THE WMO PRECIPITATION ENHANCEMENT PROJECT (PEP)

- PROGRESS TO DATE AND PRESENT STATUS -

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1. INTRODUCTION

The WMO Weather Modification Program evolved from events in the early 1970's when, partly as a result of the Sahel drought and partly due to rising general interest in the subject, the WMO received more and more requests for advice and assistance in the field of weather modification. Several possible responses were discussed and proposed by the WMO Commission for Atmopsheric Sciences (CAS) Working Group on Cloud Physics and Weather Modification which had been established by CAS under the chairmanship of Professor R. List. These were considered by the WMO Executive Committee at its twenty-sixth session in May-June 1974. The Executive Committee asked the working group to also act as the Executive Committee Panel of Experts on Weather Modification (hereinafter referred to as the EC Panel) and at the same time called on WMO to give the lead in weather modification activities, and this finally provided the general context for such a program.

Following this, the EC Panel, meeting in late 1974 felt that the objectives set out by the Executive Committee could never be properly achieved if WMO's role remained restricted to providing advice based only on theory. The EC Panel agreed that the stage had been reached when WMO, if it were to fulfill its basic function as the leading international agency in meteorology, must initiate action in the field of weather modification by launching a carefully and scientifically planned and coordinated weather modification program. A fundamental component of the program would be scientifically planned and evaluated experiments in various types of weather modification, but most especially on precipitation enhancement.

The Panel drew up an outline for a new WMO program on weather modification, incorporating the Rain Enhancement Project, and unanimously agreed to request the Secretary-General to submit the proposals to Seventh Congress for consideration and possible approval.

In considering the proposed Weather Modification Program, the Seventh Congress meeting in May 1974 "agreed that the time had come for the Organization to become more active in the field in order to be able to respond competently to requests for advice from Members, the United Nations and other international organizations concerning weather modification". Congress recognized that there were many forms of weather modification receiving attention in several countries but agreed that precipitation enhancement was of the highest priority.

The Congress went on to "agree that scientifically convincing answers concerning the feasibility of precipitation enhancement could best be advanced through an internationally planned, executed and scientifically evaluated

exercise as proposed in the Precipitation Enhancement Project (PEP). In order that the conclusions drawn from the PEP may command wide acceptance in the scientific community, Congress stressed that the experiment must be meticulously prepared, executed and evaluated. Moreover, the experiment would have to be conducted over a sufficient number of years to detect any effect against a background of strong 'noise' represented by natural variations of rainfall amounts. The first stage of the Precipitation Enhancement Project should be detailed studies of cloud populations, including their dynamical and microphysical structure. This should not only permit the selection of a basis for advice to individual Members in assessing the possibility of successful precipitation enhancement projects in their own countries". Thus, with the adoption of a resolution setting up the WMO Weather Modification Program, PEP formally came into being as a major component of the Program.

2. ORGANIZATIONAL STRUCTURE

For WMO to embark on such an ambitious and complex international experiment, an appropriate organizational framework was needed. Three groups were identified as being necessary to carry out the experiment; their main functions were indicated below.

The already existing EC Panel had the heaviest responsibility during the initial planning stages of PEP since it was necessary that careful consideration be given to all the scientific aspects of the project. The EC Panel continues to provide the overall scientific guidance to the project, will assess the results of each phase, and provide advice both to the Executive Committee and the PEP Board on the scientific and technical requirements for continuation of the project.

Once the potential site for the project was selected and field measurements were required, the PEP Board was formed. The Board has the critical responsibility of ensuring that sufficient and continuing resources are provided to achieve the scientific objectives. The Board, therefore, consists of senior representatives from the meteorological services (or other meteorological research agencies) in the host country and in the Member States of WMO who are making major contributions to PEP.

The formidable task of ensuring the smooth functioning of PEP and coordinating all the planning and field activities rests with the WMO Secretariat. A special Scientific Planning Group (SPG) for PEP has been formed within the Secretariat, consisting of a Leader and Scientific Officer based in Geneva, and a Field Project Coordinator based at the site for PEP in Spain.

In addition to the above three groups, several informal meetings of invited experts have been called over the past five years to consider specialized aspects of PEP such as:

> hydrological aspects; cloud seeding reagents; areal extent of seeding effects; aircraft instrumentation; environmental aspects; dispersion of seeding materials and, most recently, general considerations of statistical design.

The truly international involvement and interest in PEP can be judged by the fact that the above-mentioned meetings, plus other planning sessions, totalled twelve. Seven different countries acted as hosts, with over one hundred scientists from ten separate countries participating.

3. OBJECTIVES OF PEP

The Seventh Congress of WMO stated that "It is the goal of this project to establish when and under what conditions precipitation enhancement can be achieved artificially in a given region. By the time of completion of the PEP, scientific advances in understanding precipitation forming processes may well allow more general application of the results of other regions and to other forms of modification".

This general goal was formulated into a series of more specific objectives by the EC Panel in November 1975 and they were subsequently approved by the Executive Committee in May 1976. The eight objectives are as follows:

(a) To provide Members with reliable information about the probabilities of successful artificial intervention in meteorological processes with the object of increasing the amount of precipitation over an area of the order of 10,000 km^2. The size of the area for the proposed project (i.e. the target and nearby control areas) should be somewhere around 50,000 km^2, a scale large enough to provide adequate evaluation of scientific feasibility and economic benefit, but small enough to permit the use of adequate methods for seeding and observations.

(b) To demonstrate, at a satisfactory statistical significance level over a relatively short experimental period (five years), that any increase observed is not a chance event but is associated with the seeding. The principal evaluation of this experiment will be in terms of precipitation at the ground.

(c) To obtain sufficient understanding of the meteorology and cloud physics in the area of the experiment to ensure that the statistical association of seeding, and any increase in precipitation, will be generally acceptable as a cause-and-effect relationship.

(d) To make an examination outside the target area in order to determine whether any benefits of seeding extend over areas greater than the target area, or whether there has merely been a comparatively local redistribution of precipitation.

(e) To make systematic measurements, varying from mesoscale to cloud microstructure, in order to develop additional covariates to strengthen the power of the statistical analysis.

(f) To obtain well-documented scientific evidence that may lead to the optimization of the effects of seeding. For this purpose, a series of systematic cloud physics measurements should be taken on a routine basis. This would allow the application of statistical stratification techniques

to relevant physical parameters, and could shed more light on the quantitative aspects of seeding techniques.

(g) To be able to make some recommendations about the applicablility of the PEP procedures to other areas of the world.

(h) To assess the environmental impact of precipitation enhancement activities, both within and outside the experiment target area.

A further discussion of the rationale behind these objects is given by List (1976).

4. THE SITE-SELECTION PROCESS

Clearly, one of the major considerations in planning for PEP is the selection of the best site for the experiment. In order to meet the broad criteria for this selection laid down by the Seventh Congress, a selection procedure in three phases has been followed.

An initial list of criteria for the suitability of sites for the PEP experiment was drawn up and formed the basis of the first questionnaire sent out to all Members in October 1975. The questionnaire asked interested countries to suggest sites for PEP and to give some information on the proposed sites, including climatological data. Those sixteen countries that responded positively were sent a second questionnaire early in 1976 soliciting additional and more detailed information, especially on the logistics offered by the proposed sites. These questionnaires were evaluated by the EC Panel using an objective rating scheme resulting in the selection of six potentially suitable sites.

The second phase of the site-selection process was designed to narrow this list down to two or three sites, the maximum number at which it would be reasible to conduct the intensive physical measurements, investigations and other studies necessary before a final decision on the site could be made. This second phase actually consisted of three separate activities carried out in parallel. First, careful on-the-spot surveys were made of each site by a small team of specialists in order to explore with the local meteorologists such items as the meteorological conditions, the availability of climatological data and the operational facilities at the site itself. Secondly, each of the six countries was asked to send detailed rainfall data for the proposed site to the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. Numerial-statistical simulation experiments were then carried out by the CSIRO using the technique developed by Twomey and Robertson (1973) on these data in order to help determine whether the raingage network would provide adquate data to be able to detect a 10-20 per cent change in precipitation over a five-year period. (The results for the proposed Spanish site are given by Shaw in PEP Report No. 10). Thirdly, each of the six countries was asked to carry out detailed synoptic-climatological studies which would give information on the frequency and characteristics of the rain-producing weather systems over the area in question.

After the results of all these studies were very carefully evaluated, the EC Panel recommended in January 1978 that two potential sites - one in Australia and the other in Spain - be investigated further in the third and final phase of the site-selection process. When the PEP Board at its second session (April 1978) considered the available resources, it was however apparent that these were not sufficient to conduct detailed on-site physical investigations at two sites. Since it was noted that the geographical location of Spain made it much easier for most of the contributing Member countries to consider a multi-year involvement in a program there, the Board decided that the program be implemented in Spain only and should commence in January 1979.

5. LEGAL FRAMEWORK FOR CONDUCTING PEP

Once the decision was made to carry out actual field observations in Spain for the final site-selection phase (SSP-3), it was necessary to draw up an agreement that would form the legal and administrative framework for the project. Negotiations thereupon took place between the WMO Secretariat and the Spanish National Meteorological Service during the second half of 1978 and the text of the Agreement was approved by the Council of Ministers of the Spanish Government in December 1978. The Agreement was signed at a formal ceremony in Madrid on 23 January 1979.

The Agreement contains, among other things, clauses on the privileges and immunities of WMO and its officials as well as those of participating Member countries; authorization for access to and the use of facilities in Spain; conditions for the entry of personnel and equipment into Spain; fiscal exemptions from taxes; liability and settlement of disputes. As an annex to the Agreement, a "Protocole d'exécution" outlines in more detail the administrative procedures for implementing the terms of the Agreement.

The basic Agreement is essentially between Spain and the WMO. Any Member State wishing to participate actively in the SSP-3 project, by sending equipment or personnel to Spain, is required to deliver a note to the Spanish Government signifying its agreement to be a participating Member State.

6. SOME CHARACTERISTICS OF THE SPANISH SITE

The proposed site for PEP in Spain is the Duero River basin centered on the city of Valladolid which is located 160 km northwest of Madrid. The basin gets its name from the main river, the Duero, which has its source in the Cordillera Iberica to the east. The basin is bounded on three sides - the north, east and south - by mountain ranges rising to between 2,000 and 2,500 m. The basin is more open to the west and southwest where lower hills rise to a height of about 1,000 m in eastern Portugal.

Within the basin, there is an area of about 50,000 km^2 with fairly uniform terrain gently sloping upwards from an elevation of 700 m in the

southwest to nearly 1,000 m in the northeast at the foot of the mountain ranges. For hydrological studies that may be associated with PEP, the site has the advantage of being a well-defined closed basin with only one outlet through Portugal to the Atlantic Ocean. The region is also equipped with a large network of stream gaging stations, some with long records.

The climate of the basin is presented in detail in PEP Report No. 10. The mean annual precipitation on the floor of the basin varies between 300 and 500 mm. This rain is fairly uniformly distributed through the months September to June with a pronounced minimum occurring in July and August (Fig. 1). In the non-irrigated areas, this amount is only marginally sufficient to support the agriculture of the region and thus any increase that could be produced by weather modification has the potential of being economically very beneficial.

Long-term records - some up to 40 years or more - are available from several hundred raingages providing daily 24-hour rainfall amounts throughout the basin. Nineteen existing recording stations, of which ten have 15-20 years of record provide a detailed base for numerical simulations required in designing the eventual PEP seeding experiment. Using these rainfall data and correlating them with historical weather maps, it has been found that most of the rain falling in the basin occurs with winds from the westerly sector, especially from the WSW when the airflow is least impeded as it enters the basin.

7. FIRST YEAR OF FIELD MEASUREMENTS

The Observational Program

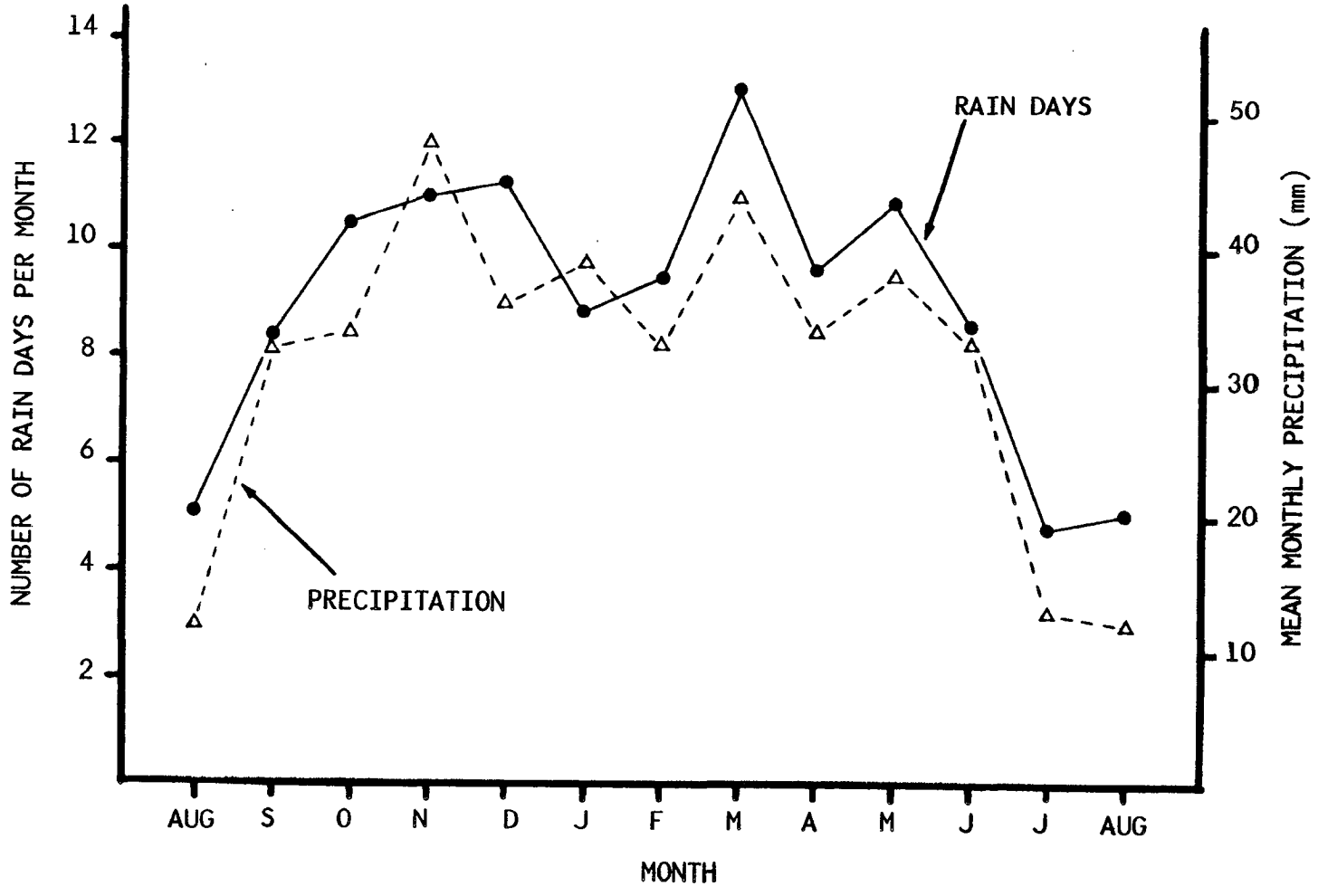
The third and final phase of the site selection process (SSP-3) for the WMO Precipitation Enhancement Project (PEP) began at the proposed site in Spain in March 1979, somewhat later in the season than originally planned. This was due to unforeseen difficulties - a not unusual circumstance during the start-up of any major meteorological field program. The important point is that a start was in fact made in 1979 and some very useful observations were obtained. At the same time the participants gained valuable experience in operating in the Spanish environment and are thus in a much better position to plan ensuing field activities.

The detailed objectives of the SSP-3 of PEP are given in the Operations Plan (PEP Report No. 11) but can be summarized as follows:

> "To establish by on-site physical investigations whether the clouds in the pre-selected site are seedable and, if so, whether they occur with sufficient temporal or spatial frequency to make a seeding experiment scientifically viable".

The observational and analysis program for the SSP-3 has been designed in such a way that not only will the above basic question be answered, but also that a better understanding will be gained of cloud physics processes and the precipitation mechanisms operating at the site.

FIGURE 1.



Rain Days and Mean Monthly Precipitation-Duero River Basin

An overview of the 1979 field program together with a catalog of the data obtained has been prepared by the Field Project Coordinator and published as PEP Report No. 15. A summary of the observation systems operating, the period of observations and an indication of the amount of data collected is given in Table 1. It can be seen that basic observing systems were operating from mid-February until early May but, in addition, during a nine-day period commencing at the end of March, a more intensive observing program was conducted with the participation of several groups from France. A very serious gap in the 1979 program was the lack of a weather radar system, however, this deficiency has now been corrected.

Preliminary assessment of the results

Preliminary results were presented by the Field Project Coordinator and principal scientists from the groups making aircraft measurements, to the ninth session of EC Panel meeting in Geneva in September 1979. Although the detailed analyses of the aircraft data are continuing and will eventually be published, the EC Panel was able to draw the following necessarily limited conclusions regarding the first season:

> "The clouds studies were fairly typical in microstructure of a modified maritime air mass with droplet concentrations generally less than 500 cm^{-3}. In general, the individual droplet size distributions available at the time of writing this report had a cut-off at about 25 μm diameter. Ninety percent of the observations showed a liquid water content considered to be less than 0.5 gm m^{-3}. Ice particle concentrations of 10 to 50 l^{-1} were found over significant cloud volumes on many flights, most of which were made in clouds whose tops were at tempeatures below $-10^{o}C$. However, until the results are studied in more detail (particularly in regard to the variation in supercooled water and ice particle concentration with respect to cloud age), no firm conclusions can be drawn in regard to the suitability of these clouds for seeding".

The above statement must be qualified because the actual field observations coverd only about one-half of the period being considered for the PEP seeding experiment, and it is not known how representative the conditions encountered were of the longer term average. A study of the general weather conditions during SSP-3/1979, published as PEP Report No. 18, in fact suggests that the weather in 1979 was dominated by a cool northwesterly flow and more convective activity than normal. It was for this reason that the EC Panel felt it essential to have at least two more full seasons of observations before it would be in a position to recommend whether the site in Spain would be suitable for the proposed PEP seeding experiment.

8. THE SECOND SEASON OF FIELD MEASUREMENTS IN 1980

The Plan

During the summer of 1979, as it became known what additional facilities

TABLE 1.

Summary of the main observations made during SSP-3/1979 in Spain

Observing System	Period of observations	Frequency of observations
Queen Air aircraft (USA)	14 March - 8 May	28 flights
DC-7 (FRANCE)	27 March - 4 April	13 flights
Synoptic laboratory (SPAIN)	20 March - 9 May	all days
Radiosonde (FRANCE/SPAIN)	14 March - 8 May	60 ascents
METEOSAT satellite receiver (FRANCE)	27 March - 27 April	73 visual photos 129 IR photos
Time-lapse/all-sky cameras (FRANCE)	28 March - 5 April	8 days
Raindrop distrometer (SWITZERLAND)	14 March - 28 April	92 hours
CCN sampler (FRANCE/SPAIN)	23 March - 9 May	124 samples
Pluviograph network-19 stns (SPAIN)	14 March - 8 May	daily charts

would be avilable in Spain and what the scope of resources provided by the participating Members would be, a plan was drawn up for the second season of measurements. The proposed plan was still somewhat less than the ideal contained in PEP Report No. 11 but the EC Panel felt that it was a scientifically viable plan and, therefore, recommended it to the PEP Board for implementation.

The PEP Board, meeting in late September 1979, after reviewing the resources offered by the participating countries, approved the plan and thus gave the green light for the second field season. At the same time the Board considered it necessary to formulate a series of key questions to be answered so that the results of the 1980 season could be assessed, at least in a preliminary way, before making recommendations to the thirty-second session of the Executive Committee of WMO, to be held in May, 1980, regarding the future course for PEP.

A planning session for SSP-3/1980 was therefore held in Boulder, Colorado, in December 1979 including principal scientists from several participating countries and staff of the SPG for PEP. The meeting agreed on a series of questions which it felt would be answerd from the data obtained by the various observing systems. Detailed consideration was given to the operating mode of the radar, the processing of the radar data logged by the digitizer, the optimum flight paths for the instrumented cloud physics aircraft and how all the data collected by these systems together with the synoptic weather data and satellite data would be catalogued, processed and analyzed. All of this would be used in an effort to meet the prime objective of SSP-3 and decide whether, and for how long, conditions suitable for glaciogenic seeding exist in time and space at the PEP site.

Preparations at the Site

Preparation of the field site at the Villanubla airbase near Vallodolid, Spain, by the Spanish National Meteorological Institute, continued during 1979 and the following facilities are now available for use by project participants. The core facility is the Operations Center located in a hangar which has been completely refurbished. Ample office, laboratory and workshop space will be available, together with a photographic darkroom and small canteen. The communications center and synoptic weather laboratory will provide a complete weather forecasting center both for day-to-day operational planning and for post-analysis of the association between synoptic patterns and cloud types, precipitation patterns, etc. Additional recording raingages are being installed by the Institute and a small staff of meteorologists and technicians will be provided to operate all these facilities.

The radar site about 1.2 km from the Operations Center was prepared in September and the MRL-5 3/10 cm radar provided to PEP by the USSR arrived by road transport from Moscow early in October. A team of Soviet engineers and technicians installed the radar system and had it operating by the end of October. A radar digitizer used by Canada for GATE was shipped to Spain and within 10 days was interfaced with the radar. Test data tapes were obtained on weather systems and indicated that the interfacing was highly

successful, due in large measure to the careful planning after preliminary contacts between the Soviet and Canadian engineers in October 1978.

The start of observations in February 1980

By the middle of February 1980 most of the equipment and personnel were on-site in Spain and the first aircraft mission was flown on 15 February. The major contributions to the 1980 program are listed below in alphabetic order by country:

Australia: one cloud physicist with airborne CCN counter; additional computer simulations on rainfall data at CSIRO.

Bulgaria: two specialists in cloud physics.

Canada: radar digitizer and operating technician.

France: minibus rawinsonde system; ground CNN measurements; raindrop distrometer; two light aircraft for one month for some cloud physics measurements; satellite data processing.

Spain: support facilities indicated above.

U.S.A.: Queen Air fully instrumented cloud physics aircraft with ground computer processing system and crew; one synoptic meteorologist.

U.S.S.R.: MRL-5 dual (3 cm/10 cm) wave-length radar with scientist and operating personnel; two cloud physics specialists.

Switzerland: Raindrop distrometer and meteorologist (part-time).

The 1980 measurement program is expected to continue through until mid-May.

9. OTHER ASPECTS OF SITE SELECTION

Although the cloud characteristics being determined by the field measurements, provide the most important inputs into the site selection, other necessary studies are going on in parallel. These are statistical design and economic benefit aspects.

Statistical design and evaluation

The objectives for PEP listed in Section 3 clearly indicate that both statistical analyses and physical understanding will play a major role in the evaluation and interpretation of the results of PEP. It is equally clear that not enough details of the rainfall patterns and cloud structures at the proposed PEP site in Spain are known at this time to prepare the statistical design for PEP, nor is it indeed yet necessary. However, it was felt useful to further discuss the general philosophy of statistical

design and to recommend further studies that should be carried out during the site-selection phase so that the best possible design can be made for the seeding experiment itself. Accordingly, a small group of experts met at the headquarters of the USSR State Committee for Hydrometeorlogy and the Control of Natural Environment, in Moscow from 29 October to 2 November 1979, to review the current state-of-the-art in the statistical design and evaluation of precipitation enhancement programs. The meeting was able to benefit from the fact that several of the participants had previously attended the two concurrent meetings on weather modification and on statistical applications sponsored by the American Meteorological Society in Banff, Canada from 1-12 October 1979. Many of the papers and much of the discussions at these AMS meetings were of direct relevance to PEP and advantage was taken to hold informal discussions regarding PEP and a working document was prepared as a basis for more intensive discussion in Moscow. The results of themeeting have been summarized and published as PEP Report No. 17.

Economic benefit studies

Another important aspect of the final choice of season for the seeding experiment is the potential economic benefit that might accrue in the region. The prime beneficiary of any additional water is expected to be agriculture. An expert visited the site for two weeks in November 1979 to meet with meteorologists, hydrologists, agriculturists, foresters, etc. from a number of government agencies, institute and universities. It appears that a substantial amount of relevant data is available and it will, therefore, by possible to carry out studies of the economic benefit of any additional rainfall in the Duero River basin.

10. FUTURE PROSPECTS FOR PEP

The Eighth Congress recognized the importance of continuing PEP and, therefore, asked that it be given high priority within the WMO. Adequate funding wqas allocated to PEP, thus ensuring that the SPG can continue its coordination and management function over the next four-year financial period (1980 to 1983 inclusive). However, at the same time Congress also agreed "that the continuation of PEP must depend not only on sufficient resources being committed by Member States but also on the suitability of the site in Spain for an actual seeding experiment and instructed the Executive Committee to review carefully the progress of PEP and, on the advice of the EC Panel regarding the scientific viability of continuation, release and funds accordingly".

Thus, the future of PEP depends very critically on the assessment of the SSP-3 field observations now being gathered at the proposed site in Spain. A final decision on whether the clouds occurring at the site are in fact suitable for an actual experiment using glaciogeric seeding will probably not be possible until after the 1981 field season. If the decision is positive, then many other factors will have to be given urgent consideration.

These include carrying out seeding calibration and dispersion trials (if they have not already been done by 1981), selection of the optimum location for the target area within the larger experimental region and a final design that will ensure the objectives of PEP being met.

Ultimately, however, the success of PEP will depend on the contributions from the host country and the participating Members and especially on the enthusiasm and dedication of the involved scientists, both in making the necessary field observations and in carrying out the detailed analysis and interpretation of the results.

11. PEP PUBLICATIONS

When the WMO Weather Modification Program was set up it was the wish of the Executive Committee that information on the activities of PEP be given wide distribution. In order to accomplish this, a series of PEP reports was initiated in 1976. Not only do these reports give the full details of the progress of PEP, but they serve as a useful guide to Member states of WMO who need information on the factors to be considered in carrying out their own program. To date nineteen reports have been issued as listed below:

Report No. 1 - Report of the First Session of the Interim Precipitation Enhancement Project Board, Geneva, November 1976

Report No. 2 - Position Papers used in the Preparation of the Plan for PEP.

Report No. 3 - Plan for the Precipitation Enhancement Project

Report No. 4 - A Review of the Hydrological Aspect of Evaluation of Precipitation Enhancement.

Report No. 5 - Cloud Seeding Reagents

Report No. 6 - Areal Extent of Seeding Effects in Relation to the Precipitation Enhancement Project.

Report No. 7 - Aircraft Instrumentation for Cloud Physics Research and Weather Modification Programs.

Report No. 8 - Report of the Second Session of the Interim Precipitation Enhancement Project Board, Geneva, April 1978

Report No. 9 - PEP Design Document

Report No. 10 - Survey of the Climatology and Synoptic Weather Patterns at the Proposed PEP Site in Spain

Report No. 11 - Operations Plan for Site-Selection Phase 3

Report No. 12 - Preliminary Environmental Impact Study of the Site Proposed for PEP

Report No. 13 - WMO Training Workshop on Weather Modification for Meteorologists - Lecture Notes

Report No. 14 - The Dispersion of Cloud Seeding Reagents

Report No. 15 - PEP Site Selection Phase-3, 1979 Field Program - Overview and Data Catalogue

Report No. 16 - Report of the Third Session of the Precipitation Enhancement Project Board, Geneva, September 1979

Report No. 17 - Statistical Design Considerations for Precipitation Enhancement Projects

Report No. 18 - PEP Site Selection Phase-3, 1979 Field Program - General Weather Conditions and Rainfall Characteristics

Report No. 19 - PEP Site Selection Phase-3, 1979 Field Program - Studies of Precipitation Patterns

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