A STUDY OF GROUNDWATER DISCHARGE AS REFLECTED IN THE HARDNESS OF TOTAL RUNOFF

BY

George F. Pinder
Department of Mines
July, 1967

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this project was to study the relationship between stream chemistry and the groundwater contribution to stream flow. The factors considered in this investigation were 1) time since the last major storm, 2) position in the stream (upper, middle and lower segments of the stream, 3) size of the stream. The investigation of each factor individually and the interaction of one factor with another were incorporated into the experimental design.

The Musquodoboit River (total length of approximately 40 miles) and Flip Brook (total length of approximately one mile) were chosen for this project.

METHOD OF STUDY

Samples of water were selected from three equidistant points on each of two streams daily for a period of six days. Sampling was initiated immediately after a major storm and continued until low stream flow made accurate sampling impracticable. The samples were analyzed for total hardness only, but other ions will be considered on receipt of the necessary field equipment. The statistical analysis was generated for a factorial arrangement of treatments since this method provides the most efficient use of experimental information.

STATISTICAL ANALYSIS

The calculations for the statistical analysis using the tabular method are given in table 1 and the significant effects are presented in table 2 using the 0.05 level of significance. The significant coefficients for position in the stream are -4.25 for the linear effect and 0.31 for the quadratic; for the effect of time after rainfall the linear coefficient is 0.83 and the quadratic 0.19.

Level	Observation	Operation 1	Operation 2	Operation 3	Divisor	Sum of Squares	Effect
000	21	61	154	1021	36		
100	17	93	148	-102	24	433.5	N_1
200	23	64	161	+22	72	6.7	N_2
010	35	84	175	+201	36	1122.2	S_1
110	29	70	183	-168	24	1176.0	$N_1 S_1$
210	29	91	200	+12	72	2.0	$N_2 S_1$
001	20	67	-4	349	420	290.0	T_1
101	22	108	-16	-150	280	80.3	$N_1 T_1$
201	22	73	-12	-2	840	0.0	$N_2 T_1$
011	37	110	-19	161	420	61.7	$S_1 T_1$
111	28	75	-22	-236	280	198.9	$N_1 S_1 T_1$
211	19	125	-29	56	840	3.7	$N_2 S_1 T_1$
002	18	2	16	95	504	17.9	T_2
102	24	-6	-2	-3	336	0.0	$N_1 T_2$
202	28	2	-4	167	1008	21.6	$N_2 T_2$
012	41	-18	-5	105	504	21.8	$S_1 T_2$
112	31	10	6	9	336	0.2	$N_1 S_1 T_2$
212	19	-22	11	-21	1008	0.4	$N_2 S_1 T_2$
003	20	3	+32	-71	1080	0.4	T_3
103	24	-22	+20	-55	720	4.2	$N_1 T_3$
203	23	7	+21	-77	2160	2.7	$N_2 T_3$
013	47	-29	41	-109	1080	11.0	$S_1 T_3$
113	36	+9	37	-111	720	17.1	$N_1 S_1 T_3$
213	25	-38	50	+11	2160	0.0	$N_2 S_1 T_3$
004	21	10	-8	+33	168	6.4	T_4
104	24	6	-20	+19	112	3.2	$N_1 T_4$
204	23	-2	-32	-3	336	0.0	$N_2 T_4$
014	52	0	-25	35	168	7.2	$S_1 T_4$
114	35	-2	-36	-1	112	0.0	$N_1 S_1 T_4$
214	23	-2	-47	-7	336	0.1	$N_2 S_1 T_4$
005	21	-5	-4	+11	1512	0.0	T_5
105	24	0	2	-65	1008	4.1	$N_1 T_5$
205	30	1	0	-55	3024	1.0	$N_2 T_5$
015	62	5	5	133	1512	11.6	$S_1 T_5$
115	39	3	4	111	1008	12.2	$N_1 S_1 T_5$
215	24	8	5	49	3024	0.7	$N_2 S_1 T_5$

Coefficients

	0	1	2	
0	1	1	1	3
1	-1	0	+1	2
2	+1	-2	+1	6
	1	-1	3	

	0	1	
0	+1	+1	2
1	-1	+1	2
	0	2	

	0	1	2	3	4	5	
0	1	1	1	1	1	1	6
1	-5	-3	-1	1	+3	+5	70
2	+5	-1	-4	-4	-1	+5	84
3	-5	+7	+4	-4	-7	+5	180
4	+1	-3	+2	+2	-3	+1	28
5	-1	+5	-10	+10	-5	+1	252
	-4	6	-8	6	-12	18	

Table 1. Calculations for the statistical analysis of the study of hardness in the Musquodoboit River and Flip Brook, Nova Scotia.

Significant Effects	0.05 F Calculated	Coefficients
Linear effect of position	433.5	-4.25
Quadratic effect of position	6.7	0.306
Main effect of stream	1122.2	
Linear effect of time	290.0	0.831
Quadratic effect of time	17.9	0.188
Linear position - stream interaction	1176.0	
Linear position - linear time interaction	80.3	
Quadratic position - quadratic time interaction	27.6	
Stream - linear time interaction	61.7	
Stream - quadratic time interaction	21.8	
Stream - cubic time interaction	11.0	
Stream - quartic time interaction	7.2	
Stream - fifth order in time interaction	11.6	
Linear position - stream - time interaction	45.7	

Table 2. Significant effects of the study of hardness in the Musquodoboit River and Flip Brook, Nova Scotia (0.05 level of significance.)

DISCUSSION OF RESULTS

Introduction

It is apparent from figure 1 that there is a significant difference in the absolute value of the hardness of these streams and in the magnitude of the changes in them over time. The mean hardness is lower in the river and the fluctuations over time are small relative to those in the brook.

Effect of Stream Size

Figure 1 illustrates the variation between streams which is supported by the significant value for the main effects of this factor. The total hardness is higher and there is a greater difference between the upper, middle and lower segments in the values for the brook than for the river. The rate of increase and the maximum value of hardness are also higher in the brook. The overall higher value for hardness may be due to the fact that the brook is underlain entirely by carbonates while these rocks occur only along 50% of the length of the river. Ground-water, rich in carbonates, would be contributed over a relatively greater proportion of the reach of the brook. A second possibility is that the ratio of groundwater flow to surface runoff may be greater in the brook than the river and the carbonate-rich subsurface flow is the determining factor.

Effect of Position along Stream

The hardness decreases with distance upstream from the river mouth when time is held constant. This is shown by the negative value for the linear coefficient; the positive value for the quadratic coefficient suggests, however, that the decrease begins to level off in the upstream area. An explanation for this phenomenon is not readily apparent. The increase downstream may be due to a closer proximity of bedrock in the downstream area as a result of erosion of Pleistocene drift. The thick drift sequences in

HARDNESS AS A FUNCTION OF TIME

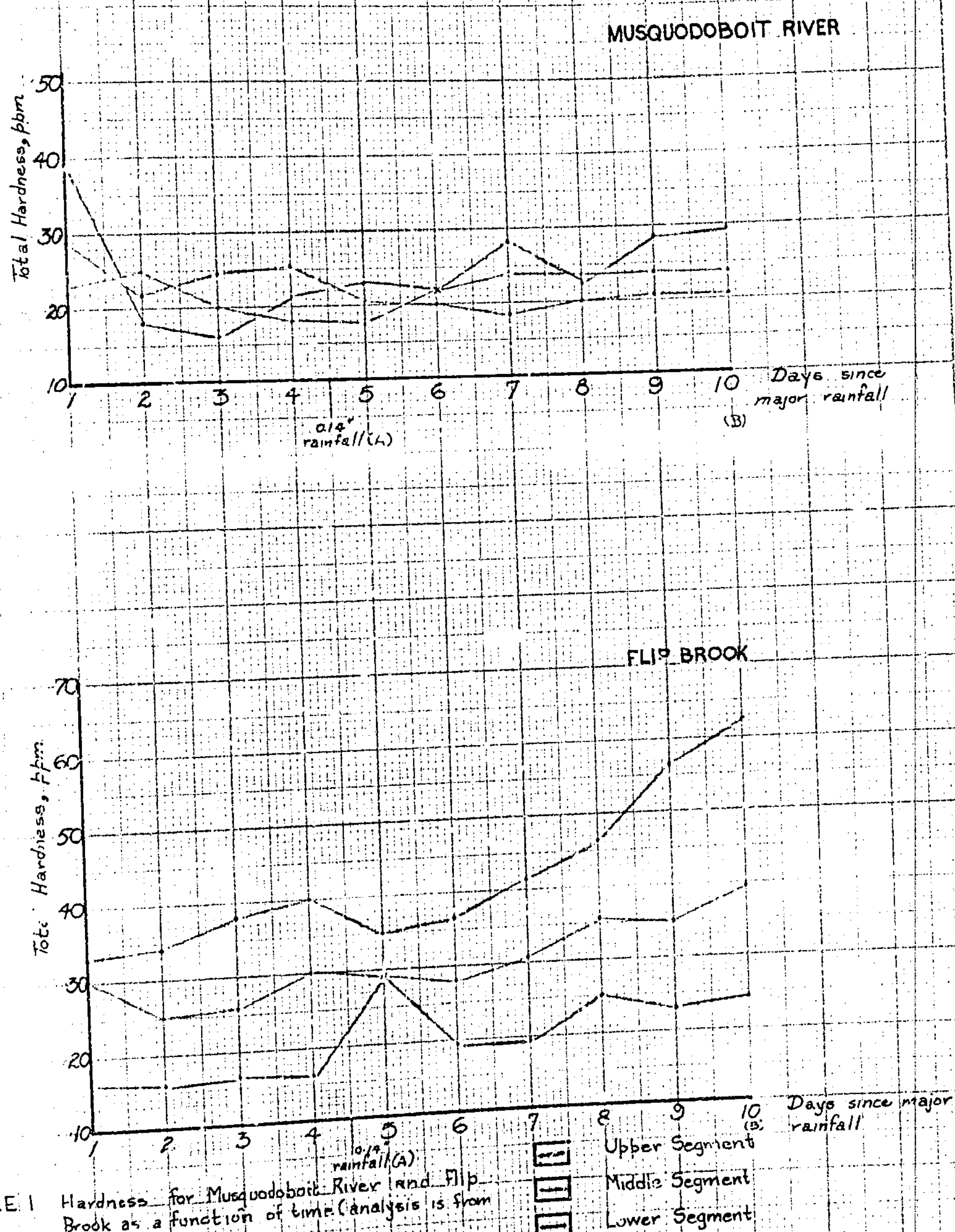

FIGURE 1 Hardness for Musquodoboit River and Flip Brook as a function of time (analysis is from points A to B).

the brook area and headwaters of the river support this hypothesis. This explanation would necessitate local flow systems carrying groundwater through the drift with negligible interaction with the regional flow system penetrating the limestone bedrock aquifer.

The thick drift sequences in the brook watershed and headwaters of the river support this hypothesis. The abundance of seepage faces in till in the brook area also suggest lateral movement through the Pleistocene.

Effect of Time Period Since Last Rainfall

The pronounced linear effect of time is easily seen in figure 1. The positive linear and quadratic coefficients indicate that the hardness increases at an increasing rate as the period of time from the last storm increases. This phenomenon is particularly apparent in the brook and also appears in the river when the sampling period is extended (this is poorly indicated in this experiment but is supported by recent data not developed here). The increased hardness is probably due to the influence of groundwater runoff which is likely predominant towards the end of the sampling period. The precise relationship between chemistry and the groundwater component of runoff requires hydrographs which were not available for this study. The initial high values in the upstream areas immediately after the storm would suggest a sudden discharge of highly mineralized groundwater due to the increased hydraulic gradient. Surface runoff may also have contributed to this increase through the solution of decomposed organic material.

Interactions

Table 2 lists the various significant interactions of the factors in this experiment . It shows that the effect of position in the stream is dependent upon time and the stream sampled; it also indicates that the effect of stream size is strongly dependent upon the point in time at which the comparison is made and that there is a complex dependence of the three factors, position, stream size and time. The significant interactions justify, in themselves, the use of factorial arrangements of treatments since in other methods of analysis this information is irretrievable.

CONCLUSIONS

1) The hardness of the streams sampled decreased at a decreasing rate from the mouth towards the headwaters;

2) the hardness in Flip brook was significantly higher than in the Musquodoboit River;

3) the hardness in the streams increased at an increasing rate with an increase in the period of time since the last rainfall;

4) the phenomenon of stream chemistry, as indicated by hardness, can be studied as a process dependent upon groundwater runoff and should be a useful tool in studying groundwater discharge.