can be done. However, here again the situation develops under known climatic conditions and when these are evident, an armoured tug-boat could be employed to keep the mouth of the river free from ice floes carried in from the lake by the winds and to help keep the river ice moving out. On the other hand, under extreme conditions it would probably be too dangerous to operate a boat in these confined quarters and then under these circumstances, as pointed out above, there is little that can be done to remedy the situation. Further, in view of the infrequent occurrence of this type of blockage, it would not be practical to have an ice-breaker which could cope with the situation on hand.

The Grand River extends northward from Lake Erie for a distance of more than 180 miles and because of its position and direction of flow the break-up in the lower part usually occurs first, and much of this ice has a chance to escape before the spring run-off from the upper reaches comes down and the flood hazard is considerably lessened.

It is apparent that these ice conditions almost always arise when the spring thaw is sudden and particularly when the winter has been severe. The coincidence of heavy rains with the thaw augments the flood waters and tends to aggravate conditions still further. Ice jams with their attending floods do not usually develop following a mild winter when the sheet ice would not be too thick, or if the spring thaw comes gradually, permitting the sheet ice to rot in place.

It has been suggested that added discharge capacity for this dam could be obtained by lowering or removing entirely the sills across one or more of the existing sluiceways and installing stop-logs or gates to provide the necessary control. Such work would provide greater discharge capacity and might ease the icing conditions, but it is extremely doubtful that this work would be feasible. This is an old structure underlain by stone-filled timber cribs and, while these timbers are fairly sound, there is no way of knowing just how far the work would have to be carried to restore the dam to a safe and satisfactory condition should the timbers be disturbed. Therefore any major alterations to the present structure are not recommended.

As an alternative flood prevention measure a dike could be constructed along the river bank parallel to Main Street which would provide up to three feet of additional freeboard at this point. The dike, commencing at the northerly end of the dam, would run westerly along the river bank to Thompson Creek, thence northward to tie into the Canadian National Railway embankment east of the Robinson Road crossing. The elevation of the base of rail at this point is 588.2 feet and the dike could therefore be constructed to elevation 588.0. Main Street varies in elevation from 584.1 at Queen Street to 586.2 between John and Helen Streets, sags to 584.5 feet between Helen and George Streets and then rises to 586.0 at Thompson Creek. The land north of Main Street is from 2 to 3 feet lower than Main Street, with an elevation of 582.0 being noted for the intersection of Queen and Lock Streets. Robinson Road along the west side of Thompson Creek varies in elevation from about 586 feet at Main Street to 586.4 at the creek crossing to 588 at the railway crossing. Thus it will be seen that the dike may be raised approximately 2 feet higher by terminating at the railway embankment rather than following the creek around and tying into the road embankment.

This dike would have a minimum top width of 8 feet with 2:1 and 1.5 to 1 side slopes on the river and town sides respectively. The slopes of the structure would be sodded throughout except for a distance of 500 feet above the dam, and a 300-foot stretch around the nose of the dike at the confluence of Thompson Creek where the river slopes would be rip-rapped to prevent scouring. Main Street would have to be raised and regraded for a short distance to pass over the dike where it crosses this street, and culverts, fitted with flap gates or valves, would have to be installed on either side of the street to permit drainage through the dike to the river. During times of high flows these culverts would be closed to prevent the flood-waters from backing up through the dike.

The estimated cost of this scheme, which includes filling in the small bay at the entrance to the old feeder canal but not possible land costs, is $102,000.00.

While this scheme is cheaper than any other scheme which involves the removal of the dam, it does little to improve the situation existing at Dunnville. As pointed out before, the dam is an old structure and will require substantial repairs from time to time in addition to the annual maintenance costs. The present bridge crossing provided by the dam is inadequate for modern traffic and will have to be replaced shortly in any case. It could be done to advantage at this time. In addition to permitting the construction of a new bridge, the removal of the old dam would allow fish and small vessels to pass up stream, would eliminate one serious flood hazard and would provide for flood flows substantially greater than any that have occurred in the past.

The estimated cost of removing the old dam, constructing a new bridge and developing the reclaimed area as a park site is $475,000.00. Of this amount approximately $428,000.00 may be charged directly to the bridge which will be largely subsidized and therefore the ultimate cost of this scheme, to the local municipalities, will be about the same as that for the alternative diking proposition.

10. Other Trouble Areas

The reservoir storage and the expedients recommended provide flood protection for the major trouble areas but they may not prevent flooding of some intermediate rural properties along the rivers. Where there are obstructions such as shoals with growth on them and sharp bends which result in local flooding they should be cleaned out and the sharp bends eased, and particularly so if they are the cause of persistent ice jams.

No survey other than visual inspection has been made of these conditions and it is not possible, therefore, to give a reliable estimate. It is known that there is much cleaning out to be done but it is believed that most of the excavation can be bulldozed to the banks of the river cheaply and that $150,000.00 should cover this type of work.

11. Summary of Costs

The estimated cost of the foregoing expedients is summarized as follows:

Places	Those not necessary if there is no delay in providing reservoirs $	Those that are necessary and which are the Recommended Schemes $	Possible Alternative Schemes $
1. Galt		55,000	
2. Brantford		100,110	
3. Paris	145,650		
4. New Hamburg		90,000	
5. Plattsville		3,500	
6. Drayton		267,444	251,792
7. Guelph	65,000		
8. Hespeler	142,500		
9. Dunnville & Port Maitland		475,000	102,000
10. Other trouble Areas		150,000	
Total estimated cost of expedients	353,150	1,141,054	
Total possible cost	$1,494,204		

TABLE H-6

PART II

CHAPTER 6

HYDROLOGY

1. Definitions of the Hydrologic and Run-off Cycles

"The hydrologic cycle is the term applied to the general circulation of water in its various states from the seas, to the atmosphere, to the ground, and back to the seas again.

"The run-off cycle is the descriptive term applied to that portion of the hydrologic cycle between incident precipitation over land areas and the subsequent discharge through stream channels or the direct return to the atmosphere through evapotranspiration."* It is this phase of the hydrologic cycle that concerns spring floods and low summer flows.

2. Component Parts of the Run-off Cycle (Fig. H-29)

Brief definitions of the phases of the run-off cycle for an incident summer storm follow:

Evaporation	- precipitation returned to the atmosphere by the sun's radiation
Transpiration	- that portion which supplies vegetative growth, and is discharged to the atmosphere as water vapour
Interception	- that portion which is retained temporarily on the surface of vegetation, buildings, etc.
Depression storage	- that portion of water which is held in surface depressions.
Channel precipitation	- that portion which falls directly on the surface of streams or lakes.
Surface run-off	- that portion which reaches the streams or any rivulet by travelling over the soil surface.
Interflow or subsurface flow	- that portion which infiltrates the soil surface, and moves laterally through the upper soil horizons until its course is intercepted by a stream channel or until it returns to the surface at some point down slope from its point of infiltration.

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* Linsley, Kohler and Paulus. Applied Hydrology, Copyright, 1949. Courtesy of McGraw-Hill Book Co., New York.

Soil moisture - that portion which moistens or wets the soil, and when in sufficient quantity, percolates to the ground-water table.

Ground water - that portion in the super-saturated pervious soil which moves or slowly flows by devious routes through the pervious or semi-pervious soil or rock and ultimately finds an outlet and discharges into streams or emerges as springs.

The ground-water flow makes but a very small contribution to peak discharges, and is the source of the permanent or base summer and winter flow.

3. Precipitation

Precipitation is the source of all stream flow, and to a large degree the stream flow characteristics are determined by those of the precipitation.

Reference is made to Table H-7 and Fig. H-30. Comparing the monthly precipitation with the corresponding percentages of run-off, in general it will be seen that the percentage of spring run-off (for the most part surface run-off) is very high and that during the summer months, particularly after a drought, the percentage of run-off is comparatively low. For some of the spring months the percentage is over 200, which is accounted for by the accumulation of snow from the previous months. Apart from this accumulation, the run-off during the spring freshet is usually over 85 and could approach 100 per cent, depending upon the type of soil, its condition, the slopes and the temperature.

For summer rainstorms the percentage of run-off is much less and for the period of an individual storm the run-off may vary from 20 per cent or less, after a drought in July or August, to as much as 65 per cent in May (which is often a wet month with the ground nearly saturated), depending upon the intensity and duration of the rain, the temperature, the type of soil and its condition, the slopes, forest cover, land use, and other physical features which retard or affect run-off.

From the foregoing, it is evident that flood flows at the spring break-up are more common than at any other time of the year due to the melting of accumulated snow and ice which may be accompanied by rain. However, intense thunder or hurricane storms can produce high run-off peaks and it is necessary to consider all types of storms in order to calculate the peak flows and storage required to control floods.

TABLE H-7

THE MONTHLY PRECIPITATION ON THE GRAND WATERSHED
FOR THE MAXIMUM AND MINIMUM YEARS OF RUN-OFF ON RECORD,
AND THE AVERAGE FOR THE PERIOD 1916-1948
TOGETHER WITH THE CORRESPONDING RUN-OFF AND PERCENTAGE.

Month	Max. Year 1946-47			Min. Year 1930-31			Average Year		
	Pre-cip'n (in.)	Run-Off (in.)	Per Cent	Pre-cip'n (in.)	Run-Off (in.)	Per Cent	Pre-cip'n (in.)	Run-Off (in.)	Per Cent
Oct.	3.65	0.22	6.0	1.33	0.10	7.5	2.86	0.35	12.2
Nov.	1.59	0.30	18.0	1.99	0.11	5.5	2.54	0.69	27.2
Dec.	3.61	0.43	11.9	1.70	0.16	9.4	2.51	0.70	27.9
Jan.	4.01	0.99	24.7	2.59	0.10	3.9	2.73	0.78	28.6
Feb.	1.74	0.67	38.5	1.23	0.10	8.1	2.23	0.71	31.8
March	2.94	1.64	55.8	2.35	0.54	23.0	2.48	2.90	116.9
April	3.46	7.70	222.5	2.21	2.51	113.6	2.57	2.94	114.4
May	5.28	3.12	59.1	2.75	0.48	17.5	3.45	1.11	32.2
June	4.73	2.55	53.9	2.87	0.19	6.6	2.97	0.54	18.2
July	4.54	0.85	18.7	3.64	0.26	7.1	3.39	0.33	9.7
Aug.	2.04	0.55	27.0	3.11	0.13	4.2	2.70	0.23	8.5
Sept.	2.59	0.50	19.3	2.45	0.11	4.5	3.05	0.27	8.5

The total monthly precipiation on the Grand Watershed is also shown graphically on Figure H-30 from 1916 to 1949.

(a) Definition of Precipitation and the Purpose of Precipitation Records

Precipitation is the condensation of moisture from the atmosphere, which appears mainly in the form of rain and snow, occasionally in the form of hail, sleet or dew, and to a very small extent from the condensation of fog. In order to determine the storage that is required to control floods, increase subsequent low flows and the spillway capacity for dams, a reliable knowledge of the volume and rate of run-off or stream flow is necessary. This is possible through the study and the application of meteorological and hydrometric records, which are data concerning the amount of precipitation that falls on the ground, what becomes of it, how quickly it reaches the main channels, and in what volume it flows.

(b) Meteorological Stations

(1) Classification of Stations and Records

There is evidence that rainfall measurements were made in India as early as the fourth century B.C., but modern meteorology, made possible by the use of instruments, began only about the middle of the nineteenth century. From that time on the network of meteorological stations has grown, having received great impetus in recent years with the advent of the aeroplane. At the present time a network of stations covers most of the world and in the interests of air travel will continue to grow in order that weather forecasts may be more dependable.

In Canada it is probable that the early missionaries made some meteorological observations, but they left no useful records. The first station to be established in Canada was at Toronto in 1840 by Lieutenant Riddell, who came out from England the previous year. The Toronto station has kept continuous records since that time. Canada's network of stations is administered at Ottawa by the Meteorological Division of the Department of Transport. Monthly reports are published which show daily records of temperature, precipitation, atmospheric pressure, relative humidity, cloud amount, sunshine duration and the velocity and direction of wind. The stations are classified according to their equipment and personnel, and quoting from their publications the classification is as follows:

"Class I - A station where standard equipment consists of a mercurial barometer, wet, dry, maximum and minimum thermometers, anemometer, barograph and rain gauge. At most of these stations complete observations are taken four times daily at fixed synoptic hours, viz. 01.30, 07.30, 13.30 and 19.30 hrs. E.S.T. At the stations designated by 'T', the synoptic reports are immediately communicated by means of radio and telegraph to the teletype network linking all forecast offices in Canada.

(A) - indicates that the observations are taken at an airport.

(R) - indicates that the observations are taken at a radio range station, at which there is no airport.

(S) - indicates that the observations are taken at a seaplane base.

Class II - A station where the equipment consists of a maximum and minimum thermometer and a rain gauge, although at a few stations the equipment is more extensive.

Class III - The meteorological equipment consists only of a rain gauge.

Class IIM or IIIM:- A station in operation during the summer months only.

Chief Stations:- These are denoted by the letter 'F' indicating that these stations are Dominion Public Weather Offices and/or District Aviation Forecast Offices where forecasts are issued regularly.

At stations designated by 'C' the equipment consists only of a sunshine recorder and/or an anemometer."

The stations which may be used to determine precipitation and climatic conditions on the Grand Watershed are as follows:

Meteorological Stations in the Grand Watershed and Vicinity	Classification of Station	Years of Records
* Redickville	Class II	5
Mount Forest	"	26
Alton	"	43
* Shand Dam	"	11
Georgetown	"	65
Kitchener	"	26
Guelph	"	47
Stratford	"	67
Woodstock	"	68
Brantford	"	54
* Paris	"	48
Hamilton	"	49

(2) <u>Precipitation on the Grand Watershed</u>

Table H-7 shows the monthly precipitation on the Grand Watershed for the wettest and driest years on record, and the average monthly precipitation for the period 1916 to 1948 inclusive. It also shows, from the hydrometric records at Galt, the depth in inches of the corresponding run-off and its percentage of the precipitation. The precipitation is shown as depth of water in inches for each month of the year, the coefficient 0.1 being used to convert the snowfall of the winter months to the equivalent depth of water.

(3) <u>Stations used and method of apportionment</u>

Meteorological records have not been used to determine the spring run-off, but they have been used in Fig. H-30 to show the effect of climatic conditions on run-off, for all the records of the Galt gauge. They have also been used later in Chapter 15 to determine the reservoir space to be reserved for a hypothetical summer storm, which might occur on the watershed. The stations used are shown in the above list.

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* Records used when available and as a supplement to neighbouring stations.

The distribution of precipitation may be determined by the arithmetic mean of the stations, the isohyetal method or the Thiessen method. The Thiessen method has been used in this report, although when checked with the results using the simple arithmetic mean of the stations there was very little difference. The isohyetal method is probably the most accurate, but the map-making is laborious and the difference from the method used is hardly worth the effort.

Fig. H-31 shows the Thiessen method and is described as follows:

The network of stations was plotted to scale and

> "perpendicular bisectors to the lines connecting the stations. The polygons thus formed around each station are the boundaries of the effective area assumed to be controlled by the station, i.e., the area which is closer to the station than any other station. The area governed by each station is planimetered and expressed as a percentage of the whole area. Weighted average rainfall for the basin is computed by multiplying each station precipitation amount by its assigned percentage area of totaling". *

(4) The value of weather forecasts and meteorological records to determine stream flow

Meteorological records usually antedate hydrometric records which, when available, are used for hydraulic problems described later. With run-off and storage problems, if there are no hydrometric records for a watershed and none for similar or nearby watersheds for comparison, it may be necessary to resort to the meteorological records and the use of empirical formulae, together with a study of the geophysical characteristics, in order to determine the run-off that might be expected from an area. Results from this method are uncertain and unsatisfactory. If hydrometric records are available, though covering only a few years, and long-term meteorological records for the watershed are available, they may be correlated to give a satisfactory solution. In latitudes to the south where there are no serious snow and ice

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* Linsley, Kohler and Paulhus. Applied Hydrology.

problems and rainstorms are the chief flood concern, even with long-term hydrometric records, antedated by meteorological records, the two are usually correlated by means of the unit hydrograph method to determine run-off for an assumed or hypothetical storm. For spring floods, however, conditioned by ice jams, snow and ice cover and other variable agencies, the unit hydrograph method is not so suitable.

This applies particularly to the Grand flood problem, since the Galt gauge covers about the same period as the meteorological records.

4. Run-Off and Stream Flow

Run-off is the amount of water a drainage area supplies to the open stream, and is the excess of precipitation over evaporation, transpiration and deep seepage. Figure H-29 shows phases of the run-off cycle for a summer storm, the sequence of events shown by the phenomena as occurring simultaneously at four specified times throughout the cycle. The cycle for spring run-off is the same in principle, but the conditions are different from those of summer storms. At the time of the spring break-up, as already noted, the ground is saturated or frozen and consequently much less water reaches the ground-water table. There is no transpiration and small evaporation, and the rate and the amount of run-off from snow melt and rain in the spring are much greater due to these ground conditions.

Stream flow or run-off consists of surface flow plus the ground-water flow, which is constantly entering the stream channel all along its course. Surface flow is that portion of rainfall and melted snow and ice which reaches the stream channels directly by flowing over the ground surface. It is the component which forestry and land use practices strive to conserve, by retaining or retarding it as much as possible, and by promoting deeper and more rapid percolation to the water table. (Surface flow also includes precipitation falling on the surface of the stream and its tributary ponds, lakes and reservoirs.) It usually constitutes the greater portion of stream flow, and is responsible for the fluctuations in the stream flow. The ground water flow (percolation) to the stream is going on continuously and supplies the stream flow during periods of drought. This phase is known as the base flow. Run-off is termed discharge or flow when it reaches a watercourse.

(a) Hydrometric Stations

(1) Their value in determining stream flow

* Hydrometric gauges record the run-off after it reaches the stream or river as flow or discharge. Flow is expressed in terms of cubic feet per second (c.f.s.) of water which passes the section of the river at the gauge. These records combine all of the many geophysical and meteorological factors, previously listed, which influence the volume and the rate of run-off. When reliable and continuous, the value of the records of a gauge increases with the years of operation. A gauge having 25 or more years of reliable and continuous records provides sufficient and the best data to determine the flow or rate of run-off for our spring flood problems and, conversely, the amount of storage that is required to increase and sustain low flows.

Since the rate of run-off varies greatly over a watershed, if satisfactory flows are to be determined for many places along the river and its tributaries, gauges should be installed at or near those places. If the watershed has one reliable and continuous long-term gauge strategically located, the records of other gauges, even if only a few years in operation, may be related (as will be later explained) to those of the long-term gauge, and so satisfactory flows determined. The Galt gauge is a reliable long-term gauge, ranking with the best in Ontario.

(2) Gauge installations and their rating curves

Gauges are installed at strategic points on the

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* Hereafter called "gauges".

river and its tributaries. They consist of rods graduated in feet and hundredths of a foot, affixed to bridges or other structures on a stretch of the river of uniform width with banks if possible above flood stages, the banks or bed of the river not subject to erosion and not affected by back-water.

The gauges are of two general types: those which are read manually twice daily, and oftener during flood periods, usually called staff gauges; and automatic gauges which have a special housing and the water level stages are recorded by a continuous line on graph paper, from which the stage may be read for any time of the day.

The river at the site of a gauge is cross-sectioned, and the velocity measured with current meters across the section at different depths and at various times between the low and high stages of the river, and the average or mean discharge determined for each of various stages. These measurements are, in part, repeated periodically in order to check any changes in discharge that might occur due to shifting and scouring of the river bed, or any alteration of the original section. From this data a rating curve (Figs. H-32 and H-33) is prepared for the gauge whereby the discharge in c.f.s. may be read from the curve for any reading of the gauge. With the stages for flood peaks, which are usually not practicable to measure, the curve can usually be reliably extrapolated, provided the river does not overflow its banks at the gauging stretch.

(3) The history of installations in Southern Ontario

The systematic measurement of stream flow was begun in 1912 by the Ontario Hydro-Electric Power Commission, but as they were only interested in the development of hydro-electric power, metering stations were usually established only on those streams indicating such a potential, and on the Grand where some were established they were discontinued after a few years of operation. In 1919, following a co-operative agreement between the Hydro Commission and the then Department of the Interior, the Dominion, Water and Power Bureau (now the Water Resources Division of the Department of Northern Affairs and National Resources, referred to hereafter as the "Bureau") assumed the responsibility of the hydrometric work. Unfortunately hydro-power development was still the motive, and the meterings were confined to those streams where such development appeared feasible. In 1944, when the Department of Planning and Development was established, they requested the Bureau to install gauges on many of the rivers in Southern Ontario which owing to their "flashy" nature had not been considered suitable for power, and therefore had not been metered. In all, about 26 new gauging stations have been set up in Southern Ontario. On the Grand, however, most of the new stations were set up by the Grand River Conservation Commission.

Fig. H-1 shows the location of gauges on the Grand Watershed, and in Table H-8 they are listed, showing their location and years of records, whether automatic or manual, and their drainage areas.

The Grand is among those rivers to which reference is made. Fifteen gauges were set up by the Hydro in 1914, and all except the Galt gauge were discontinued after from two to nine years of operation. The gauges at Canning and Brantford were renewed in 1947 and 1948, and new gauges were installed at Conestogo and Marsville in 1946 and 1948 respectively, all of them automatic. The Hespeler gauge was renewed in 1948 but, as it was not dependable, was discontinued, and a gauge was set up at Guelph. The Galt gauge, fortunately, has been maintained from its inception. It was converted from a staff to an automatic gauge in 1947 and has to date 37 years of continuous records. Except above the elevation or stage where it overflows its banks, the records and rating curve can be relied upon, as that section of the river, owing to its solid rock and boulder bed, is subject to little change by erosion or deposits. For this reason, and also for its strategic location,

TABLE H-8

DRAINAGE AREAS AND PERIOD OF RECORDS FOR HYDROMETRIC GAUGES ON THE GRAND WATERSHED

Gauge	River	Drainage Area Sq. Miles	Period of Records	Number of Years
* Waldemar	Grand	259.6	1947-	
Belwood	Grand	299.4	1914-23	10
* Shand	Grand	309.2	1954	
Conestogo	Grand	555.5	1914-23	10
Salem	Irvine Creek	81.2	1914-16	3
Drayton	Conestogo	125.2	1950-	
St. Jacob's	Conestogo	306.6	1914-16	3
* Conestogo	Conestogo	317.0	1946	
Oustic	Speed	21.0	1954	
Caraher's Bridge	Speed	66.5	1914-17	4
Guelph (above)	Speed	104.0	1954-	
Guelph (below)	Speed	229.2	1950-	
Hespeler	Speed	274.8	1914-28) 1948-49)	16
Galt Creek (at Galt)	Galt Creek	34.4	1914-16	3
* Galt	Grand	1,357.9	1914	
Glen Morris	Grand	1,380.5	1914-20	7
New Hamburg	Nith	209.1	1950-	
* Canning	Nith	398.4	1914-17) 1920-25) 1947-)	3 5
Princeton	Horner Creek	62.0	1954	
Burford	Whiteman's Creek	145.8	1914-16	3
* Brantford	Grand	2,008.6	1914-22) 1949-)	8
Onondaga	Fairchild's Creek	149.9	1914-16	3
York	Grand	2,345.9	1914-23	10
York	Boston Creek	138.8	1914-16	3

* Automatic recording gauges.

the Galt gauge is the master gauge for determining the amount and rate of run-off for the various drainage areas of the watershed.

(b) Run-off Characteristics

As previously shown, precipitation is the source of all stream flow and to a large degree the stream flow characteristics are determined by those of the precipitation. In addition there are many other factors which influence the amount of run-off (Hayford *has shown that there are at least 23 factors affecting run-off) classified as variable or more or less permanent, sub-divided as follows:

(1) The Variable Factors: Climatic

- a Precipitation
    - Amount
    - Intensity
    - Area covered
    - Seasonal distribution
    - Proportion of snow and ice
- b Temperature
- c Relative humidity
- d Wind

(2) The Permanent Factors: Drainage Area Characteristics

- a General: Location
    - Size
    - Shape
- b Topography: Surface slopes
    - Water areas
- c Geology: Character of surface
    - " " subsurface
- d Condition: Cultivated
    - Vegetation
    - Drainage

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* Hayford and Folse. A New Method of Estimating Stream Flow.

(3) Storage

Natural lakes, ponds and swamps
Artificial reservoirs
Ground storage

(c) Spring Freshet Run-Off

In southern Ontario there is a decided difference in the run-off conditions for summer storms from those at the time of the spring freshet, the latter being much more severe.

At the time of the spring break-up there is no transpiration and small evaporation, but the rate of run-off is much greater due to the depth and weight of accumulated snow, the temperature, whether accompanied by rain or sunshine, the condition of the ground - dry, wet, saturated, frozen or ice - the slopes and the river gradients, all of which affect the rate of the run-off.

The most adverse condition for spring floods would be a heavy accumulation of snow on ice or frozen ground, with heavy rain, high continuous temperatures and ice jams.

(d) Run-Off Ratios

As previously stated the run-off varies greatly over the watershed. The run-off and its rate for the Conestogo and Upper Grand drainage areas is greater than that of the Nith or the Speed, and in general, both volume and rate of run-off increase in all these drainage areas from their outlets to the headwaters. In order to determine the storage required for the flood problem and the spillway capacity for the dams, it is necessary to determine the volume and rate of run-off for extreme flood periods for the drainage areas above the flooded areas, and the proposed dams. For this reason gauges should be installed as soon as possible at or near these places.

From Fig. H-1 it will be seen that the discontinued and operating gauges are located near the confluence of the Grand tributaries, and at other strategic places. The volume of run-off and extreme maximum mean daily flows can be determined (approximately only in some instances) at these places having only short-term records by relating them to the Galt gauge by establishing run-off ratios, and applying them to the volume and flows at Galt. Table H-9 shows these ratios for the volume of run-off and the maximum mean daily flow for the flood periods on record. For volume they were computed by totalling the flow records for a 12-day spring flood period for gauges above Galt (14 days for those below Galt) for each year of the available short-term records, and relating them with the volume of the corresponding flood period at Galt, the run-off ratio for gauges above Galt being:

$$\frac{\text{The volume of 12 days spring flood flow at the short-term gauge}}{\text{The volume of 12 days spring flood flow at the Galt Gauge}}$$

with 14 days substituted for the gauges below Galt when related to Brantford gauge.

The results from the above equation for each of the available flood periods, (some of which were weighted) were averaged and tabulated.

Ratios for the maximum mean daily flows for spring floods were determined in the same way namely:-

$$\frac{\text{The maximum mean daily at the short-term gauge}}{\text{The maximum mean daily at Galt}}$$

The ratios of volumes were used to determine the storage distribution in diagram Fig. H-34 and the ratios of maximum mean dailies for extreme flows at the gauges and other places on the watershed.

TABLE H-9

FLOW RATIOS RELATIVE TO GALT AND BRANTFORD GAUGES

Ratios determined from the maximum mean daily and flow volume over the flood periods for the available years of record

RATIOS RELATIVE TO GALT

Gauge Location	Drainage Areas	Volume for Flood Period	Max. Mean Daily for Period
Conestogo (Grand River)	0.40907	0.44963	0.39307
* Conestogo (Conestogo River)	0.23336	0.35449	0.42788
Hespeler (Speed River)	0.20244	0.15718	0.12488
Belwood (Grand River)	0.22048	0.29412	0.23877
Salem (Irving Creek)	0.05979	0.07909	0.07165
Brantford (Grand River)	1.47913	1.42860	1.33579

RATIOS RELATIVE TO BRANTFORD

Galt (Grand River)	0.67596	0.69999	0.74862
Canning (Nith River)	0.19832	0.17354	0.16359
Burford (Whiteman's Creek)	0.06521	0.05159	0.03930

* Includes 3 years' records at St. Jacob's

CHAPTER 7

HYDROGRAPHS [+]

1. Definition and Characteristics

The hydrograph is a plot of flow against time and is a correct expression of the detailed run-off of a stream resulting from all the varying physical conditions which have occurred on the drainage area above the gauging station previous to the time which it represents.* Generally the vertical ordinate represents the rate of flow in cubic feet per second and the horizontal ordinate, or abscissa, time which is usually expressed in hours or days.

It is by means of the hydrograph that the volume of storage herein is determined. Fig. H-35 shows continuous hydrographs for the Galt gauge from 1914 to 1950, and Fig. H-36 shows hydrographs for all the other short-term gauges on the watershed for the years they were in operation.

Fig. H-37 shows on a larger scale hydrographs at Galt, for the severest spring floods of record, viz. 1929, 1943, 1947 and 1948. The area of the hydrograph for any period of time represents the volume of water which has passed the gauge. In order to avoid the use of astronomical numbers, volume is expressed in acre feet, instead of cubic feet.

Flood hydrographs are, roughly, triangles or a series of triangles rising from, and receding to, the normal or base flow. The left limb (the rising or accession limb) rises from the base flow to the maximum mean daily, or the apex of the triangle. Actually, for timed flows the apex is not a point, but is slightly blunted or rounded. When at the apex, all of the surface run-off has reached the river and the right

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[+] See Appendix "C" for revisions to analysis procedures.
* Definition given in "Hydrology" by Professor D.W. Mead.

limb (the falling or recession limb) represents the lowering of the "valley storage", or the falling stages of the water level of the river until it is down to base flow. The rising and falling limbs are slightly concave, but may be assumed to be straight lines and the apex assumed to be a point in calculations without serious error. The interval of time between base flows is the "flood period".

2. Magnitude of the Hypothetical Spring Flood and Method used to Determine Storage

When hydrometric records are available the amount of storage that would be required to control any particular flood in the past is not a difficult problem. For a future or "hypothetical flood", however, having a greater magnitude than any known flood, the problem becomes extremely complex, especially with ice and snow conditions at the time of the spring break-up. Under these circumstances there is no means whereby storage may be determined with mathematical certainty. There are various approaches to the problem, all of which are approximations. As stated in Chapter 4, some Hydrologists prefer the Unit Hydrograph Method, which is a correlation of hydrometric and meteorological records. Where a precipiation to run-off ratio may be accurately determined this method is satisfactory, but in Southern Ontario, owing to the widely varying factors of temperature and ground conditions and particularly snow and ice accumulations, such a ratio has not been readily available.

In Chapter 4, storage has been provided for a spring flood 1-1/3 times greater in volume than the greatest flood on record, viz. April 1947. With 20 years or more of records, a run-off graph for spring freshets showing maximum mean daily flows against total run-off between base flows may be developed. By increasing the maximum run-off by one-third or more, the corresponding mean daily flow and total run-off for a possible future flood are determined.

With 36 years of hydrometric records for Galt, many of which record major floods, it is believed that the construction of a hydrograph at the gauge for the hypothetical spring flood based on the run-off graph and using a factor of 1-1/3, will give a close approximation and the best answer to the storage problem.

3. Construction of the Hypothetical Hydrograph

It can be shown that, for the purpose of determining storage, the hypothetical hydrograph may be assumed to be a triangle, and when the flood run-off, or the area of the triangle, is known, the base or flood duration and the apex or maximum mean daily may then be determined approximately.

(a) Hypothetical Hydrograph may be Assumed to Approximate a Triangle

An examination of Figure H-35 shows that the hydrographs for the flood periods, which have been plotted from the Galt gauge records, are either triangular in shape or are broken up into several smaller triangles. The hydrographs for June 1935, December - January 1940-41, and March - April 1941 have only one apex and are definitely triangular in shape, or are a close approach to a triangle. Those for the month of March in the years 1917, 1919, 1935 and 1948, except for a slight deflection, have also but one apex; those of March - April 1929 and April 1947, years of bad floods, have two triangles or runs each.

The hydrographs would all be triangular with one apex, but for climatic influences and ice jams. In summer and fall any split in the hydrograph is due either to a break in the general storm, a lag in run-off on one or more of the tributaries, or to unequal timing or distribution of the rainfall. At the spring break-up there are other factors which split up the hydrograph, the chief ones being intervals of freezing temperatures which delay the snow melt, or ice jams which may hold back flood waters for a time and then later release them suddenly. These conditions are exemplified in the 1922 March - April break-up period during which time there were six breaks in the hydrograph. There was a large volume of run-off during this period and although some flooding was caused by ice jams it would have been a major flood had it not been for the intervals of freezing temperatures which lengthened the duration and lowered flood crests. Fig. H-4 of the great flood of 1947 is a good example of the effect of freezing temperatures. From April 6 to April 8 the average daily temperatures dropped from 41°* to 28°, or from a maximum of 53° to a minimum of 20°, which caused a recession or drop in the hydrograph between those dates; and then rose abruptly between the 10th and the 12th of April, with the daily mean temperature rising to 50°. There was an estimated average of 20 inches of snow melt run-off and, had the average temperature remained high, there would have been only one run of a shorter duration period and consequently a higher apex which would have produced a flood of even greater magnitude.

Since a definite volume of flow is to be provided for the hypothetical spring flood period and as one apex gives the highest rate of flow, therefore an unbroken hydrograph or triangle would give the best results, in which the most adverse conditions would be satisfied.

(b) Determination of the Base or Flood Duration

An examination of the hydrographs of the flood periods at Galt showed that the duration period did not vary greatly for summer storms, it being about 6 days only. With the spring floods, however, there is a wide spread from 10 days to as much as 26 days, but as was pointed out in the previous subsection, the long periods have been dissipated and have several minor peak flows. The major floods vary by only a few days; the pattern being that as the peak increases the duration

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* Degrees Fahrenheit, and the average for the watershed.

of the flood period decreases, depending upon the breaks in the hydrographs. The damaging floods of from 10 to 15 days' duration are therefore the concern of the flood problem, and those of longer duration may be disregarded. Twelve days is about the average duration for the major floods at Galt and is the duration period which is used in the next subsection in preparing the run-off graph.

(c) Determination of the Apex or Maximum Mean Daily Flow

The apex of the hypothetical hydrograph has been determined by means of a "run-off graph" (Fig. H-38), which is a graphical correlation of the two variables, namely the volume of flow in acre feet and the maximum mean daily in c.f.s. for all of the spring flood periods of record. From this graph the maximum mean daily or apex may be determined by extrapolation for the volume of flow which has been provided for the hypothetical spring flood period.

As stated above, the major flood periods showed that the duration at Galt gauge varied between 10 and 15 days. For the purpose of comparison three run-off graphs were prepared for the spring run-off periods at Galt, viz. for 10, 12 and 15 days' duration. From these graphs it was found that the resulting storage using the 12-day period was 14.4 per cent more than for the 10-day period and only 2 per cent less than for 15 days. The 12-day period therefore has been used below to determine the maximum mean daily at the apex of the triangle. Later it will be seen that, using this function and that of the established area of the triangle and solving for the base, the duration is actually 10.1845 days, and hence the hydrograph was adjusted to conform to the 12-day run-off period premise.

(d) Run-off Graph

The run-off graph was prepared as follows:

(1) the area or volume of flow for the period was found by summing the flow records for each day, and converting the result into acre feet. The volume for the flood period was

plotted on cross-section paper relative to the maximum mean daily flow for the period, the volumes being to a horizontal scale and the maximum mean dailies to the vertical. All of the spring flood periods from 1916 to 1950 inclusive were plotted.

(2) The arithmetic mean was determined for the volumes of all the periods and also for the maximum mean dailies, by taking the summation of these and dividing the results respectively by the number of periods. The arithmetic mean was plotted, and a horizontal and vertical axis drawn through that point.

(3) Moments were taken on both sides about the horizontal axis, the moment M = YQ, Y being the vertical measurement of the points to the horizontal axis and Q the volume for the period. The sum of the moments on each side of the horizontal axis was divided by the number of the periods on each side giving values of A and B respectively. A straight line joining points A and B (when plotted) passed through the arithmetical mean. Moments were taken in a similar manner about the vertical axis, and the corresponding points C and D plotted. The straight line joining these points also passed through the arithmetical mean. These lines do not coincide, but form an angle* at the arithmetical mean, due to the variable agencies which influence spring run-off.

(4) The lines AC and DB were bisected at E and F respectively, which gives an average for the co-ordinates, and points on the line EF and EF produced are co-ordinates of a correlation between the maximum mean daily, relative to any volume of flow for a 12-day period.

The greatest volume at Galt for a 12-day run-off occurred in April 1947, from the 4th to the 15th, and was 403,502 acre feet. For the hypothetical spring flood the volume is:-

430502 x 1-1/3 = 574,003 acre feet.

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* This angle is much smaller for summer storm periods than for those for spring run-off.

From Fig. H-38 the corresponding maximum mean daily flow for the hypothetical flood is 56,830 c.f.s.

(e) Adjustment of the Base or Flood Duration

Using the determined area and altitude functions in the triangular hypothetical hydrograph and solving for the base gives a duration of:-

$$\text{Base} = \frac{2\ \text{area}}{\text{height} \times 1.98347} = \frac{2 \times 574003}{56830 \times 1.98347} = 10.1845 \text{ days}$$

Fig. H-39 shows the constructed hypothetical spring flood hydrograph at Galt. The triangle has been adjusted to conform to the 12-day period, by extending the average base flow at the up and down limbs to 12 days, and reducing the area of the triangle by an equal amount.

Fig. H-37 shows the adjusted hypothetical spring flood at Galt, superimposed on those for the spring floods of 1929, 1943, 1947 and 1948. The similarity of the hydrographs is noteworthy as it indicates that the triangular concept for flood periods is fundamentally sound. The channel capacity storage which is determined in the next chapter from the hypothetical hydrograph may not be absolute, but it is believed to be a very close approximation.

CHAPTER 8

FLOOD CONTROL STORAGE

1. Above Galt

(a) Channel Capacity at Galt

The "channel capacity" for a place which is subject to flooding is the maximum flow in cubic feet per second which can be contained within the river channel without flooding. Expressed in another way, it is the highest stage or water level that the river can reach without overflowing its banks . Where dikes are proposed or already in place, it may be related to some stage on the dikes.

A reliable "channel capacity" for each place flooded is essential for the solution of the flood problem at that place. If there is a rated gauge at the flooded area in question, the channel capacity flow can be determined at any flood time by relating the elevation of the overflow point with the corresponding elevation of the gauge, and the rate or flow for channel capacity determined from the gauge's rating curve. If the gauge is not too far away, it may be obtained in the same way if the slope of the river or the difference in elevation is known between the gauge and the point of overflow. If the gauge is some distance away and the average stream velocity between the points is known, it may be determined at flood time by having an observer at the flooded area and another at the gauge, one noting the time at which the river reaches "channel capacity" flow and the other reading the gauge at timed intervals.

The Galt automatic gauge is located in a housing at the Concession Street bridge (Fig. H-20). The point where the river overflows is at the east end of the Galt dam, about 4,000 feet upstream. It also overflows, at about the same time, the right bank at the south side of Galt below the gauge.

The above observations for "channel capacity" at Galt were not necessary, however. In the spring of 1949 there was no flood and from local investigations it was learned that the river stage just reached "channel capacity". From the automatic gauge chart the peak occurred at noon, March 23, and the gauge reading was 864.92.* From the rating curve (Fig. H-32) the "channel capacity" is 30,650 c.f.s.

(b) Galt the Key Point for Flood Control

Except for Drayton, there were no floods during the spring of 1949 at any of the other trouble areas. Therefore the amount of storage required to satisfy the Galt flood problem, provided the reservoirs are strategically located, will also satisfy the trouble areas above Galt. Galt, therefore, with its master gauge, is the key point of the flood problems upstream and also downstream, after the latter drainage area has been accounted for by additional storage and for some channel improvement.

(c) Storage Required Above Galt

Space is provided in reservoirs for four independent purposes, and the amount for each determined; the total of these is the flood control storage required, viz:

(1) Channel capacity storage
(2) Dead storage
(3) Operational storage
(4) Boost discharge storage
(5) Total storage above Galt

(1) Channel Capacity Storage

The channel capacity storage above Galt is the equivalent of the volume of water which overflows at Galt. It is represented on the hypothetical hydrograph (Fig. H-39) by the area above the line 30,650 c.f.s., the channel capacity rate of flow. The triangular area above this line is

$$\frac{2.311}{2} \text{ in. } \times 13.09 = 15.12549 \text{ sq. in.}$$

1 square inch = 7,933.88 acre feet

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* Geodetic Survey of Canada datum.

Therefore the channel capacity storage =

15,12549 sq. in. x 7,933.88 = 120,003 acre feet.

(2) Dead Storage

A reservoir should never be drained bone dry. A certain amount of water is retained to protect the discharge tubes at the foot of the dam, and to facilitate enough silting of the reservoir bottom in the immediate vicinity of the dam in order to protect natural and artificial seals against damage. Dead storage space therefore is not used for flood control, nor is the water available to supplement low flows at the end of a dry period.

The amount of dead storage depends upon the gradient of the bed of the reservoir and its width in the vicinity of the dam, and will vary for each reservoir.

The estimated dead storage for the watershed has been based on the average held in Belwood Lake during its years of operation, which is about 2 per cent of its total capacity, or the equivalent of 2,737 per cent of its channel capacity storage.

Based upon the above channel capacity storage for the watershed:-

The total dead storage is approximately

$$\frac{2,737}{100} \times 120,003 = 3,284 \text{ acre feet.}$$

(3) Operational Storage

Operational storage is a cushion which will enable the control of the flows through Galt to approach, but not exceed, the channel capacity.

Part III on Water Conservation shows that 119,140 acre feet of water (called "conservation storage") is to be stored in the reservoirs during the spring run-off period, in order to increase and sustain the low flows until the following spring. If cheap storage were available, space would be provided in the reservoirs for conservation storage and also that for flood control. In this case the problem of dam control during spring floods would be simplified. The cost of storage, however, on the Grand, as with most watersheds in Southern Ontario, is very high. Hence it is necessary to use the space in the reservoirs (called "dual-purpose reservoirs") for both purposes: during the spring flood period the controller of the dam system must operate it in a manner which will prevent a flood, and at the same time fill the reservoirs to the conservation storage level, a very uncertain and exacting task. His anxiety is great at this time. He has to regulate the discharge of many dams, most of which are some distance upstream, time and route their discharges so that the flows through Galt (explained in the next section) will conform approximately to the hypothetical hydrograph, and not exceed the channel capacity. He has to make provision for ice jam, and regulate the dams in such a manner as to prevent flooding at the other trouble areas above and below Galt. He is concerned with the amount of snow cover, the condition of the soil, but in particular what the weather ahead will be during and immediately following the spring run-off. It is assumed that, prior to the spring break-up, the condition of the soil will be known, and that the average weight of snow pack for the various areas of the watershed will have been determined by field observers, from which the controller will know approximately the potential volume of run-off. What he does not know is the behaviour of the snow melt, or if he will also have to contend with heavy rainfall. Meteorological forecasts are indispensable and future scientific research combined with more stations will increase their dependability. At the present time, however, "No method of accurately forecasting the weather for more than 48 hours in advance has yet been devised that meets the approval of the larger part of the meteorological profession".* Whereas a period of at least two weeks is required for our purposes.

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* Authority: Charles D. Hopkins, Jr. Ass. M.A.S.C.E., U.S. Weather Bureau, River Forecast Centre.

From the foregoing remarks, it is obvious that during the spring run-off period the operator cannot control the flows at Galt, holding them at the channel capacity stage. He must have a lower stage to provide a margin of freeboard, or a cushion below channel capacity, for an objective.

With the complexitities of spring run-off, and the above unpredictable factors, it is apparent that there is no rational means by which the freeboard can be determined. It depends upon the judgment of the controller and at this time can only be estimated. An estimate therefore of one foot has been made which is believed to be a minimum of latitude for the operation of the reservoirs. From Fig. H-39 it will be seen that a foot below the channel capacity line represents 41,170 acre feet of operational storage.

Also from Fig. H-39 it will be seen that an inch of freeboard below the channel capacity averages:

$$\frac{208,397 - 120,003}{24} = 3,683 \text{ acre feet}$$

or approximately $368,300 for each inch of freeboard, a considerable amount for a small error in the estimate. The plan, however, will be a long-term program and later experience in operation may show whether too much or too little freeboard has been provided; if it is not enough or is too great, there would be time to adjust the plan accordingly.

The operational storage estimate is contingent upon the following premises:

a That the control of the dams is under efficient management, with adequate personnel and equipment.

b That surveys are made to observe the condition of the soil, the depth to the ground-water table, to record the accumulation of snow during the winter, particularly the condition of the soil, and the depth and the weight of the snow pack at the spring break-up.

c The rapid assembly at the control centre of rainfall and run-off information, stream gauge records at the areas subject to flooding, at the dams and any other strategic places.

d A sound and rapid system of communications together with an emergency operating plan in the event of failure of the communication system. The system should be such that information from the operation personnel at gauges, dams, meteorological stations and any other places that would influence the control of the dams would be rapidly transmitted to the control centre, and that instructions issued by the control centre would be transmitted quickly.

e That a basic plan of operation is installed at each reservoir.

f That weather forecasts are obtained by the best means available.

g That discharge curves are prepared for the control valves of the discharge tubes, gates and spillways together with curves for storage capacities and time of wave travel.

h Any other measures employed that would increase the efficiency of the control centre.

(4) Boost Discharge Storage

Boost storage is a necessary increase in the head of water at the dam in order that the dam, during the first part of the spring run-off period, may be able to discharge a volume of water equal to the inflow into the reservoir. In order that the function of the boost storage may be understood, some particulars concerning dam regulation which conform to the hypothetical hydrograph should be explained.

For the hypothetical spring flood period, and for floods approaching this magnitude, the regulation of the dams should be such that the flows through Galt should conform approximately to the hypothetical hydrograph; which means that the flow should follow the rising limb, until the flow reaches the stage between the operational and channel capacity rates (26,490 c.f.s. and 30,650 c.f.s. respectively); if, during this interval of the rising limb, the discharge from the dams is equal to the inflow into the reservoirs, the flows through Galt will conform to the hydrograph. After the flows have reached that stage, the inflow into the reservoirs would be greater than the discharge from the dams, the water level in the reservoirs would rise and the reservoirs would be full at the time the falling limb reached the channel capacity rate of flow. At this time the peak of the flood has passed, the surface run-off is complete and the surplus run-off is all in the river and its tributaries. Provided there is no further precipitation or added discharge from the reservoir, the stages at Galt would conform to the falling limb, and recede to base flow.

If during the rising interval, the discharge from the dams should be less than the inflow into the reservoirs, the reservoirs would fill prematurely, and if the run-off were of the hypothetical magnitude, would result in a flood. Consequently, in order that the dams may be able to discharge the inflow, provision must be made in both the design of the discharge tubes and the head of water over them.

At the beginning of the spring break-up, any conservation storage left in the reservoirs would be dumped to the dead storage level to provide space for the approaching flood. At the dead storage level it would not be practicable to provide discharge tubes of sufficient size and number to discharge the inflow at such a low head. Hence, the head must be increased, or "boost discharge storage" provided, to the extent that tubes may be designed economically to discharge the inflow.

The volume of the boost storage required depends upon the drainage area of the reservoir, the amount of the run-off and the design of the dam, and will vary for each reservoir. The design of the dams is beyond the scope of this report, but since an allowance for boost discharge storage is necessary at this time, it has been estimated at 4,926 acre feet or about 4.1 per cent of the channel capacity storage.

The boost storage is reserved space which would probably be filled during the usual heavy base flow preceding the freshet, in order that the head of water is available in time to discharge the inflow.

The boost storage may be used at the end of dry periods to supplement low flows.

(5) Total Storage Above Galt

The storage above Galt is summarized as follows:

	Storage Acre Feet	Percentage of Total Storage
(1) For Channel Capacity	120,003	70.85
(2) For Dead Storage	3,284	1.94
(3) For Operation	41,170	24.30
(4) For Boost Flow	4,926	2.91
Total Storage above Galt	169,383	100.00

The efficiency in the operation of the dual-purpose reservoirs $= \frac{120,003}{120,003 + 41,170} \times 100 = 74.46$ per cent.

(d) Remarks Concerning Dam Operation for a Moderate or Light Spring Run-off

The preceding remarks on dam regulation apply to the hypothetical flood or to major floods, such as those of 1947 or 1948, which might be anticipated. It would not apply if it is known that the spring run-off would be moderate or light, as with such high discharges during the rising limb, there might not be enough inflow later to fill the reservoirs to the conservation storage level. The control centre will know the potential volume of run-off at the initial stage of the break-up and, although there can be no forecast of rain for the spring run-off period upon which to base their judgment, it is believed that sufficient storage has been provided to prevent floods up to the hypothetical magnitude and at the same time permit sufficient freedom of operation to store enough water to satisfy the low-flow problem.

2. Above Brantford

There is an additional 650.7 square miles of drainage area between Galt and Brantford, and consequently the storage which has been provided for Galt is not sufficient to completely satisfy the flood problems at Paris, Brantford and other places below. Nor could this storage be expected to provide any relief for those places along the Nith River which are subject to flooding. Thus additional storage and other flood control measures are required for this area.

In computing the amount of control required at Brantford the same methods as were used for determining the storage required above Galt were followed, viz:

(a) Construction of a run-off graph for all the past spring freshet flows and determining the maximum mean daily flow and total volume of run-off for the hypothetical spring flood;

(b) Constructing a hydrograph for the hypothetical spring flood;

(c) Fixing the channel capacity flow;

(d) Determining the channel capacity, boost flow and dead storage required to give the required protection.

(a) Run-off Graph (Figure H-40)

The construction of the run-off graph for Brantford was the same as that for Galt except in this case a 14-day run-off period was used instead of a 12-day period. Trial run-off graphs for 12-, 13- and 15-day periods were also prepared, but it was found that the 14-day period gave the best results.

It has been shown that the greatest flood (in respect to volume of flow) occurred at Galt in 1947. There are no hydrometric records for Brantford for 1947, but it seems logical to assume that this flood would be the greatest for Brantford also, and that the relative flows for Brantford can be determined by means of the Brantford/Galt run-off ratio previously determined. Thus the 14-day run-off volume for the 1947 spring flood at Brantford would be:

$$\text{Total 14-day run-off volume at Galt} \times \frac{\text{Brantford}}{\text{Galt}} \text{ run-off ratio}$$

= 455,900 x 1.43365 = 653,601 acre feet,

and for the hypothetical spring flood at Brantford the total volume would be:

653,601 x 1-1/3 = 871,468 acre feet.

From the run-off graph the maximum mean daily flow for this volume is 69,400 c.f.s.

(b) Hydrograph for the Hypothetical Spring Flood

With the above values, the hydrograph for the hypothetical spring flood was developed for Brantford (Figure H-41). On solving for the base of the hydrograph, or the "flood duration period", it was found that the duration worked out to 12.62 days and the hydrograph was adjusted to agree with the 14-day premise. The adjustment, which was made in the same manner as that for the Galt hydrograph, only amounted to 1.6 per cent of the total volume represented by the hydrograph and would be even less in that portion above the channel capacity flow line, or the volume with which the storage calculations are directly concerned.

(c) Fixing the Channel Capacity Flow

According to the Brantford City Engineer, the peak flow for the 1949 spring freshet just reached what he would consider to be the channel capacity flow at that point. This flow was 33,570 c.f.s ., and the water reached an elevation of 656.8 feet on the gauge at the L.E. and N. Railway bridge. At this stage there was from 5 to 6 feet of freeboard on the existing dikes, which provides a good margin of safety, but there was some slight flooding over the lower parts of the broad flats south of the city which are not protected in any manner.

Since 1949 some channel improvement work has been done at Brantford which has altered the flow regimen of the river locally. This work consisted of removing the trees and brush from the islands above the municipal dam and dredging the river bed for a short distance below the L.E. and N. Railway bridge and has resulted in lower water stages in this part of the channel with correspondingly higher stages in the lower part south of the city. The reduction in stage at the gauge amounts to 0.87 feet at a flow of 33,570 c.f.s., or in other words, the channel capacity flow at this point has been increased to 37,790 c.f.s. (present flow for elevation 656.8 feet at the gauge). However, with the relatively higher downstream stages, the channel capacity has in effect been reduced, and unless the dredging is continued well downstream, the spring flows will still have to be limited to 33,570 c.f.s. at the gauge to prevent flooding. The subsequent storage calculations showed that with this channel capacity flow about 233,950 acre feet of channel capacity storage, or 113,947 acre feet in addition to that being provided above Galt, would be required to provide the same degree of protection for Brantford.

This amount of storage could be substantially reduced by increasing the channel capacity by means of some further channel improvement work at Brantford. It will be shown later that only some 20,000 acre feet of conservation storage is required between Galt and Brantford to satisfy the summer flow requirements for the latter, and therefore only a small part of this storage may be justified on this basis. Also, similar calculations for the Nith River drainage area showed that only 30,000 acre feet were required to satisfy the flood problems within that area. Thus, in the interest of economy, a combination of reservoirs and local protective works that will adequately serve the purpose is recommended.

There are two comparatively good reservoir sites on the Nith River which have a combined capacity of 42,400 acre feet, and it is proposed to develop these to their economical limits and fix the channel capacity relative to this storage. With these two reservoirs, the total channel capacity storage above Brantford would be:

Channel capacity storage above Galt	120,003	acre feet
Channel capacity storage below Galt	39,814	" "
Channel capacity storage above Brantford	159,817	" "

the channel capacity storage between Galt and Brantford being equal to the total storage available in the Nithburg and Ayr Reservoirs less 2.7 per cent for dead storage and 4.1 per cent for boost flow storage.

With this amount of storage, a channel capacity flow of 39,340 c.f.s. would be required at Brantford. This flow would be equivalent to a water level stage of 657.1 feet at the gauge, which would still leave a good margin of freeboard on the existing dike system, but some additional diking would be needed to protect the low flats below the city.

(d) Storage Required for the Hypothetical Spring Flood

The storage required above Brantford to supplement that being provided above Galt and thus satisfy the flood problem at Brantford has been determined above. In this case it was found expedient to adjust the channel capacity flow to suit the storage available rather than to fix the channel capacity flow and then determine the amount of storage that would be necessary to reduce the hypothetical spring flood flow to that figure.

As stated above, about 233,950 acre feet of effective flood control storage would be needed to protect Brantford against floods of the hypothetical magnitude at the present channel capacity flow of 33,570 c.f.s. By raising this channel capacity flow to 39,340 c.f.s. the required storage would be reduced to 159,817 acre feet, a reduction of some 74,133 acre feet. Reservoirs to impound the balance of storage required at the present channel capacity (74,133 acre feet) would cost approximately $7,400,000, whereas the same degree of protection could be provided by a limited amount of channel improvement at a fraction of this cost, viz. $100,110 as shown in Chapter 5, Section 2.

As there is ample freeboard on the dikes at Brantford, no allowance has been made for operational storage. The 42,400 acre feet of storage in the Nith River, in conjunction with the dikes and channel improvement which have been recommended, will also safely pass flood flows through Paris and the trouble areas of the Nith.

The minimum storage derived for the watershed to satisfy the hypothetical flood problem amounts to:

Storage above Galt	169,383	acre	feet
Storage in the Nith River	42,400	"	"
Total storage above Brantford	211,783	"	"

CHAPTER 9

GENERAL DESCRIPTION OF FIELD SURVEYS

1. Topographical Surveys of Damsites, Reservoirs and Channel Improvement Areas

Ground contour surveys have been made by the firm of H. G. Acres and Company of three reservoirs, viz. Lake Belwood, Glen Allan and Luther. They also made a contour survey of the damsite area of the Montrose (formerly Pilkington) Reservoir, with a limited amount of subsurface exploration. This Department has since made reconnaissance contour surveys of practically all of the available reservoir sites on the Grand River and its tributaries above Galt (including Montrose), and those on the Nith River and Whiteman's Creek above Brantford - a total of 22 sites which are shown on Fig. H-1.

Substantial bench marks were established at each of the damsites by lines of checked levels from geodetic bench marks. Tentative damsite lines were chosen by ground surface inspection, profiled by stadia, and tied in to a reference line astronomically observed for bearing. The reference lines may be re-established when making future surveys.

Contour surveys were made of the reservoir sites by means of altimeters (barometers) with level control in conjunction with aerial photographs. From pin-pointed elevations on the photographs, plans were prepared, using a stereo-comparagraph, showing 10-foot contours and any other features of interest such as rivers, roads, lot and concession lines, buildings, etc.

Two types of the Wallace and Tiernan altimeters were used (viz. the FA 176 and FA 112), the former being the better type, but not available until the latter part of the survey.

Circumstances did not permit a test of the FA 112 type, but a test was made with the FA 176 type on a portion of the Thamesford Reservoir on the Middle Branch of the Thames, which had been contoured by a ground survey in 1945.

A comparison of the reservoir volumes showed that near the bottom there was a wide variation of 40 per cent; halfway up, 21 per cent; and at the top or reservoir capacity (a depth of 50 feet) they differed by only 6.4 per cent. It was not a fair test, however, for either the altimeters or the "stereo-comparagraph"; as the water level of the river, (the control points for the lower contours of the reservoir), although noted at the time the survey was made, was not determined at the time that the area was photographed.

These surveys are only a fraction of the cost of the more orthodox types, and it is not the intention that they should be substituted for the latter. They were made in order that a choice from many reservoirs could be made by comparing their ultimate capacities. An error of 6.4 per cent is well within limits for this purpose, but not for definite storage. The lower stages of the storage curves shown on the plans are not reliable.

Ground stadia surveys (of sufficient detail), with level control, were made at the major trouble areas to make an approximate estimate of cost of any channel improvement that might be necessary, in conjunction with storage in reservoirs.

2. Sub-Surface Investigations of the Damsites

Except in the north and the east portions of the watershed, where the Guelph dolomites lie close to the surface, the Grand Valley is covered with varying thicknesses of complex glacial deposits. This condition is particularly evident in the Nith and Conestogo valleys, where available evidence shows depths to bedrock of as much as 150 feet in extremely heterogeneous material.

Consequently, it was decided that with the limited time and means available, information as to the general depth to bedrock over the proposed foundation areas would be more valuable than isolated boreholes at each site. This entails leaving detailed examination of the overburden by drill holes at the selected damsites for a later sub-surface exploration program.

After consultation with geophysical authorities, it was decided that the electrical resistivity technique would be the most rapid and economical method of making these depth determinations, so that a contour plan of the bedrock surface over an area of 400' x 1000' at the proposed damsites could be prepared. The field work was done by a crew from Geophysical Explorations Ltd., in May and June 1951, at eight sites, the results of which (except the Canning site, later eliminated) are shown herein.

The following pages are extracts quoted from the report to the Department by Mr. Sherwin F. Kelly, president, Geophysical Explorations Ltd., giving an explanation of the method and his interpretation of the results, together with Figs. H-42 to H-48 inclusive, which were prepared by this Department, showing surface and sub-surface contours and profiles across the damsites areas.

"(a) <u>Electrical Resistivity Technique</u>

The electrical resistivity technique takes advantage of the fact that different types of rock and mineral formations exhibit different electrical resistivities.

"To measure the electrical resistivity of sub-soil formations, a known electrical current is passed through the ground between two points (the power electrodes), and the potential drop occasioned by the resistances of the underlying formations is then observed, between two intermediate points (the reading electrodes). Electrical contact is made with the earth at the above-mentioned four points by thrusting small steel rods a foot or so into the soil.

"By expanding the separations of the electrodes about a fixed center point, the variations in electrical resistivity in a vertical column beneath the fixed station may be measured to any convenient depth.

"This technique of expanding the electrode separations is known as the depth determination method. The electrode separation at which a definite change in resistivity occurs will equal the depth at which the corresponding change in geological formation can be expected. When the bedrock and the overburden differ in their electrical resistivities, this technique can then be used to determine the depth to bedrock. Normally, bedrock exhibits a considerably higher electrical resistivity than the overburden; this is particularly true when bedrock is of igneous or metamorphic character. Within the overburden, gravel and boulders usually show a high resistivity, sand and gravel an intermediate one and clay and silt normally possess a low resistivity. A given material, however, will show a lower resistivity when wet than when it is dry.

"When overburden material of high resistivity, such as a layer of boulders or clean gravel, lies directly on bedrock which also possesses high resistivity, it may not be possible to distinguish between the two formations. In this case, the depth to the top of the boulder or gravel layer may mistakenly be given as depth to bedrock.

"Since the electrical characteristics of geological formations will vary somewhat from area to area, it is advisable to conduct test observations close to wells which have penetrated bedrock, and the logs of which are available.

"Normally, resistivity depth determinations are accurate within ± 10 per cent. When the electrode separations are increased by 5 foot intervals, as is the usual practice, the 10 per cent figure will not apply to depths of less than 50 feet. For shallower overburden, then, an accuracy of ± 5 feet is to be anticipated. Shorter increases in the electrode separations (say 2 ft.) may be used if a greater accuracy is desired for the measurement of shallow depths.

(b) Discussion of Results

"Information as to the probable geological character of the bedrock was obtained from Geological Survey

Memoir 226 'Paleozoic Geology of the Brantford Area, Ontario', by J.F. Caley, 1941, and the geological map of the Waterloo area included in that report. This material will hereafter be referred to simply as the geological report.

"At the Everton site the bedrock is Lockport dolomite; at the Guelph site it is the Guelph dolomite; at the Ayr, Canning, Freeport, St. Jacobs and Wallenstein sites the bedrock is the salina formation, consisting of dolomite and shale; at the Nithburg site the underlying bedrock is the Norfolk formation, consisting of limestone and calcareous sandstone, with occasional clay partings.

"At each of the sites studied, the geophysical work was to be carried out, in principle, at 18 stations. These were to be spaced at 200 ft. intervals along three parallel lines, also 200 ft. apart. Each line was to be 1,000 ft. long so that there would be six stations on each line, or profile. These lines are designated Upper Line, Centre Line and Down Line; the designations Upper Line and Down Line refer respectively to the lines upstream and downstream from the Centre Line. At several sites this plan required modification, sometimes due to objections by property owners, sometimes due to natural obstacles. These modifications were made in such a manner as to achieve, as closely as possible, the desired objective of providing three bedrock profiles.

"At each of the sites referred to, electrical depth determinations were made by the technique of expanding the electrode separation to a maximum spacing of 600 feet. That is, with all four electrodes equally spaced, the maximum separation between adjacent electrodes was 200 feet, thus giving a depth penetration of 200 feet. In a few cases it was not possible to carry the electrode spacing quite that far, due to interference by such features as bridge abutments and river banks. With shallow bedrock this is not important, but in one or two instances where bedrock is quite deep, the resulting short curve of the plotted results did not permit adequate interpretation. Fortunately, such instances were not frequent, and did not interfere with the establishing of the general rock profiles.

"In quoting elevations in this report, and entering them on the maps, decimals will be omitted and the figures given to the nearest foot. Elevations are related to G.S.C. Datum.

(1) <u>Nithburg Damsite - Fig. H-42</u>

"According to the geological report previously referred to, the underlying bedrock is the Norfolk formation composed mainly of limestone, somewhat thin-bedded and with occasional argillaceous partings. The depths to bedrock vary from a minimum of 150 ft. to a maximum of 183 ft.

"The resistivities recorded in the near-surface material were all low, indicating predominantly silty overburden, or considerable clay interbedded with sand; bedrock resistivities were moderately high, corresponding to the predominantly calcareous nature of the bedrock.

"The rock elevations are higher in the vicinity of the west ends of the three lines, where the elevations range from about 1,000 feet (G.S.C. Datum), beneath the river bed, to 1,022 feet to 1,024 feet at the stations 0 + 00. To the east of the river, the elevations vary from a low of 970 feet to a high of 994 feet. Bedrock surface appears to be somewhat irregular, rather than having a definite slope.

(2) <u>Ayr Damsite - Fig. H-43</u>

"According to the geological report previously mentioned, the bedrock in this area is the Salina formation, consisting of thin and irregularly bedded shales, both calcareous and argillaceous, and interbedded dolomite in thin beds. The Salina can be divided broadly into four zones consisting of upper dolomite, lower shale and lower dolomite, according to the predominant rock types in each zone. It is therefore uncertain as to whether a given site will be on bedrock predominantly shaley or predominantly dolomitic.

"Most of the stations are in low, swampy ground except for the 0 + 00 stations on each line. The depths to rock at this site were practically all quite close to 100 feet; the shallowest determination (a questionable one) was 88 feet, and the deepest was 118 feet. The moderately low resistivities observed at long electrode separations lead to the conclusion that bedrock at this site is probably shaley in character.

"The resistivities of the overburden are, in the main, also low, indicating that it will be of a silty character, or mixed sand and clay. Exceptions to this were noted on the Upper Line at stations 0 + 00 and 10 + 00, and on the Down Line at 2 + 00. At these locations the overburden will probably be more sandy in nature.

(3) <u>Everton Damsite - Fig. H-44</u>

"According to the geological map in the report referred to, the bedrock in this area is the Lockport dolomite, of which numerous outcrops are visible. The electrical resistivities observed here rise abruptly to high values, as would be expected with this type of bedrock under a shallow overburden. In fact, at the Everton site the overburden is so shallow, and the resultant resistivity curves are so steep that in only a very few instances is it possible to pick an inflection in the curve indicative of the transition from overburden to bedrock. This indicates that the overburden is probably less than 15 feet deep at those stations where this occurs. Even in those cases where deeper bedrock (24 ft. and 19 ft.) is indicated, at stations 2 + 00 and 4 + 00 on the Upper Line, there is some doubt as to whether or not the overburden is actually that deep. Bedrock may be closer to the surface and the inflection point on the curves for these two stations may actually correspond to a transition from a broken up or weathered bedrock to a sounder, underlying stratum. At stations 2 + 00 and 4 + 00 on the Centre Line, and at 4 + 00 on the Down Line, the rise of the plotted resistivity curves is somewhat less abrupt than at most of the other stations, which may mean that the near-surface bedrock is somewhat broken up or weathered, and therefore more permeable to ground water. No inflection on the curves is observed, however, which would indicate a sharp transition from broken to solid strata.

"The determination at the Everton site indicates a definitely shallow bedrock, with elevations higher than 1,200 ft., although at station 2 + 00 on the Upper Line, the bedrock surface may be just slightly under 1,200 ft. elevation.

(4) Freeport Damsite - Fig. H-45

"The geological map in the report previously referred to shows this site to be underlain by the Salina formation, very close to its contact with the underlying Guelph dolomite. As the lower portion of the Salina is predominantly dolomitic, it therefore seems probable that the bedrock is a dolomite. This conclusion is reinforced by the high resistivities recorded at long electrode separations, indicating a bedrock of calcareous or dolomitic nature, rather than a shale.

"Most of the determinations were in low ground on the northeast bank of the Grand River.

"The overburden has a moderately high resistivity at this location, so probably consists predominantly of sandy material. At a few stations, lower values were observed, indicating a more silty character, or possibly more clay intercalated with the sand. This was particularly noticeable on all three lines at stations 0 + 00 and 2 + 00, and on the Centre Line at 4 + 00, and near the river at station 7 + 70 on the Down Line. A similar but less pronounced character of the resistivity depth curves was observed at station 4 + 00 on the Upper Line and station 9 + 50 near the river, on the Centre Line. The resistivity of the overburden rises at depth, probably indicating a more sandy character, or intercalated gravel, near bedrock. As a result, the resistivities of overburden tend to merge with the resistivities of bedrock and render it somewhat difficult to make a distinction between the two.

"The depth of overburden at the Freeport site varies from a minimum of 67 feet to a maximum of 116 feet. The two extremes were observed at adjacent stations, 0 + 00 and 2 + 00 on the Down Line, where the maximum surface elevation contrast between adjacent stations, also occurs.

"The bedrock underlying the river ends of the profiles seems to have, in general, a lower elevation than the bedrock underlying the north-easterly ends.

"(5) Guelph Damsite - Fig. H-46

"The bedrock in the Guelph area is the Guelph formation, which consists of thin bedded dolomite of a prevailingly pure dolomitic composition, according to the geological report previously cited. Only one line, the Down Line, was run completely.

"The bedrock depths at Guelph are quite shallow, the maximum depth observed being 20 feet.

"The bedrock resistivities at this site are quite high, corresponding with the pure character of the underlying dolomite. The very shallowness of the overburden presented some difficulties in the interpretation of the curves drawn up from the readings. This arose from the fact that the very high bedrock resistivity caused the readings, even with the shorter electrode separations, to increase very rapidly, and the plotted curves then rose so steeply as to present difficulties when attempting to pick the inflections usually indicative of the transition from one formation to another.

(6) St. Jacobs Damsite - Fig. H-47

"The bedrock in this area, according to the geological report previously referred to, is in the Salina formation, already discussed in connection with the Ayr site. The depths to bedrock at this site range from a minimum of 125 feet to a maximum of 175 feet.

"The moderately low resistivities of the bedrock in this area lead to the conclusion that the bedrock is shaley in character. The overburden also has low resistivities, so that it may be expected to be largely silty, or with considerable clay mixed with sand or gravel.

"The depth resistivity curves indicate, at several locations, that water will be found in a stratum of the overburden lying on bedrock, but as the overburden seems to be fairly silty it is doubtful if these would make very good sources of water supply.

(7) Wallenstein Damsite - Fig. H-48

"The bedrock of this vicinity is the Salina formation, described above in connection with the Ayr site.

"The depths to bedrock at this location vary from a minimum of 60 feet at station 8 + 00 on the Down Line and station 2 + 00 on the Centre Line, to a maximum of 119 feet at station 10 + 00 on the Upper Line.

"The bedrock resistivities at this location exhibit moderate values, indicating that it is probably a shale somewhat calcareous or dolomitic in nature. Surface resistivities in the main are also moderate, indicating a silty-sandy material, except that at some stations the values are higher and probably correspond to more sandy or gravelly material. The higher resistivities are particularly noticeable on the Upper Line and Centre Lines at stations 8 + 00, on the Centre Line at 2 + 00 and on the Down Line at 4 + 00.

"The depth resistivity curves, while not too clear in this respect, seem to indicate that bedrock carries water at stations 6 + 48 and 8 + 00 on the Upper Line, at stations 6 + 00 and 8 + 00 on the Centre Line, and at station 4 + 00 on the Down Line."

PART III

CHAPTER 10

SUMMER FLOW AND STREAM POLLUTION

1. General

The second phase of the hydraulic problem in the Grand River is that of providing increased flows, particularly during the summer and early autumn months. This phase of the problem is generally considered to be secondary to that of flood control but with the Grand it is just as important and justifies in no small measure the comparatively costly flood control reservoirs. The proposed widespread system of reservoirs would be so integrated in design and operation that the water impounded during the time of the high spring flows could be carried over and then released to augment the low flows during periods of drought.

2. Summer and Low Flow Conditions

A summary of the maximum, minimum, mean daily and monthly mean flows for the Grand River at Galt and Brantford is shown in Table H-10. An examination of this table indicates that the river usually reaches its lowest flow in the late summer and early autumn. August is generally the lowest month followed by September, July, October and June in that order. In August 1936 the monthly mean fell to 47 c.f.s. with a correspondingly low mean daily of 26 c.f.s. The most pronounced period of low flow was the period from June 1930 to February 1931 although the years 1933, 1934 and 1936 all yielded lower monthly and daily flows for shorter periods. During the period June 1930 to February 1931, which is the period for which increased flows would normally be provided, the monthly mean flows varied from 93 to 298 c.f.s. with an average flow for the period of 153 c.f.s. The Galt gauge was the only gauge on the river in operation at the time and there is no way of knowing what the relative flows were at other points along the

GALT GAUGE - GRAND RIVER

Maximum and Minimum Mean Daily and Mean Monthly Flows in Cubic Feet Per Second for the Years 1914 to 1950

from Hydrometric Records of the Water & Power Bureau, Ottawa.

Year	January			February			March			April			May			June			July			August			September			October			November			December		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1914	2,880	169	422	2,250	140	445	11,700	215	2,428	9,050	765	1,826	1,300	239	531	300	105	236	265	71	178	432	55	174	490	85	215	272	91	185	1,025	180	402	1,670	202	460
1915	610	216	334	2,892	296	770	5,549	778	2,179	8,926	634	2,212	796	194	436	898	134	272	945	146	359	4,370	194	1,361	8,789	350	1,735	2,626	325	980	3,950	325	1,045	1,890	223	643
1916	13,710	515	3,029	9,250	186	954	19,700	247	2,167	15,080	1,480	4,792	4,740	950	1,705	5,340	610	2,052	530	148	256	154	104	134	190	92	126	460	146	231	400	182	253	530	198	337
1917	680	242	386	420	226	305	25,390	450	4,503	10,824	818	2,634	3,070	315	1,009	2,519	400	909	10,450	276	2,494	656	190	291	248	144	205	660	203	369	750	203	355	510	182	284
1918	373	131	250	9,520	161	2,154	21,710	760	5,759	9,570	555	1,875	1,130	301	487	530	175	273	264	69	162	210	65	135	1,530	161	532	1,450	238	485	1,530	330	683	10,600	413	1,925
1919	2,040	413	708	695	286	431	30,090	845	4,995	9,780	685	2,294	9,040	580	2,244	1,360	161	374	182	56	114	203	61	120	301	74	140	570	99	205	5,760	183	580	3,020	270	540
1920	270	242	261	240	225	232	20,150	235	4,740	7,840	765	2,210	1,280	288	472	1,060	111	418	1,690	162	425	415	148	232	253	81	158	750	162	329	2,220	365	895	6,480	585	1,680
1921	3,610	315	1,310	1,590	288	500	17,030	375	4,520	8,560	765	2,210	5,600	333	1,130	1,570	155	496	3,200	173	590	440	111	226	225	90	153	2,400	187	625	4,180	292	800	10,260	283	1,310
1922	835	190	386	4,390	287	890	14,010	820	4,070	23,850	885	5,360	920	269	615	2,060	193	500	455	155	238	380	75	203	770	87	271	337	134	211	283	186	258	425	187	263
1923	192	170	188	208	141	158	8,560	225	2,500	17,400	735	4,610	12,700	466	2,540	1,410	261	610	390	86	197	189	77	136	412	178	260	350	110	245	530	178	310	5,330	224	1,220
1924	2,800	396	1,040	590	345	454	10,800	340	2,380	16,120	800	4,270	7,880	745	2,810	905	269	520	473	196	314	560	160	317	402	139	207	1,250	121	304	335	109	183	580	124	269
1925	-	-	155	6,280	-	1,400	16,660	1,020	4,870	2,200	530	1,100	485	109	300	157	52	87	195	49	99	203	49	119	330	55	143	910	109	296	7,250	424	2,110	4,010	305	655
1926	875	290	458	935	244	391	8,840	305	2,350	14,520	2,040	7,250	4,430	515	1,280	2,200	181	535	170	103	132	5,760	95	815	2,460	267	750	3,040	440	1,230	13,010	1,470	3,900	1,760	-	770
1927	-	-	441	-	-	455	20,610	-	5,280	4,320	755	1,500	5,310	500	1,530	3,810	435	960	6,190	151	1,030	462	127	223	207	133	168	496	177	296	2,820	160	590	2,860	-	1,360
1928	-	-	1,040	-	-	665	26,750	-	4,120	15,470	1,090	4,120	1,310	402	680	840	239	510	4,010	157	650	1,860	136	493	500	106	207	2,090	157	755	6,830	675	1,970	-	-	2,070
1929	-	-	1,430	-	-	610	26,850	-	6,430	29,720	1,040	5,280	5,190	825	1,840	735	223	383	880	142	319	211	98	142	127	63	95	545	73	182	1,040	-	410	-	-	273
1930	-	-	2,050	-	-	3,160	3,930	1,420	2,200	11,350	720	4,030	5,290	414	1,260	427	167	298	307	85	178	177	57	93	151	65	104	174	87	117	181	90	133	-	-	195
1931	-	-	126	-	-	136	-	-	645	6,630	525	3,060	1,440	259	565	423	148	229	795	142	310	239	100	155	303	69	141	188	100	147	2,340	167	760	-	-	2,170
1932	-	-	3,420	-	-	2,400	-	-	1,940	11,100	540	3,490	1,840	500	910	1,930	130	424	465	181	275	2,030	157	388	8,020	139	945	1,860	346	540	5,620	625	2,200	-	-	2,100
1933	-	-	1,210	-	-	775	-	-	1,590	15,470	795	5,090	4,180	414	955	970	103	298	195	41	107	151	52	83	136	38	68	170	71	115	985	80	212	-	-	680
1934	-	-	965	-	-	310	-	-	2,820	15,160	980	5,440	875	203	486	291	92	146	133	41	80	90	38	61	142	29	99	184	63	114	445	115	266	409	83	167
1935	-	-	590	-	-	455	18,630	-	3,530	940	307	525	1,410	369	630	11,480	239	1,400	1,260	148	350	148	36	86	87	44	68	136	65	98	1,870	127	580	-	-	390
1936	-	-	201	-	-	313	13,150	810	3,980	-	590	2,030	2,540	170	650	2,380	67	415	97	38	55	77	26	47	188	39	91	364	151	224	1,490	112	307	-	-	1,150
1937	-	-	4,230	-	-	3,180	1,180	267	595	12,050	1,190	4,250	4,000	595	1,210	520	139	308	423	77	152	409	69	162	207	80	146	725	136	274	535	163	306	351	124	190
1938	-	-	175	16,060	455	3,590	19,750	455	4,680	4,690	545	1,460	1,680	432	680	355	133	227	170	100	140	1,810	106	345	825	121	225	207	100	150	347	109	177	373	97	200
1939	1,580	142	414	-	243	474	15,190	475	2,660	23,110	1,950	6,720	1,600	460	700	590	154	304	640	77	191	233	82	142	151	85	120	209	90	136	325	109	174	241	80	155
1940	-	-	106	-	-	118	320	103	137	21,200	525	5,270	9,740	540	2,110	3,620	410	1,290	1,500	173	427	2,630	85	294	2,420	380	810	3,200	290	775	7,370	700	1,800	20,400	540	3,040
1941	-	-	1,200	-	-	500	3,140	-	885	13,680	615	4,810	560	205	346	440	133	241	370	118	199	560	118	167	405	73	164	870	95	421	2,410	650	1,120	6,110	258	980
1942	640	340	449	460	197	276	20,280	229	4,910	8,620	435	2,590	14,090	405	1,720	14,030	241	1,590	675	121	243	263	121	167	6,480	124	830	2,760	345	1,550	10,890	1,460	2,830	4,250	430	1,000
1943	2,890	620	1,100	8,670	630	2,360	22,340	1,250	5,470	25,620	1,540	4,890	24,120	925	3,660	1,640	201	660	925	205	318	1,000	193	359	920	250	428	900	254	500	2,020	545	1,040	650	173	340
1944	2,890	121	419	1,040	250	440	13,390	300	2,340	13,230	1,390	4,220	3,470	360	1,390	1,960	267	660	1,220	144	355	945	155	269	630	201	302	580	259	391	525	213	327	430	201	343
1945	515	254	331	490	221	314	16,780	480	4,360	9,640	550	2,240	13,710	1,010	3,310	4,140	380	1,460	4,240	209	660	840	169	334	2,700	267	625	6,000	700	1,890	2,220	705	1,330	970	405	670
1946	11,230	475	1,880	1,830	455	840	18,670	540	4,670	835	390	600	1,250	415	750	650	272	406	735	305	444	640	295	410	590	151	283	600	112	246	530	277	370	2,300	155	505
1947	4,200	440	1,170	1,950	415	875	7,830	350	1,930	36,800	2,160	9,240	10,820	975	3,690	22,160	530	3,110	7,290	390	1,010	1,190	365	650	1,010	470	610	485	263	373	480	263	393	2,050	258	722
1948	-	-	505	-	-	781	37,700	730	7,180	6,070	989	1,830	2,260	455	1,070	1,450	209	441	1,330	272	520	395	250	343	360	137	252	193	88	148	2,180	121	476	430	154	250
1949	7,330	213	1,540	5,560	340	2,130	23,200	514	3,900	4,410	782	1,560	619	222	371	460	215	366	642	208	340	410	192	266	340	202	261	894	179	292	295	158	211	13,000	195	2,200
1950	12,900	1,060	3,450	1,350	361	879	22,500	392	2,980	26,800	1,550	4,960	1,460	425	672	1,640	370	510	1,020	280	427	915	246	454	580	388	452									

BRANTFORD GAUGE - GRAND RIVER

Maximum and Minimum Mean Daily and Mean Monthly Flows in Cubic Feet Per Second for the Years 1914-1922 & 1943-1950

from Hydrometric Records of the Water & Power Bureau, Ottawa.

Year	January			February			March			April			May			June			July			August			September			October			November			December		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1914	5,520	465	904	3,840	1,010	1,760	19,370	1,110	4,015	11,700	1,050	3,057	2,315	415	998	2,515	170	485	340	70	240	535	30	211	950	70	341	535	140	342	1,660	275	626	2,792	346	834
1915	872	410	667	6,310	600	1,672	8,025	1,756	3,899	11,160	1,044	3,419	1,380	620	882	1,336	305	721	1,964	208	679	7,214	620	2,359	9,800	620	2,214	4,160	763	1,508	6,260	620	1,645	3,520	710	1,138
1916	19,860	1,150	6,337	17,330	600	1,918	23,060	520	3,069	15,480	2,100	6,419	10,510	1,900	3,284	6,440	1,120	3,387	1,080	422	633	510	373	441	540	163	295	905	278	498	860	374	573	1,000	330	663
1917	1,130	535	799	980	409	645	29,562	880	6,550	16,893	1,334	4,324	6,282	627	1,835	5,148	880	1,788	22,625	494	4,820	1,110	225	487	430	182	290	1,210	210	535	1,150	446	639	755	312	563
1918	545	24	265	17,020	154	5,628	21,870	4,880	13,895	13,090	1,110	2,932	1,550	460	860	1,050	235	504	367	86	230	446	62	197	3,080	166	1,002	2,400	560	857	2,500	820	1,266	15,180	890	3,168
1919	1,760	484	982	970	365	657	37,360	1,260	6,612	13,330	1,400	3,698	13,840	1,210	3,898	2,100	442	819	515	205	373	560	185	352	835	165	394	955	257	452	2,670	545	895	7,250	445	1,010
1920	442	400	417	398	380	388	25,570	380	7,301	12,530	1,250	3,270	2,140	418	765	1,370	276	590	2,110	345	635	670	250	392	407	198	318	1,000	250	482	3,620	630	1,450	10,500	1,180	2,740
1921	6,340	560	2,130	2,530	550	930	19,330	730	6,760	16,880	1,200	3,590	6,440	630	1,830	2,270	480	1,000	4,800	380	1,110	1,460	250	565	675	257	404	3,260	328	1,020	5,900	508	1,320	10,450	790	2,050
1922	1,360	430	730	11,870	545	2,190	20,900	1,170	5,680	31,820	1,320	7,820	1,120	392	790	4,270	412	990	600	320	479	610	276	429	985	249	473									
1948	-	-	765	-	-	1,410	47,800	1,220	10,460	6,630	1,510	2,620	4,460	639	1,680	1,610	325	623	2,030	564	794	659	450	522	-	-	455	372	65	281	3,220	242	816	799	242	530
1949	12,400	534	2,400	10,500	-	3,530	24,600	881	5,080	5,710	1,220	2,140	1,130	447	678	728	405	561	830	310	471	537	218	379	720	320	467	1,240	328	504	509	245	379	25,100	376	3,530
1950	14,200	-	5,330	2,960	777	1,630	35,500	635	5,060	45,100	1,790	6,750	1,740	596	906	1,220	532	661	1,920	477	691	1,300	436	663	818	544	633									

TABLE H-10

river. It is certain, however, that the flows below Galt would be correspondingly low and that, in all probability, many of the headwater streams would dry up altogether and the upper stretches of the river would be reduced to a mere trickle. Further, this low-water stage usually occurs at a time when the temperatures are highest and when water is needed most, all of which combine to make the situation more serious and the need for correcting it more urgent.

The existing condition where the river is being used as a sewer outlet on the one hand and as a public water supply on the other is not a desirable one, but there is no economical alternative. When the river water is used and reused, as in this case, it may readily be realized how the existing undesirable conditions along the river would be further aggravated by the lack of natural river flow. With a low-water stage the river becomes increasingly polluted, with added dangers to the health and welfare of all who would use the water. Production in the many plants along the river which use this water source as a supply for their processing may be seriously interfered with and their fire hazard increased. Another condition which always accompanies the low flows is that pools and backwater areas form along the river where algae and other wastes accumulate. When this occurs the water becomes stagnant and the algae and wastes decay, producing foul odours and an unsightly mess. As a consequence, the riverside residents are forced to put up with this nuisance at a time when they could best enjoy the river and any potential recreational value the river may have had is destroyed.

3. Objectives in Stream Purity*

Before any intelligent discussion can be undertaken concerning the state or usefulness of a stream for any particular need, it is first necessary to reach a definite agreement about the measuring stick for such state or conditions.

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* See Appendix A: "Objectives for Water Quality" by the Pollution Control Board of Ontario.

Wherever possible this definition of quality should be a quantitative one which must, beyond any doubt, gauge the qualities which are considered desirable. This subject is sufficiently important to bear the closest study.

When the land was new, and before men came, the streams were ponded by fallen trees and the soil was covered with vegetation. Under these conditions there was little erosion and the streams were pure. One could drink from any stream in this untravelled land with confidence and pleasure. Even under these conditions some erosion resulted from spring floods, but this produced but minute effects on the rivers.

But even this water was not truly pure, yet its pristine purity met the needs of man. Today our streams are far removed in character from those pictured above, and it is impossible and altogether undesirable for one to hope for their return to this original state.

Stream water originates from water vapour in the sky. When the temperature of the cloud is lowered raindrops are formed, which plummet to earth carrying with them dissolved gases and dust particles from the atmosphere. In addition, raindrops may contain bacteria - fortunately, for the most part, harmless. Rain-water is thus not pure water at all, but is the nearest thing to pure water occurring naturally.

As rain-water runs over and through the soil it picks up chemicals which produce the well-known characteristics of colour, odour, taste, hardness*, etc., to an extent depending upon the geology of the region. In fact rain-water is well known as being soft, mildly corrosive to metals, and of neutral, if not unpleasant, taste. Water containing much mineral matter as a result of percolating through soil is usually hard and is usually pleasant to taste (depending on the nature and quantity of the chemical). Generally speaking, we do not think of either

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* The property which causes pipes to become scale-coated, or which forms a curd with soap.

of these waters as being polluted since, in either case, the water has come by these constituents in a natural manner, yet each is unfit for a number of human uses. In general, water is considered as being polluted if it is unfit for a particular use. Thus water may be polluted in respect to use for human needs as a drinking-water supply and still be fit for certain recreational and industrial uses.

In general, an aim for stream purity which does not seem unreasonable is to arrange for the treatment of wastes prior to their discharge into streams so that anyone coming upon a stream might be expected to use <u>only a reasonable amount of judgment</u> in estimating the purpose to which the water may be put. This would not necessarily mean that all surface waters would be expected to be safe to drink, but that the water would be safe for washing and swimming. In addition, there should be no physical evidence of pollution, and in all respects the aesthetic values of the stream should be safeguarded. In other words, it is impossible to attain pristine purity for our streams, and a compromise in quality is necessary. Thus the point at which a water is considered polluted is a relative one, and the determination of exact standards is difficult. The time has now come in our country's development to demand that riparian water rights be observed for reasons other than water power. An attempt will be made to delineate these "rights" in the light of modern developments.

4. Water Uses on the River

(a) Domestic Water Supply*

Brantford and Dunnville are the only municipalities on the river at present which use the river water directly as a source of public water supply. Other municipalities along the river have their wells drilled close enough to the river to have their water supply affected both in quality and quantity by the flow conditions of the river and thus to a

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* See Appendix B: "Domestic Water Supply from Georgian Bay".

certain extent are dependent upon the river water. Further, in many cases, these wells have been developed to their maximum capacity and the respective municipalities may have to resort to the river for additional supplies in the very near future.

(b) Industrial Water Supply

Industrial plants located along the banks of the river make use of the river water in their operations. Textile industries use the water for washing their raw materials and a number of chemical plants use the river water in the preparation and treatment of their products.

(c) Water Power

The physical features of the river are such that water power cannot be developed economically along the river. However, several large plants do use the water as a source of power but find that the fluctuating flow conditions interfere with such use. In most cases it is used as an auxiliary source to satisfy the "peak load".

(d) Sewage Disposal

The river furnishes the only means of disposal for nearly all the waste products of the human and industrial activities in the watershed. This is probably the greatest single use, outside of drainage, served by the river today and is the one which is causing much concern to those who live along its banks.

A number of municipalities within the watershed are served by sewer systems, some providing partial sewage treatment with greater or lesser efficiency. Actually the effect of industrial wastes upon the main stream and the tributaries is more pronounced than that of domestic sewage. The municipalities in the following list discharge sewage to the Grand River, and no claim is made for the completeness of this list* since individual industries and unsewered communities are

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* Based in part upon report by Department of Health, Aug. 8, 1949.

numerous along the river and its tributaries, and many have private sewers discharging to the stream.

Municipality	Population	Sewage Treatment
Fergus	3,387	Primary treatment
Waterloo	11,991	Primary treatment
Kitchener	44,867	Spring Valley - secondary treatment Doon Valley - primary treatment
Preston	7,619	Secondary treatment
Galt	19,207	Primary treatment
Brantford	36,727	No treatment
Dunnville	4,478	No treatment
Elmira	2,589	Primary treatment
Guelph	27,386	Secondary treatment
Hespeler	3,862	Secondary treatment

A partial list of the municipalities without a public sewer system, but which lie on the Grand or its tributaries is:

Municipalities

Caledonia
Cayuga
Onondaga
Paris
Glen Morris
Blair
Freeport
Breslau
Elora
Grand Valley
Plattsville
New Hamburg
Wellesley
Millbank
Ayr
St. George
Eden Mills
Rockwood
Conestogo
Drayton
Moorefield

These communities will sooner or later contribute to the pollution of the Grand River unless the sewage is adequately treated before-hand.

It may be seen from the foregoing that the present sewered population totals about 162,100. From the reports of the Department of Health it is found that the water consumption totals about 32 c.f.s. Since all of this water reaches the sewers, and since the amount of water from private supplies is unknown, it can be safely said that the sewage flow is from 30 to 35 c.f.s., while the minimum flow of the river at Galt, as has been pointed out, has fallen as low as 26 c.f.s. In other words, the sewage entering the river may be expected to exceed the natural flow in some places.

Figure 49 indicates a record of total population, and an estimate of sewage flow from municipalities on the Grand River. By extrapolation it is possible to estimate future conditions with sufficient accuracy to indicate the main feature of the trend in the pollution of the river. From Figure H-49 it is estimated that the sewered population in another 50 years will be between 250,000 and 325,000, based on the growth of the cities and towns listed above as having sewer systems at present. Based on these data it is therefore estimated that the sewage flow reaching the river will be at least 60 c.f.s. by the year 2000.

5. Stream Flow and Quality Requirements

Increased low flows serve many useful purposes, the main ones of which may be summarized as follows:

(a) Agriculture
(b) Domestic water supply
(c) Industrial and commercial water supplies
(d) To dilute and carry away domestic and industrial wastes
(e) Recreation
(f) Fire protection
(g) Power development

(a) Agriculture

It is generally recognized that the country-wide standard of prosperity is closely related to the productivity of the soil. It is possible to control nearly all the factories governing productivity, at a price; among these is water. Irrigation has been practised in other lands for many years and is rapidly becoming common practice in many farming areas within the watershed. It has been well proven that the proper control of moisture greatly increases the productive capacity of the soil and it has also been proven that a moisture deficiency exists naturally in Ontario. This has been demonstrated by Mrs. M. Sanderson*; and the list below indicates the deficiencies which existed on the Grand Watershed at Guelph for the years 1923-1948 and which might be considered as being representative for the whole watershed.

MOISTURE DEFICIENCIES† IN INCHES AT GUELPH

1923 - 1948							
1923	0.70	1930	6.88	1937	0.79	1944	3.08
1924	0.48	1931	4.06	1938	3.45	1945	3.15
1925	1.87	1932	0.41	1939	9.22	1946	4.18
1926	0.08	1933	8.35	1940	0.08	1947	5.68
1927	2.15	1934	5.99	1941	5.87	1948	5.80
1928	0.00	1935	4.72	1942	3.34		
1929	5.96	1936	7.86	1943	3.02		

There is, of course, some ground-water recharge even at ordinary low flows, but this is small in comparison to that resulting from reservoir storage. In the instance cited above the average moisture deficiency for the period of record is 3.74 inches which represents 13,600 cubic feet of water for each acre of land. This would be best stored in the ground, where it would be equal to about one foot in water table elevation. Although it is scarcely possible to provide the quantity of water for optimum growth, these figures will serve to emphasize the need for water conservation. The quantity of water which can be seen in a reservoir may only be a fraction

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* Mrs. M. Sanderson, Moisture Relationships in Southern Ontario. Scientific Agriculture, Vol. 30. June 1950.

† Determined by the Thornthwaite Method.

of that stored. In fact, even when a reservoir is silted up it may still be a real factor in sustaining higher water table elevations and summer flows.

(b) Domestic Water Supply

As a domestic water supply source the Grand River provides water for drinking, washing and the operation of sanitary conveniences. This water serves not only residences but hospitals, schools, churches, etc., of the municipalities along the river. Since it is not economically feasible to supply water of different quality for each of these various uses, the standard of quality governing drinking-water fixes the character of the entire domestic supply. Domestic water supplies require high standards of river quality and where a stream is used for this purpose a high degree of treatment of wastes must be called for. (Treatment of these wastes from industries is not always easy and the cost of constructing and maintaining disposal works would handicap many industries in competition with similar industries which could dispose of their wastes cheaply.) Conservation reservoirs which would provide increased low flows and a greater dilution of such wastes would have a most beneficial effect.

(c) Industrial and Commercial Water Supply

The above paragraph on domestic water supply may also be applied to this supply, since water for these purposes may need to be as safe and free from tastes, odours, etc., as a domestic supply. In fact, some industrial and commercial needs are only met by a water of quality meeting the "drinking-water standards" and others may require even higher standards. Boiler waters and water for laundries usually require chemical treatment. The special needs of industries must ordinarily be met by the industries concerned, but they could exercise their riparian rights and demand that any pollutant which might be detrimental to their water supply be excluded from the river or be diluted to the point where they would not be put to the expense of further treatment.

(d) To Dilute and Carry Away Domestic and Industrial Wastes

As stated before, the problem of stream pollution is second only to that of flood control. In fact, Dr. A. E. Berry of the Ontario Department of Health says in his report on Stream Sanitation*: "Flood control may be highly significant in some watersheds. Soil erosion may predominate in others. As between these factors, in the Grand River project, it was generally agreed that sanitation was the more important". Nevertheless this is an important phase of the problem and the comprehensive plan and program for the watershed should be one which would afford the maximum water storage which could be used during periods of low flow for the dilution and abatement of pollution. Health may be endangered by domestic sewage and industrial wastes through public water supplies and recreational use of the affected waters. This becomes more apparent when it is brought to mind that during dry seasons the flow in the river drops so low that at many points along the valley it is only equal to the quantity of sewage reaching it. Conservation storage† would alleviate this condition and bring about economy in the treatment of sewage.

(e) Recreation

Recreational uses, including swimming, boating and fishing, require that there should be an adequate supply of water at all times and that there should be no physical evidence of pollution nor chemicals present in the stream which would adversely affect plant or fish life. In many places, particularly on the lower Grand River, the water is unsafe for these purposes due to the amount of pollution present in the water. This condition is most offensive during the summer

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* Berry, A.E. Stream Sanitation. Presented to a Conference on River Valley Development held at London, Ontario, October 1944.

† Conservation storage is water held over from wet periods for release in times of drought to augment the stream flows,

months when low flows combined with high temperatures produce a stream foul in appearance and odour - and at the time when these facilities are needed most.

The Shand Dam and Reservoir have greatly improved the condition of the river, particularly in the upper reaches, but additional storage is necessary to satisfy even the present-day needs. Further, the population and industrial development along the river is increasing constantly and the present situation will steadily become worse unless steps are taken now to provide adequate water for dilution of these wastes.

(f) Fire Protection

Requirements for this purpose are simply quantity of neutral water (neither scale-forming nor corrosive) and that the supply be available at all times. In built-up areas it is common to have one water supply to serve all purposes. Where a large industry is conveniently located it is often economical to install its own fire system and under these circumstances the water may be grossly polluted with sewage and industrial wastes without ill effects.

(g) Power Development

Schemes for large-scale power development on the Grand River have been put forth from time to time. Due to the flashy nature of the river, the steep gradients and other adverse factors such projects are not practicable and no consideration has been given to this phase of river development. However, there are many existing power dams along the Grand River and its tributaries which will benefit directly by the proposed stream flow regulation. Each spring these dams suffer heavy damage from the extremely high flows and then their output is severely reduced during the balance of the year by virtue of the low flows. Thus it may be readily seen how a water conservation plan which would tend to level out the seasonal flow fluctuations would reduce maintenance costs and permit a greater power output, which would also mean a distinct saving to the mills in steam or electrical power costs.

6. Stream Standards

As may be seen from the foregoing, the uses to which streams are put places limits on the amounts of various substances which may be present in the water. In general these requirements may be classified as aesthetic, bacteriological, chemical and the dissolved oxygen content, and whereas the establishing of standards of quality is very difficult it is thought necessary. It is essential that stream standards once established be under continuous review and that they should not be too rigid. Standards must take into account the economic aspects of the life of the population along the stream for its entire length. It is desirable that the problems of water supply and sewage disposal for all the people in the Grand River be integrated so that the best method of dealing with their problems can be put into effect. By modern methods of water treatments it is possible to make almost any water acceptable for a domestic supply. If, however, the cost of treatment is made excessive by virtue of the discharge of a particular industrial waste farther upstream, then there should be a means of assessing the responsibility and the cost.

(a) Aesthetic

There should be no evidence of pollution to the physical senses (i.e. sight or smell) when samples of polluted and unpolluted waters are compared, or on examination of the shoreline and river bed below the sewer outfalls.

At times of low flow algae and other wastes, accumulate on shallows and in slack-water pools along the shoreline and stagnate. In order to alleviate this condition and to have water flowing over the various dams along the streams the flow should be placed as high as possible. Such a condition would give the river a healthy appearance and enhance the area generally, but it is hard to justify the cost of this on the basis of aesthetic benefits alone.

(b) Bacterial

The Province of Ontario recommendation for bathing waters in streams is that the coliform index* should not exceed 2,400 M.P.N.† Standards of other health departments vary from 5 to 5,000 coliform bacteria per 100 ml.** of water. However, this type of standard is not based on exact statistics of the causes of epidemics and research in this matter is badly needed. The United States Public Health Service has a program under way which when completed may help provide the necessary standards.

It is to be emphasized that no rigid bacterial standard can be applied to the river as a whole because of the present high bacteria counts and because the reduction of these by chlorination is not satisfactory. If certain areas are to be protected for swimming and other recreational purposes, the coliform index of 2,400 M.P.N. should be used and special precautions taken in design and operation of the disinfection facilities of the plants involved.

(c) Chemical

The problem of limiting the quantities of various chemicals which may be discharged into a stream is beyond the scope of this study. Needless to say, any chemical which may by its quantity or character have undesirable effects upon the stream or use of the stream should be limited in quantity. The number of such chemicals defies listing and an example is given of phenols. Phenol compounds react with chlorine used in the disinfection of public supplies, forming objectionable tastes

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* The number of bacteria per 100 millilitre which are identified as being of the type which originate in the lower intestine of man. This index is a statistical statement of the most probable number being present, as exact determinations are not possible nor significant.

† M.P.N. - most probable number.

** ml. - millilitre.

and odours when present in quantities over about 0.001 p.p.m.* Thus an attempt should be made to limit the phenol compounds to the above figure.

Fish respond adversely to numerous chemicals such as phenolic wastes, but for the most part their tolerance is considerably above the limits which are permitted in streams which are used for public water supplies. Although many cities now secure water from ground sources this cannot hope to be continued indefinitely, so the chemicals in the stream should be limited to those tolerated in surface water supplies, since it is impractical to attempt to alter the water chemically.

(d) Oxygen

Opinions on the extent by which the oxygen content may be lowered vary considerably and values of 3 to 5 p.p.m. of oxygen remaining in the water have been recorded. Mr. M.M. Ellis† of the U.S. Bureau of Fisheries has concluded that 5 p.p.m. dissolved oxygen is the lowest value which may reasonably be expected to maintain a good condition for the varied fish fauna of warm-water fishes in our inland streams if the water temperature be 68 degrees Fahrenheit or above. Therefore the pollutional loading of a stream should be restricted so that the dissolved oxygen content should not fall below 5 p.p.m. for any extended period of time.

The effect of photosynthesis (sunlight on chlorophyll-bearing plants) is to absorb the sun's energy in converting carbon dioxide to plant growth with a simultaneous release of oxygen. This activity releases large amounts of oxygen on sunny days, resulting in a great difference in the dissolved oxygen content during the day and night.

During the winter when ice covers the river all the oxygen required by decomposition of pollutional elements

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* P.P.M. - parts per million.

† Ellis, M.M. Detection and Measurement of Stream Pollution. U.S. Bureau of Fisheries, Bulletin 22, 1937, page 365.

must be supplied by the water, whereas during the summer reaeration may occur from the atmosphere.* This lowered availability of oxygen during the winter is largely offset by the slower rate of decomposition during the colder weather.

The amount of oxygen required to fully saturate water varies with the temperature and the amount of other dissolved materials. For distilled water at atmospheric pressure of 30 inches of mercury the following quantities of oxygen will provide saturation.

Temperature		Parts per million of Oxygen at Saturation
Centigrade	Fahrenheit	
0	32	14.66
5	41	12.80
10	50	11.33
15	59	10.15
20	68	9.17
25	77	8.38
30	86	7.63

Thus it may be understood that even with stream flow regulation it would be difficult to sustain a minimum oxygen standard and values of 3 p.p.m. might occur for short periods where the design value was 5 p.p.m.

As shown above the commonly accepted units of stream quality measurements are: (1) aesthetic - the physical condition of the stream, (2) bacterial population, (3) quantity of undesirable chemicals present and (4) the dissolved oxygen content of the water. The detailed procedure for making these tests is described in "Standard Methods for Examination of Water and Sewage" published by the American Public Health Association. On the whole the oxygen tests are the most convenient and valuable as the characteristics of a polluted stream and the conditions associated with pollution result from the

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* The oxygen content of the atmosphere is 20.9 per cent.

utilization of the stream's oxygen reserve. Thus by examining the oxygen balance of a stream it is usually possible to determine the degree of pollution present and the amount of treatment or dilution that will be necessary to provide a water suitable for the required purposes. Industrial wastes, however, are exceedingly diversified and ever-changing and often have a potential pollutional value which could not be detected by this method.

7. Pollution Studies

The tests conducted by the Department were the dissolved oxygen (D.O.) and the biochemical oxygen demand (B.O.D.) tests. Test collections of both fish and river bottom invertebrates were also made at each of the stations where water samples were taken as a further check on the condition of the stream at these points.

(a) Oxygen Content and Demand

The dissolved oxygen was determined by the sodium azide modification of the Winkler method both for the original and the five-day tests. The only departure from the recommended procedure was in using a 15°C* temperature for the incubation of the B.O.D. samples instead of 20°C. The conversion to B.O.D. values for temperatures otner than 15°C may be made from the following data:

Time	At 15°C	At 20°C	At 25°C
5 days	1.00	1.27	1.56
10 days	1.39	1.67	1.92

It was found that the temperature of the incubation space used (an abandoned well) did not vary more than 1°C from the 15°C average during the entire length of time the tests were being run.

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* 15°C - 15 degrees Centigrade, equivalent to 59° Fahrenheit, also see Stream Sanitation by E.B. Phelps for conversion table.

Sample points chosen are shown on Figure H-50. These points coincide with those used by the Ontario Department of Health for their test work although a number of additional sites were used.

The sampling method used was to carefully remove a pail of water from a slow-moving stretch of the river. The water was siphoned into an 8-ounce (250 ml.) glass-stoppered bottle and allowed to overflow sufficiently to change the water at least once. A second bottle was filled in the same way. One bottle was used for the D.O. test and the other for the B.O.D. test. The D.O. test was always carried out the same day if not immediately on sampling. Samples not tested immediately and those to be used for the B.O.D. test were immediately placed in an iced container and kept at a temperature of 33° to 40°. There is practically no oxidation at this low temperature and the results of the subsequent tests were not impaired in any way by the delay. At the end of the two-day run (the time taken to visit each of the stations to collect the samples) the B.O.D. samples were placed in the incubator for reading five days later. The results of these tests are given in Table H-11.

(b) <u>Fish and Invertebrate Collections</u>

To substantiate the B.O.D. and D.O. tests, collections of both fish and bottom invertebrates were made at most of the stations. At certain places, as, for instance, at Dunnville, Onondaga and Galt, the river conditions were such that insect collections could not be conveniently made, and at these stations fish collections were confined to the ponded areas. As a general indication of the degree of pollution of the stream, the number of fish species taken in the various sections are useful. The total numbers of different species of mayflies identified in the nymphal stage substantiated the findings on fish, as a comparison of Tables H-12 and H-13 will show.

Station and Test	Flow in C.F.S.	Water Temp. °F	Dissolved Oxy. P.P.M. D.O. Test	Dissolved Oxy. P.P.M. B.O.D. Test	5 Day 15°C B.O.D. P.P.M.
DUNNVILLE					
Aug. 16, 5.00 pm		76	7.0	4.2	2.8
Aug. 23, 2.25 pm		75	7.8	7.6	0.2
Aug. 30, 1.50 pm		72	8.0	6.4	1.6
Sept. 6, 2.40 pm		69	8.6	7.0	1.6
CAYUGA					
Aug. 16, 3.45 pm		77	10.2	8.7	1.5
Aug. 23, 1.35 pm		74	8.8	6.8	2.0
Aug. 30, 1.05 pm		71	7.8	5.4	2.4
Sept. 6, 2.10 pm		69	9.2	6.6	2.6
CALEDONIA					
Aug. 16, 3.00 pm		76	6.4	4.1	2.3
Aug. 23, 1.00 pm		74	9.8	6.2	3.6
Aug. 30, 12.25 pm		72	7.0	4.8	2.2
Sept. 6, 1.30 pm		68	11.0	7.5	3.5
ONONDAGA					
Aug. 16, 2.15 pm		77	9.2	5.4	3.8
Aug. 23, 12.10 pm		71	11.0	5.5	5.5
Aug. 30, 12 noon		71	4.8	2.6	1.2
Sept. 6, 12.15 pm		68	9.4	---	---
NEWPORT					
Aug. 16, 12 noon	315	73	4.96	1.0	4.0
Aug. 23, 11.40 am	300	69	5.4	2.1	3.3
Aug. 30, 11.30 am	478	70	5.0	1.8	3.2
Sept. 6, 11.45 am	383	67	7.0	4.2	2.8
BRANTFORD					
Aug. 11, 12 noon	405	78	7.0	0.42	6.6
Aug. 16, 11.00 am	315	72	8.6	7.5	1.1
Aug. 23, 11.00 pm	300	69	10.5	9.2	1.3
Aug. 30, 10.50 am	478	69	7.7	6.4	1.3
Sept. 6, 10.50 am	383	64	9.6	7.8	1.8

Station and Test	Flow in C.F.S.	Water Temp. °F	Dissolved Oxy. P.P.M. D.O. Test	Dissolved Oxy. P.P.M. B.O.D. Test	5 Day 15°C B.O.D. P.P.M.
PARIS DAM					
Aug. 11, 11.00 am		77	6.8	1.98	4.8
Aug. 16, 10.30 am		69	5.6	4.6	1.0
Aug. 23, 10.25 am		67	6.1	3.8	2.3
Aug. 30, 10.30 am		69	6.0	3.2	2.8
Sept. 6, 10.30 am		64	6.4	4.7	1.7
GLEN MORRIS					
Aug. 11, 10.40 am		77	7.1	2.60	4.5
Aug. 16, 10.00 am		69	8.24	6.0	2.2
Aug. 23, 10.05 am		66	7.4	5.1	2.3
Aug. 30, 10.00 pm		67	7.3	6.0	1.3
Sept. 6, 10.10 am		63	9.0	7.0	2.0
RIVERVIEW					
Aug. 11, 10.20 am		77	7.7	2.82	4.9
Aug. 16, 9.35 am		68	7.1	5.4	1.7
Aug. 23, 9.45 am		66	8.1	5.4	2.7
Aug. 30, 9.40 am		68	8.0	4.0	1.0
Sept. 6, 9.45 am		63	9.0	7.4	1.6
GALT					
Aug. 11, 10.00 am	311	77	7.5	2.02	5.48
Aug. 17, 9.00 am	218	72	6.4	0.0	6.4
Aug. 23, 9.00 am	195	69	8.4	5.6	2.9
Aug. 30, 9.00 am	268	70	7.6	5.4	2.2
Sept. 6, 8.50 am	202	66	7.0	6.0	1.0
BLAIR					
Aug. 12, 1.40 pm		75	8.22	5.2	3.0
Aug. 17, 10.35 am		72	6.6	3.9	2.7
Aug. 23, 10.45 am		67	6.1	4.0	2.1
Aug. 31, 10.00 am		65	5.8	4.2	1.6
Sept. 7, 9.50 am		61	3.0	0.4	2.6
FREEPORT					
Aug. 12, 1.25 pm		77	10.0	7.3	2.7
Aug. 17, 1.05 pm		74	9.6	8.5	1.1
Aug. 23, 11.10 am		69	8.5	6.8	1.7
Aug. 31, 10.25 am		68	7.2	6.2	2.0
Sept. 7, 10.05 am		60	8.2	6.9	1.3

Station and Test	Flow in C.F.S.	Water Temp. °F	Dissolved Oxy. P.P.M. D.O. Test	Dissolved Oxy. P.P.M. B.O.D. Test	5 Day 15°C B.O.D. P.P.M.
BRESLAU					
Aug. 12, 11.50 am		75	8.1	5.1	2.0
Aug. 17, 1.30 pm		73	7.7	6.3	1.4
Aug. 23, 11.50 am		69	7.5	4.0	3.5
Aug. 31, 10.50 am		67	7.0	5.2	1.8
Sept. 7, 10.30 am		60	7.5	5.8	1.7
BRIDGEPORT					
Aug. 12, 11.30 am		74	8.3	6.0	2.3
Aug. 17, 1.50 am		73	8.4	7.8	1.6
Aug. 23, 12.05 pm		70	8.2	7.0	1.2
Aug. 31, 11.10 am		68	8.7	7.6	1.1
Sept. 7, 10.45 am		60	9.0	8.2	0.8
CONESTOGO					
Aug. 17, 3.05 pm		73	9.8	8.3	1.5
Aug. 23, 12.30 pm		71	9.3	8.0	1.3
Aug. 31, 11.40 am		67	9.5	8.6	0.9
Sept. 7, 11.15 am		59	9.4	8.2	1.2
ELORA BRIDGE					
Aug. 17, 3.30 pm		71	10.5	10.6	---
Aug. 23, 12.50 pm		70	10.2	9.2	1.0
Aug. 31, 12.10 pm		68	10.2	9.2	1.0
Sept. 7, 11.40 am		59	8.0	6.6	1.4
ELORA DAM					
Aug. 17, 4.00 pm	0	72	6.5	5.5	1.0
Aug. 23, 1.55 pm	0	70	7.5	5.9	1.6
Aug. 31, 12.40 pm	1	69	7.2	5.9	1.3
Sept. 7, 12 noon	1	60	7.2	5.6	1.6

TABLE H-11

RESULTS OF D.O. AND B.O.D. TESTS

SUMMER - 1949

TABLE H-11

TABLE H-12

FISH COLLECTION

Species	Grand River Station No.																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Common white sucker			*		*	*	*	*	*		*					*		*	*
Hogsucker						*	*										*	*	
Northern redhorse	*		*																
Carp			?					*	*		*	?	*	*	*		*		
Longnose dace						*	*	*	*			*	*	*	*	*	*	*	*
Blacknose dace											*	*	*	*	*			*	
Hornyhead chub	*		*			*	*		*		*	*			*		*	*	
Creek chub								*	*		*	*	*	*	*	*	*	*	
Redbelly dace											*								
Fathead minnow									*			*	*	*			*		*
Bluntnose minnow	*	*	*		*	*		*	*		*	*	*	*	*	*	*	*	
Common shiner			*			*	*	*	*		*	*	*	*	*	*	*	*	*
Rosyface shiner		*	*		*		*	*	*					*	*	*	*		
Mimic shiner	*																		
Spotfin shiner		*	*		*	*													
Blacknose shiner																			*
Brown bullhead	*			*		*		*											
Stonecat						*	*	*	*					*					
Golden shiner											*								
Pike			*		*														
Killifish	*																		
Yellow perch	*																		
Blackside darter	*	*	*			*											*		
Johnny darter			*			*					*			*		*	*	*	
Least darter											*					*	*		*
Iowa darter																		*	*
Rainbow darter		*	*			*	*	*	*					*	*	*	*	*	
Barred fantail																*	*		
Log-perch	*		*				*												
Small-mouth bass	*	*	*			*	*								*		*	*	
Large-mouth bass	*	*																	
Pumpkinseed	*																		
Long-ear sunfish													*	*					
Bluegill	*	*									*								
Rock bass	*	*	*	*		*	*	*	*			*	*		*	*	*	*	*
Muddler																		*	*
Brook silversides	*																		
Brook stickleback											*								*
No. of species	15	9	15	2	4	15	11	11	12	0	13	9	9	12	13	11	16	14	10

TABLE H-13

TOTAL NUMBERS OF SPECIES OF MAYFLIES IDENTIFIED FROM SAMPLE COLLECTIONS

Location	Grand River Station No.	Mayfly Species Identified
Dunnville	1	0
	2	10
	3	6
Onondaga	4	0
	5	1
Brantford	6	12
Paris	7	13
	8	12
	9	8
Galt	10	0
	11	7
	12	8
	13	6
Freeport	14	8
	15	5
	16	14
Conestogo	17	18
Elora Bridge	18	10
Elora Dam	19	12

(c) Bacterial Counts

Bacteriological tests are very useful in indicating the extent of sewage pollution in that they are extremely sensitive. The Department of Health has taken samples along the Grand for a number of years, and some of the results of these tests are given in Table H-14. This information is taken from a report by Dr. A. E. Berry, Director, Sanitary Engineering Division, Department of Health, dated August 8, 1949. Much care must be taken in interpreting bacteriological results, since the effects of disinfection by chlorination may give low counts even with sewage effluents. The effects of the present level of high pollution may be noted by a study of this table.

8. Flow Regulation Requirements

A study of the results from the foregoing tests indicates that increased flows in the river are obviously necessary. And it may be pointed out here that the flows in the river at the time when the tests were made were considerably higher than those experienced during dry years such as 1936. The flows at the time of the tests varied from 202 to 311 c.f.s. at Galt and from 300 to 478 c.f.s. at Brantford. Had these tests been made during such a year as 1936, when the mean monthly flow for August dropped to 47 c.f.s., the results would have been more pronounced. The purpose of increased flow is primarily one of (a) providing adequate dilution for sewage wastes, (b) providing adequate water for those municipalities using the river as a source of water supply, and (c) improving the general appearance of the stream.

It is apparent that should all sewage wastes be excluded from the stream the problem resolves itself. However, the same end could theoretically be achieved by removing all pollutional elements from the sewage through complete sewage treatment. The problem of providing ample water for all

TABLE H-14

BACTERIOLOGICAL ANALYSIS - 1949

Sample Point	Coliform Organisms M.P.N.* per 100 M.L.†		
	Mean	Maximum	Minimum
Below Dundalk (1 sample)		100	
Above Grand Valley	665	1,000	100
Below Grand Valley	665	1,000	100
Belwood Bridge	40	100	10
Bridge below Shand Dam	40	100	10
Bridge below Fergus	23,330	50,000	10,000
Elora Dam	123,300	170,000	100,000
First Bridge below Elora	900	2,500	100
Conestogo Bridge	200	400	100
Bridgeport Bridge	865	1,000	600
Above Spring Valley Plant	3,966,670	10,000,000	900,000
Breslau Bridge	3,363,330	10,000,000	10,000
Freeport Bridge	5,050	10,000	100
Above Doon Outfall	5,330	10,000	Less than 10
Blair Bridge	386,670	1,000,000	6,000
Above Preston Outfall	34,000	1,000,000	1,000
Galt Dam	1,000	1,000	1,000
Riverside Bridge	4,000	10,000	1,000
Glen Morris	4,000	10,000	1,000
Paris Dam	550	1,000	100
Below Paris	5,500	10,000	1,000
Brantford W.W. Canal	550	1,000	100
Below Brantford Outfall	550,000	10,000,000	100,000

* M.P.N. - Most probable number

† M.L. - Millilitre

consumers on the river would still remain, but this need is not so great as that for sewage dilution. Presumably the proper course is a compromise between these two extremes.

The extent of dilution is dictated by the amount of sewage wastes reaching the stream and upon the flow in the stream. These items are inseparable partners to the problem, and it is common practice to consider the measurements of bacterial population and of dissolved oxygen in arriving at a solution.

It may be safely said that the only way of controlling the bacterial population is through sewage treatment followed by suitable disinfection methods. The need for sewage treatment prior to disinfection is well recognized if any guarantee as to effective control is required. With large municipalities the variations of sewage strength and flow rate are such as to make effective disinfection possible only after primary treatment*. With smaller municipalities such as those encountered along the Grand, secondary treatment is required to produce the desired result (using current methods of treatment), This solution is a costly one both in construction and in operation and maintenance.

Sufficient dilution to sustain a minimum of 5 p.p.m. of dissolved oxygen in a stream will usually result in a water with reasonably acceptable appearance, etc. For this reason the determination of oxygen content has been a subject of considerable study in stream pollution surveys. The result of plotting dissolved oxygen content is what is termed the "oxygen-sag" curve. Two such curves, plotted from the results of the survey, are presented in Figures H-51 and H-52. Figure H-53 shows the calculated oxygen-sag curves for pollution condition existing in 1949 at 68° fahrenheit. The oxygen-sag

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* Primary treatment consists of sedimentation and sludge digestion. Secondary treatment consists of primary treatment followed by either the activated sludge or filtration process.

curve is a result of a biochemical oxygen demand (B.O.D.) of organic compounds in the water and of a re-aeration through the free water surface. To complicate matters, sunlight acting upon aquatic plants causes a considerable release of oxygen on sunny days. The effect of these influences results in the widely different pattern of dissolved oxygen content of the river at Brantford.

For the two days shown the following data apply:

Date	Flow c.f.s.	Water Temp. °F.	5 Day 15° at Brantford p.p.m.	D.O. of River[*] p.p.m.	Saturation Quan. of D.O. p.p.m.
Tues. Aug.23	300	69	1.3	10.5	9.07
Tues. Aug.30	478	69	1.3	7.7	9.07

and illustrate the large effect of aquatic growths in the shallow water of the river above Brantford. Naturally the benefits of this form of re-aeration (photo-synthesis) are not to be counted upon for maintaining satisfactory conditions in the stream.

The rate of biochemical oxygen demand has been shown to follow mathematical laws[†] as has the phenomenon of aeration.[**] The former depends primarily upon the amount of oxidizable material present at any time whereas the latter is purely mechanical, depending upon the undersaturation of the water and the amount of fluid turbulence. Considerable study has been given to this problem since G. M. Fair published the first thorough mathematical analysis of the phenomenon in 1936.[††]

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[*] Above Wilke's Dam.

[†] Any book on sewage disposal and treatment treats this subject in detail.

[**] Natural Purification of Streams by D. W. Silliman, Queen's University Master's Thesis.

[††] The principles were recognized by H. W. Streeter and E. B. Phelps much earlier and covered in U.S. Health Service Public Health Bulletins. G. M. Fair Sewage Works Journal, 1936.

The results of an analysis of the oxygen-sag curve for the Grand River below Brantford (the most critical section) under present conditions are given in Figure H-53. From this figure it may be seen that at the present time flows of less than 400 c.f.s. at this point place the river in a condition which is not satisfactory and that the flow should be at least 500 c.f.s. at Brantford. The corresponding flow for Galt by areal proportion would be 350 c.f.s.

CHAPTER 11

CONSERVATION STORAGE

1. Basis for Conservation Storage Calculations

As previously stated the minimum quantity of stream flow at Galt and Brantford for present needs is 350 c.f.s. and 500 c.f.s. respectively. There are 38 years of continuous flow records for Galt covering the period 1913 to the present and eleven years of records for Brantford covering the periods 1914 to 1922 and 1948 to the present. It was thought that the long-term records of Galt would form the best basis for the study of this problem with supplementary studies for Brantford being based on a comparison of the years of records for Brantford with those for the corresponding years at Galt. Thus, ratios may be determined and the final result obtained for the latter.

2. Development of the Planning Year

A study of the Grand River flow records at Galt indicates that any year, on the basis of the minimum flow set for Galt, might be divided into two periods.

Period A - months with a mean monthly flow equal to or greater than 350 c.f.s.

Period B - months with a mean monthly flow less than 350 c.f.s.

Data showing the number of times during the 37 years of flow records that the monthly mean flow for each month was less than 350 c.f.s.

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
9	9	1	0	2	12	23	29	22	22	13	13
Period B		Period A			Period B						

From the above it will be noted that theoretically only the month of April should be included in period A, but both March and May are known to have comparatively high flows and in view of the few times that the flow in these months has fallen below the minimum requirements it is thought that they also could be included in this period. Further, the possibilities of low flows ever occurring in each of these months in any one year are indeed very remote. The remaining months during which the flow has failed from 9 to 29 times in the past 37 years may be grouped together in period B.

Again it will be noted that the calendar year arrangement of the months results in a split of period B. Similarly, the water-year would also give a split period B. Therefore, for the convenience of this study and for the purpose of expediting flood routing in the future when the plan is put into being, it would appear logical to regroup the months in order to make these periods continuous and this Department proposes to establish the "Planning-year". Such a year would commence March 1 and continue through to February 28 of the following year and would be divided as follows:

Period A 92 days Mar. Apr. May	Period B 273 days June July Aug. Sept. Oct. Nov. Dec. Jan. Feb.
Replenishing	Draft

Period A - or the replenishing period is the period of high flows and practically all the flooding occurs during this time. The reservoirs would be filled to their summer flow capacity during this period and beyond, depending upon the magnitude of the spring freshet.

Period B - or the draft period includes the months during which the flows are generally low and must be increased by additional flow released from the storage reservoirs in order to maintain the minimum permissible flow.

3. Conservation Storage Requirements

In determining the amount of storage required for summer flow it is first necessary to decide upon the degree of protection against low flows that is to be provided. Protection may be provided for, say, the average low period, the driest period on record or still drier periods which might be expected to occur at less frequent intervals. Based on the average year determined for Galt, flows less than the minimum may be expected for about 46 per cent of the years or on the driest year about 3 per cent of the years of record, and from the probability studies (Figure H-54) low period (period B) average flows of 133 c.f.s., 115 c.f.s. and 94 c.f.s. might be expected once in 100 years, 200 years and 500 years respectively.

The decision must also take into account the use for which the water is being supplied and the benefits to be derived. If the water is to be used to furnish drinking water for the municipalities along the river and to subsequently dilute sewage from these settlements, then it is important that the flow does not fall below its predetermined minimum. If, on the other hand, it is merely to dilute sewage effluent and enhance the river generally, then it would not be so important to maintain a given minimum flow for all times and an increased flow to a lesser degree would be sufficient for short periods.

Should storage be provided for some future low flow as might be expected, then for the majority of the years only partial benefits would be obtained from the reservoirs. Even if storage were provided for the driest period on record there would be years during which only a small part of the water would be used (taking the calendar years 1915, 1926 and 1932 for example, there is only one month in each of these years when the mean monthly flow was less than 350 c.f.s.).

In contrast to this, should storage be provided on the basis of, say, the average year, then there would be years when there would not be sufficient storage to maintain the minimum flow throughout the period of drought. Based on past records, such conditions would exist in varying degrees for approximately 57 per cent of the summer periods and, in all, little betterment would be achieved. It is considered that provision for the driest period on record would afford maximum use of the reservoirs and at the same time provide satisfactory flows throughout periods of drought for the majority of the time. Further it is felt that once this system of reservoirs is put into operation the hidden storage resulting from raised water tables would be sufficient to maintain the minimum flow even during drier periods and thus yield a satisfactory rate of flow for practically all years. In view of this, summer flow calculations for the Grand will be based on the driest low flow period on record.

4. Determination of the Basic Conservation Storage

From Table H-15 showing the monthly mean flows for the Galt gauge arranged according to the "Planning-year" (see p. 190), the periods of lowest flow for the years of record may readily be selected, and from the frequency curve (Figure H-54) the approximate low flows for less frequent intervals may also be obtained. The lowest or most critical flow period was that of June 1, 1930, to February 28, 1931, when the mean flow for the 273-day period was 153 c.f.s. or 197 c.f.s. below the required flow. The basic storage necessary to sustain the minimum allowable flow throughout such a period would be

197 c.f.s. x 273 days = 53,781 c.f.s. - days
1 c.f.s. - day is equivalent to 1.98347 acre feet

Therefore the required basic storage would be
1.98347 x 53,781 = 106,673 acre feet.

The data for the above low flow period together with that for other dry periods is summarized as follows:

Flow Period	Mean Flow for Period c.f.s.	C.f.s. Days Deficiency	Basic Storage Req'd to Sustain 350 c.f.s.
Average year	639	2,958	5,867
3rd driest year	220	35,490	70,393
2nd driest year	161	51,597	102,341
Driest year	153	53,781	106,673
100 year	133	59,241	117,503
200 year	113	64,155	127,250
500 year	94	69,888	138,621

Note: Above summary is based on a 273-day period.

There are only 10 years of flow records for Brantford covering the periods 1914 to 1922 and 1948 to the

SUMMARY OF MEAN MONTHLY DISCHARGES - GRAND RIVER AT GALT - ARRANGED FOR THE "PLANNING YEAR"

Spring Runoff Accretion Period – Reservoirs Filled 3 Months or 92 days					Runoff for the following Summer, Fall and Winter Draft Period of Reservoirs – Flow in the River is Increased and Sustained 9 Months or 273 days											
Cubic Feet Per Second					Cubic Feet Per Second											
Year	Mar.	April	May	Av'ge for Period	Years	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Total for Period	Av'ge for Period
1914	2,428	1,826	531	1,595	1914–15	236	178	174	215	185	402	460	334	770	2,954	328
1915	2,179	2,212	436	1,609	1915–16	272	359	1,361	1,735	980	1,045	643	3,029	954	10,378	1,153
1916	2,167	4,792	1,705	2,888	1916–17	2,052	256	134	126	231	252	337	386	305	4,080	453
1917	4,503	2,634	1,009	2,715	1917–18	909	2,494	291	205	369	355	284	250	2,154	7,311	812
1918	5,759	1,875	487	2,707	1918–19	273	162	135	532	485	682	1,925	708	431	5,334	593
1919	4,995	2,294	2,244	3,178	1919–20	374	114	120	140	205	580	540	261	232	2,566	285
1920	4,740	2,210	472	2,474	1920–21	418	425	232	158	329	895	1,680	1,310	500	5,947	661
1921	4,520	2,210	1,130	2,620	1921–22	496	590	226	153	625	800	1,310	386	890	5,476	608
1922	4,070	5,360	615	3,348	1922–23	484	238	203	275	211	258	263	188	158	2,278	253
1923	2,500	4,610	2,540	3,217	1923–24	610	197	136	260	245	310	1,220	1,040	454	4,472	497
1924	2,380	4,270	2,810	3,153	1924–25	520	314	317	207	304	183	269	155	1,400	3,669	408
1925	4,870	1,100	300	2,090	1925–26	87	99	119	143	296	2,110	655	458	391	4,358	484
1926	2,350	7,250	1,280	3,627	1926–27	535	132	815	750	1,230	3,900	770	441	455	9,028	1,003
1927	5,280	1,500	1,530	2,770	1927–28	960	1,030	223	168	296	590	1,360	1,040	665	6,332	703
1928	4,120	4,120	680	2,973	1928–29	510	650	493	207	755	1,970	2,070	1,430	610	8,695	966
1929	6,430	5,280	1,840	4,517	1929–30	383	319	142	95	182	410	273	2,050	3,160	7,014	779
1930	2,200	4,030	1,260	2,497	1930–31	298	178	93	104	117	133	195	126	136	1,380	153
1931	645	3,060	565	1,423	1931–32	229	310	155	141	147	760	2,170	3,420	2,400	9,732	1,081
1932	1,940	3,490	910	2,113	1932–33	424	275	388	945	540	2,200	2,100	1,210	775	8,857	984
1933	1,590	5,090	955	2,545	1933–34	298	107	83	68	115	212	680	965	310	2,838	315
1934	2,820	5,440	486	2,915	1934–35	146	80	61	99	114	266	167	590	455	1,978	220
1935	3,530	525	630	1,562	1935–36	1,400	350	86	68	98	580	390	201	313	3,486	387
1936	3,980	2,030	650	2,220	1936–37	415	55	47	91	224	307	1,150	4,230	3,180	9,699	1,078
1937	595	4,250	1,210	2,018	1937–38	308	152	162	146	274	306	190	175	3,590	5,303	589
1938	4,680	1,460	680	2,273	1938–39	227	140	345	225	150	177	200	414	474	2,352	261
1939	2,660	6,720	700	3,360	1939–40	304	191	142	120	136	174	155	106	118	1,446	161
1940	137	5,270	2,110	2,506	1940–41	1,290	427	294	810	775	1,800	3,040	1,200	500	10,116	1,124
1941	885	4,810	346	2,014	1941–42	241	199	167	164	421	1,120	980	449	276	4,017	446
1942	4,910	2,590	1,720	3,073	1942–43	1,590	243	167	830	1,150	2,830	1,000	1,100	2,360	11,270	1,252
1943	5,470	4,890	3,660	4,673	1943–44	660	318	359	428	500	1,040	340	419	440	4,504	500
1944	2,340	4,220	1,390	2,650	1944–45	660	355	269	302	391	327	343	331	314	3,292	366
1945	4,360	2,240	3,310	3,303	1945–46	1,460	660	334	625	1,890	1,330	670	1,880	840	9,689	1,076
1946	4,670	600	750	2,007	1946–47	406	444	410	283	246	370	505	1,170	875	4,709	523
1947	1,930	9,380	3,690	5,000	1947–48	3,110	1,010	650	610	373	393	722	505	781	8,154	906
1948	7,180	1,830	1,070	3,360	1948–49	441	520	343	252	148	476	250	1,540	2,130	6,100	678
1949	3,900	1,560	371	1,944	1949–50	366	340	266	261	292	211	2,200	3,450	879	8,265	918
Minimum Year 1931	645	3,060	565	1,423	Minimum Year 1930–31	298	178	93	104	117	133	195	126	136	1,380	153
Maximum Year 1947	1,930	9,380	3,690	5,000	Maximum Year 1942–43	1,590	243	167	830	1,150	2,830	1,000	1,100	2,360	11,270	1,252
Av'ge for 36 Years	3,436	3,528	1,280	2,748	Av'ge for 36 Years	650	387	272	332	418	827	876	1,027	964	5,753	639

Spring Runoff Accretion Period – Reservoirs Filled 3 Months or 92 days					Runoff for the following Summer, Fall and Winter Draft Period of Reservoirs – Flow in the River is Increased and Sustained 9 Months or 273 days											
Acre Feet					Acre Feet											
Year	Mar.	April	May	Total for Period	Years	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Total for Period	Av'ge for Period
1914	149,292	108,654	32,650	290,596	1914–15	14,043	10,945	10,699	12,793	11,375	23,921	28,284	20,537	42,764	175,361	19,484
1915	133,981	131,623	26,809	292,413	1915–16	16,185	22,074	83,685	103,240	60,258	62,182	39,536	186,246	52,982	626,388	69,598
1916	133,244	285,144	104,836	523,224	1916–17	122,102	15,741	8,239	7,497	14,204	15,054	20,721	23,734	16,939	244,231	27,136
1917	276,879	156,734	62,041	495,654	1917–18	54,089	153,350	17,893	12,198	22,689	21,124	17,462	15,372	119,627	433,804	48,200
1918	354,107	111,570	29,944	495,621	1918–19	16,245	9,961	8,301	31,656	29,821	40,641	118,364	43,533	23,936	322,458	35,828
1919	307,130	136,502	137,978	581,610	1919–20	22,254	7,010	7,378	8,331	12,605	34,512	33,203	16,048	12,885	154,226	17,136
1920	291,451	131,504	29,022	451,977	1920–21	24,873	26,132	14,265	9,402	20,229	53,256	103,299	80,549	27,769	359,774	39,974
1921	277,924	131,504	69,481	478,909	1921–22	29,514	36,278	13,896	9,104	38,430	47,603	80,549	23,734	49,428	328,536	36,504
1922	250,254	318,942	37,815	607,011	1922–23	28,800	14,634	12,482	16,364	12,974	15,352	16,171	11,560	8,775	137,112	15,234
1923	153,719	274,314	156,178	584,211	1923–24	36,297	12,113	8,362	15,471	15,064	18,446	75,015	63,947	25,214	269,929	29,992
1924	146,340	254,082	172,780	573,202	1924–25	30,942	19,307	19,491	12,317	18,692	10,889	16,540	9,531	77,752	215,461	23,940
1925	299,444	65,454	18,446	383,344	1925–26	5,177	6,087	7,317	8,509	18,200	125,554	40,274	28,161	21,715	260,994	28,999
1926	144,496	431,405	78,704	654,605	1926–27	31,835	8,116	50,112	44,628	75,630	232,066	47,345	27,116	25,269	542,117	60,235
1927	324,654	89,256	94,076	507,986	1927–28	57,124	63,332	13,712	9,997	18,200	35,107	83,623	63,947	36,932	381,974	42,441
1928	253,329	245,157	41,812	540,298	1928–29	30,347	39,967	30,313	12,317	46,423	117,223	127,279	87,927	33,878	525,674	58,408
1929	395,365	314,182	113,137	822,684	1929–30	22,790	19,614	8,731	5,653	11,191	24,397	16,786	126,050	175,497	410,709	45,634
1930	135,273	239,802	77,474	452,549	1930–31	17,732	10,945	5,718	6,188	7,194	7,914	11,990	7,747	7,553	82,981	9,220
1931	39,659	182,083	34,740	256,482	1931–32	13,626	19,061	9,531	8,390	9,039	45,223	133,428	210,288	133,289	581,875	64,652
1932	119,286	207,669	55,954	382,909	1932–33	25,230	16,909	23,857	56,231	33,203	130,909	129,124	74,400	43,041	532,904	59,211
1933	97,765	302,876	58,721	459,362	1933–34	17,732	6,579	5,103	4,046	7,071	12,615	41,812	59,335	17,216	171,509	19,056
1934	173,395	323,702	29,883	526,980	1934–35	8,687	4,919	3,751	5,891	7,010	15,828	10,268	36,278	25,269	117,901	13,100
1935	217,051	31,240	38,737	287,028	1935–36	83,306	21,521	5,288	4,046	6,026	34,512	23,980	12,359	17,383	208,421	23,158
1936	244,721	120,793	39,967	405,481	1936–37	24,694	3,382	2,890	5,415	13,773	18,268	70,711	260,092	176,608	575,833	63,981
1937	36,585	252,892	74,400	363,877	1937–38	18,327	9,346	9,961	8,687	16,848	18,208	11,683	10,760	199,378	303,198	33,688
1938	287,762	86,876	41,812	416,450	1938–39	13,507	8,608	21,213	13,388	9,223	10,532	12,297	25,456	26,325	140,549	15,616
1939	163,557	399,868	43,041	606,466	1939–40	18,089	11,744	8,731	7,140	8,362	10,354	9,531	6,518	6,553	87,022	9,669
1940	8,423	313,587	129,739	451,749	1940–41	76,760	26,255	18,077	48,198	47,653	107,107	186,922	73,785	27,769	612,526	68,058
1941	54,416	286,215	21,275	361,906	1941–42	14,340	12,236	10,268	9,759	25,886	66,645	60,258	27,608	15,328	242,328	26,925
1942	301,904	154,116	105,759	561,779	1942–43	94,611	14,941	10,268	49,388	70,711	168,397	61,488	67,636	131,068	668,508	74,278
1943	336,337	290,975	225,045	852,357	1943–44	39,273	19,553	22,074	25,468	30,744	61,884	20,906	25,763	24,436	270,101	30,011
1944	143,881	251,107	85,468	480,456	1944–45	39,273	21,828	16,540	17,970	24,042	19,458	21,090	20,352	17,439	197,992	21,999
1945	268,086	133,289	203,524	604,899	1945–46	86,876	40,582	20,537	37,190	116,212	79,140	41,197	115,597	46,651	583,982	64,886
1946	287,147	35,702	46,116	368,965	1946–47	24,159	27,300	25,210	16,840	15,126	22,016	31,051	71,940	48,595	282,237	31,359
1947	118,671	558,148	226,889	903,708	1947–48	185,058	62,102	39,967	36,297	22,935	23,385	44,394	31,051	43,375	488,564	54,284
1948	441,481	108,892	65,792	616,165	1948–49	26,241	31,973	21,090	14,995	9,100	28,324	15,372	94,691	118,294	360,080	40,008
1949	239,802	92,826	22,812	355,440	1949–50	21,778	20,906	16,356	15,531	17,954	12,555	135,273	212,132	48,817	501,302	55,700
Minimum Year 1931	39,659	182,083	34,740	256,482	Minimum Year 1930–31	17,732	10,945	5,718	6,188	7,194	7,914	11,990	7,747	7,553	82,981	9,220
Maximum Year 1947	118,671	558,148	226,889	903,708	Maximum Year 1942–43	94,611	14,941	10,268	49,388	70,711	168,397	61,488	67,636	131,068	668,508	74,278
Av'ge for 36 Years	211,300	209,963	78,690	499,954	Av'ge for 36 Years	38,695	23,779	16,994	19,753	25,690	49,223	53,855	63,155	53,536	344,680	38,298

TABLE H-15

present. Unfortunately, there are no records available for the three driest periods indicated by the Galt records, namely 1930-31, 1934-35 and 1939-40. However, by comparing the average flows for the nine-month periods for the corresponding years of records for Galt and Brantford respectively a ratio may be obtained which could be applied to the flow at Galt to give a fairly reliable flow for Brantford.

The following data shows a comparison of the average flows for corresponding periods together with the Brantford to Galt flow ratios.

Period	Average Flow for the Period		Ratio Brantford to Galt
	Galt	Brantford	
1914-15	328	609	1.8567
1915-16	1,153	2,058	1.7849
1916-17	453	881	1.9448
1917-18	812	1,668	2.0542
1918-19	593	985	1.6610
1919-20	285	566	1.9860
1920-21	661	1,074	1.6248
1921-22	608	1,154	1.8980
1948-49	678	1,106	1.6313
1949-50	918	1,364	1.4858
Average Ratio			1.7927

Figure H-55, showing the flow hydrographs for the three driest periods on record with the flow demand hydrographs superimposed on each, illustrates graphically the storage required to sustain the minimum permissible flow at Galt. This figure also shows that, even during such dry years as these, there was more than enough surplus flow during the spring run-off period to satisfy the water needs for the following months.

The mean flow at Galt for the nine-month period June 1, 1930, to February 28, 1931, was 153 c.f.s. The mean flow at Brantford for the same period would be approximately 153 x 1.7927 = 274 c.f.s. or 226 c.f.s. below the required minimum. Thus the basic conservation storage required to satisfy the low flow problem at Brantford would be -

226 x 273 x 1.98347 = 122,376 acre feet.

Of this amount 106,673 acre feet would be held above Galt and the remainder (15,703 acre feet) would be held in the reservoirs on the Nith River.

5. Conservation Storage Losses

It will be noted that in the above section the conservation storage has been referred to as the "basic conservation storage". In other words, the above amount of storage is the net amount required to fulfil the flow needs and does not take into account storage losses which must be provided for.

(a) Loss by Dead Storage

Dead storage has been explained in the chapter on flood control and the storage space lost for flood control purposes through dead storage would also apply here. Normally this volume of water would be in the reservoirs at all times and might be used to augment the low flows under extreme conditions. However, allowances should be made for this volume of water in order to determine the total volume that should be on hand at the beginning of the draft period. The dead storage volume will vary for each reservoir and consequently for each system of reservoirs, and therefore cannot be definitely determined until the reservoirs have been finally selected and the dam designed for each. In the Shand Reservoir this loss amounts to about 2 per cent of the maximum flood storage capacity and on this basis the total loss by this factor has been estimated at 4,236 acre feet.

(b) Loss by Seepage, Evaporation and Ice Formation

In a reservoir there is always some loss due to seepage, evaporation and, in this case where the flow is to be sustained throughout the winter months, there will be a further loss due to ice forming in the reservoir which cannot be discharged. Seepage losses are usually not serious and may be disregarded, since it is thought that the additional hidden storage due to raised water tables will at least compensate for the water lost in this manner.

Evaporation loss is a direct function of the water surface area and is usually expressed in inches of depth. The rate of evaporation varies directly with temperature and wind velocity. From the first of June until the end of October the water surface evaporation generally exceeds precipitation by approximately 12 inches and may be as high as 20 inches. For the period of June 1 to October 31, 1930, (Table H-16) the evaporation loss amounted to 16.6 inches. During November the precipitation is usually greater than the evaporation and the reservoirs may gain a little storage, but if the weather were cold enough this precipitation would be in the form of snow which would remain on the ground and could not be relied upon to augment the storage in the reservoirs. Similarly the precipitation during December, January and February would most likely be in the form of snow and should be disregarded.

In addition to losing the winter's precipitation in the form of snow there is a further loss due to ice forming in the reservoirs. The amount of ice forming will vary directly with the temperature and may be calculated. However, there is not sufficient data available at present and for the purpose of this report the ice has been estimated at 8 inches for December increasing to 16 inches by the end of February.

In order to determine approximately the evaporation and ice losses for the period under consideration it would be necessary to prepare drawdown curves for each of the proposed reservoirs from which the water surface area of the whole reservoir system at any time may be determined. This would entail a great deal of work and in view of the uncertainty of the other factors and the assumptions that would be necessary it would not appear to merit such detail at this point.

TABLE H-16

LOSS DUE TO EVAPORATION AND ICE FORMATION FOR THE DRIEST PERIOD ON RECORD, VIZ: JUNE 1, 1930 - MARCH 22, 1931

Month	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Precipitation (Inches) *	2.87	1.80	1.98	1.31	1.47	2.16	† 1.71	† 2.59	† 1.45	† 1.46
Evaporation (Inches) *	6.37	7.00	6.27	4.40	2.03	0.53	0.0	0.0	0.0	0.0
Water Equivalent of Ice Formation						Inches Feet	7.27 0.606	3.63 0.302	3.63 0.303	1.81 0.15
Difference Inches Feet	- 3.50 0.29	- 5.20 0.43	- 4.29 0.378	- 3.09 0.258	- 0.56 0.047	+ 1.63 0.137	- 7.27 0.606	- 3.63 0.302	- 3.63 0.303	+ 1.81 0.15
Progressive Loss: Inches Feet	- 3.50 0.29	- 8.70 0.73	- 12.99 1.08	- 16.08 1.34	- 16.64 1.39	- 15.01 1.25	- 22.28 1.856	- 25.91 2.158	- 29.56 2.462	- 27.74 2.31

* Precipitation and Evaporation figures are the average for meteorological stations at Guelph, Kitchener and Alton

† Precipitation December to March may be snow on ice surface and thus not available as discharge

Accordingly, the month by month loss for the Shand Reservoir was worked out (Table H-17) based on the driest period on record and the assumption that this reservoir would provide about 35 per cent of the net conservation storage required for Galt.

From Table H-17 the evaporation and ice loss amounted to 2,740 acre feet or approximately 7.3 per cent of the conservation storage being provided by this reservoir. It is considered that 7 per cent would be a fair average for all the reservoirs and that this factor could be applied to the whole system to determine the total loss within reasonable limits. On this basis the total evaporation and ice loss would be 122,376 x 0.07 = 8,566 acre feet.

6. Total Conservation Storage Required

The total storage required to sustain the minimum allowable flows for the driest period on record would be -

Basic storage	122,376 acre feet
Dead storage	4,236 acre feet
To compensate for evaporation and ice losses	8,566 acre feet
Total	135,178 acre feet

7. Conservation Storage Available

The flood control reservoir systems previously outlined provide storage capacities of from 212,305 to 239,015 acre feet. However, all of this potential storage space would not be available for conservation storage, as, firstly, sufficient capacity must be kept available at all times to provide for effective control of "summer" floods that might occur after the spring freshet due to heavy rainfall and, secondly, for the years of low run-off some of the reservoirs would not fill to their potential conservation storage level.

CONSERVATION STORAGE LOSS BY EVAPORATION AND ICE FORMATION

Month by month drawdown of storage and the loss due to surface evaporation and the formation of ice for the Shand Reservoir for the driest period on record. (June 1, 1930 - February 28, 1931).

Date 1930-31	Monthly Mean Flow at Galt	Flow Deficiency at Galt	No. of Days	Monthly Drawdown for Galt	Portion of drawdown from Shand	Storage Remaining in Reservoir	Water Surface Elevation	Water Surface Area	Mean Water Surface Area	Net Results of Precipitation Evap'n and Ice Formation		Storage Remaining in Reservoir
	c.f.s.	c.f.s.		Ac.Ft.	Ac.Ft.	Ac.Ft.	Ft.	Ac.	Ac.	Depth-Ft.	Ac.Ft.	Ac.Ft.
June 1					(1)			1,625				41,069
	298	52	30	3,098	1,084				1,610	-0.292	-470	
June 30						39,985	1,390	1,595				39,515
	178	172	31	10,590	3,707				1,543	-0.433	-668	
July 31						35,808	1,387	1,490				35,140
	93	257	31	15,823	5,538				1,423	-0.378	-538	
Aug. 31						29,602	1,382	1,355				29,064
	104	246	30	14,657	5,130				1,295	-0.258	-334	
Sept.30						23,934	1,378	1,235				23,600
	117	233	31	14,346	5,021				1,168	-0.047	- 55	
Oct. 31						18,579	1,373	1,100				18,524
	133	217	30	12,929	4,525				1,025	+0.137	+142	
Nov. 30						13,999	1,369	950				14,141
	195	155	31	9,543	3,340				868	-0.606	-526	
Dec. 31						10,801	1,366	785				10,275
	126	224	31	13,791	4,827				638	-0.303	-193	
Jan. 31						5,448	1,357	490				5,255
	136	214	28	11,900	4,165				323	-0.303	- 98	
Feb. 28						1,090	1,343	155				992
TOTALS				106,677	37,337						-2,740	

(1) The percentage evaporation and ice loss is $\frac{2740}{37337}$ x 100 = 7.3% of the net conservation storage.

TABLE H-17

(a) Space Reserved for a Hypothetical Rainfall

In determining the minimum space which must be held in reserve to meet this contingency the same principles as were used to determine the spring flood control storage were followed out, the "summer" flood being based on the run-off from a hypothetical rainfall which might reasonably be expected to occur any time after the spring freshet.

The possibility of such a storm occurring during the spring freshet has already been provided for in the hypothetical spring flood. June 1 is normally the beginning of the dry period when the impounded water is discharged to augment the low flows and the water level of the reservoirs would be progressively lowered and would reach a stage where there would be no concern for the hypothetical rain. During the month of May the reservoirs would be filled to the determined level and as it is often a wet month it is a time for caution. The most critical period and the one which causes the controller concern and anxiety is the time immediately following a severe spring freshet. It is assumed that the snow melt will have been completed or nearly so and that the spring flows will have receded to base flow. The ground at that time would be saturated and possibly still partially frozen and with a heavy rain the run-off factor would be very high. It is improbable that a hypothetical spring flood would shortly be followed by a hypothetical rainfall, but a condition is possible whereby, with a late spring and with a heavy snow blanket, the snow melt might be rapid due to a sudden rise in temperature and then the hypothetical rain might follow on the heels of this spring run-off.

For the average spring run-off period the dams could be operated so that the reservoirs would not exceed the conservation level, which would leave sufficient space available for the unpredictable.

To determine the hypothetical rainfall all the available precipitation records covering the period 1921 to

1947 inclusive for each of the meteorological stations within and adjacent to the watershed were examined in conjunction with the stream flow records. From these records it was noted that the greater storms were generally only local in effect while the wide-spread storms were comparatively light in terms of inches of rainfall. The percentage of run-off for individual storms varied greatly, with a maximum run-off factor of 49.6 per cent being recorded for the May 11 - 16, 1943, storm.

After weighing all the various factors it was decided to take the mean of the greatest storms which had been recorded at each of the meteorological stations and assume that this mean rainfall might occur over the entire drainage area at the same time. Further it was assumed that such a storm might have a run-off factor of 65 per cent and that the run-off would be completed in a six-day period. (Six days was the average duration of the run-off periods for all the greater rainstorms.)

The following list shows the meteorological stations used for this study together with the amount of precipitation and duration of the greatest rainstorm for each.

Meteorological Station	Greatest Rainstorms on Record for the months May-June		
	Date Storm Began	Precipitation Depth in Inches	Duration Days
Grand Valley	June 28, 1939	4.66	3
Stratford	June 9, 1922	4.68	4
Paris	June 8, 1922	4.47	4
Brantford	June 8, 1922	3.88	4
Mt. Forest	May 15, 1923	5.40	5
Kitchener	May 15, 1923	3.63	4
Guelph	May 29, 1942	3.05	4
Alton	May 31, 1947	2.37	3
Mean of Storms		4.017	

From this list the rainfall for the proposed hypothetical storm would be 4.02 inches which with a 65-per cent run-off factor would produce a run-off volume at Galt equal to:

$$\frac{4.02}{12} \times 0.65 \times 1,357 \times 640 = 189,294 \text{ acre feet.}$$

From the run-off graph prepared for Galt for the run-off from all the greater rainstorms the maximum mean daily flow for the above volume is approximately 38,400 c.f.s.

With these values a hydrograph for this hypothetical rainstorm was constructed for Galt by combining the above flow on top of a base flow of 2,000 c.f.s. (Figure H-56). The average base flow at Galt immediately following the spring floods is approximately 2,000 c.f.s. and this was added to the hypothetical rainstorm flood to provide a further margin of safety and for the possibility of this storm occurring shortly after the spring flood before the streams have had time to return to normal flow. With a channel capacity flow of 26,490 c.f.s. at Galt the storage space which would have to be held in reserve above Galt for this hypothetical storm would be 24,831 acre feet.

Similar calculations for Brantford were not possible owing to the lack of flow records at that point, but it was considered that a sufficiently accurate value might be obtained for the additional area above Brantford by a direct proportion by area. On this basis the total reserve space required above Brantford would be:

$$24{,}831 \times \frac{2006.8}{1357.86} = 36{,}698 \text{ acre feet}$$

Of this total amount, 24,831 acre feet of storage space would be reserved in the reservoirs above Galt and the balance of 11,867 acre feet in the reservoirs on the Nith.

(b) <u>Spring Run-off Available for Storage</u>

Table H-18 showing the surplus spring run-off for the minimum, maximum and average years was prepared to indicate the amount of water that might be expected from each of the reservoir drainage areas for the spring run-off period and includes all the flow above base flow from the commencement of the spring freshet through to the end of May. To compensate for any low flows during this period it was assumed that a base

TABLE H-18

SPRING RUN-OFF ABOVE BASE FLOW AVAILABLE FOR STORAGE - FROM BEGINNING OF BREAK-UP TO END OF MAY
(BASED ON 36 YEARS OF FLOW RECORDS AT GALT)

Stream	Reservoir	Storage Capacity	Drainage Area	Run-Off in Acre Feet					
				Minimum Year - 1931		Maximum Year - 1943		36-Year Average	
		Acre Feet	Square Miles	Per Sq. Mile	Total	Per Sq. Mile	Total	Per Sq. Mile	Total
Grand	Luther	10,000	21.10	210.72	4,446*	835.93	17,638	441.58	9,317
	Shand	49,600	308.49		65,005		257,876		136,223
	Montrose	53,485	450.80		94,993		376,837		199,064
	Freeport	11,881	960.54		140,555		557,601		294,548
Conestogo	Glen Allan	45,060	219.47	215.10	47,208	853.34	183,332	450.78	98,933
	Wallenstein	16,583	243.60		52,398*		203,489		109,810
	St. Jacobs	13,255	295.83		63,633*		247,119		133,354
Speed	Guelph	11,575	102.95	219.50	22,598	870.77	89,646	459.98	47,355
Eramosa	Hespeler	9,666	250.90	119.99	30,105	476.02	119,433	251.45	63,089
	Everton	15,000	42.45		5,094*		20,207		10,674*
	Arkell	11,913	103.22		12,385		49,135		25,955
Nith	Nithburg	18,800	125.10	133.16	16,658	528.26	66,085	279.05	34,909
	Ayr	23,704	329.80		43,932		174,283		92,064

* Insufficient run-off to fill reservoir.

Run-off value shown opposite each reservoir is the total for the whole drainage area above their respective sites.

flow of 0.25 c.f.s. per square mile* would be passed through the reservoirs and this was subtracted from the total run-off for the period. From this table it will be noted that for the minimum year Luther, Wallenstein, St. Jacobs and Everton could not be relied upon to fill even their gross conservation storage level.† However, this is not serious. Both Luther and Everton will have storage capacities greater than is necessary to contain the hypothetical spring flood run-off from their respective areas, and therefore, if necessary, could carry some water over from wetter periods to satisfy a drier period. The Wallenstein and St. Jacobs Reservoirs, which would be used in the Freeport Group systems, are located well down stream and would only be required to make up the balance of storage that could not be placed in headwater reservoirs and thus would not be required to fill to their gross conservation storage capacity in any case.

For the maximum year the run-off would be more than sufficient to fill the reservoirs to capacity and even during the average year all the reservoirs, except Everton, could be filled. Everton for the average year would have over 10,000 acre feet of water available for storage, which would be more than enough to satisfy the low flow problem in this area.

As stated above, the various flood control systems provide from 212,305 to 239,015 acre feet of storage. After making due allowances for reservoir losses, space to be reserved for a hypothetical rainstorm and for the fact that certain reservoirs would not fill to their full potential conservation storage level during low years, there would be approximately from 160,592 to 187,392 acre feet of storage available in the respective systems. Thus these systems would

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* A flow of 0.25 c.f.s. per square mile corresponds to a flow of 350 c.f.s. at Galt.

† Gross conservation storage level is equivalent to the maximum storage level less the space to be reserved for the hypothetical summer flood and the volume set aside as dead storage.

provide approximately 38,216 to 65,016 acre feet of storage over and above that required to satisfy the low flow problem for the driest nine-month period on record. This additional storage space might be held in reserve to provide a further margin of safety for summer storms which would permit greater leeway for operating the dual-purpose reservoir system.

8. Distribution of Conservation Storage

It has been shown above that 135,178 acre feet of conservation storage are necessary to satisfy the minimum flow requirements of the watershed for periods of drought equal to the driest period on record. This storage would be provided by operating the flood control reservoirs as dual-purpose units. The seasonal occurrence of the major floods on the Grand makes it possible to use a large portion of the flood control storage space for conservation storage after the danger from spring floods has passed. However, reasonable caution must be observed to ensure that sufficient storage space is reserved to meet the flood control requirements for any subsequent "summer" flood which might be expected. If there were no distinct seasonal pattern of flood behaviour then it would be necessary to keep the maximum control storage space available at all times and the conservation storage space would have to be provided over and above that for flood control.

It has been pointed out above that there is an abundance of flood control storage space over that required for flow maintenance and thus the conservation storage may be distributed amongst these reservoirs to advantage. Obviously this storage should be placed as far up stream as is feasible in order to benefit the greatest number of people. Therefore, as much of the conservation storage as possible would be held in the headwater reservoirs - Luther, Shand, Glen Allan, Everton and Nithburg; and the balance would be held in the Ayr, Montrose or Freeport and Hespeler Reservoirs. As already stated the Guelph Reservoir, being situated so close to the city of Guelph, would not be suitable for summer flow and would probably be used as a detention reservoir or be kept dry.

Table H-19 shows possible conservation storage distributions for Reservoir Systems 1 and 3. These figures are only approximate since many of the factors cannot be determined until the dams have actually been designed and a plan for operating the reservoir system worked out.

The diagram in Fig. H-57 illustrates the total space in the reservoir system for conservation and flood storage and the space provided for the various storage losses.

POSSIBLE CONSERVATION STORAGE DISTRIBUTION FOR SYSTEMS 1 AND 3

Assuming that only sufficient storage would be retained to satisfy the flow requirements for the driest year. Also shows distribution of space to be reserved in the reservoir system for a hypothetical summer storm and the approximate storage losses due to dead storage, evaporation and ice formation.

Reservoirs	Maximum Storage Capacity Available Acre Feet	Loss Through Dead Storage[1] Acre Feet	Space Reserved for Hypothetical Summer Storm[2] - Acre Feet		Gross Conservation Storage Space Available June 1 - Acre Feet		Distribution of Storage to Sustain Required Flows[3] - Acre Feet		Net Conservation Storage Available Acre Feet	
			System 1	System 3	System 1	System 3	System 1	System 3	System 1	System 3
Luther	10,000	200	544	764	9,256	9,036	4,446[4]	4,446[4]	4,155	4,155
Shand	49,600	992	7,405	10,401	41,203	38,207	41,203	38,206	38,507	35,708
Montrose	53,485	1,070	3,666		48,749		20,640		19,291	
Freeport	11,881	238		961		10,682		(5)		(5)
Glen Allan	45,060	916	9,156	6,532	34,988	37,612	34,988	37,612	32,699	35,151
Wallenstein	16,583	322		717		15,544		13,479[4]		12,597
St. Jacobs	13,255	265		1,553		11,437		7,469		6,980
Guelph	11,575	232	1,667	1,602	9,676	9,741	(5)	(5)	(5)	(5)
Everton	15,000	300	688	661	14,012	14,039	5,094[4]	5,094[4]	4,761	4,761
Hespeler	9,666	193	1,705	1,640	7,768	7,833	7,768	7,833	7,260	7,321
Nithburg	18,800	376	4,368	4,368	14,056	14,056	14,056	14,056	13,136	13,136
Ayr	23,704	474	7,499	7,499	15,731	15,731	2,747	2,747	2,567	2,567
TOTALS			36,698	36,698	195,439	183,918	130,942	130,942	122,376	122,376

Notes:

1. Dead Storage loss estimated at 2% of maximum storage capacity of the reservoirs.
2. Reservoir space of 36,698 acre feet to be provided for the hypothetical summer storm.
3. Net Conservation Storage plus the estimated 7% loss for evaporation and ice loss.
4. This is the maximum filling potential of these reservoirs for the driest spring run-off period on record. (See Table H-18)
5. The Freeport and Guelph Reservoirs might be left dry or used as summer lakes.

TABLE H-19

CHAPTER 12

SUMMARY AND RECOMMENDATIONS

1. Summary

From surveys and studies which have been made the hydraulic report shows that the remedial measures proposed to control floods will also satisfy the low flow problem. The causes of floods, their magnitude and remedial measures have been described together with expedients for the main places which are subject to floods; namely, Galt, Brantford, Guelph, Paris, Hespeler, Drayton, New Hamburg, Plattsville, Dunnville and Port Maitland. The report submits a plan for a system of reservoirs and other conservation measures that will provide protection against a planned-for or hypothetical flood which is from 1.33 to 1.41 times* greater in magnitude than the 1947 spring flood - the greatest in the 35 years of hydrometric records. The report shows that although proper land use practices and reforestation are the initial approach to the flood and low flow problem, they alone are not sufficient, and a system of regulated dual-purpose reservoirs in conjunction with some channel improvement and diking is necessary to satisfy these problems.

Galt has been selected as the key to both problems for two specific reasons.

(1) The Galt gauge is the only one on the watershed which has long continuous records

(2) The reservoirs are so strategically located that in conjunction with some channel improvement and diking, and regulated to pass flood flows safely through Galt they satisfy the other trouble areas above Galt and together with the Nith Reservoirs, those below Galt.

The ratio of run-off for the various drainage areas of the Grand and its main tributaries was determined by

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* Degree of protection depending upon selection of reservoirs.

establishing run-off ratios between the years of records of the short-term hydrometric gauges and the same years for the Galt gauge.

The storage above Galt was determined by means of the hydrograph. In Chapter 8 it has been shown that the hydrograph may be considered as an approximate triangle for the hypothetical flood, and accordingly a hydrograph for this flood was constructed for Galt by means of a run-off graph from which the apex of the triangle, or a maximum mean daily flow at Galt of 56,830 c.f.s., was determined. The channel capacity flow, for a flooding stage at elevation 864.92, is 30,650 c.f.s. The area above this line represents the channel capacity storage and is equivalent to 120,003 acre feet.

The report shows theoretically that 120,003 acre feet of "channel capacity storage" is the amount of water to be held in the reservoirs upstream to prevent the river overflowing at Galt, but that substantial additional storage space is necessary to operate the reservoirs and safely pass the flood flows through Galt; viz,

Operational storage 41,170 acre feet, which allows for one foot of freeboard at Galt below the channel capacity stage for dam regulation in order to pass safely flood flows through Galt;

Dead storage 3,284 acre feet to facilitate sealing by silting the bottom of the reservoir at the dam and for the protection of the discharge tubes;

Boost discharge storage 4,926 acre feet which, together with the dead storage, will enable the tubes to discharge a volume equal to the inflow into the reservoirs until such time as the rate of flow at Galt has reached the freeboard stage or the theoretical time that the filling of the reservoirs begins.

These four storage classifications total 169,383 acre feet above Galt.

The same method was used for Brantford with the exception that it was not necessary to provide operational storage at Brantford, the channel capacity at Brantford being at elevation 657.1 (equivalent to 39,346 c.f.s.) and the top of the dikes at the gauge at 663.5 or 6.4 feet of freeboard, which is ample for dam operation. The additional storage required above Brantford is 42,400 acre feet, or a total of 211,783 acre feet of flood control storage for the watershed.

Above Galt the storage was allocated to the Grand and its tributaries as far as possible in proportion to the run-off ratios (Table H-9 and Fig. H-34). The additional 42,400 acre feet of storage required for Brantford and Paris and the other trouble areas on the Nith was all put in the Nith River.

Twenty-three reservoir sites were surveyed, 13 of which were selected for further investigation, and from these a system of 9 or an alternative system of 11 or 12 reservoirs was chosen to satisfy the flood control and low flow problems.

In Table H-2 five systems of reservoirs, numbered from 1 to 5, have been submitted for comparison showing the storage and cost of each. The five systems are basically in two groups. The Montrose Group, Systems 1, 2 and 5, consisting of 9 reservoirs each and of which all the dams except Nithburg and Ayr on the Nith River could be built on rock foundations, provide more storage, cost less for maintenance and for construction than the Freeport Group. In the Freeport Group, Systems 3 and 4, there are 11 and 12 reservoirs respectively, Montrose being replaced by 2 and possibly 3 others, viz, Freeport, Wallenstein and St. Jacobs. With the Freeport Group 290 square miles of drainage area is brought within the system, and control is extended 23 miles farther downstream to a point only 12 miles above Galt. For this reason it might be possible to reduce the freeboard at Galt, and hence the operational storage, to the extent that either the Wallenstein or the St. Jacobs Reservoir could be eliminated. As with Nithburg and Ayr, however, Freeport, Wallenstein and St. Jacobs have overburden exceeding 75 feet, and these dams would have to be built on concrete mats requiring extensive subsurface exploration and a more detailed preliminary design to determine the cost.

Systems 1 and 2 are similar, except that the Arkell Reservoir, which may interest the City of Guelph, has been substituted for that of Hespeler. The same applies to Systems 3 and 4. System 5 includes the same reservoirs as System 1 but has the capacity of the Montrose and Everton Reservoirs reduced to conform to the determined flood control storage, viz, 211,783 acre feet in order to show the cost $1,570,000 for the extra 24,480 acre feet of storage.

Until the feasibility and a firmer cost of construction is known for the Freeport, Wallenstein and St. Jacobs Dams and the extent that they would reduce the freeboard at Galt, no definite recommendation can be made at this time. However, because Montrose has a capacity greater than the sum of the other three, has a rock foundation and would require the maintenance of only one reservoir instead of possibly three, System 1 is favoured at this time and may be said to be tentatively preferred.

With certain exceptions, it has been shown that the reservoir sites should be developed to their full capacity and that consequently this 24,480 acre feet of extra storage would be worthwhile for one or more purposes; namely, to offset loss by silting and in the meantime increase the flood protection from 1.33 to 1.41 times the 1947 flood, which would give greater assurance and freedom in dam operation; or the freeboard at Galt could be increased if necessary; or sustained flows could be further increased; or another retention type lake could be made available.

Table H-18 shows the extent of reservoir filling for the maximum, minimum and average run-off periods of record from the rise from base flow at the beginning of the spring run-off period until the end of May. Thus it shows the total amount of water that could be impounded but does not account for the discharges from the dams of major floods, which would be made at the beginning of the spring run-off period until the freeboard stage had been reached at Galt. Hence its practical application would apply only if it was definitely known that the spring run-off would be light.

The work at trouble areas where channel improvement and diking are also necessary is the same for all the systems submitted. For Galt, Paris, Guelph, Hespeler and Ayr the reservoirs alone in each system provide full protection for a flood of the hypothetical magnitude. The same applies for Brantford, with provision made to extend the present dikes in order to seal off the flats south of the city.

At New Hamburg and Plattsville some diking and channel improvement is necessary in conjunction with storage.

There is no provision for a reservoir above Drayton. Instead, two channel improvement schemes with dikes have been proposed, both of which are designed for the hypothetical flood. At Port Maitland, where flooding is caused largely by ice jamming in the mouth of the river, an armoured tug-boat has been suggested. At Dunnville some local improvement is necessary to alleviate the flood hazard due to ice conditions for which two schemes have been shown. One scheme is the removal of the dam and the building of a new bridge to replace the present old structure, at an estimated cost of $475,000. The other or alternative scheme is to leave the dam in place and seal off the town by a dike, at an estimated cost of $102,000. The alternative scheme does not improve the ice conditions nor is it as effective as the former scheme and is therefore not recommended.

Although the reservoir system alone will give Paris, Hespeler and Guelph full protection against the hypothetical flood, it may be necessary to do some channel improvement and diking at those places if, during the interim of a long-term construction of the reservoir system, the flood damage sustained justifies this extra expenditure. Surveys and costs for these expedients have been shown for Paris and Hespeler. No surveys were made at Guelph since it was understood at the time that the city were intending to assume this responsibility.

Provision has been made to clean out the rivers by clearing and dredging in places where growth and accumulated deposits obstruct the flow.

The total estimated cost of reservoir storage for flood control and river improvement is as follows:

For reservoirs and dams (System 1)	$22,110,000
For channel improvement and diking that is necessary as well as the reservoirs	991,054
For cleaning debris from the rivers	150,000
Total estimated cost of the program	$23,251,054
Extra costs of expedients that may be necessary at Paris, Hespeler and Guelph owing to delay in providing reservoirs	$ 353,150

The reservoirs listed in the systems and their damsites have been briefly described and a minimum spillway capacity shown.

It has been shown that a sustained flow throughout the year of not less than 350 c.f.s. at Galt and 500 c.f.s. at Brantford is required to dilute the effluent from municipal sewage and industrial waste in conjunction with treatment of the same to the extent that the water in the river will be safe for domestic and recreational use, and that a mimimum of 135,178 acre feet of conservation storage based on the driest year of 35 years of records is required for this purpose. This is the total storage with certain losses in storage space having been accounted for, viz, dead storage (4,236 acre feet), evaporation and ice (8,566 acre feet). Also reserve space in the reservoirs has been accounted for to provide for a hypothetical summer storm which might follow the spring break-up (36,698 acre feet).

The total holding capacity of the reservoirs in System 1 is .... 236,785 ac. ft.

The required conservation storage and reserved space is .... 171,876 ac. ft.

The surplus conservation storage if all the reservoirs are full at the end of the spring break-up period .... 64,909 ac. ft.

or a surplus of $\frac{64,909}{135,178} \times 100 = 48$ per cent of conservation storage, which is equivalent to a sustained flow of 470 c.f.s. at Galt and 740 c.f.s. at Brantford.

The above assured flows in the river will be of benefit to any existing hydraulic power plants.

2. Recommendations

The recommendations for flood control, water conservation and increased flow are as follows:

(1) That a system of reservoirs be constructed in conjunction with diking and channel improvements (at some specified trouble areas) which will give protection throughout the watershed against floods 1-1/3 times the magnitude of the 1947 flood.

(2) As funds become available that the projects shown in the table following this page be constructed.

(3) That the Guelph Reservoir be of the retention type.

(4) That at Drayton, where there is no reservoir protection, and at New Hamburg, where there is only partial reservoir protection, diking and channel improvement be given priority.

(5) That no diking or channel improvement be carried out at places which will have full reservoir protection unless, due to delay of reservoir construction, the flood damage in the meantime would justify the expenditure.

(6) That a diamond drilling program be carried out at the damsites listed under item 2 to the extent that

the depth of overburden, soil classification, the structure of ledge rock and the damsite line may be fixed, and that a preliminary design may be made of the dams and firm costs determined. That the drilling be done at an early date in order that a decision may be made between the Montrose and Freeport systems of reservoirs.

Reservoirs	Cost System 1 Montrose Group $	Cost Alternative System 3 Freeport Group $	Diking and/or Channel Improvement	Cost $
Glen Allan	5,400,000	5,400,000	Galt	55,000
			Drayton	267,444
Guelph	1,620,000	1,620,000	Hespeler(a)	142,500
Everton	1,300,000	1,300,000	Paris(b)	145,650
Ayr	2,500,000	2,500,000	New Hamburg	90,000
Hespeler	980,000	980,000	Brantford	100,110
Montrose	7,010,000		Guelph(a)	65,000
Freeport		*1,840,000		
St. Jacobs		*2,700,000	Plattsville	3,500
Wallenstein(d)		*3,030,000	Dunnville	475,000
Nithburg	3,300,000	*3,300,000		
			Cleaning river bed	150,000
Total	22,110,000	22,670,000		1,494,204

* Estimate questionable due to excessive depth of overburden

(a) Not necessary if Guelph and Everton Dams are constructed.

(b) Not necessary if Glen Allan and Ayr Dams are constructed.

(d) Possibility of eliminating Wallenstein if freeboard at Galt can be reduced sufficiently.

(7) That steps be taken to purchase or lease the property required for reservoir sites, those in particular close to urban centres which might be built upon.

(8) That hydrometric gauges be installed at or near the approved damsites.

(9) That the land use and reforestation measures recommended be implemented.

(10) That snow survey stations be established at strategic points on the watershed, and that the condition of the ground be observed and the depth and water content of the snow measured from time to time in order that an estimate may be made of the amount of spring run-off to be expected from snow melt.

(11) That as the dams come into operation, the control organization be expanded and equipped and that the system of communication between the control centre and the dams, trouble areas, gauges, snow survey stations and meteorological stations be such that there will be a rapid assembly of all reports to the control centre and instructions rapidly issued therefrom. Also, that an emergency operating plan be set up in the event of failure of the communication system.

(12) That the discharge from the dams will provide a minimum flow of 350 c.f.s. at Galt and 500 c.f.s. at Brantford daily throughout the year.

(13) That precautionary measures be taken by means of a detailed emergency plan, with demolition material and personnel experienced in its use available during flood periods for all dams which have no free overflow spillway. Then, however improbable, should an emergency arise in which it would not be possible to open the control gates and it became necessary to prevent flood waters topping the dam, one or more of the gates could be sacrificed in order to avoid a possible disaster through the failure of a dam.

(14) That immediate measures be taken to prevent any further pollution of the river and that a program be instituted to clear up the existing pollution.

(15) That some form of control be established to regulate and restrict the use of water from any natural swamps, lakes, ponds and stream channels for irrigation purposes.

APPENDIX A

OBJECTIVES FOR WATER QUALITY CONTROL IN ONTARIO
ADOPTED BY THE POLLUTION CONTROL BOARD, MAY 5, 1953

These objectives are for all waters in the Province of Ontario, and it is anticipated that in certain specific instances, influenced by local conditions, more stringent requirements may be found necessary.

GENERAL OBJECTIVES

All wastes, including sanitary sewage, storm water, and industrial effluents, shall be in such condition when discharged into any receiving waters that they will not create conditions which will adversely affect the use of these waters for the following purposes; source of domestic water supply, navigation, fish and wildlife, bathing, recreation, agriculture and other riparian activities.

In general, adverse conditions are caused by:

(A) Excessive bacterial, physical or chemical contamination.
(B) Unnatural deposits in the stream, interfering with navigation, fish and wildlife, bathing, recreation, or destruction of aesthetic values.
(C) Toxic substances and materials imparting objectionable tastes and odours to waters used for domestic or industrial purposes.
(D) Floating materials, including oils, grease, garbage, sewage solids, or other refuse.
(E) Discharges causing abnormal temperature, colour or other changes.

SPECIFIC OBJECTIVES

In more specific terms, adequate controls of pollution will necessitate the following objectives for:

(A) Sanitary Sewage, Storm Water, and Wastes from Water Craft

Sufficient treatment for adequate removal or reduction of solids, bacteria and chemical constituents which may interfere unreasonably with the use of these waters for the purposes afore-mentioned.

Adequate protection for these waters, except in certain specific instances influenced by local conditions, should be provided if the coliform M.P.N. Median value does not exceed 2,400 per 100 ml. at any point in the waters following initial dilution.

(B) Industrial Wastes

(1) Chemical Wastes - Phenolic Type

Industrial waste effluents from phenolic hydrocarbon and other chemical plants will cause objectionable tastes or odours in drinking or industrial water supplies and may taint the flesh of fish.

Adequate protection should be provided for these waters if the concentration of phenol or phenolic equivalents does not exceed an average of 2 p.p.b. and a maximum of 5 p.p.b. at any point in these waters following initial dilution. This quality in the receiving waters will probably be attained if plant effluents are limited to 20 p.p.b. of phenol or phenolic equivalents.

Some of the industries producing phenolic wastes are: coke, synthetic resin, oil refining, petroleum cracking, tar, road oil, creosoting, wood distillation, and dye manufacturing plants.

(2) Chemical Wastes, Other than Phenolic

Adequate protection should be provided if:

(a) The pH of these waters following initial dilution is not less than 6.7 nor more than 8.5. This quality in the receiving waters will probably be attained if plant effluents are adjusted to a pH value within the range of 5.5 and 10.6.

(b) The iron content of these waters following initial dilution does not exceed 0.3 p.p.m. This quality in the receiving waters will probably be attained if plant effluents are limited to 17 p.p.m. of iron in terms of Fe.

(c) The odour-producing substances in the effluent are reduced to a point that following initial dilution with these waters the mixture does not have a threshold odour number in excess of 4 due to such added material.

(d) Unnatural colour and turbidity of the wastes are reduced to a point that these waters will not be offensive in appearance or otherwise unattractive for the afore-mentioned uses.

(e) Oil and floating solids are reduced to a point such that they will not create fire hazards, coat hulls of water craft, injure fish or wildlife or their habitat, or will adversely affect public or private recreational development or other legitimate shoreline developments or uses. Protection should be provided for these waters if plant effluents or storm water discharges from premises do not contain oils, as determined by extraction in excess of 15 p.p.m., or a sufficient amount to create more than a faint irridescence.

Some of the industries producing chemical wastes other than phenolic are: oil wells and petroleum refineries, gasoline filling stations and bulk stations, styrene co-polymer, synthetic pharmaceutical, synthetic fibre, iron and steel, alkali chemical, rubber fabricating, dye manufacturing, and acid manufacturing plants.

(3) Highly Toxic Wastes

Adequate protection should be provided for these waters if materials highly toxic to human, fish, aquatic, or wildlife are eliminated.

Some of the industries producing highly toxic wastes are: metal plating and finishing plants discharging cyanides, chromium or other toxic wastes; chemical and pharmaceutical plants and coke ovens. Wastes containing toxic concentrations of free halogens and wastes containing resin and fatty acid soaps are included in this category.

(4) Deoxygenating Wastes

Adequate protection of these waters should result if sufficient treatment is provided for the substantial removal of solids, bacteria, chemical constitutents and other substances capable of reducing the dissolved oxygen content of these waters unreasonably. In addition to sewage some of the industries producing these wastes are: tanneries, glue and gelatine plants, alcohol, including breweries and distilleries, wool scouring, textile, pulp and paper, food processing plants such as meat packing and dairy plants, corn products, beet sugar, fish processing and dehydration plants.

APPENDIX B

Domestic Water Supplies from the Great Lakes

The proposal has often been made to pump water from the Great Lakes to supply the domestic needs of the Grand Watershed.

The foregoing report has shown that a minimum water storage capacity of 211,783 acre-feet should be provided for flood protection purposes and, if the proposed flood control program is instituted, at least 160,600 acre-feet* of stored water would be made available for use throughout the period of low flow which normally follows the spring freshets. This would be water which is presently being wasted each year and is doing untold damage as it makes its way to Lake Erie. This amount of water alone would be sufficient to supply more than half the annual needs of all the major municipalities on the watershed and does not take into account the normal river flows throughout the remainder of the year.

The stream flow records for Brantford show that during a 30-day spring freshet period in 1948 enough water was discharged at this point to supply the city of Brantford for 79 years or sufficient for all the municipalities on the accompanying list for 24 years at their present rate of consumption. Throughout the peak day of the March 1950 spring flood the Grand River was discharging enough water each second to satisfy the full daily requirements of the whole watershed. Thus it is evident that with regulation the existing water resources of the watershed could easily satisfy the demand.

In addition to the above a brief study was made into the cost of pumping water from the lakes. The relatively simple scheme of pumping water from Georgian Bay over into the headwaters of the Grand River thence to the individual

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* 1 acre-foot is equivalent to 271,472 imperial gallons.

WATER CONSUMPTION

CITIES, TOWNS AND SELECTED VILLAGES
GRAND WATERSHED

Place	Population	Year	Consumption - Gallons	
			Annual	Daily per Capita
Kitchener	50,363	1952	1,838,225,000	100
Brantford	37,295	1952	1,674,866,000	123
Guelph	28,617	1952	1,945,133,000	186
Galt	20,801	1952	535,000,000	70
Waterloo	12,449	1952	* 351,775,000	77
Preston	8,189	1952	275,137,000	92
Paris	5,337	1952	181,245,000	93
Dunnville	4,593	1953	207,144,200	124
Hespeler	3,780	1952	214,122,000	155
Fergus	3,515	1953	93,205,000	73
Caledonia	1,700	1952	26,000,000	42
Elora	1,360	1952	17,000,000	34
Total	177,999		7,358,852,200	

* Estimated

Note: Figures shown for Brantford, Paris, Dunnville and Fergus received direct from Municipal Offices.

Figures for other places shown were taken from Municipal Statistics Annual Report - 1952.

municipalities by the river itself only was considered, as any system to pipe water to each municipality would be prohibitive in cost. Even this scheme would be costly as will be shown.

From the topographic sheets it was calculated that a pipe line from Lake Huron would need to be 55.6 miles long and would rise to a maximum height of 1,022 feet above the lake. On the other hand, a line from Georgian Bay would only be 20.8 miles in length with a maximum rise of 1,122 feet. Therefore it is apparent that the latter would be more economical and this source was assumed in the study. It was also assumed that the average daily water consumption would be about 20,000,000 gallons and that the present sources would continue to yield about 65 per cent of this demand. Thus the following cost estimate is based on a pumpage of 7,000,000 gallons per day.

Data used were as follows:

Distance:	Georgian Bay to the headwaters of the Grand River	20.8 miles
	Greatest vertical lift	1,122 0 feet
	Flow to be pumped	7.0 m.g.d
Pipe line (assumed diameter)		24.0 inches
Hazen and Williams "C" for steel pipe		130
Cost of pipe per lineal foot coated, wrapped and laid in place		$ 20.00
Power cost per k.w. hour		2.7 to 0.33¢
Over-all efficiency		70%

The computations based on the above value are:

Length of pipe line	20.8 miles	=	109,824	feet
Friction loss	2.34 x 109,824	=	258	"
Static lift			1,122	"
Total head			1,380	"

Cost of pipe line	$20 x 109,824 -	$2,196,480
" " 3 pump houses		20,000
" " 6 pumps and equipment		50,000
" " miscellaneous equipment		30,000
Total cost of equipment		$2,296,480

Annual power cost based on prevailing sliding scale of 2.7 to 0.33¢ per k.w. hour - $150,000.

The cost of the project is shown below in two ways:

(a) Total annual charges

(b) Total capitalized cost

(a) Total annual charges	
1. Capital costs	
(1) Annual interest charges 5% =	$ 114,824
(2) Annual depreciation 5% sinking fund	13,687
	128,511
2. Power costs	150,000
Total annual charges	$ 278,511
(b) Total capitalized costs	
1. First costs	2,296,480
2. Depreciation	244,575
3. Power costs	2,709,834
Total capitalized cost	$5,250,889

The total capitalized cost consists of the sum of the first cost, the capitalized value of depreciation and the capitalized value of the power cost to the year 2000 (46 years).

It should be noted that each municipality would be required to pump its own water from the river and treat the water as might be required Thus the cost shown above, amounting to about 11 cents per 1,000 gallons would be a surcharge on the additional costs required for pumping and treatment.

From this preliminary study it can be seen that pumping water from Lake Huron or Georgian Bay to the Grand Watershed would be a costly undertaking. In addition there are other practical draw-backs even to the relatively simple scheme outlined above.

APPENDIX C

THE EFFECT OF HURRICANE STORMS ON THE GRAND WATERSHED

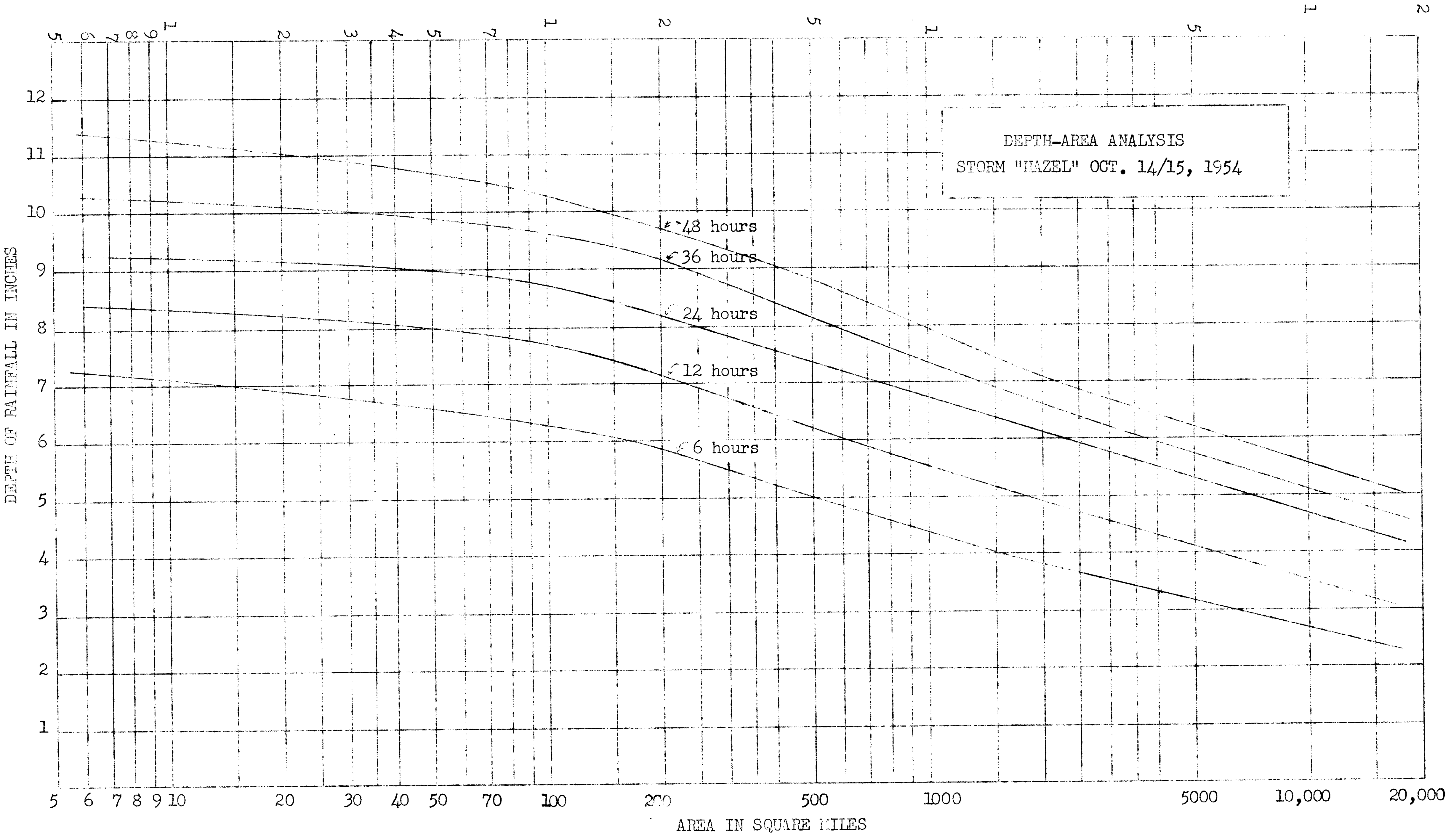
The purpose of this appendix is to acknowledge the occurrence of hurricane "Hazel" during October 14-15, 1954 and to indicate what the effect of such storms would be on the proposed flood control and water conservation program for the Grand Watershed.

This storm precipitated rainfall amounts in excess of, and over a wider area, than any storm previously recorded in Southern Ontario. The resultant run-off from the rivers in the path of this storm was high and in several cases the peak flows were three to four times higher than those previously recorded.

The 48-hour rainfall varied from 3 inches along the Lake Huron shoreline to a maximum recorded point rainfall of 8.41 inches at Snelgrove just north of the town of Brampton, tapering off to 3 inches along a north-south line through Whitby and Dorset on the east. However, from unofficial "bucket" measurements and stream run-off studies there is reason to believe that the true amount and intensity of this rainfall was greater in some areas than is indicated by the official records.

Measurements made in miscellaneous containers around the Humber Watershed and the area immediately to the north indicate spot rainfalls as high as 11 inches in 48 hours. These measurements were taken by Dr. D. V. Anderson, Research Division, Department of Lands and Forests and were carefully investigated before being accepted and are considered to be reliable. An isohyetal map was prepared using all the above-mentioned precipitation values - both the official weather stations and the "bucket" measurements - and the accompanying "Depth-Area Analysis Curves" were computed.

The peak flows on the Grand River and its tributaries resulting from this storm as it occurred over the



DEPTH-AREA ANALYSIS
STORM "HAZEL" OCT. 14/15, 1954

watershed together with the previously recorded peak flows at the recording gauging stations are shown below.

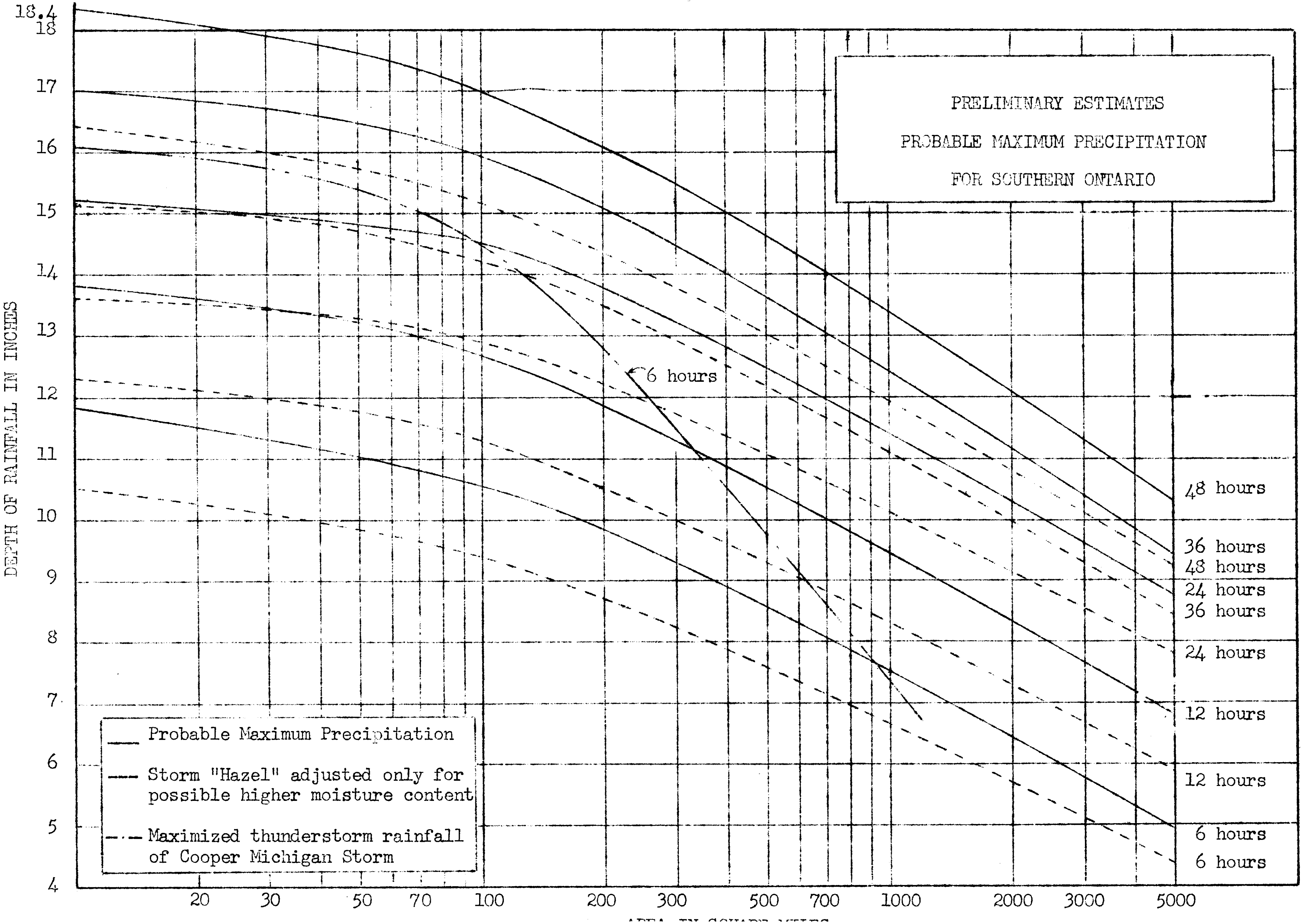
Gauging Station	Peak Flow Storm Hazel	Previous Record Peak	
		Flow	Date
Waldemar	9,917 c.f.s.	14,071 c.f.s.	Apr. 4, 1950*
Conestogo	38,330 c.f.s.	23,132 c.f.s.	Mar. 23, 1949
Galt	46,300 c.f.s.	46,280 c.f.s.	Mar. 20, 1948
Canning	15,265 c.f.s.	12,608 c.f.s.	Apr. 5, 1950
Brantford	52,354 c.f.s. **	50,460 c.f.s.	Apr. 5, 1950

* Recorded at Marsville, former location of Waldemar Station.

** This flow would have been considerably higher had peak flows from Nith River and Grand River above Paris coincided.

As indicated above, the storm centre passed to the east of the Grand Watershed and it is evident that if this storm had been centred over the Grand the above flows could have been considerably higher. Furthermore, more recent studies have shown that even greater storms are probable in the future with consequently higher flood discharges. The accompanying graph shows the probable maximum precipitation for Southern Ontario. This graph, based on an analysis of past storms and other meteorological data, indicates the upper limits for storms of this type in Southern Ontario but there is little doubt that such storms are physically possible and must be taken into consideration in the design of any flow regulating works.

The flood control system outlined in the foregoing report is designed to give flood protection against all floods up to and including a flood 1-1/3 times greater than the 1947 spring flood which was the greatest on record at the time this study was undertaken. The proposed system, as pointed out in the report, would not guarantee full protection against all flooding in the future as protection beyond the


PRELIMINARY ESTIMATES
PROBABLE MAXIMUM PRECIPITATION
FOR SOUTHERN ONTARIO
DEPTH OF RAINFALL IN INCHES
18.4
18
17
16
15
14
13
12
11
10
9
8
7
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5
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20
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70
100
200
300
500
700
1000
2000
3000
5000
6 hours
48 hours
36 hours
48 hours
24 hours
36 hours
24 hours
12 hours
12 hours
6 hours
6 hours
Probable Maximum Precipitation
Storm "Hazel" adjusted only for possible higher moisture content
Maximized thunderstorm rainfall of Cooper Michigan Storm

extent stated was not considered to be economically sound in view of the infrequent occurrence of such floods.

However, in considering the design of the spillways of the various dams where the failure of such structures would create a hazard in itself and endanger the lives of people living in the valleys, it was necessary to provide for the maximum flow considered reasonably possible.

On the basis of the flood flows resulting from storm "Hazel" as it occurred over the Conestogo drainage area and recorded at Drayton and Conestogo, it was estimated that the peak flow at this damsite was 26,100 c.f.s. or a run-off rate of about 119 c.s.m. By centering storm "Hazel" over this area, orienting it to give the greatest amount of rainfall on the area and assuming a run-off factor of 80 per cent, it is estimated that the peak flow would have been 45,300 c.f.s. at the damsite or equivalent to a rate of run-off of about 206 c.s.m. which is still below the discharge capacity of the dam as designed.

However, as a result of the floods produced by this storm it is now evident that "summer" floods can be more critical than spring floods as was concluded in the foregoing report and studies are continuing to determine the maximum peak flows to be expected as a result of the probable maximum rainfall storms shown on the accompanying graph.

This revised basis for flood control studies will also affect the proposed operation of the reservoirs. Previously the records indicated a distinct seasonal flood pattern which permitted the holding over of large volumes of storage for use throughout the dry months. However, with the advent of hurricane storms which usually occur in the late summer or early fall, it will be necessary to adjust the reservoir releases so sufficient storage would be available to provide for floods which could occur at this time.