MEAN PRECIPITATION AND SNOWFALL MAPS FOR A MOUNTAINOUS AREA OF POTENTIAL URBAN DEVELOPMENT

By

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Introduction

The relevant question often asked when considering "Water in Land Use Planning" concerns the possible inadequacy of supply. However, in the case of the mountain slopes to the north of Vancouver, Canada, the more relevant questions relate to periods of over-supply of rain and snow in the context of urban development on the slopes.

The current study arose out of proposals to construct a new eight-lane transportation corridor across or under Burrard Inlet to connect the growing satellite communities of North and West Vancouver to the downtown core of the city. The proposal was termed the "Third Crossing" since it was to supplement the existing Lions Gate suspension bridge over the first narrows and the six-lane highway bridge at the second narrows of Burrard Inlet (Figure 1 (b)).

While including some facilities for future rapid transit, the plan appeared to many to commit the city to further freeway development. This led to the inevitable outcries of numerous citizens' groups concerned with the present and future environment of the city and surrounding areas. Governmental response was to initiate that relatively recent but increasingly common phenomenon termed an Environmental Impact Study, of which a climatological analysis was a part.

It was suggested that ease of access created by a new transportation facility could give further impetus to urbanization north of the city and in particular along and up the slopes of the mountains ringing the area. Since it has long been known that both mean annual precipitation and snowfall increase with elevation, the climatological suitability of areas as yet undeveloped and the effects of urbanization, particularly on run-off, pose significant problems to the town planner.

To provide the background material for such an assessment it was necessary to prepare a basic climatological analysis on the scale of a city. This was made difficult by the mountainous nature of the area and the scarcity of data from higher elevation terrain. However, use of available precipitation data to develop a simple model based upon elevation and distance into mountain valleys in conjunction with streamflow information made possible at least a "first estimate" mapping of mean annual precipitation and snowfall over the study area. These analyses are described in the following sections.

Mean Annual Precipitation

The bulk of Vancouver's precipitation falls as rain (at sea-level) during the winter season when southwestern British Columbia lies in the direct path of storms moving inland from the Pacific Ocean. The seaward facing slopes of the mountains of Vancouver Island and the Olympic Penninsula receive the initial onslaught of the storms. In the lee of those mountains a rainshadow extends eastward across the Straights of Georgia. This is reflected in annual precipitation averaging about 40 inches in parts of the delta to the south of Vancouver and along the Sechelt Penninsula to the northwest. As the storms continue eastward and impinge upon the mainland coastal mountains the air is again forced to rise and to release more of its moisture load in the form of increased precipitation over the area.

The data base for analysis of the distribution of this precipitation is severely limited. While there are about 35 climatological stations active in the area north of

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Burrard Inlet (Table 1 and Figure 1 (a)) most are near sea level or clustered in areas already urbanized; yet it is the currently undeveloped areas of higher elevation that are of primary interest. Difficulties are further compounded by extremely large spatial variations in the local climate. Individual readings are not generally representative of conditions at adjoining locations. Therefore the analysis was performed by constructing a simple model taking into account two topographic factors having a pronounced effect on the production of precipitation.

1. The mountain slopes which provide a mechanism for lifting the air and thereby increasing the amount of precipitation.
2. The valleys and channels that open out to the general air flow and provide a funnelling effect that results in increased precipitation due to convergence of the air.

The altitudinal relationship was derived by comparing data from the three available high level stations (above 2,000 ft.) with data from corresponding stations at the bottom of the respective mountain slopes. These data are plotted in Figure 2. The slope of the line is similar for all three of the mountain transects - Mt. Seymour, Hollyburn Ridge and Tunnel Camp - and indicate an increase in annual precipitation of approximately 12 inches per 1,000 feet increase in elevation.

The second factor of importance is valley convergence. Data were available from two valleys - Capilano and Seymour - and show an increase in annual precipitation along the axis of the valley of approximately 15 inches per 100 foot increase in elevation (Figure 2). In terms of distance from the valley entrance, this would be equivalent to an increase in precipitation of 8 inches per mile for Seymour Valley and 13 inches per mile for Capilano Valley.

Although the channelling effect is most pronounced in the main valleys it is also a factor contributing to the precipitation in the narrow, steep valleys that extend up the mountain slopes. Mosquito Creek observing site (Figure 1 (a)) was in a narrow indentation extending up the slope of Grouse Mountain. The area is therefore affected by both the lifting of the air by the mountain slope and the convergence effect of the valley and, indeed, the position of Mosquito Creek on the graph (Figure 2) shows the additional precipitation resulting from the channelling effect.

The above data suggest that valley convergence is an effective factor adding to that of elevation in increasing precipitation. Maximum precipitation values are therefore likely to be found on the mountains at the heads of the main valleys that open out to the prevailing winds. On this basis a preliminary map was drawn, indicating annual precipitation in excess of 200 inches over several of the mountain barriers.

Since raingauges are absent from the areas assumed to receive the greatest precipitation, streamflow records were utilized to obtain an independent estimate of mean precipitation over catchment areas of 10 to 100 square miles. The simplified water balance (Equation 1) was used, where P equals mean precipitation, R equals runoff and E equals mean evapotranspiration.

$$P = R + E \qquad (1)$$

A value of 20 inches was adopted for the annual evapotranspiration. Ferguson et al (1970) indicate mean annual small lake evaporation near sea-level in the Howe Sound area of just over 28 inches. The dry summer period produces most of this evaporation. Much of the heavy winter rain runs directly to the sea. Thus occasional water limitation combined with the somewhat lower values of potential evapotranspiration on higher slopes suggests a value lower than 28 inches.

Another approach is through the energy budget (Equations 2 and 3), where N equals mean net radiation, H equals mean sensible heat transfer, E equals mean latent heat transfer, and B equals the mean Bowen ratio.

$$N = H + E \qquad (2)$$

$$B = H / E \qquad (3)$$

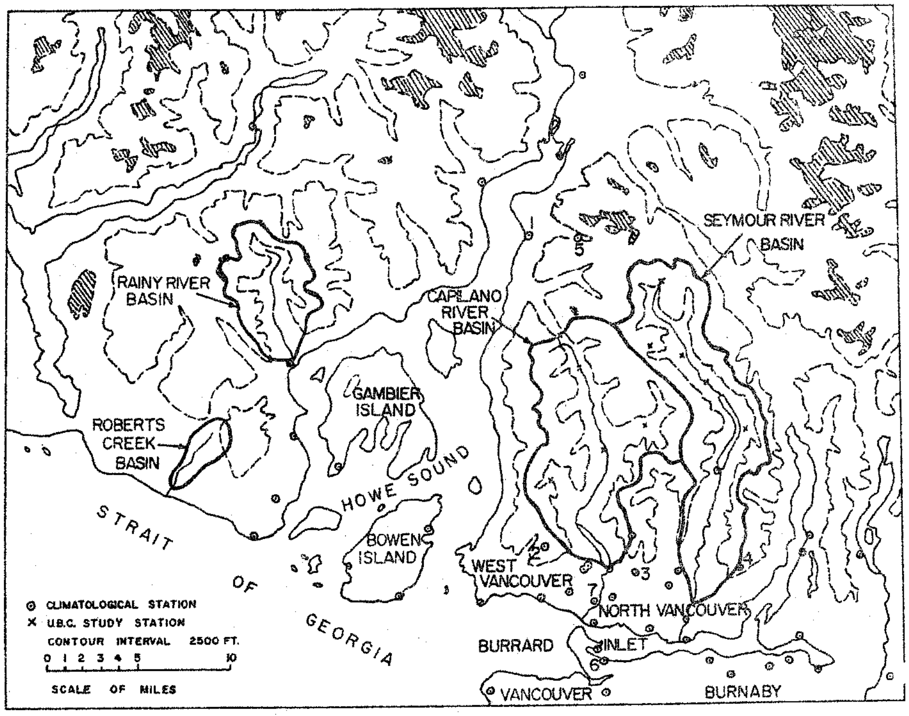

FIG. 1(a) STUDY AREA SHOWING CLIMATOLOGICAL STATIONS, GAUGED CATCHMENTS AND TOPOGRAPHY

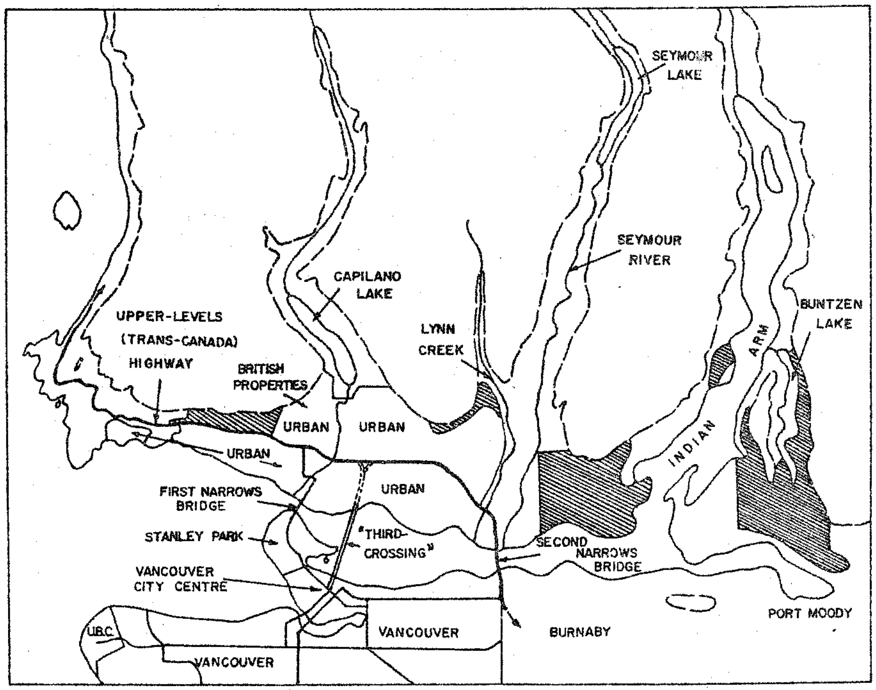

FIG. 1(b) DETAILED STUDY AREA SHOWING EXISTING AND PROPOSED CROSSINGS OF BURRARD INLET, URBANIZED AREAS NORTH OF THE INLET AND APPROXIMATE BOUNDARIES OF LAND BELOW 1,000 FEET. POTENTIALLY SUITABLE FOR URBAN USE (CROSS-HATCHED).

Hay (1970) indicates a mean annual net radiation receipt of near 40 kilo-langleys. This is the equivalent of 26.8 inches of evapotranspiration. Budyko (1963) gives a mean Bowen ratio of 0.5 for the coniferous forests of southwestern British Columbia. Thus, according to equations 2 and 3 a mean annual evapotranspiration of 17.8 inches could be expected. A value of 20 inches was adopted as a reasonable compromise between this and the pan-based values. Since runoff is much larger than evapotranspiration, the final estimates of precipitation are not overly sensitive to the choice of evapotranspiration amount.

Results of the computations based upon streamflow records for catchments with greater than 10 years of record are presented in Table 2. Values were adjusted to the 1931-60 normal period using the long term station Vancouver PMO. The catchments listed are outlined in Figure 1(a).

Adjustments were made to the preliminary isohyets on the mean annual precipitation map to produce a result consistent with the streamflow data as well as the precipitation data. In general the values indicated by the model for higher terrain appeared to be well justified by the observed runoff. The final version of the mean annual precipitation map is presented in Figure 3.

Snowfall

The mean annual snowfall is, of course, closely related to the mean annual precipitation and the the elevation of the site. The altitudinal relationship was derived from a comparison of data from sets of high and low altitude stations (Figure 4). It was found that annual snowfall increases by approximately 80 inches per 1,000 ft. increase in elevation. This is partly due to the general orographic increase in precipitation with elevation, but the controlling factor is the decrease in ambient air temperature. Empirically, the percentage of the mean annual precipitation that falls in the form of snow increases by 6 to 8 per cent per 1,000 ft. increase in elevation from a 3 to 4 per cent base near sea level. Thus Figures 3 and 4 were utilized to map the distribution of mean annual snowfall as presented in Figure 5.

Annual snowfall amounts range from 20 to 25 inches near Burrard Inlet through 100 inches over the upper urbanized regions of West Vancouver (1,200 ft.) to estimated values of over 700 inches on some of the mountain barriers at the heads of open valleys. Dut to latitudinal effects associated with distance from the sea and accessibility to colder continental air masses during winter, a larger percentage of the annual precipitation falls in the form of snow at the head of Howe Sound than near Burrard Inlet.

The average number of days per year when snowfall occurs is strongly dependent on elevation above the first 500 ft. Figure 6 illustrates that the number of snowfall days increases by 27 days per 1,000 ft. increase in elevation once above the first 500 ft. Since the total number of precipitation days is fairly constant over the area (Knox, 1969) this reflects the fact that rain often occurs near sea level when it is snowing on the upper slopes. Large snowfalls are also more likely on higher terrain. Table 3 summarises the percentage frequencies of days with snowfall and days with 4 inches or more of snowfall at two high altitude - low altitude station pairs.

The Table indicates that snow days during the December to March period are 5 to 10 times as frequent on Hollyburn Ridge as in West Vancouver. Even more striking, when the 4 inch criteria is used the number is from 10 to 20 times as great. Thus the frequency of heavy snowfalls increases very markedly with height, above sea level on the upper slopes.

Implications for Urban Land Use Planning

Mean annual precipitation and mean annual snowfall are useful parameters in determining the general livability and accessibility of an area. Thay relate to the costs of keeping roads open, constructing buildings and establishing drainage systems. Figures 2 - 6 provide at least a first estimate of the distribution of rainfall and snowfall over the mountainous areas north of Burrard Inlet and around Howe Sound.

Land use classification studies have identified areas along the lower mountain slopes of the north shore of Burrard Inlet as being potentially suitable for urban development (Figure 1(b)). These areas are restricted to maximum elevations of 1,200 ft. and

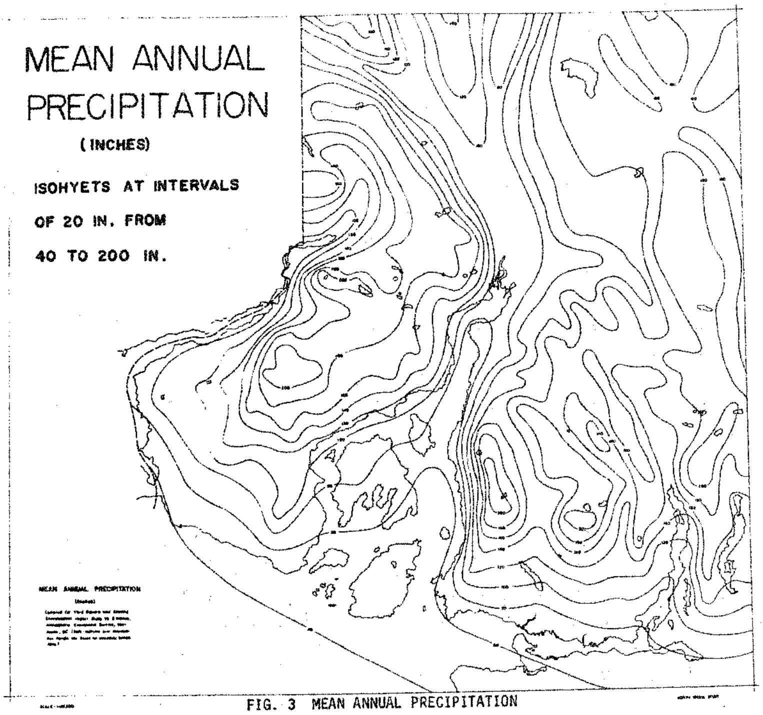

FIG. 3 MEAN ANNUAL PRECIPITATION

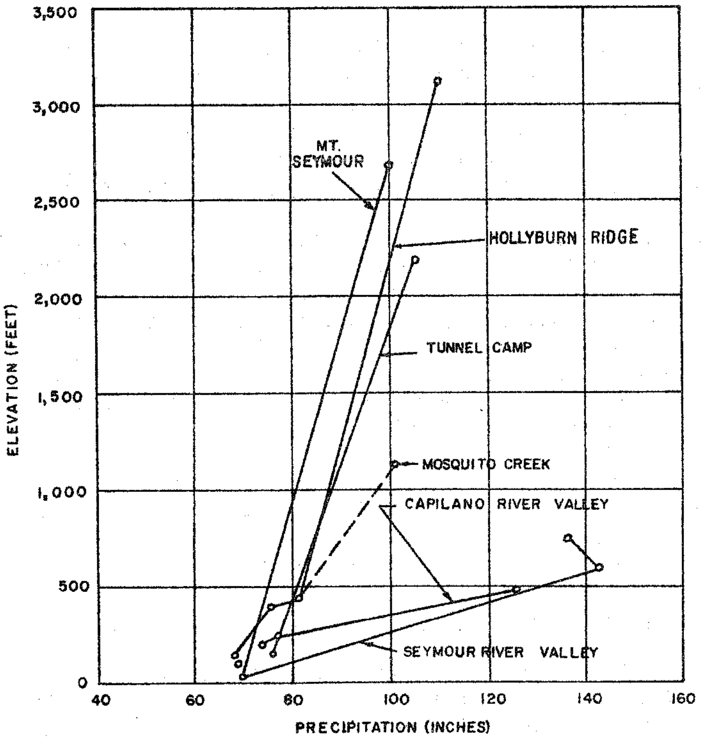

FIG. 2 VARIATION OF TOTAL ANNUAL PRECIPITATION WITH ELEVATION OVER MOUNTAIN SLOPES AND ALONG AXES OF VALLEYS.

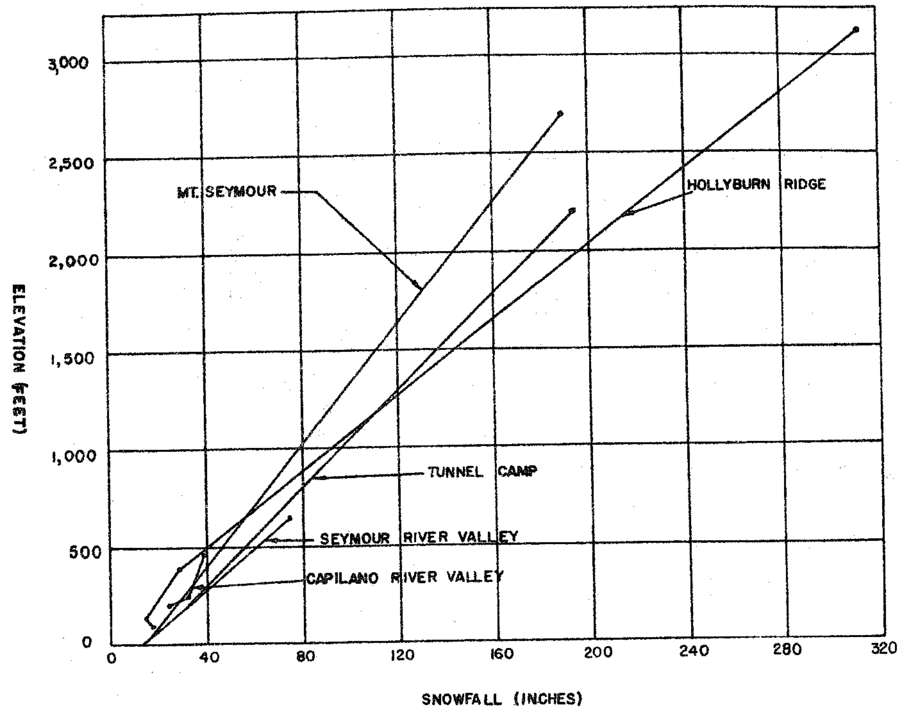

FIG. 4 VARIATION OF TOTAL ANNUAL SNOWFALL WITH ELEVATION OVER MOUNTAIN SLOPES AND ALONG AXES OF VALLEYS.

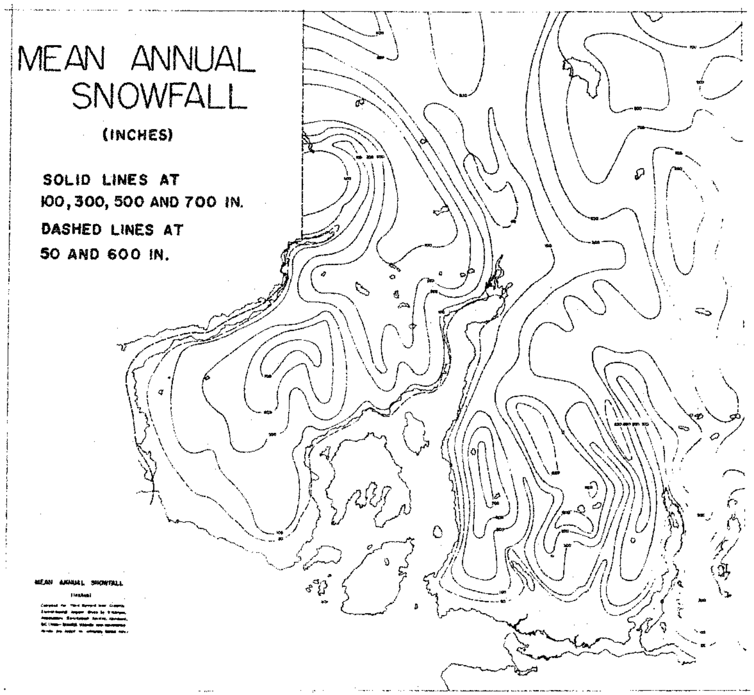

FIG. 5 MEAN ANNUAL SNOWFALL.

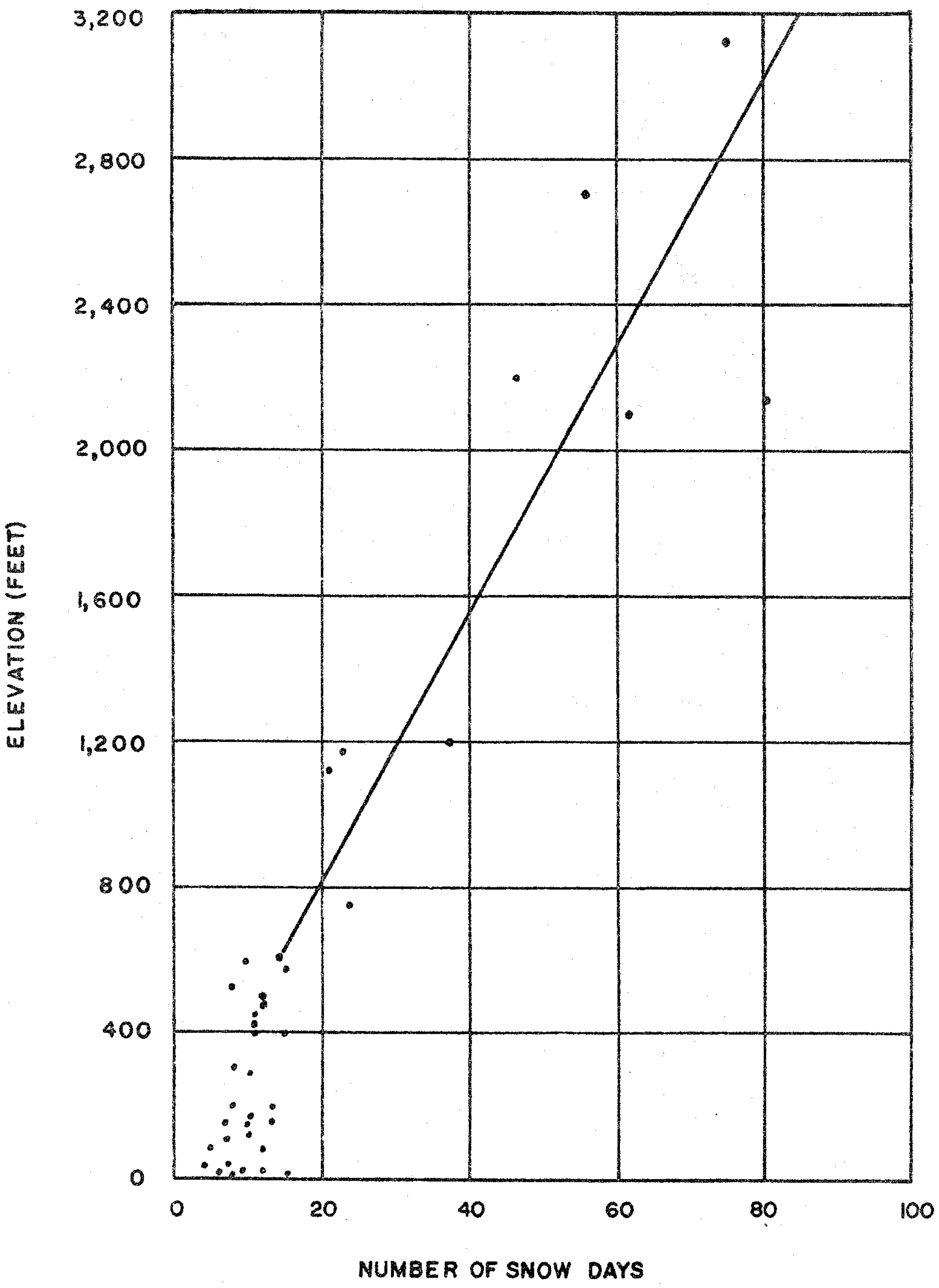

FIG. 6 INCREASE WITH ELEVATION OF THE AVERAGE ANNUAL NUMBER OF DAYS WITH SNOWFALL.

1,050 ft. in West and North Vancouver respectively by municipal bylaw. Since some development has now reached those elevations direct knowledge of the problems encountered can be gained.

At elevations of 1,000 - 1,200 ft. an annual average of up to 100 inches of precipitation including 100 inches of snowfall occurs. The effect of this amount of snow on urban living is primarily on accessibility to vehicular traffic. Additional snow removal resources must be provided since, as previously noted, 16 additional snowfall days per year are added as development progresses from 600 to 1,200 ft. and snowfall amounts increase from 60 to 100 inches. However experience indicates that a well planned program can cope successfully with this quantity of snow, even on sloping terrain.

The District of North Vancouver snow removal program successfully keeps all roads open at the elevations and road grades under consideration. Public transit operates satisfactorily. There are, of course, periods when schedules are not strictly maintained but service is not curtailed. In fact the main factor hampering traffic is not the amount of snow but the ice that forms on roads with steep grades. This problem is checked by the application of salt and sand.

Similarly, in West Vancouver salting and sanding of main traffic arteries begins with the first fall of snow. Heavier snow clearing equipment is activated when approximately 4 inches has accumulated.

Despite increased cost snowfall encountered at elevations up to 1,200 ft. does not seriously limit traffic if adequate equipment is available. In fact many towns in British Columbia receive far in excess of 100 inches (e.g. Revelstoke receives 162 inches) and Canada's largest city, Montreal, averages close to 100 inches. On the other hand in the city of Vancouver side roads are not generally cleared of snow and winter driving is often a problem even though annual snowfall averages only 20 - 25 inches.

Should regulations be relaxed in the future and development be allowed beyond current elevations, costs and difficulties would increase markedly. Daily snowfalls of 4 inches or more occur an average of twice per year near sea level, but over 30 times per year on Hollyburn Ridge, (at 3,120 ft. elevation). Large snowfalls of 8 inches or greater occur once in 3 years near sea level but 11 times per year on Hollyburn Ridge. Thus, building design would have to be strengthened against possible loads and maintaining access would become a much more serious problem. An indication of this is the fact that a fire truck is now maintained at the top of the British Properties to ensure emergency service during the winter in the event of heavy snow conditions.

Whereas heavy snowfall relates primarily to construction of building and to road access, the impact of heavy rainfall coupled with steeply sloping terrain is on runoff and drainage problems. Annual precipitation of 90 - 100 inches is expected over much of the area of potential development coupled with still higher values on the slopes above. Most of the precipitation is concentrated in the winter season. These facts point to the high costs involved in construction of adequate drainage systems to handle storm runoff.

With a wet climate and steep slopes storms persisting for 1 to 2 days may create severe overloading of drainage systems. For example, a recent 30-hour summer storm (July 11 - 12, 1972) produced 4 inches of rain near Burrard Inlet, 6 inches over upper urban areas and greater than 10 inches on Hollyburn Ridge. Such a vigorous frontal storm was unprecedented in July even though it was moderate in terms of winter events (i.e. 3-year return period). As a result exposed gravels from ongoing highway construction and other debris blocked culverts and drains. Water poured across roadways and private property resulting in several hundreds of thousands of dollars in damages. Five months later the Christmas Day storm set new 24-hour records at a number of locations and once again water cascaded through public and private property.

Certain public officials have recently voiced suggestions that a moratorium be placed upon further construction on the slopes of Hollyburn Ridge until complete studies of its hydrology are made. Hopefully some of the data presented here will aid in these and other studies of the North Shore - Howe Sound area.

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