I. INTRODUCTION

High mountain Lake Sevan is the principal regulator of the Armenian water resources used for irrigation, energy, and general water supply purposes. The lake resources have diminished substantially. In less than 50 years some 23 billion cubic meters of water have been drained from Lake Sevan, which constitutes about 40% of its secular resources. As a result, the lake water level has lowered by more than 18 meters.

Lake Sevan waters irrigate vast territories where valuable agricultural crops are cultivated. The estimated need from Lake Sevan waters is approximately 500 million cubic meters per year. However, only about 170 million cubic meters can be taken from the lake without lowering its water level. Hence, the Lake Sevan problem is to find additional sources which could provide for 330 million cubic meters of water per year. At the same time the problem of lake conservation is a strong aspect.

River water from neighboring basins is used to solve a portion of the problem. Another method of obtaining supplemental water is cloud modification.

2. THE EXPERIMENT

The principal task of the experiment is to study the possibility of artificial precipitation enhancement in the Lake Sevan Basin. However, besides the practical importance of this work, the Sevan experiment has a number of scientific, technical, and organizational aspects. They are:

A. Estimation of precipitation amounts that can be obtained in Lake Sevan Basin by cloud system modification.

B. Estimation of the possible effect of cloud modification in the Lake Sevan Basin on precipitation amounts in the adjacent areas.

C. Development of a notion on precipitation producing mechanisms in the Lake Sevan Basin.

D. Obtaining detailed data on precipitation distribution in the basin.

E. Testing new cloud modification methods.

F. Optimizing the conditions and techniques of modification.

G. Generalizing the experience and results obtained for use in other regions.

3. METEOROLOGY

Physico-meteorological conditions in the Lake Sevan Basin are favorable for conducting precipitation enhancement experiments. The mean annual precipitation in the Lake Sevan Basin is approximately 550mm, ranging from 370mm at the lake surface to 800-1,000mm near the mountain peaks of the Gegamsky Range (Fig. 1).

Fig. 1 Annual precipitation amount distribution in Lake Sevan Basin.

The numbers of precipitation days during the year range from 110 days in the lake region to 140 days near the peaks of the Gegamsky Range. The majority of these days are associated with 10 to 120 passing fronts. In winter the precipitation falls mainly from stratiform clouds, and in the summer from convective clouds.

4. PRELIMINARY CONSIDERATIONS

To solve the above mentioned tasks, a meteorological site is being created in the Lake Sevan Basin. This is now equipped with modification and control means necessary for conducting preliminary precipitation enhancement experiments and estimating the results.

Cloud modification experiments aimed at obtaining additional precipitation are based on cloud phase instability. Silver iodide is used as the nucleating reagent. Remote control pyrotechnic ground generators and aircraft serve as the seeding methods.

Rational arrangement of the generators called
for the information on basic circulation parameters in the Lake Sevan Basin, as well as on the character of the reagent diffusion. The circulation in the Lake Sevan Basin was studied by simulation methods. This involved blowing the basin model in the wind tunnel (Gorlin, 1973; Vulfson, 1975) and by numerical modeling (Sherskov, 1978). In the numerical modeling studies, the temperature difference between the lake surface and the land was taken into consideration.

Model blowing in the wind tunnel revealed the complicating nature of the air circulation in the Lake Sevan Basin. It becomes especially clear in the vertical motion field (Fig. 2). There are areas of rather intensive ascending and descending currents over the lake.

In particular, the numerical simulation indicated that in winter the ascending motions over the non-freezing lake are comparable with and often exceed the upslope motions. The existence of the lake seems equivalent to the existence of the mountain range with rather steep slopes.

Preliminary calculations of the reagent diffusion showed that with the generators installed near the range peaks at a distance of 6 to 8 km from each other, the area seeding efficiency will be 20% to 40% depending on the meteorological conditions.

"Yak-40" aircraft equipped with pyrotechnic cartridge cassettes and acetone generators are used for airborne seeding.

A Meteotron type installation based on six turbo-jets with a common after burner is being constructed in the Lake Sevan Basin as a non-traditional modification means. The ascending air jet formed by the Meteotron is supposed to be used for local rearrangement of frontal strati or nimbostrati into cumulonimbus for the purpose of transforming widespread precipitation into a shower type near the installation. Theoretical calculations indirectly confirm the possibility of such transformation.

5. EVALUATION

The experiment effectiveness will be evaluated by the results from direct measurements of precipitation amounts. A provisional precipitation gage network based on standard equipment has been established for this purpose which, together with the already existing network, comprises 81 separate points. The gage locations are in places of habitation situated mainly near the lake. An automated precipitation gage network is established to provide for equal density of precipitation observations over the whole basin area, including the mountain region and the lake surface. The network will consist of two subsystems. The first is an "operative" one consisting of a few tens of temperature, wind, and precipitation detectors which will record their indication several times each day. The second is a "memorizing" one which will store precipitation information for about six months at about 200 points. The first subsystem will be used mainly for making decisions on cloud modification and controlling meteorological conditions during the experiments. The second subsystem will be used for providing an estimate of the effect for use in numerical studies.

The amount of snow precipitation will be estimated at each point by the increase of the snow water content, which in turn will be determined by the decrease of the cosmic ray intensity within the snow (Kolomeets, 1979). At present there are nine automatic meteorological stations established in the basin mountain region. A fully automated precipitation gage network will be finalized in 1983. Radio locators will also be used as an indirect method for measurement of precipitation amounts.

At present the site has at its disposal the following:

A) Eight groups of remote control ground generators (46 units) equipped with 966 cassettes (21 cassettes at each generator) with silver iodide based pyrotechnic compound. The cassettes can be fired at all or individual generators, all at once, or in sequence and in any quantity. The burning time of each cassette is about one hour. There are about $10^{14}$ ice forming particles released in the atmosphere during each hour.

B) "Yak-40" aircraft equipped for cloud seeding.

C) Two radio locators for cloud and precipitation observations.
90 precipitation gage network points including 9 automatic meteorological stations.

In addition to the above, a "Supermeteotron" installation is being constructed at the Lake Sevan site. The distribution of instrumentation is shown in Fig. 4.

Fig. 4. Meteorological site scheme

6. EXPERIMENTAL PHASE

The planning of the experiment was based on complex considerations of the following questions:

A) The results of climate-synoptic analysis of precipitation formation processes in the Lake Sevan Basin, some precipitation climatological data, and in particular the precipitation forming ability of different clouds or cloud systems.

B) Experimental unit duration for different cloud systems suitable for modification, the adequacy of the available precipitation gage network, and the requirements for the precipitation gage network now under design.

C) Modification schemes commonly used in experiments on precipitation enhancement and the expedience of its application on Lake Sevan Basin conditions.

D) Necessary and desirable physico-meteorological information on decision-making processes, considerations on operating the experiment, and estimation of results.

E) The development of numerical models which may be useful in both the development of modification methods and for providing an estimate for experimental results.

F) Possible predictors based on statistical models, numerical models, or historic synoptico-meteorological data.


The above mentioned points are illustrated in Figure 5. The solid lines show current investigated questions or actions which have been carried out. The dotted lines illustrate the activities now in progress.

It seems impossible to find modification and control sites far enough from each other in the Lake Sevan Basin, thus cross-over seeding schemes have been rejected. A randomized modification scheme within a single site turned out to be the only possible scheme and this was subsequently adopted.

As a modification objective the winter frontal clouds with low and medium levels and independent of precipitation were taken. In summer, the non-precipitating cumulus clouds were taken.

The seedability conditions for winter frontal clouds are considered to be:

A) The existence of layers of supercooled liquid cloud droplets

B) Wind directions in the range of 160° to 330° in azimuth at levels of 700 mb and 500 mb

C) The 700 mb temperature not to exceed -3°C

D) The possibility for nuclei from either the generators or the aircraft to reach the supercooled cloud layers.

In the case of seedability conditions for summer cumulus clouds, the following criteria are pertinent:

A) Existence of a convective cloud system with thickness not less than 2-3 km.

B) Single convective clouds with thickness of more than 4 km within the basin.

C) Synoptic situation favorable for convection.

D) Existence of supercooled cloud droplets with temperatures not warmer than -7°C.

E) The absence of significant natural crystallization.

The 12-hour period from 0700 to 1900 hours (an interval between two referenced times of precipitation measurements on the meteostations) was taken as the experimental unit length in convective cloud modification. The 24-hour period from the referenced time of precipitation observations preceding the beginning of seeding is the experimental unit length in winter frontal cloud modification. The 24-hour period following the modification events are declared "buffer" periods to avoid the possible effects from contamination of the basin by ice nuclei. These 24-hour periods cannot be used as experimental units independent of the weather.

A block diagram which illustrates how the head of this experiment makes decisions on the modification activities is shown in Figure 6.

The head of the experiment at a certain time (T) makes a modification decision on the basis of synoptico-meteorological data, the existence of specific cloud types, and the general conditions under which modification can be attempted. The head gives orders to start the observations in accordance with available programs, calculates the quantity of required nucleating reagent, estimates the locations of the introduction of the reagent, and carries out the randomization procedure (opens envelopes which contain "yes" or "no" instructions). In the case of "yes", the generators are started or the airborne seeding
is initiated. In the case of "no", the false starting of ground generators is made and the aircraft carries out only cloud and atmospheric parameter observations. The experimental unit and the operation of equipment is known only to the person who opens the envelope.

7. FURTHER EVALUATION CONSIDERATIONS

The estimation of results from precipitation enhancement experiments is one of the most complicated and least investigated questions in this field. An estimation of precipitation enhancement with the help of sampling sums (Kolmogorov, 1979) was adopted as the principal method for the statistical analysis of the results of precipitation enhancement experiments in the Lake Sevan Basin. The above mentioned estimation is made by comparing precipitation sums on modification days and on control days. A "reconstructed" precipitation amount is used for the estimation. This method allows for an estimate of precipitation sums for the days when precipitation was not actually measured.

Generally speaking, estimations by way of comparing precipitation for modification days and
control days have been made during previous years. However, the results obtained were not evaluated by confidence intervals, or were evaluated in supposition of certain mathematical models of the effect (Gabriel, 1967), or stochastic model types (Neyman, 1967), describing data on natural precipitation amounts. The advantage of the method suggested by Kolmogorov over previous methods is that it allows an estimate of the modification effects by confidence intervals without the above mentioned suppositions. Variance of the estimate of modification effects can be substantially reduced if there are good predictors of precipitation amounts at the site. Much attention has been devoted to the discovery of such predictors.

At present a statistical model of precipitation amounts per experimental units, depending upon synoptico-meteorological conditions, is being developed. The construction of such a model is based on many years' data on precipitation amounts in the Lake Sevan Basin as well as on data from atmospheric phenomena which cause or attend precipitation. These phenomena comprise the existence and types of atmospheric fronts, their direction and speed, the cloud forms and heights, the stratification of air masses in which precipitation is formed, values of temperature, moisture and pressure near the earth's surface and at standard levels, barometric and thermal tendencies, wind direction and speed, etc. The construction of such models should provide an opportunity to forecast the average natural precipitation amount in the basin by the combination of the above mentioned cloud and atmospheric phenomena. A special data archive is being established for the model development.

Under certain synoptic conditions, the precipitation amounts in the control sites outside the Lake Sevan Basin correlate quite well with precipitation amounts within the basin. The models can use these data for particular cases of predictors. Depending on all conditions, the precipitation amounts in the Lake Sevan Basin will be "forecast" from the precipitation amounts at one or combinations of other sites.

8. REFERENCES


