HYDROGRAPH SEPARATION USING NATURAL ISOTOPE AND CONDUCTANCE METHODS IN THE WEST KOOTENAY AREA OF BRITISH COLUMBIA

by

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ABSTRACT

The storm runoff of small springs and seeps in the West Kootenays was subjected to hydrograph separation using oxygen-18 and conductance methodologies. The results showed that the vast majority of storm discharge was groundwater. Under peak flow conditions, the ratio of prestorm water to storm water was 0.93 for Morley Spring, 0.88 for Anderson Creek, 0.87 for Elliott Creek, 0.84 for Chou Creek and 0.85 for Tank Creek. Further comparison between prestorm discharge and storm water indicated that the groundwater probably originated as spring snow melt. These implications are discussed with regard to the various logging development plans currently being proposed for the study sites.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 - INTRODUCTION

Problem

Within the Nelson Forest Region there are numerous small springs and streams that are currently being used as sources of both domestic and irrigational water. Although licenced by the Ministry of Environment, Water Management Branch, these riparian proprietors have no legal recourse should this resource be disrupted due to an officially sanctioned, but poorly planned development scheme. The mandate of the Water Management Branch is simply to insure that the springs are not licenced beyond their sustainable yield and to establish a temporal priority for water use. It is difficult, however to determine the exact yield of these local water resources as they are very susceptible to changes in the weather. The accuracy of predicting a sustainable yield is further complicated by the fact that on any given day a licencee is not likely to use his entire entitlement and therefore a considerable surplus may be generated.

The mandate of the Ministry of Forests, however, includes managing British Columbia's forest resources for the benefit of all provincial residents. An apparent conflict of interest arises when licenced riparians interpret a proposed logging plan as a threat to their water supply. Residents often feel that the forest resource is being managed without due consideration of local concerns.

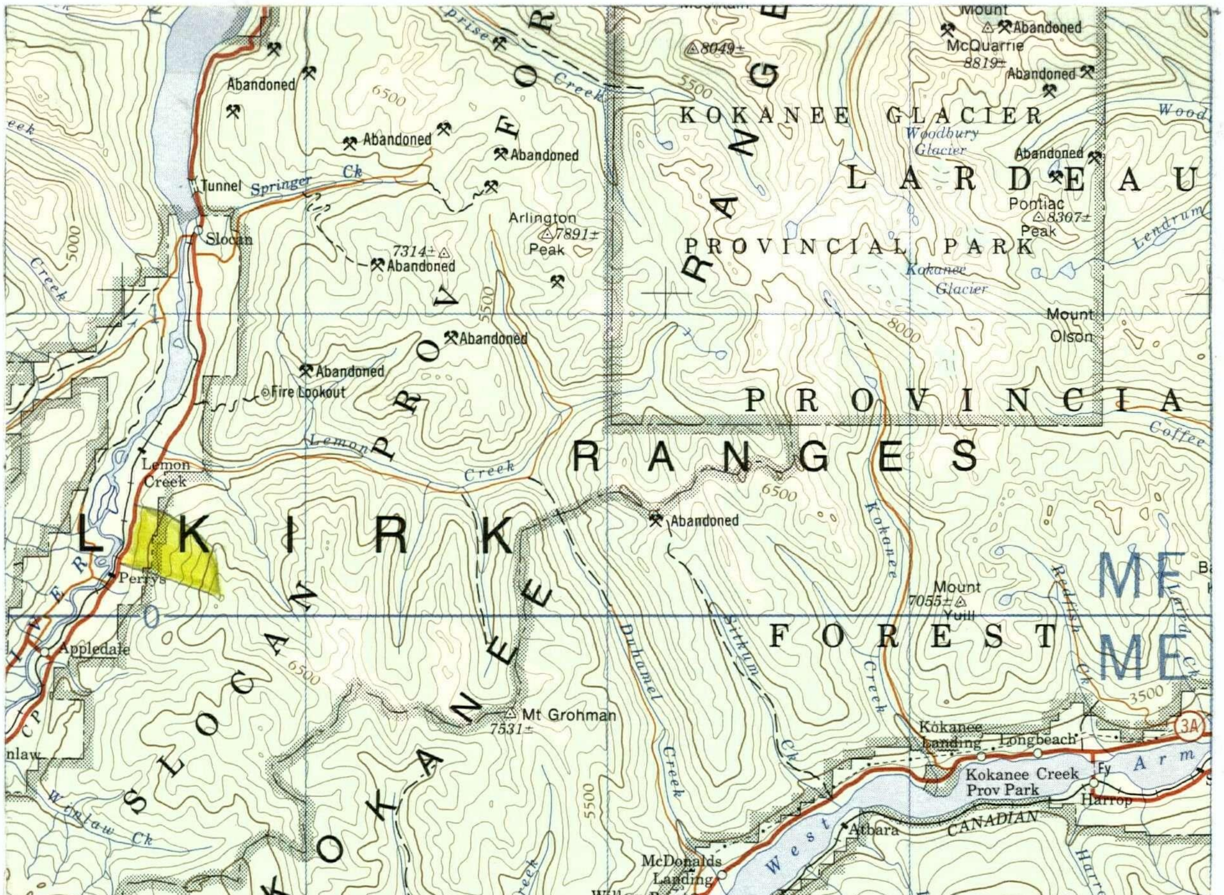
Such problems have recently been brought to the fore in public meetings convened by the Nelson Region of the Ministry of Forests to discuss proposed developments in the Slocan Valley and

Kootenay Lake areas (Fig. 1). These areas contain many small flow systems. The physical characteristics of these systems are not easily identified and as such they may present a management problem for future development. With the aim of obtaining an amicable solution to these problems, the regional headquarters of the Ministry of Forests, in conjunction with the concerned district, have intensified their studies of the physical parameters governing the areas in question.

Objectives

The aim of this study was to determine the relative contributions of prestorm water and storm runoff to total flow in selected small springs and creeks within the Kootenays. This will be accomplished using both the isotopic and conductance methods of hydrograph separation. The results of this analysis will indicate the relative contributions of overland flow, interflow and groundwater to total storm runoff.

As a secondary objective, the relative contributions of the components to total storm runoff will be combined with previously established knowledge in the field of forest hydrology to obtain insight into the functioning of the local springs and creeks in the Nelson Lake and Slocan Valley areas. This information will be used to evaluate how future development plans might affect the quality and quantity of the water resource. If adverse impacts are anticipated recommendations will be made as to how the various development schemes could be implemented to minimize any deleterious effects.



0 5 10 15 20 25

kilometers

(highlighting delineates study areas)

Fig. 1 West Kootenays

Review

In addition to the variables of geology, topography and climate, natural vegetative cover has a large influence on watershed hydrology. It has been shown that vegetative cover decreases runoff through interception and subsequent evaporation (Helvey 1971). A forest canopy will reduce the throughfall of precipitation and thereby limit the amount of water infiltrating the ground. The magnitude of this effect depends upon the type and intensity of the precipitation, as well as variables such as percent crown closure, tree height and tree species.

Vegetative cover also decreases the amount of runoff through transpiration (Hewlett and Nutter 1969). This effect is greatest during the spring and summer when the majority of plant growth occurs. The actual amount of water transpired will depend upon the type of plant (its surface area and rooting depth) and the availability of water (as reflected in the climate and the ability of the soil to retain available moisture). Croft (1948) found that evapotranspiration of riparian vegetation can account for up to 33% of total flow during the late summer.

The rooting system of plants is also responsible for maintaining a high void ratio within the soil. The void ratio, in turn, increases detention storage thus decreasing peak flow, prolonging runoff and maintaining a high percolation rate. If the vegetation is removed the soil may become more compacted resulting in an increase in the ratio of overland flow to subsurface flow (Chamberlin 1972). Retention storage, on the other hand, is primarily a function of soil particle size. Vegetative cover can indirectly affect the amount of moisture held by the soil through inputs of decomposing litter. Although forest harvesting may cause a temporary reduction in the organic material available to the soil it is unlikely to have a large effect upon the retention storage as the time required for regeneration of vegetative cover is short in comparison to soil genesis.

A well developed plant canopy will also reduce evaporation from the soil surface by blocking incident radiation. This effect is further enhanced by vegetation which lowers the vapour pressure gradient by sheltering the moist soil from surface winds.

Vegetative cover also influences the quantity and distribution of a snow pack (Golding 1974). In a dense forest the overall snow pack will be reduced due to interception. In a more open or patch cut forest the accumulation may be increased due to the turbulence caused by the uneven canopy. With very little vegetative cover, however, the snow pack may be reduced due to drift and scour.

When the different effects of vegetative cover are tallied, it seems quite clear that the total discharge of a watershed will not be reduced if the forest cover is removed, and in fact, in most cases it will increase (Anderson, Hoover and Reinhart 1976). Due to the many different forces exerted by vegetative cover over runoff patterns and considering the difficulty of obtaining precise, reliable data, pretreatment quantification of this statement is difficult. These factors also make this empirical relationship site-specific and therefore the information concerning one watershed cannot be transferred to another area without a high probability of error.

In some instances, however, the effect of vegetative cover on total yield is not as important as the time distribution of runoff. Some researchers have shown that plant cover can improve soil structure and thereby increase its percolation rate and moisture storage capacity. This effect can in turn lead to an increase in groundwater flow as opposed to surface runoff (Bates 1934, Tennessee Valley Authority 1955). The net result of these effects is to more evenly distribute runoff throughout the year. These results, however, are only likely to occur in extreme cases such as the revegetation of abused farmland.

Studies have also shown that removal of vegetative cover will increase the total amount of water available for runoff which, in turn, will increase flow during the summer and fall periods when the demand for water is greatest (Reinhart, Eschner, Trimble 1963). Rothacher (1970) found that for a watershed in Oregon, 80% of a measured increase in runoff took place during the winter months. The 20% of the increased runoff that occurred over the summer, however, represented a 150% increase in the pretreatment low flow measurements, for every square kilometer clearcut this represents an increase of 1.3×10^{6} l per day. Rothacher (1970) attributes this increase to reduced evapotranspiration, which leads to a greater amount of water being held in both retention and detention storage.

There still seems to be considerable controversy over the effects of forest harvesting practices on peak flows. Although Anderson and Hobba (1959) determined that an observed increase in the size of peak streamflow was attributable to logging practices, Harris (1977) failed to detect any significant difference in the size of peak flow after clearcutting a watershed in western Oregon. Studies conducted by Cheng (1975) and deVries and Chow (1973) in British Columbia found a decrease in the size of peak flows after clearcutting as did Harr and McCorison (1979) in Oregon. deVries and Cheng attributed this reduction to the disruption of the subsurface channel networks due to logging. Other studies (Harr, Harper, Krygier, Hsieh 1975, Harr 1976) found an increase in peak runoff, but attributed it to a high degree of soil disturbance and not to the removal of vegetative cover.

The fact that forests are a renewable resource means that under normal logging practices the system will tend to return to its natural state once the treatment is completed. Again, the exact rate of recovery will depend upon many factors, but natural revegetation usually reduces the initial effects on water yield by about 50% after the first 10 years (Anderson, Hoover, Reinhart 1976).

The hydrology of a watershed is not only affected by its vegetative cover but also by practices associated with forest harvesting, such as road building, skidding and slash burning (Harr, Harper, Krygier, Hsieh 1975). These practices usually have the effect of soil compaction and thereby reduce infiltration rates and storage capacities. Under extreme conditions, such as on the surfaces of roads, compaction may result in the generation of surface flow , which can lead to higher peak flows during storm conditions and lower flows under drier conditions. The magnitude of this effect, however, is likely to be small as the area dedicated to road construction usually represents only a small proportion of the total watershed. Zimmer (1981) found that unless at least 12% of the watershed was covered by road construction there was no significant change in the magnitude of peak flows.

The diversion of subsurface flow to surface runoff is further illustrated in a study conducted by Megahan (1972). He found that the cut bank of a haul road intercepted 28% of all subsurface flow with the result of decreasing soil moisture in down slope locations.

As previously noted, the change in the hydrology of a watershed after forest harvesting may be partially due to the change in the ratio of direct runoff to base flow. Until the advent of stable isotope methodologies, the separation of a hydrograph into its component parts of surface flow and interflow (storm runoff) and groundwater flow (prestorm runoff) was accomplished geometrically (Wilson 1969). One of the most common methods of isolating base flow from the rest of the hydrograph involves extrapolating the prestorm recessional limb to a point under the peak of the storm hydrograph (Fig. 2). From here the line is extended for a distance N on the recessional limb of the stream hydrograph according to the equation:

$$N=A^{0.11} \qquad \text{(Eq.1)}$$

where N is time in days from the peak of the hydrograph and A is the area of the drainage basin in square kilometers (Linsley, Kohler, Paulhus 1976). Anything below this line is labeled as

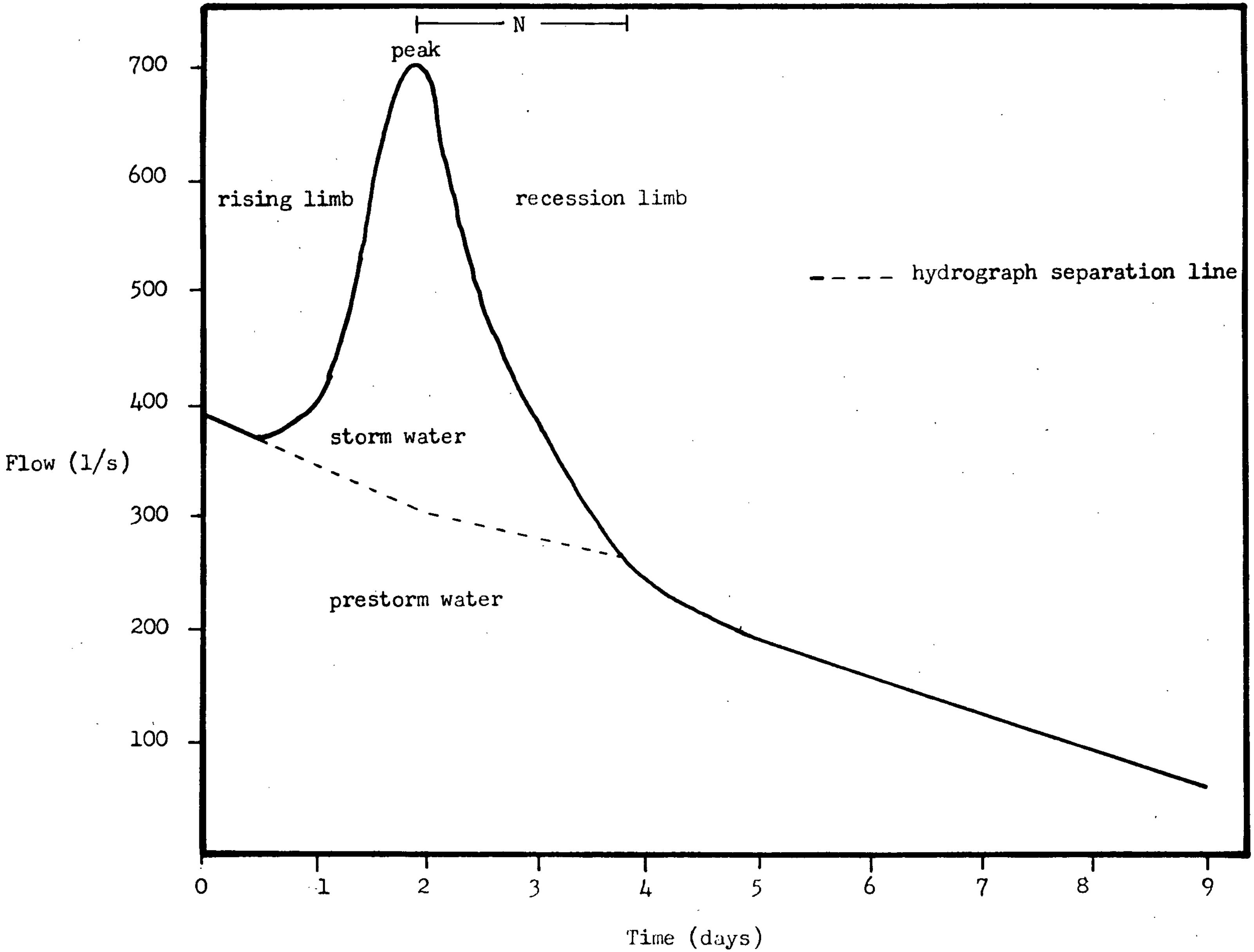


Fig. 2 Geometric Hydrograph Separation

base flow, while the part of the hydrograph above the line is considered to be direct runoff. In the example cited in Fig. 2, 43% of the peak runoff is labeled as originating as prestorm water.

Another method of hydrograph separation originally devised by Barnes in 1939 entails plotting the discharge measurements on a logarithmic scale and time on a linear scale (Ward 1967). The base flow is then determined by extending the recession limb of the hydrograph backwards from its point of inflection until it intersects a vertical line dropped from the point of maximum discharge. From here the line is then connected to the initial inflection point of the hydrograph. Using the same data as cited in Fig. 2 this second method allocates approximately 52% of the peak runoff to prestorm water (Figs. 3 & 4).

Hewlett also has an arbitrary method of isolating the prestorm component of a hydrograph (Hewlett, Hibbard 1967). His constant slope method extends a tangent from the initial inflection point on the rising limb until it intersects the recession limb. The slope of this line was set to 3.66 $l/s/km^2/hr$. The illustration of this method in Fig. 5 indicates that approximately 65% of peak flow originated as prestorm water.

From the hydrographs depicting these methods it is evident that each attributes a different value to the base flow component. As such they do not reflect quantitative measurements and are only valid when used in analytical comparisons (e.g., the classification of stream response to precipitation inputs).

The advent of quantitive methods of hydrograph separation began in 1967 when LaSala obtained a close correlation between

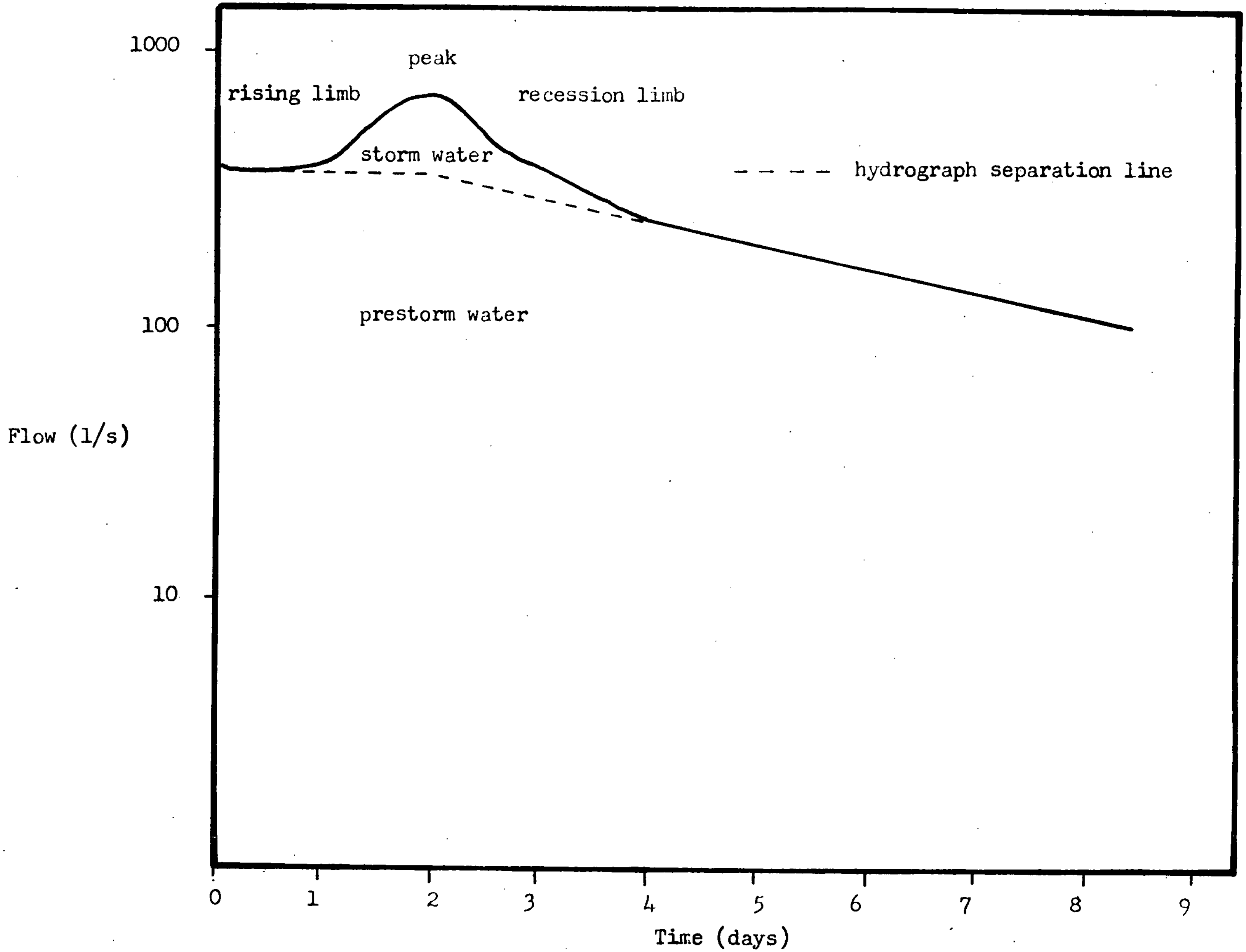


Fig. 3 Barnes method of hydrograph separation on a logarithmic scale

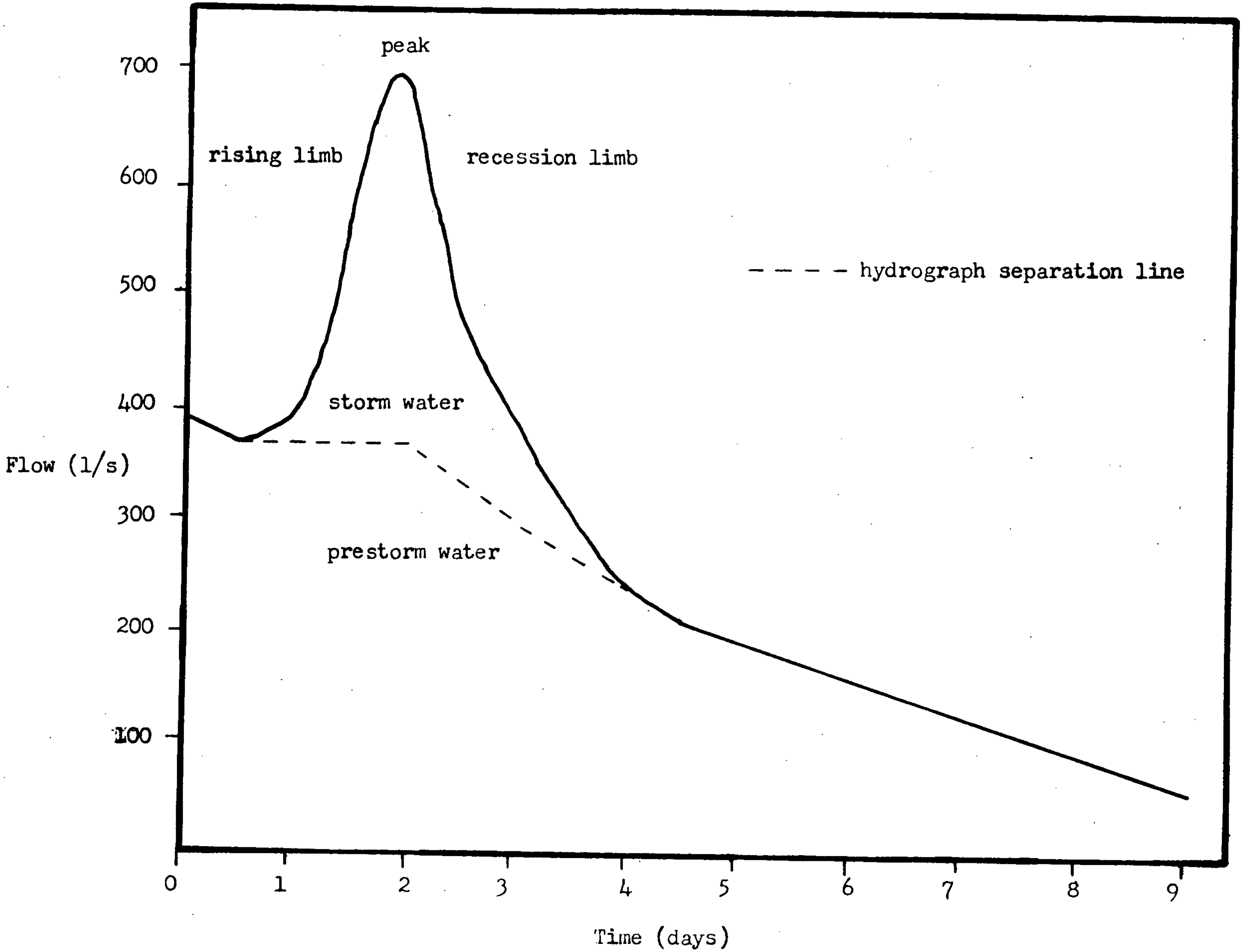


Fig. 4 Barnes method of hydrograph separation converted to a linear scale

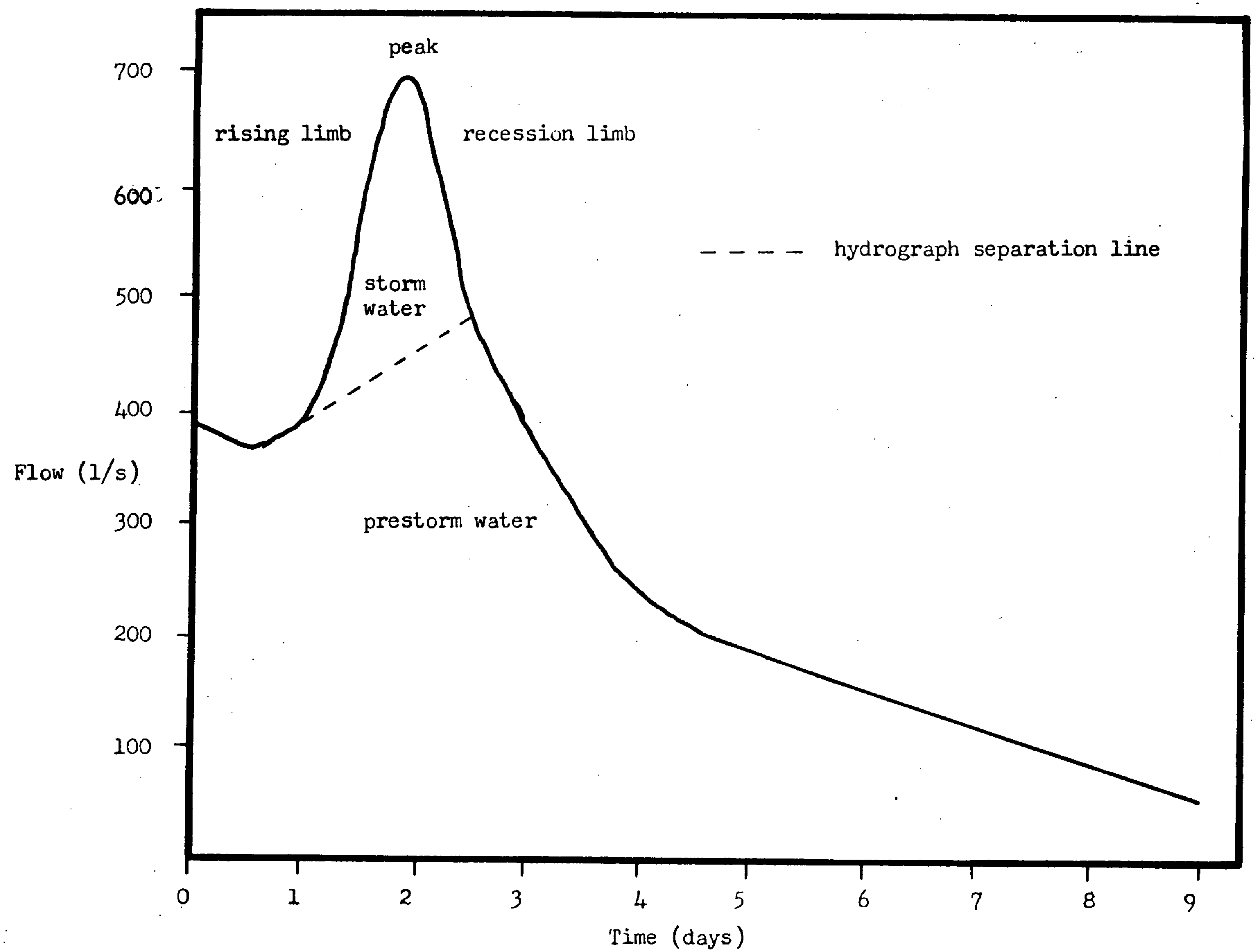


Fig. 5 Hewlett's constant slope method of hydrograph separation

the total dissolved solid (TDS) loading of stream water samples and the stream's discharge. A few years later Pinder and Jones (1969) and Newbury, Cherry and Cox (1969) used the relative concentrations of various ions in groundwater and stream discharge as a method of hydrograph separation.

The study conducted by Pinder and Jones (1969) took place in three watersheds in Nova Scotia. Instead of measuring the relative abundance of TDS within the water samples they separated groundwater flow from direct runoff by measuring the relative concentrations of specific ions. When these values were averaged they found that at peak discharge groundwater accounted for as much as 42% of total runoff. During the study, however, Pinder and Jones found that prestorm water taken from the head waters of a stream contained appreciably fewer ions than water samples taken from the lower reaches of the same water course. They attributed this finding to the difference in the geological composition of the substrate and to the amount of time the water was resident in the various strata prior to discharge. The accuracy of this method of hydrograph separation is therefore influenced by the chemical reactions taking place between runoff and the substrate.

In the study conducted by Newbury, Cherry and Cox (1969) specific ions were also used as the basis of hydrograph separation but they were also able to prove a close correlation between the average concentration of the sum of the ions and the electrical conductivity of the water sample. In addition to differentiating between prestorm water and storm water they were able to separate direct runoff into overland flow and interflow.

By using a network of piezometers they were able to show that the concentration of sulfate ions in interflow was negligible. Within the study site the time required for runoff to pickup traces of sulfate was such that only groundwater displayed any appreciable concentration of this ion. This study showed the groundwater component of total runoff to be as high as 41%.

From these studies it is obvious that the use of ions as a method of hydrograph separation can quantify the amount of runoff attributable to groundwater. Although the inherent inaccuracy of this method may be considerable, unlike the graphical methods of hydrograph separation it reflects the true dynamics of the runoff system.

In the mid 1970's Sklash, Farvolden and Fritz (1975) began using the ratio of oxygen-18 to oxygen-16 in water as a means of hydrograph separation. Their study was based on the premise that due to recharge and dispersion processes, groundwater attains a uniform isotopic content that reflects the average of the annual precipitation events. Therefore the water deposited by a storm that has a different ratio of oxygen-18 to oxygen-16 would produce a change in the isotopic content of the prestorm water.

Since oxygen-18 is a stable isotope, its relative abundance can only be changed through fractionation or mixing. Fractionation in water is dependent upon differing vapor pressures, and under the saturated conditions of a precipitation event is unlikely to result in a perceptible difference in the isotopic ratio. As a result, the isotopic content of prestorm water can only be altered through mixing with storm water. For short duration precipitation events the change in the number of oxygen-18 atoms present in total runoff will provide a means by which prestorm water can be distinguished from the water accumulated by the drainage basin during the storm. A more detailed explanation of the use of natural isotopes in hydrology can be found in Fritz (1981) and Faure (1977).

The study areas selected by Sklash, Farvolden and Fritz (1975) were two large (700 sq. km) watersheds in southern Ontario. The soils were primarily glacial sand and till and were predominantly used as farm land. On 16 May 1974 a storm deposited approximately 2.5 cm of rain on the study areas and hydrographs and water samples were collected. Sklash's interpretation of the results of isotopic analysis showed that at peak discharges, up to 70% of the flow was groundwater. The proportion of groundwater contributing to the storm discharge was found to be larger in downstream areas than in upstream areas. This trend was attributed in part to more efficient groundwater drainage in downstream areas. Fig. 6 is an example of the data obtained at one of the sampling sites. It is the same hydrograph as that used in the previous examples but in this instance the separation line quantitatively represents the amount of groundwater contributing to the storm runoff. This method of hydrograph separation reveals that 66% of the peak runoff can be attributed to prestorm water.

The prevalance of oxygen-18 in any given sample is always expressed as a ratio (r) of the abundance of the heavier oxygen atoms to those of oxygen-16.

$$r(\text{sample}) = {}^{18}O/{}^{16}O \qquad \text{(Eq. 2)}$$

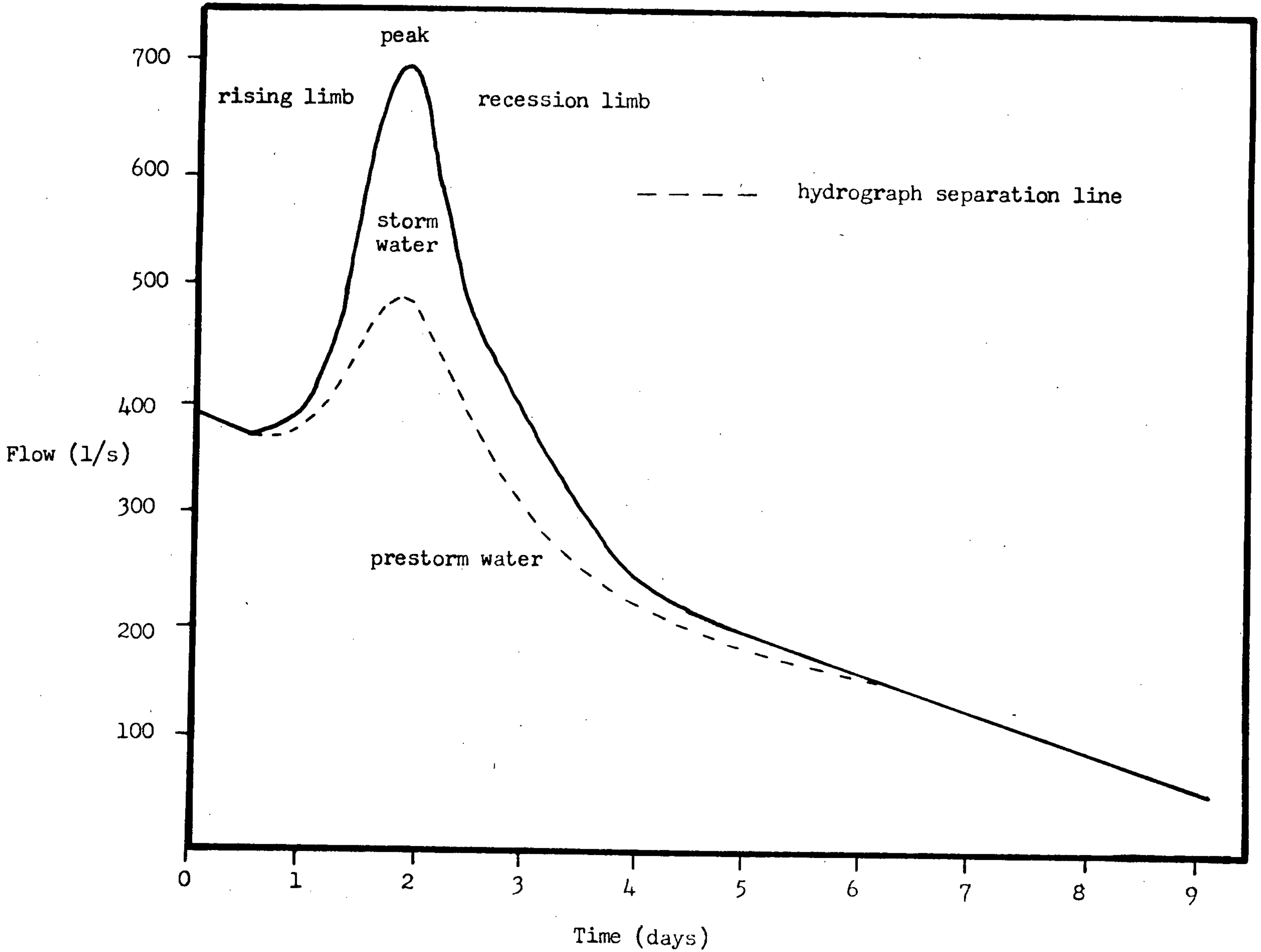


Fig. 6 Isotopic method of hydrograph separation

By convention this value is compared to a standard ratio and the difference recorded as a del (d) value (Jacobs, Russell, Wilson 1974).

$$d^{18}O=[r(sample)-r(standard)]/r(standard) \qquad (Eq.\ 3)$$

If the sample has a higher ratio of oxygen-18 atoms than does the standard it is said to be enriched and is denoted by a positive value (e.g., $d^{18}O=+5.0$). If the reverse is true, the sample is said to be depleted and the numerical value is preceded by a negative sign (e.g., $d^{18}O=-5.0$). In most studies this value is then multiplied by 1000 to give a final determination in parts per thousand (‰) or g/l.

When determining the oxygen-18 content of water the most widely used reference is Standard Mean Ocean Water (SMOW), and by convention this is taken as having an isotopic content of par (i.e, $d^{18}O=0.0$).

Since both oxygen-18 and oxygen-16 are stable isotopes (not undergoing radioactive decay) their relative abundance is controlled through fractionation (α).

$$\alpha = \frac{dx/x}{dy/y} \qquad (Eq.\ 4)$$

Where α is the fractionation factor, x is the amount of oxygen-18 atoms in a specific phase, (e.g., liquid), and dx is the amount of oxygen-18 atoms in another phase, (e.g. gaseous). y is the number of oxygen-16 atoms in the first phase and dy is the number of oxygen-16 atoms in the second phase. The fractionation factor between liquid water and water vapour in equilibrium at $25^{o}C$, equals 1.0092. In other words, liquid water is enriched by 9.2 parts per thousand of oxygen-18 molecules when compared to water vapour.

The fractionation factor is directly dependent upon the temperature. As temperature decreases the fractionation factor increases. For example, the fractionation factor for water at $0^{o}C = 1.0111$. Within the ecosystem, this relationship is exhibited by different physical effects. These effects are summarized by Siegenthaler (1979), where he recognizes three distinct categories:

1. The temperature phenomenon, which is illustrated by a gradual decrease in heavy isotope concentration when going from lower to higher latitudes. For example the oxygen-18 content of precipitation at the poles averages about -50‰. whereas at the equator this value is near 0‰. This is further demonstrated by the seasonal variation in isotopic content of precipitation. Precipitation from winter storms is likely to be more depleted in oxygen-18 molecules then precipitation resulting from a summer storm.

2. The continental phenomenon, which manifests itself as a decrease in the oxygen-18 content of precipitation as one moves inland from the coast of a continent. As an air mass moves inland oxygen-18 molecules are preferentially removed during the condensation process.

3. The altitude phenomenon, which is revealed by the lowering of oxygen-18 content with an increase in altitude. Quantitatively the average gradient for oxygen-18 is approximately 0.2‰ per 100 m.

In most cases, hydrograph separation as determined with conductance data is unlikely to be as accurate as the results obtained from isotopic measurements because the ionic composition of a solution is not a conservative property. The magnitude of the discrepancy will vary according to the parameters of ionic concentration of the solution and the substrate, the temperature, pH and the resident time of the solution in the groundwater system.

Since conductance measures only the abundance of ionic species, the total dissolved solid loading of a sample is determined using the following formula:

$$TDS=AC \quad \text{(Eq. 5)}$$

If the conductance (C) is measured in microsiemens (uS) the total dissolved solids (TDS) is expressed in mg/l. The constant (A) varies between 0.55 and 0.75 depending upon the ionic composition of the solution. To determine the exact value of this constant the TDS loading of a sample must be found using another method of analysis. Usually this alternate method involves the evaporation of a given volume of water and the weighting of the solid residues.

To use the isotopic or conductance methods as tools for hydrograph separation, a number of conditions must be met. Firstly, the prestorm water in the stream and the storm precipitation must be significantly different in oxygen-18 content (ie. the precipitation must be either enriched or depleted with respect to the prestorm runoff). This requirement insures that there will be a change in the oxygen-18 ratio of the storm runoff due to mixing of prestorm water and precipitation. In most cases the oxygen-18 content of the groundwater is homogeneous and reflects the average value of preceding precipitation events. The time base for calculating this average will depend upon the rate of turnover of groundwater within the system. Secondly, the storm must be sufficiently large to cover most of the watershed and produce enough precipitation to influence the hydrograph. These conditions apply equally to the conductance method of hydrograph separation.

As isotope and conductance methods are only capable of separating discharge into prestorm and storm water the following assumptions must be made in order to further subdivide runoff into its component parts of groundwater flow, subsurface storm flow or interflow, overland flow and channel interception. Since overland flow and channel interception only occur during precipitation events they do not contribute to prestorm runoff. Furthermore, as Freeze (1974) pointed out, only convex slopes that feed deeply incised stream channels are likely to generate interflow in any appreciable quantities. As such conditions are not found within the examined study areas it is unlikely that interflow is a major contributor to storm runoff. For the most part then, all prestorm water can be considered as groundwater flow.

CHAPTER 2 - METHODS

In each of the study areas a specific site was selected where the stream discharge could be easily measured. The method of flow measurement varied to account for the differences in topography, anticipated peak stage height and preexisting structures such as water supply intakes. Stream water samples were obtained and flow conditions were monitored. The exact sampling scheme used in each of the study sites will be detailed later in this paper.

A transect of rain gauges was established throughout each watershed to account for the possibility of differential fractionation within the rainfall (due to altitude). The rain gauge network encompassed the full range of elevations within each basin. The study area of each basin was then roughly sketched in order to obtain a more detailed understanding of factors such as vegetative cover, geology, soils and topography.

With the advent of a storm event the stream water sampling frequency was increased. The actual interval between each successive measurement varied according to the time required to complete one circuit of all the sampling sites within the study area. Once the storm had passed, rain water samples were collected from the various rain gauges.

The post-event sampling frequency and duration were governed by the recession rate of the hydrograph, although each site was monitored for at least 24 h after the peak flow condition was recorded. All samples were stored in air-tight plastic bottles until required for analysis.

The samples were analyzed for oxygen-18 content using the mass spectrometer in the Department of Geophysics of the

University of British Columbia (Ahern 1975). This instrument first establishes an equilibrium in oxygen-18 atoms between the water sample and the carrier carbon dioxide. The molecules of carbon dioxide are then passed through a magnetic field which accelerates them along a curvilinear path. The result is that the molecules containing oxygen-18 atoms separate from those possessing only oxygen-16 atoms due to the difference in their molecular weights. The two resulting beams are then focused into separate collection cups where they generate a current that is dependent upon their relative abundance. The processing of this signal yields the ratio of oxygen-18 to oxygen-16 molecules in the original sample. This facility enables readings accurate to 0.15% (one and a half part per ten thousand).

Conductivity measurements were made using a CDM 2e conductance meter which simply measures the flow of electrons through a 1 cm distance of solution. The accurate resolution of the conductance meter is 2.0 uS.

The instrument was calibrated by immersing the detector head into a 0.2 mole solution of potassiun chloride which was stabilized at 18°C. Under these conditions the meter was adjusted to read a conductance of 11,160 uS (Analytical Quality Control Laboratory, 1972). The samples were then filtered to remove any suspended sediments or organic materials. After each reading the detector head was rinsed in distilled water to reduce the likelihood of inter-sample contamination. Each reading was corrected for temperature so that the final measurements reflect the conductance of the sample at 25°C.

Both isotopic and conductance analyses were done in duplicate and the mean values calculated.

From the flow measurement data, stream hydrographs were constructed. The instantaneous prestorm runoff (Qs) was calculated using the standard mixing equation (Fritz, Cherry, Weyer, Sklash, 1976):

$$Qs = \frac{Ct - Ce}{Cp - Ce}\, Qt \qquad \text{(Eq. 6)}$$

Where Qt is the volume of the instantaneous total runoff, Ct is the isotopic or conductance value of the total runoff, Ce is the isotopic or conductance value of the precipitation and Cp is the isotopic or conductance value of the prestorm runoff. The subsurface component of the hydrograph was plotted using both types of analysis. An example of this calculation, using the data obtained from the Chou Creek site yields the following figures:

Subsurface flow calculations using data from Table 5 at 1520 hrs. 9 September 1982.

Using isotopic data:

$$Qs = \frac{(17.15) - (13.53)}{(17.66) - (13.53)}\, 0.55 \qquad Qs = 0.48 \text{ l/s} \qquad \text{(Eq. 7)}$$

Using conductance data:

$$Qs = \frac{(274) - (13)}{(322) - (13)}\, 0.55 \qquad Qs = 0.46 \text{ l/s} \qquad \text{(Eq. 8)}$$

Equation 6 assumes that the measured variable within the prestorm water is uniform and stable throughout the period of measurement. As mentioned earlier, because of its conservative properties, this assumption is probably safe as regards oxygen-

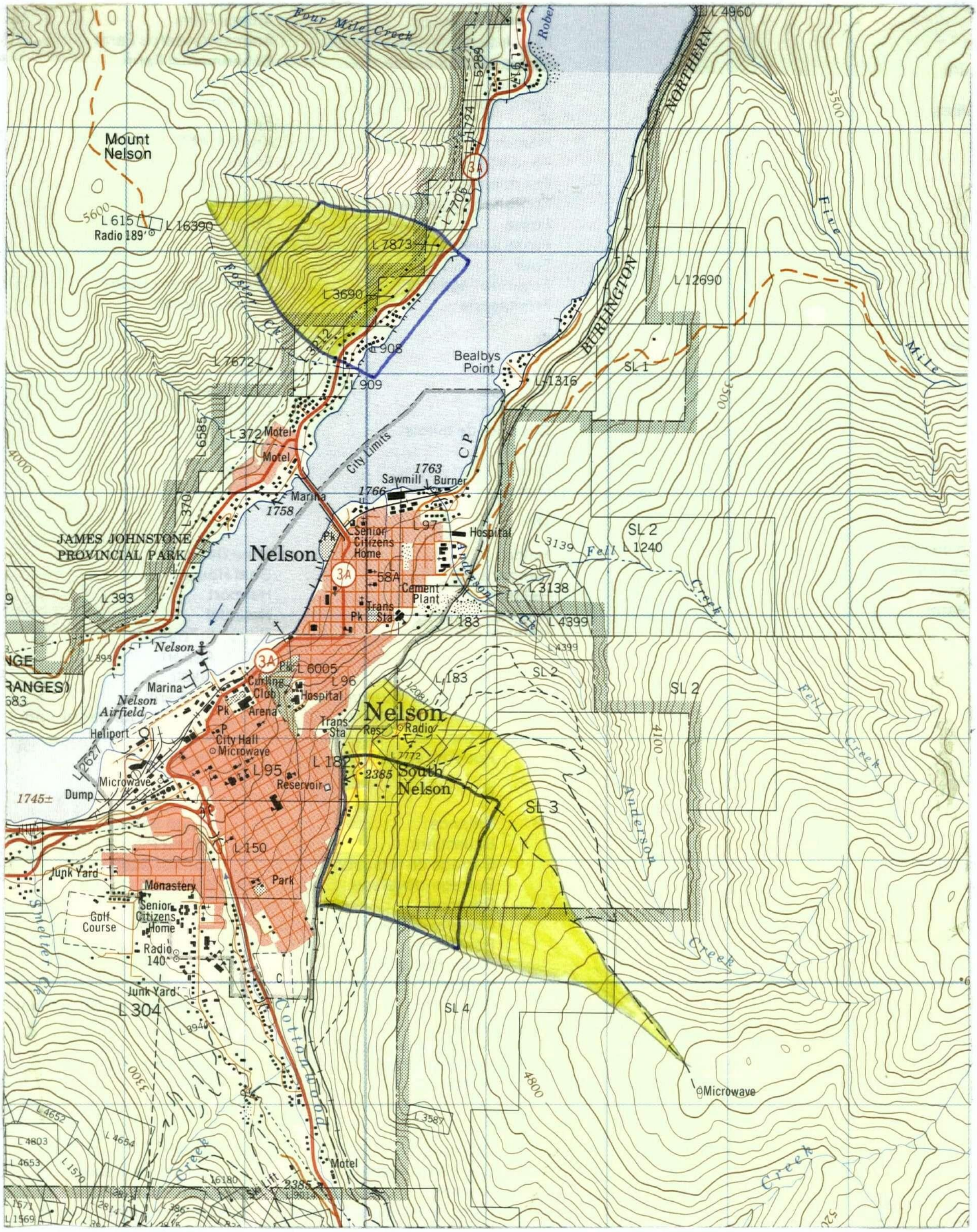
18. The ionic concentration of prestorm water, on the other hand, may be influenced by chemical processes and therefore may contradict this assumption over a long period of measurement. The equation further assumes that the measured variable within the precipitation remains constant throughout the period of measurement. Although a particular storm event may vary in its isotopic or ionic content through time, the accuracy of this assumption can be monitored through the analysis of precipitation samples.

CHAPTER 3 - MOUNTAIN STATION STUDY AREA

Area Description

The first study area to be examined covered approximately 270 ha and lay just east of Nelson city limits (Fig. 7). The slope is convex and has a mean inclination of 36^{o} in the lower regions and 12^{o} near the top. Instead of a single large water course, the area is drained by a number of small intermittent creeks (Fig. 8). The geological maps of this region indicate that the bedrock belongs to the Rossland Volcanic group. The soils within the area are predominantly Calamity, Sombric Humo-Feric Podzols (Jungen 1980). Calamity soils are well to rapidly drained but may be associated with minor inclusions of imperfectly drained seepage areas. This area belongs to the Interior Cedar-Hemlock zone of ecological classification (Watts 1983). The hillside was logged approximately 70 years ago and is now largely covered with mature Douglas fir and larch, except for a central region in which a steep slope provides a poor colluvial soil. In the central part of the slope the vegetation is more open and is dominated by lodgepole pine.

At the time of this investigation there were a total of 34 water licences held within the study area, with a total demand of 470 m^3/day. One of the more heavily licenced streams (64.6 m^3/day) and the one of primary importance in this study was Tank Creek. Tank Creek seems to originate from a number of small seeps at about the 900 m level. Postle Spring is characteristic of such a seep and was also selected as a monitoring site in this study.



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kilometers

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Fig. 7 Mountain Station and North Shore Study Areas

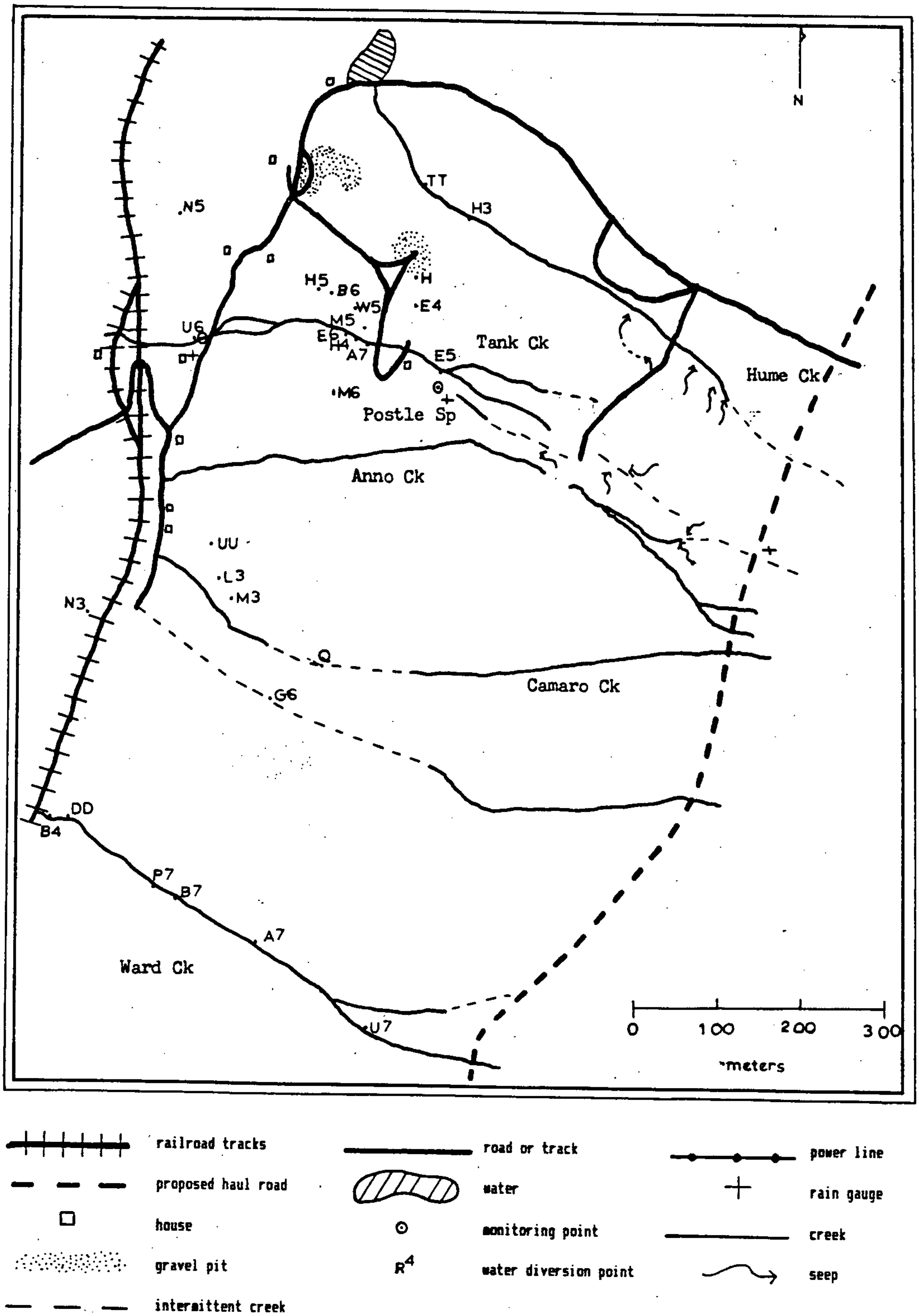


Fig. 8 Mountain Station study area

From the surface gullying, it was evident that the length of the stream varied with seasonal runoff patterns. Local residents in the Mountain Station area confirmed this observation. They reported a decrease in flow as the summer progresses. To date however, only minor water shortages have been experienced and these were during quite severe drought conditions.

The British Columbia Forest Service proposal for the Mountain Station region calls for forest harvesting in the area of Five Mile Creek. At present, the most likely route for a main haul road transects the Mountain Station study area at approximately the 1100 m level. Physical examination of the topography in this area reveals a rather abrupt change in soil conditions. Below the site the soil is relatively deep and exhibits distinct horizons. Above the site, however, the soil is less developed and shows signs of colluvial deposits. There also appears to be a change in soil moisture conditions as inferred from a change in biota. The area below the proposed road is covered by hemlock and Douglas fir while the upper area contains an abundance of more xerophytic species such as lodgepole pine. This evidence, plus the fact that there is an abrupt increase in the slope above this point tends to support the hypothesis that the proposed haul road is sited at the top of a discharge area. Local residents in the Mountain Station area are concerned that logging development will have a detrimental effect upon their water supply.

Study Sites and Methods

In addition to the monitoring points on Tank Creek and Postle Spring (Fig. 8), Anderson Creek was also examined. The Inland Waters Directorate of the Water Survey of Canada maintains a recording stream gauge and weir just above the City of Nelson's reservoir (Fig. 7). The Anderson Creek watershed covers 907 ha The basin areas of the other study sites could not be accurately determined due to frequent undulations in the relief. Furthermore it is unlikely that relief is a good indication of basin area when used on such a small scale because the fractured nature of the parent material and bedrock will undoubtedly allow water to transect these boundaries.

The flow at Tank Creek monitoring site was measured by sandbagging a 30 cm wide weir into the stream bank. Although no leaks were visible, there was probably considerable seepage around the ends of the weir as the soil in this area appeared to have a high permeability.

The water at the Postle Spring monitoring point was collected from a rock face by an earthen berm and then directed through a plastic pipe into a settling box. Flow measurements were then made using the bucket and stopwatch method. The actual sampling frequencies for the specific study sites within the Mountain Station study area are listed in Tables 2, 3 and 4.

Within the Mountain Station study area rain gauges were placed along the Tank Creek transect at the 650, 900, 1125 and 1350 m elevations (Fig. 8, 1350 raingauge not showen). In addition, two rain gauges were placed in the Anderson Creek watershed, one near the monitoring point at an elevation of 750 m and the other approximately 500 m further upstream at an elevation of 900 m.

Results

A storm meeting all the requirements for quantitative hydrograph separation, as detailed in the review section of this paper, covered the study area at approximately 0100 h on 11 August 1982. Prior to this storm the soil in the watersheds was close to saturation as a number of small precipitation events (< 2mm having no effect upon the stream hydrograph) had preceded the frontal system. The storm ended at about 1100 h on the same day having reached a maximum intensity of 14 mm/h and precipitating a total of 32 mm of rain. Analysis of the rain water samples produced the values listed in Table 1.

Table 2 lists the sampling frequency and flow measurement data for Tank Creek, and Fig. 9 depicts these data as a hydrograph. The stream increased its flow 5.7 l/s from its prestorm discharge. The isotopic content of the storm runoff also increased as the rain water contained substantially more oxygen-18 than did the prestorm runoff, as a consequence, the del value of the stream water increased from -18.22‰ to a high of -17.21‰. The 12 uS conductivity of the rain water obviously had a dilution effect upon the stream water as it caused the conductivity to drop from 206 uS to a low of 190 uS. The correlation between the isotopic and the conductance methods of hydrograph separation for Tank Creek resulted in a Pearson r value of -0.97. Furthermore a two-tailed t-test indicated that this correlation was significant at the 0.001 level.

Table 1

The Results of the Analyses of Rainwater Samples for the Mountain Station Study Site

TANK CREEK TRANSECT

ELEVATION (m)	DATE	TIME	RAIN (mm)	CONDUCTANCE (uS)	^{18}O (‰)
650	11 Aug	0845	10	13	-12.72
		1110	9	8	-12.80
		1310	12	12	-12.66
900	11 Aug	0900	12	15	-12.58
		1140	9	8	-12.59
		1325	12	17	-13.03
1125	12 Aug	1225	31	14	-12.83
1350	12 Aug	1250	34	15	-12.72

ANDERSON CREEK TRANSECT

ELEVATION (m)	DATE	TIME	RAIN (mm)	CONDUCTANCE (uS)	^{18}O (‰)
750	11 Aug	0725	10	12	-12.48
		1040	8	16	-12.68
		1230	13	7	-12.91
900	12 Aug	1130	31	11	-12.62

Table 2

The Results of the Analyses of Stream Flow Samples for the Tank Creek Study Site

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
0930	9 Aug	7.3	204	-18.03
1600	10 Aug	4.2	206	-18.18
0230	11 Aug	3.0	206	-18.22
0845	11 Aug	4.4	197	-17.63
1110	11 Aug	8.7	190	-17.21
1310	11 Aug	7.3	197	-17.55
1515	11 Aug	6.5	199	-17.75
1720	11 Aug	6.1	201	-17.98
1920	11 Aug	5.7	203	-18.02
0945	12 Aug	4.6	202	-18.16
1830	12 Aug	4.4	205	-18.19
Rain water			12	-12.72

peak flow = 8.7 l/s

prestorm water at peak flow as calculated through isotopic analysis = 7.0 l/s or 81% of total flow.

prestorm water at peak flow as calculated through analysis of conductance = 7.8 l/s or 90% of total flow.

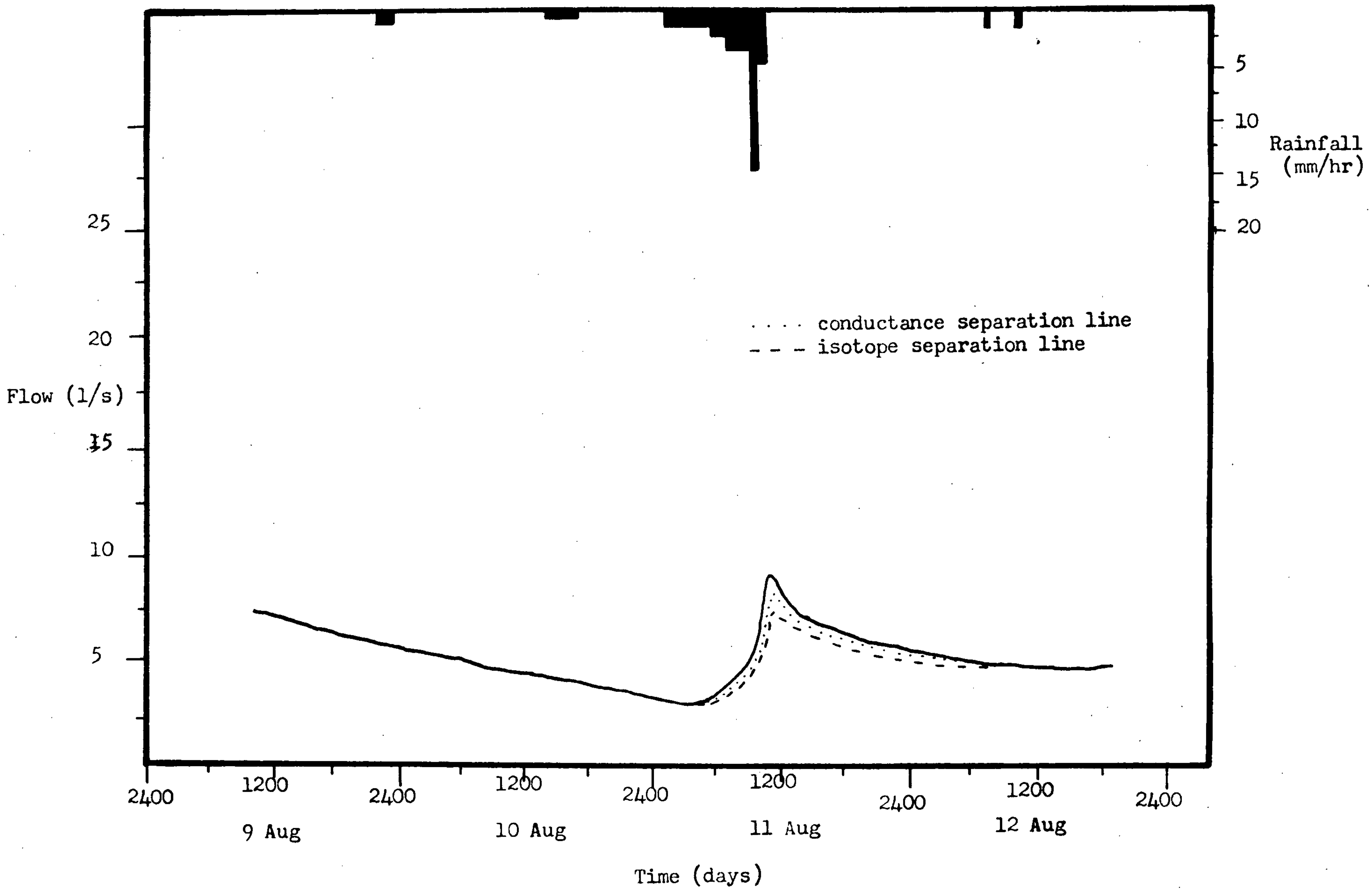


Fig.9 Tank Creek Hydrograph

Table 3

The Results of the Analyses of Stream Flow Samples for the Postle Spring Study Site

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
0900	9 Aug	0.27	228	-18.15
1545	10 Aug	0.27	230	-18.22
0250	11 Aug	0.27	230	-18.24
0900	11 Aug	0.27	228	-17.95
1140	11 Aug	0.27	225	-17.93
1325	11 Aug	0.27	225	-17.97
1530	11 Aug	0.27	229	-18.14
1740	11 Aug	0.27	229	-18.15
0820	12 Aug	0.28	228	-18.17
1900	12 Aug	0.27	230	-18.19
Rain water			12	-12.72

peak flow = 0.27 l/s

prestorm water at peak flow as calculated through isotopic analysis = 0.25 l/s or 92% of total flow.

prestorm water at peak flow as calculated through analysis of conductance = 0.26 l/s or 96% of total flow.

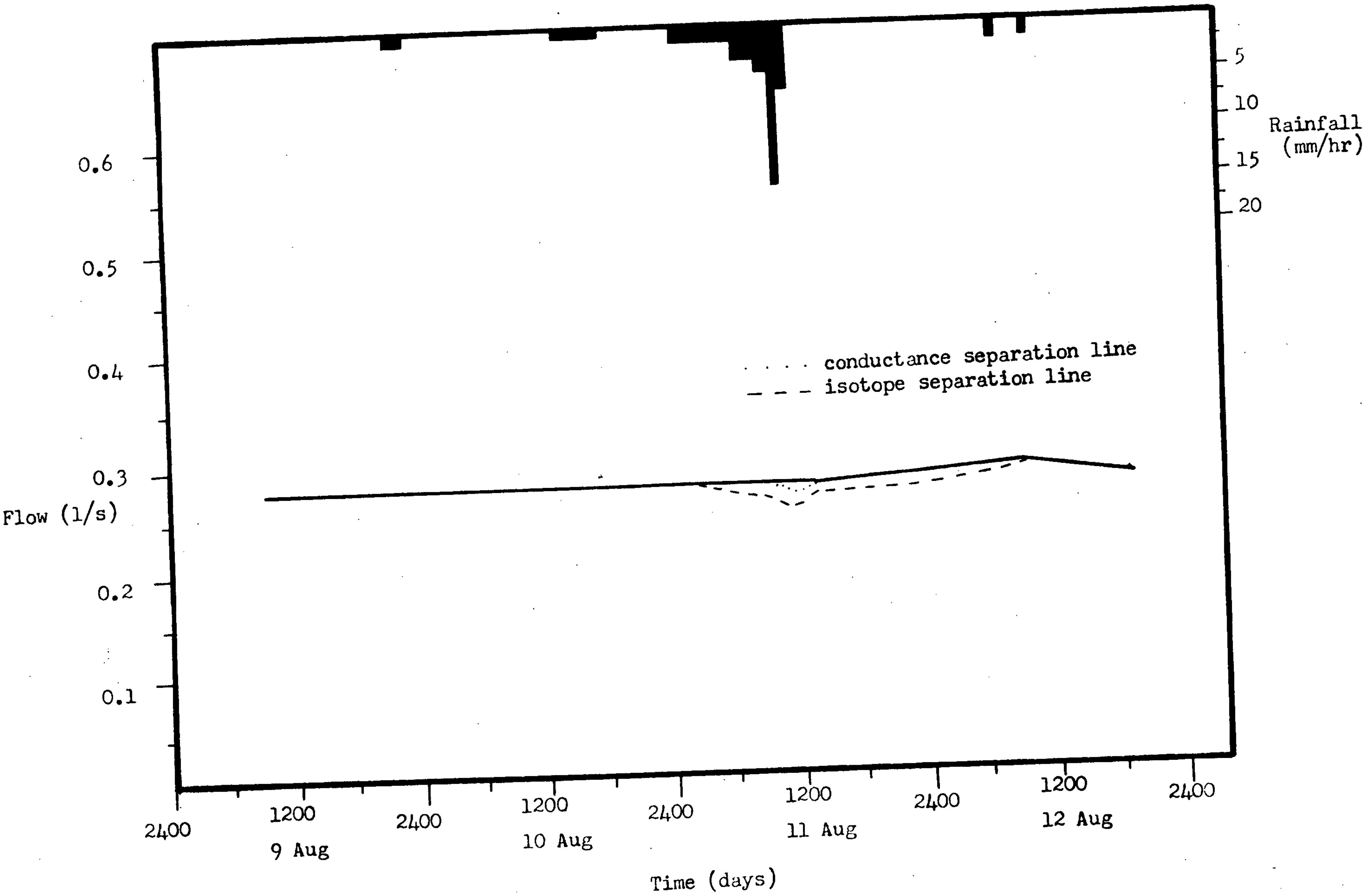


Fig. 10 Postle Spring Hydrograph

Table 4

The Results of the Analyses of Stream Flow Samples for the Anderson Creek Study Site

basin area = 9.07 km^2

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
0950	9 Aug	75	99	-17.80
1630	10 Aug	70	96	-17.82
0200	11 Aug	67	98	-17.83
0725	11 Aug	107	92	-17.72
1040	11 Aug	181	90	-17.39
1230	11 Aug	208	85	-17.40
1430	11 Aug	173	89	-17.49
1650	11 Aug	134	93	-17.58
1855	11 Aug	123	93	-17.63
0850	12 Aug	95	95	-17.68
1800	12 Aug	80	96	-17.76
Rain water			12	-12.72

peak flow = 211 l/s

prestorm water at peak flow as calculated through isotopic analysis = 192 l/s or 91% of total flow.

prestorm water at peak flow as calculated through analysis of conductance = 179 l/s or 85% of total flow.

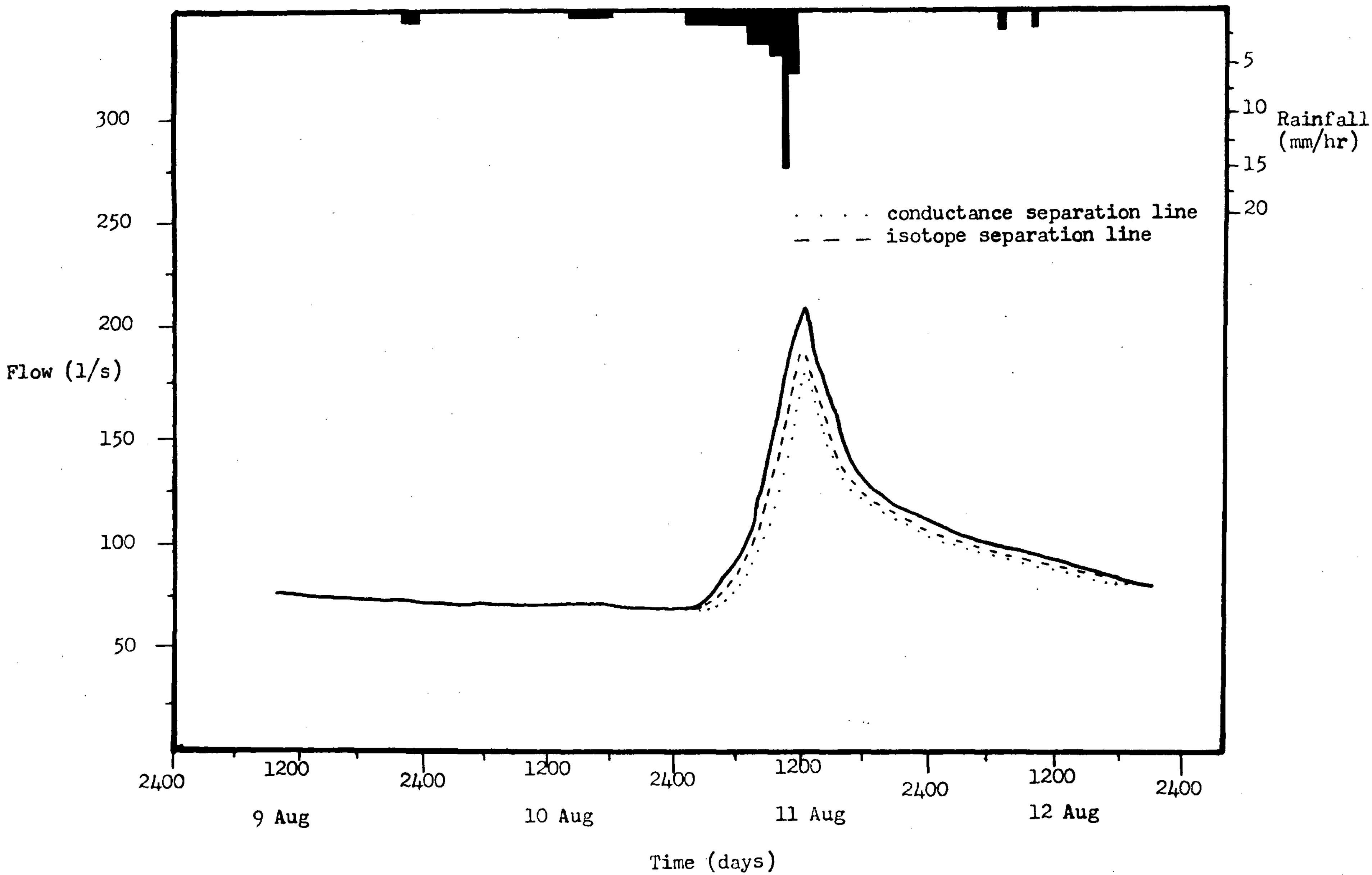


Fig. 11 Anderson Cerrk Hydrograph

Table 3 and Fig. 10 depict similar measurements for the Postle Spring monitoring site although the magnitudes of the effects are greatly decreased due to the small size of the seep. The statistical analysis for this study site resulted in a r value of -0.85 and the t value indicated that this was significant at the 0.01 level.

The data collected at Anderson Creek monitoring site are given in Table 4 and Fig. 11. The correlation for this study site proved to be -0.83 and this value was significant to the 0.01 level.

Discussion of Findings

The lack of response to the precipitation as exhibited by the flow data obtained for Postle Spring, indicates that the discharge from the spring was independent of the storm event, as the reliable detection limit for this method of flow measurement is well below 0.01 l/s.

The oxygen-18 and conductance data however, reveal a definite aberration. The 0.31 ‰ change in the isotope content of the spring water is well above the analytical limitations of the mass spectrometer and therefore indicates the presence of a dilution effect within the system. A similar conclusion can be drawn from the 5 uS drop in the conductance values.

These data suggest that the major factor controlling the flow rate is the hydraulic conductivity of the porous medium as opposed to the hydraulic head. In this particular instance it seems that the rock fractures carrying the water to the surface were already at capacity prior to the storm event, and therefore the expected increase in hydraulic head caused by the precipitation had little effect. Nevertheless the detection of the dilution effect indicates that at peak flow approximately 6% of the water expelled from the spring originated from the storm. This storm water probably originated as a combination of both channel interception and subsurface storm flow. Its lack of impact upon total runoff is probably a reflection of the errors involved in flow measurement on such a small scale.

The data obtained for Tank Creek shows that approximately 85% of the peak runoff can be attributed to prestorm water. Since this creek has its origin in seeps similar to Postle Spring and since Postle Spring had a prestorm component of 94%, it is likely that the 9% increase in surface runoff is gained between the 900 m and the 650 m levels as this is the difference in elevation between the Postle Spring and the Tank Creek monitoring points. Field examination of the slope suggests that the lower regions are most responsible for this phenomenon. As the slope of the hillside decreases, the surface area drained by Tank Creek increases.

The larger size of the Anderson Creek watershed as compared to Tank Creek can easily be discerned from the data. The time to peak for Tank Creek was approximately 8 h whereas Anderson Creek took 10.5 h to reach its maximum flow. Although these times to peak values are not exact, due to the intermittent sampling schedule, the resolution is sufficiently detailed to confirm this trend. When the oxygen-18 and conductance values are averaged they show that 88% of the peak flow can be attributed to prestorm water. Because interflow is an unlikely occurrence in this type of terrain, as previously noted, and as no overland flow was observed throughout the storm it would appear that most of the 12% of the water that originated from the storm entered the stream as groundwater flow. The minor contribution of channel interception is indicated by the recession limbs of both types of analysis. If channel interception were a large factor in storm runoff one would expect to see a sharp reduction in the contribution of storm water after the precipitation had stopped. The minor contribution of channel interception is further supported by the measurements of the surface area of Anderson Creek. When this value is expressed as a function of the whole watershed area it is seen that channel interception accounts for less than 0.05% of the storm water runoff. This calculation is only approximate, however, as the exact surface area of Anderson Creek and its ephemeral contributers is difficult to determine. Furthermore, the interception of some of the precipitation by the canopy of the riparian vegetation will tend to further decrease the amount of runoff attributable to channel interception as calculated by this method.

Since the area of the Anderson Creek drainage basin is known to be 9.07 km^2 and assuming that the precipitation released by the storm over this area was a uniform 32 mm, a number of rough calculations can be made in order to quantify the storm runoff. From the data it would appear that approximately 2.9×10^8 l of rain fell on the Anderson Creek watershed. Because of factors such as canopy interception and subsequent evaporation the net amount of storm water injected into the drainage basin is unknown. If, however, through interpolation, the total runoff and mean separation limbs of the Anderson Creek hydrograph are extended to the point of convergence the total runoff of the storm hydrograph is estimated as 1.55×10^{7} l (17.0mm), of this value only 1.22×10^{6} l (1.3mm) can be attributed to storm water.

Hewlett's hydrograph response factor is a quantitative expression of the efficiency of a drainage basin and is defined as the ratio of storm runoff to precipitation (Hewlett 1967). Usually this calculation is based on annual data and the value of direct runoff is determined using Hewlett's constant slope method of hydrograph separation. This measurement has some value when applied to specific storm events. Using the data as determined in the present study Anderson Creek has a response factor of 0.042. This value indicates that Anderson Creek has a very well regulated response to precipitation events. The hydrograph response factor for Anderson Creek as indicated by Hewlett's constant slope method of hydrograph separation is quite similar in that it renders a value of 0.057. The discrepancy between these two values is likely attributable to the different values obtained for direct runoff as determined by the isotopic method of hydrograph separation and Hewlett's constant slope method.

The rainwater samples from the different elevations were found to be remarkably similar in both oxygen-18 content and conductance. The absence of any altitude effect is probably attributable to the fact that the prevailing winds were from the south-west, which places the study area in a localized rain shadow since the systems will engage the other side of the mountain first. As a result, precipitation originated from an even cloud base which had a uniform isotopic content.

The vast difference between the del value of the rain water (-12.72‰) and the prestorm runoff (-18.18‰) is explained by the seasonal fractionation effect. The lower temperatures of winter will reduce the oxygen-18 concentration of precipitation during these months. The water then infiltrates into the groundwater system during the spring melt. Continual sampling for oxygen-18 throughout the year may provide insight into the size and recharge rate of this aquifer.

Conclusions

The obvious conclusion is that during the summer the majority of the runoff in the Mountain Station drainage system originates as groundwater and that the infrequent summer storms can play only a minor role in groundwater recharge. By far the dominant factor in the hydrology of this area is the recharge of the groundwater system by snow melt. Heatherington (1977) drew similar conclusions when he investigated two small watersheds in the Creston area of the East Kootenay. This is further supported by examination of the runoff record for Anderson Creek and the meteorological records for Nelson. The record shows that approximately 61% of annual runoff occurs during the peak snowmelt months of May and June whereas only 14% of annual precipitation occurs during the same time period.

The proposed road at the south end of the study area may cause a minor increase in the spring season runoff as the result of directing upslope snow melt into stream channels but with the correct placement of culverts this is unlikely to be a problem.

Since it appears that the road is to be located at the top of the groundwater discharge area it is unlikely to cause a noticeable decrease in the sustained yield of the local creeks. The proposed road is also sufficiently upstream of any of the present water licences to preclude a sedimentation problem. Although these findings are only based on a single set of data it seems unlikely that the construction of the haul road in its proposed location will have any serious effect upon the quantity or the quality of the water within the study area.

CHAPTER 4 - NORTH SHORE STUDY AREA

Area Description

The North Shore study area is on the south-east side of Mount Nelson approximately 3 km outside of the city limits along highway 3A toward Balfour (Fig. 7). Morley Spring, which was the sole monitoring point in this study area, is located near the bottom of an old rock scree. The slope above the monitoring point is a fairly uniform 38^{o} and is partially covered with immature Douglas fir and larch. About 25% of the slope is either exposed bedrock or old slide areas. Although the hillside was logged off approximately 50 years ago it would appear that most of the mass movement and shallow soil horizons predated this operation. The geology of this area is quite different from that of the Mountain Station study area as the bedrock belongs to the Nelson Granite group. Examination of a number of profiles indicated that the soil in this area is a Buhl Creek, Lithic Humo-feric Podzol (Jungen 1980). This type of soil is classified as being rapidly drained although there may be some sites that are imperfectly drained due to long periods of continuous seepage. The ecological classification of this area has it belonging to the Interior Ceadr-Hemlock zone (Watts 1983).

At present the water from Morley Spring is totally diverted into a large holding tank which is located upslope of highway 3A. From there the water crosses the road and is distributed to 8 individual licence holders. The system is licenced for a total of 31 m^3/day which is 7 m^3/day more than could be supplied by the prestorm flow on the day measured. In most circumstances this over-licencing is not a problem as not everyone uses their full entitlement every day and the large storage tank provides a means by which the surplus water can be held for future use. Under late summer drought conditions, however, the licencees are often forced to adopt a rationing scheme.

This scenario is typical of many areas along the north shore of Kootenay Arm. The region is a popular recreation site and is expanding rapidly. The availability of a potable water supply is one of the limiting factors in recreational and residential development. At present there is no central water works to service this region and residents seem reluctant to use lake water for domestic purposes. As a result, all springs and seeps in this area are heavily licenced.

The Water Management Branch has difficulty in assessing the exact potential of each of the springs in this area, and during dry spells the senior licence holders complain that they are unable to obtain their full entitlement. The oxygen isotope and conductance analyses may shed some light on the dynamics of the system and thereby permit more accurate licencing.

Study Site and Methods

The flow at the Morley Spring monitoring site was measured using the bucket and stopwatch method. Since the entire flow was diverted into a plastic drainage pipe at its origin there was no need to build an additional structure. Although all of the surface flow was trapped there may have been some leakage through the stream bed. Leakage would affect the data in an absolute sense, but would make little difference from a pragmatic standpoint as this water is also lost to potential users of the resource.

Rain gauges were placed next to the flow monitoring point at an elevation of 550 m and further up the slope at the 1000 m level (Fig. 12).

Results

The same storm that was recorded at the Mountain Station study area was monitored for the North Shore study area. Between the hours of 0100 and 1130 on 11 August 1982 the storm deposited an average of 31mm of rain (Table 5). In response to this precipitation, Morley Spring increased its flow from a pre-event low of 0.30 l/s. to a peak of 0.38 l/s. The conductance values also changed from 141 to 129 uS and the oxygen-18 content increased from -18.27 ‰ to -17.83 ‰ . The inter-method correlation for this study site is -0.88 and the two-tailed t-value indicates a significance to greater then the 0.001 level. This data can be found in Table 6 or graphically represented in Fig. 13.

In order to determine how accurately the isotopic and conductance methods were duplicated, the data for each of the two runs were subjected to statistical analysis. The statistical results for the conductance method indicated a perfect correlation (ie r=1.0). Furthermore, a two-tailed t-value of -20.06 with 123 degrees of freedom effectively eliminates the probability of this correlation occuring by chance. The intra-method correlation coefficient for the isotopic data was similarly high, yielding a r value of 0.99. Again the two-tailed

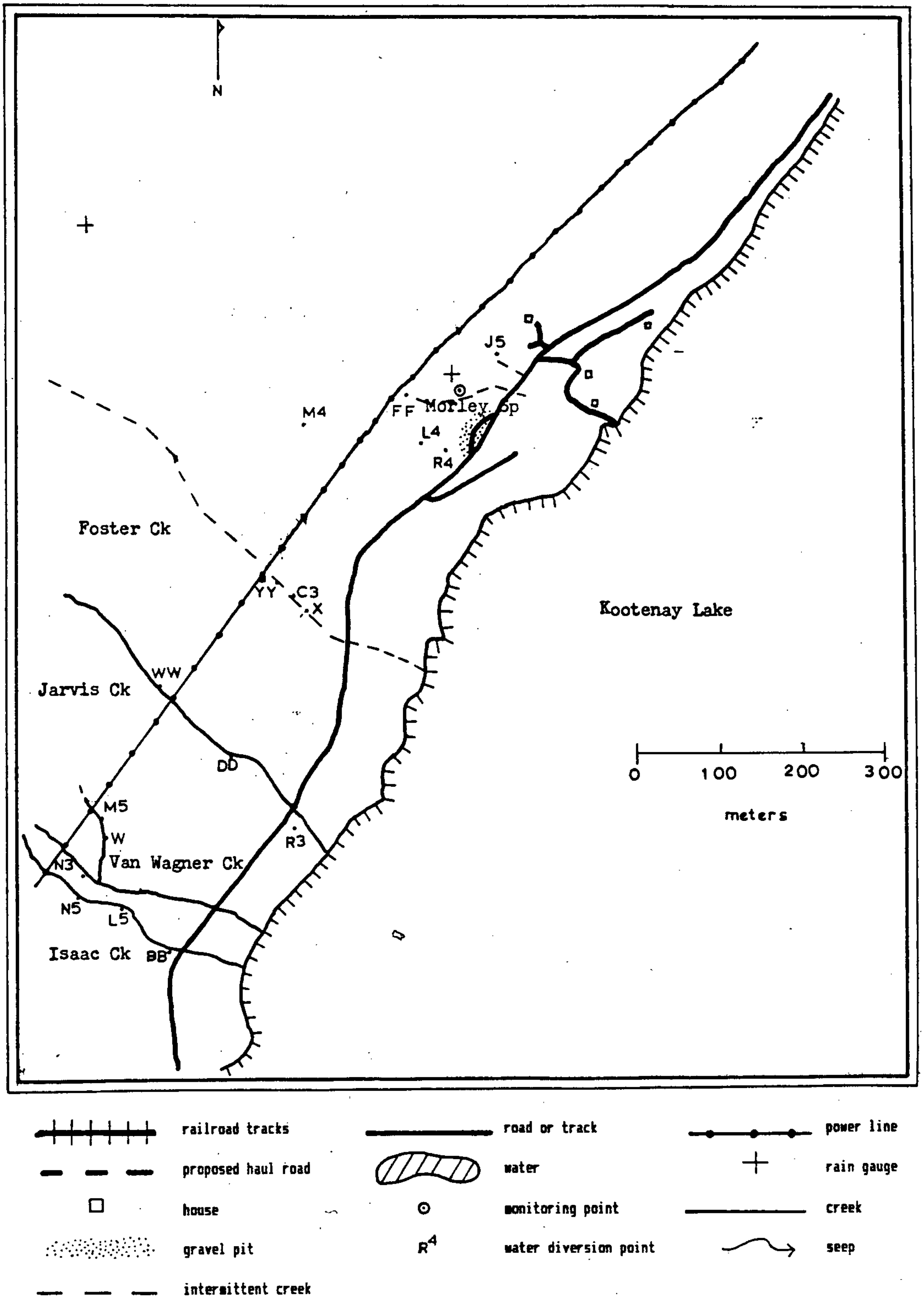


Fig. 12 North Shore study area

Table 5

The Results of the Analyses of Rainwater Samples for the North Shore Study Area

MORLEY SPRING TRANSECT

ELEVATION (m)	DATE	TIME	RAIN (mm)	CONDUCTANCE (uS)	^{18}O (‰)
550	11 AUG	0830	7	8	-12.71
		1050	7	11	-12.75
		1250	15	14	-12.81
1000	12 Aug	1035	34	16	-12.63

Table 6

The Results of the Analyses of the Stream Flow Samples for the Morley Spring Study Site

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
1005	9 Aug	0.31	127	-17.90
1645	10 Aug	0.30	138	-18.18
0215	11 Aug	0.30	141	-18.27
0830	11 Aug	0.29	133	-18.02
1050	11 Aug	0.31	133	-17.78
1250	11 Aug	0.33	129	-17.83
1450	11 Aug	0.38	132	-17.96
1705	11 Aug	0.31	134	-18.07
1905	11 Aug	0.30	137	-18.19
1010	12 Aug	0.30	138	-18.25
1815	12 Aug	0.30	139	-18.28
Rain water			12	-12.72

peak flow = 0.38 l/s

prestorm water at peak flow as calculated through isotopic analysis = 0.36 l/s or 95% of total flow.

prestorm water at peak flow as determined through analysis of conductance = 0.35 l/s or 91% of total flow.

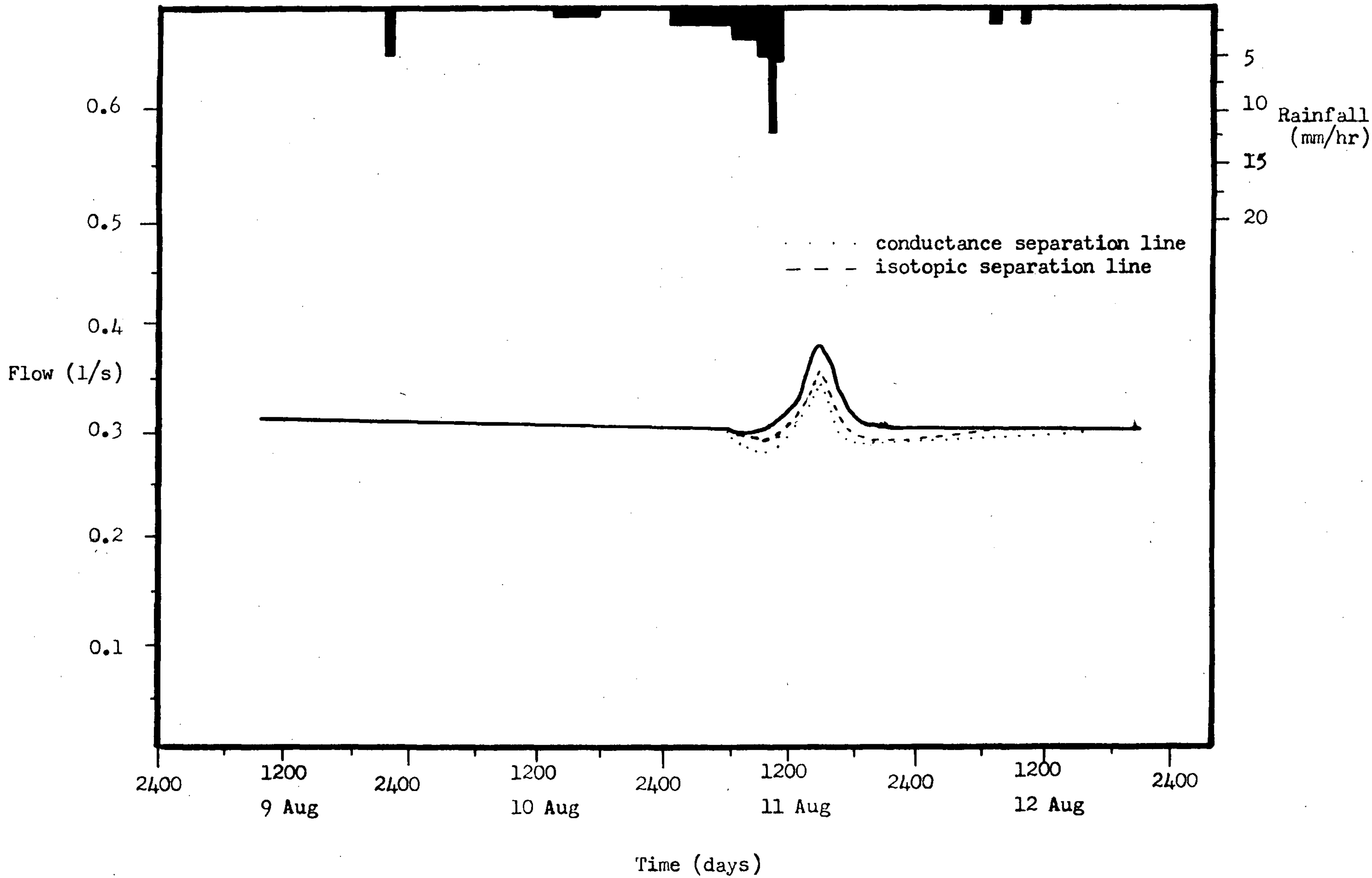


Fig. 13 Morley Spring Hydrograph

t-value indicated that the probability of this correlation occuring randomly was zero.

Discussion of Findings

The average of the two types of analysis showed that approximately 93% of the peak flow was due to prestorm water. It is interesting to note that even after 31 mm of precipitation the flow of Morley Spring increased only 0.09 l/s. Although this increase is considerably more than that at Postle Spring it would seem to represent a similar system. Since there was no sign of any overland flow and because Morley Spring originates from a rock face, the 7% of runoff that is attributable to storm water must have entered the system as either groundwater or interflow.

Conclusions

As in the Mountain Station study site it appears that most of the storm runoff is attributable to groundwater. In this case there is little that can be done to increase the rate of flow. Although there are currently no forest harvesting proposals for the North Shore area, it is unlikely that such operations would influence the water quantity through altering the evapotranspiration rates, as the water resource is probably independent of water used locally in plant transpiration. Since it is likely that a large part of the runoff from Morley Spring is the result of snow melt, as indicated by the low value of oxygen-18 in the prestorm water, the large scale removal of the forest cover can be expected to result in an increased rate of ablation of the winter snow pack. This increased rate of melting may in turn reduce the amount of water available for runoff during the summer months. Furthermore if the hillside is logged, caution should be taken when road building, since the slope is not stable and Morley Spring lies at the bottom of an old scree. Further slides may bury the resource and render it unuseable.

It is unlikely that the small springs and seeps of the North Shore area will be able to meet the requirements of future residents. Extensive development of this area will require the construction of a centralized reservoir system or a change in attitude by local residents concerning the use of lake water for domestic purposes.

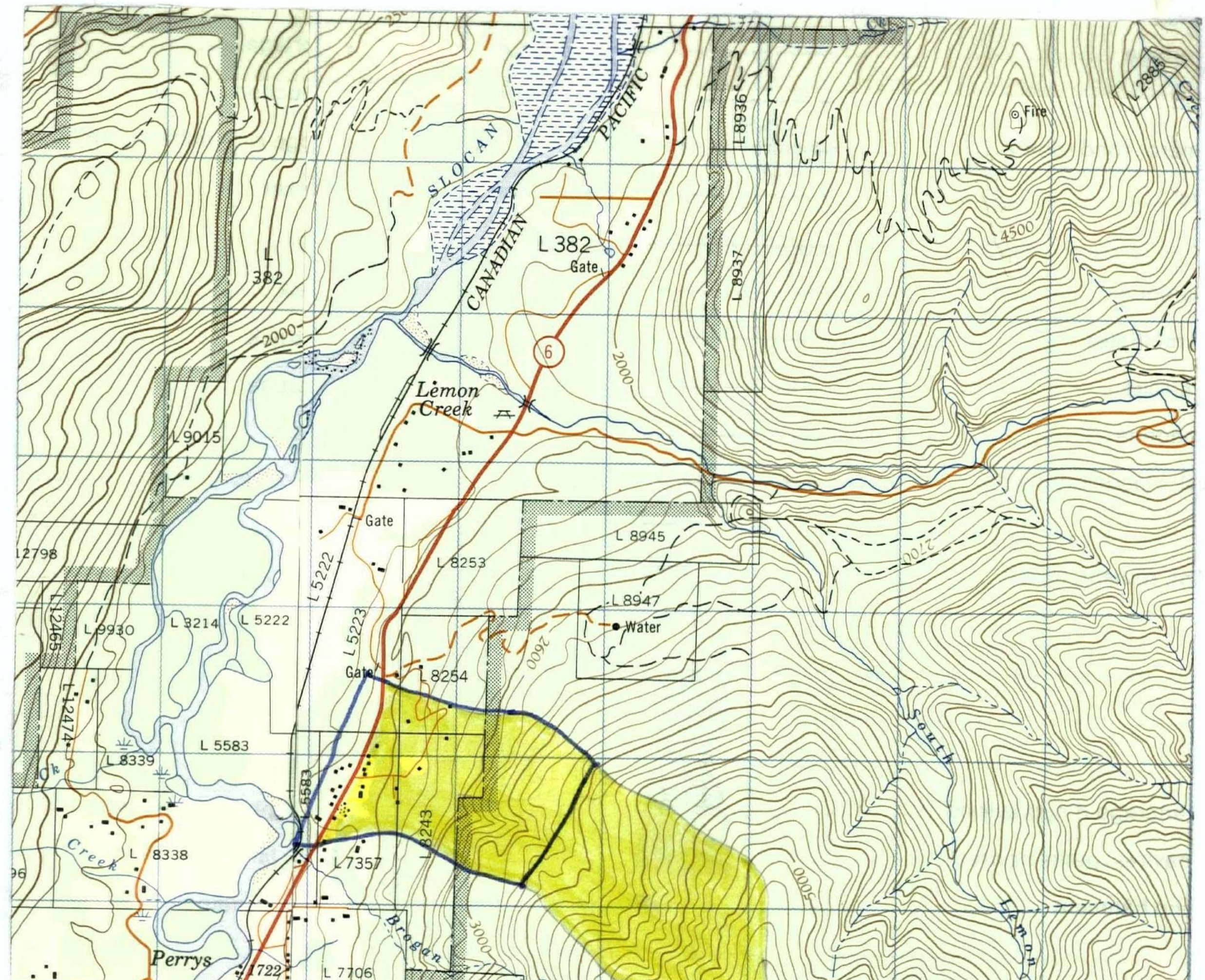
CHAPTER 3 - SLOCAN VALLEY STUDY AREA

Area Description

The area examined within the Slocan Valley is near South Lemon Creek and encompasses approximately 285 ha (Fig. 14). Although the lower region has an average slope of 20^{o} the topography is quite undulating with numerous small, almost flat areas. Most of these level stretches of ground have been cleared The slope in the upper regions, however, is much more uniform and has a mean inclination of 32^{o}. The region is largely covered with mature Douglas fir and larch. This study area also belongs to the Interior Cedar-Hemlock zone of ecological classifaction (Watts 1983).

The geology of the area is similar to that of the North Shore study area, with bedrock consisting of Nelson Granite. Approximately 70% of the soil within the study area belongs to the Slocan series of Ortho Humo-feric Podzols while the remaining 30% belongs to the Buhl Creek series (Jungen 1980). The Slocan series is associated with a moderately compact glacial till parent material and, as such, is well drained.

There are currently 11 water licences held within the study area which represent a total demand of 72 m^3/day. Of this total, a demand of 52 m^3/day is placed on Elliott Creek, which has its origin in many small upslope tributaries. Elliott Creek goes permanently underground approximately 200 m short of the main highway. This is probably due to the coarse gravels which underlie soils within the river valley. The high permeability of the substrate permits rapid infiltration, and the stream water merely percolates down to the water table and travels to the



(highlighting delineates study area)
(insert depicts area of sketch map)

Fig. 14 Slocan Valley

Slocan River as groundwater.

The remaining 20 m^3/day of the total licence demand is assigned to Chou Creek. Chou Creek originates in a 1 ha area of flat land which is located at the base of a steep slope (Fig. 15). In this area a number of small collection trenches have been dug by the local residents to improve flow conditions. The creek then flows on the surface for approximately 300 m before going underground. The exact surface length of Chou Creek is largely dependent upon the soil moisture conditions, as during storm events it may be extended another 200 m downstream.

The residents of the area have experienced water restrictions during low flow conditions, and are concerned by one of the Ministry of Forests proposals in the Slocan Valley access plan which calls for construction of a haul road just above their water diversion points. Although nothing has been formalized, it would appear that this proposal is the most viable option from engineering and financial standpoints. Therefore, this study was conducted to gain a better understanding of the hydrology of the area, with the hope that this information would forestall any deleterious development.

Study Sites and Methods

Elliott Creek is currently gauged by the Inland Waters Directorate of the Water Survey of Canada. This weir was also selected as a monitoring site in the present study. Flow from Chou Creek was measured using the bucket and stopwatch method, and utilized the earth berm and plastic pipe of the uppermost diversion point. As previously mentioned, Chou Creek originates

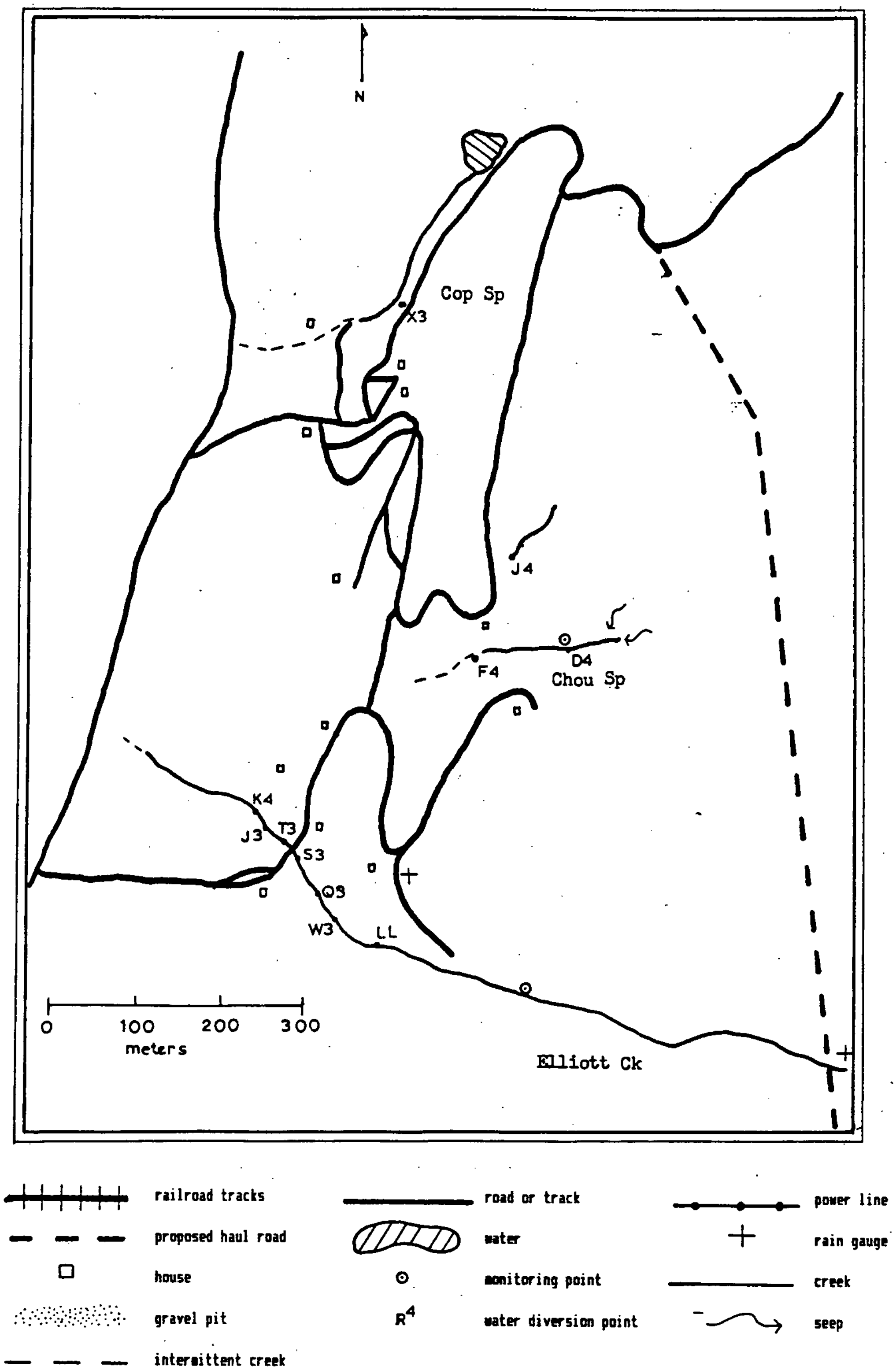


Fig. 15 Slocan Valley study area

as an area source, and because of the lack of a definite stream channel the monitoring point was designed to measure that part of the total flow which could actually be diverted for useful purposes. Rain gauges were placed at the 600, 900 and 1200 m elevations, the lower two of which are indicated on Fig. 15.

Results

A frontal system passed over the study area at 1000 h on 9 September 1982. Precipitation continued fairly continuously until 0600 h the following morning, depositing an average of 25 mm of rain. The data produced by the analysis of the rainwater samples is listed in Table 7. The antecedent soil moisture conditions were near saturation, as a previous weather system had dropped rain over the study area approximately 3 days earlier, and since that time the temperature had remained cool and the sky overcast. Table 8 lists the data obtained for Chou Creek and Fig. 16 depicts this information as a hydrograph. Similar data can be found for Elliott Creek in Table 9 and Fig. 17. The correlation coefficient between the two types of analysis was -0.69 for Chou Creek and -0.61 for Elliott Creek and the corresponding t values indicate levels of significance of 0.10 and 0.05 respectively.

Discussion of Findings

The Chou Creek hydrograph shows that approximately 84% of the total peak runoff is prestorm water. The Elliott Creek hydrograph is quite similar as it shows 87% of the peak flow as prestorm water. Unfortunately, due to the difficulty in measuring the drainage area of Chou Creek these two watersheds can not be compared on a unit area basis. The similarity between

Table 7

The Results of the Analyses of Rainwater Samples for the Slocan Valley Study Site

ELLIOTT CREEK TRANSECT

ELEVATION (m)	DATE	TIME	RAIN (mm)	CONDUCTANCE (uS)	^{18}O (‰)
600	9 Sep	1200	2	16	-13.60
		1530	6	11	-13.50
		1900	5	9	-13.69
		2130	3	16	-13.44
	10 Sep	1230	8	14	-13.52
900	10 Sep	1320	24	20	-13.48
1200	10 Sep	1350	27	15	-13.19

Table 8

The Results of the Analyses of Stream Flow Samples for the Chou Creek Study Site

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
0600	8 Sep	0.16	320	-17.63
1530	8 Sep	0.16	322	-17.66
1150	9 Sep	0.41	304	-17.44
1520	9 Sep	0.55	274	-17.15
1855	9 Sep	0.52	288	-17.31
2120	9 Sep	0.48	285	-17.27
0850	10 Sep	0.38	315	-17.42
1145	10 Sep	0.36	305	-17.08
2200	10 Sep	0.30	312	-17.19
0550	11 Sep	0.25	318	-17.34
Rain water			13	-13.53

peak flow = 0.56 l/s

prestorm water at peak flow as calculated through isotopic analysis = 0.48 l/s or 86% of total flow.

prestorm water at peak flow as calculated through analysis of conductance = 0.46 or 82% of total flow.

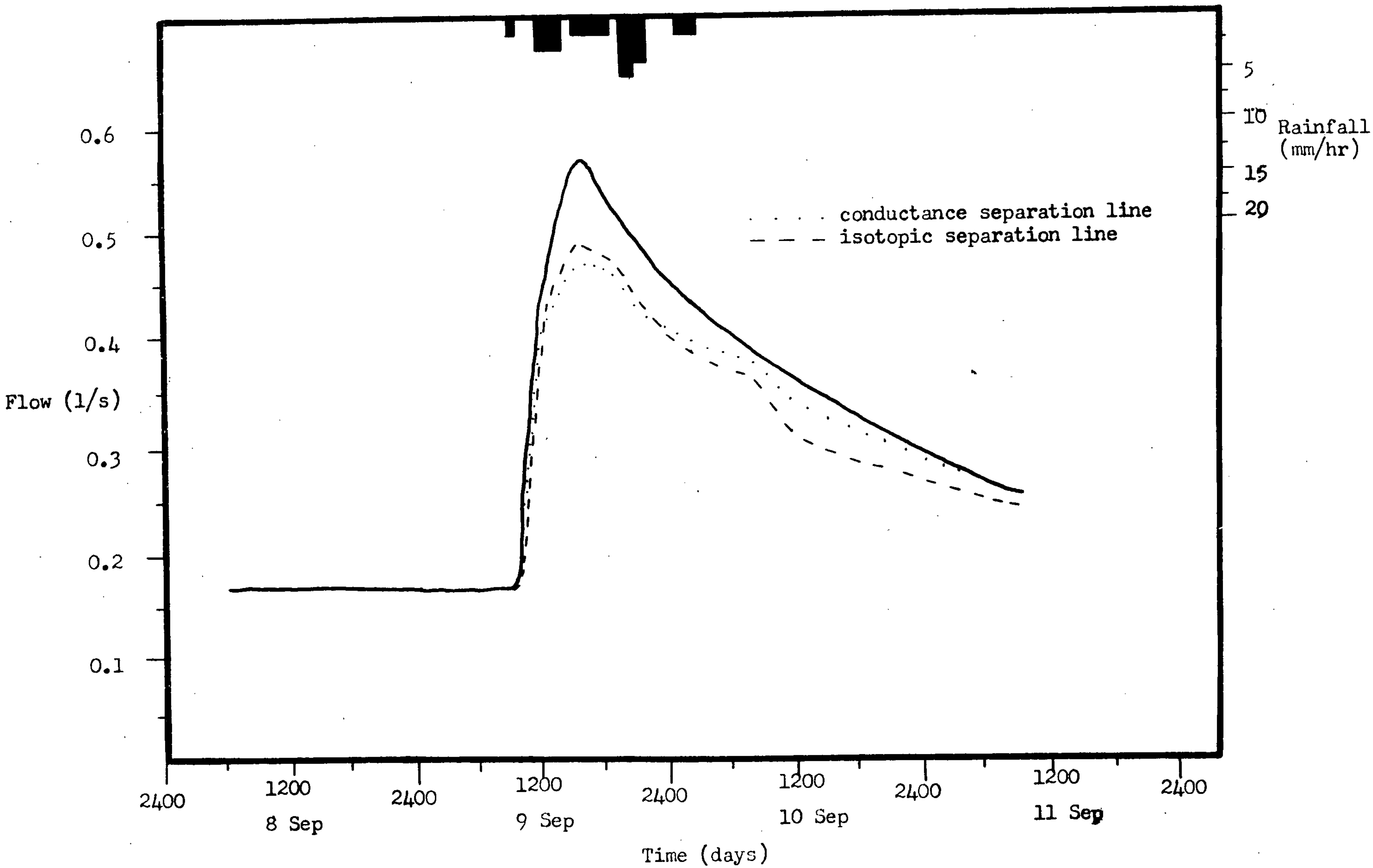


Fig. 16 Chou Creek Hydrograph

Table 9

The Results of the Analyses of Stream Flow Samples for the Elliott Creek Study Site

basin area = 2.4 km^2

TIME	DATE	FLOW (l/s)	CONDUCTIVITY (uS)	^{18}O (‰)
0610	8 Sep	5	195	-18.55
1550	8 Sep	5	199	-18.57
1200	9 Sep	7	189	-18.40
1535	9 Sep	10	187	-18.31
1905	9 Sep	16	184	-18.26
2130	9 Sep	18	180	-18.02
0900	10 Sep	14	179	-17.86
1155	10 Sep	13	187	-17.85
2210	10 Sep	11	189	-17.90
0610	11 Sep	10	193	-17.96
Rain water			13	-13.53

peak flow = 18.5 l/s

prestorm water at peak flow as calculated through isotopic analysis = 16.0 l/s or 86% of total flow.

prestorm water at peak flow as calculated through analysis of conductance = 16.5 l/s or 89% of total flow.

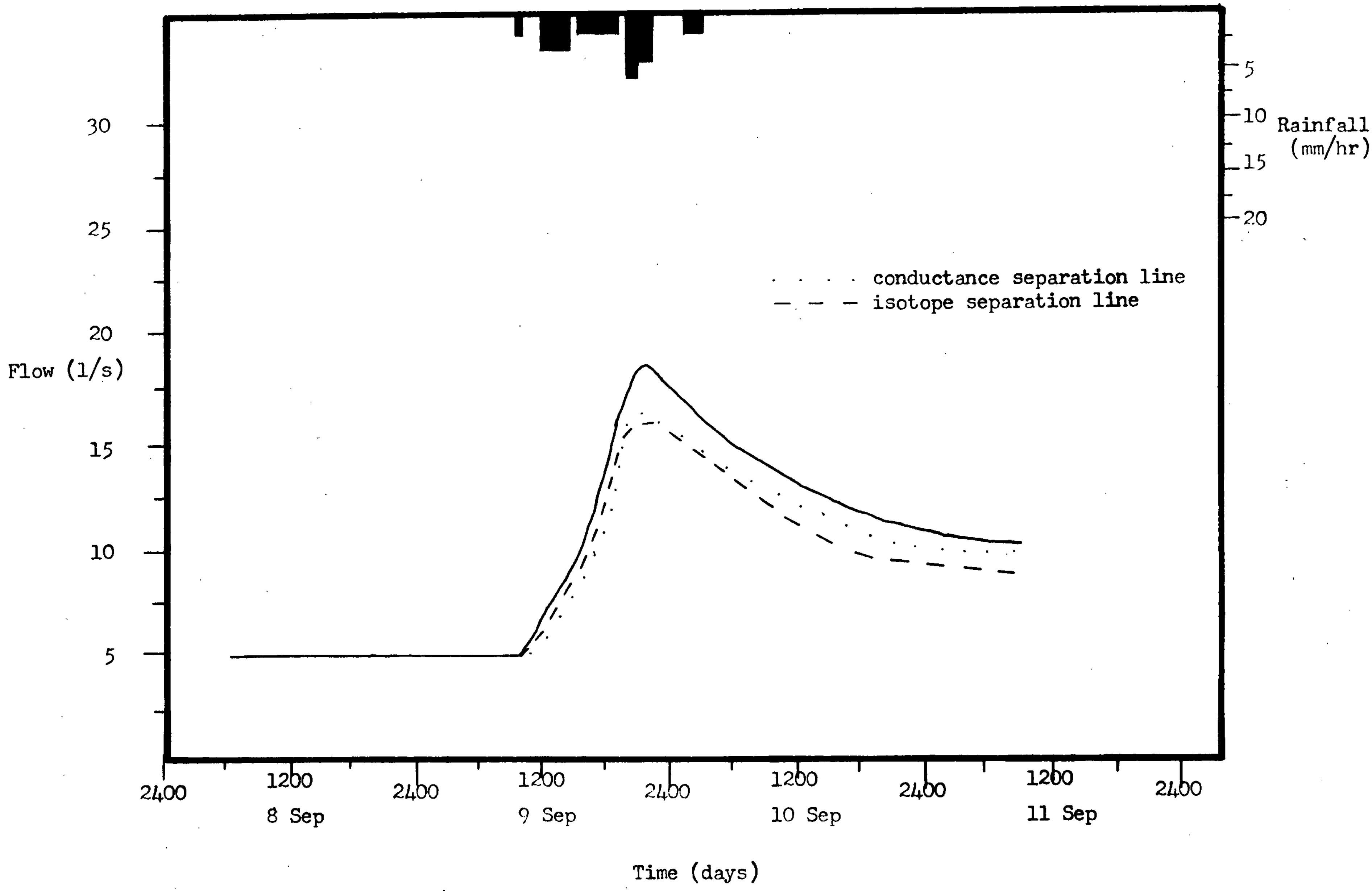


Fig. 17 Elliott Creek Hydrograph

the two creeks, however, is further illustrated in the magnitude of the increased flow. The peak discharge of Chou Creek was 3.5 times as high as the prestorm low, whereas the flow of Elliott Creek increased 3.8 times.

The obvious difference between the hydrograph obtained for Chou Creek and that recorded for Elliott Creek is the time to peak factor. Chou Creek took only 3.5 h to reach its peak from the prestorm low whereas Elliott Creek took 11 h Given that the hydraulic conductivity and gradients are similar in both catchments this anomaly obviously reflects the different size of the respective drainage areas. Size differences are also illustrated in the recession limb of the Chou Creek hydrograph. The secondary peaks indicated by the conductance and isotope analysis lines were probably caused by a small shower after the passage of the main frontal system and do not show up in the total runoff hydrograph because of sampling error. Although subjected to the same shower these peaks are not detectable on the recession limb of the Elliott Creek hydrograph. This masking effect is probably due to the delay incurred by the larger creek as the result of channel routing.

When the rain water samples were analyzed for their oxygen-18 content they were again found to be almost identical despite their elevational differences. It is interesting to note, however, that the isotopic spread between the rain water and the prestorm groundwater is less than found in the other two study areas. One contributing factor to this trend may be related to the change in the ratio of snow melt groundwater to summer rain storm groundwater. As the summer progresses the snow melt component of the groundwater decreases due to runoff, while the rain component of the groundwater is added to by storms. This trend may be further enhanced by the decrease in the isotopic content of the rain water itself. As the warmer temperatures of summer abate, the fractionation ratio will change. Although this trend is based on only two storms, it would seem to support the theory that the majority of groundwater is snow melt.

Conclusions

It is obvious from the data collected in this study area, that again the large majority of storm discharge originates from groundwater. In the case of Elliott Creek the proposed development should, if anything, increase the stream flow due to a reduction in evapotranspiration.

In the case of Chou Creek however, the effect of the proposed development is not as clear. The convoluted topography and type of surficial deposits within the study site make exact delineation of the watershed difficult. It is unlikly that relief is a good indicator of subsurface divides. Given the size of the study site then, any attempt to estimate the area drained by Chou Creek is likely to be dominated by measurement errors. It is therefore impossible to determine the percentage of the watershed that would be disrupted by road development. Although one would normally expect an increase in snow pack accumulation as the result of the partial clearing associated with road construction, the preceding fact precludes accurate quantification of this effect.

The construction of a haul road that transects the Chou Creek area, however, may compact the surficial material enough to significantly reduce its hydraulic conductivity. If this surficial material is compacted down to an impermeable layer it may cause the diversion of upslope runoff out of the Chou Creek watershed. Culverting alone would be an ineffective solution to the problem as it will likely result in an increased surface runoff rate and thereby reduce the critical low flow conditions. A better solution to the problem is to increase the distance between the proposed development and Chou Creek. If the haul road were built further upslope of the Chou Creek discharge area, and if care was taken in the placement of culverts so as not to divert surface water out of the drainage basin, the proposed development is unlikely to have any significant effect upon the water quality or quantity of the spring.

CHAPTER 6 - STUDY CONCLUSIONS

The findings of this study indicate that the amount of runoff attributed to prestorm water can be determined using either isotopic or conductance methods. It would appear that the use of these methodologies in hydrograph separation produce valid results regardless of the size of the watercourse, and that the limiting factor in this type of procedure is the accuracy of flow measurement. Furthermore, this study also indicates that groundwater is the major runoff component of storm hydrographs within the area of the Kootenays studied. This finding is consistent with the recent studies of Martinec (1975), Fritz, Cherry, Weyer, and Sklash (1976) and Sklash and Farvolden (1979), but is in contradiction to the earlier studies of Horton (1933) and Hewlett and Hibbert (1967) where the vast majority of storm runoff was attributed to storm water.

The fact that the majority of storm runoff is groundwater provides further insight into the conceptual models of storm flow generation. Within the study areas the overland flow model as originally proposed by Horton in 1933 and later modified by Beston in 1964 can be eliminated as major contributors to storm runoff as both of these theories imply that storm water is the major component of peak runoff. The theory of subsurface storm flow or interflow, as developed by Hewlett and Nutter in 1967 states that the major component of storm runoff is precipitation which has infiltrated the upper soil horizons and travels to the stream laterally above the watertable. The production of this translatory flow requires a heterogeneous soil which favours horizontal as opposed to vertical hydraulic conductivity. Although these conditions are not rare within the areas examined in this study, Hewlett and Nutter's model cannot account for the high percentage of runoff attributable to prestorm water.

The results of the present study, however, are similar to those of Sklash and Farvolden (1979) in that they both attribute a large percentage of storm runoff to prestorm water. In their work Sklash and Farvolden theorized that this runoff component may result from the formation of a groundwater ridge. They speculate that such a ridge may form near the stream channel where the water table is close to the surface and the time required for percolation to the water table is minimal. Such a groundwater ridge will result in an increased hydraulic gradient near the stream channel and thereby provide an explanation for the rapid response of the stream to precipitation. This runoff theory, however, was developed by modeling isotropic homogeneous conditions of hydraulic conductivity and therefore may not be an accurate predictor of the processes involved in the more varied environment found within a natural drainage basin.

In some cases, the rapid runoff may be caused by the percolation of the wetting front. In such a model a decrease in the thickness of the capillary fringe could be attributed to increased pressure within the soil; this, in turn would increase the hydraulic gradient of the water table, freeing more water to runoff. To obtain further information on these theories, the experimental design as used in the present study would have to be augmented with a network of piezometers.

The finding that most of the storm-generated runoff in the present study area consists primarily of prestorm groundwater is useful information to the forest hydrologist, as it gives some indication of the susceptibility of the watershed to the deleterious effects of forest harvesting practices. In circumstances such as the ones of this study, the diversion of precipitation from groundwater to surface water flow (as may result from road construction or soil compaction) is unlikely to have an appreciable effect on the overall hydrology of the watershed as any reduction in the groundwater flow as a result of these practices will represent only a small part of the total groundwater component. Furthermore, when incorporating the other effects of forest harvesting, such as the reduction of canopy interception and transpiration, any potential reduction in the groundwater component is likely to be totally masked by an overall increase of water available for runoff.

In reviewing the results of inter-method statistical analysis there seems to be a reasonable correlation for the Mountain Station and North Shore study areas although the same can not be said for the Slocan Valley study sites. As alluded to earlier the poor correlations found within the Slocan Valley study area may be attributed to some type of chemical reaction that is affecting the ionic composition of the runoff. Although a adequate explanation for this finding can not be substantiated on a single set of data, this anomaly would tend to support the continued use of both methods of analysis as independant checks.

A continuation of our studies over a longer period of time may provide additional insight into the physical characteristics governing the flow system. For instance, the data for all three study sites were obtained when the prestorm soil moisture conditions were near saturation. This condition can be explained as a combination of both the close proximity of preceding storm events and the fact that the study sites represent a local groundwater discharge area. It would be interesting to repeat this study under different soil moisture conditions to see what effect this variable has on the flow system. Additional information may also be obtained by conducting a similar experiment with longer duration and higher intensity storms. With additional data the hydraulic conductivities and detention storage capacities of the watershed could be calculated.

A final improvement may be to conduct experiments in different seasons. As previously mentioned, it would appear that the majority of the groundwater flow had its origins as snow melt. If sampling were continued throughout the winter it may be possible to determine the location of the recharge area and the expanse of the aquifer.

GLOSSARY

Channel interception - precipitation falling on the water course.

Detention storage - pore water which is susceptible to the influences of gravity.

Direct runoff - the sum of channel interception, overland flow and interflow.

Discharge - the volume of water flowing from the watershed.

Fractionation - changing the original isotopic composition of a solution through the preferential concentration of lighter isotopes.

Groundwater - water below the phreatic surface.

Groundwater flow - that part of the total stream discharge that moves to the water course laterally below the water table as saturated flow.

Hydraulic conductivity - a parameter governing the flow of a fluid through a porous medium that is dependent upon both the properties of the medium and the fluid.

Hydraulic gradient - the change in the hydraulic head over a given distance.

Infiltration - the process by which water passes through the soil surface.

Interflow - (subsurface storm flow) that part of the total stream discharge that moves to the water course laterally through the upper soil horizons as saturated or unsaturated flow.

Mixing - changing the original isotopic composition of a solution by adding water of a different isotopic content.

Overland flow - (surface flow) that part of total stream discharge that moves to the water course laterally over the soil surface without infiltration.

Percolation - the advance of water through the soil.

Prestorm water - all the water present in the watershed prior to a particular precipitation event.

Retention storage - water held by capillary force in small pores.

Storm water - that part of the total stream discharge that is added to the watershed by a particular precipitation event.

Subsurface flow - flow through a porous media in both the saturated and unsaturated state.

Water table - the surface at which fluid pressure is equal to atmospheric pressure.

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