PREDICTION OF SEASONAL SNOWMELT RUNOFF IN THE OKANAGAN VALLEY

By

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Introduction

The Okanagan River watershed is a wide glaciated valley that forms a deep north-south cut in the Thompson plateau in the British Columbia interior. The valley experiences a semi-arid climate, with only limited amounts of runoff generated throughout the elevation range that extends to 7,000 feet above sea level.

Seasonal snowmelt runoff prediction has proved to be particularly difficult in the Okanagan Valley in British Columbia. The low residual volumes of snowmelt and rainfall runoff are quite sensitive to variations in soil moisture and groundwater storage. Secondary effects, such as the timing and the rate of snowmelt, also appear relatively more significant in the region than in areas of water abundance. Statistical regression solutions to the forecasting problem that have been developed over the last 20 years with the use of snowpack water equivalent indices and other hydrological parameters have proven to be rather disappointing and appear to lack the reliability necessary for sophisticated water level control of Okanagan Lake. This experience in seasonal water supply prediction led to the belief that the answers to the problem of hydrological forecasting are most likely to emerge from a better physical understanding of the hydrological cycle.

This paper discusses the results of the International Hydrological Decade research programme IWB-RB-37, BC-8 initiated by the British Columbia Water Resources Service, Department of Lands, Forests and Water Resources. The study could be expected to show whether the lowland areas that receive an average annual rainfall of 14 to 20 inches produce much surface or groundwater runoff. Interactions between different components of the hydrological cycle were investigated in order to obtain a better quantitative description of them. Detailed hydrological investigation of the Carrs Landing Watershed -- a localized lowland area in the Okanagan Valley -- began in 1966. Since that time it has been possible to assess the relative importance of different sub-basin parameters in the evaluation of the regional runoff situation. The research study has pointed to the potential value of the groundwater recharge movements in the intermediate elevation range, and has led to the rational development of a new method for the direct evaluation of the runoff potential in the Okanagan Valley.

Description of the Study Area

The Carrs Landing Watershed faces westward on the drainage divide between Kalamalka Lake-Wood Lake and Okanagan Lake. The location of the study area is shown in Figure 1. The divide rises to a maximum elevation of 3,500 feet and forms a low level drainage area down to the existing Okanagan Lake level of 1,120 feet. The surface drainage characteristics in the area show very few signs of recent erosion providing evidence of a low runoff potential that seems to indicate that the present-day climate in the Okanagan Valley is not noticeably modifying the topographic and erosional features in the study basin. In this respect, the study basin is not representative of the full elevation range in the Okanagan Valley as only low level land is included.

In general, the soils that have developed on the glacial till have a sandy matrix and allow high infiltration rates. Beneath the surface soils, water transmission rates decrease with increasing compactness of the basal till, the unweathered till itself being of low porosity, and having a very slow rate of water transmission. The bed rock also has a low porosity, and this is made evident by natural ponds between rock ridges in the forest. Similar ponds are developed in dugouts and natural depressions in the glacial till.

As a result of the thin mantle of till at the higher elevations, there appears to be strong bedrock control of the groundwater movements. The subsurface water appears to flow in shallow local flow systems from the sandy recharge zones on the drainage divide and

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down the till slopes under a very thin blanket of reworked colluvium. The gulley patterns of the flow system and the vegetation distribution in the study area are shown in Figure 2. The Carrs Landing area does not appear to produce significant amounts of surface runoff, and does not extend into the higher elevation zones in the Okanagan Valley that may reasonably be expected to produce the seasonal water surplus for early summer.

This fact that streamflow is essentially non-existent helps in obtaining a useful prediction index from groundwater measurements of the expected seasonal runoff that originates from other areas in the Okanagan Valley.

An Evaluation of the Subsurface Flow System in the Carrs Landing Area

The peculiarities of the Carrs Landing Watershed substantially reduce the problems of watershed modelling and hydrologic analysis. The area has a surface drainage system, but it is largely inactive. The important significance of the fact that streamflow is essentially non-existent is that the hydrologic function of the area becomes quite predictable and assumes an exceptionally damped response, that is, very substantial time delays tend to be associated with the conversion of precipitation excess into catchment discharge. The area may thus be considered as a 'base flow watershed', with only a sub-surface component of the normal watershed surface-subsurface flow system. In terms of runoff production, the surface component can be considered as hydrologically dormant.

The stability of the hydrologic function of the area is derived from the protection from erratic bursts of runoff activity that is afforded by snowpack insulation, substantial soil moisture deficits in the surface soil horizons, and high infiltration capacities especially in the forested areas. The only rapid changes to the state of the subsurface flow system appear to occur at the time of winter snowpack depletion. The potential of runoff originating from rainfall probably falls rapidly after the disappearance of the snow, and it is doubtful that much spring and summer rainfall ever reaches the water table. The fact that there is no rapid exodus of water from the watershed area in the spring means that local water budgeting is possible without the necessity of redistribution of routed streamflow quantities within the catchment area. Instrumentation can therefore permit measurement and/or estimation of the short-term fluctuations in the components of the hydrological cycle at different elevations throughout the watershed. In addition, the subsurface flow system can be evaluated from groundwater and soil moisture observations to give an indication of the time delay and storage associated with the underground drainage network.

Several wells were located along the paths of the dormant surface drainage system, and these have provided an indication of the time delay and attenuation of the input to the flow system at the upper elevations in the watershed. Other dry wells were established at lower elevations, indicating that the particular sub-surface locations were not part of the lateral underground flow system, and that the vertical flux of water into the soil profile was insufficient to percolate down to and saturate the deeper soil horizons.

The recorded fluctuations in the water table at the various locations in the Carrs Landing Watershed are shown in Figures 3 and 4 for the period 1965 to 1970. The contrast between the annual cycle of the groundwater movements at the different elevations is quite apparent, varying from the shallow recharge conditions at the higher elevations (Sites No. 3 and No. 8) to the deeper and less predictable fluctuations at the lower elevations (Site No. 6). The site locations are shown in Figure 2. The groundwater observations at Site No. 5, located at an intermediate point in the flow system, show similarities to both the shallow recharge conditions and the deeper irregular fluctuations at Site No. 6. In the recharge areas near the drainage divide, the range of water table elevations for both the grassland and the forested area is nearly 10 feet. Quantitative evaluation of the significance of these water table fluctuations has been determined directly for the upper elevations through a water balance analysis. A similar evaluation of the more erratic groundwater fluctuations in the lower part of the watershed is more difficult because of the lateral inflow component of the flow system which produces a surcharge to the water table in the latter part of the summer when the surface soil conditions are at their driest. The long-term fluctuations in the water table provide an indication of important subsurface controls that control the groundwater runoff in the Carrs Landing watershed.

The Results of a Water Balance Analysis

Greater understanding of the complex Okanagan Valley watershed is likely to result

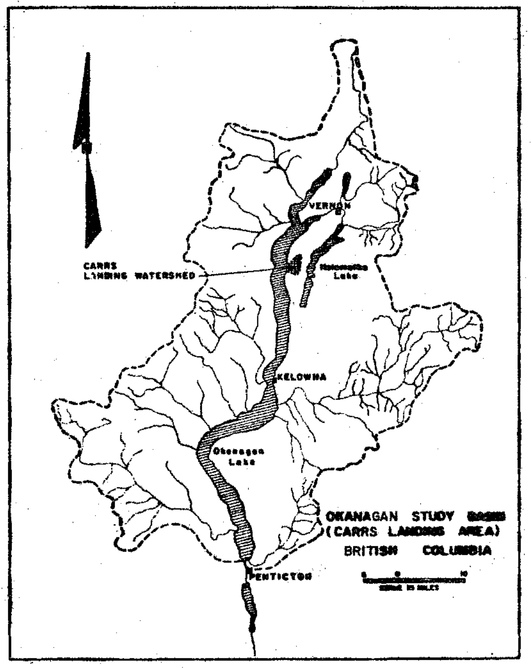

Fig. I LOCATION OF STUDY AREA.

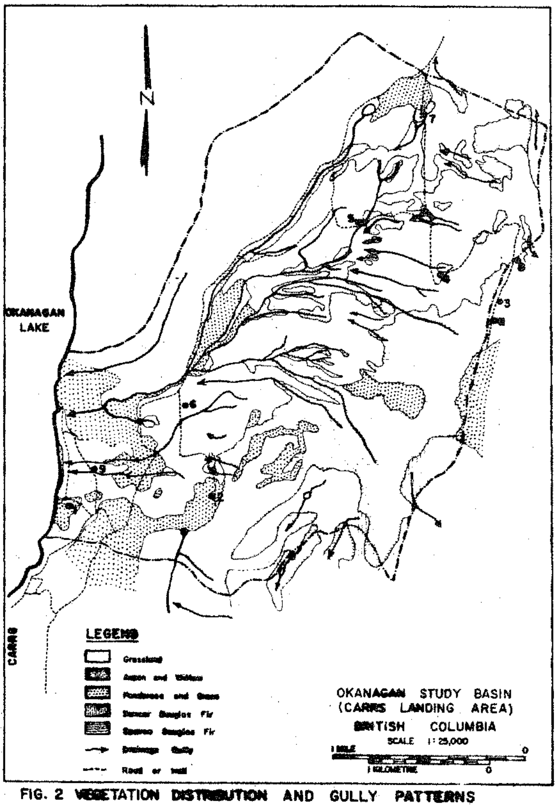

FIG. 2 VEGETATION DISTRIBUTION AND GULLY PATTERNS

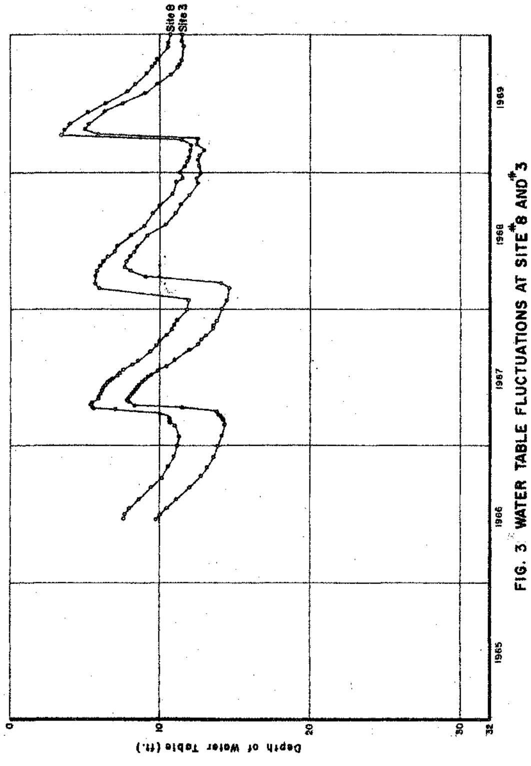

FIG. 3 WATER TABLE FLUCTUATIONS AT SITE #8 AND #3

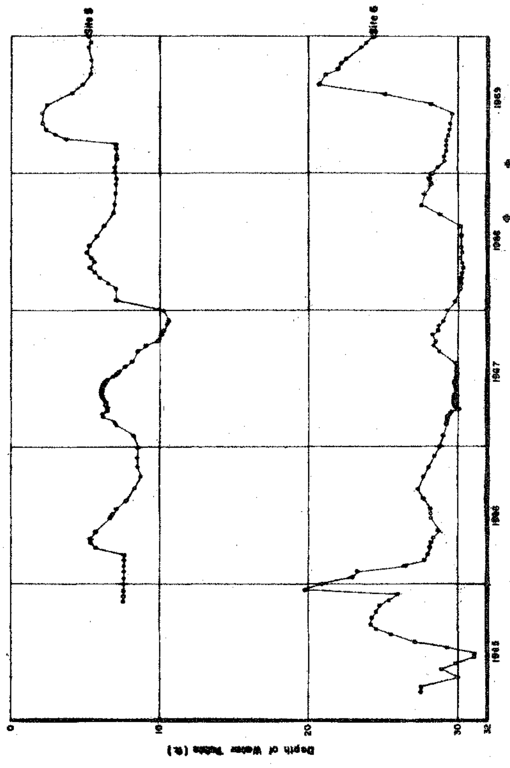

FIG. 4 WATER TABLE FLUCTUATIONS AT SITE #8 AND #6

from an expanded awareness of physical hydrology. Inevitably, the application of selected hydrological parameters for seasonal runoff forecasting will be assisted by the knowledge of the relationship of the indexed parameter to its hydrological environment.

A water balance analysis was, therefore, developed for the 1967-68 and 1968-69 winter periods to simulate the pattern of winter snowmelt in the Carrs Landing area. The reconstitution of the timing and the pattern of snowmelt was most effective for the snowpacks in the forested area on the drainage divide. The results of the simulation analysis for 1967-68 and 1968-69 are shown in Figures 5 and 6. The simulated melting pattern could only be obtained from daily radiation and other meteorological data by empirically accounting for information that was not easily determined, such as the heat conduction from the ground and the melt at the ground interface, the forest canopy density and the transmission of short-wave radiation, and the temperature of the snowpack and its condition through the accumulation and melt season.

The prediction in measurement of the water equivalent of the shallow snowpacks, and the reliability of the soil moisture measurements near the ground interface inhibit the discussion of the allocation of the winter precipitation input of snowpack and soil moisture storage. In fact, the sparseness of suitable winter snowfall data below the drainage divide meant that the melting pattern for the very shallow snowpacks below 3,000 feet could not be substantiated to any reasonable degree. However, the water balance analysis at the upper elevation does give a clear illustration of the allocation of the water from snowpack depletion to the soil moisture storage and the groundwater zones.

There appears to be a two to three week delay between the disappearance of the snowpack and the consequent rise in the water table. This may be attributed to the low permeability of the underlying medium and the tortuous paths of water movement to the point of groundwater potential measurement, roughly 50 feet below the surface. Although it is difficult to place a precise quantitative interpretation on the significance of the local groundwater rise in the drainage divide, the water budget analysis together with similar water table surcharges recorded elsewhere in the Carrs Landing area, suggests that an areal basis, some three to four inches of the seven to eight inches of water precipitation recorded in 1967 and 1968 did find its way to the groundwater zone.

Identification of a Parameter for Runoff Potential Evaluation

Some conceptual identification of the physical processes that lead to streamflow ought to be relevant to the problem of selecting the most likely set of physical conditions in the Carrs Landing area under which a useful prediction index of runoff potential might be established. A knowledge of how runoff does occur could provide the supporting evidence to show that under certain restrictive conditions a method of direct evaluation of groundwater recharge can be expected to be a natural 'representative' index of runoff potential. In areas that produce no visible signs of runoff, the depletion of the smaller lowland snowpacks can cause water table changes that are probably the result of the same but less pronounced mechanism that generates streamflow in the higher elevation areas. Recharge evaluation in the lower elevation range should be a useful representation of the mechanisms of runoff generation in the higher elevation areas in the Okanagan Valley.

In forested areas the high infiltration capacity of the ground is widespread, hence, the recharge to the water table is likely to be more uniform than in open areas. It should, therefore, be possible to obtain a reasonable evaluation of the areal groundwater recharge from selected wells in the forested areas of the Carrs Landing Watershed. The potential for recharge evaluation should be greatest on the forested parts of the drainage divide of the Carrs Landing area, not only as a result of groundwater divides being noted as areas of concentrated groundwater recharge, almost to the exclusion of the valley slopes (Toth, 1963). The potential of recharge evaluation as a method for seasonal runoff prediction should therefore be greatest in this area.

The elevation parameter does increase the complexity of the problem of runoff volume forecasting in the Okanagan Valley since the changes in local climate with elevation ensure that the different physical processes that promote streamflow are at different stages of completion throughout the elevation range. However, exploitation can be made of some of the runoff characteristics accruing from the influence of elevation. All things being equal, snowpack water equivalents and runoff potential increase with elevation. This fact, together with an inverse temperature-elevation relationship, ensures that the lowland snowpacks will disappear in advance of the upland snowpacks. Even if the snow melts at different times in different years, the melting pattern is always the same (Geiger, 1965). Thus, the elevation parameter could be considered of important practical significance if soil moisture and groundwater indices in the recharge areas in the middle elevation range act as antecedent indices for the higher elevations. The development and use of such prediction indices could give advance warning of the infiltration potential of the Okanagan Valley watershed, which together with basin precipitation estimates, could lead to improved runoff forecasts.

The Potential of Recharge Evaluation for Runoff Prediction

On the drainage divide of the Carrs Landing Watershed, fluctuations in the depth of the water table of almost 10 feet are quite common. The water table appears to be in a very slow state of recession for all but a few weeks of the year and there does not appear to be much lateral subsurface flow on the divide at the time of snowmelt. Consequently, practically all of the changes in water storage that occur at the time of snowmelt can be measured. There should be some prediction parameter potential in the water table movements.

The direct evaluation of groundwater storage has normally been considered impractical because of the general unrepresentativeness of groundwater well observations, and the great variability in groundwater conditions over basin areas (Corps of Engineers, 1955). Thus, the 'field' evaluation of runoff potential by recharge observation after the disappearance of the snowpacks at the lower elevations must remain uncertain, despite the rationalizations concerning the causal nature of runoff. There will always exist the possible lack of representativeness between the recharge measurements taken on the drainage divide of the Carrs Landing Watershed early in the runoff seasons, and the basinwide conditions.

Nevertheless, by the end of the 1969 runoff season, it did appear that a significant relationship was developing between selected well observations that were taken in the 3,000 feet elevation range in the Carrs Landing area during March and April and the seasonal basin runoff that was to follow. The evidence provided during the three-year period 1967 to 1969 is given by the elementary relationship:

$$I = 50H - 20$$

where I = the maximum Okanagan Lake net inflow recorded from April 1, in units of Thousands Acre-Feet. (This usually occurred 80 to 100 days after April 1); and H = the water table rise in feet at Well No. WR-66-46, Site No. 3, Carrs Landing Watershed.

However in 1970 the relationship badly overestimated the seasonal inflow. The exceptionally low inflow in 1970 defies a reasonable explanation at the present time. Runoff contributions from rainfall occurring after April 1 were undoubtedly lower than in other years and an even smaller residual of the lower upper elevation snowpacks appears to have occurred as streamflow. The data is shown graphically in Figure 7 and is listed in Table 1.

The Carrs Landing data shows that the recharge efficiency as defined by the ratio of the groundwater recharge to the maximum recorded winter snowpack water-equivalent at the 3,000 feet elevation, is highly variable. This clearly points to the even lower utility of lowland snowpack water-equivalents for basinwide runoff prediction. Other groundwater observations in the Carrs Landing area also appear to have a lower utility as a result of being either in areas where the recharge is likely to be less uniform, or through being located in lower parts of the subsurface flow system. Observation wells in the open areas near the drainage divide respond several weeks before those in the forested area and can give some initial idea of what the recharge in the forested area is likely to be.

The direct measurement of recharge to the groundwater table avoids the necessity of determining the water storage potential in the soil zone. However, it has to be recognized that the use of the recharge data inherently assumes that the water table rise will be directly proportional to the volume of meltwater that passes through the soil complex. If reliance is to be placed on this antecedent index of regional runoff, then it would also appear necessary to check on the geohydrologic homogeneity of the medium through which these fluctuations occur. If the underlying medium is stratified, and if this effect produces a variable porosity in the soil matrix through which the surcharges to the water table take place, then the recharge index measured by the rise in the water table will

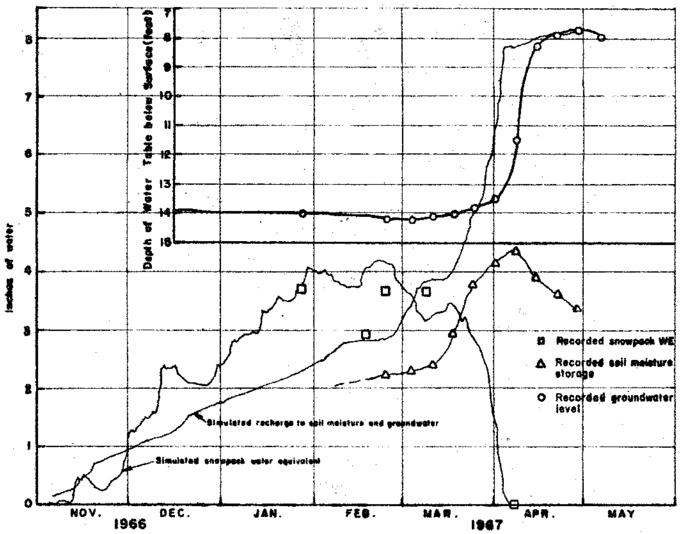

FIG. 5 WINTER WATER BUDGET ANALYSIS AT SITE #3 (ELEV. 3000 FT.)

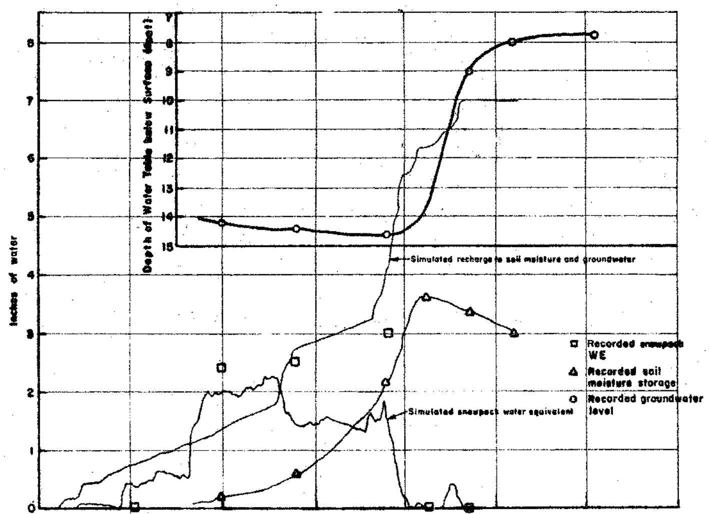

FIG. 6 WINTER WATER BUDGET ANALYSIS AT SITE #3 (ELEV. 3000 FT.)

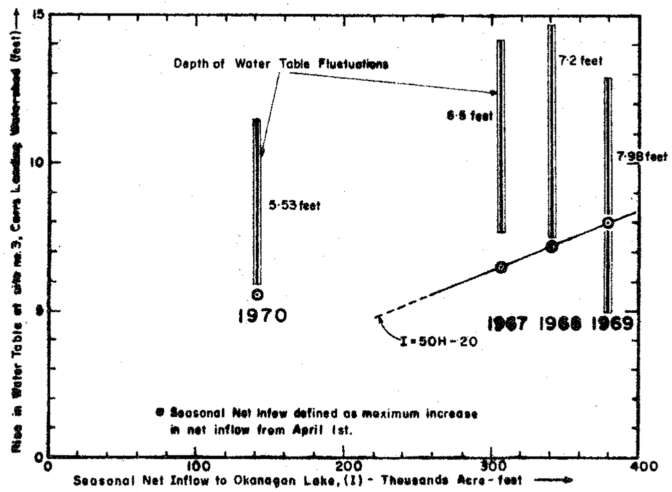

Figure 7. RELATIONSHIP BETWEEN GROUNDWATER RECHARGE AND SEASONAL INFLOW.

YEAR	1967	1968	1969	1970
Maximum Winter Snowpack Water Equivalent at 3,000 feet elevation (Carrs Landing), W (inches)	3.6 (Feb.25)	3.0 (Feb.24)	6.5 (Mar.16)	5.2 (Mar.16)
Minimum Level of Well at site #3, before snowmelt, L (feet)	14.2 (Mar. 4)	14.7 (Feb.24)	12.90 (Mar. 1)	11.46 (Mar.14)
Maximum Level at Well at site #3, after snowmelt, T. (feet)	7.7 (Apr.29)	7.5 (Apr.20)	4.92 (Apr.26)	5.94 (Apr.21)
Groundwater Recharge, R=T-L (feet)	6.5	7.2	7.98	5.53
Recharge Efficiency, E=R/W (feet/inch.snow W/E)	1.81	2.40	1.23	1.06
Maximum Seasonal Inflow into Okanagan Lake, from April 1 (thousands acre-feet)	307.2	342.0	380.0	144.0

TABLE 1 - RECHARGE DATA FOR SEASONAL RUNOFF PREDICTION

inevitably be poor as a result of the variable depths through which these changes take place. The range of water table changes for 1967 to 1970 is shown in Figure 5.

Conclusions Concerning the Hydrological Problem of Long-Term Forecasting

1. Of the many physical parameters that were analyzed in the search for a new method for the prediction of the behaviour of the Okanagan Valley Watershed, the direct evaluation of water recharge in the forested part of the Carrs Landing drainage divide should provide the greatest potential for seasonal runoff prediction. One is, in fact, looking for a type of point measurement that does all of the integrating of the environmental influences at that location. Some significance might then be logically placed on fluctuations within a groundwater table resulting from recharge from winter precipitation that has had to pass through two buffer zones, both the land surface snowpack and the soil moisture storage zone. It is then quite possible that the integrated effect of snowpack depletion can be measured at elevations where there is substantial groundwater recharge, especially if there does not appear to be any form of surface runoff, or significant lateral subsurface flow during the period of groundwater recharge, that would prevent the environmental changes over the winter from being contained at that location.

2. Runoff potential is not that deterministic, as it cannot be verified directly through physical measurement at intermediate points through the runoff season. A snowcourse water equivalent index may give an idea of what this potential runoff could be, but there are sufficient unknowns concerning the transfer of snow precipitation to streamflow that such indices may not be good relative quantitative indices of the residual quantities of water that will be left after various losses to soil storage and relatively permanent groundwater storage. It is this type of argument that leads to the suggestion that improved correlation might be found between measurements taken to monitor the quantities of water that have passed through the soil complex and that are temporarily stored in a water table condition as part of the snowmelt runoff flow system and the amount of runoff that is eventually measured as an aggregate inflow quantity at Okanagan Lake level. Such evaluation of groundwater recharge will only have a useful long-range forecast utility if it can be obtained below elevations that generate the major part of the regional runoff and if it can be obtained in advance of the seasonal snowmelt inflow. Although the direct evaluation of recharge can directly integrate the effects of antecedent autumn rainfall and the effect of the rate of snowmelt in the early priming of the snowfields, the forecast cannot account for the additional factors that will continue to control the melt of the heavier snowpacks of the higher elevations.

3. Many of the uncertainties associated with the problem of seasonal prediction of the Okanagan Valley water supply remain to be resolved. Neither the data-intensive statistical techniques that are used from February through to the end of the inflow season in June or July, nor the 'field' method based upon direct recharge evaluation are reliable enough to allow confident control of Okanagan Lake levels. The nature of various influences within the catchment may lead to the development of a new prediction parameter in the catchment itself, but in the final analysis, confidence and justification in its use will only arise as a result of proven reliability. It will have to stand the test of time, and this calibration may take some years. It remains to be seen how reliable and representative such physical determinations are in future years for hydrological forecasting. It also remains to be seen how modifications can be developed to allow for contingencies occurring after the recharge forecast date, which generally occurs in April. Seasonal inflow forecasting will always have to rely on statistical techniques early in the inflow season, since the recharge evaluation can only be made after the snow has melted at the 3,000 feet elevation.

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