RESEARCH REQUIRED TO MAKE CLOUD SEEDING A QUANTITATIVE SCIENCE

By

C. J. Todd and Paul B. MacCready, Jr.[1]

The field of cloud seeding for increasing rainfall is now becoming rather widely accepted because of favorable results being discovered in careful evaluation studies. The most exhaustive statistical study of results is that undertaken by the President's Advisory Committee on Weather Control, which found highly statistical significance for rainfall increases in seeded west coast storms. The present strong interest in learning more about cloud seeding is evidenced by the number of prominent men backing cloud seeding research bills in both state and federal legislatures.

Since 1949 when the major large scale projects first began, there has been very little research in this field, and the techniques used at present vary negligibly from those of 8 years ago. The statistically verified precipitation increases have resulted from these standard techniques. It is logical to assume that cloud seeding techniques can be improved tremendously, and therefore result in larger or more numerous precipitation increases. The improved techniques will come from applied basic research. The precipitation mechanisms must be understood quantitatively as well as qualitatively before a seeder can determine how to maximize the precipitation in a given circumstance.

This paper describes what we feel is a logical approach to putting practical cloud seeding on a valid engineering basis. If it proves possible to be able to understand the role of nuclei in various precipitation situations, then it is only an engineering problem to introduce the nuclei required to optimize nature's mechanism. The important factor is knowing what nuclei distribution is desired. Once this is known, the question of whether to seed from airplanes, the ground, balloons, rockets or other devices will resolve itself. Seeding projects of the future will undoubtedly cost considerably more than the past, but they can be expected to produce appreciably larger results — and the results will be predictable and verifiable.

Right now we can expect to obtain a fairly comprehensive answer to first order accuracy to the question of what conditions can permit large seeding effects. We can even expect to determine quantitatively how much increased precipitation should result. This information would be found from graphs which would show, if one knew certain initial conditions, what rainfall mechanism would be active and what rainfall rate would occur at various times and how completely the cloud moisture would be removed by precipitation. The initial conditions to be known about any cloud are simply the cloud base temperature, the rate and updraft, and the concentration of freezing nuclei available through the range of sub-freezing temperatures. This last initial condition is the one that can be varied by cloud seeding. More variables must be introduced for a complete evaluation of precipitation potentialities, but the ones listed here are the primary ones, and they appear to yield useful results without requiring the complication of more variables.

With the graphs just described, it is possible to compare the differences in precipitation resulting from different concentrations of freezing nuclei. By referring to the charts, the cloud seeder could determine the optimum seeding concentration for the class of clouds in question. The watershed manager could determine from previously obtained data what the cloud seeding potentialities were for his watershed.

The main problem in seeding then reduces to the development of these precipitation graphs. There are two approaches to the problem —— the observational and the computational. For the observational approach one could first ascertain what variables should be observed, and then make a large number of observations of all the variables over many areas and times, and plot the charts from the accumulated data. Actually the measurement problems are severe, especially the measurements of freezing nuclei concentration and measurements of the entire cloud cycle. The computational approach is to start from theory and deduce the rainfall rate as it changes for each set of initial conditions. The computations promise to be of a most involved and tedious type but they would be ideal for electronic computation. This major effort, using computing machines, would cost but a fraction of the empirical approach. The objections to the theoretical method are that the theory has not been sufficiently developed to provide sufficient confidence in the answers it produces. One should feel confidence in the correctness of the shape of the curves and relative position of different curves, but the absolute accuracy could be poor. The ideal project therefore is a carefully planned combination of observational and computational approaches, because relatively few observations are required to check the theory and keep it in the realm of reasonable accuracy.

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[1] Meteorology Research Incorporated, Pasadena, California

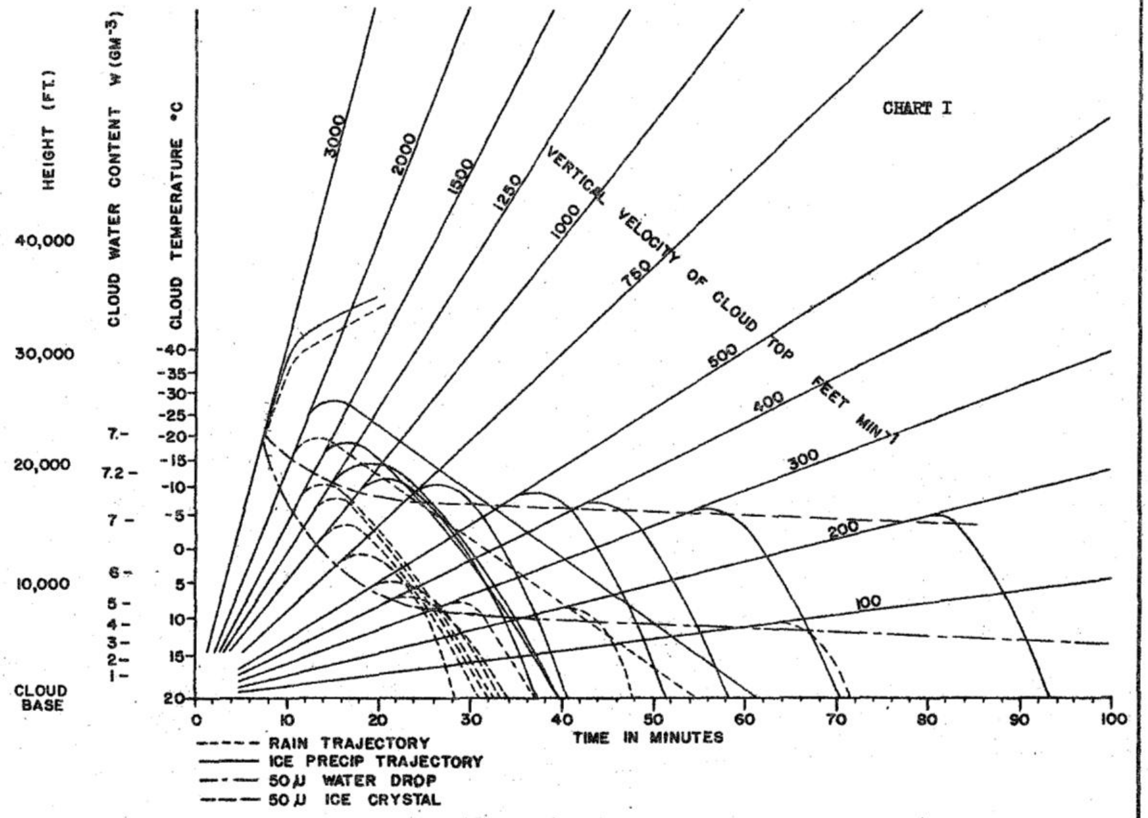
CHART I
HEIGHT (FT.)
CLOUD WATER CONTENT W (GM^{-3})
CLOUD TEMPERATURE °C
40,000
30,000
20,000
10,000
CLOUD BASE
7.-
7.2 -
7 -
6 -
5 -
4 -
3 -
2 -
1 -
-40
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
3000
2000
1500
1250
1000
750
500
400
300
200
100
VERTICAL VELOCITY OF CLOUD TOP FEET MIN^{-1}
0
10
20
30
40
50
60
70
80
90
100
TIME IN MINUTES
RAIN TRAJECTORY
ICE PRECIP TRAJECTORY
50 μ WATER DROP
50 μ ICE CRYSTAL

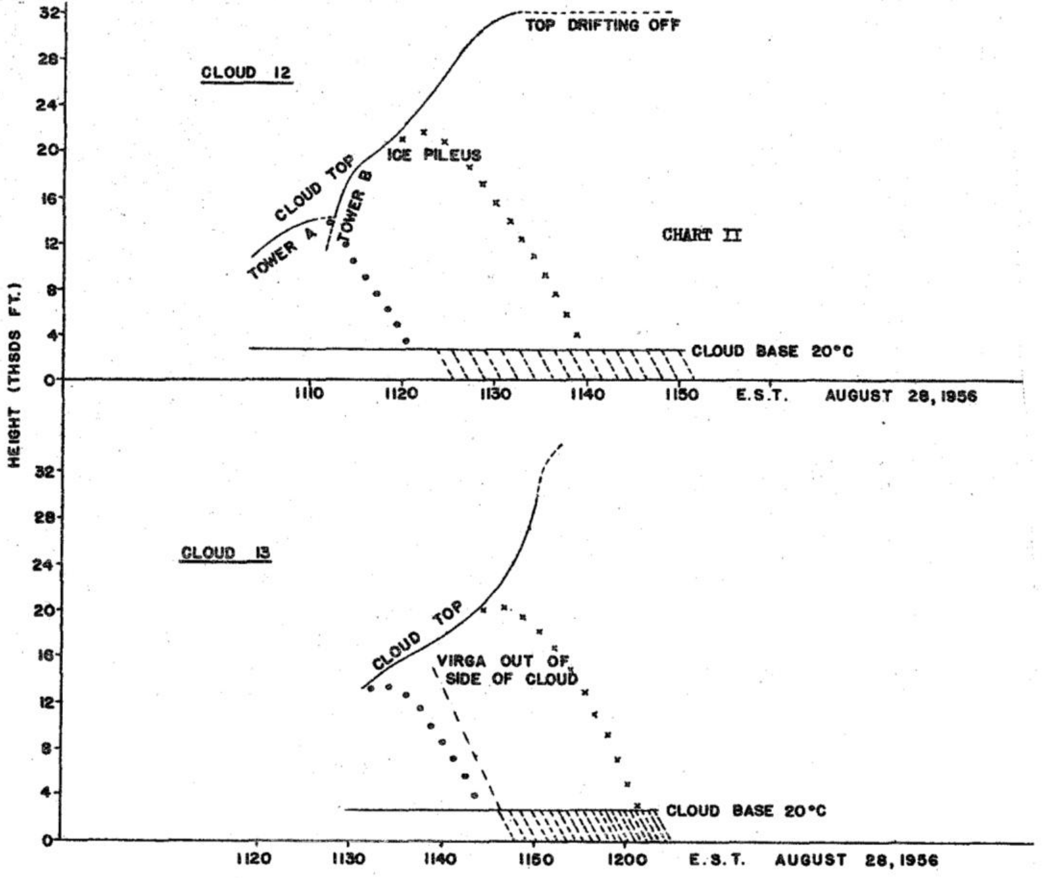
CHART II
HEIGHT (THSDS FT.)
CLOUD 12
32
28
24
20
16
12
8
4
0
TOP DRIFTING OFF
ICE PILEUS
CLOUD TOP
TOWER A
TOWER B
CLOUD BASE 20°C
1110
1120
1130
1140
1150
E.S.T. AUGUST 28, 1956
CLOUD 13
32
28
24
20
16
12
8
4
0
CLOUD TOP
VIRGA OUT OF SIDE OF CLOUD
CLOUD BASE 20°C
1120
1130
1140
1150
1200
E.S.T. AUGUST 28, 1956

Although progress in solving cloud seeding problems has apparently been slow during the past eight years, theories concerning the separate items which comprise the complete precipitation process have been accumulating. People have not made major computational efforts based on the theories because they did not have enough confidence in them. Recently, however, some research groups have gone through rather complete computations and shown that measurements agree well with the integrated theories. Dr. East, of McGill University, demonstrated very good agreement between the radar echoes in clouds and computations of the timing of warm cloud precipitation processes. We extended that work to cover a wide range of cloud vertical velocities and base temperatures. We extended it also to show rain initiating from the cloud base, and to cover ice initiated precipitation, as well as condensation coalescence precipitation (the so-called warm cloud rain or water initiated rain). We found good agreement between the time that the theory predicted for the first occurrence of rain from the base of the clouds and the time of the actual occurrences. We are at present trying to check out theoretical computations over a wider range. If the computations prove valid, they will show many things concerning the conditions under which seeding can be feasible. So far our computations and observations have only been concerned with the initiation of rain. If they show rain will occur, they indicate the time it will start, and whether it was caused by the ice or the water mechanism. The same basic theory should yield implications about rainfall rates and how much of the cloud moisture will be removed by precipitation, but such computations will be much more complicated than those which we have already made.

The studies have accented convective clouds and particularly the idealized summer shower situations. The same techniques and reasoning would be involved in studying the details of other storm situations such as the winter west coast frontal sequences, and, in fact, some of the results are directly applicable.

Not all of the building blocks of the complete precipitation mechanism theory are sufficiently formed to put into place, but the success of the simple model discussed here shows that the weaknesses in the theory are not severe. In the complete computations, one must include the height and time variations and inter-relationships between upcurrent strength, temperature, water content and freezing and condensation nuclei concentration, and perhaps even electrical effects.

We have some examples of curves showing the theoretical time of precipitation initiation, if initiation is by the warm cloud - condensation coalescence process or the ice crystal process. Chart I (Reference I) is for clouds with bases at 20C and it covers a wide range of vertical velocities The slanting line represents the change in height of the cloud top in time for each of the different vertical velocities represented. The dashed line shows the trajectory of the warm cloud rain. The point of break away from the cloud top line shows where drops are big enough to start falling away from the air in which they originated. The point at which the curve intersects the time axis indicates the time at which rain would emerge from the base of the cloud. The same sorts of curves are worked out for ice initiated precipitation, assuming that ice nuclei are available at temperatures just below freezing. (Actual nucleation will be slower than this). A study of this chart shows that if the cloud base temperature is 20C, the warm cloud process always starts precipitation before the ice process.

An example of how this was applied to clouds observed in Boca Raton, Florida, on Project Seabreeze for the Advisory Committee on Weather Control is shown in Chart II. Here the solid lines represent the growth of the cloud tops in time. The straight solid line represents the cloud base and the hashing below represents the observed rain. The dotted line is the trajectory of the first rain as predicted by theory. The stars show the theoretical trajectory of the first ice initiated precipitation. On Project Seabreeze the theoretical curve fit the actual observed precipitation time with a root mean squared error of 3.5 minutes.

Chart III shows theoretical precipitation initiation curves for clouds more typical of West coast precipitation. The cloud base temperature is plus 5C. Note that here the ice initiated precipitation is always earlier than the warm cloud rain if ice nuclei are available.

A little study of these curves shows that ice initiated precipitation can start 20 to 30 minutes earlier than condensation coalescence initiated precipitation. This means that there are some conditions in which clouds might precipitate substantially if ice nuclei are present and yet not last long enough for condensation coalescence precipitation to get started. Conventional cloud seeding involves stimulating only the ice mechanism. The curves show that even with perfect freezing nuclei seeding, warm cloud rain may grow first, and the artificial nuclei only be effective in later cloud development stages when its effects are hard to observe.

In summary, we are finding that we can be quantitative in discussing the starting time of precipitation. The initiation of precipitation has important ramifications in cloud seeding, even

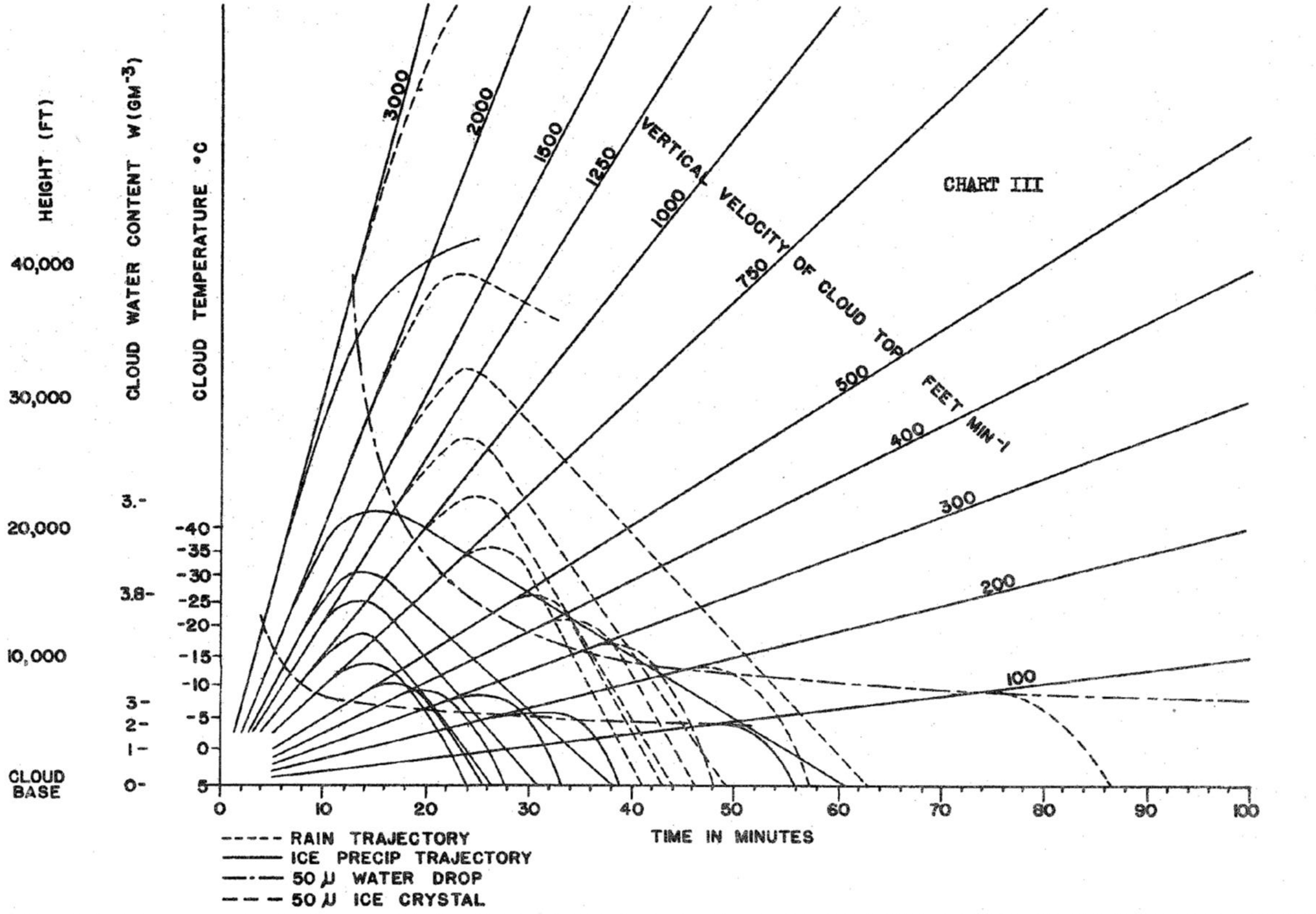
CHART III
VERTICAL VELOCITY OF CLOUD TOP FEET MIN-1
3000
2000
1500
1250
1000
750
500
400
300
200
100
HEIGHT (FT)
40,000
30,000
20,000
10,000
CLOUD BASE
CLOUD WATER CONTENT W(GM-3)
3.-
3.8-
3-
2-
1-
0-
CLOUD TEMPERATURE °C
-40
-35
-30
-25
-20
-15
-10
-5
0
5
0
10
20
30
40
50
60
70
80
90
100
TIME IN MINUTES
RAIN TRAJECTORY
ICE PRECIP TRAJECTORY
50 μ WATER DROP
50 μ ICE CRYSTAL

though it is only a small part of the whole problem. We feel that so far the surface has barely been scratched with respect to exhausting the potentialities of solving precipitation problems. The science of cloud physics seems to be developed to the point where it would be profitable to start developing the solution to rain fall rate problems. The solutions to these problems would put the theory of cloud seeding on a quantitative engineering basis; the cloud seeder would be provided with charts on which he can intelligently base his operations plans, and predict his chance for success. If the theory of cloud seeding could be put on a quantitative basis, then it would be possible to decide in which areas cloud seeding could contribute enough to be economically valuable, and in which areas it would not be justifiable. It would be possible to decide whether some cloud seeding should be done from a few ground generators to blanket an area, or whether the concentration of nuclei is highly critical and the utmost control, using radar and radar aircraft, might be necessary to achieve the full economical benefits from seeding. Any developments in the engineering of cloud seeding for precipitation increases will doubtlessly also be of value in understanding hail and lightning prevention.

Reference: MacCready, P. B.; Smith, T. B.; Todd, C. J.; Beesmer, K. M., "Physical Evaluation of Cloud Seeding Effects", report to President's Advisory Committee on Weather Control by Meteorology Research, Inc., Pasadena, Dec. 21, 1956

SNOW REMOVAL PROBLEMS IN THE PROVINCE OF BRITISH COLUMBIA

By

F. E. Dembiske[1]

The problems of removing snow from the roads and highways in British Columbia are great in extent and variety.

The provinces' highways maintenance work is relegated to the various maintenance districts set up throughout the province. There are 48 electoral districts in the province and each district has its own Department of Highways administration, maintenance and repair depot set up under the direction of a District Engineer or a District Superintendent. For better administration, several districts are now combined into a region headed by a Regional Engineer, but though these districts are combined for administration purposes, each district maintains its own establishment of maintenance crews and is responsible for all maintenance, including snow removal, of all roads in the district, whether these roads are main provincial highways, arterial highways, secondary highways, main feeder roads, side roads, farm roads and trails.

A District Engineer or Maintenance Engineer begins his preparation for snow removal about the middle of July. All roads in his district are listed on a priority-service basis, determined by either traffic count; public service - such as school bus service, mail routes, milk runs, daily commuters runs, etc. Main highways and arterial highways are, of course, given highest priority for snow removal service, but the engineer must not and cannot neglect these service routes for therein lies the source of the most of his public relations problems locally. It is surprising sometimes how little snow it takes to create a fuss with certain pressure groups such as Boards of Trade, Women's Institutes, Farmer's Institutes, P.T.A. Groups, Community Association Groups, etc.

After carefully studying the anticipated requirements of snow removal service in his district, the Engineer then considers his equipment requirements to handle his snow removal program. Invariably he comes to the conclusion that he is short from four to eight snow plowing units, but, being an optimistic type, he requisitions same from Headquarters through the Equipment Engineer. Now, snow removal costs for the districts are handled through an open account on General Revenues and are disbursed to the various districts at the end of each month when total costs have been submitted to the Departmental Comptroller. The Engineer is under strict orders to practice rigid economy in snow removal work without curtailing any necessary service. But the purchasing of equipment is handled through a vote and invariably the vote is far too small to handle all winter equipmer

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1/ Senior Maintenance Engineer, Department of Highways, Province of British Columbia.