A STUDY OF THE SPRINGS IN THE UPPER SULPHUR CREEK BASIN

by

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ABSTRACT

Sulphur Creek, which occupies a basin to the north and west of Ancaster, Ontario, is fed by approximately 100 springs. This is the first detailed investigation of these springs. The results of this study are presented and a number of interesting conclusions have been drawn from them. Several directions for further research are also indicated.

Physical analysis of the springs has revealed that they are on a planar, lacustrine blue clay aquiclude, which was formed as a result of meltwater ponding against an ice lobe, during the late Wisconsin glaciation. The meltwater lake covered most of the Sulphur Creek Basin, as indicated by the fact that blue clay was found all along the Creek's course. However, further research is required to determine the exact extent of this proglacial lake.

A preliminary study of six springs was also undertaken in hope of determining the residence time of the groundwaters feeding the springs. It was found that there are significant short term trends in spring temperature, solute abundancies and ^{18}O composition with season, suggesting that the residence times are surprisingly short. Also, the trends in the above variables suggest that groundwater residence time tends to vary from spring to spring. However, there are contradictions in trend when different variables are compared, which again suggests that further research is warranted.

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CHAPTER 1

INTRODUCTION

1.1 Objectives of the Study

This study was undertaken to investigate the nature and occurrence of springs in the Upper Sulphur Creek Basin. The first objective was to map the location of the springs, and to classify them according to size. A physical analysis of the springs was carried out to determine the reasons for their occurrence. This included determining spring elevations, studying the aquifer soils that their source waters flow through, finding their relationship to the local history of glacial deposits, and finding the relationships between the springs and the rest of the basin. Next, detailed studies of sample springs were undertaken to establish their dynamics. Finally, a summary and recommendations for further study are also presented. Field work was carried out from June 1981 through to the end of January 1982.

1.2 Physical Characteristics of the Study Area

1.2.1 Location

The location of Sulphur Creek Basin is depicted in Figure 1.1. The Creek has as its source a line of springs extending for 4.5 km along the edge of the escarpment, west of Ancaster. It flows northeast from the springline until it eventually merges with Ancaster Creek and then Spencer Creek. From there it drains into Lake Ontario via Cootes Paradise and Hamilton Harbour.

Sulphur Creek Basin occupies 14 km^2 of the Upper Dundas Valley. It is bounded in the west and south by a very flat lying drainage divide which separates it from southwest-flowing tributaries of the Grand River. The headwater thalwegs of the Grand often lack erosional channels in this area and appear to have running water only during the spring thaws. This seems to indicate that flow from this area is to Sulphur Creek via sub-surface drainage. However, when the soil is frozen, any snowmelt or rain is conveyed to the Grand by relief-induced surface drainage. The divide could therefore be seasonal, and the catchment area of these springs may be considerably larger (+1.0 km^2) than relief indicates. Located to the north is Spencer Creek and its tributaries, and in the east is the drainage basin of Ancaster Creek. Relief is more pronounced to the north and east, and these divides are quite well defined.

The actual study area is shown in Figure 1.2. It covers approximately 4 km^2 of the upper basin and incorporated close to 100 springs and seeps. The springs that were studied in detail are specifically indicated on the map.

1.2.2 Local Climate

This part of Ontario enjoys a humid continental-type climate. The watershed averages 100 to 125 days of precipitation per year, with mean annual precipitation of

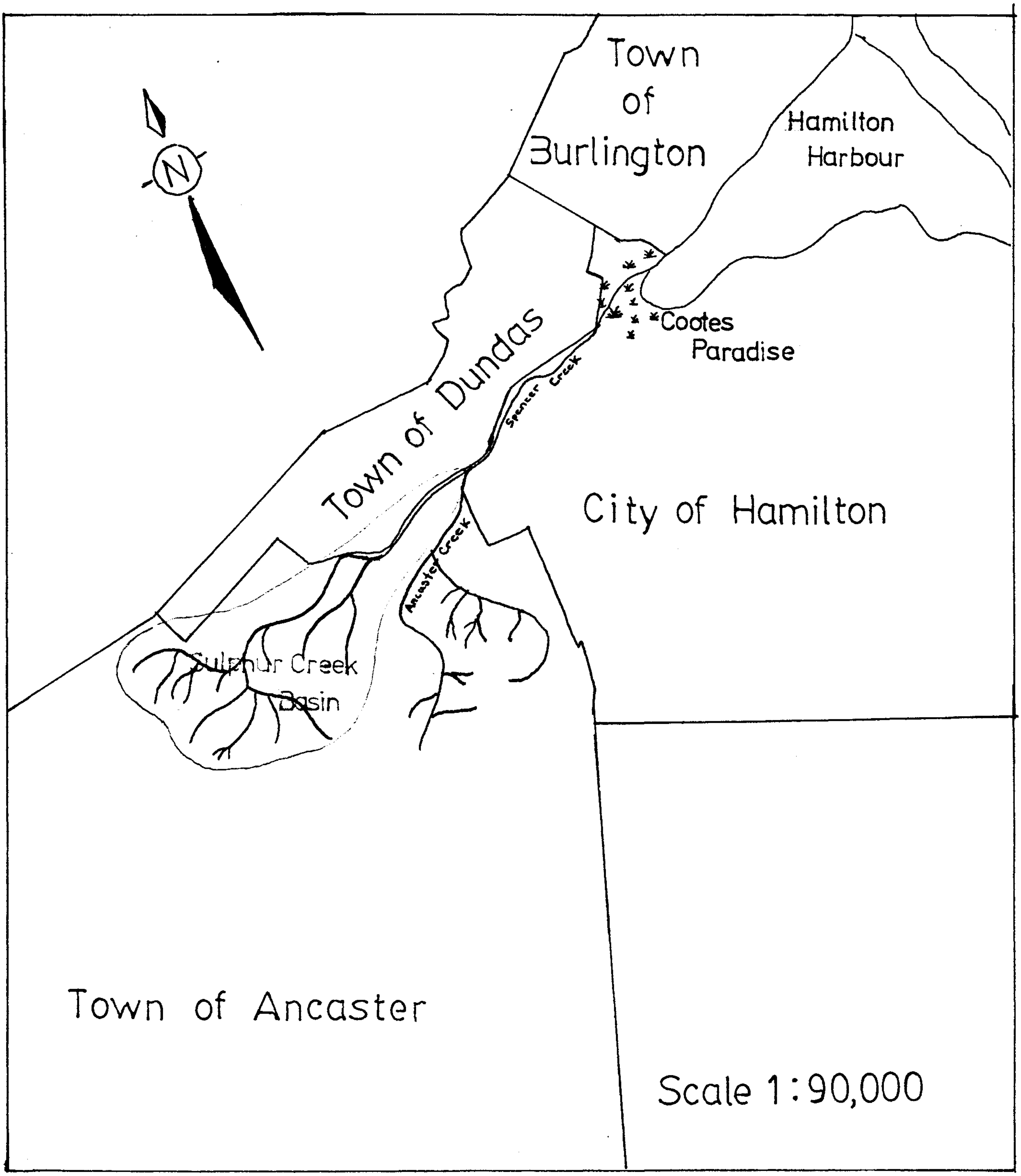
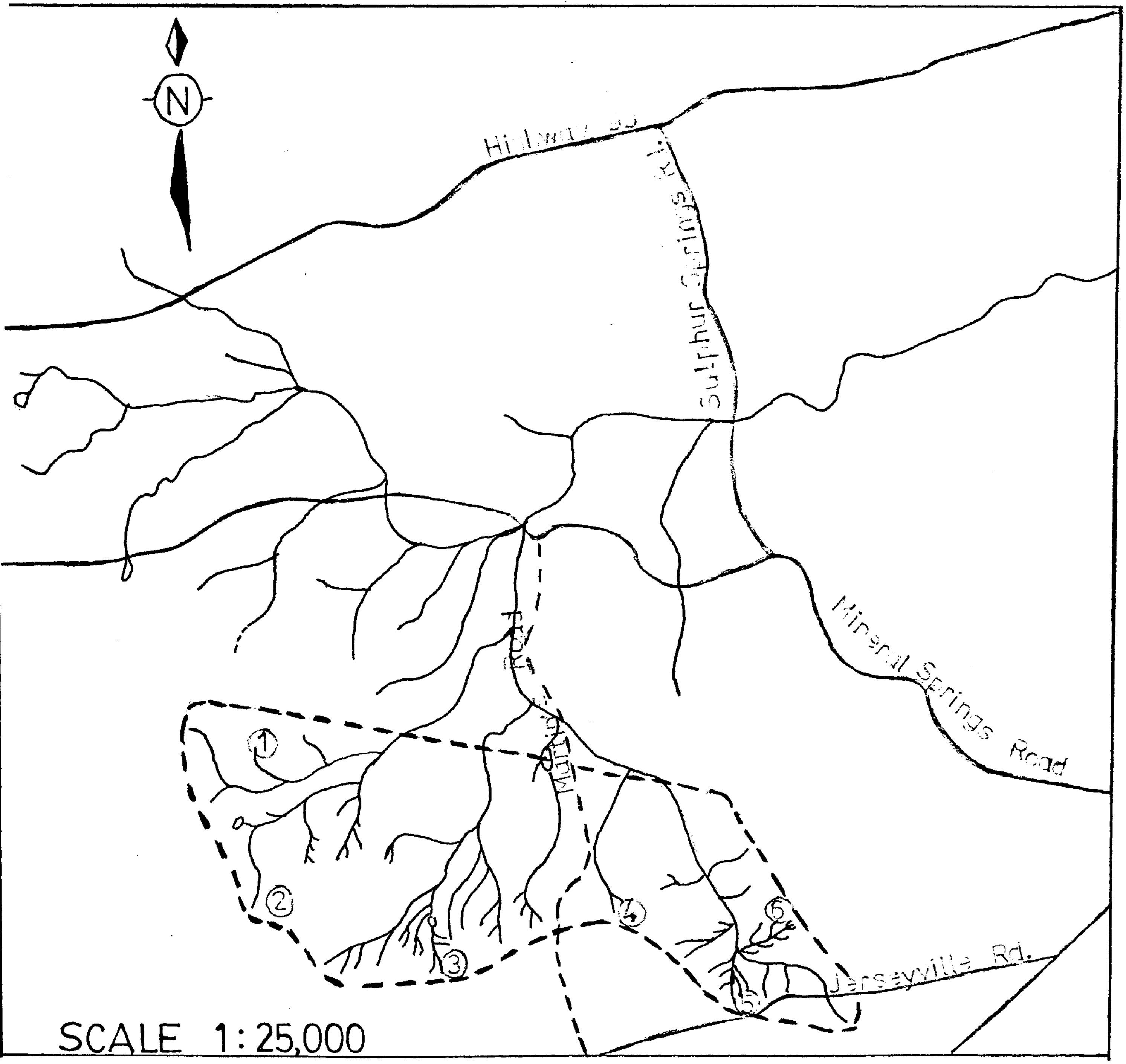


FIGURE 1.1 Location of Sulphur Creek Basin



①-⑥ Springs studied in Detail

FIGURE 1.2 The Study Area

855 mm. Mean annual temperature for the area is about 10°C. This encompasses a range from July mean temperature of 21°C to the January mean of -6°C. Winter temperatures are cold enough to ensure that 150 to 200 mm of annual precipitation (water equivalent) comes as snow. Winter freeze-up occurs around mid-December when average temperatures fall below the 0°C mark. Spring snowmelt occurs in mid to late March.

Despite the low winter temperatures and the abundance of snow in the area, which results in ground freeze-up, the springs continue to flow throughout the winter. There are, however, annual icings where swamps and channels draining the springs flow to the main creek. In saturated areas, where channels draining springs are obstructed by roadwork or in flat swampy spots below springs, ice may extend in wide patches for more than 100 m downstream of the springs.

1.2.3 Bedrock Geology

The Sulphur Creek Basin is underlain by Paleozoic sedimentary rocks which dip very slightly to the south-west. The upper part of the basin, which includes most of the springs studied, is underlain by the Guelph Formation. It is of Silurian Age and is a porous, coarse textured, brown dolomite. This formation overlies the more resistant Lockport Formation, which outcrops just northeast of the study area. The Lockport is characterized by fine to medium grained dolomites with abundant chert nodules. Underlying the Lockport (further downstream) are older Silurian and Ordovician systems, consisting mainly of sandstone and shales.

1.2.4 Physiography

The southern Ontario region has been glaciated at least four times during the Pleistocene Period of the last 2 million years. One result of the glaciations has been the development of the Dundas Valley re-entrant, in which Sulphur Creek Basin is located. Due to weaknesses in the strata of the escarpment, on the west shore of Lake Ontario, glaciers were able to remove large portions of the Lockport dolomites. As a result, the escarpment was eroded 30-40 km back and a re-entrant valley was formed. This valley is a prominent indentation into the escarpment aligned in a northeast-southwest direction. Sulphur Creek Basin occupies a smaller, north-south trending offshoot valley near the southwest end of the Dundas Valley re-entrant.

Tills deposited during the last period of continental glaciation, 10,000 to 30,000 years ago, now cover the re-entrant valley. This period, known as the Wisconsin, has left hundreds of stratigraphic feet of till and outwash deposited in places and has obliterated any evidence of the three previous glaciations in the area. The till almost completely covers the bedrock escarpment and also forms a topography of rolling hills throughout the Sulphur Creek Basin, the largest hills being closest to the escarpment. Sulphur Creek cuts deeply through the till and has exposed the dolomite bedrock in places. Striations showing a southwest direction of glacial movement were seen on one of the outcrops.

The Wisconsin glaciation ended approximately 12,000 years BP, after many retreats and readvances. This marked the beginning of the post-glacial Holocene period. This period began with a phase of rapid dissection of the glacial deposits, possibly until trunk channels came to rest on bedrock or close to it. This created a rugged ravine topography. Since then, channel extension, vegetation and soil development predominated until the 19th century when the area was settled and deforested.

1.2.5 Soils

There are two soil series in the study area, the Ancaster and the Springvale series. The Springvale series is located at the head of the Sulphur Creek Basin, and includes well drained soils with 30 to 40 cm of sand overlying coarse outwash gravels. The springs do not emerge from this soil series, but are affected by it nevertheless. In the northern portion of the study area gravel pits have been made in the Springvale soil. Gravel has since slumped down the escarpment edge into the Sulphur Creek Basin and has disrupted the drainage system in the area considerably.

The springs actually emerge from the Ancaster soil series, which covers the remainder of the basin. This series consists predominantly of well-drained silty clay loam materials, but layers and inclusions of sand, gravel and clay loam are also common. This is expected, as the parent material from which the series was derived was a glacial till. This glacial till was very calcareous and had a high base content. The soils that have developed, however, have become acidic because of the loss of calcium and other bases by the leaching action of downward percolating groundwater.

1.2.6 Vegetation and Land Use

As mentioned, the study area topographically consists of hills composed mainly of glacial till and/or outwash. Since agricultural or urban development is almost impossible on the steep slopes, they are mostly covered by natural, second-growth vegetation. Soil and climatic conditions favour mixed deciduous and hardwood trees in the area. In the low-lying areas near the springs, where drainage is not well organized as yet, expanses of swamp vegetation flourish. Most of the study area, which is owned by the Conservation Authority, is now left in this natural state.

Above the escarpment, land use is predominantly agricultural, as there are many farms. The Springvale sand loam soils of the area are extensively used for potato production and growing corn, grains, winter wheats and forage. Agricultural production is limited along the edge of the escarpment, however, because of the many steep slopes and their accompanying problems of erosion and management.

To the east of this agricultural land are the Ancaster residential areas. This urban developnent has clearly interfered with the Sulphur Creek drainage pattern. Jerseyville Road, built in the early 1950's, has disrupted the southern most portion of the headwaters. The drainage has also been disrupted to the west due to the presence of a large gravel pit, as discussed earlier.

The Conservation Authority also owns much of the basin area downstream from the springs and therefore most of this area is also in its natural state. There is the occasional fruit orchard as well, because the well-drained silt loam soils of the Ancaster series are easily worked and fertile. As the Creek approaches Dundas, large urban developments begin to encroach upon the remainder of the basin area.

1.2.7 Relief and Drainage

The major relief in the area is provided by the Niagara escarpment and the rolling hills of glacial till. Sulphur Creek has its source springs very near the top of the escarpment at an elevation of over 200 m. Drainage in this area is variably organized. The water of the springs and seeps quickly collects to form about 70 First Order channels, which eventually join to form four major Third Order tributaries. The study area encompasses the three eastern Third Order streams and their associated springs (see Figure 1.1). The main channel of Sulphur Creek is a Fourth Order tributary when it enters Ancaster Creek at an altitude of about 90 m. At this point the Creek is 5-6 m wide and approximately 1 m deep.

The gradient of the Creek is relatively low, indicating a river that is fairly mature or one that is perched on bedrock. In many places the Creek displays large and mauture meanders. The mean channel gradient (represented as the ratio of vertical drop to horizontal distance), decreases inversely with increasing stream order, as Horton's Law predicts. The Fourth and Third Order streams have mean channel slopes of .012 and .015, respectively. The Second and First Order streams, which flow down the escarpment slopes, have steeper gradients, approximately .042 and .061, respectively.

CHAPTER 2

PHYSICAL ANALYSIS OF THE SPRINGS

2.1 Introduction

In this section of the thesis, the physical aspects of the springs feeding Sulphur Creek will be discussed.

2.1.1 The Nature of Springs

A spring is defined as a natural flow of groundwater on to the earth's surface. Springs will occur wherever the groundwater table intersects the surface. The groundwater table, or simply the water table, represents the upper boundary of the phreatic zone, an underground zone in which the soil or bedrock is completely saturated. Geological observation has shown that the water table usually follows the surface topography, only in a more subdued form.

Most groundwaters near the surface are in motion. They are collected in, and flow through, relatively porous and permeable layers called aquifers. Water flow through aquifers is mainly gravity controlled, with springs usually representing a low point in the local subsurface drainage system. The source area providing the underground water which flows to a spring, is known as the catchment area.

Groundwater flow is complicated by aquicludes, which are relatively impermeable, geologic units. Water flowing downwards through an aquifer will tend to follow along the surface of, rather than through, any aquicludes encountered. In this case, springs occur where the top of the aquiclude intersects or is near the surface.

2.1.2 Springs of the Sulphur Creek Basin

There are many springs in the Sulphur Creek Basin. These are usually found in small, bowl-shaped indentations at or near the base of the basin head hill slopes in the basin. The area around any given spring was usually saturated, and marked by well developed swamp vegetation.

Most of these springs are permanent, and their combined output during dry periods constitutes the baseflow of Sulphur Creek. Due to the great density of springs in the upper basin, it was surmised from the beginning that the water table must be perched on a near-surface aquiclude.

2.2 Elevations of the Springs

The elevations of the springs were obtained by levelling and by altimeter. Their distribution and elevation is shown in Figure 2.1. As can be seen, the elevations of the springs range from 213 to 227 m above sea level, with the single exception the most southerly spring, located south of Jerseyville Road, at 245 m. Disregarding this case, which is conspicuously isolated, it is evident that the remainder of the springs emerge at similar elevations across the basin, with elevations decreasing uniformly as one moves downstream. This indicates that the aquiclude is a planar layer, which dips gently and uniformly to the northeast.

Figure 2.1.1 is an overlay contour map showing the spring height distribution.

2.3 The Blue Clay Aquiclude

Field research has revealed that the impermeable layer underlying the springs is a well-sorted dense blue-grey clay. This was encountered .25 to .5 m below all the springs with the exception of the one south of Jerseyville Road. Overlying this blue clay one could often find a reddish-brown clay, which appeared to simply be oxidized blue clay. At the "contact" between the layers, the clay is mottled red-brown and blue-grey. This grades upward into the pure red-brown clay and downward into the pure blue-grey clay, respectively.

Not only does this blue clay underlie the springs, but it is also exposed in many places along the Creek (Figure 2.2). Exposures of blue clay occur in many areas where the Creek has undercut the banks. Groundwater could be seen flowing atop these blue clay sections, indicating that this blue clay layer is indeed the impermeable layer, or aquiclude, on which the water table is perched.

Piping and piping sinkholes are also seen in the basin. These occur where flood plain alluvium and slope flank alluvium lies directly on blue clay at the Creek channel edges (see Figure 2.2).

Figure 2.3 shows pictures of one of the sections of blue clay which has been undercut by the Creek. It is evident that this one meter section of clay has been deposited

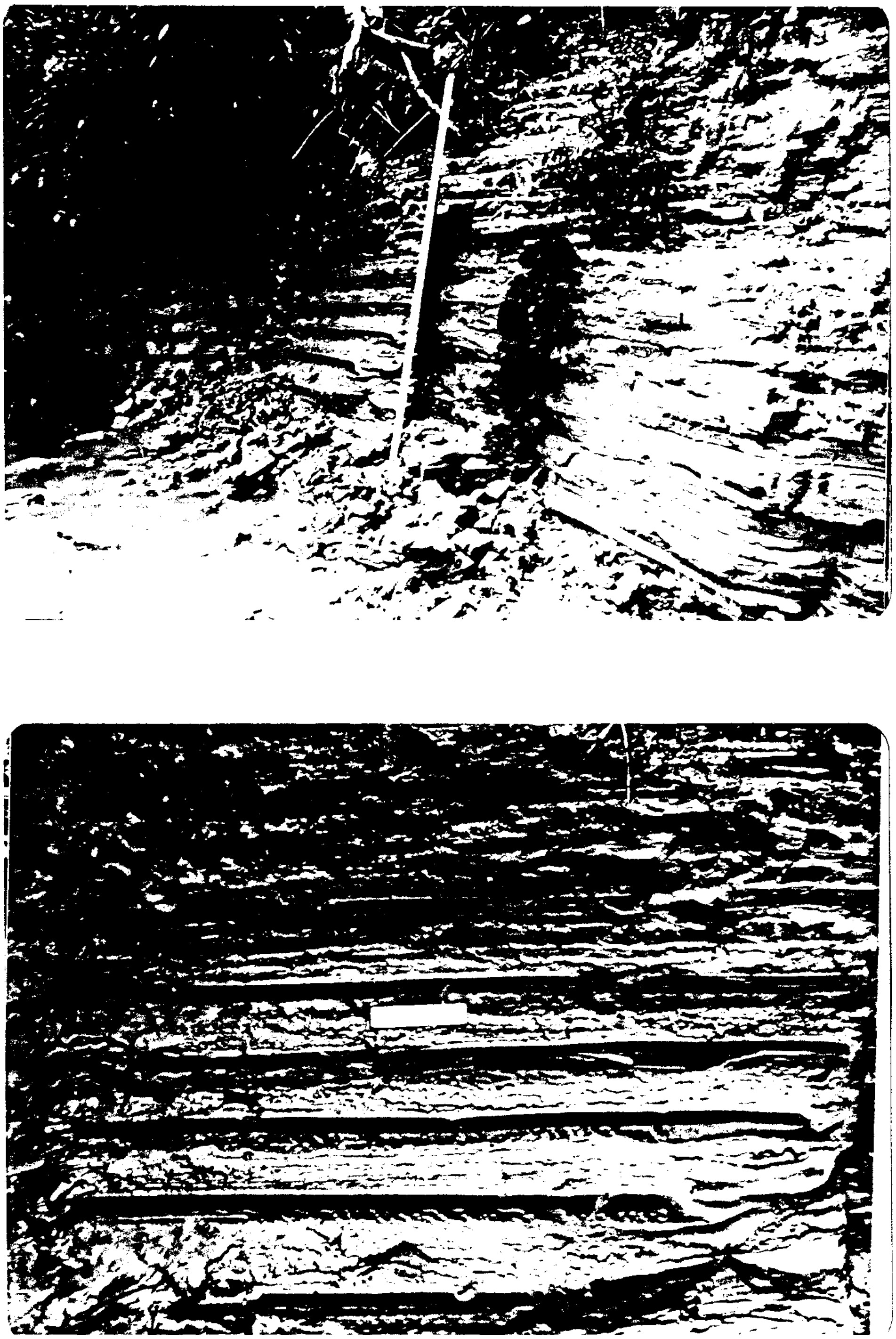


FIGURE 2.3 Exposure Showing "Varved Clay"

in distinct layers. These layers appear as alternating light bands, 8-10 cm thick and finer layers 2-4 cm thick.

Depositional sequences of this kind in clays are well known and well documented, and are called "varved clays". These are generally associated with lakes in cold environments. The coarser clay layers are deposited in the summer when the lake surface and rivers feeding it are active. The finer clays then settle out in the winter when the lake is ice covered and waters are calm.

Based upon these findings, together with the elevation data, conclusions can be drawn concerning the origin of this clay. The uniformity of particle size and the presence of varved clays are diagnostic of a lacustrine environment. However, Hurst (1962) and others working in the Hamilton area have suggested that these clays represent glacial basal till deposits.

At this point, consideration of the spring blue clay elevation data should dispel any uncertainties. A basal clay till resulting from glacial movement across an area can be expected to form an irregular surface. It is very improbable that a basal till would be deposited in a layer that is planar, and uniform in grainsize across so large an area. Its proven planar extent to strike in Figure 2.1 is 3.4 km. Also, the association of varved clays with basal till is impossible.

Therefore, it must be concluded that the blue clay which makes up the aquiclude is lacustrine in origin. A lake must have been formed as a result of meltwater ponding against an ice lobe which occupied the Lake Ontario basin during the Wisconsin glacial retreat.

2.3.1 Extent of the Proglacial Lake

The extent of the proglacial lake, in which the blue clay aquiclude was deposited is not exactly known. However, since blue clay was found all along Sulphur Creek, it seems that practically all the basin was at one time covered by water (see Figure 2.2 for the locations where blue clay was found). The lake must have extended to near the drainage divide between Sulphur Creek Basin and the Grand River Basin, since all the springs studied were underlain by blue clay. It is questionable whether the lake extended as far south as the spring located near Jerseyville Road, because blue clay was not found within a meter of the surface at this spring. The blue clay may simply be deeper beneath the spring, or may not even be present here at all. If the latter is the case then this spring may be perched on the impermeable Lockport dolomite, rather than on the blue clay layer. This would explain its unique elevation. However, studies of borings done in the Ancaster region have indicated the presence of a layer described as "brown-grey clayey silt" 5 to 15 m below the surface. If this is the same layer, then the proglacial lake may have extended to the south of Jerseyville Road, covering the area that is now Ancaster. Evidence of this is, however, indefinite since the boring data available is neither consistent nor detailed enough to draw any conclusions.

To adequately define the boundaries of this lake to the south and west, better boring data will be required. However, in his thesis, Hurst defined the position of a proglacial lake shoreline which fits our observed data and which lies just within the present Grand River-Sulphur Creek drainage divide, and also to the south of Ancaster. (See Figure 2.2.) This very likely marks the extent of the lake in this direction, although further research should be done before reaching any definite conclusions.

Borings of the area surrounding Sulphur Creek Basin were also studied, in hopes of determining the north and east extent of the proglacial lake. As mentioned, blue clay was seen along the Creek, indicating that the proglacial lake must have extended almost to the Sulphur-Ancaster Creek confluence. Drill hole borings past this point, show the presence of a layer described as "very stiff grey silty clay". The locations of the boring holes and the elevations at which the "stiff grey silty clay" were encountered are included on Figure 2.2. The elevations of this clay vary considerably and it is quite possibly a basal till. However, more extensive research is required to determine the nature and origin of this clay. At present, based on the evidence available, we can not justify assuming that the proglacial lake, which formed the blue clay aquiclude, extended past the mouth of Sulphur Creek. Further and more detailed research will be required to define more clearly the north and east boundaries of the proglacial lake.

2.4 Water Flow Through the Aquifer

Overlying the blue clay aquiclude is the Ancaster soil series--a silty clay loam soil. This permeable soil represents the aquifer through which groundwater feeds the springs. The average thickness of this layer is approximately 15 m, encompassing a range from close to 30 m from the tops of the hills to the blue clay aquiclude, to less than a meter on the flat grounds where the springs emerge.

The downwards movement of soil water, first through the unsaturated vadose zone above the water table, and then through the saturated phreatic zone to the springs occurs as follows. Water flow in the vadose zone is entirely gravity controlled and hence essentially downward. Flow in the phreatic zone is of a different nature; each unit volume of water contains a certain amount of potential energy, called its "head", which is dependent upon its relative elevation and pressure. Surfaces along which unit volumes of water have an equal head are called equipotential surfaces and exist in the phreatic zone. Groundwater flow in this zone is along flowlines which are perpendicular to the equipotential surfaces. What this means is that in the phreatic zone, groundwater flow is from the tops of hills (areas of high potential) to the bottoms of the valleys (areas of low potential). In the Sulphur Creek Basin, this flow pattern is interrupted by the blue clay aquiclude. Groundwater moving along the flow lines is forced to flow along the surface of the blue clay. Where the clay layer intersects the surface the flow emerges as springs.

Of interest is the fact that subsurface flow in the aquifer near the springs was shown to be distinctly channelized.

This was evident by the fact that one pit dug alongside a spring would remain virtually dry, while another only a meter away would fill up with water in a matter of seconds. This suggests that there is a local piping system in the subsurface behind each spring and that a distributary system at the mouth of the pipes has developed. This means that the location of the springs is relatively permanent, since seasonal or storm induced springs would not have the time required to organize flow into a distributing system of discrete channels.

The permanent nature of the springs was confirmed by direct observation. Flow continued through the driest parts of the summer and the coldest days of the winter. This is further proof of the fact that these springs are perched on the blue clay.

A few springs caused by seasonal or storm-induced wet periods were also noted in the basin. In these, low lying areas are saturated by a rising water table and spring flow occurs. Later, when the water table falls, the springs dry up. The permanent springs of the Sulphur Creek Basin only change position slightly with changing water table and do not dry up. They are obviously not very dependent upon any seasonal variations of water table height. As long as a shallow zone above the aquiclude exists, these springs will continue to flow.

2.5 Size and Distribution of the Springs

The classification of springs sizes was based on their types of flow regime and upon the size and organization of their drainage channels. Precise discharge measurements were not attempted as the spring flows were low (less than 1 litre/second) and proper repeated monitoring of such flows was beyond the scope of this thesis. The springs classified as small were those which had no discernible surface flow. Water movement occurred as seepage through a saturated surface layer and no real drainage channels had developed. Flow through these springs is also intermittent. The intermediate-small springs were marked by isolated pools, with sluggish film flow along poorly defined channels. These waters became organized into a small channel, 5-10 cm in width, about 5 m downstream from the spring. Springs which became organized into larger channels, 10-20 cm in width, that emerged from bowl-shaped saturated ground areas, were classified as being large-intermediate sized springs. The large springs, though still located in bowl shaped indentations of saturated ground, issued from clearly defined points. Flow from these points was of sufficient volume that it was immediately organized into deep surface channels, of greater than 30 cm in width.

The classification by size of the springs is shown in Figure 2.1. The largest springs, those which emit the most water, tend to be located at valley heads bordering the escarpment. They are therefore also located at the highest elevations, with smaller springs generally being located further downslope. This type of distribution occurs because the escarpment is marked by a series of outwards extending ridges or spurs and incutting valleys. This can be seen on Figure 2.1.1, which shows the topography in the spring area.

In this sort of situation equipotential lines tend to be concentric around valley heads, with almost zero potential at the outermost extent of spurs and ridges. As a result, water flow through the aquifer is focused at the valley heads. Hence, the largest springs are found here, with springs generally decreasing in size downslope as flow potential decreases. Springs will also generally decrease in size with decreasing catchment area or depth of the aquifer. The largest springs are claculated to have average catchment volumes of 1.4 x 10^6 m^3, while the smallest springs have catchment volumes of only 5.0 x 10^4 m^3. Since aquifer depth decreases downstream from the escarpment due to a decrease in hill size, the catchment volume for the springs also tends to decrease downstream and hence with elevation. This, however, is just a general trend. Small springs can be seen at valley heads and at high elevations, and likewise large springs are occasionally seen at lower elevations. This is because springs at lower elevations have captured large catchment volumes, while springs at higher elevations have small catchment volumes because they are close to the drainage divide.

There are so many springs in the area because there are so many valleys, each of which concentrates aquifer throughflow. This results in numerous small, rather than a few large catchment volumes and hence springs.

2.6 Genetic Relationship Between the Springs and the Surrounding Area

The Wisconsin glaciation was, as mentioned earlier, very dynamic in the southern Ontario region. The study area was scoured by repeated advances of the ice sheet, which removed all surficial deposits resulting from any previous glaciations. During the final ice retreat, a proglacial lake formed locally as a result of meltwater ponding against an ice lobe which occupied the Lake Ontario basin. It was at this time that the varved clay aquiclude, which underlies the study area, was formed. A count of the layers showed 10 distinct sets, indicating the lake was present for at least 10 years. This lake subsequently receded, and the area was covered by thick till or outwash deposits. As a result, the clays grade into a coarsening upwards sequence; silts and clays at the base followed by small boulders and cobbles, in a sandy matrix, above. As the outwash flow receded, a final complex layer of outwash gravel and sand lenses was left behind.

In the following post-glacial period, rapid dissection of the glacial deposits occurred by meltwater streams creating a rugged rolling topography of hills. Sulphur Creek cuts right through the deposits, finally coming to rest at or near the underlying bedrock. Springs result wherever the glacial deposits (aquifer) had been eroded sufficiently to expose the underlying lacustrine clay layer. Vegetation, when it returned to the basin, stabilized it, with only minimal erosion occurring since then. Thus, the valley and glacial deposits precede the springs, which formed only when dissection of the deposits had exposed the underlying aquiclude.

However, since their formation, springs themselves have eroded into the hill slopes behind them, further shaping the basin. As a result the springs now occupy bowl-shaped depressions, with considerably steepened slopes where they cut into the hills. If one assumes that hill slopes were originally rectiplanar at their bases, then the distance the springs have eroded back can be calculated. Taking the original hillslope at the point where spring erosion induced steepening occurs and extending the original slope using a theodolite, the approximate position of the hill where it intersected the valley floor can be found. The distance from there to the point where the hill now intersects the valley floor (at the spring head) represents the extent of spring sapping. Measurements were taken at 10 springs, and it was found that erosion of 2 to 13 meters had taken place, with a mean of 8 meters. It was not the size of the springs that governed the amount of spring sapping, but rather the stability of the hill behind the spring. Hills covered in dense vegetation due to their gentle slopes have not allowed much spring sapping to erode them.

Therefore, though the valley deposits preceded the springs, the springs today are shaping the valley.

CHAPTER 3

FEATURES OF THE CHEMICAL AND ISOTOPIC BEHAVIOUR OF THE SPRINGS

3.1 Introduction

A preliminary study was undertaken to determine whether there were significant variations in spring temperatures, solute abundancies and ^{18}O isotopic composition with season. Six springs across the area (shown on Figure 1.2) were chosen. Water temperatures were obtained with calibrated thermistors and a multi-meter, from October through to late January. Spring 4's temperatures were also taken in the summer months. The ^{18}O content of the six studied springs was also measured by a mass spectrometer on three separate collecting days. These variables were studied in hopes of determining the residence time of the groundwaters feeding the springs.

The waters of the six springs were also analyzed with respect to Mg^{2+} and Ca^{2+} content (both expressed as mg/l $CaCO_3$). Spring 4 was again studied during the summer months, when it was analyzed for pH, temperature, alkalinity (HCO_3^-) and Ca^{2+} and Mg^{2+}. The equilibrium partial pressure of CO_2 (P_{CO_2}) and the saturation state of the water with respect to calcite (SI_C) were then determined for this spring. Although this chemical analysis of the spring waters is limited. Further tentative conclusions concerning the dynamics of the springs may be drawn.

3.2 Temperatures

Temperatures at Spring 4 were recorded beginning June 15, 1981. Five further springs were added for comparison at the beginning of October, to observe the onset of winter conditions. Figure 3.1 shows a graph of the temperature of the six springs from October to January and Table 3.2 and Figure 3.2 show values and a graph of Spring 4 summer temperatures, respectively. The temperatures were measured by thermistors, which were placed about 10-15 cm in the ground, at the spring sites and are believed to record true ground temperatures at emergence, ie. before the water was warmed or cooled to surface ambient temperatures.

Spring waters tend to have consistently lower temperatures than air temperatures during the warmer months and higher temperatures during the colder months. This reflects the moderating influence of the aquifer soils through which groundwaters, feeding the springs, flow. If strong groundwater effects are neglected, then in this part of Ontario it can be assumed that ground temperatures will vary no more than ±1°C from the annual mean temperature of 10°C below a depth of approximately 10 m. Geothermal gradient effects will be scarcely noticeable at depths less than 100 m, which is much greater than the depth of the aquifer being considered here.

Spring water temperatures give an indication of the relative residence time of groundwaters. Waters which have

TABLE 3.1

WATER HARDNESS OF THE SPRINGS

Spring	Classification	Date	Total Hardness (ppm)	Ca^{2+}(ppm)	Mg^{2+}(ppm)	Ca/Mg
1	Intermediate Cooler	Oct 23/81	98	80	18	4.44
		Nov 6/81	116	82	34	2.41
		Nov 13/81	112	88	24	3.67
2	Fast-cooler	Oct 23/81	224	173	71	2.44
		Nov 6/81	240	162	78	2.08
		Nov 13/81	202	126	76	1.66
3	Intermediate Cooler	Oct 23/81	114	94	20	4.70
		Nov 6/81	100	64	36	1.78
		Nov 13/81	128	124	4	--
4	Fast-cooler	Oct 23/81	214	131	83	1.58
		Nov 6/81	218	126	92	1.37
		Nov 13/81	194	134	60	2.23
5	Intermediate Cooler	Oct 23/81	199	150	49	3.06
		Nov 6/81	258	192	66	2.91
		Nov 13/81	200	130	70	1.86
6	Slow-cooler	Oct 23/81	235	168	67	2.51
		Nov 6/81	188	120	68	1.76
		Nov 13/81	256	168	88	1.91

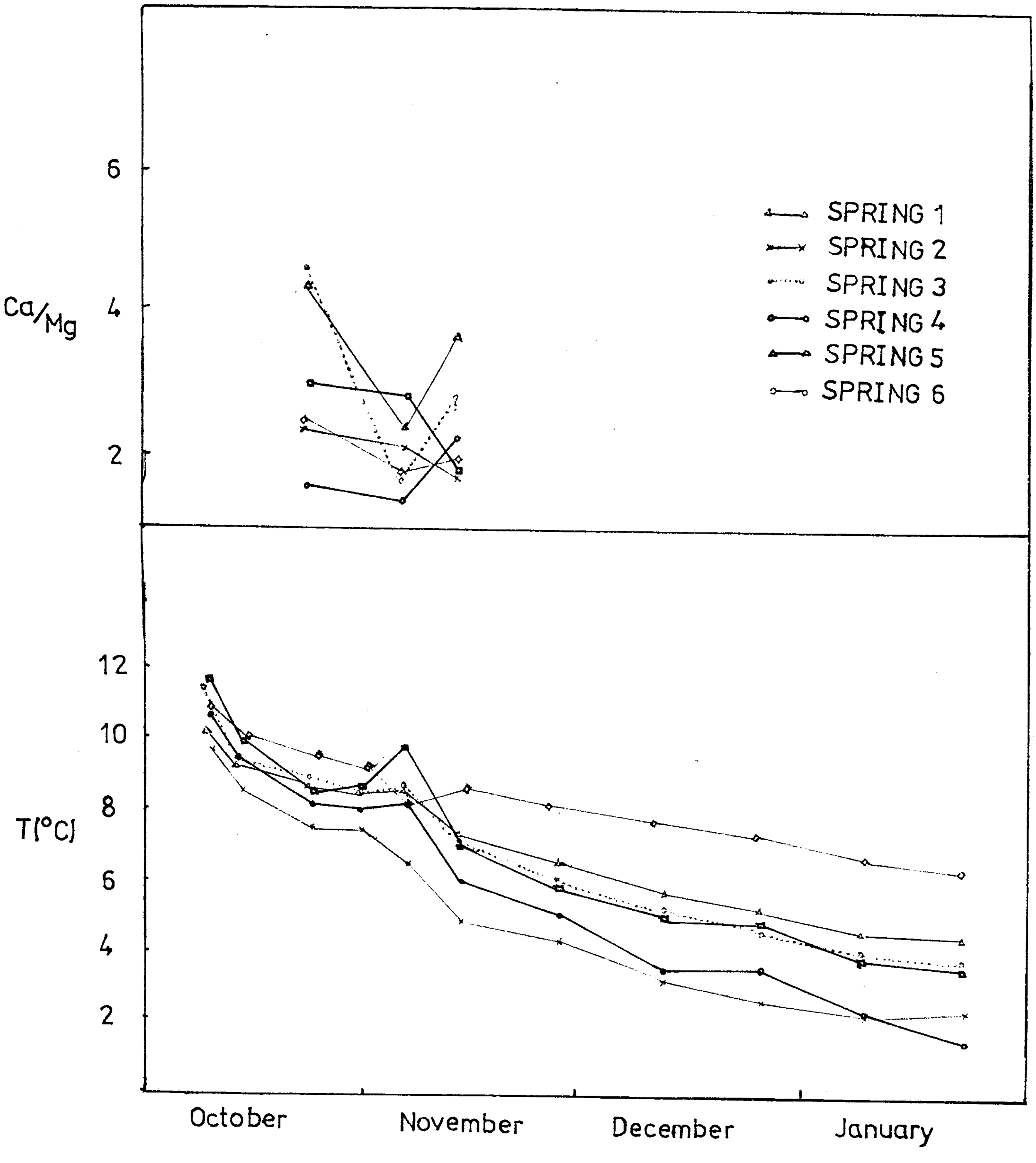


FIGURE 3.1 Variation in Ca/Mg Ratio and Temperature with Time

TABLE 3.2

SUMMARY OF SPRING 4 WATER ANALYSES

Date	pH	T(°C)	Total Hardness (ppm)	Ca^{2+}(ppm)	Mg^{2+}(ppm)	HCO_3^-(ppm)	Ca/Mg	SI_C	Log P_{CO_2}
June 15/81	8.1	14.0	35.84	20.0	15.84	261.08	1.26	-.141	-2.854
June 22/81	8.4	14.0	67.52	56.0	11.52	203.74	4.86	.481	-3.153
June 29/81	8.6	17.0	70.72	49.6	21.12	264.74	2.35	.745	-3.310
July 06/81	8.8	16.0	59.68	35.2	24.48	267.18	1.44	.799	-3.545
July 13/81	8.6	17.0	52.16	32.0	20.16	279.38	1.59	.584	-3.325
July 20/81	8.3	17.0	81.44	68.0	13.44	234.24	5.06	.224	-3.104
July 21/81	8.5	17.5	90.88	76.0	14.88	248.88	5.11	.761	-3.303
July 27/81	8.1	17.0	96.48	79.2	17.28	264.74	4.58	.536	-2.851
July 29/81	8.0	14.0	87.68	75.2	12.48	234.24	6.03	.359	-2.796
Aug 04/81	8.4	18.0	88.00	68.8	19.20	254.98	3.58	.663	-3.168
Aug 10/81	8.3	17.0	87.68	70.4	17.28	269.62	4.07	.595	-3.044
Oct 23/81	-	8.32	214	131	83	-	1.58	-	-
Nov 06/81	-	8.24	218	126	92	-	1.37	-	-
Nov 13/81	-	6.20	194	134	60	-	2.23	-	-

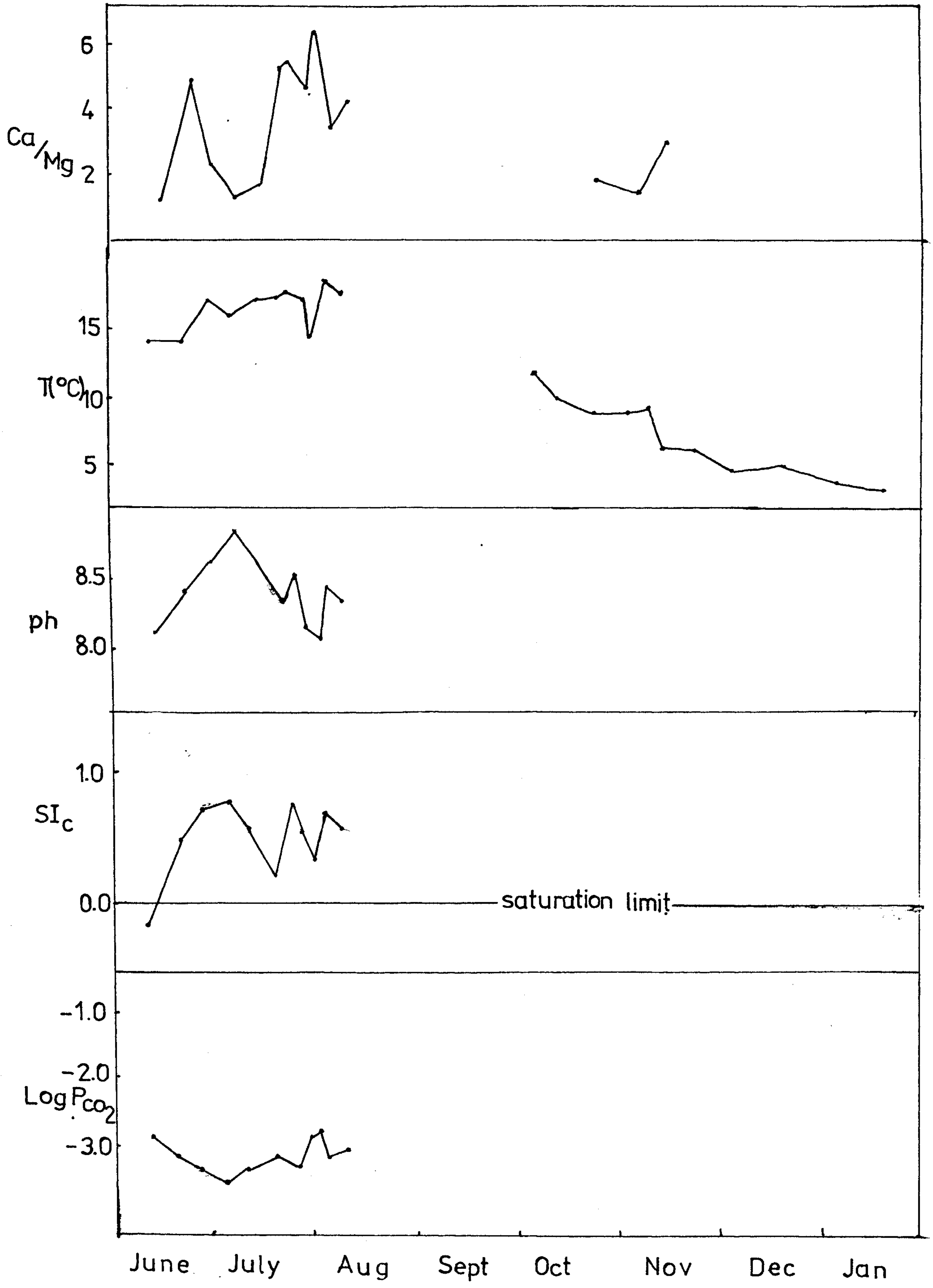


FIGURE 3.2 Water Chemistry of Spring 4

temperatures near the mean annual air temperatures and do not vary much, have long residence times. They have had time to become moderated by their surroundings. It is probably true to say that a majority of granular aquifer springs, where the aquifer is deeper than 10 m or so, are of this "invariant type".

The springs studied, however, show large variations in temperature with time. At Spring 4, temperatures of the spring water in the summer months range from 14°C to 18°C, but are clearly not stable. (See Table 3.2.) For instance, on July 27 spring water temperature was 17°C, while on July 29 water temperature dropped to 14°C. Since measurements on July 29 were taken directly following a rain event, a very fast flow through time at the peak of a storm is indicated. Also the water temperature on June 15 was 14° C, which suggests that the annual thaw waters have already been discharged. Therefore, water from rain or snowmelt recharges the aquifer and is quickly passed through to the spring with very little time to be modified by the surroundings. This, however, contrasts strongly with the baseflow recession behaviour, ie. springs of this type are expected to dry up as rain and snowmelt quickly diminishes. The fact that the springs don't dry up is due to the presence of the blue clay layer.

Temperature measurements of the six springs, not only decrease from October to January, but also fluctuate. A slight rise of 1.0 to 2.0°C was recorded in mid-October. This also indicates that the spring waters have a short residence time underground.

The October to late January records also vary from spring to spring, indicating that each has significantly different residence times. Figure 3.1 shows that the range of temperature opens up substantially over the observing period. At the start of the record on October 6, it is less than 2°C (from 9.75 to 11.50°C). By January 23 the range is about 2.5 times greater (from 1.92 to 6.47°C).

The range tends to widen like this because air temperatures drop well below the mean average temperature of 10°C as the season progresses. Temperature measurements began in early October, at about the time of the fall equinox, when air temperatures and ground temperatures were near the mean. Since the spring waters are modified by the soil aquifer, they too exhibit temperatures around the 10°C mark with little variation from spring to spring. As the season progressed air temperatures decreased, causing the temperatures of the spring waters to decrease. Because of the moderating effect of the soil aquifer, which was better noted as air temperatures fell below the mean, the spring water temperatures decreased at a much slower rate than the air temperatures. The rate of decrease in water temperatures also varied from spring to spring, causing the temperature range to open substantially as the season progressed. The rate of spring water cooling reflects the residence time of the groundwaters.

Three classes of springs, based on the rate at which their waters cooled as the season progressed, were noted from Figure 3.1. Temperatures of Springs 2 and 4 drop the lowest and fastest and are hence termed <u>fast-coolers</u>. They are assumed to have very short residence times. Spring 6, on the other hand, is termed a slow-cooler. By January the spring water temperature had dropped only about 5°C since the beginning of October. The temperature on January 23 was 6.5°C, indicating that the groundwater has had time to be modified by the soil aquifer, ie. it has a fairly long residence time. The three remaining springs 1,3 and 5 have almost identical behaviours with very little range between them and hence their residence times underground are assumed to be quite similar. These springs lie between the fast and slow coolers and are therefore called intermediate-coolers.

The physical characteristics of the springs were studied in hopes of finding explanations for these observations. The six springs all issued from clearly defined points and developed into channels almost immediately. They were classified as large and were found at very similar elevations. Spring 1 is an exception as it was slightly smaller, being classified as intermediate-large and at a lower elevation. However, Spring 1's water temperatures were the same as Spring 3 and 5's, which were also classified as intermediate-coolers. It, therefore, seems that the size and elevation do not influence temperature observations of the six springs studied.

Although the physical characteristics of the springs are quite similar and therefore do not offer an explanation for the different temperature observations of the springs, Spring 6's extraordinarily high temperatures may be explained by its location. This spring is in the valley directly below a residential subdivision of west Ancaster. Houses located on the street directly to the south of the spring still use septic tanks to dispose of their water. Perhaps this water, which is much warmer than normal precipitation at this time of year, is percolating fairly rapidly downwards until it encounters the aquiclude and then emerges at the springs in the area. If this is the case, Spring 6's water temperatures may not reflect a long residence time underground, but rather a very fast flow through time from the recharge subdivision area to the spring itself.

3.3 $\delta^{18}O‰$ Content

The stable isotope, oxygen-18, is also used as an indicator of the rate of water movement from the recharge area to the discharge points, ie. the residence time of the groundwater. A mass spectrometer was used to measure the isotope ratio $^{18}O/^{16}O$ in the water molecules of the various samples. These ratios are expressed in delta units (δ) as per mille (parts per thousand or % o), relative to an arbitrary standard known as the Standard Mean Ocean Water (SMOW).

$$\delta^{18}O\%\,o = \frac{1000 \times ({}^{18}O/{}^{16}O_{sample} - {}^{18}O/{}^{16}O_{standard})}{{}^{18}O/{}^{16}O_{standard}}$$

The ^{18}O concentration of waters changes as a result of evaporation, condensation, freezing, melting, chemical reaction or biological processes. The process by which isotope content of a substance changes is known as isotopic fractionation.

The ^{18}O content of the springs and precipitation in the area are shown in Table 3.3 and plotted against time in Figure 3.3. The ^{18}O content of the rain and snow is well below the ^{18}O content of the springs, indicating that the aquifer is richer in the heavy isotope species, ^{18}O, relative to the precipitation. The richer ^{18}O isotope values in the groundwater measured at the springs represents heavier water that fell during the late summer or early fall.

As temperatures become colder, the δ^{18}O‰ in precipitation decreases due to a decrease in proportional evaporation of the heavier isotope at the source. The δ^{18}O‰ in the spring waters decrease, indicating that the groundwaters of the springs do not have time to be significantly modified by their surroundings, ie. they have short residence times. This, however, is just a general trend. Springs 1 and 5, which are classified as intermediate-coolers, (implying residence times of intermediate duration) show little change in δ^{18}O‰ from October to January. Springs 2 and 4, classified as fast-coolers, tend to decrease similarly in ^{18}O content as the season progresses (a change of -0.804‰ and -0.888‰ were noted for Springs 2 and 4, respectively), reflecting the short residence time of these waters.

The ^{18}O content of Springs 3 and 6 varied the most with time, which contradicts the conclusions drawn from temperature observations. Spring 3 was classified as an intermediate cooler, and its ^{18}O content is therefore expected to follow a similar trend as Springs 1 and 5, which is not the case. Spring 6, the only slow-cooler, is expected to show the least variability in ^{18}O content, reflecting its long residence time underground. Instead, this spring shows the highest change in δ^{18}O‰ values; a change of -2.346‰ was observed. This variance could indicate, as suggested earlier, that the waters of this spring do not have a long

TABLE 3.3

$\delta^{18}O$% o CONTENT OF THE SPRING WATERS

Spring	$\delta^{18}O$ (SMOW) (% o) Oct 23/81	Nov 13/81	Jan 23/82	Δ % o
1	-10.727	-10.788	-10.850	-0.123
2	-10.679	-10.996	-11.483	-0.804
3	-10.189	-11.109	-11.724	-1.535
4	-10.685	-11.200	-11.573	-0.888
5	-10.539	-10.500	-10.854	-0.315
6	-10.278	-10.080	-12.624	-2.346
$\bar{X}$	-10.504	-10.778	-11.513	

Rain = -15.305 % o(Oct 24/81)

Snow at 4 cm = -18.113 % o
26 cm = -20.625 % o (Jan 23/82)
48 cm = -15.563 % o

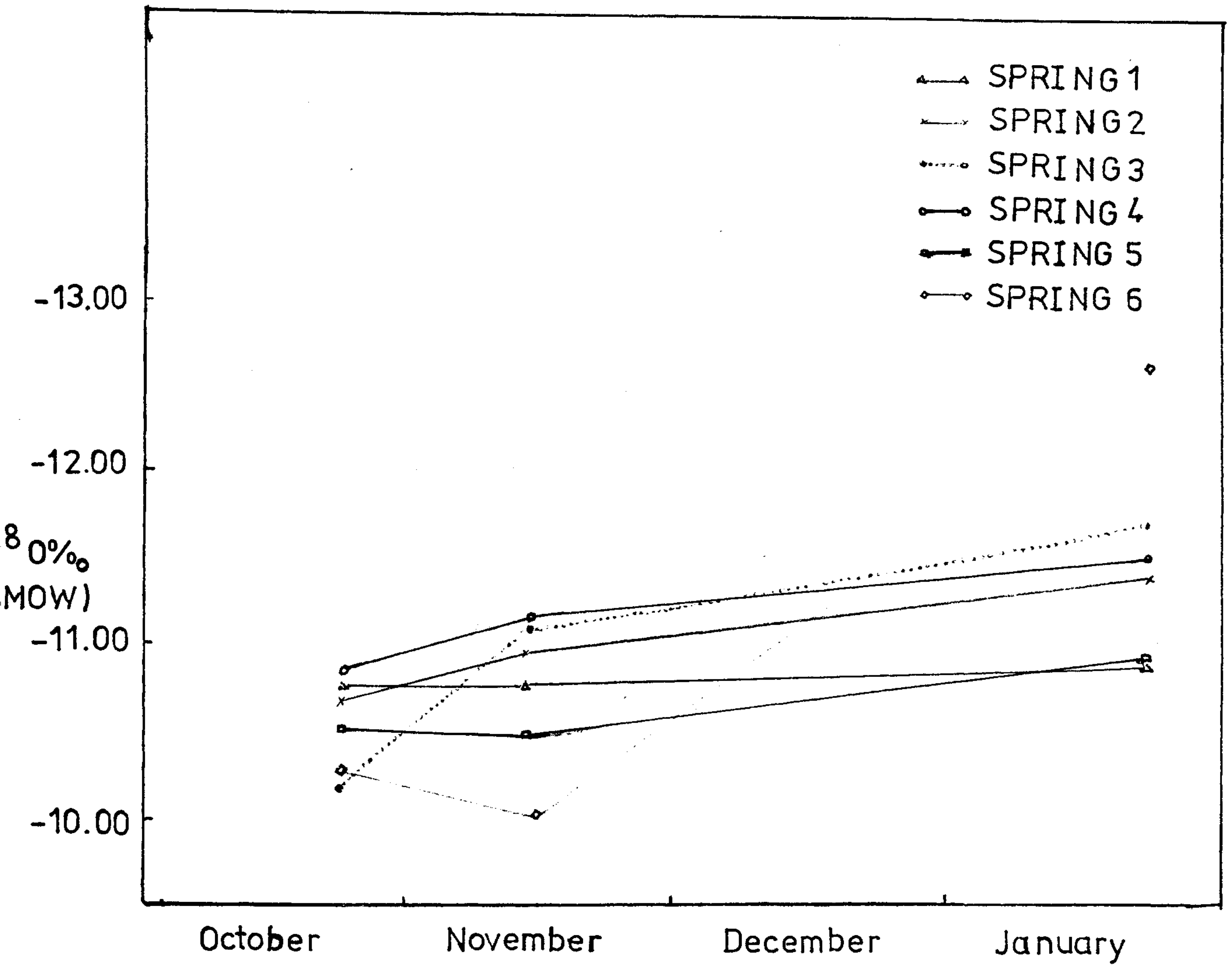


FIGURE 3.3 Variation in $\delta^{18}O$‰ Content with Time

residence time underground, but rather a very short residence time. The spring waters are warmer than the other springs because their recharge waters are warmer, ie. the recharge waters could be from septic tanks in west Ancaster.

3.4 Water Chemistry

3.4.1 The Chemical Process

As mentioned, the Ancaster soil series of silty clay loam, represents the aquifer through which groundwater feeds the springs. This soil is derived from glacial till and/or outwash rich in calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Dissolution of these minerals involves a solid phase (the minerals), a liquid phase (H_2O), and a gaseous source (CO_2 from the atmosphere). The dissolution of the calcite and dolomite in the soils probably takes place in contact with an enriched soil CO_2 atmosphere and is hence an open system as well.

The dissolution process proceeds through a series of steps called the reaction mechanism. The individual reactions are as follows:

	STEPS
$CO_2(aq) + H_2O \rightleftharpoons H_2CO_3$	1
$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$	2
$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$	3
$H^+ + CaCO_3 \rightleftharpoons Ca^{2+} + HCO_3^-$	4
$2H^+ + CaMg(CO_3)_2 \rightleftharpoons Ca^{2+} + Mg^{2+} + 2HCO_3^-$	5

In step 1, carbon dioxide from the atmosphere dissolves in water to produce carbonic acid. This dissociates to produce hydrogen ions and bicarbonate ions, which in turn dissociate to produce more hydrogen ions, (steps 2 and 3.) (The hydrolization of water $H_2O \rightleftharpoons H^+ + OH^-$, also produces hydrogen ions. This, however, is a continuing process and not a quantitatively significant part of the reaction mechanism.) The dissociated hydrogen ions then react with the calcite and dolomite, liberating calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions into the groundwater solution and bicarbonate (HCO_3^-) ions.

This reaction proceeds until a dynamic equilibrium is reached, ie. the amount of forward reaction (the accumulation of products) is equal to the amount of backward reaction (the reprecipitation of the products). Some of the factors that control the dynamic equilibrium of a system are temperature, pressure, CO_2 concentration and additional H^+ concentration. Any variations in these parameters cause the reaction mechanism to proceed towards a new equilibrium. The bedrock dolomites, which underlie the study area, are protected from the chemical process by the calcareous soils and the blue clay layer. Any of the products, Mg^{2+}, Ca^{2+} and HCO_3^-, present in the spring waters, are derived from the dissociation of the calcite and dolomite in the soils and the blue clay.

3.4.2 Water Hardness

The water hardness values are shown in Table 3.1 for the six study springs and in Table 3.2 for Spring 4 during the summer months.

The hardness values, taken in early fall, vary from spring to spring, as well as with time, which means the dissolution of calcite and dolomite in the soils varies. The dissolution of calcite and dolomite vary as a result of the differing physical characteristics of the groundwaters, both spatially and temporally. For instance, water temperatures change, due to their residence time underground. This results in changes in the amount of Ca^{2+} and Mg^{2+} that can be added to solution, and hence hardness values. However, when comparing the water hardness values with the springs classified as slow, fast or intermediate coolers, no pattern emerges. From the small sample the residence time underground seems to have little influence on the hardness of the spring waters, except perhaps that Springs 1 and 3, which are both classified as intermediate-coolers have the lowest hardness values, ie. total hardness is less than 120 ppm while others have values of 200 ppm. Further chemical analysis of the spring waters is required before any conclusions can be drawn with respect to spring water residence time and water hardness.

Spring 4, classified as a fast-cooler, shows a large variation in water hardness with time, reflecting its short residence time. Hardness values tend to be low in the early summer, ie. less than 70 ppm, and increase to over 200 ppm in the early fall. This could be due to the increase in biotic activity in the late summer and early fall, which results in an increase in soil CO_2. This increase makes it possible for more Ca^{2+} and Mg^{2+} to be taken into the groundwater. As air temperatures decrease, the P_{CO_2} of the groundwater increases, also causing the total hardness to increase.

These factors could explain why water hardness values are much higher in the fall. However, no definite conclusions can be drawn due to lack of seasonal data.

The Niagaran dolomites of southern Ontario and hence the glacial tills and/or outwash are Ca-rich, having a general formula $Ca_{1.2}Mg_{0.8}(CO_3)_2$. Therefore, the Ca/Mg ratio of the dolomites in the area are 120:80 or 1.50. The Ca/Mg ratios of the six springs, although they vary, all tend to be higher than this value of 1.50. This is because Ca^{2+} is added to solution faster than Mg^{2+}. It takes longer for the Mg^{2+} in the dolomite to be taken into solution and often Ca^{2+} must precipitate out before any Mg^{2+} can be taken into solution. As a result there is usually more than 120 ppm of Ca^{2+} in the spring waters and less than 80 ppm Mg^{2+}, resulting in Ca/Mg ratios greater than 1.50.

The Ca/Mg ratios of the six springs, shown in Table 3.1 and on Figure 3.1, reveal that the intermediate-coolers have higher ratios than the fast or slow coolers. This means that proportionally more Mg^{2+} has been taken into solution in comparison to Ca^{2+}. This could be a reflection of their residence time underground, although no definite conclusions can be drawn due to the limited amount of data.

Table 3.2 and Figure 3.2 show values and graphs of Ca/Mg ratios and pH, SI_C and log P_{CO_2} values for Spring 4, respectively. As mentioned, this spring is classified as a fast-cooler and the variability in the Ca/Mg ratios and other values, reflect the short residence time of the spring waters. The saturation index of the spring with respect to calcite (SI_C) reveals that, for the most part, the water is slightly supersaturated ($SI_C > 0$). This could be a result of the increase in temperature in the summer, as groundwaters reach the spring points. The SI_C tends to increase as the Ca/Mg ratio increases (ie. more Ca^{2+} has been added to solution) and also as temperature and pH increases.

pH refers to the activity (effective concentration) of hydrogen ions in the water, expressed as the negative logarithm of the H^+ activity in moles per litre. A pH of 7 indicates a water (at 25°C) having equal H^+ and OH^- activities. The pH of Spring 4 during the summer month was above 8.00, indicating that the spring was slightly alkaline, ie. the waters are capable of neutralizing the acidic H^+ ions. This means that the spring waters are incapable of dissolving very much more Ca^{2+} and Mg^{2+} from the soils due to the relatively low activity of the H^+ions. In fact, Spring 4's waters are supersaturated with respect to calcite, ie. no more Ca^{2+} can be taken into solution.

The alkalinity of waters is produced by carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. Sources of these ions include CO_2 from the atmosphere and CO_2 produced by biota of the soils.

3.5 Conclusions

A very preliminary study of one large spring in the summer, amplified to include five other large examples during the fall-to-winter change of season was undertaken. This study revealed strong seasonal or short term trends in the composition of the water (^{18}O proportion), its temperature, and selected chemical variables. The results tend to suggest that residence times may be surprisingly short in what are quite deep, fine-grained granular aquifers feeding perennial springs. They also suggest that the large springs might be further sub-classified into fast, intermediate or slow-coolers as described above. However, there are contradictions in trend when different variables are compared. This suggests that more detailed research is warranted.

CHAPTER 4

SUMMARY AND RECOMMENDATIONS

The springs feeding Sulphur Creek, were studied with respect to their physical aspects and their chemical and isotopic behaviour. The results of this study, already presented in their respective sections, are summarized below.

The springs emerge at similar elevations across the basin, with elevations decreasing uniformly as one moves down stream. This suggests that the springs are perched on a very planar aquiclude. This aquiclude is a lacustrine blue clay layer, deposited as a result of meltwater ponding during the late Wisconsin glaciation. Blue clay was found all along Sulphur Creek, indicating that the proglacial lake covered practically all the basin. Drill hole borings of the surrounding area were studied in hopes of determining the extent of the lake, but no definite conclusions could be drawn. A more detailed study of the drill hole borings, to determine the extent of the blue clay and proglacial lake, is suggested.

There are many springs in the Sulphur Creek Basin as a result of the numerous hills and valleys. These springs are of a permanent nature as they are controlled by the blue clay aquifer. The springs were classified by size according to their type of flow regime and the organization of their drainage channels. It was found that the spring size decreases downstream as elevation decreases. This is because the largest valleys, which concentrate aquifer flow, are located near the escarpment at the highest elevations.

The aquifer, through which groundwater feeding the springs flows, is a clay loam soil. It was deposited atop the lacustrine blue clay layer as outwash flow from the glacier as it receded. Meltwater streams rapidly dissected these deposits until the blue clay layer was sufficiently exposed and springs began flowing. Therefore, the valley and glacial deposits precede the springs. However, since then the springs have eroded back considerably into the hill slopes behind them, further shaping the basin.

A preliminary study of the chemical and isotopic behaviour of six large springs in the study area also provided some interesting conclusions, as to the residence time of the groundwaters. The study revealed strong short term trends in the composition of the water (^{18}O proportion), its temperature and selected chemical variables, which suggests that residence times are very short. Spring temperature data, taken from the fall-to-winter change of season, suggested that the springs could be further sub-classified with respect to residence time. They were classified as fast, intermediate or slower coolers; fast-coolers having the shortest residence time and slow-coolers longest. However, there are contradictions in trend when ^{18}O content and water hardness values of the spring waters are compared to these results. This indicates that further research is required. It is suggested that spring temperatures, ^{18}O content and chemical analysis be carried out for a full year so that definite conclusions with respect to seasonal variations and residence time can be drawn.

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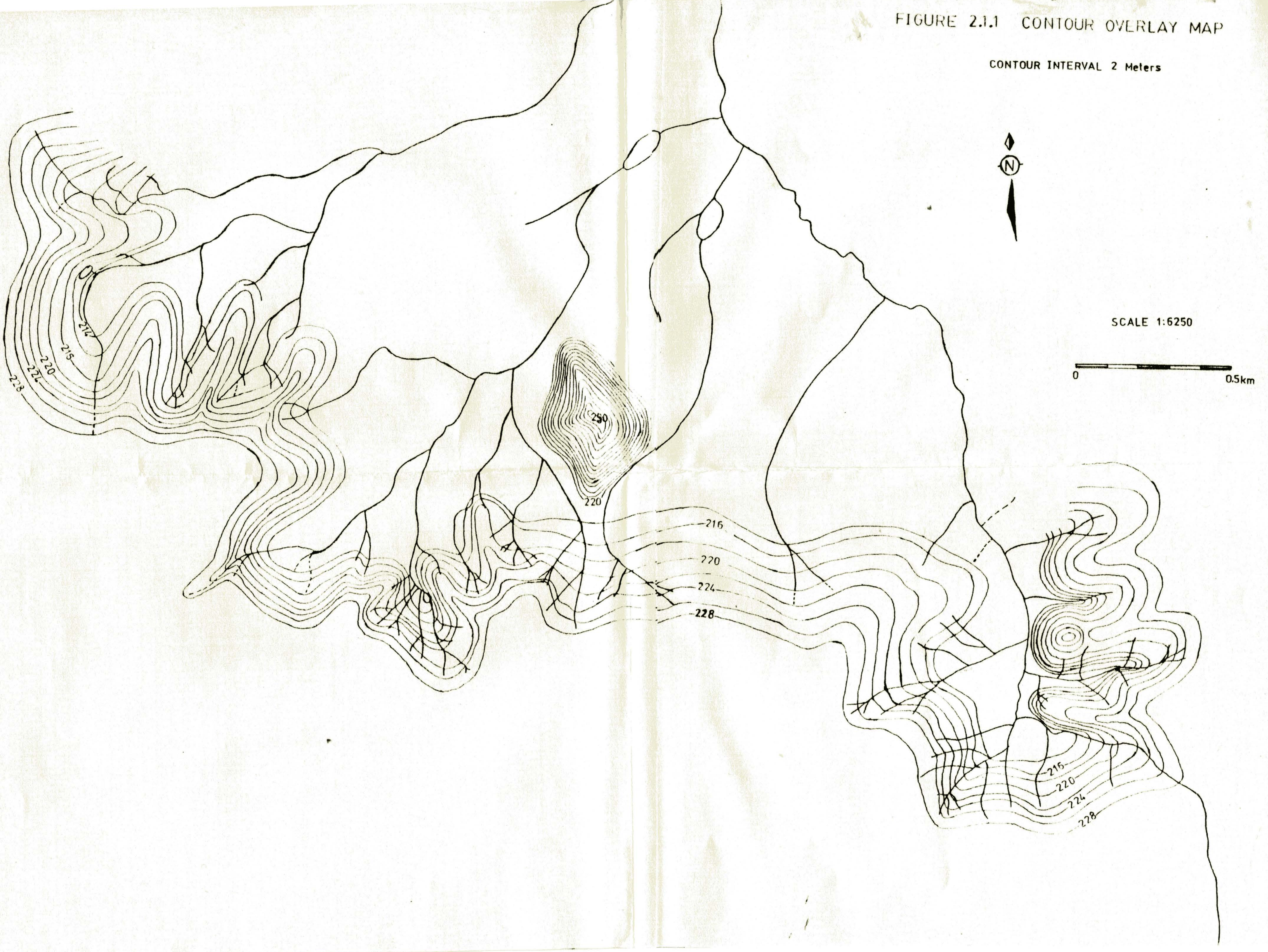
FIGURE 2.1.1 CONTOUR OVERLAY MAP

CONTOUR INTERVAL 2 Meters



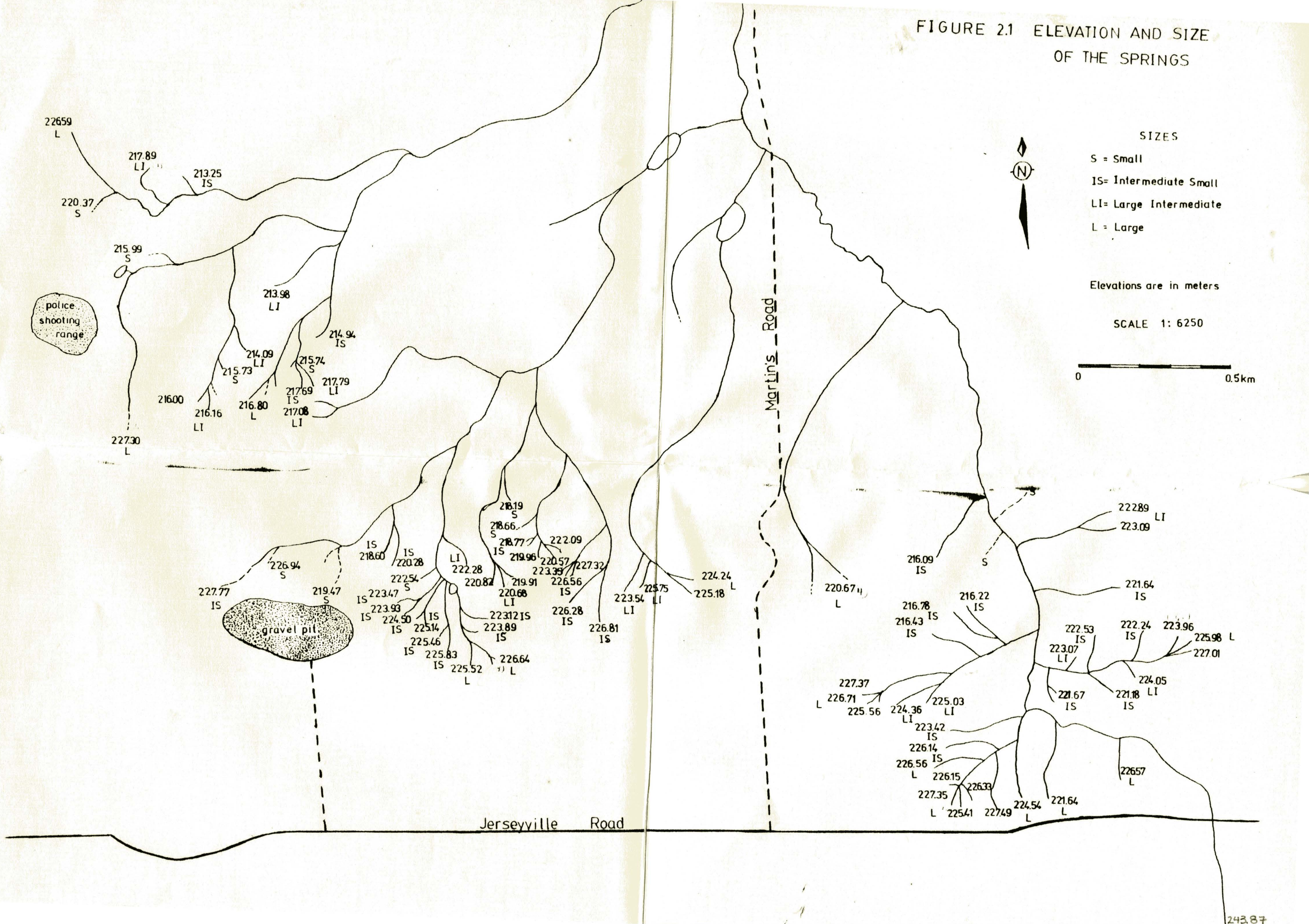


FIGURE 2.1 ELEVATION AND SIZE OF THE SPRINGS