R-89-14

PROGRAMME AL GHAIT - MOROCCO WINTER SNOWPACK AUGMENTATION PROJECT

A COOPERATIVE PROJECT BETWEEN THE KINGDOM OF MOROCCO AND THE UNITED STATES

UNDER
PARTICIPATING AGENCY SERVICE AGREEMENT
IMA-0190-P-IW-4093-00

FINAL REPORT
Submitted to
U.S. Agency for International Development
Washington, D.C.

SEPTEMBER 1989

U.S. DEPARTMENT OF THE INTERIOR
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16. ABSTRACT

From 1984 to 1989 the Governments of Morocco and the United States cooperated in Programme Al Ghait, a $12,000,000 project to investigate the feasibility of augmenting water supplies in Morocco through weather modification. A demonstration project was set up in the upper Oum er Rbia basin, which is on the northwestern side of the central High Atlas Mountains. Promising cloud formations were treated with silver iodide released from aircraft and, beginning in 1987, from a network of ground-based generators. Clouds were seeded on 144 days over the five winters of operations. An extensive effort went into developing the required infrastructure, providing modern equipment, and training over 100 Moroccan personnel to conduct and evaluate the project. The project provided Morocco with its first weather radar and its first airborne system for collection of cloud physics data. New rawinsonde stations were established at Beni Mellal and Tissa to obtain upper air data every 12 hours. A satellite ground receiving station and an image processing system were provided to monitor clouds. Extensive communications and microcomputing systems were provided to transmit and analyze scientific data. Airflow and precipitation models were adapted to Morocco to guide operational decisions. Scientific studies by Reclamation and its contractors and Moroccan scientists concentrated on the seedability of clouds over the Atlas Mountains and statistical methods of evaluating effects of cloud seeding. Seedable conditions, as indicated by the presence of supercooled liquid water in clouds at concentrations up to 0.7 g/m^3 at temperatures down to -12 °C, were found to occur on 15 to 30 days per winter. The evaluation studies, which were based on a target-control design using streamflow as the response variable, indicated that 6 years of experimentation would be required to provide a 50-percent probability of detecting a 10-percent increase in streamflow due to seeding. The potential effects of augmented streamflow upon the operation of the Oum er Rbia River and upon the local and national economy were studied with the aid of computer models. This report covers the project design, the contributions of the two Governments involved, the development of Moroccan institutions to handle such a complex program, the technology transfer and scientific studies accomplished, and the results of the streamflow and economic analyses using models. A section on problems encountered and lessons learned is included for the benefit of other persons or agencies contemplating large, complex projects involving more than one national government.

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SI METRIC

September 1989

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

ACKNOWLEDGMENTS

The authors acknowledge the support of His Majesty King Hassan II, whose interest in weather modification made Programme Al Ghait possible.

Dr. Stephen Lintner of the U.S. Agency for International Development's (USAID) Washington Office, Mr. Harry Petrequin of the USAID Mission in Morocco, and Dr. Bernard Silverman of Reclamation worked closely together in getting the project started. The USAID Mission in Morocco and the staff of the American Embassy in Casablanca provided much assistance. Our deep appreciation is expressed to Mission Directors Robert Chase and Charles Johnson, and to their staffs. Mr. Richard Jackson, American Consul General, graciously hosted two large receptions at his residence for project personnel and visiting water resources experts.

The personal interest of General Kabbaj, the project's "Haut Coordonnateur," accounted largely for its speedy implementation. Colonel Mohamed Bamaarouf was diligent in fulfilling the Royal Air Force commitment to the project. Mr. Amed Bensari, Director of the National Meteorological Organization, had overall responsibility for the project on the civilian side, while the project's Director, Mr. Saad Benarafa, provided skillful supervision on a day-to-day basis. Mr. El Bachir Loukah performed effectively as Deputy Director following his appointment in 1987. Special thanks go to the Operations Team, led by Mr. Moustafa Maidane and Mr. Yvon Le Goff, and the Equipment Team, led by Mr. Brahim Louaked and Mr. Mohamed Megdani, for their excellent performance.

The personnel from the Royal Air Force who flew the seeding aircraft were originally led by Lts. Hamri and Idouba and currently are led by Captain Chouham. Captain Maanan coordinated the flight operations with the Programme Al Ghait Operations Team. All flying missions were conducted with skill and dedication. The project is also indebted to the base commanders at Kenitra, Khouribga, and Anfa, who provided excellent facilities and assistance to the air crews.

Mr. El Bachir Loukah contributed to chapter 3 of this report and also provided a critical review of the entire document. The Scientific Analysis and Evaluation Team contributed to the text of chapter 8. Mr. Baddour and his American counterpart, Dr. Rasmussen, wrote the section on cloud physics studies; Mr. Nbou and Dr. Johnson, the radar studies; Mr. Benassi and Dr. Matthews, airflow modeling studies; Mr. El Majdoub and Mr. Medina, precipitation modeling studies; Mr. Abidi and Mr. Verdin, snow cover and runoff modeling studies; and Mr. Mrabet and Mr. Medina, statistical evaluation studies. The team's excellent work is leading to international recognition of the capabilities of Moroccan scientists.

The authors also wish to acknowledge the contributions of individuals in other agencies of the Government of Morocco who routinely assisted the project. The Ministry of the Interior, through the Provincial Governors at Azilal, Beni Mellal, and Khouribga, was most helpful in the provision of project facilities. Mr. Smouni and Mr. Laabi of the Ministry of Mines and Energy and Mr. Boutayeb and Mr. Obaklace of the Ministry of Equipment provided reservoir and streamflow data, as well as assistance in river modeling.

Many American technical experts were in Morocco for extended periods as employees of Programme Al Ghait contractors. Chapters 4 and 6 list all such individuals. Noteworthy contributions were made by persons from the University of North Dakota, including Dean John Odegard, whose early involvement contributed to the project's initiation, and Drs. C. A. Grainger and Jeff Stith and Mr. Roger Tilbury, who collected cloud physics data. The staff of Colorado International Corporation, including Dr. Larry Davis, President, Mr. Dennis Treddenick, and Mr. John Welker, provided technical assistance with various electronic equipment. Significant contributions were made by persons from North American Weather Consultants, including Mr. Keith Brown, President, and Mr. Robert Cox. Special thanks go to Dr. Paul Mielke, Jr., of Colorado State University, who provided a formal course in statistical evaluation techniques, and Dr. Gabor Vali, University of Wyoming, who taught a course on the scientific aspects of weather modification.

Finally, we acknowledge the valuable services of the external evaluation teams. The persons who served on the various teams were Professor Stanley Changnon of the University of Illinois, Dr. Joseph Warburton of the University of Nevada, Dr. Harold Orville of the South Dakota School of Mines and Technology, and Mr. Lynn Rose, formerly of the North Dakota Atmospheric Resource Board.

Thanks go to the editor, Jeanette Ballentine, and to the secretaries who typed the manuscript, Pat Veasman and Renate Colloton.

EXECUTIVE SUMMARY

The Kingdom of Morocco established Programme Al Ghait in the early 1980's as an emergency response to a severe, prolonged drought. Its primary goal was to utilize weather modification techniques to augment rainfall. In 1983, at the direction of His Majesty King Hassan II, the Government of Morocco (GOM) requested assistance with the project from the United States of America (USA). The U.S. Agency for International Development (USAID) signed an agreement with GOM in May 1984 to initiate a $6 million technical assistance program that provided both scientific equipment and training for the project, making Programme Al Ghait a joint USA-GOM undertaking.

The primary objectives of the joint project were to:

1. Implement a scientifically based cloud seeding demonstration program for winter precipitation augmentation over the upper portion of the Oued Oum Er Rbia basin in the Atlas Mountains to alleviate the existing drought conditions, assess the amount of additional water produced in the river/reservoir system as a result of the demonstration program, and evaluate the effects of increased winter precipitation on runoff and its subsequent uses.

2. Examine cloud and precipitation processes to improve the scientific basis of the demonstration program and obtain evidence of its physical plausibility.

3. Concurrent with the first two objectives, transfer winter precipitation augmentation technology through informal and formal training to enable Moroccan personnel to design, plan, implement, monitor, and evaluate similar winter precipitation augmentation projects over the mountainous areas of Morocco.

4. Increase the awareness of the need for an improved water management program in the Oued Oum Er Rbia basin which would consider weather modification as one of many water resources options.

These objectives were largely attained during the past 5 years.

Institutional Structure

Programme Al Ghait was established by His Majesty King Hassan II under the "Haut Coordonnateur," General Kabbaj of the Royal Air Force (FRA), and his Project Manager, Colonel Bamaarouf. The project grant agreement was administered by Mr. Bensari, Director of the National Meteorological Organization (Direction de la Meteorologie Nationale, or DMN), and Colonel Bamaarouf. Mr. Benarafa, Director of the project, and Mr. Loukah, Deputy Director, led a team of over 50 meteorologists, technicians, and observers from the DMN and more than 10 pilots and 20 supporting aircraft mechanics and technicians from the FRA. These personnel were dedicated to cloud seeding operations, scientific data collection, and analysis.

The Moroccan contributions, which totaled about $7 million in facilities and services, included over 100 personnel, facilities for personnel and equipment at all project sites, cloud seeding aircraft, and ground-based silver iodide generators for seeding, complete with operators and maintenance. Facilities for project management, direction of operations, equipment maintenance and supply, data archiving, and scientific analysis were provided by the DMN in Casablanca. The GOM provided the field operations center and facilities for Morocco's first weather radar in Khouribga, 180 kilometers southeast of Casablanca. Rawinsonde launch facilities were built at Beni Mellal and Tissa, about 230 and 260 kilometers southeast of Casablanca, respectively.

Airborne seeding operations were conducted up to the spring of 1986 by four OV-10 aircraft based at Marrakech and thereafter by two King Air 100 aircraft based at Kenitra, 200 kilometers northeast of Casablanca. One of the King Airs was equipped with Morocco's first cloud physics data acquisition system in 1987. In addition, a radar-equipped Alpha Jet was available for high-altitude seeding missions throughout the duration of the project. It was normally based at Meknes.

American assistance provided over $2 million in scientific equipment and supplies. These included the weather radar with its digital recording system, a cloud physics data acquisition system, aircraft navigation systems, a satellite direct-readout ground station and analysis system, 2 rawinsonde systems, 12 microcomputers and software for them, radio communications systems, telecopier and facsimile data receivers, electronics workshop and test equipment, tools, and miscellaneous other hardware and expendable supplies. The balance of the $4 million was provided in technology transfer, which included long- and short-term training programs, both formal and informal, project design and management, and administrative assistance for procurement.

Scientific basis. - The project was designed to use the latest available technology in winter orographic cloud seeding to increase the precipitation efficiency of cold clouds in the Central High Atlas Mountains in the vicinity of 32° N. and 7° W. The project used silver iodide (AgI) as the seeding agent. Silver iodide particles act as ice nuclei, converting supercooled cloud droplets to ice crystals, which can grow rapidly into snowflakes. The silver iodide was released from aircraft, ground-based seeding generators, or both during periods when seedable clouds existed that could affect the target area. The methods were similar to those successfully employed in operational and research projects in the Sierra Nevada of California, an area with climate and geography similar to those of Morocco.

Project design. - Due to the severity of the ongoing drought, the cloud seeding plan called for the treatment of all storms with seeding potential that were expected to affect the drainage area of about 7000 km^2 feeding Bin El Ouidane reservoir. A target-control design was selected for the statistical evaluation. This design required the selection of a control area near the target. Cloud systems affecting the control area were not to be treated, but measurements would be made for eventual use in the evaluation of seeding effects. Streamflow was selected as the primary response variable for the statistical evaluation because lengthy records existed for the target and control areas. Streamflow is also the variable of primary importance to Moroccan water resources needs.

Major Achievements

1. Implementation of field operations. - The field program was initiated in July 1984 with the construction of facilities and staffing of project headquarters and field sites. Headquarters were set up at the Casablanca Anfa Airport. Field sites, including the radar operations center and a rawinsonde station, were activated. Cloud seeding aircraft were modified for cloud seeding and placed on station at Marrakech.

A detailed scientific operations plan was developed for Morocco and used to guide meteorological and technical personnel in the daily conduct of operations. Seeding operations began in November 1984 and continued through May 1985. The same operational season applied in subsequent field seasons through May 1989. As previously noted, after the spring of 1986, aerial cloud seeding was accomplished by King Air aircraft operated from Kenitra.

Cloud seeding efficiency was less than desired for the first 2.5 years, when all seeding was conducted by aircraft and field personnel were still receiving basic training. Seeding efficiency increased substantially, from less than 15 to more than 70 percent, after ground-based silver iodide generators were installed in January 1987 to provide more continuous seeding.

Field operations conducted from 1984 to 1989 resulted in the seeding of 15 to 25 storm events during each season, with a total of 144 seeded days during the 5 years. Weather forecasts were prepared for each day from November through April of each season. Radar surveillance was maintained throughout all storms affecting the area except when equipment failed.

During 1985, a specially instrumented jet aircraft from the University of North Dakota was operated in Morocco to collect cloud physics data pertaining to the seedability of winter clouds. Beginning in 1987, the project's specially instrumented King Air collected detailed data on cases considered important to physical studies. Analyses of these data have helped in developing and refining seeding strategies and procedures.

2. **Transfer of technology.** - The technology transfer process was the most important aspect of the project. The process involved the training of personnel, acquisition of vital equipment, and the conduct of a demonstration cloud seeding program. Three phases of training were employed with Moroccan scientists and technicians to provide a solid foundation for them to fully conduct the project. The training consisted of (a) informal on-the-job training, (b) formal seminars and lectures which presented the theoretical basis of weather modification and cloud physics principles, and (c) joint collaborative studies which reinforced previous material and dealt in depth with scientific information on Moroccan clouds and weather, cloud seeding strategies, and improved evaluation of seeding results.

On-the-job training of electronics technicians and engineers was particularly emphasized in their training. Scientists from the United States presented courses and seminars in Morocco, and Moroccan scientists and engineers visited the United States where various training and collaborative studies were conducted. Over 50 scientists received direct training from 20 American experts. Over 30 student-months of formal seminar training were received in Morocco by meteorologists, technicians, and engineers. In addition, four scientists completed their Master of Science degrees in the United States. Two other students were funded under the USAID sector support training project and completed theses on topics related to the project. Nine electronics technicians spent more than 23 person-months training in the United States. Eight operational and four research meteorologists spent more than 25 person-months conducting studies and learning about American scientific techniques on American projects in the United States. These scientists and engineers returned to Morocco to implement their new knowledge on project operations and scientific and evaluation studies.

3. Scientific analysis and evaluation. - A number of physical studies have been conducted as part of Programme Al Ghait. Some of these have concentrated on understanding seeding opportunities in Morocco. Physical studies with measurements taken inside precipitating storms of the High Atlas indicate that conditions which are favorable to seeding occur frequently and extend over large areas. Analyses of supercooled clouds observed in 1985 by the University of North Dakota cloud physics aircraft indicated that supercooled liquid water occurred often, with concentrations ranging from 0.2 to 0.7 g/m^3 in the absence of natural ice at temperatures of -5 to -12 °C. These conditions are considered favorable for cloud seeding and, to some degree, more so than those found in the Sierra Nevada of California, where ice occurred more frequently. Cloud physics data collected after 1987 with the instrumented King Air have confirmed the earlier estimates of frequency and areal extent of regions of opportunity for seeding. Radar, satellite, and numerical modeling studies are being conducted to better define the frequency of favorable opportunities and the areal extent of seedable conditions detected in the cloud physics analyses.

Statistical analysis of historical target and control streamflow data indicated that at least 6 years with cloud treatment are necessary to provide a 50-percent probability of detecting a 10-percent increase in streamflow. However, only 1.5 years of seeded results are available for evaluation, as a result of the elimination for analysis purposes of the first 2.5 seasons of seeding due to the low initial cloud seeding efficiency (less than 15 percent) and unavailability of control streamflow for the 1988-89 season. With only a 1.5-year treated sample available, which represents about one-fourth of the required data, it was decided not to analyze any seeded results because they could be misleading. Even when the 1988-89 results become available, at least 4 more years of efficient cloud seeding are required for the statistical evaluation.

4. Increased awareness of weather modification as a water resources management option. - Hydrologic and economic studies were designed to assess the economic feasibility of cloud seeding programs in Morocco. These studies were conducted by Moroccan water resources agencies working with Reclamation hydrologic and economic experts and DMN scientists to develop objective methods for the evaluation of hydrologic impacts on the Moroccan economy. Through close cooperation and collaboration, the water resources management institutions in Morocco eventually became aware of Programme Al Ghait and its potential for impacts on their operations. American experts presented special seminars and workshops to the Moroccan water resources experts and Programme Al Ghait staff. Such meetings increased interest in weather modification as an additional tool in water resources management. Preliminary results of conducted studies provided additional credence to its feasibility for that purpose.

Hydrologic studies produced some interesting results. Numerical river simulation models that included the hydroelectric generating characteristics of powerplants and irrigation and domestic water diversions within the Oued Oum Er Rbia basin were used to simulate the effects of additional water from November to July of the period 1940 to 1985. The additional water represented the effects of 5- and 10-percent increases in monthly streamflow due to seeding. The Administration de Hydraulique (Hydraulique) river model that was employed gave results indicating significant increases of 46 and 89 gigawatt hours (GWh) above the normal annual average hydroelectric power generation for the 5-and 10-percent streamflow increases, respectively. The National Electrical Organization (ONE) river model produced about 30 percent more power in similar simulations over the 46-year period, supporting the Hydraulique model estimates. Annual average reservoir storage increased 60 and 100 millions of cubic meters (M m^3) above the normal for the 5-and 10-percent augmented flows in simulations performed. This resulted in irrigation water diversion increases of 28.5 and 53.0 M m^3. Domestic water demands were largely fully met without the enhancements from seeding; however, simulations indicated an average annual increased delivery of 2.5 and 4.6 M m^3 for the respective 5- and 10-percent increases.

Economic analysis of the hydrologic impacts and project costs and benefits indicates that the benefits from cloud seeding will most likely exceed the costs. Initial hydrologic river model simulations indicate that augmented hydroelectric power, irrigation water, and municipal and industrial water will provide a benefit-to-cost ratio greater than 1.0 as a result of seeding. Note that benefit-to-cost estimates were based on a sensitivity analysis using a range of values for water, agricultural products, and hydroelectric power, which are difficult to establish without a comprehensive evaluation of any subsidies. The available data used in this economic analysis were incomplete; therefore, additional studies are needed to provide a better range of estimates of benefit-to-cost ratios.

Lessons Learned

A number of useful lessons were learned during the past 5 years which may benefit future projects. Noteworthy were the following items:

Management

- A **National Steering Committee** (NSC) which coordinated interagency activities and expedited installation and construction of facilities was very helpful for project coordination among agencies and throughout the country.
- A **Project Steering Committee** (PSC) which coordinated project activities and made critical decisions with direct USAID and Resident Scientific Advisor (RSA) input was found to be very effective in managing the project.
- American project implementation would have been more efficient with an **implementation team** of three resident experts in electronics, weather modification operations, and scientific project management. In future projects, such a team should be provided and the electronics and operations experts should reside in the host country during the first 6 to 12 months.
- A complete **scientific operations plan** and set of **position descriptions** and specific **work plans** for all personnel should be prepared at the beginning of any future projects for personnel management and scientific guidance.
- A complete staff should be assigned at the outset of each project, and personnel assigned to a project should remain with it throughout its existence.
- The **data management position** is a critical scientific position for scientific data collection, quality control, and archival. This position should be filled at the beginning of projects

and all data handling procedures established during the first 6 months and maintained by the scientific team.

- **Annual monitoring reviews** by senior experts who initially designed the project were very helpful in maintaining the project's continuity and its original goals and objectives and should be provided in future projects.

- **External evaluation team** monitoring of the project was found useful when combined with the annual monitoring reviews and should be provided in future projects.

Training

- **Long-term training** was found to be an excellent alternative for specific research contracts. The master's-level student research and theses on project-related topics were very successful in transferring high-level expertise to Morocco and accomplishing research goals. This type of activity is highly recommended.

- Long-term students should start their training at the beginning of the project so that their findings contribute to the project design and they may participate in its operations and evaluation.

- **Scientific collaboration** between individual Moroccan and American experts in cloud physics, radar, numerical modeling, and field operations was found to be very effective with scientific interaction in Morocco followed by continued research in the United States. Frequent quarterly or trimester trips to Morocco and annual trips to the United States were the most productive. This form of informal scientific interaction and educational exchange was one of the most successful aspects of technology transfer and is highly recommended for future projects.

- **Peace Corps English language training** was very successful and is recommended for future projects.

Operations

- Sufficient time and resources for the conduct of field operations and the physical and statistical evaluation of results should be incorporated into the original project design to permit a comprehensive evaluation of the seeding effects so that the host country may make sound scientific and economic decisions regarding the application of weather modification as a water resources management option.

- **Co-location of operational and research facilities** such as aircraft, operations directors, and scientific teams is highly recommended.

- **A comprehensive equipment procurement, installation, inventory control, and training plan** is needed at the beginning of the project. This plan should include detailed training needs for electronics and maintenance technicians and equipment managers.

Recommendations

1. The Moroccan Government should continue the project to reach scientifically sound results and to arrive at a final decision as to the project's capability as a water resources management option. - The project should be continued for a minimum of 4 more years to acquire a seeded sample adequate to determine whether cloud seeding effects are large enough to be economically beneficial. In order to obtain the required sample, the project should continue to follow the existing management plan including the conduct of:

- Regular PSC meetings.
- Scheduled NSC meetings and annual reviews.
- Normal cloud seeding operations, data collection, and scientific and evaluation studies following the project design and operations plan utilizing the existing facilities and trained personnel.

The following items are seen as vital to be accomplished in connection with continuation of the project:

- Fund an annual budget in both dirhams and foreign exchanges as appropriate to support the continued execution of Programme Al Ghait, including its personnel, equipment and supplies, and cloud seeding materials.
- Establish an autonomous officially constituted and recognized organization whose primary mission is to carry out Programme Al Ghait.
- Complete the installation of the ground-based seeding generator network, so that all of the current target area is seeded during all seedable events.
- Continue scientific operations and data collection in accordance with the Operations Plan.
- Execute a formal agreement between the Programme Al Ghait organization and the FRA whereby the FRA continues to provide the aircraft and seeding materials required to carry out the seeding operations.
- Execute a formal agreement among Programme Al Ghait and ONE and Hydraulique whereby ONE and Hydraulique provide promptly the streamflow data for evaluating the program.

Funding to continue the project will require a significant increase from the Ministry of Finance above the previous budgets for 1984-89, when American funds provided many expendable supplies, instruments, and parts.

2. The scientific research capabilities should be enhanced. - The scientific team has begun a series of interesting and useful studies which should be completed. This work will require more time and effort for detailed scientific analyses, data quality control, and development and refinement of software and data bases for the display and processing of information. Larger data samples and better stratification of events into homogeneous samples are needed to draw sound scientific conclusions.

Research results should be published in scientific journals and presented at professional meetings. Presentation of results to other Moroccan water resources experts will help them to understand the conditions that may produce opportunities for precipitation enhancement and subsequent improvements in water resources. Presentations to the international scientific community will improve the general understanding of the physical processes of precipitation in northwest Africa and the potential for weather modification in that region, so other nations may benefit from Morocco's experience. More general studies from the Programme Al Ghait data sets may lead also to better weather forecasting and understanding of the structure of storm systems in that region.

Specific scientific data collection and studies recommended for the project include the following:

- Studies of the radar and satellite data should be expanded to describe the mesosynoptic physical characteristics of precipitation events in Morocco. These results should then be combined with the cloud microphysical observations and numerical modeling simulations to better understand the physical mechanisms that cause precipitation in Morocco. Radar data collection and quality control should continue in accordance with the Operations Plan through 1993.

- Additional data collection and analyses are needed in the areas of cloud physics and statistical evaluation. These data should be collected from 1989 to 1993 in order to continue existing analyses and provide required expanded sample sizes.

- Statistical-physical evaluation techniques that deal with the large natural variations of precipitation in the target and control areas need further study. The search for covariates for the statistical evaluation should be expanded to at least further exploration of the use of the Rhea model. This research will require continued effort and careful analysis. The numerical modeling work of Mr. El Majdoub and Mr. Abidi should be continued to better quantify the precipitation and runoff received in Morocco and lend support to other studies that are dealing with the physical mechanisms of the precipitation process.

3. **The United States should continue involvement in the project.** - Continued American participation in the project was recommended by the Final External Evaluation Report and the Annual Monitoring Report in 1989. Those reports recommended continued involvement for at least the next 4 years until a sound scientific result can be obtained.

The United States should look for ways to support continued scientific collaboration after the end of the current USAID project to ensure that sound scientific results can be obtained over the next 4 years. This assistance would consist of:

- Continued monitoring of the GOM progress in successfully implementing recommendations 1 and 2 above, and if the monitoring indicates that the GOM is successfully continuing Programme Al Ghait, then the United States should consider limited additional assistance in the areas of:

  - Statistical evaluation studies.
  - Improved application of numerical precipitation and air flow models.
  - Expanded and improved cloud physics aircraft data collection and analysis.
  - Improved radar data collection and analysis.
  - Mesoscale analyses and storm system seedability studies.
  - Expanded and improved hydrologic and economic applications studies.

In summary, the joint Moroccan-American Programme Al Ghait has been a successful program of technical assistance and technology transfer. It has resulted in the establishment of a well-trained team of meteorologists and technicians who are able to conduct scientific weather modification operations and physical and evaluation studies on data collected. This type of scientific exchange has benefited the Moroccan meteorological service and the international meteorological community through the increased scientific observational capabilities and the basic knowledge gained from the project's scientific studies. These new observational capabilities will contribute new data to the international community to better understand daily weather and global climate.

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APPENDIX

GLOSSARY OF TERMS

AgCl	silver chloride
AgI	silver iodide
ALIGU	American Language Institute, Georgetown University
AMG	Ateliers Mecaniques Generales
AMR	annual monitoring review
APT	automatic picture transmission
ATC	Air Traffic Control
AVHRR	Advanced Very High Resolution Radiometer
Barrage	Dam
CAF	Club Alpine Francais
CIC	Colorado International Corporation
cm	centimeter
CSU	Colorado State University
CTT	cloud top temperature
CUT	Coordinated Universal Time
DARR	Division of Atmospheric Resources Research
DAS	Data Acquisition System
dBZ	radar reflectivity log of power returned
DCP	data collection platform
DH	dirham
DH/m^3	dirhams per cubic meter
DMN	Direction de la Meteorologie Nationale - National Meteorological Organization
DVIP	digital video integrated processor
EEC	Enterprise Electronics Corporation
EET	External Evaluation Team
El.	elevation
FRA	Forces Royales Air - Royal Moroccan Air Force
ft	feet
g	gram
g/m^3	grams per cubic meter
GHz	gigahertz
GIS	geographic information system
GNS	Global Navigation Systems
GOM	Government of Morocco
GRE	Graduate Records Examination
GWh	gigawatt hour
h	hour
ha	hectare
HP	Hewlett-Packard
hPa	hectoPascal = 1 mb
Hydraulique	Administration de Hydraulique
IBM	International Business Machines
IDC	interest during construction
IFF	Identification Friend or Foe
IFR	instrument flight rules
IPC	ice particle concentration

GLOSSARY OF TERMS - Continued

JSEP .... Joint Scientific Evaluation Project
km .... kilometer
kW .... kilowatt
kWh .... kilowatt hour
LAD .... least absolute deviations
LWC .... liquid water content
m .... meter
m.s.l. .... mean sea level
mb .... millibar
MDH .... million dirhams
MEM .... Morocco Energy Model
μm .... micrometer
mm .... millimeter
M m^3 .... millions of cubic meters
MRPP .... multiresponse permutation procedures
μs .... microsecond
MSS .... Multispectral Scanner
NaI .... sodium iodide
NAS .... National Academy of Science
NAWC .... North American Weather Consultants
NMFC .... National Meteorological Forecasting Center
nmi .... nautical mile
NOAA .... National Oceanic and Atmospheric Administration
NSC .... National Steering Committee
OCP .... Office Cherifien des Phosphate
OER basin .... Oued Oum Er Rbia basin
OJT .... on-the-job training
OM&R .... operation, maintenance, and repair
ONE .... Office National L'Electricite - National Electrical Organization
OPS .... Operations
ORMVA .... Office Regional de la Mise Valeur Agricole
PASA .... Participating Agency Service Agreement
PC .... personal computer
PEP .... Precipitation Enhancement Project
pibals .... pilot balloons
PPI .... plan position indicator
PSC .... Project Steering Committee
PTT .... Post, Telephone, and Telegraph
RHI .... range height indicator
RIVER .... river/reservoir model
ROP .... region of potential
RSA .... Resident Scientific Advisor
RTM .... Radio Television system of Morocco
SAET .... Scientific Analysis and Evaluation Team
SCPP .... Sierra Cooperative Pilot Project
SDUS .... Secondary Data Users Station

GLOSSARY OF TERMS - Continued

SLW .... supercooled liquid water
SPD .... Service de Planification et de Documentation
SRM .... Snowmelt Runoff Model
TACAN .... Tactical Air Navigation
THETA .... Theta Associates, Inc.
TIROS .... TV Infrared Operational Satellite
TOEFL .... Test of English as a Foreign Language
UND .... University of North Dakota
UNDP .... United Nations Development Project
USA .... United States of America
USAID .... U.S. Agency for International Development
USBR .... U.S. Department of the Interior, Bureau of Reclamation
USDA .... U.S. Department of Agriculture
USG .... U.S. Government
VCR .... video camera recorder
VFR .... visual flight rules
VHF .... very high frequency
VHF-AM .... very high frequency-amplitude modulated radio system
VHF-FM .... very high frequency-frequency modulated radio system
VLF .... very low frequency
VOR/DME .... Voice Omni Range/Distance Measuring Equipment
WMO .... World Meteorological Organization
WWCI .... Western Weather Consultants, Inc.
yr .... year

1. INTRODUCTION

1.1 Drought Prior to Programme Al Ghait

Generally dry conditions began in Morocco in 1975. A serious drought began in the water year of 1981 (September 1, 1980, to August 31, 1981), with precipitation ranging from 40 to 60 percent below normal in important agricultural areas (especially in central Morocco), severely reducing the country's water supply. Comparable precipitation deficiencies had not occurred since the late 1930's. Overall, the following (1982) water year was slightly less dry, but brought a shift in the precipitation distribution with the greatest deficiency in the north. The 1983 water year had the worst precipitation deficits since the drought started; precipitation amounts nationwide ranged from 40 to 80 percent below normal. There was a slight increase in precipitation during the 1984 water year, but accumulations still ranged from 20 to 40 percent below normal. The 4-year cumulative precipitation deficiency was over 120 percent of yearly normal in much of the central, southern, and eastern areas. Ground-water storage and reservoir supplies were in great part depleted. Reservoirs held about 10 to 20 percent of their normal capacity, and many were under their minimum operating level. Before 1980 hydroelectric power had met about 30 percent of the nation's energy needs; by 1984 the corresponding figure was down to 8 percent. The social and economic impact of the drought, considered to be the worst in modern history, was compounded by greatly increased demand for additional water resources caused by rapid population growth, urbanization, industrialization, and expansion of irrigation.

1.2 Establishment of Programme Al Ghait

Weather modification to increase precipitation had been attempted in Morocco several times prior to the serious drought which began in 1980. In the 1950's, officials of the colonial administration had contracted with a private firm from the United States for cloud seeding to increase precipitation over a portion of the Atlas Mountains. It is difficult to specify the net results of the seeding operations.

At the direction of His Majesty King Hassan II, Government of Morocco (GOM) officials investigated the possibility of using weather modification to increase precipitation during the drought of the early 1980's. The GOM created a high-level committee to supervise and coordinate its weather modification activities, which were organized under the title of Programme Al Ghait. Personnel of the National Meteorological Organization (Direction de la Meteorologie Nationale, or DMN) and the Moroccan Royal Air Force (Forces Royales Air, or FRA) collaborated in the conduct of some experimental cloud seeding flights in 1982 and 1983 using an Alpha Jet trainer to drop pyrotechnic flares containing 20 grams of silver iodide each into rising convective cloud towers. The committee also conducted a series of meetings to acquaint administrators, technical experts, and public leaders with the weather modification program.

1.3 United States Support of Programme Al Ghait

In June 1983, at the direction of His Majesty King Hassan II, the GOM requested assistance from the United States with Programme Al Ghait. Specifically, the GOM requested help from the U.S. Agency for International Development (USAID) to mitigate the severe drought in Morocco and to improve the ability of the National Meteorological Organization to conduct effective weather modification projects. Following receipt of this request for assistance with Programme Al Ghait, USAID turned to the National Academy of Science (NAS) for advice on how to proceed. The NAS convened a meeting of experts on weather modification in Washington, D.C., in August 1983 to consider how the U.S. Government (USG) should respond to requests from foreign governments for assistance with weather modification projects. The NAS provided a cautious assessment of the possibilities for success in such projects, but did not rule out entirely the chance of a useful result. The request was then cleared by the National Security Council.

With support from USAID under a Participating Agency Service Agreement (PASA) with the U.S. Bureau of Reclamation (Reclamation), a team of four American scientists led by Dr. Bernard Silverman of Reclamation visited Morocco in November 1983 to investigate the possibilities for cloud seeding in that country. After a thorough review of the facilities and evaluation of the potential for weather modification in Morocco, the team prepared a "Weather Modification Assessment for the Kingdom of Morocco" (Silverman et al., 1983); they concluded that a winter cloud seeding demonstration program over a portion of the High Atlas Mountains appeared worthwhile. On the basis of the assessment, negotiations went forward for continued Reclamation participation in Programme Al Ghait.

In May 1984 the Kingdom of Morocco, acting through its Ministry of Transportation (the parent agency of DMN), and the United States of America, acting through USAID, signed a Project Grant Agreement for a multiyear winter snowpack augmentation project in Morocco. The agreement provided six million dollars ($6,000,000) in USAID funds and a matching amount from the GOM in services, personnel, and materials for the execution of a winter cloud seeding demonstration project in the High Atlas Mountains.

USAID implemented the project through a second PASA with Reclamation. Under the terms of the PASA, Reclamation provided overall scientific management and administered USAID's $6,000,000 program. In partial fulfillment of the requirement to provide scientific management, Dr. David Matthews was stationed in Casablanca, Morocco, as a Resident Scientific Advisor (RSA) from August 1984 through August 1988 to coordinate the technical assistance effort. In addition, modern meteorological and communications equipment, as well as technical training in how to use and maintain the equipment, was provided under the program. The program also included training for Moroccan meteorologists in the technology of weather modification and collaboration between Reclamation and GOM scientists on the project evaluation. The first operational field season began in November 1984, and operations have continually become more technically sophisticated and extensive.

1.4 Goal and Objectives of Programme Al Ghait

With the signing of the Project Grant Agreement, Programme Al Ghait became a joint project between the United States and Morocco, with the goal to increase manageable water resources in Morocco through the implementation of a scientifically based weather modification project on a demonstration basis. The purpose of the project was to assist the development within the GOM of an ability to design, plan, implement, monitor, and evaluate scientifically based weather modification programs in Morocco (Lintner and Silverman, 1984).

In late April and early May 1985, an external evaluation of the project was conducted by a team of three U.S. experts in weather modification from outside Reclamation. One of the key findings from their assessment of the project's status was that there were "at least nine objectives, some non-complementary, with a lack of agreement by the participating institutions as to their priorities" (Changnon et al., 1985). They recommended that Reclamation, USAID, and GOM collaborate "to develop a more clearly focused set of prioritized objectives which all agencies can agree upon and which can be clearly translated into operational and research guidelines and actions." Subsequently, the following primary objectives were established for Programme Al Ghait:

1. Implement a scientifically based cloud seeding demonstration program for winter precipitation augmentation over the upper portion of the Oued Oum Er Rbia basin in the Atlas Mountains to help alleviate the current drought conditions, assess the amount of additional water produced in the river/reservoir system as a result of the demonstration program, and evaluate the effects of increased winter precipitation on runoff and its subsequent uses.

2. Examine cloud and precipitation processes to improve the scientific basis of the demonstration program and obtain evidence of its physical plausibility.

3. Concurrent with the first two objectives, transfer winter precipitation augmentation technology through informal and formal training to enable Moroccan personnel to design, plan, implement, monitor, and evaluate similar winter precipitation augmentation projects over the mountainous areas of Morocco.

4. Increase awareness of the need for an improved water resources management program in the Oued Oum Er Rbia basin and of the contribution that weather modification can make to the water resources.

The work described in the remainder of this report was intended to fulfill the objectives just stated.

1.5 Program Management

Responsibility for the program management rested jointly between the USG and the GOM. To provide an effective management team, a Project Steering Committee (PSC) was established to manage the day-to-day issues within the project. Issues beyond the immediate conduct of the project were managed through the National Steering Committee (NSC), which interfaced with other ministries and agencies within Morocco.

1.5.1 Project Steering Committee. - As of 1987, the PSC was comprised of Mr. Amed Bensari, Director of DMN; Colonel Mohamed Bamaarouf, the coordinator for FRA; Mr. Saad Benarafa, Project Director; Mr. El Bachir Loukah, Deputy Project Director; Mr. Brahim Louaked, Equipment Coordinator; Mr. Harry Petrequin, Deputy Mission Director; the USAID Mission Project Officer; and Dr. David Matthews, RSA. When the USAID Environmental Coordinator for Asia/Near East [Dr. Stephen Lintner (1984-87); Mr. Glen Whaley (1988)] and Dr. Bernard Silverman of Reclamation were in Morocco for the annual monitoring reviews, they served as *ex officio* members of the PSC.

The PSC was authorized to approve required changes in the project design, to discuss problems, and to identify solutions to problems in project management, implementation, monitoring, and evaluation.

1.5.2 National Steering Committee. - The NSC was organized to provide national support to the project and serve as liaison between the two primary implementing agencies (DMN and FRA) and other interested GOM agencies. It was comprised of representatives from the following ministries and agencies: Ministry of Transport, Ministry of Defense, Ministry of the Interior, Ministry of Mines and Energy, Ministry of Agriculture, Ministry of Post and Telecommunications, and the National Center of Coordination and Planning of Technical and Scientific Research. The committee met once each year to review progress and make recommendations.

1.5.3 Mission project officer. - The project was in the portfolio of the Mission's Energy and Natural Resources Division, which was directed by Mr. Stephen Klein. The USAID Mission project officer was responsible for in-country project administration and routine monitoring. He coordinated with the Resident Scientific Advisor to ensure project performance and represented the Mission on the Project Steering Committee. The series of Mission project officers – John Giusti (1984-85), Robert Kahn (1986, 1988), Samir Zoghby (1986-87), and Eric Loken (1988-89) – provided excellent support to the project and guided the critical management decisions. Their experience in developing and implementing technical assistance projects contributed greatly to the successful implementation of Programme Al Ghait. Specific assistance included coordination of training with the Mission training officer and coordination with other Mission offices including Planning, Agriculture, and Economics, and within Energy and Natural Resources .

1.5.4 Resident scientific advisor. - Reclamation assigned a scientist full time to the field program in Morocco. Dr. David Matthews moved to Casablanca and served as the RSA at the project headquarters at Casablanca Anfa Airport. He provided scientific management, technical monitoring of contractors in the field, and project coordination. He worked with the Moroccan meteorological and technical team on a day-to-day basis in developing a scientifically sound program and providing advice and training in its execution.

1.5.5 Annual monitoring review. - The project plans called for an Annual Monitoring Review (AMR) by Dr. Bernard A. Silverman of Reclamation and the Environmental Coordinator, Bureau for Asia/Near East of the USAID Washington Office. Each year the AMR team visited Morocco and reviewed the project with the PSC and the USAID Mission. They visited all project field sites and the facilities of cooperating GOM organizations to examine the scientific quality of the project and verify the use of suspension criteria in cloud seeding operations. The monitoring team provided expertise regarding the scientific basis of the project, operations, management, and environmental issues.

1.5.6 External evaluation. - Three senior experts in the scientific, operational, and water resources aspects of the project were selected to provide an independent review of the project and advise Reclamation, the PSC, and the USAID Mission on the progress toward its objectives. The team made three in-country reviews, each of 2 weeks' duration. The team focused on the scientific design, project implementation, project management, institutional development, transfer of technology and training, and the water resources planning and management.

1.5.7 Coordination with other donors. - Given the need identified in the Weather Modification Assessment (Silverman et al., 1983) and the Project Paper (Lintner and Silverman, 1984) to improve water resources and land use management, the USAID Mission attempted to coordinate with other donors, particularly the World Bank. It provided information on the findings of the project, especially with regard to institutional development and personnel training needs in water resources planning and management, to other interested parties in multilateral, bilateral, and international organizations in an attempt to attract additional resources in addressing these problems. As information becomes available from the scientific and economic evaluations, it will be provided to other donors, particularly those interested in providing capital for development of infrastructure in the water, forestry, rangelands, and watershed management sectors. The Mission and RSA coordinated training of DMN personnel in programs offered by the European Space Agency and the USG's National Oceanic and Atmospheric Administration with support from the United Nations Development Project.

The following chapters of the report summarize the inputs to the program from the GOM and the USG and the program outputs in terms of technology transfer and scientific studies, and provide a summary of lessons learned.

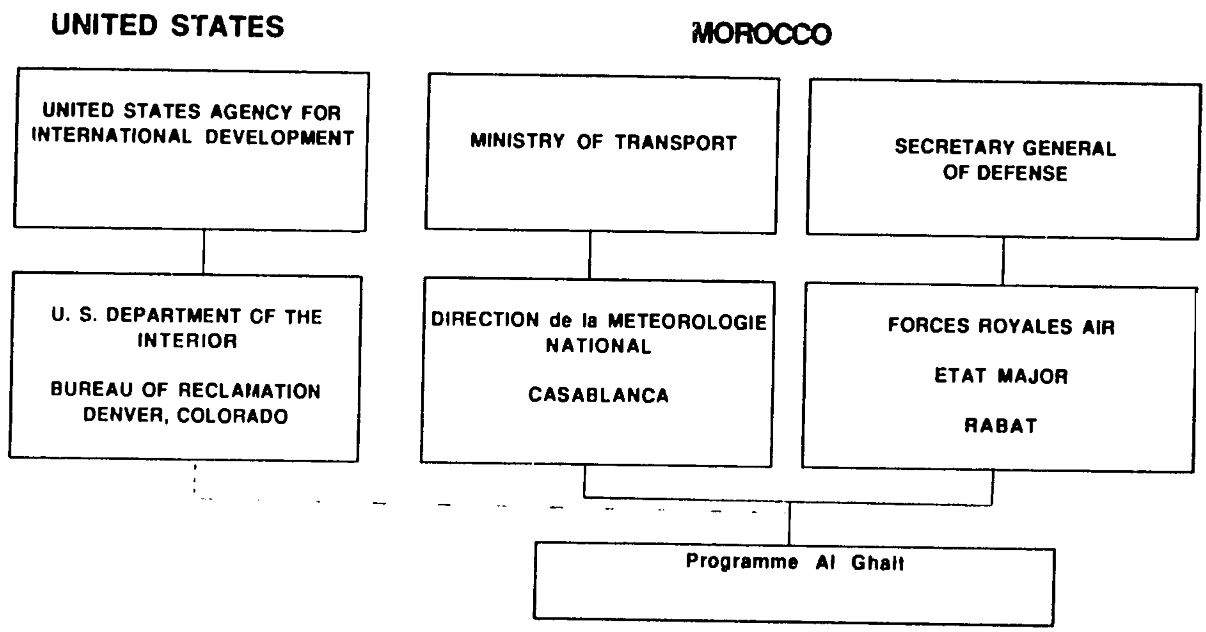


Figure 1.1. - Principal organizations supporting the Moroccan Winter Snowpack Augmentation Project - Programme Al Ghait from the United States and Morocco.

2. SCIENTIFIC DESIGN OF PROGRAMME AL GHAIT

2.1 Purpose and Approach

The purpose of the project was to develop within GOM an ability to design, plan, implement, monitor, and evaluate scientifically based programs of winter snowpack augmentation in the context of water resources management. The institutional development of the DMN, through the transfer of weather modification technology to their staff, providing of new equipment, and training on the equipment operation and maintenance, was considered to be of primary importance.

The first step in developing the operational design for Programme Al Ghait, taken during the November 1983 assessment visit, was to examine results of cloud seeding in regions having climates similar to that of Morocco to see what operational approaches, if any, had provided evidence of increases in precipitation. Initial comparisons indicated that some precipitation augmentation projects in California were suitable analogues of the Moroccan situation. Both Morocco and California have Mediterranean climates with pronounced winter maxima of precipitation, and both receive most of their precipitation as maritime air masses flowing inland impinge upon high mountain ranges. The 1983 assessment noted that operational cloud seeding programs in California aimed at increasing winter orographic precipitation had given statistical indications of increases of 3 to 10 percent in annual runoff from precipitation. Most of these projects involved the release of silver iodide (AgI) crystals to form additional ice particles in supercooled clouds or mixed-phase clouds. The AgI generators were operated either on the ground or on aircraft flying at temperatures slightly below 0 °C.

Development of the operational plan for the Winter Snowpack Augmentation Project required a more in-depth evaluation of the climate of Morocco, especially as it related to the frequency and duration of winter orographic cloud seeding opportunities. Since no cloud physics data were available for Morocco, the collection of sample data sets followed by an analysis of these data for seedability was given high priority. This was necessary so that cloud seeding procedures could be designed to maximize seeding effectiveness.

The demonstration project was designed to be evolutionary in its implementation. Initial emphasis was devoted to acquisition and installation of the equipment and facilities necessary for conducting cloud seeding operations, initiation of training in the various dimensions of the project, and establishment of an organizational and operational framework for the project. Initial operations were restricted to VFR (visual flight rules) airborne seeding of the target area during daylight hours using only uniform, simplified flight procedures. After the operations personnel gained additional knowledge and experience and the necessary equipment and facilities had been installed, the seeding operations were extended to include IFR (instrument flight rules) airborne seeding and ground-based seeding using manually operated silver iodide generators.

In order to ensure the technically responsible and economically feasible application of cloud seeding technology as a water resources management tool rather than as an emergency response to drought conditions, the project design included physical, statistical, and economic evaluations to provide a basis for a rational decisionmaking process governing the use of this technology. The Winter Snowpack Augmentation Project's Evaluation Program was developed in four major parts as follows:

1. Physical evaluation. - To determine the seedability of winter clouds over mountainous areas of Morocco.

2. Statistical evaluation. - To determine the amount of additional streamflow produced as the result of cloud seeding operations.

3. Economic evaluation. - To determine the costs and benefits of the production and use of additional streamflow as the result of cloud seeding operations.

4. Application activities. - Studies and training which apply the findings and recommendations of the physical and economic evaluations to practical issues in water resources management.

2.2 Choice of Location

2.2.1 Climatology. - The choice of a location for a demonstration project depended upon a number of factors, including facilities and communications. However, climatological considerations played a key role in the selection.

Morocco is located on the northwest corner of Africa and has a varied topography including coastal plains, upland plateaus, and rugged mountains. Its climate is determined by its latitude and its topography.

The subtropical high-pressure zone that encircles the earth around 30° N. often extends from east to west across southern or central Morocco. The Azores high-pressure area, which is part of this zone, strongly controls the weather over the northwestern part of Africa and accounts for the prevailing dryness. From November through April, the Azores high-pressure area sometimes shifts westward, which allows storms of polar origin to affect most of Morocco north of 30° N. Generally speaking, Morocco has a very dry summer, centered around July, and two wet periods in early winter (November-December) and late winter (February-March) separated by a somewhat drier January.

The winter storms follow one of the two principal storm tracks, namely, west-to-east and north-to-south. The two storm tracks are associated with zonal and meridional flow, respectively. The established statistics show that the storms associated with a meridional circulation appear to be three times more frequent than those associated with a zonal circulation.

In autumn the principal cause of precipitation is low-pressure areas moving into Morocco from the northwest and associated passages of cold fronts marking the leading edges of polar air masses. A cold front passage is frequently preceded by a flow of moist, tropical air from the southwest that results in widespread precipitation over the High Atlas Mountains. In the late-winter wet period (after January's typically drier weather), incursions of the Mediterranean front into Morocco from the northeast play a major role in the production of precipitation.

The geographical distribution of normal annual precipitation shows clearly the effects of latitude and topography. In the coastal plains, the average annual precipitation drops from 800 millimeters at Tangier in the north to 400 millimeters at Casablanca in the central area, and finally to

240 millimeters at Agadir in the southwest. This is due to the protective action of the Azores high-pressure ridge extending toward southern Morocco.

The High Atlas is the longest and most massive of the Moroccan mountain ranges. It extends from the Bay of Agadir on the Atlantic Ocean in the southwest to about 125 kilometers south of the Mediterranean Sea near the Moroccan/Algerian border in the northeast (fig. 2.1). With a southwest-northeast orientation, a mean altitude of about 3000 meters above mean sea level, and peaks extending from 3500 meters to above 4000 meters, the High Atlas constitutes an effective barrier to the oceanic storms. Because the air flowing over Morocco during winter storms usually comes from a westerly or northerly direction, regions southeast of the High Atlas are much drier than places at the same latitude but located northwest of the High Atlas.

The heaviest rains tend to fall on the windward slopes of the mountains. There are three important rainfall maxima; they are located in the Rif Mountains in northern Morocco (1600 mm annually at Outka), the northern part of the Middle Atlas (1100 mm at Ifrane), and the central High Atlas (around 1000 mm at the higher elevations).

The mean frequency of storms that affect Morocco during the November-April period ranges from two to five per month; storms occur most frequently during December, February, and March. Except for situations with cyclogenesis in the vicinity of Morocco, which can last from 5 to 7 days, zonal and meridional storms do not exceed 2 or 3 days' duration. In general, the duration of storms is longer in autumn and winter than in spring, when the duration may be limited to a day.

The mean number of days with precipitation per year on the northwestern side of the High Atlas Mountains ranges from 60 to 65 in the north, 45 to 50 in the center, and 30 to 35 in the south. The intensity of precipitation varies in time and space; its value may range from 0.5 to 15 mm/h and, under certain conditions, may reach 30 to 40 mm/h, inducing floods.

Despite the low latitude, Moroccan mountains have frequent and important snowfalls in November and December, and more in January and February. The freezing level in the winter in the central High Atlas is usually around 2500 meters. During winter storms of polar origin, snow is commonly observed down to 1000 meters elevation. The snow that falls below the 2000-meter level melts quickly and contributes to the runoff in near real-time leaving, nevertheless, an important proportion of the High Atlas with extended snowpack. Snow depth averages from a few centimeters in the lower elevations to as much as 150 centimeters near the crest.

2.2.2 Choice of target and control areas. - On the basis of the apparent success of precipitation projects in the California mountains and the results of other studies indicating the feasibility of seeding winter orographic clouds, it was determined rather early that the most promising approach would be to select a demonstration area in the High Atlas Mountains.

Six major rivers drain the northwest side of the mountains and cross the semiarid agricultural zone. These river basins contain most of the reservoirs and feed seven of the nation's nine major irrigation districts. Discussions with GOM personnel familiar with the country's water supply situation led to the choice of the drainage basin of the Oued Oum Er Rbia in the central High Atlas Mountains as the target area for the demonstration project. This basin has a series of dams, hydroelectric generating facilities, and irrigation projects that could effectively distribute additional water supplies generated by cloud seeding operations. The Oued Tensift basin located in the High

Atlas southwest of the target area was selected as the control area for the project. Figure 2.2 shows a map of central Morocco with the target and control areas and the principal field site locations.

The primary target area was that portion of the Oued Oum Er Rbia drainage basin northwest of the High Atlas Divide containing the headwaters of streams that flow into three principal reservoirs: Bin El Ouidane, Ait Chouarit (Hassan I Dam), and Moulay Youssef. For the purpose of Programme Al Ghait, the High Atlas Divide within the target area was defined by a line running from southwest to northeast (235 to 055°) at a perpendicular distance of 150 kilometers from the project radar site, which was set at Khouribga. The target area, extending from 31.25 to 32.50° N. and from 5.25 to 7.25° W., formed a rectangle 220 kilometers long by 65 kilometers wide (14 300 km^2 in area) northwest of the crest. Figure 2.3 shows a cross section of the mountains in the primary target area along a line perpendicular from the project radar at Khouribga to the crest of the High Atlas.

The target and control areas both have long periods of streamflow records, permitting a statistical target-control evaluation of seeding effects. Since the primary evaluation of Programme Al Ghait is through the application of statistical techniques capable of detecting changes in streamflow into Bin El Ouidane reservoir, cloud seeding operations have been concentrated on the northeastern two-thirds of the High Atlas target area that drains into this reservoir.

2.3 Physical Basis of Project

2.3.1 Seeding hypothesis. - Initial analyses of the thermodynamic structure of winter storms in Morocco indicated that ice phase seeding of clouds containing supercooled water for microphysical effects, the so-called static seeding hypothesis, should be the physical basis for the demonstration project. This hypothesis holds that introduction of artificial ice nuclei can lead to the formation of additional snowflakes in clouds. It is called the static seeding hypothesis to contrast it with hypotheses involving changes in the dynamics of the cloud systems.

> "According to the static seeding hypothesis a cloud is postulated to be seedable [WMO, 1982] if it contains supercooled water that is or will be under-utilized by the cloud's natural precipitation process, that will not be eroded by competitive depletion processes and that will last long enough in sufficient quantities to permit growth of additional precipitation particles induced by seeding to sizes that can reach the ground. If the amount and persistence of supercooled water in a cloud is high, then the depletion rate of water associated with natural precipitation development, cloud ice evolution, and entrainment is likely to be low, and the opportunity for seeding tends to be high. The coexistence of ice in the cloud is only a deterrent to seeding if it exists in sizes and concentrations which cause the supercooled water to be depleted faster than seeding can exploit it" (Silverman, 1986).

2.3.2 Seedability of clouds in Morocco. - Clouds are seedable under the static seeding hypothesis if they contain supercooled liquid water that can be converted to precipitation with ice nucleants. Because very little was known of the winter clouds over the target area at the beginning of Programme Al Ghait, the defining of clouds suitable for seeding has been an evolving process. It was expected originally that the clouds to be treated would be mainly stratiform, orographic clouds. Previous work in California and elsewhere had suggested that orographic clouds with top temperatures colder than -20 °C would contain enough ice crystals to use effectively any supercooled liquid water that might be present. Since the effectiveness of artificial ice nucleants increases markedly as the temperature falls below the threshold of activity around -5 °C, it was initially anticipated that most seeding operations would involve supercooled, stable orographic clouds with cloud top temperatures in the -5 to -20 °C range.

Evaluation of the precipitation events during the first field season (1984-85) showed that they were usually associated with synoptic scale storms and that the cloud types changed as the storm fronts moved across the target area. Bands of convective clouds were observed frequently.

As a part of Al Ghait, the University of North Dakota (UND) Citation II research aircraft was operated in Morocco in 1985. Preliminary examination of the cloud physics data collected by the UND aircraft indicated that most of the clouds sampled were convective. The typical supercooled liquid water concentrations were between 0.3 and 0.5 g/m^3, but concentrations up to 3 g/m^3 were observed in small regions. Many of the convective clouds that were sampled developed frozen precipitation particles. However, at least two of the water-rich clouds that were studied intensively failed to develop appreciable amounts of ice at -12 °C. Some of the supercooled clouds produced small ice particles, but not solid precipitation, at the sampling level. These preliminary observations indicated seedability for some clouds over the target area (Grainger and Stith, 1987).

2.3.3 Criteria for selection. - A distinction was made between orographic, mainly stratiform clouds and semi-isolated convective clouds in establishing criteria for clouds to be seeded (Hartzell et al., 1986). The criteria adopted that year, based on cloud top temperature (CTT) and cloud thickness, were:

- For stable orographic or layer clouds with only weak embedded convection:

  -5 °C > CTT > -20 °C and cloud thickness over 1 kilometer.

- For convective clouds:

  -10 °C > CTT > -25 °C and cloud thickness over 2 kilometers.

The reasons for establishing different criteria were as follows. Although AgI particles are not very active as ice nuclei at temperatures around -5 °C and diffusional growth is slow, seeding clouds with top temperatures near -5 °C is practical if the clouds last long enough for precipitation to develop. This might be the case for orographic clouds more than 1 kilometer thick, but not for convective clouds, whose lifetimes are often as short as 10 or 15 minutes. Likewise, convective clouds less than 2 kilometers thick probably would not last long enough to develop precipitation. Stable layer clouds (possibly with weak embedded convection) with top temperatures colder than -20 °C and convective clouds with top temperatures colder than -25 °C usually contain enough natural ice to use effectively the available liquid water (Grant and Elliott, 1974; Gagin, 1981).

2.3.4 Seeding agent. - The team of American scientists who made the 1983 assessment for the Kingdom of Morocco suggested that because AgI was the most tested and proven agent available for seeding winter storms, it should be used exclusively for the demonstration project. A provision in the Project Grant Agreement made GOM responsible for the purchase of the seeding agent; they agreed to use AgI exclusively for Programme Al Ghait.

Silver iodide can be produced from a wide variety of generating devices. Liquid-fueled generators have proven cost effective and reliable on many projects and therefore were recommended by Reclamation for the demonstration project. The seeding agent recommended was a 2AgI-NaI (silver iodide - sodium iodide) solution in acetone. This seeding agent has been used for over 30 years in almost all countries engaged in precipitation augmentation activities. Experience has shown that the 2AgI-NaI solution is relatively easy to handle and produces few operational problems. However, the primary reason that 2AgI-NaI was recommended, rather than another AgI solution, was to minimize the uncertainties in the nucleation stage of the seeding process. Nuclei produced from it nucleate ice by the condensation-freezing mechanism at a rapid rate that is independent of liquid water concentration, which was a relatively unknown quantity in Moroccan clouds. Moreover, if supersaturated conditions are encountered, as might be the case in the orographically ascending air and the embedded convection, the nucleation rate might be even faster.

Various strengths of AgI solutions have been used on precipitation augmentation projects around the world. The seeding agent used during the 1984-85 and 1985-86 field seasons was an AgI-AgCl (silver iodide - silver chloride) solution containing 4 percent by weight of AgI. This solution caused some technical problems to the Lohse airborne generators, including nozzle obstruction. To avoid those critical problems and to minimize the uncertainties in the nucleation stage of the seeding strategy, Reclamation recommended that a solution of 2AgI-NaI (silver iodide - sodium iodide) containing 2 percent by weight of AgI be used in the following field seasons. This recommendation was adopted. A seeding rate of about 200 g AgI per hour per Lohse generator was set; this was achieved by a burn rate of about 11 liters of solution per hour.

Reclamation's recommendation that a 2-percent rather than a 4-percent solution be used was based on the high probability that burning the stronger solution would not substantially change the number of nuclei obtained; rather, coagulation would result in the production of larger nuclei (Dennis, 1980). As the nucleation rate of 2AgI-NaI is independent of particle size, the only advantage of a 4-percent solution would be the very slight increase in nuclei output, which was judged not to be cost effective.

2.4 Scientific Operations Plan

Cloud seeding operations were conducted by the DMN's Division of Research in Casablanca. The project's operations team consisted of more than 50 trained meteorologists, meteorological technicians, and electronics technicians located from Casablanca to Khouribga, Beni Mellal, and Azilal. The operations team was assisted by a scientific team of six meteorologists located in the project's analysis center in Casablanca. FRA pilots and technicians for the seeding aircraft were stationed with the aircraft at bases near Meknes and Kenitra. The on-duty operations director guided aircraft and ground-based seeding operations using data from a 5-centimeter weather radar at Khouribga, an upper air sounding system at Beni Mellal, a satellite downlink at Casablanca, and near real-time meteorological and visual observations from the project area. A detailed operations plan outlined the specific decisionmaking criteria (including suspension criteria) and operational procedures for all aspects of the project from the declaration of project status to opportunity recognition, conduct of cloud seeding operations, instrumented aircraft cloud physics research flights, and data collection (Hartzell et al., 1986).

2.4.1 Decision procedure for seeding operations. - Each Programme Al Ghait field season for cloud seeding operations began on November 1 and continued through April 30. During this 6-month period, routine operations were scheduled, unless otherwise suspended, for 24 hours a day, 7 days a week. Each day's cloud seeding activities were determined by following the "Daily Operational Decision Procedure" shown in figure 2.4. Four key categories had to be evaluated favorably before seeding operations were initiated: (a) the weather forecast stated that there was a potential for suitable clouds over the target area, (b) project equipment needed to conduct seeding activities was operational, (c) project personnel were available to operate the equipment and monitor the seeding, and (d) suspension criteria did not require the temporary suspension of seeding activities. Checklists were used to evaluate and document the daily status of each of these key categories. This decision procedure is described in detail in the *Operations Plan for Programme Al Ghait*, which was first written during the 1984-85 season and then updated yearly.

Each day at 0900 local time, a joint briefing via radio was held between the Operations Control Center at Khouribga and the Operations Support Center in Casablanca. After reviewing the status of equipment, personnel, and suspension criteria, detailed presentations were made of the synoptic and mesoscale weather situations. The project coordinator then presented the 24-hour forecast for the target area and the decision on project status, which was normally a decision he made jointly with the on-duty operations director. This information was then immediately relayed via Telex to operations personnel located at Beni Mellal, Azilal, Meknes, and Kenitra. The four project status categories are defined below:

- Stand down: No operations expected during the next 24 hours.

- Available standby: Operations expected in 2 to 24 hours.

- Ready standby: Operations expected in less than 2 hours.
(Exception - Pilots of project aircraft required a minimum of 6 hours' advance notice for aircraft operations.)

- Operations: Seeding operations requested or in progress.

2.4.2 Seeding opportunity forecasting and nowcasting. - Weather forecasting was needed to support operational decisionmaking for Programme Al Ghait. Of primary importance was the forecasting of clouds that would provide a potential for seeding operations. The forecast was used to place project personnel in either "available standby" or "stand down" status. It was highly desirable to declare the "available standby" status 24 hours in advance of when potential seeding operations were anticipated; a minimum of 6 hours' notice was required for project aircraft operations.

In order to initiate or terminate actual seeding operations effectively, the forecasters had to continue watching the weather after the day's forecast had been issued. They were practicing "nowcasting," which is the term applied to forecasting weather conditions expected to exist within the next 2 hours. The information required for nowcasting was obtained by monitoring real-time satellite, radar, mountain weather, and pilot observations for the project area.

Since the success of cloud seeding to enhance precipitation depends on many factors, such as the presence of supercooled liquid water, the concentration of natural ice crystals, stability, nucleating agents, dispersal methods, transport and dispersion of seeding material, and time available in-cloud for diffusional growth of ice nuclei, and since Programme Al Ghait did not have available ground-based instrumentation to make measurements of supercooled liquid water and ice, the selection of seeding opportunities was almost always based on traditional forecasts. Most of the time, the assumption was made that seeding potential existed whenever the first four of the following conditions were observed:

1. Cloud base height was less than 3000 meters m.s.l., which was the mean altitude of the High Atlas crest in the target area. (If estimated from rawinsonde data, cloud base height was defined as the level where the temperature-dew point spread was less than 3 °C.)

2. Cloud depth was greater than 1000 meters for stable orographic clouds or layer clouds with only weak embedded convection, but greater than 2000 meters for semi-isolated cumulus congestus. (If estimated from rawinsonde data, "cloud" was defined as the layers where the relative humidity with respect to water was 85 percent or greater.)

3. Cloud top temperature (from aircraft, satellite, and/or rawinsonde data) appeared to be suitable for seeding (generally between -5 and -20 °C, but between -10 and -25 °C for semi-isolated cumulus congestus).

4. Airflow below the 700-hPa level (approximately 3000 m) was suitable for targeting seeding material upslope into the barrier (between 220 and 360°).

Other conditions considered favorable but not necessary included:

5. Rawinsonde data from Beni Mellal and/or Tissa indicated potential instability (defined as regions where the equivalent potential temperature, Theta E, decreased with height).

6. Radar echoes from precipitation were existing in or moving toward the target area.

7. Real-time visual observations from mountain sites indicated the occurrence of precipitation and suitable clouds.

8. Satellite images indicated significant cloud cover over or moving into the target area.

9. Rawinsonde data from Beni Mellal and/or Tissa indicated significant supercooled liquid water available for precipitation.

2.4.3 Seeding techniques and operations. - Cloud base height and temperature profile changed from storm to storm depending on the origin of the storm, or during the same storm according to its stage of evolution. The appropriate delivery technique was selected in view of each mesoscale situation. Warm surface temperatures associated with high cloud bases (greater than 1000 m above ground level), trapping temperature inversions, and non-upslope low-level airflow sometimes precluded ground seeding. However, even under these conditions, airborne acetone generators and/or droppable pyrotechnic flares could be employed. At times, ground-based and airborne seeding operations were conducted simultaneously.

Beginning with the 1987-88 field season, a primary input to the selection of the seeding aircraft flight path and the ground-based generators used for operational seeding was the latest analysis from the ATLAS targeting model (sec. 8.2), which incorporated rawinsonde data from Beni Mellal and Tissa, when available. The model was empirical and two-dimensional and involved assumptions about airflow, ice nucleation, particle growth, and fall speed. The two dimensions were distance transverse to the mountain barrier and height; variations in the flow field along the barrier were assumed to be negligible. This model was adapted from the diagnostic targeting model that had been developed and used on Reclamation's Sierra Cooperative Pilot Project (SCPP). Adaptation of the model for use in Morocco is discussed in section 2.6.4.

2.4.3.1 Aircraft seeding operations. - At the inception of the project in 1984, the primary strategy was to use OV-10 Bronco-type aircraft for daytime seeding in VFR conditions beneath cloud bases upwind of the target area. With the assignment of two King Air 100 aircraft to the project in 1986 to replace the OV-10 aircraft, it became possible to release AgI nuclei directly into clouds in the desired temperature range of -5 to -12 °C. (The preferred seeding level was at -10 °C).

During the 1984-85 and 1985-86 field seasons, the OV-10's performed seeding operations by flying back and forth along fixed tracks (patrol seeding) about 10 kilometers upwind of the first ridge crest (Middle Atlas range). Many technical problems such as burner malfunctions, aircraft engine problems, Identification Friend or Foe (IFF)/transponder problems, low cloud bases, icing, severe convective weather, and strong winds were major causes of lost seeding opportunities. In addition, the seeding with OV-10 aircraft was restricted to daylight hours.

Beginning in the 1986-87 field season, the higher performance and well-instrumented King Air 100 aircraft flew various and more flexible tracks, including seeding under IFR and icing conditions. Nevertheless, airborne seeding operations continued to be limited to daylight hours. Moreover, the installation of the cloud physics data system on one of the King Air 100 seeding aircraft during the same field season further limited the availability of aircraft for seeding missions. Fortunately, the introduction of ground-based seeding generators at that time made the operations less dependent on the seeding aircraft. Figure 2.5 shows the King Air aircraft with the cloud physics data collection system and the Lohse seeding generators.

During convective band passages and when convective clouds were somewhat isolated, which was nearly always the case in springtime, cloud top seeding was performed by an Alpha Jet dropping flares into the updraft region of developing cells (one or two 20-g AgI pyrotechnic cartridges per updraft region). The nominal flight level generally assigned for the Alpha Jet was 4000 to 4600 meters (13,000 to 15,000 ft) m.s.l., which satisfied terrain clearance requirements (900 m above highest mountain peak in the vicinity) and also provided for seeding clouds with tops rising through the temperature range of -10 to -15 °C.

2.4.3.2 Ground-based seeding operations. - The transport and dispersion of particulate plumes in rough terrain are complex and not well known, but are a fundamental consideration in siting ground-based AgI generators. The requirements include achieving nuclei transport to cloud base, good targeting, and appropriate ice crystal concentrations. Microscale circulations, such as slope and valley wind systems, make good targeting extremely difficult. Low-level wind measurements were taken by pilot balloons (pibals) from several potential generator sites during storms in order to assist in targeting. In addition, boundary layer inversions can inhibit vertical turbulent transport of the seeding plume, although this tendency is offset in many storms by decreased atmosphere stability.

During the beginning of the third field season (1986-87), seven 150-liter-capacity ground-based generators were installed in an arc within the target area at the sites determined as being technically and logistically feasible (fig. 2.2); these sites were approximately 10 kilometers apart. Three additional generators of the same type were available for installation at other sites; however, these generators were held by the GOM as backups for the seven that were routinely used for seeding operations. Reclamation repeatedly recommended that these three backup generators be installed at sites already selected in order to increase the area and magnitude of the seeding effect within the target basin.

Beginning in January 1987, ground-based seeding operations were conducted whenever suitable clouds were forecast to exist over the target area for longer than 3 hours, there was no capping temperature inversion, and low-level wind conditions would carry the ground-released AgI upslope, allowing the nuclei to enter the clouds and rise above the -5 °C level over the target area. The selection of which generators to operate was primarily based on the targeting wind direction. The ATLAS targeting model (sec. 8.2) proved to be very useful by showing the estimated plume from each generator site, the points of nucleation, and the areal coverage of seeding impact on the ground. Once a generator was turned on, it was left on for a minimum of 3 hours. Figure 2.6 shows the mountain field site at Tissa where a ground seeding generator is located with the rawinsonde and automatic mountain observation system.

The chemical solution used for ground-based seeding was a silver iodide-sodium iodide (2AgI-NaI) solution containing 2 percent of AgI by weight. Some of its properties have been discussed already in connection with its use in airborne generators. Studies at Colorado State University established that hygroscopic condensation-freezing nucleant aerosols such as the 2AgI-NaI will survive passage through warm cloud and function to produce ice crystals when the nucleating temperature level is reached (DeMott et al., 1985). This information was relevant for ground-based seeding in Morocco. The flow rate on the generators was set to produce a seeding rate of about 20 grams of AgI per hour per generator.

2.4.4 Cloud physics aircraft operations. - An integral part of Programme Al Ghait was the scientific analysis and evaluation of cloud physics data for the determination of seedability (sec. 8.1). Cloud physics data for this purpose were collected by the UND research aircraft during two separate periods in 1985: January 23-April 30 and September 24-December 15 (Grainger and Stith, 1987). Most of the data were collected upwind of and over the target area in the Oum Er Rbia River basin. However, some data were collected over the Tensift River basin (control area southwest of the target area) and over other regions, such as the Sebou and Sous River basins. The data collected by the UND aircraft contributed greatly to verifying the assumptions used in forecasting or nowcasting the seeding potential (sec. 2.4.2) and improving personnel experience, thus maximizing seeding effectiveness.

In February 1987, one of the FRA King Air 100 seeding aircraft was instrumented with a basic instrumentation package and data acquisition system. (See section 8.1 for a description of the instrumentation.) The availability of this instrumented Moroccan King Air during March-April 1987 and two following field seasons (1987-88 and 1988-89) for cloud physics data collection provided the project with a very important data set. Due to the lack of previous cloud physics data over Morocco, representative samples were collected from all cloud types that appeared to have any possibility of seeding potential.

2.4.5 Operational use of meteorological surveillance equipment. - Under the Project Grant Agreement, the USG furnished GOM various equipment needed for conducting and evaluating the project, excluding AgI nuclei generators. (These equipment items are listed and described in section 4.6.) Three of the U.S.-furnished equipment items provided input data for real-time decisionmaking for cloud seeding operations; these were the rawinsonde, radar, and satellite systems. The operational uses of these three systems for meteorological surveillance of the project area are discussed in the following sections.

2.4.5.1 Rawinsonde operations. - Project rawinsonde (upper air observations of wind, temperature, humidity, and pressure) operations were conducted daily at the DMN's weather station near Beni Mellal. Reclamation provided two Weather Measure 8020 Series rawinsonde tracking stations (one was a refurbished Reclamation system); these were both initially installed at Beni Mellal. The second system provided backup in case of equipment malfunction to ensure that near real-time upper air observations were available for project use. Figure 2.7 shows the rawinsonde system in Beni Mellal with the front range of the High Atlas Mountains of the target area to the south.

During the 6-month winter field season, upper air observations were made routinely twice daily at the standard synoptic times of 0000 and 1200 CUT (Coordinated Universal Time). When requested in advance by the operations director, special 0600 CUT and/or 1800 CUT soundings supplemented the synoptic data during periods when the project was on standby or during cloud seeding operations to provide the most current information for decisionmaking. After the sounding data had been processed in Beni Mellal, they were telexed to project sites at Casablanca and Khouribga for further analysis. The use of these data in the ATLAS targeting model (sec. 8.2) provided a primary input to the selection of the seeding aircraft flight path and the ground-based generators used for seeding.

In the spring of 1988, the backup rawinsonde system was moved to Tissa (near Azilal) so that comparisons could be made of some simultaneous soundings made from the two sites during seeding operations. The dual soundings were also used to test an option in the ATLAS targeting model that used data from two soundings instead of one. The two-sounding option was expected to improve the accuracy of the model's predictions.

2.4.5.2 Radar operations. - The radar set that Reclamation procured for project use was the first weather radar set ever installed in Morocco. The system selected was an Enterprise Electronics WR100-2/77 C-band set. The radar wavelength was 5.4 centimeters. It was equipped with an antenna 2.4 meters in diameter, which provided a nominal beam width of 1.6°. Its primary purposes were the direction of airborne seeding and cloud physics aircraft operations and the observation of severe weather that might endanger aircraft. For this reason an IFF system was included in the radar system. Detailed specifications for the radar are discussed in section 4.6.2.

Figure 2.8 shows the weather radar at Khouribga with the VHF radio antenna for air-to-ground communications and the radar console with its microprocessor computers for data analysis and archival.

Both plan position indicator (PPI) and range-height indicator (RHI) displays were provided at the radar set. Microprocessors for recording both IFF and radar reflectivity data were integrated into the radar. A radar remote scope showing the PPI display was installed in the project coordination center in Casablanca.

The radar system was used operationally for the following purposes:

- For surveillance of the project area (operated 24 hours a day) for weather situations indicating conditions suitable for cloud seeding operations.

- To track project aircraft during seeding operations and during cloud physics data collection flights.

- To watch for the development of severe weather that would require the temporary suspension of seeding operations.

- For the collection of radar (PPI and RHI) and IFF data to be used in the postanalyses of seeding operations and cloud physics data collection flights.

The Operations Plan called for the on-duty operations director to be at the radar during all project aircraft operations. His duties included directing the seeding operations in real-time and watching for indications of severe weather echoes that would be hazardous for the aircraft.

2.4.5.3 Satellite downlink station operations. - A National Oceanic and Atmospheric Administration (NOAA) secondary satellite downlink station with a color enhancement microprocessor system and a laserfax unit for hard copies of satellite images was installed in the project's operations support center in Casablanca. Figure 2.9 shows the satellite ground station in Casablanca with the C-1000 microprocessor and laserfax satellite image processor. Satellite imagery was collected routinely every half hour from METEOSAT (the European Space Agency's meteorological satellite). In addition, satellite imagery was collected occasionally from NOAA polar orbiting satellites during their optimum orbits for Morocco. These data were evaluated in real-time to determine the types of clouds, approximate cloud top temperature, areal coverage of the clouds, and cloud movement relevant to the project's target area.

The color-enhanced digital satellite data provided only ranges of cloud top temperature; for example, light blue indicated -5 to -15 °C and green indicated -15 to -25 °C. However, even these approximate temperature values aided the operations director in the real-time assessment of clouds for potential seedability.

2.4.6 Data management. - The Reclamation experts involved in Programme Al Ghait considered the establishment of a viable data management plan as a basic need for the project. The Reclamation team believed that the organization of data collection and archiving would have great impacts on the long-term development of weather modification capabilities in Morocco. They recommended that GOM assign a trained meteorologist to the position of data manager on a full-time basis. Reclamation also recommended that the data management plan finally adopted should cover the following topics:

- Data sources
- Data collection
- Data documentation
- Data quality control
- Data inventory
- Data archival
- Data accessibility
- Data software

The requirements and approaches recommended for these eight components to the data management plan were stated in the *Evolving Work Plan for the Joint Scientific Evaluation Project Within Programme Al Ghait* (Bureau of Reclamation, 1987). Guidelines on data management were also included in the *Operations Plan for Programme Al Ghait* (Hartzell et al., 1986).

2.4.7 Operational efficiency. - It was planned that calculations would be made to determine the operational efficiency. Dividing the actual number of airborne and/or ground-based seeding hours by the number of hours with favorable seeding conditions and multiplying this ratio by 100 would give an "operational efficiency" in percent.

Because the project was designed as an operational demonstration program and not as a research program, sophisticated equipment was not available to provide continuous measurements for the determination of seedability. Section 2.4.2 lists the meteorological parameters used to forecast or nowcast seedable conditions. However, the evaluation of these parameters was somewhat subjective and depended upon the experience of the meteorologist filling the position of on-duty operations director.

It was soon realized that accurate calculations of operational efficiency would be impossible because the data did not exist for continuous determinations of seedability. Therefore, the decision was made to use a simple, objective approach for obtaining estimates of when seedable conditions existed over the target area. This approach was to assume that seedable conditions existed whenever the project radar at Khouribga observed echoes from precipitation over the target area, the color-enhanced satellite data, rawinsonde, or aircraft observations indicated cloud top temperatures were in the -5 to -25 °C range, and the airflow below the 700-hPa level on the latest Beni Mellal sounding was in the 220 to 360° range. It was realized that the radar might not be able to detect some clouds suitable for seeding, either because they were not yet precipitating or because the precipitation was below the detectable limits for the range and beam width involved. This was especially true with snowfall, which produces less intense radar echoes than rainfall at the corresponding precipitation rate. It was also realized that some of the clouds detected by the radar probably were not suitable for seeding.

2.5 Statistical Design

A sound statistical design was crucial to the assessment of Programme Al Ghait, both at the end of the original 5-year project and for continuing assessments of seeding efforts beyond 1989. The severe drought of the early 1980's forced Al Ghait into an operational-type demonstration project, where all storms that appeared suitable for seeding were actually seeded. Seeding all suitable storms limited the statistical design choices to target-only or target-control, with historical data supplying the nontreated sample required for purposes of comparison. The project plan called for a design having a basic foundation consisting of a target-control statistical analysis using streamflow data from the target area and the adjacent upwind Tensift basin control area (sec. 2.2.1). The design was done jointly by an expert at Colorado State University and a Reclamation meteorologist/statistician (Mielke and Medina, 1987). The implementation of this design is discussed in chapter 9.

2.5.1 Design for evaluation of seeding effects on streamflow. - Historical, daily streamflow data were available commencing in 1962 from both the target and the proposed control areas. No historical precipitation data were available for high elevation sites within the target or the control areas. Therefore, a target-control design with streamflow as the primary response variable was selected. Evaluation was to be performed with time units that led to reliable results in the shortest demonstration period.

Hydrographs for the target and control streamflow indicated that the primary runoff period was November through June, while the spring melt from high elevations started in March and decreased to a base flow in July. Fast streamflow response observed with some storms suggested that monthly analyses might be productive. It was found that for the historical data set available, the monthly and seasonal streamflows in the Tensift control area were well correlated with streamflows in the Bin El Ouidane watershed (linear correlation exceeded 0.8). The statistical techniques least-absolute-deviations (LAD) regression and multi-response permutation procedures (MRPP), as described by Mielke and Medina (1987) and Mielke et al. (1982), were selected for the evaluation.

Computer simulations were carried out on the historical data to determine the number of years the project would have to run, under various scenarios, to produce a statistically meaningful result. Each simulation assumed some fixed increase in target streamflow due to seeding and some specified significance level to be met or exceeded before an effect would be judged as not likely to have occurred by chance.

Estimated project duration values were obtained for assumed 10 and 15 percent increases from seeding under a variety of assumptions regarding required significance levels and probability of detection of an effect (Mielke and Medina, 1987). For example, the simulation studies indicated that applying a 10-percent increase to target quantities randomly selected from the historical data set suggested that the project would have to operate for 6 years to provide a 50-percent probability of detecting the increase at a significance level of 0.1. Complete results are given in chapter 9.

The analyses by Mielke and Medina assumed that all seedable storms were seeded. Nontreatment or low treatment efficiency of some storms would lengthen the period required to achieve statistically meaningful results.

Application of LAD and MRPP generates estimates of P-values (probability that differences in the data samples could have occurred by chance), but not estimates of the seeding effects on streamflow. Estimates of cloud seeding effects will be obtained by use of double ratios. The double ratio, DR, is defined as

$$DR = \frac{T_s / T_h}{C_s / C_h}$$

where:

T_s = the mean target streamflow for the seeded period
T_h = the mean target streamflow for the historical period
C_s = the mean control streamflow for the seeded period
C_h = the mean control streamflow for the historical period

The procedure is applicable with any selected time units provided that, once selected, they are employed throughout the project.

2.5.2 Adaptation of the Rhea orographic precipitation model. - Rhea (1978) developed a two-dimensional, steady-state, multi-layer model to diagnose the effects of topography on winter precipitation in western Colorado. The model used rawinsonde data and a fine mesh topographic grid. Reclamation believed that the Rhea model could be useful to Programme Al Ghait, both as a forecast tool and as a covariate with streamflow to be used in the statistical evaluation. If useful as a covariate, model-predicted values could be added to the statistical evaluation to shorten the time period required to obtain statistically meaningful results.

The task of adapting the Rhea model to Morocco was undertaken as a thesis topic by a Moroccan student, Mr. Ali El Majdoub, working on his M.S. degree in Meteorology at the South Dakota School of Mines and Technology (El Majdoub, 1989). Mr. El Majdoub focused on adapting the model so that it could be used with the latest rawinsonde data from Beni Mellal to forecast target precipitation. Because his work was not completed until April 1989, it has not been possible to test this model operationally on a daily basis, but monthly and seasonal sums are obtainable.

The model output parameter planned for use as a covariate for the statistical evaluation was target cumulative volume of precipitation for the November-April period. Model-predicted volume of precipitation, integrated over the target, was to be compared with actual seasonal (November-July) streamflow using least squares multiple regression. This analysis work and results are discussed in section 8.3.

2.6 Physical Evaluation Plan

2.6.1 Background. - The development and implementation of a scientific evaluation plan were considered to be essential for the success of Programme Al Ghait. However, because early efforts were concentrated on the installation of equipment and the implementation of cloud seeding operations, little attention was given to the scientific evaluation effort until late 1986. In December 1986, the decision was made to perform the scientific evaluation of Programme Al Ghait within Reclamation instead of through a subcontractor. Although one reason for this decision was to conserve project funds, it was judged that Reclamation staff were fully capable of accomplishing the evaluation. Furthermore, performing the work within Reclamation provided more flexibility in the preparation and execution of the evaluation plan.

A work plan for the scientific evaluation of Programme Al Ghait was drafted during January-February 1987. In March 1987, Dr. Arnett Dennis presented this draft plan to the PSC in Morocco. He learned that the GOM had assigned five recently trained M.S.-level meteorologists to the project. Three more Moroccan meteorologists were in long-term training working toward M.S. degrees in Meteorology in the United States and would be returning to the project. The GOM designated these eight individuals as the Moroccan Scientific Analysis and Evaluation Team (SAET) to participate in the project evaluation.

As a result of agreements reached during the third Annual Monitoring Review by Lintner and Silverman in April 1987, the scientific evaluation of Programme Al Ghait became a joint, collaborative effort between GOM and Reclamation. (Details on the collaboration are in chapter 6.)

In June 1987, Reclamation completed an *Evolving Work Plan for the Joint Scientific Evaluation Project Within Programme Al Ghait*. The data management and statistical evaluation tasks that were included in this plan have been discussed in sections 2.4.6 and 2.5, respectively. The following sections describe the physical studies that were planned to be accomplished jointly by GOM and Reclamation scientists.

2.6.2 Cloud physics and seedability study. - Programme Al Ghait was based on the assumption that supercooled liquid water is present in some clouds over Morocco and that the supercooled liquid water provides a source for additional precipitation to be released through seeding with ice-forming AgI nuclei. Therefore, the determination of seedability was pursued primarily on the basis of aircraft observations of the availability and persistence of supercooled liquid water regions. The study plan was that data from both the UND research aircraft and an instrumented Moroccan King Air 100 aircraft would be analyzed.

Generally, the analyses were to follow approaches formulated in the World Meteorological Organization's Precipitation Enhancement Project (PEP). In particular, the concept of regions of potential (ROP) as discussed by WMO (1982) was to form the basis for the analysis of cloud physics aircraft data. The following steps were envisioned for the ROP analyses:

1. A stratification by cloud type would be established using objective discriminators to the maximum extent possible. The PEP experienced a rapid progression of cyclonic systems producing a great variety of clouds. Similar cyclonic systems were expected to pass over the Programme Al Ghait target area; however, it would be necessary to take account of the orographic forcing over the Atlas Mountains.

2. Statistical summaries of the UND aircraft data were to be prepared along the lines used in the PEP. The prospects of beneficial cloud seeding for each cloud class defined in step 1 above would give a preliminary assessment based on these statistics.

3. The implementation of the ROP analysis would proceed by identifying candidate regions on the basis of observations of supercooled liquid water by the aircraft and by estimating the persistence of the liquid water on the basis of the aircraft observations or the character of the clouds. Basing the recognition of ROP on aircraft observations, the PEP defined the requirements in practical terms as:

a. The cloud temperature must be colder than -4 °C.

b. The average liquid water content must be greater than 0.1 g/m^3 for regions greater than 10 kilometers in horizontal extent, or greater than 0.3 g/m^3 for regions of smaller horizontal extent.

c. The characteristics stated in item b above must persist for periods longer than 10 minutes.

d. Cloud depth must be greater than 1 kilometer.

Chapter 8 discusses the work accomplished and findings for the Joint Scientific Evaluation Project (JSEP).

2.6.3 Radar echo study. - The radar set was obtained and located to be used primarily as a tool for conducting cloud seeding operations and providing coverage of central Morocco for use by the DMN (sec. 2.4.5.2). The display and analysis software for radar and IFF track data were prepared under subcontract by Colorado International Corporation (CIC). This software was written for the Z-80-based microprocessors used with the integrated radar system. The diskettes from the Z-80 microprocessors are 8 inches in diameter and not directly compatible with the IBM PC/AT microcomputers subsequently purchased by Reclamation for data management and analysis purposes. To solve the floppy disk incompatibility, interface hardware and software were purchased to transfer the data from the 8-inch diskettes to smaller 5.25-inch diskettes used in the IBM microcomputers. This hardware, combined with computer subroutines for the IBM microcomputers, permitted access to radar and IFF data on the IBM systems located in the analysis center. These subroutines unpacked, calibrated, and returned an array with data in engineering units to the application program calling them.

None of the CIC applications programs for analyzing and displaying the data were converted for use on the IBM microcomputers. However, applications programs for the IBM microcomputers that displayed the radar and IFF data were desirable. Development of such applications programs was planned under the JSEP.

The objectives for the radar study were to help in understanding the Moroccan precipitation processes and in recognizing seeding opportunities. Achieving these objectives required investigation of the relationships between the cloud microphysical data and radar echo patterns. Section 8.4 discusses the findings of this study.

2.6.4 Airflow targeting models. - Accurate targeting of seeding materials was important for maximizing the effectiveness of the project seeding operations. A substantial effort was made on Reclamation's SCPP in the Sierra Nevada of California to develop a model which could be used operationally to target seeding effects of both airborne and ground-based generators. The basic scheme employed in the SCPP targeting model was developed early in the SCPP program (Elliott, 1981); subsequently, the flow parameterizations were developed considerably (Elliott and Rhea, 1984; Rhea and Elliott, 1986). One of the Moroccan meteorologists in the United States for long-term training, Mr. El Bachir Loukah, adapted a version of this model that used only one rawinsonde to the High Atlas target area as his M.S. thesis project (Loukah, 1986).

SCPP scientists continued to work on the SCPP targeting model during 1986 and 1987 to improve its accuracy and, therefore, its usefulness. This work is summarized in the final report from Electronics Techniques, Inc., on SCPP Meteorological and Statistical Support (Huggins et al., 1986) and in a paper published in the *Journal of Climate and Applied Meteorology* (Rauber et al., 1988). Rauber et al. concluded that a version of the model using as input rawinsonde data from two locations (base and crest of the mountain barrier) was considerably more accurate than the one-rawinsonde version.

Reclamation suggested that, as a part of JSEP, the first version of the Moroccan targeting model adapted by Mr. Loukah be upgraded to include the latest changes to the SCPP model, including the ability to use input data from two rawinsondes. This suggestion was accepted by GOM. The improvements to the model that resulted are described by Benassi (1988) and in section 8.2.

2.6.5 Mesoscale analyses. - The term "mesoscale" was coined to describe atmospheric phenomena too small to be detected with standard meteorological networks, but too large to be observed entirely by one observer. Fujita (1986) set boundaries for the mesoscale at 4 to 400 kilometers. Different scales have been defined by others as mesoscale; for example, Orlanski (1975) set the boundaries at 2 to 2000 kilometers. The decision was made that the Fujita classification would be used on Programme Al Ghait.

Mesoscale weather systems include mesohighs accompanied by precipitation, mesolows, gust fronts, squall lines, and convective bands within cyclones. Convective bands near the California coast appeared to be very suitable for airborne patrol-type seeding, according to statistical analyses of the Santa Barbara experiment (Elliott et al., 1971). Preliminary evaluations of precipitation and radar data from the 1984-85 Morocco field season indicated that convective bands are important precipitation-producing mesoscale systems over the Atlas Mountains. Matthews (1983) found that mesoscale convective bands in Texas produced significant precipitation and identified an objective means of classifying mesoscale cloud and precipitation systems. A similar approach was planned for use in Al Ghait to determine the types of systems that contribute to precipitation and their relative seedability.

The objective for the planned mesoscale analyses for Programme Al Ghait was to develop analysis procedures that could be used in near real-time to forecast periods with seedable clouds. A case study approach was planned that combined project data from all available sources for selected precipitation events over the target area that were seeded and that had reasonably good data bases. In particular, studies were planned to determine the frequency of occurrence and the character of convective bands approaching and crossing the Middle and High Atlas Mountains in order to assess the seedability of this potentially important cloud type.

2.7 Economic Evaluation Plan

The assessment of the costs of cloud seeding operations and potential benefits from additional streamflow resulting from those operations was considered an essential part of the Winter Snowpack Augmentation Project from its inception. It was planned that this assessment would assist GOM in the development of strategies for the application of cloud seeding as an option in managing the country's water resources.

The economic evaluation work plan, developed in 1987 by Reclamation scientists, included the hydrologic evaluation. Since actual streamflow increases were not yet available from the statistical evaluation, the economic evaluation was based on assumed percentage increases in streamflow. Details of the economic evaluation are reported in chapter 10. The following sections state the purpose and objectives for the hydrologic and economic studies.

2.7.1 Hydrologic study. - The primary purpose of the hydrologic study was to evaluate the distribution and use patterns of additional streamflow that might be produced from the Winter Snowpack Augmentation Project. Specifically, the objective was to determine quantitative differences between hydrologic parameters measured under a "preproject" (natural flow) condition versus those under a "postproject" (enhanced flow) condition. The study plan called for simulated increases of 5 and 10 percent to be evaluated. Hydraulique's computer model RIVER for the Oued Oum Er Rbia basin was chosen for this study, as it already was operational at Hydraulique. The hydrologic impacts as estimated by the model RIVER were to be used in the economic study.

2.7.2 Economic study. - The economic study was intended to provide a cost-benefit analysis of the value of additional streamflow that might be produced as the result of cloud seeding versus the total cost of cloud seeding operations. More specifically, the study was planned to determine the effects of additional water on the Oued Oum Er Rbia basin's distribution and use of water resources for hydroelectric power generation, domestic and industrial uses, and irrigation for crop production. The assessment of benefits from augmented precipitation was to be based, in part, upon the hydrologic impacts estimated by the model RIVER.

The components of this study were:

- Identify and evaluate estimated economic benefits from increased water supply for hydroelectric power generation, domestic and industrial uses, and irrigation for crop production.

- Identify all costs related to capital investments and annual operating expenses for Programme Al Ghait.

- Calculate the identified estimated benefits and costs to establish estimated benefit-to-cost ratios for Programme Al Ghait.

2.8 Application Activities Plan

The application activities plan recommended by Lintner and Silverman (1986) in their Second Annual Monitoring Report called for two areas of activity, namely, water resources management application studies and an annual seminar series. The overall purpose was to conduct studies and training that would apply the findings and recommendations of the statistical, physical, and economic evaluations to practical issues in Morocco's water resources management.

2.8.1 Water resources management application studies. - The purpose of these studies was to provide guidelines and procedures for the application of the findings and recommendations of the statistical, physical, and economic evaluations to practical problems of continued cloud seeding operations in the central High Atlas target area after the termination of the USAID project support.

Initial plans called for the Water Resources Management Applications Studies to be prepared by a joint Reclamation-GOM team. These studies were to integrate the findings and recommendations of the statistical, physical, and economic studies into practical guidance for the planning and management of weather modification in Morocco. They were to emphasize the conditions, places, and times that weather modification would be an economic intervention in the target basin. They would also serve to integrate the provisions of the suspension criteria, which are designed to avoid environmental damage from weather modification, into the decisionmaking process.

The final design plan for these studies was to be prepared concurrently with the receipt of initial findings of the statistical, physical, and economic evaluations. Due to the late availability of project-related data, most of the initial findings for these evaluations were not available until the summer of 1989; consequently, developing the final design for these studies and completing the related work are recommended as future project activities (ch. 12).

2.8.2 Seminar series. - The purpose of the seminar series was to provide for development of an integrated understanding of the design, implementation, and evaluation of scientifically based programs of winter snowpack augmentation by members of the Moroccan scientific and technical team for Programme Al Ghait. To support this stated purpose, Lintner and Silverman (1986) recommended three annual seminars, each of 2 weeks' duration, as part of the training plan for technology transfer. The subject areas for these seminars were:

Seminar 1: Scientific Aspects of Weather Modification

Seminar 2: Engineering and Implementation of Cloud Seeding Strategies

Seminar 3: Decisionmaking for Precipitation Enhancement as a Water Resources Management Technique

Seminar 1 was given under a subcontract by Dr. Gabor Vali, Theta Associates, in Casablanca during October 1986 (ch. 6). The seminar was well received by Moroccan project and other meteorologists.

During the Third Annual Monitoring Review (Lintner and Silverman, 1987), the Moroccan SAET indicated that the seminar topics originally proposed for Seminar 2 were adequately covered by Dr. Vali in Seminar 1. By mutual agreement, new topics were chosen for Seminar 2 that dealt with the physical evaluation of seeding effects. However, GOM subsequently requested that this seminar be canceled, as the new topics were not directly applicable to Programme Al Ghait. Reclamation agreed with this request.

The External Evaluation Team (EET) (Changnon et al., 1987) recommended that Seminar 3 be replaced by a conference of high-level decisionmakers in Morocco. They noted that one of the objectives for the project was to increase awareness of the need for an improved water resources management program in the Oued Oum Er Rbia basin and of the potential role of weather modification in managing the water resources of the basin. This recommendation was discussed by Lintner and Silverman at a PSC meeting during the Third Annual Monitoring Review in April 1987. It was agreed that Seminar 3 would be replaced by a Joint Summary Review during the summer of 1989, which would summarize the results of the project with respect to its objectives, highlighting what was accomplished and what remains to be done. The Joint Summary Review is currently scheduled as a 1-day meeting in Morocco in September 1989.

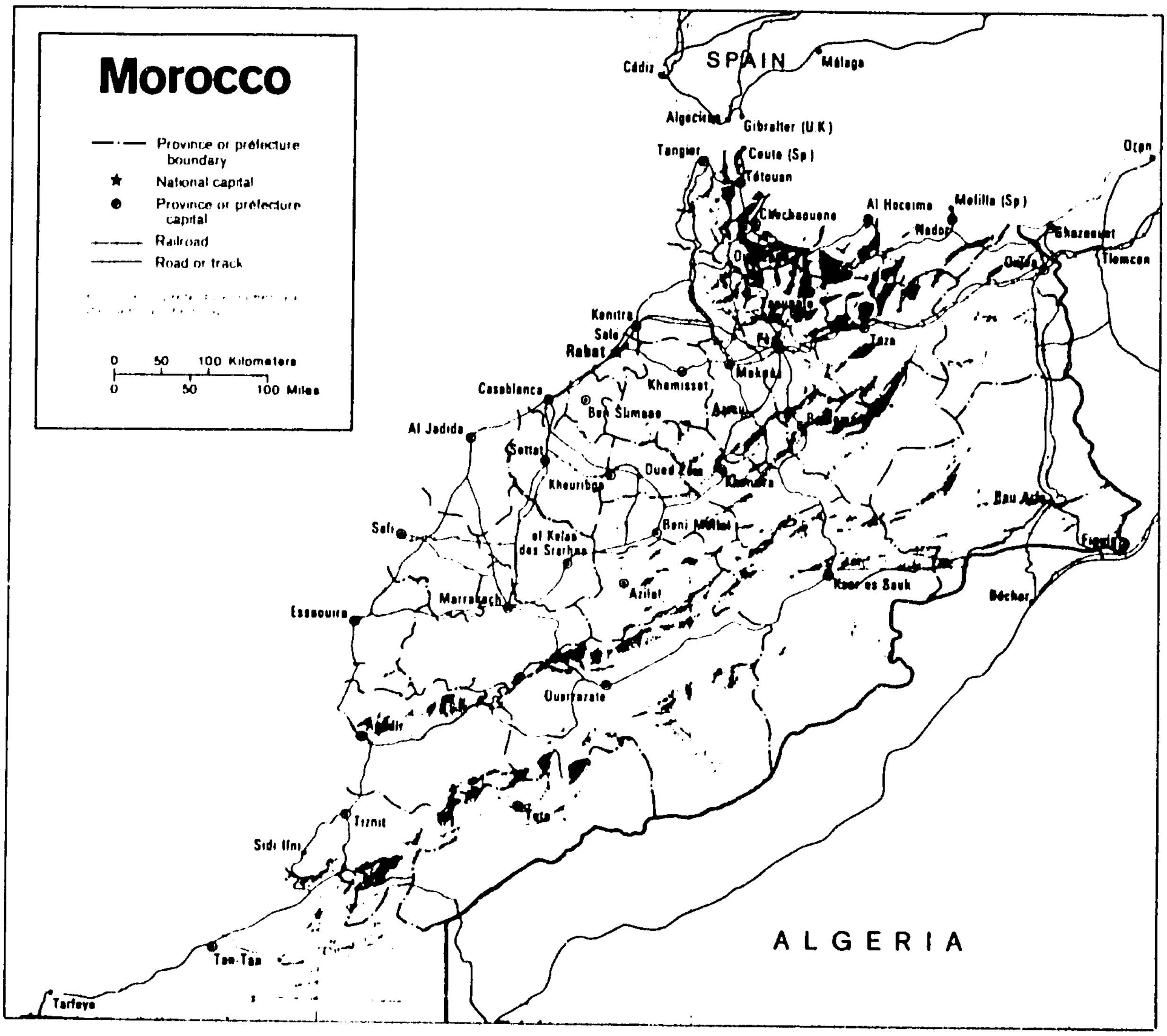


Figure 2.1. - Map of northern Morocco showing principal mountain ranges and location of the target and control areas.

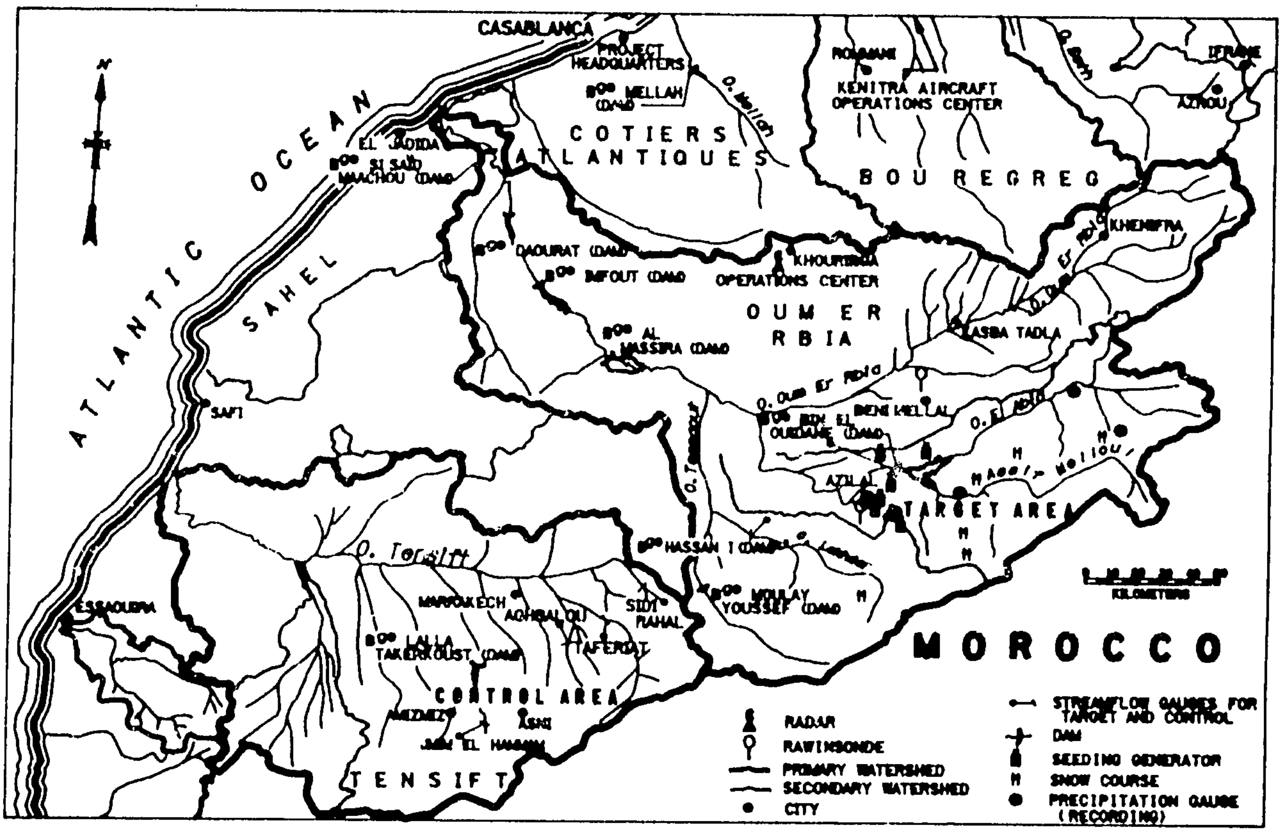


Figure 2.2. - Map of central Morocco showing the project's field operations sites, target and control areas, seeding generator sites, and major observation sites for snowcourses and precipitation gauges and rawinsondes.

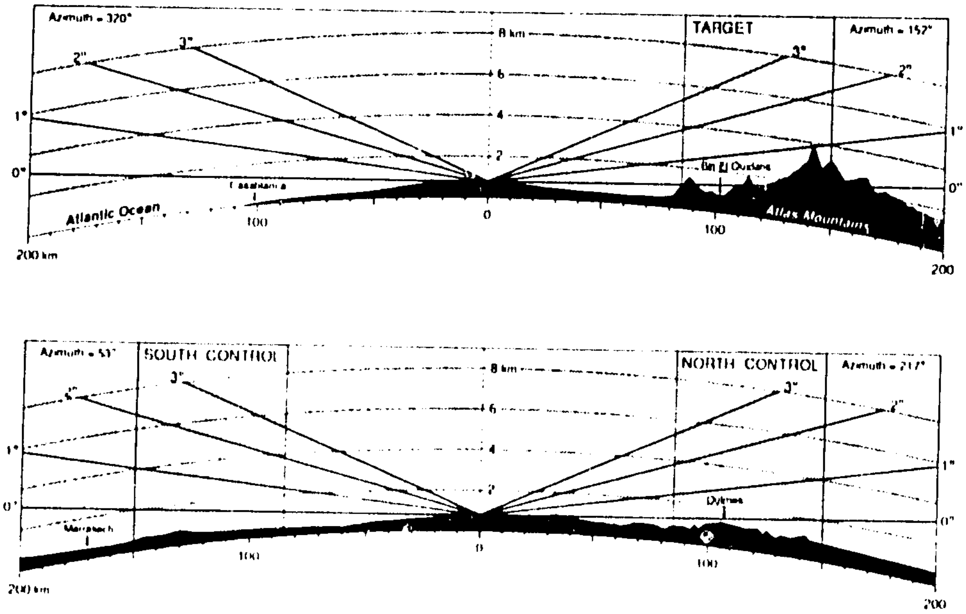


Figure 2.3. - Cross section of terrain along a line through the radar site perpendicular to the crest of the High Atlas.

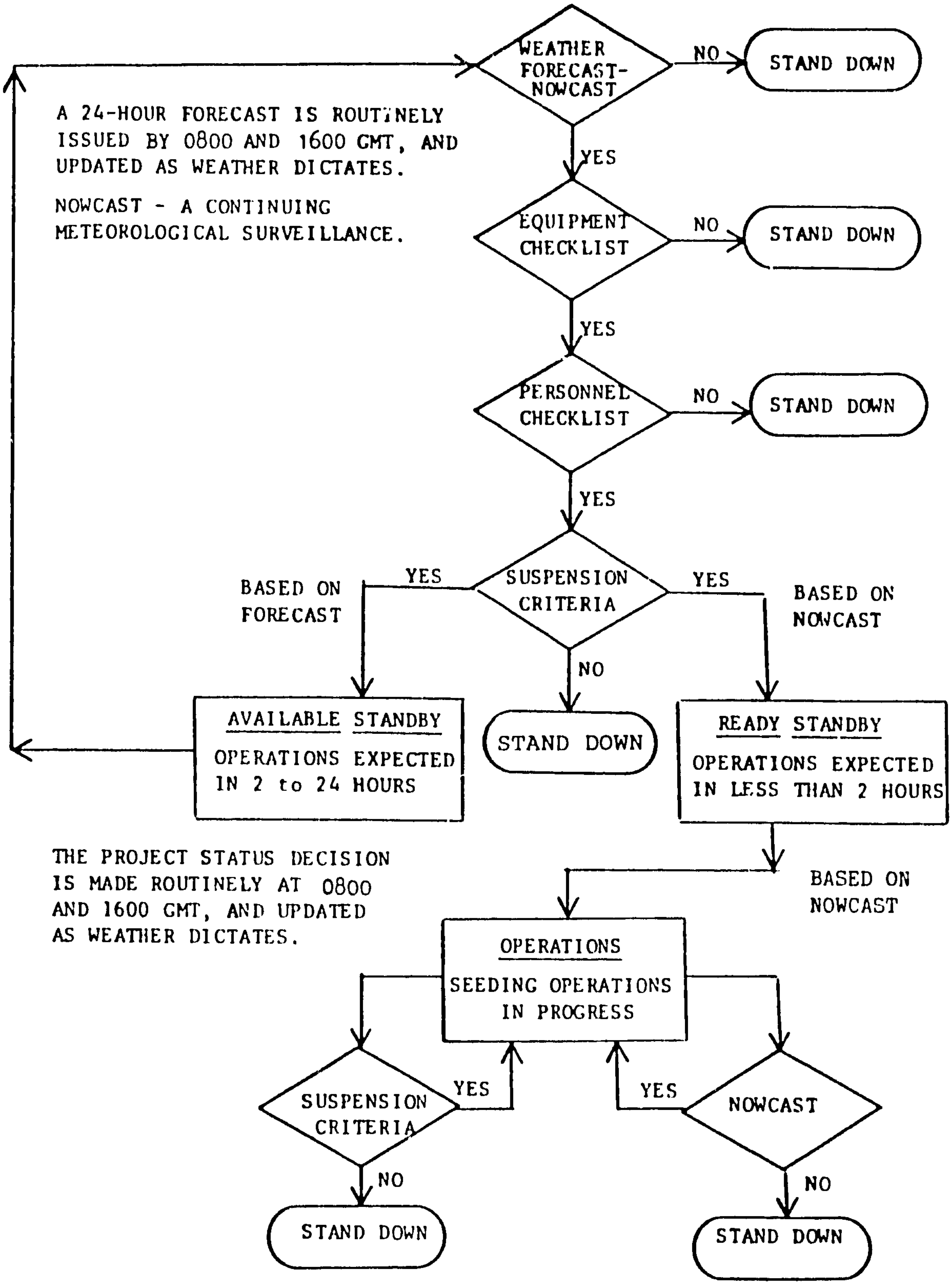


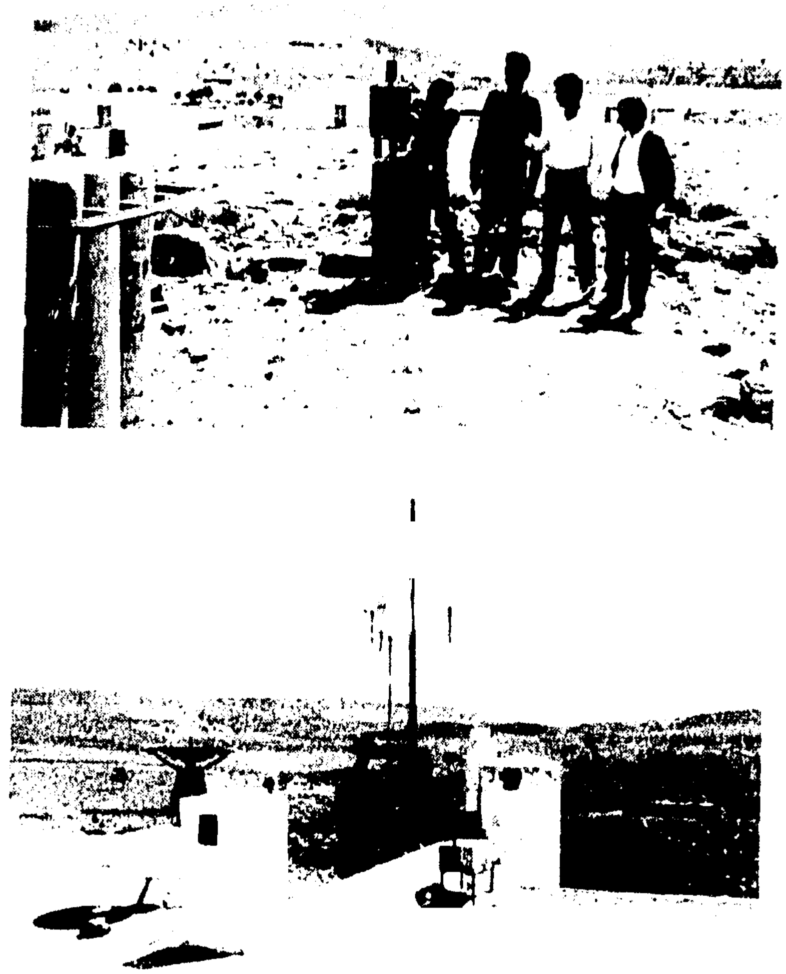
Figure 2.4. - Daily operational decision procedure showing the process by which the operational status was determined in an objective manner.

(a)

(b)

(c)

Figure 2.5. - Cloud physics and seeding aircraft, a Royal Moroccan Air Force King Air 100 (a), with cloud physics instrument system (b), and Lohse seeding generator (c).

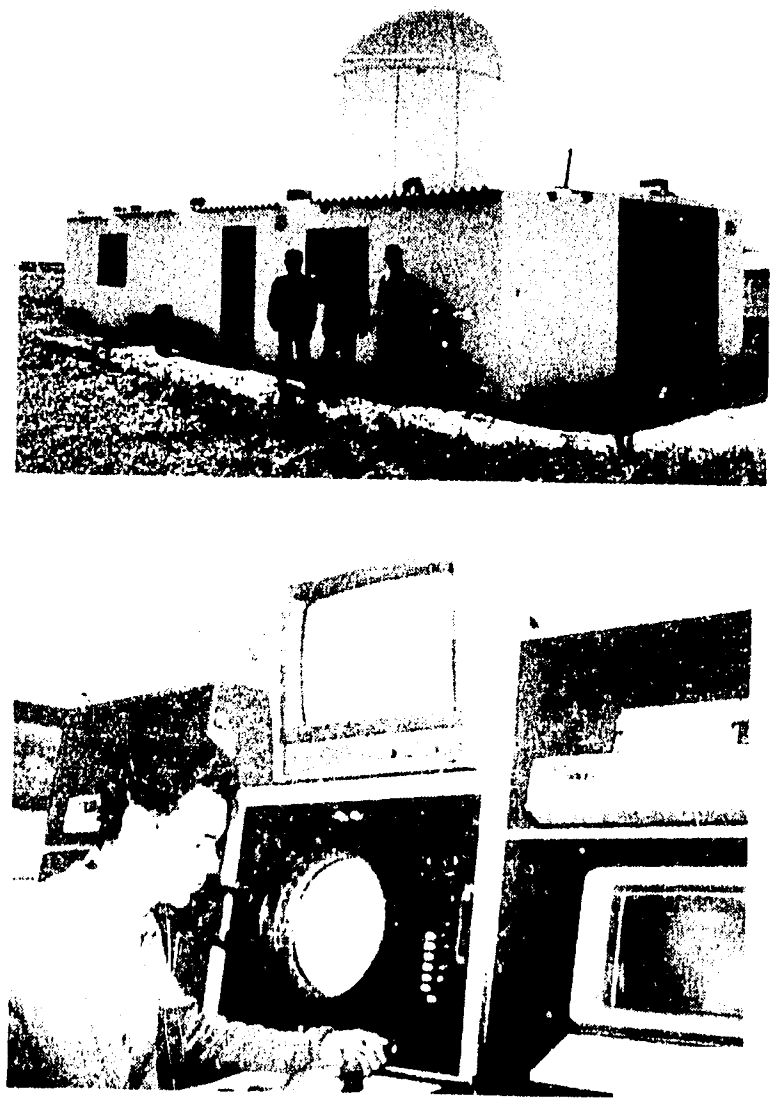


(a)

(b)

Figure 2.6. - Ground seeding generator operations center at Azilal-Tissa in the central High Atlas Mountains, showing the seeding generator (a), and rawinsonde weather balloon tracking system and meteorological instruments (b).

Figure 2.7. - Rawinsonde station at Beni Mellal showing the rawinsonde antenna on the roof and the front range of the High Atlas Mountains in the background.



(a)

(b)

Figure 2.8. - Radar facility at Khouribga showing the radome (a) and interior with radar scope and microprocessing computers for data analysis and archival (b).

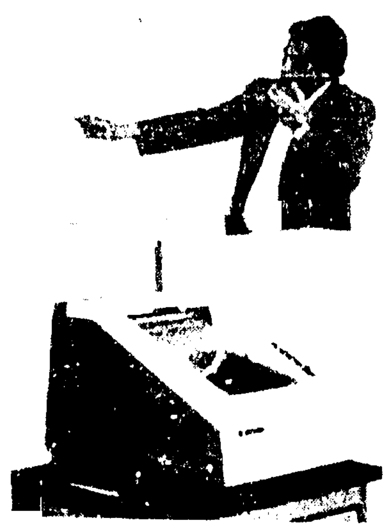


Figure 2.9. - Satellite Secondary Data Users Station (SDUS) with color enhancement system for satellite imagery processing in the Casablanca operational coordination center.

3. CONTRIBUTIONS BY THE GOVERNMENT OF MOROCCO

The Government of Morocco was primarily responsible for the provision of personnel and facilities and for the execution of cloud seeding operations in the Central High Atlas Mountains. The GOM officials in the FRA and DMN provided direction and management of the project and conducted scientific studies in cloud physics, radar, satellite, and numerical modeling. A comprehensive review of the GOM efforts is presented in their final project report (Programme Al Ghait, 1989). This chapter provides a summary of the major contributions of the GOM.

3.1 Financial Contributions

The originally planned GOM commitment called for a total of $6,410,000 for Programme Al Ghait. Of this amount, the DMN was to contribute about $3,800,000, the FRA about $2,500,000, and Royal Air Maroc about $40,000. Estimates of actual contributions in funds, resources, and services are given in table 3.1.

Table 3.1. - Programme Al Ghait - Total Government of Morocco costs.*

	DH (dirhams)	$ (dollars)
1. Staff salaries		
DMN	17,037,000	2,129,625.00
FRA	2,632,500	329,062.50
Subtotal	19,669,500	2,458,687.50
2. Administrative costs (office facilities, utilities, communications, shipping, transport, etc.)		
DMN	15,436,800	1,929,600.00
FRA	2,563,000	320,375.00
Subtotal	17,999,800	2,249,975.00
3. Equipment, materials, supplies, and subsistence/travel costs		
DMN	3,500,000	437,500.00
FRA	13,637,263	1,704,657.88
Subtotal	17,137,263	2,142,157.88
4. Other ministries and agencies		
Ministry of the Interior	800,000	100,000.00
OCP	600,000	75,000.00
Royal Air Maroc	751,907	93,988.38
TOTAL	56,958,470	7,119,808.75

*Based on the 1989 DMN budget totals documented in Mr. E. Loken's memorandum of June 6, 1989, and on the 1989 FRA totals for 5 years from Colonel Bamaarouf, June 1989.

3.2 Program Management

The management structure of Programme Al Ghait was outlined in section 1.5 and is shown in figure 3.1. The project was managed for the most part by Moroccans. All members of the National Steering Committee (NSC), most members of the Project Steering Committee (PSC), and the project director were GOM personnel.

The NSC was comprised of representatives of the different GOM ministries with interests in the project, as follows:

- Ministry of Transport (parent agency of DMN)
- Ministry of Defense (parent agency of FRA)
- Ministry of the Interior and Information
- Ministry of Mines and Energy
- Ministry of Equipment
- Ministry of Agriculture
- National Police Force (Gendarmerie Royale)
- Ministry of Posts and Telecommunications
- National Center for Coordination and Planning of Technical and Scientific Research.

The NSC met at least once a year to coordinate the different contributions and to solve any problems that could not be solved by the PSC.

The PSC was comprised of four persons from GOM and two employees of the USG. The Moroccan members were:

- A high-ranking officer of the FRA
- The Director of DMN
- Director of Programme Al Ghait (Chief of the Division of Research and Development of DMN)
- Deputy Director of Programme Al Ghait.

This group met biweekly or monthly to manage the project. They were authorized to make any necessary changes in the project and solve major issues.

Day-to-day project management was provided by the project director. A deputy project director was appointed in early 1987 to assist in this task.

3.3 Personnel and Services

In addition to the Moroccan managers mentioned in section 3.2, the GOM provided most of the personnel required to carry out the project. Figure 3.2 shows the project organization as of 1987. Most of the Al Ghait operating personnel were organized into four principal teams, with one or more coordinators assigned to manage each team. Three of the teams consisted mainly of DMN personnel, and the fourth team consisted entirely of FRA personnel. The functions of the four teams are described in the following sections.

3.3.1 Operations team. - The main role of the operations team was to coordinate, control, and execute the various project operations. As figure 3.2 shows, the team was comprised of individuals based at several locations. There were two coordinators and two operations directors in Casablanca, as well as a number of scientists working in such areas as analysis of cloud pictures obtained by satellite. The Khouribga center was normally manned by a station chief, three operations directors, four air traffic controllers, five radar operators, and six weather observers. An operations director and 15 ground generator operators were stationed at Azilal. There were six rawinsonde operators at the Beni Mellal rawinsonde station. All of the members of the operations team were DMN personnel except for the air traffic controllers at Khouribga, who belonged to FRA.

3.3.2 Air Force team. - The Air Force team in Programme Al Ghait was led by an FRA coordinator who was assigned full time in Casablanca to coordinate Programme Al Ghait aircraft operations. Fifteen pilots and six mechanics were assigned to the team. They were based at Kenitra to fly and maintain the project aircraft.

3.3.3 Maintenance and supply team. - The main job of the maintenance and supply team was to install the project equipment and keep it in operation. The team leader and his deputy were located in Casablanca. Two technicians were assigned full time to Kenitra to maintain the instrumentation on the project aircraft, including the King Air outfitted for cloud physics observations. Five technicians were assigned full time to maintain the radar and other facilities at Khouribga. One technician was assigned full time to Beni Mellal to maintain the rawinsonde station and its equipment. One technician was assigned full time to Azilal to maintain silver iodide generators for ground-based operations and all equipment installed at the different ground generator sites. Six other technicians were assigned to the maintenance and supply team on a part-time basis. They were based in Casablanca and available to help the full-time members of the team whenever the need arose. All of the persons in the maintenance and supply team were from DMN.

3.3.4 Scientific Analysis and Evaluation Team (SAET). - The objectives of the SAET were as follows:

- To develop and improve the scientific level and the efficiency of the project operations.
- To physically evaluate the seeding effects.
- To establish the long-range statistical, hydrologic, and economic evaluation of the project.

The SAET was comprised of six groups, each led by a scientist with postgraduate training to the M.S. level. The names of the groups and their composition were as follows:

- Evaluation and data analysis group: one M.S. scientist as leader, three technicians.
- Aircraft data analysis and cloud microphysics group: one M.S. scientist as leader, one engineer, and two electronics technicians.
- Microphysics and targeting modeling group: one M.S. scientist as leader, one engineer, and one technician.
- Radar analysis group: one M.S. scientist as leader, one engineer, and one technician.
- Mesoscale analysis group: one M.S. scientist as leader, one engineer.
- Data management group: one M.S. scientist as leader (same leader as evaluation and data analysis group), one engineer, and two technicians.

Between 1986 and 1989, four SAET members returned to Morocco from long-term training at the South Dakota School of Mines and Technology with M.S. degrees in Meteorology. Their presence significantly enhanced the SAET. In addition, one of them, Mr. Loukah, assumed the position of deputy director of the project.

3.3.5 Other personnel. - The FRA assigned another small team, the Aleliers Mecaniques Generales (AMG), to manage all the shipments of equipment between Morocco and the United States for Programme Al Ghait. The AMG team also maintained the project's cars. Another small military team was assigned to the project to manage the chemicals used for seeding.

3.4 Facilities and Equipment

3.4.1 Contributions by National Meteorological Organization (DMN). -

3.4.1.1 Casablanca. - Facilities provided by DMN at Casablanca included:

- A room for reception of satellite and radar data and operational coordination.
- An air-conditioned room for computers and data storage.
- A warehouse for project equipment.
- A workshop for maintenance of meteorological instruments.
- An electronics laboratory.
- A meeting room for lectures and seminars.
- Offices for the RSA, SAET, operations team, and maintenance and supply team.

Equipment provided by DMN at Casablanca included considerable quantities of standard meteorological instrumentation and test equipment.

3.4.1.2 Beni Mellal. - The DMN took the lead in providing facilities at Beni Mellal, although other agencies also contributed. The facilities at Beni Mellal included shop space for the maintenance and repair of meteorological instruments used for surface observations as well as rawinsondes. Since Beni Mellal was selected at the beginning of the project as the site for rawinsonde launches, a large sounding room and one preparation room were provided. A balloon inflation shelter and a storage room were constructed for the project.

3.4.2 Moroccan Royal Air Force (FRA). -

3.4.2.1 Aircraft. - At the start of the project, FRA equipped four OV-10 aircraft with acetone-fueled silver iodide generators for seeding. The OV-10's were operated during the 1984-85 season and for part of 1985-86. Beginning in the spring of 1986, FRA provided two King Air 100 aircraft, also equipped with acetone generators, to perform the aircraft seeding. One of the King Air's was instrumented to take cloud physics observations beginning in 1986-87. FRA also provided one Alpha Jet equipped with racks for dropping silver iodide flares. The Alpha Jet was available for the entire project. It was used mostly for seeding isolated convective clouds, sometimes on an experimental basis.

3.4.2.2 Bases for aircraft. - The OV-10's were based at Marrakech Air Force Base; the King Air's were based at Kenitra Air Force Base; and the Alpha Jet was based at Meknes. All crews, except for the Alpha Jet, were based at Kenitra Air Force Base. Crews were posted temporarily from Kenitra to Marrakech to operate the OV-10 aircraft.

Ground facilities at Kenitra included hangar space for the King Air's, shop space for aircraft maintenance and storage of seeding materials, a briefing room, a weather station, and offices and rest areas for the crews. A separate workshop and office area was provided for the members of the maintenance and supply team responsible for installation and maintenance of the cloud physics data acquisition system on the instrumented King Air.

The military base at Marrakech provided maintenance and an operations base for the OV-10 aircraft used for seeding during the first two seasons. Seeding equipment was stored and maintained there. From January to April 1985, the base also provided hangar space and offices for the operation of the UND Citation. A briefing room, a weather station, and communication to Casablanca were provided. The Marrakech base was an excellent facility for operations and preliminary analysis of the first cloud physics data.

The UND Citation operation in the fall of 1985 was based at the Casablanca Anfa Airport, where AMG/Royal Air Maroc provided hangar space and DMN provided a computer room and office space to process data and brief the flight crews. Other facilities provided by FRA at Anfa throughout the project included warehouse space for project equipment (in addition to that provided by DMN) and a machine shop for maintaining project vehicles and cloud seeding equipment.

FRA supported the Alpha Jet operation out of Meknes with facilities for hangaring and servicing the airplane, including storage of silver iodide flares, a weather station and briefing room, and communications.

3.4.2.3 Khouribga operations center. - FRA played a large part in establishing the Khouribga operations center. A large building, which formerly served as the operations center at Khouribga airport, was turned over to the project by the Army and remodeled by FRA to house personnel and equipment. The radar was installed in a trailer, and a shelter was constructed to cover it. A small building was constructed near the radar trailer for the use of radar personnel and to store radar-related equipment, such as electrical generators. A new meteorological park was constructed to help in the nowcasting analysis. Power lines and telephone lines were installed to support the radar set and other equipment and provide communications between Khouribga and Casablanca.

3.4.2.4 Navigation facility. - Because coverage by existing navigational facilities was marginal near the central High Atlas, FRA provided a Tactical Air Navigation (TACAN) station to assist in the controlling of project aircraft. It was installed southwest of Beni Mellal to improve coverage of the areas where most of the seeding flights were conducted.

3.4.3 Ministry of the Interior. - The Ministry of the Interior supported the operation of the network of ground-based silver iodide generators, which was based at Azilal. Seven small buildings were built or remodeled to house the ground generator operators at the different sites. A large building with rooms for offices, storage of equipment and chemicals, and housing was provided by the Governor of Azilal for the mountain operations center. A shelter for the rawinsonde station activated at Azilal in early 1987 was under construction in early 1989.

The Governor of Khouribga contributed 600,000 DH to the construction in Khouribga and helped the project by providing solutions to local problems.

3.5 Services

3.5.1 Ministry of Transport. - The Ministry's DMN made a number of contributions to the project in addition to providing most of the staff and the facilities used by the project staff. DMN made available daily rawinsonde data from Casablanca and Agadir, as well as surface observations from all national and international synoptic stations and national secondary stations. The DMN arranged for special observations of the weather, streamflow, and reservoir levels by other GOM agencies to assist project personnel in their operational decisions.

DMN communication teams and the different maintenance teams were always available to help whenever the project requested assistance.

In addition to its contributions through DMN, the Ministry of Transport provided assistance through Royal Air Maroc. This support included more than 13 airline tickets for the project personnel going to the United States for training, and all shipments of the project equipment.

3.5.2 Ministry of Defense. - In addition to the FRA team, the air traffic controllers at Khouribga, and the facilities described in section 3.4, the Ministry of Defense provided a number of other key services to Programme Al Ghait. The FRA provided all the seeding materials used on the project, stored them, and loaded them on the seeding aircraft as required. As previously noted, the AMG team of FRA managed the shipment of project equipment between Morocco and the United States. The AMG also maintained many of the project vehicles.

The FRA transported the radar to Khouribga after it arrived in Morocco and provided support during its installation. In addition to providing a large building for the project at Khouribga, the Army's "5th GM" provided technical assistance, mechanics, and other items needed for the project.

At Kenitra, in addition to giving technical assistance to the seeding aircraft, the "BAFRA" always fed and lodged the project personnel during operations.

The Sale military base provided many English classes and food and lodging to project personnel.

3.5.3 Other ministries. -

3.5.3.1 Ministry of the Interior and Information. - The facilities provided by the Ministry of the Interior through the Governor of Azilal have been noted. The Governor provided considerable additional assistance to the project by solving various local problems. The Ministry always gave a high priority to the project, solving local administrative problems, assisting with housing and communications, providing rain gauge data from their own stations, and so on. Other specific areas in which the Ministry assisted the project included finding sites for the ground-based silver iodide generators, installing precipitation gauges, setting up communications, and arranging helicopter flights for collection of snowcourse data.

Interior's Morocco Radio-Television (RTM) provided a radio repeater site at Tazerkount, complete with tower, power supply, and a place for a seeding generator; a site for a radio station and another seeding generator at Ait M'hamed; and a site for a rawinsonde station, seeding generator, and automatic weather station at Tissa, complete with housing, office space, and electrical power.

3.5.3.2 Ministry of Mines and Energy. - The Ministry of Mines and Energy provided the propane needed to fuel the ground-based silver iodide generators for the project.

The Ministry's National Electrical Organization (ONE) worked closely with the project. They provided daily streamflow and reservoir level data by Telex each morning through DMN. Their numerical model of river management was used in the economic studies. ONE also provided special information regarding the operating characteristics of dams and irrigation systems.

3.5.3.3 Ministry of Equipment. - The Ministry's Hydraulic Administration (Hydraulique) worked closely with the project staff, providing streamflow data, including historical records, for target and potential control areas, as well as current observations of soil moisture, soil temperature, and weather conditions. To help analyze the streamflow data, Hydraulique provided their hydrological model RIVER, as well as the use of their computers to run the model. This model was used in the hydrologic modeling studies, and the results from it were applied to the economic studies. The project's economic studies benefited from the provision of economic data on irrigation projects and information on river operations. Consultations with Hydraulique's experts on all of these specialized areas of expertise were very useful to the Programme Al Ghait staff.

3.5.3.4 Ministry of Agriculture. - At the beginning of the project, the Ministry of Agriculture provided two Land Rover vehicles. The Ministry provided useful data and information during the entire project, especially the Office Regional de la Mise en Valeur Agricole de Doukkala (ORMVAD) at El Jadida and the Office Regional de la Mise en Valeur Agricole de Tadla (ORMVAT) of Kasba Tadla. Through its Waters and Forests Administration, the Ministry provided a number of sites for seeding generators, sites for recording precipitation gauges at Boutferda and Tilloguet, and other precipitation gauge sites in the Atlas Mountains.

3.5.3.5 National Police Force (Gendarmerie Royale). - The Gendarmerie Royale provided helicopters for snowcourse measurements. They also collected weather reports from remote mountain weather stations by radio and relayed them by radio or Telex to DMN.

3.5.3.6 Ministry of Post and Telecommunications. - This Ministry made new Telex and telephone lines available for the project. They expedited assignment of radio frequencies to Programme Al Ghait, thereby contributing greatly to project communications.

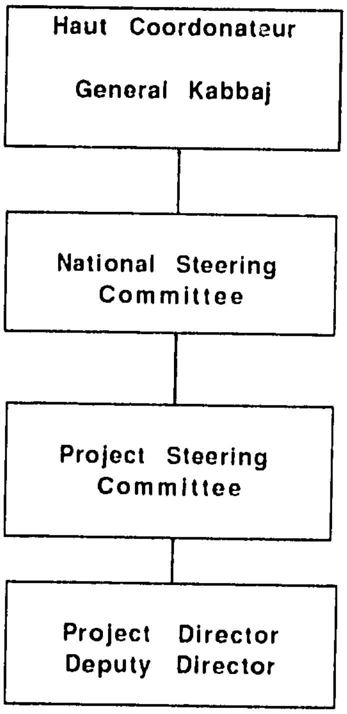


Figure 3.1 - Programme Al Ghait project management teams.

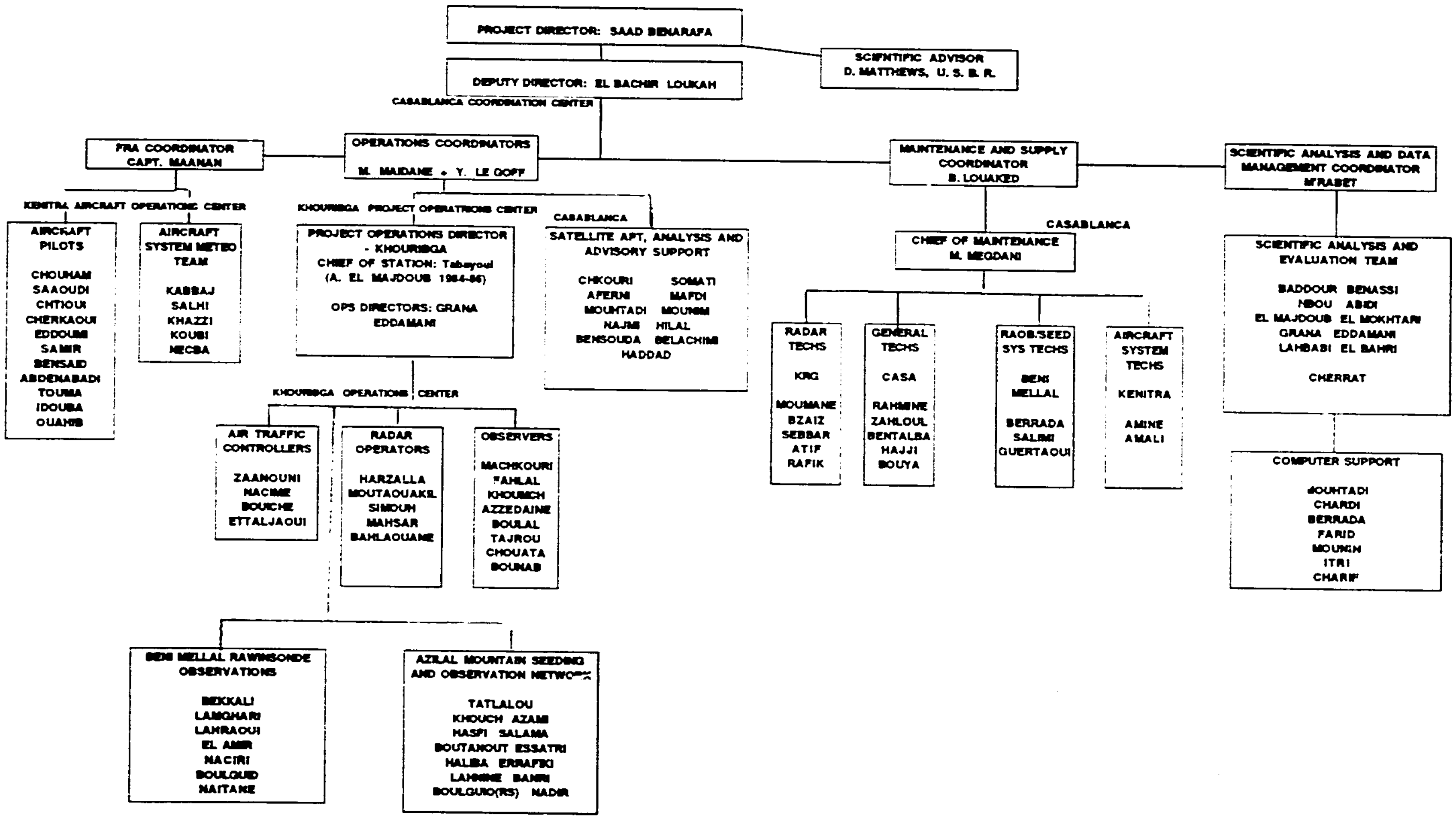


Figure 3.2. - Programme Al Ghait organization chart.

4. CONTRIBUTIONS BY THE UNITED STATES GOVERNMENT

The U.S. Government was primarily responsible for the transfer of technology and scientific equipment to assist the GOM in its development, conduct, and evaluation of a scientifically based cloud seeding demonstration program for winter precipitation augmentation in the Central High Atlas Mountains of Morocco. This chapter provides a summary of the major American contributions.

4.1 Financial

The USG contributed a total of $6,182,000 to the project. Of this amount, $6,000,000 was supplied by USAID, $114,000 by the NOAA, and $68,000 by the Peace Corps. Of the $6,000,000 provided by USAID, $272,474 was retained by the USAID Mission in Morocco to cover local expenses related to Programme Al Ghait, leaving $5,727,526 to support the Participating Agency Service Agreement (PASA) with Reclamation. The USG's financial contributions provided personnel and services, including technical training and facilities and equipment. The budget for the American contributions is shown in table 4.1.a. This provides an itemized list of support provided by the USAID Mission in Morocco, Reclamation direct costs, and subcontractor costs divided into 13 basic items. Table 4.1.b provides budget detail for Reclamation subcontracts under the PASA.

Table 4.1.a. - Summary of U.S. Government contributions to Programme Al Ghait (from PASA IMA-0194-P-IW-4093-03).

Budget item	Cost ($ x 10^3)
A. USAID Mission local account	
Personnel support	163.0
Support materials supplies	109.5
Subtotal USAID Mission	272.5
B. Reclamation PASA	
Reclamation Direct	
Resident scientific advisor	293.6
Scientific support	997.5
Administration	235.7
Participant training	27.2
Other training, overhead, equipment maintenance, etc.	348.3
Subtotal Reclamation Direct	1,902.3
C. Reclamation subcontracts	
Training	353.3
Capital equipment	1,569.7
Recurring costs, supplies, parts	444.9
Scientific/economic studies	1,004.8
External evaluation	90.9
Other: equipment, parts, training	361.6
Subtotal subcontracts	3,825.2
Subtotal Reclamation PASA	5,727.5
Total USAID contribution (A + B + C)	6,000.0
NOAA: Satellite ground station	114.0
Peace Corps: English language training	68.0
Total American contribution	6,182.0

Table 4.1.b. - Budget detail for Reclamation subcontracts.

Budget item	Cost ($ x 10^3)
A. Training	
1. French language for RSA	5.1
2. Moroccan personnel short-term in United States	98.0
3. Moroccan personnel long-term in United States	160.5
4. Air traffic control in Morocco (NAWC contract)	89.7
Subtotal	353.3
B. Capital equipment	
1. Handar weather station	18.7
2. Snowcourse equipment	3.5
3. Cloud physics data acquisition system (partial CIC contract)	201.5
4. Communication systems (radio + GNS)	279.2
5. Satellite recorder	45.9
6. Rawinsonde system	61.1
7. Basic radar from EEC	222.1
Radar system integration, onsite support, radomes (partial CIC)	422.4
8. Training on integrated radar system (partial CIC)	185.1
Training on rawinsonde system (NAWC contract)	73.3
Training on cloud physics DAS (partial CIC)	51.1
Training on ground-based AgI generators (WWCI)	5.8
Subtotal	1,569.7
C. Recurring costs for parts/supplies	
1. Communication systems	3.7
2. Satellite recorder	32.8
3. Rawinsonde operations	362.8
4. Radar system	34.3
5. Handar weather station	1.4
6. Cloud physics DAS	9.9
Subtotal	444.9
D. Scientific support/studies/training	
1. Landsat design study (Reclamation-Remote Sensing)	15.4
Abidi thesis support (digital data)	10.0
2. Statistical design (Dr. Mielke/CSU)	38.0
3. UND cloud physics aircraft (contract)	780.6
4. Operations/scientific evaluation (moved to Reclamation Direct)	0.0
5. Analysis computers (IBM PC/AT systems)	91.6
Computer software (IBM PC/AT systems)	3.4
Satellite data analysis upgrade (Abidi's system)	24.0
Additions radar/rawinsonde data microprocessor (CIC)	11.2
6. Training on statistical design (Dr. Mielke/CSU)	12.0
Training on scientific aspects of weather modification (Dr. Vali/THETA)	18.6
Subtotal	1,004.8

Table 4.1.b. - Budget detail for Reclamation subcontracts - continued.

Budget item	Cost ($ x 10^3)
E. External evaluation	
1. Changnon et al. (3 trips)	90.9
F. Miscellaneous subcontracts	
1. Miscellaneous services (mostly translation)	10.5
2. ADP computer/programming support	56.6
3. Miscellaneous equipment	134.7
4. Reserve (added FY88 and FY89 items)	159.8
Subtotal	361.6
Total Reclamation subcontracts	3,825.2

4.2 Program Management

As noted in section 1.5, responsibility for program management was shared between the USG and the GOM. The USAID Mission was responsible for the overall management of the American component through the technical expertise provided by Reclamation. Reclamation's PASA with USAID gave Reclamation the authority to manage the $5.7 million budget to meet project objectives in cooperation with the GOM.

One of the major contributions of the USG to Programme Al Ghait was management expertise. Programme Al Ghait was a very complicated program that required interactions among many agencies, both in the USG and GOM, and private firms.

The establishment of the Project Steering Committee (PSC) to manage the program on a weekly-to-monthly basis has already been noted. The suggestion to establish the committee came from USAID and was readily accepted by all other agencies involved. It is doubtful that such a complex program could have been managed successfully without the PSC. The service of USG personnel on the PSC has been noted in section 1.5. As a committee member, acting in concert with the project director, the Resident Scientific Advisor (RSA) set the agenda for the PSC meetings. He also documented the decisions reached at the PSC meetings.

Issues beyond the immediate conduct of the program were managed through the National Steering Committee, which interfaced with other ministries and agencies within Morocco. The establishment of the National Steering Committee was another recommendation made early in the history of Programme Al Ghait by the American participants.

The RSA was active in all phases of program management, both fiscal and scientific. He monitored the work of contractors in the field and worked with the Moroccan meteorological and technical personnel on a daily basis, providing advice and training in the execution of all program components. In addition, he documented the progress of the program in Monthly Project Status Reports (refer to the appendix) and in Annual Summaries of Field Operations, Equipment Status, and Technology Transfer (Matthews, 1986, 1987, 1988).

Other Reclamation personnel, notably Dr. Silverman and other members of Division of Atmospheric Resources Research (DARR), were involved in program management. When Dr. Silverman was in Morocco, he served as an *ex officio* member of the PSC. Mr. Patrick Hurley of DARR played an important role in the administration of Programme Al Ghait during its first 2 years. DARR staff members used computer programs to prepare budgets, track expenditures, maintain inventories, and record progress toward technical objectives.

USAID personnel, with their experience in organizing large programs, were invaluable to Programme Al Ghait. The USAID environmental coordinator for Asia and the Near East also served as an *ex officio* member of the PSC during his visits on the annual monitoring reviews. Dr. Stephen Lintner fulfilled this role from 1984 to 1987 inclusive, and Mr. Glen Whaley did so in 1988.

4.3 Personnel and Services Provided Directly by Reclamation

4.3.1 Technical personnel. - The two USG personnel who were stationed in Morocco from the early stages of the project have been mentioned in section 1.5, namely, the USAID Mission project officer and Reclamation's RSA. Other personnel provided by Reclamation, principally from its Denver Office (and its contractors), included scientists, engineers, economists, technicians, and administrative staff. The primary services that they provided were planning, including preparation of a scientific operational and evaluation plan, procurement and installation of equipment, transfer of skills required to operate and maintain the equipment, hydrologic and economic studies, and training on data reduction and analysis as part of the operations and scientific evaluations for the project.

Reclamation's technical team was led by Dr. Bernard Silverman in the Denver Office. It was comprised of 10 meteorologists and physical scientists, 2 hydrologists, 3 remote sensing experts, 4 economists, 2 electrical engineers, and 2 computer experts. Table 4.2 lists the members of Reclamation's technical team and the tasks assigned to each.

Table 4.2 - Reclamation's technical team for Programme Al Ghait.

Person	Tasks
Dr. Bernard Silverman	Project management and coordination
Dr. David Matthews	Resident scientific advisor
Dr. Arnett Dennis	Scientific collaboration team leader
Mr. Charles Borda	Economic modeling of power generation - benefit analysis
Mr. Glen Cascino	Design, procurement, and installation of equipment; maintenance and spare parts management; electronic technician training
Mr. Wayne Cheney	Hydrologic modeling, evaluation of potential benefits
Dr. Terry Deshler	Scientific collaboration on airflow targeting modeling
Mr. David Eckhardt	Remote sensing
Mr. Phil Goorian	Economic evaluation studies and assessment of benefit/cost ratio
Mr. William Harrison	Design of communication system, siting of radar
Mr. Curt Hartzell	Logistics, operational plans, layout of generator network, scientific collaboration on operational evaluation
Mr. Pat Hurley	Project management and procurement
Dr. Edmond Holroyd	Remote sensing of snow cover
Dr. David Johnson	Scientific collaboration on analysis of radar data, operation of aircraft instrumentation, computer systems procurement, software development

Table 4.2. - Reclamation's technical team for Programme Al Ghait - continued.

Person	Tasks
Dr. Joseph Kitchen	Hydrologic modeling and water management planning
Mr. Jack McPartland	Aircraft instrumentation system
Mr. Jonnie Medina	Scientific collaboration on statistical design, evaluation, and data management, modeling of orographic precipitation
Mr. Ron Miller	Software development, hardware design
Mr. Rufus Pepper	Economic programming and analysis
Mr. Fran Politte	Forecasting and suspension criteria
Dr. Roy Rasmussen	Scientific collaboration, analysis of cloud physics data, aircraft operations, numerical modeling
Mrs. Anne Reynolds	Data management, software design
Mr. Kent Shuyler	Economic evaluation, benefit/cost analysis
Dr. Arlin Super	Ground generator network design
Mr. Jim Verdin	Remote sensing of snow cover, runoff modeling

4.3.2 Procurement specialists and logistical support personnel. - Reclamation had the procurement responsibility for the project's equipment and technical services. This responsibility was executed by DARR personnel, who developed technical specifications for equipment and services required, and by a staff of five contract specialists led by Mrs. Shirley Allison. Mr. Patrick Hurley, Mr. Curt Hartzell, and Mr. G. J. (Joe) Montgomery of DARR were involved heavily in the procurements and in the shipment of equipment to Morocco.

In the first 6 months of the project, most of the procurement decisions were made by the DARR staff in consultation with the GOM. During this period, seven major contracts were initiated for the procurement of the radar, satellite receiver, communications equipment, and rawinsonde equipment, collection of cloud physics data, and training on the operation and maintenance of the equipment provided. During the same period, additional contracts were executed for training on air traffic control (which included the direction of seeding operations and radar operation and analysis), rawinsonde operation, and the operation and maintenance of the satellite ground station and the associated laserfax system.

During the remaining 4 years of the project, procurement of technical equipment and services continued. Over 30 major contracts were signed with private contractors and consultants in the private sector and universities. In addition, more than 50 minor purchase orders and procurements were completed.

Information on the services and equipment provided under those contracts is provided in section 4.4.

4.3.3 Foreign activities specialists. - Specialists in Reclamation's Foreign Activities Division headed by Mr. Sammie Guy in Washington, D.C., played an important role in the program. Mr. Richard Ives helped to coordinate Reclamation and USAID activities within Programme Al Ghait. Ms. Marcia Meyer and Ms. Barbara Fullwood were active in the training area, particularly in coordinating the activities of Moroccan students in the United States for short-term and long-term training.

4.4 Personnel and Services Provided Under Contract

Approximately 70 percent of the American assistance was provided by the private sector. American contractors from the business and university communities provided equipment, installed it, and trained GOM personnel on its operation and maintenance. Other services obtained from contractors included development of a statistical design for program evaluation, training on oordination of aircraft from the ground, and training on scientific analysis and evaluation of cloud physics aspects of weather modification.

The principal American contractors who provided technical expertise, equipment, and training are listed in table 4.3. Details on the equipment provided are given in section 4.6.

Table 4.3. - Principal American contractors who provided technical expertise, equipment, and training.

Contractor	Type of services or equipment provided
University of North Dakota	Cloud physics data collection
Colorado International Corporation and DETREC, Inc.	Radar equipment installation, microcomputer system design and installation, training on system operation and maintenance Cloud physics data system design and installation, operation and maintenance training Radome installation and parts management software Rawinsonde software development and training
North American Weather Consultants	Training on air traffic control, on direction of weather modification operations, and on installation, operation, and maintenance of rawinsondes
Enterprise Electronics	Radar equipment and parts, radar maintenance training
Alden Electronics	Provision and installation of satellite ground station and associated training Radio facsimile receiver Laserfax receiver, parts, and associated maintenance training
Qualimetrics Corporation	Rawinsonde system, maintenance training
Global Navigation Systems	Three complete VLF/OMEGA aircraft navigation systems
General Electric	Radio communication equipment
King Radio	Radio equipment for aircraft to ground communications
International Business Machines	Seven IBM personal computers and related training
Hewlett Packard	Vectra 386 personal computer
PCI, Inc.	Image processing system for digital satellite data
Western Weather Consultants, Inc.	Ground-based AgI nuclei generator operation and maintenance
Handar Corporation	Data collection platforms (DCP's) and automatic weather stations, training on operation and maintenance
Apple Computer	Three MacIntosh microcomputers

4.5 Technical Assistance and Technology Transfer

As table 4.3 shows, training on the operation and maintenance of equipment provided was a feature of nearly all procurements from the private sector. Additional training was provided in all aspects of weather modification operations, management, and evaluation in order to transfer relevant technology to the GOM. A complete discussion of technology transfer is given in chapter 6. The topic is summarized briefly here because it is considered to have been one of the most important American contributions to Programme Al Ghait.

Development of a cadre of specially trained personnel was accomplished through short- and long-term training using both formal and informal techniques. The short-term technical training focused on equipment operation and maintenance, familiarization with particular aspects of the program, and reinforcement of primary learning activities. Scientific collaboration between Moroccan and American meteorologists was the most successful aspect of the short-term training and transfer of technology. The long-term training emphasized the development and application of scientific and technical skills to the design, planning, and evaluation of weather modification projects and to related issues.

Short-term training was conducted by Reclamation and private contractors in the United States and in Morocco for periods of 2 to 26 weeks. Long-term training was provided for four Moroccan meteorologists at the South Dakota School of Mines and Technology; all four received M.S. degrees in Meteorology. Table 4.4 shows the specific types of training provided.

Table 4.4. - Summary of technology transfer activities.

Type of technology transfer	Months	Trainees	Trainee months
In the United States			
Long-term M.S. degrees	21.2	4	85
Meteorologist training	9	8	72
Scientific collaboration	18	9	162
Hydro-economic analysis	0.5	1	0.5
Electronic technician	2.5	10	25
Flight scientists and crew	1	1	1
Subtotal			345.5
In Morocco			
Meteorological operations	42.5	10-20	637
Scientific collaboration	59.6	4-10	357
Physical economic studies	2.6	2-10	8
Applications studies	0.4	10-30	5.7
Air traffic control - operations	2	6	12
Electronics operation/maintenance	28.7	2-6	114.8
Subtotal			1,134.5
Total training			1,480

4.6 Equipment and Facilities

4.6.1 General summary - Provision of modern equipment to assist in the conduct of operations and the scientific analysis of clouds and precipitation was a major part of the USG's contribution to Programme Al Ghait.

The equipment provided was capable of reliable data collection in the rugged operational environment of Morocco. Due to the operational nature of the project, equipment was selected that was readily available with reliable electronics and readily available spare parts. This equipment is listed in table 4.5. Note that most of the items have both project and national applications. For example, the satellite receiving station provides information on the general weather conditions affecting Morocco. Such information is of interest to the national forecasters and aviation users.

Table 4.5. - Summary of major project-funded equipment.

Equipment	Project functions	National applications
Khouribga Operations Center		
Digital radar and IFF system	Operations direction including suspension criteria and nowcasting	Analysis and forecasting of precipitation and severe storms
Laserfax satellite copier	Operations direction including nowcasting Mesoscale analysis	Nowcasting, mesoscale analysis
Weather fax receiver	Analysis and forecasting	
Weather teletype and Canonfax	Communications of data Nowcasting	Communications - Data transmission
Microcomputer systems (4)	Data collection and analysis. Scientific studies. Operations direction. Radar data collection and data management.	Climatological analysis. Scientific studies - Precipitation forecasting.
Radio transmitter/receiver	Communication to mountain sites, ATC, Casablanca Operations Support Center	Storm echo structure, analysis and nowcast communications to NMFC
Radio transmitter/receiver VHF-AM	Communication to seeding and cloud physics aircraft	Special aircraft warnings of severe storm echoes. weather advisory
Power stabilization and generation systems	Equipment operation	Maintain equipment for national applications
Calibration and maintenance equipment	Quality control and maintenance	Maintain equipment for national applications
Casablanca Scientific Research and Evaluation Center		
Satellite ground receiving station and laserfax	Classification of clouds Nowcasting and forecasting and precipitation events. Mesoscale analysis.	Mesoscale analysis severe weather warnings climatological studies

Table 4.5. - Summary of major project-funded equipment - continued.

Equipment	Project functions	National applications
Remote radar display	Monitoring of precipitation in target area, nowcasting and mesoscale analysis. Classification of seeding events.	Nowcasting and mesoscale analysis
Radio transceiver VHF-FM	Communication with operations center at Khouribga	
IBM PC/AT microcomputers (7)	Data quality control, data management and analysis, scientific evaluation of cloud physics, radar, streamflow, and precipitation data. Data transmission and communications.	Scientific software development and applications studies
Beni Mellal		
Rawinsonde system and microcomputer	Thermodynamic and wind sounding Analysis and forecasting Data collection for operations decisions, analysis and forecasting Airflow and precipitation model initialization	Analysis and forecasting in Morocco and worldwide. Climatological studies.
Azilal and Mountain Region		
Rawinsonde system	Thermodynamic and wind sounding data for operations decisions Scientific evaluation, model initialization	Analysis and forecasting of mountain weather
Pilot balloons	Airflow studies for seeding generators	Understanding of mountain meteorology
Mountain weather station	Surface observations for operations decisions Scientific evaluation	Mountain climatology Nowcasting in mountains
Snow courses (7)[1] River streamflow	Document snowpack water content snowpack water supply forecasts	Assist in streamflow forecasts and evaluation of runoff
Recording precipitation gauges (4)[1]	Calibrate satellite estimate of precipitation volume	Water resources management
	Observe time, duration, and quantity of precipitation. Physical evaluation studies.	Document mountain precipitation for climatology

Table 4.5. - Summary of major project-funded equipment - continued.

Equipment	Project functions	National applications
Kenitra		
Cloud physics data collection system on King Air 100 aircraft	Collect cloud physics data showing regions of potential for seeding in target area. Improve seeding operational efficiency. Develop microphysical hypotheses for precipitation development.	Determine temporal and spatial distribution of regions of potential for seeding. Develop better understanding of microphysical processes of precipitation development.
Ground Test Bench and electronics laboratory	Maintain and test cloud physics data system power, train electronics personnel on system operation and maintenance.	Maintain cloud physics system
USBR/DARR Denver		
IBM PC/AT microcomputers (2)	Scientific collaboration and data analysis	
HP VECTRA 386[1] scientific analyses	Data management and to IBM data transfer from training. Statistical evaluation and Rhea model analyses (shipped to Morocco in 1989)	Transfer of 9-track tapes from Hydraulique, ONE, ESA, Landsat, etc.
IBM PC/AT Image Processing[1] System	Image processing of Landsat and NOAA digital satellite data	Water resources management estimate of snowpack runoff from satellite imagery

[1] 1987-89 additions to the equipment

4.6.2 Radar system and remote transmission communications equipment. - Morocco's first weather radar - a digital 5-centimeter radar - was provided to locate regions of precipitation and guide aircraft seeding operations. This radar provided information on the intensity of precipitation, its location, and duration. It was used to locate storm systems and regions of severe weather, thereby providing information used in the suspension criteria when severe weather threatened the target area. The radar was centrally located so that most of Morocco could be within range and still provide reasonably good information over the target area which was located 90 to 150 kilometers to the southeast.

The radar set was installed at DMN's weather station near Khouribga, at a perpendicular distance of 85 to 150 kilometers from the target area at an elevation of 780 meters m.s.l. (fig. 2.2). At the 150-kilometer range, the width of the radar beam was about 4200 meters. When the antenna was operated at 1.5° elevation tilt, the bottom of the beam over the target was around 3800 meters m.s.l., while the top was 8000 meters m.s.l. (fig. 2.3). The horizontal beam width was similar, so rather large convective storms or deep orographic clouds were required to fill the radar beam. Obviously, the situation improved closer to the radar.

Special communications systems were required to transmit data from the central site at Khouribga to Casablanca. The GOM provided a dedicated telephone line which met the requirements to transmit the video signal from the radar to the operational coordination center in Casablanca. The digital video integrated processor (DVIP) in Casablanca converted the signal back to a radar echo plan position indicator (PPI) on a special color monitor shown in figure 2.9. The radar monitor stored the echo information so that special routines could be used to zoom in on various sectors of the scope and expand the image. Six different colors were used to display the relative intensity of precipitation. Range markers and a basic map background provided information on the location of echoes and their relative size. Aircraft transponder information was also displayed from the IFF antenna data. This showed the position of aircraft relative to the precipitation areas.

The radar was purchased from Enterprise Electronics Corporation (EEC). It was then configured with communications and computer equipment to record and display digital information, and was installed in a trailer and interfaced with an IFF system by the Colorado International Corporation (CIC) and DETREC, Inc.

Table 4.6. - Radar characteristics.

Frequency	5.575 GHz
Wavelength	5.4 cm
Peak power	250 kW
Pulse duration	2 μs
Pulse repetition frequency	250 s^{-1}
Minimum detectable signal	-103 dBZ
Beam width	1.6° (all planes)

4.6.3 Satellite ground receiving station and color enhancement microcomputer system. - NOAA's foreign activities division provided a basic secondary data users' station to receive satellite imagery data from METEOSAT and the NOAA polar orbiting satellite. This station was installed by NOAA and Alden Electronics engineers who provided training on its operation and maintenance in Casablanca at the project's operations coordination center. It provided real-time half-hourly visible or infrared satellite images of weather patterns and clouds over the region of Northwest Africa and Europe. Sectors could be selected for any region of the hemisphere observed by the METEOSAT geosynchronous satellite or that of NOAA or other meteorological satellites. The Color-1000 enhancement system was used to determine the relative temperatures of cloud tops and intensity of cloud and precipitation systems. It was used in the operational decisionmaking process and for national forecasting and mesoscale analyses. Figure 4.1 shows the color monitor viewing the satellite meteorology enhanced imagery and the corresponding radar echo patterns during the daily project weather briefing by Mr. Chkouri.

4.6.4 Rawinsonde systems. - Two rawinsonde systems were provided to measure the thermodynamic a[illegible]nd structure in the vicinity of the target area. These systems supplemented the existing Moroccan observations at Casablanca and Agadir, where observations were made once each day at 1200 and 0000 CUT, respectively. The project sounding systems were installed initially both in Beni Mellal, where one system provided backup to ensure availability of upper air data. In February 1988 one was moved to Tissa to provide special mountain data. The sounding data were observed regularly from Beni Mellal at 0000 and 1200 CUT, and special observations were made at 0600 during operational periods. The sounding applications are discussed in section 2.4.5 and in chapter 8. Data were used in the operational decision process and in numerical models of airflow and precipitation to determine the appropriate seeding generators and flight tracks for operations. Also, these data were used later in postanalyses of storms to improve the evaluation of seeding effects and our physical understanding of precipitation.

4.6.5 Cloud physics aircraft system and VLF-Omega navigation system. - A cloud physics data acquisition system was provided to measure the temperature, humidity, pressure, wind speed and direction, and liquid water content within clouds, and to estimate the ice particle concentrations. These data are needed to assess the potential for seeding and locate regions of potential for seeding. The cloud physics system and results are discussed in section 8.1. CIC and DETREC, Inc., designed the cloud physics data acquisition system and installed it on a GOM King Air 100 aircraft. The system uses an IBM PC/AT microcomputer to control the sensors and collect digital data for real-time data processing and analysis. Operational decisions could be made by the flight scientist and the operations director as the aircraft made observations en route to and within the target area.

A versatile and highly reliable aircraft navigation system was needed to conduct IFR flight operations over the High Atlas Mountains. Due to the very rugged terrain and lack of Voice Omni Range/Distance Measuring Equipment (VOR/DME) ground navigation systems, special navigation aids were purchased to ensure safe, well-coordinated flights over the target area. Three very low frequency (VLF)-OMEGA navigation systems were purchased from Global Navigation Systems, Inc., for the two King Air seeding aircraft and the University of North Dakota (UND) Citation cloud physics research aircraft while it was in Morocco in 1985. This third system was later used as a backup system by the GOM. The navigation systems were also required to provide exact latitude and longitude data for the King Air cloud physics data acquisition system and computation of winds.

4.6.6 Microcomputer systems for data archival, quality control, and analysis. - In order to process the large quantity of radar, rawinsonde, and aircraft data, microcomputers were provided for the SAET. Seven IBM PC/AT systems, one HP-VECTRA 386 system with a 100-megabyte hard disk and a 9-track tape drive were provided for data analysis and data management. One specialized image processing system was provided by PCI, Inc., for the landsat and NOAA satellite image processing used in the snow cover runoff modeling work of Abidi (1989). The initial radar and rawinsonde data processing was performed on Tektronix systems using a Z-80-based system. Three Tektronix microcomputers were provided with the radar, and one additional system was used at the Beni Mellal rawinsonde site to process sounding data. All data were initially collected on 8-inch floppy diskettes and later converted to 5.5-inch IBM-compatible diskettes using two Flagstaff disk drive units. The Handar automatic weather station also used an IBM PC to collect and store data from its data collection platform (DCP). Project management was conducted using three Apple Macintosh microcomputers. These systems were used for word processing, project management, and preparation of presentations and professional conference visual aids.

4.6.7 Automatic weather station. - An automatic weather station was originally provided to support aircraft operations from the operations center in Khouribga. When the concept of controlling project aircraft operations from the Khouribga center was abandoned, the station was placed in Beni Mellal, then later in Tissa to provide real-time information from the mountains. The

Handar Corporation provided the station which measured temperature, humidity, pressure, wind direction and speed, and precipitation.

4.6.8 Radio communications system. - A network of radio communications was needed to link the field sites with the operations center in Khouribga and the coordination center in Casablanca. A set of VHF-FM radios was provided to meet the voice communications needs of a large field operation that extended from Casablanca 250 kilometers southeastward to Tissa and Azilal. The radio communications consisted of ground-to-ground VHF-FM radios with frequencies assigned at 141.5 and 143.5 megahertz which passed through a repeater at Tazerkount with a frequency of 143.6 megahertz. Transmission of data used a different frequency at 155 megahertz. The communications network is described in detail in the Operations Plan. Rapid, effective communications were critical to the success of the project during operational periods when decisions and observations were transmitted throughout the project to remote areas. Without the radio communications network, delays and missed opportunities would have seriously handicapped the project. Fortunately, the GOM electronics technicians were able to maintain and operate the radio network effectively so that operations proceeded quite well. Air-to-ground radio communications on VHF-AM frequencies of 120.7 and 122.9 megahertz were installed at Khouribga to conduct aircraft operations.

During the final stage of project implementation, a radio-telex modem system was installed to provide reliable direct computer-to-computer links between Tissa, Beni Mellal, Khouribga, and Casablanca. This system will permit the real-time transmission of data, model results, and operational decisions among all field sites. The automated data links will permit better quality control of data and dissemination of information.

4.6.9 Power stabilization systems and converters. - One of the early concerns of the project was the protection of delicate electronic equipment in a relatively unstable electrical power environment. Special power conditioners and power inverters were used to stabilize the power and provide power that matched the frequency and voltage requirements of various pieces of equipment. In remote areas power was a particular problem, and backup electric generators were provided to ensure reliable power during operational periods. Two diesel generators were installed at Khouribga, and one gasoline generator was used at the TACAN site and the Beni Mellal rawinsonde site.

4.6.10 Facilities provided for training. - Reclamation and its contractors provided training facilities for the various short-term training programs conducted in the United States. These facilities ranged from laboratories and shops for electronic maintenance training to computer systems for the analysis of digital satellite imagery and numerical model simulations.

Reclamation also provided operations director training at the SCPP field office in Auburn, California. At that site, a complete meteorological operations center with remote radar display, satellite receiver, microcomputer, weather fax, and radio-telephone communications was used for on-the-job training of GOM scientists. Field trips to the SCPP 5-centimeter radar and the 0.89-centimeter radar from the University of Nevada and Reclamation's microwave radiometer provided demonstrations of how these systems were used to conduct field research in cloud seeding in the United States. Facilities in the High Sierra at remote project weather stations also were used to show how weather observations from the target area were gathered and how Reclamation maintains such equipment under difficult winter conditions.

At Montrose, Colorado, the GOM scientists visited another field site used to develop experimental seeding techniques for winter orographic clouds. This site provided an opportunity for the GOM scientists to view new, remotely controlled, ground-based generators, instrumentation systems, and communications systems used in the central Rocky Mountains.

In Denver, Reclamation's Remote Sensing Branch provided laboratory facilities to study Landsat and NOAA Advanced Very High Resolution Radiometer (AVHRR) satellite imagery for studies of snow cover over the High Atlas. Facilities provided by DARR included the Perkin Elmer computer and microcomputers for the analysis of cloud physics aircraft data collected by the UND and the development of software for use in Morocco on the project's IBM PC/AT microcomputers. In the data management training, data management systems on the larger minicomputer and on the DARR IBM PC/AT were used to show how DARR scientists manage a large data base.

Each contractor provided electronic laboratory facilities for training electronics technicians in the operation and maintenance of their equipment. These laboratory facilities ranged from basic electronics laboratories to instrumentation test facilities and radar electronics fabrication shops.

Figure 4.1. - Daily briefing using color-enhanced satellite imagery and video loop of satellite imagery. Radio communications system and video camera and monitor are shown in the Casablanca coordination center.

5. INSTITUTIONAL DEVELOPMENT AND INFRASTRUCTURE

5.1 Management Structure and Organization

The original project agreement between the GOM and the USA established the foundation for the project infrastructure and organization. It described the specific roles of different agencies and ministries and governing bodies such as the PSC and the NSC. These management teams provided the original project management as described in chapters 1 and 4. Two ministries were primarily responsible for the project within Morocco – the Ministry of Transport, DMN, and the General Secretary of Defense, FRA. The infrastructure and institutions developed within these organizations demonstrated the commitment of the GOM to the project and its continuation. The project agreement outlined the budget planned for the American and Moroccan contribution of funds, resources, and personnel.

5.1.1 Direction de la Meteorologie Nationale (DMN). - The DMN was the lead agency responsible for the overall management of the project and its implementation of scientific cloud seeding operations and their evaluation. Mr. Amed Bensari, Director of the DMN, was designated the program director. His staff managed the day-to-day operations and decisionmaking and scientific data collection and analysis. An operating unit within the Development and Research Division in Casablanca was established with an organization chart and detailed personnel management plan with position descriptions and work plans for a team of over 100 individuals stationed in Casablanca, Khouribga, Beni Mellal, Azilal, Tissa, and Kenitra. This team was described in chapter 3.

The team was stable, with few personnel changes throughout the project. Funding for the personnel was provided through the Ministry of Transport's budget for DMN. The early years were funded at a level insufficient for independent operations because the American support provided resources for all new U.S.-supplied project equipment and its maintenance and operation. The DMN provided resources and personnel to conduct the operations from 1984-89 at a level sufficient for successful operations. The Ministry of Finance has recognized Programme Al Ghait as a line item in its budget for DMN and is providing funds for its operation. (Chapter 3 describes the budget contributions, and the operating expenses are provided in section 10.5.)

5.1.2 Forces Royales Air (FRA). - The Moroccan Royal Air Force (FRA) played a key role in coordinating the project under the high-level coordination of General Kabbaj and his designated project coordinator, Colonel Bamaarouf. The FRA provided management coordination, funds and resources, and logistics support which ranged from coordination of the PSC to the conduct of aircraft seeding operations and the transportation of equipment from the United States to Morocco and its importation and delivery to the project headquarters at Casablanca. The FRA was primarily responsible for all seeding materials, seeding generators, and aircraft operations. It played a major role in the successful implementation of the Operations Plan and conduct of seeding operations. Lt. Maanan, the FRA Operations Coordinator, managed the day-to-day operations in cooperation with the DMN operations coordinators and operations directors in Casablanca and Khouribga. He was instrumental in coordinating the aircraft flight operations and the equipment importation through the FRA Aircraft Operations Group in Kenitra and the FRA AMG unit in Casablanca. Over 50 Air Force personnel were dedicated to project operations during the operational periods. The Programme Al Ghait operating unit within the FRA further demonstrated its commitment to a continued program and institutional development.

5.1.3 National Steering Committee. - The establishment of the high-level NSC led to the national recognition of Programme Al Ghait within all major participating ministries and agencies within Morocco. The NSC members reported to their respective ministries and provided special support of the project regarding interministerial issues. This elevated the visibility of the project to a high level, where it was relatively easy to overcome common bureaucratic obstacles to rapid decisionmaking and information transfer. The project developed a means of day-to-day communication at the working levels within all supporting agencies. This collegial support was especially helpful when special observations and data were needed from mountain sites and from agricultural groups. The Gendarmerie Royales provided local support from the Ministry of Interior in various provinces. Their assistance in data collection and transmission via Telex to Casablanca was very helpful and showed a regional commitment to the project.

5.2 Interactions Between Programme Al Ghait and Other Ministries and Agencies

Communications between the National Electrical Organization (ONE) and DMN were facilitated by close working relationships between DMN personnel and Mr. Smouni, ONE, which developed into strong support of daily project operations through streamflow and reservoir-level data transfer. These data were used in the routine suspension criteria analysis and the evaluation of streamflow within the target area. Mr. Smouni's team at ONE was very helpful in the development of the hydroeconomic studies. The team provided detailed information on the reservoir characteristics and operation criteria for the Bin El Ouidane Dam and the Oum Er Rbia River basin. Their information was combined with that of Hydraulique to establish the configuration of the river model which Hydraulique developed and contributed to the hydroeconomic study. The model was used to evaluate the impact of additional water due to seeding on the hydroelectric power, agricultural irrigation water deliveries, and domestic water deliveries from reservoirs within the basin. Chapter 10 describes this study in detail.

Hydraulique provided significant streamflow data for the project evaluation. Mr. Boutayeb was the primary contact person within Hydraulique who provided data and the river model (Motor Columbus et al., 1987). Mr. Obaklace, the modeling expert at Hydraulique, assisted Reclamation's hydrologic modeling expert, Mr. Cheney, during his visits to Morocco to develop the river model's configuration and program analysis software to display the model's information.

Agriculture groups in the Tadla and Doukkala ORMVA's were very helpful in providing agricultural economic data used in the economic studies. The contacts in these user groups led to continued dialogue among these distant groups and the project director and the scientific team. Their future interest in the project should lead to greater regional support and application of this new water resources development option. Written agreements to provide data and to exchange information were formally established between the DMN-Ministry of Transport and the different supporting agricultural ORMVA's.

Other evidence of institutional development is provided by the direct provision of facilities by the Ministry of Agriculture's Eaux et Forets (Water and Forests) agency. This national forestry group provided mountain sites for ground seeding generators and housing for project personnel who made observations and operated the seeding generators. Similar support from the Ministry of Interior and the Army was provided at Khouribga and in the Azilal Province. This permanent structural support greatly facilitated the project's operations and improved its effectiveness.

5.3 Personnel Management and Organizational Structure

Establishment of an informal project organization chart and management plan was of critical importance at the outset of the project. This plan evolved as the team grew from a group of 20 to 30 people to over 100. The organization chart was complete with position descriptions and individual work plans. These are described in detail in the Operations Plan (Hartzell et al., 1986).

Although the project was established as an operational group within the Ministry of Transport's DMN, it lacked the formal recognition as a separate division with its own autonomy and formal organizational structure with explicit lines of authority and responsibility. The organization chart and position descriptions outlined in the Operations Plan provided the working mechanism for the project management; however, this was never formally recognized and established with the appropriate salaries and positions for all personnel. The formal establishment of this structure remains as an important step in the formal institutionalization of the project.

5.3.1 Personnel training and development of human resources. - Within Programme Al Ghait a systematic training plan and mechanism to continually improve the level of personnel understanding and their ability to conduct scientific operations were maintained by the DMN and the FRA. Training on the various electronic systems and equipment was conducted by the maintenance coordinator and his team of expert technicians who were trained by American experts through the project's short term training program. Similar training by meteorologists who participated in the short-term training program extended the knowledge base to other personnel within DMN in Casablanca, Khouribga, and Kenitra and at remote field sites. This scientific technology transfer from trained Moroccan scientists to other supporting meteorological technicians and meteorologists improved their capabilities in forecasting, nowcasting, cloud physics, radar meteorology, and satellite meteorology, in addition to specific weather modification applications. This transfer of knowledge is leading to a stronger, more capable National Meteorological Organization with personnel who have training in the latest modern techniques for meteorological analysis and forecasting.

5.4 Improved National Meteorological Analysis and Forecasting Capabilities

The installation of Morocco's first weather radar system led to a new national capability for analysis and forecasting which the DMN is using throughout central Morocco. This radar system has improved forecasting at the National Meteorological Forecasting Center (NMFC) in Casablanca and has served as a critical tool for operational decisionmaking in the project. Similar improvements within DMN occurred with the installation of the satellite ground station and video recording system at the NMFC. This system was available to all NMFC forecasters, and it contributed to the development of better, more comprehensive analyses and forecasts throughout the country. Special project rawinsonde data from Beni Mellal and occasionally from Tissa provided improved basic thermodynamic and dynamic information for use throughout Morocco and the world. These rawinsonde data were transmitted to the WMO's data base in Europe and used by meteorological services throughout Europe and the world. Regular soundings every 12 hours at standard observation times of 0000 and 1200 CUT were provided for the first time from the site at Beni Mellal. These data supplemented the standard Moroccan observations made every 24 hours at Casablanca and Agadir. The Beni Mellal data were used in the hemispheric and regional numerical forecasting models in Europe.

The increased knowledge was transferred through the daily project operations briefings at the NMFC in Casablanca which used the data from the new radar, satellite, and rawinsonde equipment and numerical modeling analyses provided by the project's scientific team. This has led to a general improvement of the meteorological capabilities of Morocco. This large briefing involved the NMFC's forecast team in addition to the project personnel. The project briefings focused on specific, more detailed forecasts and thermodynamic analyses and cloud development analyses than the NMFC's personnel were normally exposed to. Thus the briefings led to a better understanding of the nowcasting of clouds and precipitation and its relationship to the microphysics of clouds and precipitation. Such information led to improved general forecasts for the country.

Special numerical modeling techniques developed by Mr. El Majdoub in his M.S. thesis (El Majdoub, 1989) can be applied to the prediction of precipitation in the mountainous regions of Morocco, thus leading to greatly improved local forecasts of precipitation in remote areas of Morocco. Results from Mr. Abidi's thesis research that led to a snow cover runoff model for the High Atlas can be applied to streamflow runoff predictions for major high mountain rivers which, in turn, may lead to better management of the reservoirs in Morocco. These results are of interest to the water resources management agencies of Morocco, especially ONE and Hydraulique. Mr. Abidi's satellite image processing system may also be used to perform land use classifications and study the vegetation and vitality of crops from digital satellite imagery. These applications may serve national interests beyond the scope of Programme Al Ghait, yet they show how this project has contributed to the development of diverse modern technical capabilities within DMN.

5.5 Equipment and Facilities

Programme Al Ghait required significant contributions of technical equipment and facilities in order to operate the scientifically sound weather modification project. All critical project equipment has been installed and is fully operational with Moroccan staff who are fully capable of its maintenance and repair. This has been a significant contribution to the infrastructure required for the GOM to continue the project. Details of the facilities, equipment, communications links, and training are discussed in chapters 3, 4, and 6. Some specific examples of enduring facilities and equipment are discussed in this section.

The special facilities constructed in Casablanca include the automatic picture transmission (APT) room for the satellite and radar systems and offices for the operational and scientific teams. These facilities required special telecommunications lines and radio antenna and satellite receiving antenna installations and power conditioning for delicate electronic microcomputers and equipment. These facilities are complete and fully operational.

In Khouribga a special operations center building was completely remodeled with modern power and communications equipment and a communications and power link to the radar trailer. All construction, including a building to shelter the radar and a meteorological observation site, was completed and is used for the project and for DMN's national needs.

A rawinsonde shelter and equipment facility were constructed at Beni Mellal meteorological station for rawinsonde observations. The rawinsonde equipment was installed at this facility, which has provided very reliable data since 1984. Technical personnel at Beni Mellal were trained on the operation and maintenance of this equipment.

The Azilal mountain operations center is located in buildings provided by the Governor of Azilal. Special radio communications equipment has been installed, and the storage and maintenance facility for the ground seeding generators has been provided. Sites for the ground seeding generators and their operators have been provided or constructed for the generator network from Tizi-Rhim to Refuge Tamda. These sites include two locations provided by the Radio Television system of Morocco (RTM). The Tissa site has a building for a rawinsonde and automatic weather station. This is an excellent mountain observation facility at an elevation of 1666 meters.

At Kenitra the FRA provided special aircraft maintenance and seeding generator hangar facilities and an electronics laboratory to maintain the cloud physics data system. These facilities and personnel have led to successful and effective aircraft operations.

Other facilities have been provided for rain gauges and snow courses by local provincial officials and the Gendarmerie Royale. This infrastructure should continue to help provide useful information.

5.6 Training and Educational Infrastructure

A special library of books, software, video tapes, and other documents was provided to encourage research and reinforce existing levels of education. Text books on meteorology and various aspects of statistical evaluation, mathematics, computer science, and water resources management were provided for project personnel. A complete system of software for the IBM PC/AT and HP-Vectra microcomputer systems was provided for the SAET. This software and the data base management systems will help the project and DMN staff improve their capabilities in analyzing and managing meteorological data.

A video tape recording and camera system was provided for documenting the project's development and for recording technical seminars and training programs. Training seminars, such as the statistical evaluation and design 2-week seminar in 1987, provided by American experts were video taped, as were other key elements of the technology transfer process. The video system permits review of various topics by former trainees and new personnel, reinforcing the learning process.

5.7 Political and Economic Structure

Continued operation of the project requires a sound political and economic base within the GOM. This base was provided through the Ministry of Transport and the Secretary General of Defense. Support from members of the NSC and the Prime Minister has permitted operation of the project to date. However, upon removal of American assistance in 1989, the responsibility of establishing a sound financial basis will become a GOM task. The political and financial support is yet to be clearly defined and long-term commitments demonstrated at the level to operate a sound scientific project.

6. TECHNOLOGY TRANSFER

Technology transfer was the most important American contribution to the Moroccan Winter Snowpack Augmentation Project. This transfer of knowledge encompassed the full range of topics from the conduct of operation and maintenance of equipment to the development of sophisticated statistical and numerical analysis techniques for the scientific evaluation of the project. This chapter reviews the progress in achieving the transfer of technology. Technology transfer was accomplished through short- and long-term training programs developed to support the scientific design and implementation of the project, previously described in chapters 2 and 4.

6.1 Long-term Training

The long-term training program resulted in the award of four Master of Science degrees in Meteorology from the South Dakota School of Mines and Technology. Studies at the school were designed to improve the students' skills in cloud physics, numerical modeling, dynamics, thermodynamics, mesoscale and satellite meteorology, and radar meteorology. The students' theses were based mainly on data from Morocco and were designed to produce results directly applicable to Programme Al Ghait. The four candidates and their theses topics are listed in table 6.1.

All of the students returned to Morocco to resume their duties in the areas of their specialization or in project management. Mr. El Bachir Loukah became the project deputy director and assisted Mr. Benarafa, the original project director, in managing the project from 1987-89. Mr. Loukah is expected to become the project director in September 1989 under a new formally recognized organizational structure.

Mr. Ali El Majdoub returned to his duties in May 1989 as the Khouribga operations center station chief and scientific team leader for precipitation prediction modeling. He should continue to improve and develop applications for the Rhea model for the prediction of precipitation in the operational decision and postoperation analysis and evaluation tasks. His management skills have led to improved operations direction and data management of the radar system at Khouribga.

Mr. Azzouz Abidi returned to the project as the chief of the satellite ground station team in July 1989. He should continue his research using the snow cover runoff model in the analysis and prediction of streamflow within the target area. His model has applications of interest to the water user community within Morocco, especially the ONE, which manages the Bin El Ouidane reservoir.

Mr. Mohammed El Mokhtari continued to use his skills in training other Moroccan meteorologists in the field of Meteorology at a training center in Casablanca. He provided assistance to the project director and the director of DMN in various scientific studies related to the project and in areas where English skills were required.

Two other students, who were not directly supported by the project but whose training was related to the project through the USAID Mission's Sector Support Training Project, selected topics in which they used project data and are developing applications for the DMN. One of them, Mr. Madouh, returned to Morocco and is working as a branch chief of forecasting at the national forecast center. The other, Mr. El Hilali, is still in school at the South Dakota School of Mines and Technology.

Table 6.1. - Summary of long-term training.

Name	Start date	Completion date	Total months	Course/thesis topic
El Bachir LOUKAH	Aug. 1985	Dec. 1986	17	Master of Science in Meteorology *Thesis*: Preliminary Studies of Cloud Seedability over the Atlas Mountains
Mohammed EL MOKHTARI	Aug. 1985	Aug. 1987	24	Master of Science in Meteorology *Thesis*: Mesoscale Analyses in the High Plains of the U. S.
Azzouz ABIDI	June 1987	May 1989	23	Master of Science in Meteorology *Thesis*: A Snow-Cover Runoff Model of the Atlas Mountains
Ali EL MAJDOUB	Aug. 1987	Apr. 1989	21	Master of Science in Meteorology *Thesis*: Adaptation of the Rhea Winter Orographic Precipitation Model to Morocco
Larbi MADOUH*	Jan. 1987	Jan. 1989	21	Master of Science in Meteorology *Thesis*: Parameterized Objective Forecasting for Morocco
Taoufiq El HILALI*	Sep. 1988	in progress		Master of Science in Meteorology *Thesis*: Forecasting Techniques
Azzouz ABIDI**	Oct. 1985	Sep. 1986	12	European Space Agency long-term training *Research topic*: Applied Satellite Analysis and estimation of rainfall

*Funded under USAID Sector Support Training Project 0178 and facilitated by Programme Al Ghait support.
**Funded by the European Space Agency/UNDP and facilitated by Programme Al Ghait support.

6.2 Short-term Training

Short-term training provided through the project in Morocco and in the United States consisted of seminars, short courses, and on-the-job training (OJT) followed by reinforcement in reviews and continued application of basic skills. Scientific collaboration with members of the SAET led to joint scientific studies and development of various analysis software and analysis tools for the project.

6.2.1 Electronics technicians. - Table 6.2 summarizes the short-term training program for electronics technicians. These individuals served the project well by successfully maintaining sophisticated electronic equipment and making major repairs with little external support. Training on major items of equipment, including the digital radar system, satellite ground receiving station, cloud physics aircraft data system, rawinsonde system, and other communications and computer equipment, resulted in a Moroccan capability to maintain and repair all major components in the project. The 1988-89 field program demonstrated this capability when several systems failed and the electronics technicians successfully identified the problems and repaired the equipment.

The first training in the United States was conducted by Colorado International Corporation (CIC) for the radar electronics technicians. Mr. Megdani and Mr. Moumane spent 2 months working with the CIC engineers as the Enterprise Electronics Corporation radar system was integrated with an IFF system and microprocessors and installed in a trailer. This period of OJT and laboratory review of electronics led to a basic understanding of the radar system and maintenance procedures required for the Moroccan system. The two technicians returned to Morocco and continued their training on the system with CIC electronics technicians Mr. John Welker and Mr. Rudi Flohr. Mr. Welker provided training on the radar system and communications equipment in Morocco during the field operations from 1984-86. His training was provided at Khouribga, where he concentrated on a comprehensive review of the radar equipment and data processing systems. He provided informal hands-on training for all major components of the radar and the IFF systems. Mr. Welker also showed the Khouribga team how to order spare parts and supplies, inventory parts and supplies, and perform preventive maintenance on all equipment. He also assisted in training personnel in Beni Mellal when problems occurred with the rawinsonde systems and microcomputers, and in Casablanca when various communications and radar repeater equipment failed. He trained more than 10 of the DMN electronics technicians during his three seasons in Morocco.

Maintenance training and troubleshooting for the cloud physics aircraft system were provided in November and December 1986 during fabrication of the system in the United States, and from January to March 1987 while the system was installed on an FRA King Air 100 aircraft in Morocco. The training was provided by CIC personnel Dr. Larry Davis, Mr. Dennis Treddenick, and Mr. Don Stone. The students learned how to troubleshoot a modern digital electronic data system from the sensors to the computer data acquisition and display. Technicians Mr. Amine and Mr. Amali learned how to maintain and operate Morocco's first cloud physics data system. Their capabilities were tested several times during the first field season, when they successfully identified problems and repaired the system. Dr. David Johnson, one of Reclamation's cloud physics experts, provided training on the operation of this system to the Moroccan team in February and March 1987 upon completion of the system installation. Close coordination with the FRA aircraft technicians and the flight scientist, Mr. Baddour, led to a very successful 1987-88 field season.

Other training on the electronic equipment is noted in table 6.4 which lists the informal training in Morocco. The training activities led to significant maintenance capability for all major pieces of project equipment.

Table 6.2 - Short-term training - Electronics technician maintenance and repair.

Name	Start date	Completion date	Total (person months)	Course topics
Mohamed MEGDANI	Aug. 1984	Sep. 1984	1.5	Integrated Radar/IFF System
	June 1986	June 1986	0.5	Radar System Computer IFF Aircraft Interrogation System
	July 1986	Aug. 1986	1.5	Rawinsonde Electronics Handar Automatic Station Ground Seeding Generators Precipitation Gauges
Mohamed MOUMANE	Aug. 1984	Sep. 1984	1.5	Integrated Radar/IFF System
Salah BZAIZ	June 1986	Dec. 1986	6.0	Radar and Computer Electronics IFF Aircraft Interrogation System
Abdelmoula SABBAR	June 1986	Dec. 1986	6.0	Radar and Computer Electronics IFF Aircraft Interrogation System
Said ZAHLOUL	Oct. 1985	Oct. 1985	1.0	Satellite Laserfax (NOAA)
Noureddine BENTALBA	Oct. 1985	Oct. 1985	1.0	Satellite Laserfax
Driss BERRADA	July 1986	Aug. 1986	1.5	Rawinsonde Electronics Handar Automatic Station Ground Seeding Generators Precipitation Gauges
El Mostapha AMINE	Nov. 1986	Jan. 1987	1.5	Aircraft Cloud Physics System
Abdellah AMALI	Nov. 1986	Jan. 1987	1.5	Aircraft Cloud Physics System

6.2.2 Meteorologists and operations directors. - Training for meteorologists was provided in both Morocco and the United States. Due to the high cost of U.S. training, fewer people were trained in the United States. Furthermore, when American experts visited Morocco, they met with a larger group of project scientists and provided a broader range of information. Training in the United States focused on the direction of field projects and collaboration in scientific studies. In contrast, training in Morocco concentrated on review of material studied in the United States and on the development of skills of the meteorological technicians and support personnel.

Focused short-term training was provided to the project directors and coordinators. Their training included the following topics:

- The Operations Plan and organizational structure required to operate the project.
- The scientific understanding of how, why, and when to use the various types of seeding delivery systems.
- The types of data required and data collection, including quality control procedures.

Table 6.3 summarizes the training received by the operations directors and project director while in the United States. The operations directors visited Reclamation's SCPP field research project in the Sierra Nevada of California, where they monitored and participated in the project's field operations. This training was conducted by Mr. David Reynolds, the SCPP site director, and Mr. Curt Hartzell, Reclamation meteorologist and Al Ghait operations coordinator from Denver. SCPP provided an excellent training site for the Moroccan scientists because of its physical and logistical similarity to Programme Al Ghait. The physical location of SCPP on the western coast of North America, its 36° N. latitude, and the distribution of the field equipment over a 200-kilometer-wide area led to similar meteorological conditions and logistical and operational issues. The field experience gained during the 6-week course included participation in the daily weather briefings; visits to radar, rawinsonde, and radiometer sites, as well as mountain weather stations; and participation in scientific meetings with project scientists.

The daily weather briefings provided information on the specific forecast requirements and operational management of a weather modification research project. They demonstrated the methodology used in nowcasting seedable clouds and the requirements for targeting seeding materials from aircraft and ground-based generators. Practical operational problems were reviewed at each briefing, and problem-solving techniques were used to resolve the issues. Issues such as the impact of equipment failures on field operations and the need for rapid repairs were brought out. On SCPP, equipment issues were resolved through communications with each field site for a systematic status check of all equipment and personnel.

Visits to the radar and rawinsonde sites and other observing facilities during storm conditions provided experience with the procedures that Reclamation scientists used to operate the systems and collect and quality control data. In addition, the experience provided direct field observation of how real-time analysis of meteorological data impacts cloud seeding operations and their physical evaluation. Each week on SCPP, detailed scientific debriefings were conducted with the full team of more than 20 scientists and engineers from Reclamation and its SCPP contractors. These debriefings reviewed the meteorological structure of storms and microphysical conditions observed by cloud physics aircraft and other systems. The debriefings focused on precipitation development, the transportation of seeding material to the target clouds, detection of physical changes due to seeding, and the resulting precipitation.

Similar experiences were gained by the long-term students who, during the field seasons, were given opportunities to visit and participate in SCPP as part of their university course work. These field program visits were a significant component of the technology transfer within the project.

Table 6.3. - Short-term meteorologist training in the United States.

Name	Start date	Completion date	Total (person months)	Course topics
Saad BENARAFA	May 1986	June 1986	1.0	Project Management
	Nov. 1986	Dec. 1986	0.75	Project Operations Management
El Bachir LOUKAH	May 1988	June I988	1.5	Project Management
Mustapha MAIDANE	June 1984	July 1984	1.0	Project Overview
	Nov. 1986	Dec. 1986	1.0	Project Operations Direction
Yvon LE GOFF	June 1984	July 1984	1.0	Project Overview
Ali EL MAJDOUB	Mar. 1985	Mar. 1985	0.75	Project Operations Direction
Mohamed EDDAMANI	Nov. 1986	Dec. 1986	1.0	Project Operations Direction
Laidi GRANA	Nov. 1986	Dec. 1986	1.0	Project Operations Direction
Driss TABYAOUI	Nov. 1986	Dec. 1986	1.0	Project Operations Direction

6.2.3 Cloud seeding operations methodology and physical basis. - This training was initiated upon arrival of the RSA and support teams from the United States in August 1984. Cloud seeding operations and observation of critical data required for decisionmaking were taught informally by Dr. Matthews, Mr. Politte, and Mr. McPartland during the early stages of the project. This initial review of specific forecasting and suspension criteria requirements was followed by systematic training on the rawinsonde observation system by Mr. Robert Cox, North American Weather Consultants (NAWC). He provided expert training on the system operation, data collection, and its analysis and reduction to engineering units. Table 6.4 provides a complete chronological summary of the informal short-term training conducted in Morocco.

Cloud seeding operations and nowcasting required for operations were taught by Mr. Keith Brown and Mr. Curt Hartzell during the winter and spring of 1985. During this period the project operations were in the first season's shakedown of all systems and techniques, so that the OJT provided direct experience with Moroccan conditions and equipment.

As previously noted, cloud physics observations were collected from January to April 1985 by the UND aircraft operating from Marrakech (Grainger and Stith, 1987). The cloud physics team provided informal training in project operations at debriefings held in the National Meteorological Forecasting Center in Casablanca and during special flights when Moroccan scientists participated in the flight operations. They also provided OJT to the flight teams who flew seeding missions in the OV-10 seeding aircraft and later to the King Air flight crews.

From October to December 1985, the Citation was based in Casablanca with the project's operational support center, where the cloud physicists could interact with the project team directly each day and participate in the daily briefings and decisionmaking process. The debriefings reviewed the previous flight operations and discussed the initial cloud physics observations in context with the rawinsonde, satellite, radar, and surface observations. The SAET and operations teams learned a great deal about the microphysical processes that led to precipitation in these cases and the physical analysis procedures used to study the seedability of clouds. This direct interaction resulted in a very effective transfer of technology for both practical problem solving issues and more theoretical scientific questions. One Moroccan scientist flew on each of the cloud physics missions with one of the Moroccan pilots and the UND flight scientist and crew. These flights provided excellent experience for the Moroccan scientists and flight crews. Mr. Roger Tilbury, the Citation pilot, provided excellent information about flight operations in seedable clouds with heavy icing conditions. Mr. Tilbury's 20 years' experience in flying through seedable clouds in IFR conditions was invaluable for the Moroccan flight teams.

Table 6.4. - Informal training in Morocco.*

Topic	Instructor	Period	Number of GOM trainees	Total person months of training
		1984		
Suspension criteria and severe weather forecasts Project implementation	F. Politte P. Hurley	Aug. 2-15	4	2
Mountain snow course and aircraft operations	J. McPartland	Aug. 2-15	2	1
Rawinsonde operations and maintenance	R. Cox, NAWC A. Atkins, NAWC	Aug.-Sep. Nov. 15-Dec. 12	8 8	16 8
Radar installation, Operations Plan development, aircraft operation	A. Super M. Collins K. Brown, NAWC	Sep. 27-Oct. 15	5	0.5
Air traffic controller Radar operations and analysis	G. Toth, NAWC	Oct.-Nov.	6	12
Radar training	L. Davis, CIC	Oct.	15	1.5
Radar installation and maintenance	J. Welker, CIC R. Flohr, CIC	Oct.-Dec.	5	8
Operations	C. Hartzell	Nov. 2-20	10	1.2
Satellite SDUS installation and maintenance	Carlson, NOAA Lavallee, Alden	Nov. 1-30	4	4
1984 TOTAL				54.2

*Unless otherwise noted, all instructors were Reclamation personnel.

Table 6.4. - Informal training in Morocco - continued.*

Topic	Instructor	Period	Number of GOM trainees	Total person months of training
		1985		
Radar maintenance	J. Welker, CIC	Jan.-Mar.	4	12
Operations and analysis and forecasting	K. Brown, NAWC	Feb.-Apr.	6	18
Operations direction and project management	C. Hartzell	Feb.-Mar.	10	15
UND cloud physics aircraft operations and OJT	Grainger, Stith, Tilbury, UND	Feb.-Apr. Oct.-Dec.	2 6	6 18
IFF system maintenance	D. Treddenick, CIC	Oct.	4	2
Rawinsonde refresher	R. Cox, NAWC	Oct.	8	2
Suspension criteria	A. Dennis	Oct.16-30	10	1
Radar maintenance and repair	J. Welker, CIC	Nov.-Dec.	4	8
Operations director training	C. Hartzell	Nov. 4-26	4	3
1985 TOTAL				85
		1986		
Radar maintenance and repair	J. Welker, CIC	Jan.-Apr.	4	16
Radar move and communications planning	G. Long G. Cascino	Mar.	4	2
Hydrologic/economic studies	P. Hurley W. Cheney K. Shuyler	Jan. 16-27	4	1
Operations	C. Hartzell	Sep. 14-Oct. 9	3	3
Radar repair and maintenance	J. Welker, CIC	Oct.-Dec.	2	6
Rawinsonde refresher	R. Cox, NAWC	Oct. 20-24	8	2
King Air 100 cloud physics system overview	L. Davis, CIC	Oct. 27-31	8	2
1986 TOTAL				32

*Unless otherwise noted, all instructors were Reclamation personnel.

Table 6.4. - Informal training in Morocco - continued.*

Topic	Instructor	Period	Number of GOM trainees	Total person months of training
		1987		
Cloud physics system installation, maintenance, and operation	L. Davis, CIC D. Treddenick	Feb. 8-24	4	2
	D. Stone	Feb. 8-Apr. 5	4	6
Scientific operation of cloud physics aircraft	D. Johnson	Feb. 24-Mar. 13	5	3.75
Scientific evaluation: work plan and data management	A. Dennis R. Rasmussen	Mar. 28-Apr. 3 Mar. 28-Apr. 10	10 6	2.5 3
Statistical evaluation	J. Medina	June 14-19	3	0.7
RIVER model configuration update	W. Cheney	Oct. 1-9	4	1.0
Economic evaluation study	K. Shuyler	Oct. 1-15	4	2.0
Aircraft, radar software development and OPS work plan	D. Johnson	Dec. 1-11	4	2.0
1987 TOTAL				23
		1988		
Mesoscale-nowcasting OPS development	C. Hartzell	Feb. 17-Mar. 3	5	3.7
Airflow modeling studies and software development	T. Deshler	Mar. 21-Apr. 5	5	3.7
Statistical evaluation	J. Medina	Apr. 11-21	5	2.5
Radar analysis and software development	D. Johnson	July 28-Aug. 4	4	1
Cloud physics data analysis	R. Rasmussen	July 28-Aug. 4	4	1
Operations management	C. Hartzell	Nov. 14-Dec. 3	8	2
Project management final report, scientific papers	D. Matthews	Nov. 29-Dec. 15	10	2
Cloud physics analysis and technical paper preparation	R. Rasmussen	Nov. 28-Dec. 10	4	1.5
1988 TOTAL				17.4

*Unless otherwise noted, all instructors were Reclamation personnel.

Table 6.4. - Informal training in Morocco - continued.*

Topic	Instructor	Period	Number of GOM trainees	Total person months of training
		1989		
Final report and WMO conference	D. Matthews	Mar. 6-17	10	2
Statistical evaluation studies and final report preparation preparations, external evaluation	J. Medina	Mar. 6-17	5	1
Final report preparations and annual monitoring review	D. Matthews B. Silverman J. Lease	May 16-June 3 May 25-June 3 May 26-June 3	10	2
National Steering Committee final meetings and applications study results	B. Silverman D. Matthews J. Lease	Sep. 25-29	20	1
1989 TOTAL				9
30 AMERICAN EXPERTS PRESENTED OJT DURING 47 TRIPS OVER A PERIOD OF 55 MONTHS.				
1984-89 TOTAL				220.6

*Unless otherwise noted, all instructors were Reclamation personnel.

6.2.4 Scientific design and evaluation procedures. - The statistical analysis and evaluation procedures developed by Dr. Paul Mielke, Jr., and Mr. Jon Medina for this project have been implemented by Mr. Mrabet, who has studied streamflow data for the target and control areas. Software updates were tested when Mr. Medina visited Morocco in April 1988. Rhea orographic precipitation model runs were made in March 1989 in Morocco by Mr. Mrabet and Mr. Medina. Data from the seeded period are not yet fully ready; therefore, evaluation studies have concentrated on the historical period prior to the start of the project. Mr. Mrabet has also contributed significantly to the training of all project personnel on the use of the IBM PC/AT microcomputers. His efforts have led to increased productivity of scientific analyses by nearly a dozen personnel. A special 2-week formal course on the statistical design and analysis procedures was presented by Mielke and Medina in June 1987 (sec. 6.6). The scientific design and statistical analysis procedures are discussed in chapters 2 and 9 in greater detail.

6.3 Physical Studies and Scientific Collaboration

The scientific analysis and evaluation studies began in January 1987 under the direction of Dr. Arnett Dennis, Bureau of Reclamation Principal Investigator who was responsible for the guidance of the team of scientists from Reclamation and GOM. Section 2.6 discussed the plan for these activities. This joint scientific evaluation project within Programme Al Ghait has resulted in the best scientific assessment of Al Ghait that the seeding operations and resulting data permitted within the available time. Continued scientific analysis is needed to complete the project's research and publish the results of ongoing studies.

Scientific collaboration included the development of specific studies, their design, schedules for completion, and the scientific analysis procedures and software development required for the analysis and display of information and the preparation of scientific reports. Data management techniques required for the specific data sets such as radar, cloud physics, precipitation, snow course, digital satellite imagery, etc., were reviewed and procedures developed for application in Morocco.

The first major scientific analyses were performed from late July to September 1987 in Denver by the GOM SAET consisting of Messrs. Mrabet, Baddour, Benassi, and Nbou and Reclamation's scientists. This scientific collaboration and training on the IBM microcomputers significantly improved the quality of scientific analyses and is contributing to more effective operations as described in section 6.2.3. This type of collaborative effort among Moroccan and American scientists has contributed to the practical enhancement of scientific operations and the ability of GOM scientists to effectively present their results to other Moroccan groups, as evidenced by the technical seminar in February 1988 and the team's presentations to the National Steering Committee each year. The project's scientific team presented a review to Moroccan experts in science and technology, hydrology, water management, and agriculture. The presentations were well received, and the analysis and evaluation procedures for the project met with the approval of these experts. Each year has shown a significant improvement in the team's ability. Table 6.5 summarizes the scientific collaboration studies.

One significant factor in the development of the scientific collaboration is the close working relationship between the American and Moroccan scientists. This has led to better human and scientific understanding among the team members. These relationships are producing more effective scientific research and are leading to continued development of the team's confidence and capabilities.

Table 6.5. - Scientific collaboration studies in the United States.

Scientist	Start date	End date	Months	Topics of study
Omar BADDOUR	July 1987 Sep. 1988	Sep. 1987 Oct. 1988	2.0 1.0	Cloud Physics and Seedability Cloud Physics and Seedability
Mohammed BENASSI	July 1987	Sep. 1987	2.0	GUIDE Model Development Airflow and Dispersion
	Sep. 1988	Oct. 1988	1.0	GUIDE Model Development Airflow and Dispersion
Mohammed NBOU	July 1987 Oct. 1983	Sep. 1987 Oct. 1988	2.0 1.0	Radar Studies Radar Studies
Abderrahmane MRABET	July 1987 Oct. 1988	Sep. 1987 Oct. 1988	2.0 1.0	Data Management Statistical Hydrometeorological Evaluation
Bachir LOUKAH	June 1988	July 1988	0.75	Integration of Scientific Evaluation Studies
Mustapha MAIDANE	Sep. 1988	Oct. 1988	1.0	Nowcasting and Operational Effectiveness
Mohamed El Mokhtari	Oct. 1988	Oct. 1988	1.0	Mesoscale Analysis
BADDOUR BENASSI LOUKAH	Aug. 7, 1988	Aug. 13, 1988	0.2	WMO Cloud Modeling Workshops Toulouse, France
BENARAFA BADDOUR LOUKAH	Aug. 14, 1988	Aug. 19, 1988	0.2	10th International Cloud Physics Conference - Bad Homburg, FRG
LOUKAH	June 27, 1989	Aug. 3, 1989	1.1	Project Management training
LOUAKED	June 13, 1989	July 13, 1989	1	Equipment Management Training

During the 1987-88 season, two significant periods of training and scientific collaboration occurred as part of the Phase III review and reinforcement of previous training. The joint scientific collaboration in the United States resulted in a significant improvement in the scientific analyses produced on the IBM PC/AT microcomputers in Morocco. This collaboration consisted of a 6-week period of intensive interaction among Moroccan scientific team members Messrs. Mrabet, Baddour, Benassi, and Nbou and their counterpart American scientists Drs. Johnson, Rasmussen, and Deshler and Messrs. Hartzell and Medina. Analyses focused on the statistical evaluation of streamflow data and data management procedures; cloud physics analyses of data collected from the UND cloud physics aircraft and the Moroccan cloud physics data system on the King Air; modification of the ATLAS airflow targeting model for Morocco; and the development of new radar data processing techniques for animation of radar echo evolution and motion on the IBM systems.

Upon return to Morocco, the SAET continued their studies and software development on the IBM PC/AT systems. An example of the SAET work is provided by the team's accomplishments from November to April 1988 when they developed the following items:

- New **color graphical display software for the ATLAS and GUIDE Models.** - This software clearly shows the region of transport of seeding material to the clouds, the location of nucleation, and the fallout zones diagnosed by the models. These graphical displays are illustrated in section 8.2. Analyses of effect for the ground generators and the aircraft seeding flights were routinely produced by Mr. Benassi and Mr. El Mouhtadi for operations decisions during the field season.

- Improved **graphical displays of cloud physics** data collected on the King Air aircraft. - Mr. Baddour developed new high-resolution analyses of flight tracks, cloud liquid water, and ice particle concentrations, and thermodynamic state parameters of temperature, dew point, and wind speed and direction. In addition, the STATPRO software was used to analyze the frequency of occurrence of regions of potential for seeding and to develop seasonal summaries of various meteorological variables. Cases were stratified by types of synoptic weather conditions and cloud types to better understand the natural variability.

- **Radar data** compression software. - Mr. Nbou developed this software and provided training to other personnel on its operation and on data management procedures. Dr. Johnson and Mr. Nbou developed quality control software for the digital radar data, tested it, and implemented a standard procedure for the data collection, quality control, and archival. Mr. Nbou developed software to analyze the percentage coverage of ground clutter at various elevation angles and the area of coverage of precipitation echoes. He has developed and tested procedures to estimate the quantity of precipitation within the target and control areas, its start and end times, duration, and other useful properties. The target area had a much larger region of echoes than the control. The animation software that he obtained during the U.S. training is becoming a useful operational and mesoscale analysis tool. The scientific analyses and results of these studies are presented in chapter 8.

6.4 Operations Direction, Project Management, and Logistics Procedures

In June 1988 Mr. Loukah, Project Deputy Director, completed 3 weeks of short-term training and scientific collaboration with American counterparts in the United States. His efforts focused on work with Drs. Arnett Dennis and David Johnson in planning scientific studies for the final report and developing a comprenensive report outline. Mr. Loukah received his master's degree in Meteorology from the South Dakota School of Mines and Technology in December 1986. Since his return to Morocco, he has contributed significantly to the success of the project through his management of the day-to-day tasks. His work has been an excellent example of the success of this training and his personal dedication to the project and its personnel.

6.5 Hydrologic-Economic Evaluation and Application Studies

In June 1986 a team of three Reclamation scientists under the leadership of Mr. Patrick Hurley met with GOM experts in hydrology, water management, and agriculture to initiate the river modeling and agroeconomic studies. Messrs. Hurley, Cheney, and Shuyler, Reclamation experts in river modeling, water management, and economics, met with over 20 GOM scientists and engineers from Hydraulique, ONE, and various agricultural agencies.

In April 1987 Mr. Cheney continued detailed collaboration with experts from Hydraulique and ONE in river modeling of the Oum Er Rbia basin. He has made significant progress in configuring the model with engineers in Mr. Boutayeb's section in Hydraulique. These analyses were completed during the summer of 1987 and results presented in Morocco during October. The RIVER model configuration also used information received in meetings with Mr. Smouni of ONE. Mr. Shuyler continued his evaluation of economic data collected in June 1986 and resumed his work in Morocco in October 1987 using results from the RIVER model simulations.

On September 17, 1987, a team of eight Bureau of Reclamation experts in reservoir management, dam safety, and maintenance led by Mr. William Klostermeyer, Assistant Commissioner, conducted a water resources seminar in Casablanca. They met with DMN, ONE, Hydraulique, and Agriculture officials to discuss water resources management alternatives. Their seminar received widespread recognition in the Moroccan newspapers, which discussed weather modification as an option in water resources management. A reception in their honor hosted by Mr. Richard Jackson, American Consul General, was attended by over 100 distinguished guests and water resources experts from Morocco and the United States.

The October 1987 presentations by Mr. Cheney and Mr. Shuyler indicated that the RIVER model was a very useful tool for evaluating seeding impacts on the hydroelectric, irrigation, and domestic water use. Results from the model that indicated significant contributions to hydroelectric power from an additional 10 percent increase in streamflow using data from 1940 to 1984 are discussed in chapter 10. Mr. Smouni of ONE noted that these results were consistent with his simulations.

6.6 Formal Seminars

Formal seminars were conducted to provide more technical training and scientific exchanges among the Moroccan scientists and Americans. These seminars were generally scheduled with a large group of project and DMN meteorologists at the National Meteorological Center in Casablanca. Groups of 15 to 30 people generally attended the meetings where handouts of references and slides and view graphs were used to present technical information ranging from the identification and prediction of suspension criteria to the microphysical evolution of precipitation within cloud systems over the High Atlas. The formal seminars provided an environment which was customary for the DMN team and met their expectations of training programs somewhat better than the informal training. Both methods of education were found useful for the transfer of technology.

Three highlights of the formal seminars were the presentations by Dr. Gabor Vali of Theta Associates and the University of Wyoming; Dr. Paul Mielke, Jr., Colorado State University, and Mr. Jonnie Medina's seminar on the statistical evaluation techniques; and the seminar-workshop on Water Resources Alternatives presented by Reclamation experts. These formal seminars consisted of 2-week presentations of technical material, workshops, and laboratory studies and examinations on the content of the courses.

Dr. Vali presented a 2-week concentrated course on weather modification and cloud physics complete with a reference document and three text books for each of the 15 students. This was a university-level course in the scientific aspects of weather modification, from the basic concepts of microphysical evolution of precipitation to the statistical evaluation of field experiments.

Dr. Mielke and Mr. Medina presented the statistical evaluation of cloud seeding effects using LAD regression and MRPP statistical methods. Their 2-week course in statistics and modern analysis techniques focused on the statistical design document and statistical software developed to evaluate the effects of seeding in Morocco. This formal course reviewed basic statistical methods and developed the student's understanding of sophisticated statistical analysis methods required for the evaluation of Programme Al Ghait. A text book and lecture notes were given to each student.

Table 6.6 summarizes the formal seminars presented by the American scientists and engineers from 1984-89. Over 19 seminars and workshops were presented by 20 scientists to groups ranging from 10 to 30 people.

Table 6.6. - Formal seminars in Morocco.*

Topic	Instructor	Period	Number of GOM trainees	Total GOM person months
		1985		
Use of cloud physics data (2)	C.A. Grainger, UND	Feb.	10	1
Nowcasting techniques for operations	C. Hartzell	Mar.	15	1
Santa Barbara Project connective bands (2)	K. Brown, NAWC	Apr.	20	2
Moroccan cloud physics data summaries/debriefings (4)	C.A. Grainger, UND J. Stith, UND	Oct.-Dec.	15	3
Suspension criteria Nucleation theory	A. Dennis	Oct.	15	1 1
Ground generator placement criteria	C. Hartzell	Nov.	20	1
		1986		
Hydrologic-economic study Planning seminar (3)	P. Hurley W. Cheney K. Shuyler	June	25	3.75
Ground generator operations	C. Hartzell	Sep.	10	0.5
Scientific aspects of weather modification (10)	G. Vali, Univ. Wyo.	Oct.	12	6

*Unless otherwise noted, all instructors were Reclamation personnel.

Table 6.6. - Formal seminars in Morocco - continued.*

Topic	Instructor	Period	Number of GOM trainees	Total GOM person months
		1987		
Application of cloud physics aircraft data	D. Johnson	Feb.	15	0.75
Evaluation of cloud seeding projects	A. Dennis	Mar.	15	0.75
Cloud physics data analysis Three dimensional modeling of air flow in the Sierra Nevada Mountains	R. Rasmussen	Mar.	15 15	0.75 0.75
Statistical evaluation of cloud seeding effects using MRPP statistical methods	P. Mielke, CSU J. Medina	June	15	7.0
TOTAL				30.25
Water resources alternatives workshop	W. Klostermeyer S. Guy C. Barrett R. Ives J. Schaack	Sep.	30	1.0
RIVER modeling workshop	W. Cheney	Oct.	10	0.5
Economic analysis procedure	K. Shuyler	Oct.	5	0.1
Aircraft operations	D. Johnson	Dec.	10	0.3
		1988		
Mesoscale analysis and nowcasting	C. Hartzell	Feb.	10	0.3
Airflow modeling	T. Deshler	Mar.	10	0.3
Statistical evaluation	J. Medina	Apr.	10	0.3
TOTAL				39.95

20 DIFFERENT AMERICAN EXPERTS PRESENTED SEMINARS ON 42 DAYS TO GROUPS OF 10 to 30 GOM PERSONNEL.

*Unless otherwise noted, all instructors were Reclamation personnel.

7. CONDUCT OF CLOUD SEEDING OPERATIONS

Since Programme Al Ghait began, various studies have been conducted to determine the frequency of seeding opportunities over the High Atlas and the efficiency with which those opportunities have been exploited. This chapter presents the results of the most important studies and estimated figures on operational efficiency as defined in chapter 2.

7.1 Frequency of Radar Echoes Over Target Area

Although the presence of radar echoes from precipitation over the High Atlas target area does not exactly equate to cloud seeding opportunities, a climatology of radar echoes provides useful information for planning field operations. The radar operators at Khouribga maintained a log which indicated when precipitation echoes were present. The procedures for maintaining the log were standardized and improved at the start of the 1985-86 field season. Table 7.1 gives by month the number of hours that radar echoes from precipitation were observed over the target area during the three field seasons beginning with 1985-86. The 1985-86 season had considerably more hours of precipitation echoes than the two following seasons, indicating the variability that can be expected from year to year.

Table 7.1. - Hours with precipitation echoes over the target area.

Field season	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
1985-86	159.0	99.6	81.5	220.2	147.7	102.1	**810.1**
1986-87	39.5	28.8	135.5	145.0	62.1	82.1	**493.0**
1987-88	84.0	63.0	134.0	143.0	83.5	63.0	**570.5**

The diurnal variation in precipitation echoes over the target area was examined by Moroccan project personnel using the radar operators' logs for the first four field seasons, namely, 1984-85 through 1987-88. For the present study, their results were organized by 3-hour periods, and the frequency of occurrence of precipitation echo within each period was calculated. The results are listed in table 7.2.

The mean frequency was 94 occurrences (12.5 percent) for a 3-hour time period. Generally, the radar echoes were evenly distributed around the clock, suggesting that the precipitation was associated primarily with synoptic-scale systems. The slightly higher frequency of occurrence during the afternoon and early evening (1200-2100 CUT, which is the same as local time) probably was due to increased convective activity from solar heating; this would be especially true during April.

A more thorough radar echo climatology should be developed from the radar data recorded on floppy disks.

Table 7.2. - Frequency of radar echoes over the target area by 3-hour time periods.

Time period (CUT)	Number of periods with echo	Percent with echo
0000-0300	89	11.8
0300-0600	93	12.4
0600-0900	95	12.6
0900-1200	76	10.1
1200-1500	106	14.1
1500-1800	74	9.9
1800-2100	125	16.6
2100-2400	94	12.5
Total	752	100.0

7.2 Cloud Seeding Operations Performed

The operations plan for cloud seeding activities was summarized in section 2.4. During the first two field seasons (1984-85 and 1985-86), cloud seeding operations were limited to airborne seeding during daylight hours, that is, between 0800 and 1800 local time. This approach continued during the first 2 months (November-December) of the 1986-87 field season. By January 1987 ground-based silver iodide generators had been purchased and installed by the GOM, allowing cloud seeding operations to be conducted in the target area 24 hours a day.

Table 7.3 lists the number of days and hours with cloud seeding operations by month and field season. It is apparent that the number of seeding hours increased significantly after the ground-based generators were installed in January 1987. For the 6-month field season, February had the most seeding days and hours, while December had the fewest.

Comparing the number of hours with seeding (table 7.3) with the number of hours with radar echoes over the target area (table 7.1) indicates that, although the 1985-86 season had significantly more hours of precipitation, the 1986-87 and 1987-88 seasons had more hours with seeding operations. The reason for this was that the addition of the ground-based generators in the 1986-87 season allowed seeding operations to be conducted during hours of darkness, which was prohibited for airborne operations. The 1988-89 season was relatively dry and provided fewer opportunities for conducting cloud seeding operations; however, there were several good storms (for example, March 16-19, 1989) that resulted in prolonged seeding operations.

Table 7.3. - Number of days/hours with cloud seeding operations.

Month	Field season 1984-85	1985-86	1986-87	1987-88	1988-89	Total
Nov.	4/6.5	3/1.4	2/6.5	6/76.5	5/48.5	20/139.4
Dec.	0/0.0	3/8.9	1/1.5	9/85.9	0/0.0	13/96.3
Jan.	6/20.9	4/10.3	9/69.8	8/89.6	3/28.6	30/219.2
Feb.	2/8.4	9/26.9	9/103.8	11/80.8	5/40.9	36/260.8
Mar.	2/11.1	3/8.4	5/35.1	5/53.2	6/95.3	21/203.1
Apr.	4/7.6	6/15.9	4/27.0	3/10.9	7/98.8	24/160.2
Total	**18/54.5**	**28/71.8**	**30/243.7**	**42/396.9**	**26/312.1**	**144/1079.0**

7.3 Operational Efficiency

The plan for calculating operational efficiency – that is, the percentage of hours believed to have favorable seeding conditions that were actually seeded – was stated in section 2.4.7. All available information, and not just radar data, was used to estimate the number of hours with potentially seedable clouds. In the study, operational efficiency was estimated at only 12 to 15 percent during the first (1984-85) and second (1985-86) field seasons, when cloud seeding operations were limited to airborne seeding during daylight hours. Analysis of the data for the first two field seasons revealed that the daytime airborne seeding operations followed a bimodal distribution; there was a morning maximum between the hours of 1000 and 1200 local time and an afternoon maximum between 1500 and 1700. With the number of aircraft and pilots made available by the GOM to the project, it was not possible to have more than two seeding flights per day. The low frequency at midday corresponded to refueling of the aircraft, restocking of the seeding chemicals, and lunch for the flight crews. This low efficiency was the primary reason for the decision to add ground-based cloud seeding operations during the third (1986-87) field season.

The operational efficiency estimates listed in table 7.4 cover the period after the ground-based generators became operational in January 1987 through the 1988-89 field season. This study was done by Mr. Mustapha Maidane, Operations Coordinator for Programme Al Ghait. During the postseason periods, Mr. Maidane performed detailed day-by-day studies of project data that included rawinsonde data from Beni Mellal, satellite photos, radar operator logs and PPI plots, cloud physics aircraft data (when available), the operations directors' written notes, meteorological observations from generator sites, and standard meteorological analyses. These studies were for the purpose of estimating operational efficiency and, therefore, were not detailed case studies in the classical sense.

Table 7.4 shows that the operational efficiency was about 82 percent during the 1986-87 field season after the ground-based generators were installed and remained near that level for the 1987-88 field season. During the 1988-89 field season, the efficiency improved to nearly 90 percent. Overall, the operational efficiency from January 1987 through April 1989 was 84.5 percent. The tremendous improvement compared to the first two field seasons was achieved after the operations directors had acquired training and experience and the ground-based generator network allowed cloud seeding operations to be conducted for up to 24 hours a day, if required.

There were three reasons why cloud seeding operations were sometimes not conducted when seedable clouds were present over the target area: (a) hazardous weather conditions, such as strong winds or thunderstorms, that resulted in the temporary suspension of airborne seeding operations for the safety of the aircraft and flight crew; (b) opportunities missed because of incorrect forecasts or decisions by the on-duty operations director; and (c) failure of critical equipment, which prevented seeding operations from being initiated or continued. Table 7.5 shows the number of hours of potential seeding lost to each of these causes. Although suspension of seeding operations was required in the Operations Plan (Hartzell et al., 1986) for certain conditions such as possible flooding, no potentially seedable clouds were missed because of the declaration of seeding suspensions.

Forecasting cloud seeding opportunity was very important for initiating seeding operations. Project personnel were placed on standby whenever there appeared to be any potential for suitable clouds to develop over or move into the target area. However, from the time that nowcasting indicated that suitable clouds were present, it normally took about 2 hours to initiate ground-based seeding and a minimum of 6 hours to initiate airborne seeding. Since airborne seeding was conducted only during daylight hours, requests for the seeding aircraft had to be made prior to 0800 local time.

The radar/IFF system and ground-to-air communications were essential for airborne seeding operations. The operations director needed them to maintain a close watch of echoes over the target area and warn the aircrews if any strong echoes from thunderstorms were observed. Other equipment problems that affected airborne seeding involved the aircraft, the aircraft navigation systems, and the seeding generators.

Fewer equipment problems were involved in seeding from the ground; the generators were reliable and fairly easy to maintain. Radio communications was the main equipment problem for ground-based seeding. At times it proved difficult for the operations director to relay seeding instructions to Azilal.

In summary, the operational efficiency of cloud seeding on Programme Al Ghait did not rise above 15 percent until the ground-based generators became operational in January 1987. The low operational efficiency before January 1987 has substantial implications for the project's statistical evaluation, which are discussed in chapter 9.

Table 7.4. - Efficiency of cloud seeding operations after activation of network of ground-based generators.

Month	Field season								
	1986-87			1987-88			1988-89		
	O (h)	P (h)	E (%)	O (h)	P (h)	E (%)	O (h)	P (h)	E (%)
Nov.				76.5	88.0	87.0	48.5	55.5	87.4
Dec.				85.9	93.0	92.0	0.0	0.0	
Jan.	69.8	84.0	83.3	89.6	106.0	84.5	28.6	29.6	96.6
Feb.	103.8	117.0	88.7	80.9	107.0	75.6	40.9	44.0	93.0
Mar.	35.1	60.0	58.5	53.2	63.0	84.4	95.3	115.0	82.8
Apr.	27.0	27.0	100.0	10.9	25.0	43.6	98.8	104.0	95.0
Total	235.7	288.0	**81.8**	396.9	482.0	**82.3**	312.1	348.1	**89.7**

Key: O = seeding operations, in hours
P = duration of potentially seedable clouds, in hours
E = efficiency of cloud seeding operations (O/P*100)

Table 7.5. - Proportions of missed opportunities after activation of network of ground-based generators.

Field season	Safety (h/%)	Forecast (h/%)	Equipment (h/%)	Total (h/%)
*1986-87	10/3.5	18/6.3	24/8.4	52/18.2
1987-88	27/5.6	18/3.8	40/8.3	85/17.7
1988-89	10/2.8	9/2.6	17/4.9	36/10.3
All	47/4.2	45/4.0	81/7.2	173/15.5

Key: * = does not include November and December 1986
h = hours of potentially seedable clouds missed
% = hours listed divided by total hours with potentially seedable clouds (table 7.4)
Safety = aircraft/crew safety prevented airborne seeding
Forecast = missed forecast or incorrect decision
Equipment = critical equipment failure

8. SCIENTIFIC STUDIES AND RESULTS

The SAET and their American counterparts collaborated to conduct scientific studies. The studies were initiated in late 1987 and are continuing. This chapter briefly describes the studies and preliminary results. Five studies are presented which review progress in the following areas of interest: cloud physics, airflow and cloud physics modeling, orographic precipitation modeling, radar echo studies, and snow cover mapping and snowmelt runoff.

8.1 Cloud Physics Analysis

Rainfall over Morocco is highly seasonal with most precipitation occurring during the winter months as a result of frontal passages. The High Atlas Mountains, which extend from southwest to northeast across the country, are a formidable barrier to the oncoming fronts, with some peaks over 4000 meters m.s.l. Most of the moisture falls out as rain and snow on the northwestern side of the barrier, with very little precipitation falling on the southeastern or lee side.

8.1.1 Natural precipitation processes. - As part of Programme Al Ghait, cloud physics data were collected over the Atlas Mountains by the UND Citation II aircraft between January and December 1985 (Grainger and Stith, 1987). A particularly well-documented case occurred on December 8 and 9, 1985, when data were collected over the Atlas Mountains about 200 kilometers southeast of Casablanca. The following quotation describes some of the natural precipitation processes active during this storm.

> "During December 8, 1985, a cold front passed over Morocco. The surface analysis [fig. 8.1] shows the 12Z [Z is equivalent to CUT (Coordinated Universal Time)] position of the front on December 7, 8, and 9. Associated with this front was an extensive cloud shield, shown in the visible satellite photograph at 1230Z on Dec. 8 [fig. 8.2a]. Between December 8 and 9, the front passed over the Atlas Mountains; and by December 9 (12Z), the organized cloud shield associated with the front dissipated over Libya and Tunisia and an orographic cloud formed over the high Atlas Mountains [fig. 8.2b]. Over the plains, random cumulus clouds were present. The 12Z soundings from December 8 and 9 were taken at the foot of the Atlas Mountains at Beni Mellal (150 km southeast of Casablanca and 80 km upwind of the crestline) [as shown in figure 8.3a]. The December 8 12Z sounding showed the presence of two saturated layers associated with two distinct stratiform cloud layers. The lower layer was 2700 m thick, extending from 7 °C (cloud base temperature) to -11 °C. The second layer was relatively thin and was separated from the lower layer by a 500-m dry layer. The cloud top temperature of this upper layer was -16 °C. The satellite photograph [fig. 8.2a] showed that the eastern half of Morocco was covered by stratiform cloud at that time.
>
> "Twenty-four hours later, the Beni Mellal sounding showed a relatively cooler airmass and the presence of an inversion at 600 mb, with dry air above the inversion and a saturated layer below [fig. 8.3b]. The saturated layer was associated with an orographic cloud over the Atlas Mountains and was clearly evident in the satellite photograph at that time [fig. 8.2b]. Aircraft observations showed that this orographic cloud consisted of a stratiform layer with embedded convection. The cloud top temperature for this orographic cloud was -17 °C, with corresponding base temperature of 2 °C. This type of

cloud is typical of the postfrontal period of these storms. The northwest wind at 500 mb and upper level subsidence indicate an approaching ridge and the end of the storm."

This storm represents a typical wintertime precipitation event that generally produces significant amounts of rainfall over the plains and snowpack over the mountains. A detailed analysis of the cloud physics data collected by the UND aircraft is discussed by Baddour and Rasmussen (1988, 1989) as follows:

"Microphysical observations during the main frontal passage on December 8 showed the presence of stratiform cloud layers with a weak seeder-feeder mechanism active over the mountains, at least in the portion of the storm penetrated by the aircraft. The seed crystals were aggregates of dendrites falling from an upper level cloud layer into a lower supercooled liquid water (SLW) layer. The laboratory results of Lew et. al. (1986) suggest that the rimming of aggregates can lead to rapid growth by accretion and may be an important process depleting low-level SLW in these types of storms. In regions without a seeder-feeder mechanism, SLW regions were maintained without significant depletion for over 10 minutes. In the December 8 storm, these regions occurred over the lower regions of the Atlas Mountains. In convective clouds over the plains, spherical particles up to 1 mm in diameter were observed. Model calculations showed that these particles were likely grown by direct coalescence with cloud droplets and subsequent rimming after freezing.

"During the postfrontal period of this storm, stratocumulus clouds were penetrated by the University of North Dakota aircraft. In the stratiform regions of the cloud (cloud top near -16 °C), aggregates of dendrites and stellars were observed at -10 °C, suggesting an efficient primary nucleation process near cloud top. In the convective portions of these clouds at -10 °C, drops, frozen drops, and spherical graupel were observed, suggesting an active coalescence process followed by drop freezing and subsequent rimming. High liquid water contents close to adiabatic were observed for significant periods of time in many of these clouds, suggesting that depletion of liquid water by entrainment and growing ice particles was not very efficient. Since the convection was usually embedded within a stratiform cloud layer, the environmental air entrained into the growing cloud laterally would consist to a large extent of cloudy air, and thus dilution by entrainment would not be as significant as for an isolated cumulus clouds. Updrafts in these convective clouds were generally moderate (4 to 6 m s^{-1}), allowing the particles in the upward moving cloudy air sufficient time to develop drops by coalescence in the relatively undiluted cloud cores. The model calculations show that the growth of particles by collision and coalescence with cloud droplets could produce particles of the observed sizes at the appropriate levels. Despite the relatively cold cloud base temperature (2 °C), the coalescence process was still active due to the nearly adiabatic cores."

The above observations represent only one wintertime storm over Morocco; therefore, caution must be taken in extrapolating these results to other winter storms. These results, however, show a typical winter storm sequence and reveal some of the basic precipitation mechanisms. During the frontal passage, a seeder-feeder-type mechanism was active in the Atlas Mountains, with an upper level stratiform deck feeding aggregates of dendrites and stellars into a lower supercooled cloud layer. Some parts of the system had lower cloud top heights and no upper cloud to provide ice crystals, allowing for long-lived regions of supercooled liquid water (SLW). The postfrontal stratocumulus clouds had an active coalescence process in their convective regions, leading to drop freezing and subsequent riming. Model calculations verified this behavior and showed that the moderate updrafts and high SLW concentrations were responsible for the rapid growth. Aggregates of dendrites and stellars were observed in the stratiform regions of this cloud.

8.1.2 Comparison to microphysical observations over other barriers. - In order to put the current observations into context, they are compared to microphysical observations taken over a north-south barrier of similar size and dimension which also experiences midlatitude frontal passages. In particular, they are compared to data collected over the Cascade Mountains in the State of Washington, U.S.A. An extensive observational program was conducted over this range during the winters of 1969-70, 1971-72, and 1972-1973, with simultaneous observations from both the air and ground (Hobbs, 1975).

The Cascade Mountains are situated about 225 kilometers east of the Pacific Ocean and run approximately north-south through the States of Washington and Oregon. This range is lower than the Atlas Mountains, with most peaks below 2 kilometers in elevation. Most of the winter precipitation that falls on these mountains is snow and is produced by a combination of orographic and cyclonic effects (Hobbs, 1975).

These observations showed that during prefrontal conditions the clouds were generally layered, ranging from stratus near the surface to cirrus at higher levels. There was also typically a deep layer of clear air between the tops of the orographic clouds and the bases of the frontal clouds. Usually, water saturation was not found between -10 and -20 °C during these prefrontal conditions, as evidenced by the tvpes of ice crystals observed. Over the Cascades, orographic uplift occasionally produced ice crystals (e.g., dendrites) which would have grown at water-saturated conditions. It was also common to observe crystal types which formed at temperatures below -20 °C, including bullets and columns, sideplanes, radiating assemblages of plates, and sectors. Crystal concentrations were relatively high, ranging from 25 to 1500 liter^{-1}. Liquid water usually was located within 1.5 kilometers of the surface in concentrations between 0 and 0.5 g/m^3.

In contrast, the prefrontal clouds in the Atlas Mountains case presented previously had cloud layers close together and maximum cloud tops near -16 °C, considerably warmer than the cloud tops observed in the Cascades. The warmer cloud tops account for an absence of crystal types characteristics of low temperatures in the Morocco case. Instead, crystals were observed, such as dendrites and aggregates of dendrites, which grow at water-saturated conditions at temperatures around -15 °C. The concentration of dendrites and aggregates of dendrites was orders of magnitude less than the crystal concentrations observed in the prefrontal clouds in the Cascade Mountains, reflecting the lack of cold upper clouds and, possibly, the lack of an efficient ice multiplication mechanism in the Atlas Mountains.

During the postfrontal period, the air over the Cascade Mountains became increasingly unstable and cloud tops began to lower. The orographic effect became more dominant as the winds tended to become more westerly at all levels. Due to the decrease in height of the cloud tops, low-temperature crystal types became rare and the ice particle concentrations (IPC) lower (typically less than 250 liter^{-1}). Between -8 and -14 °C, frozen drops, irregular ice particles, dendrites, and stellars were found, with rimed crystals and graupel common. At temperatures above about -8 °C, the clouds frequently contained only supercooled water.

In the Atlas Mountains case, the clouds became more convective during the postfrontal period, and the orographic effect became dominant, as shown in the satellite photograph in figure 8.2b. Frozen drops and graupel were present in the convective regions of the orographic cloud, with aggregates of dendrites and stellars present in the more stratiform portions of the cloud. These similarities suggest that the Atlas Mountains postfrontal clouds were quite similar to those in the Cascades.

8.1.3 Seedability of Moroccan clouds. - This section discusses the potential seedability of clouds described in section 8.1.1 by examining the persistence of the liquid water. Cloud physics data for this analysis were collected by the UND aircraft and by the instrumented Moroccan King Air 100 aircraft. Figure 8.4 presents the distribution of average and maximum liquid water content (LWC) observed during this period. Both plots show that liquid water was relatively abundant in these clouds.

As a first step in estimating seedability, the observed clouds were divided into classes based on clouds sampled between November 1987 and April 1988. Cloud classes were based on aircraft, rawinsonde, satellite, and radar data. The radar data were obtained from the Khouribga radar. Available satellite data included both visible and infrared images. The three main cloud classes were:

- C1. - Stratiform clouds, possibly containing embedded convection, associated with either westerly or northwesterly flow.
- C2. - Isolated convective clouds, mainly cumulus congestus, generally associated with postfrontal situations.
- C3. - Cloud systems consisting mainly of altocumulus and altostratus, associated with a tropical air mass moving over Morocco from the south.

Thirty-eight cases were analyzed. Microphysical characteristics of each cloud were analyzed using the 1-second values of SLW concentration from the Johnson-Williams probe and 1-second values of IPC from an optical ice particle counter. The analysis approach used was the region-of-potential (ROP) technique developed in the Precipitation Enhancement Project (PEP) of the World Meteorological Organization (Vali et al., 1988). An ROP was defined as a region in which:

- The average LWC was greater than 0.1 g/m^3 for a section of flight path exceeding 10 kilometers in horizontal extent, or greater than 0.3 g/m^3 for smaller sections of flight path.
- The values of LWC noted above persisted for more than 10 minutes.
- The cloud depth was greater than 1 kilometer.

The ROP analysis of the Al Ghait data consisted of identifying ROP's as defined above and determining their duration, areal extent, and estimated precipitation potential. Unfortunately, the ROP analysis was not fully implemented due to the lack of continuous data in space and time. A frequency plot was constructed for each class of clouds to display the results.

Figure 8.5 shows microphysical and thermodynamic data from typical repeated King Air penetrations of clouds in each of the three main classes. Figure 8.6 shows the frequency distributions for the LWC and IPC over all penetrations through clouds in each of the three classes. In each case, the ordinate indicates the number of 1-second observations that fall into a given category. All measurements in this data set were obtained in cloud at temperatures between -1 and -16 °C, so the water concentration is a measure of the available SLW.

Figure 8.6 shows that the three cloud classes are microphysically distinct. For instance, the SLW frequency distribution for class C2 indicates that these clouds often contained high concentrations of SLW. Class C3 clouds, on the other hand, consistently contained little or no SLW. The histogram for class C1 shows a wider distribution of water concentration. The LWC was generally very low, but it occasionally approached the levels observed in class C2 clouds.

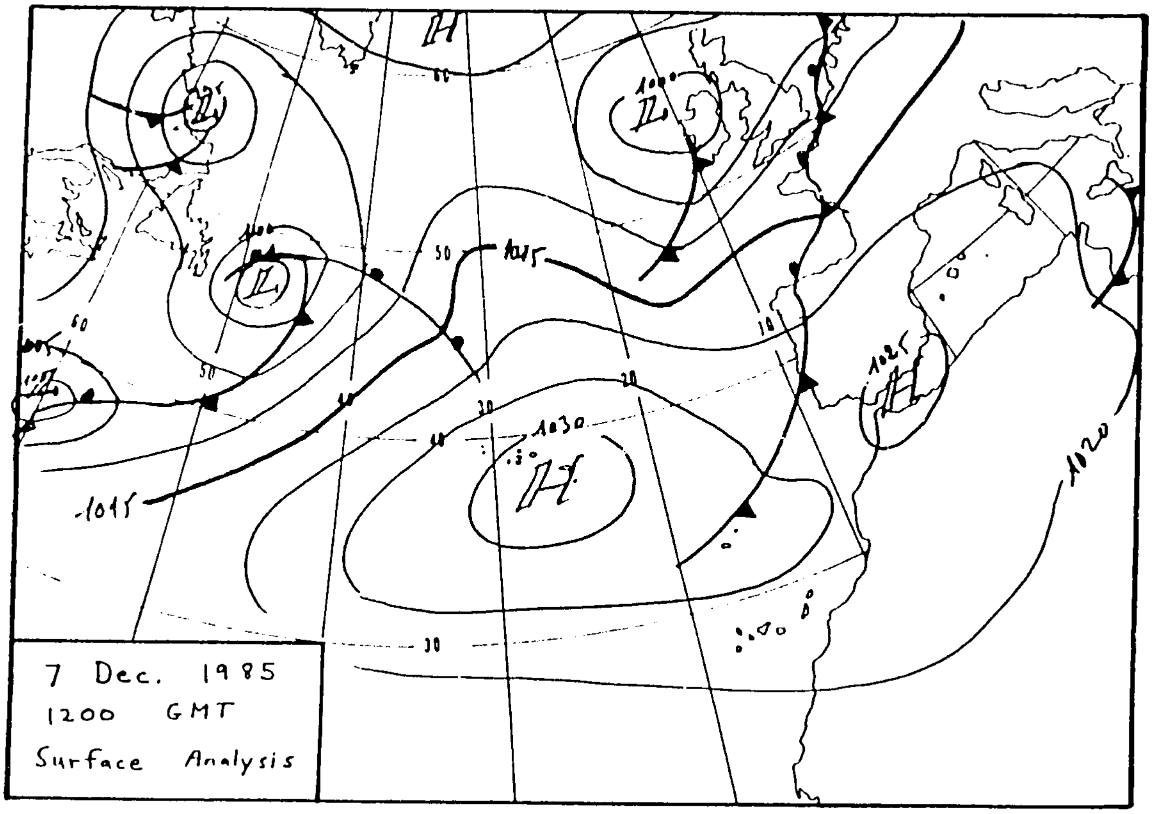
As might be expected, the IPC frequency distributions generally showed a trend opposite those of SLW concentrations. For example, the IPC for class C2 was heavily skewed toward small values, while the plot for SLW concentration shows some moderate and large values. For classes C1 and C3, the IPC distribution extended to high values, with the frequency plot for C3 clouds showing a secondary peak at high concentrations.

In summary, the analysis of 38 cases showed a microphysical distinction among three classes of clouds initially established according to air mass characteristics. The clouds in class C2, which were associated with unstable air, frequently showed high values of LWC, but seldom showed high values of IPC. This result suggests that many class C2 clouds are seedable. On the other hand, class C3 clouds did not have good seedability. Class C1 clouds had moderate seedability. It might have been useful to subdivide the C1 class to make a clearer distinction between the seedable and unseedable portions of the storms producing the C1 clouds.

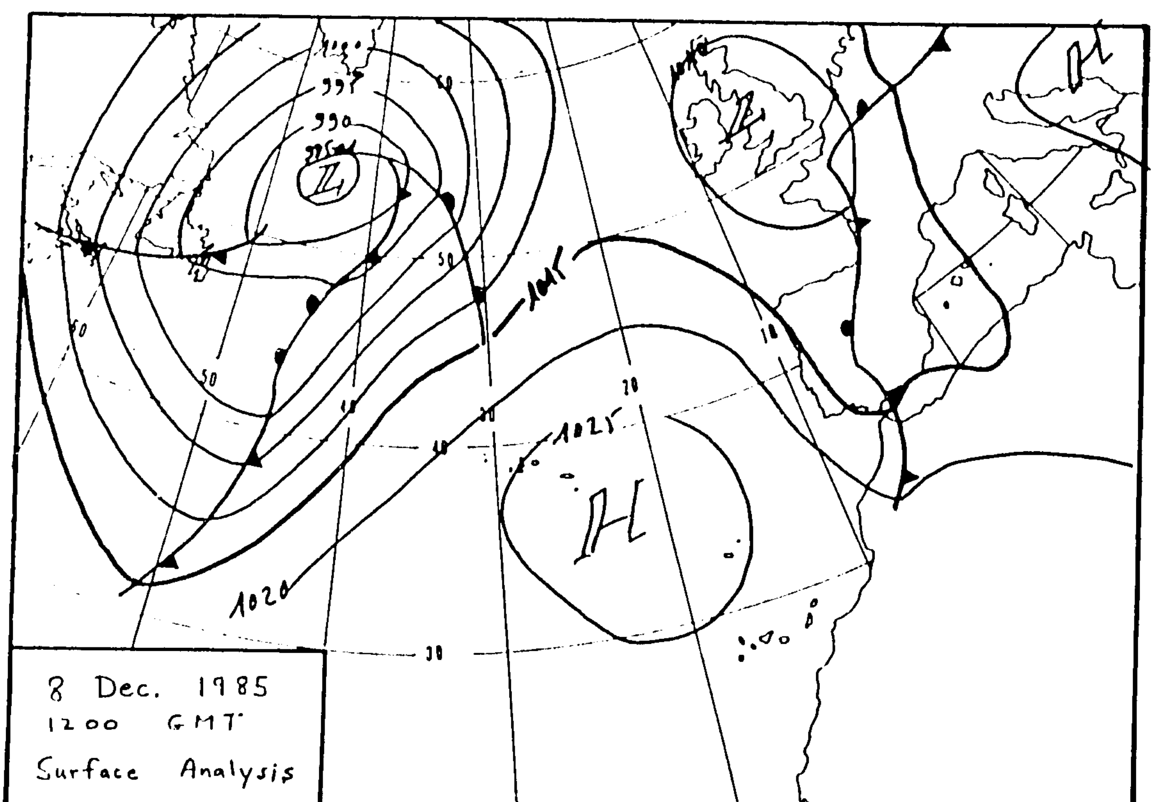
In general, the highest water concentrations and lowest IPC's were found in the cumulus congestus clouds of class C2. When storms moved in from the south or southwest to produce class C3 clouds, the flow tended to parallel the mountain barrier and did not seem to generate enough orographic lifting to produce significant concentrations of SLW. Flow from the west or northwest (class C1), on the other hand, has a significant cross-barrier component and was often found to produce significant quantities of SLW.

In order to make the results more generally applicable, the frequency of occurrence of each of these cloud classes was determined (fig. 8.7). Sixty-eight percent of the cases fell into class C1, and 24 percent fell into class C2. Only 8 percent of the cases fell into the least seedable class (C3).

These results suggest that the cloud systems occurring over Morocco are likely to be good candidates for seeding in most cases. Further study needs to be done to extend the sample size and to determine the areal extent and duration of each of these cloud categories.

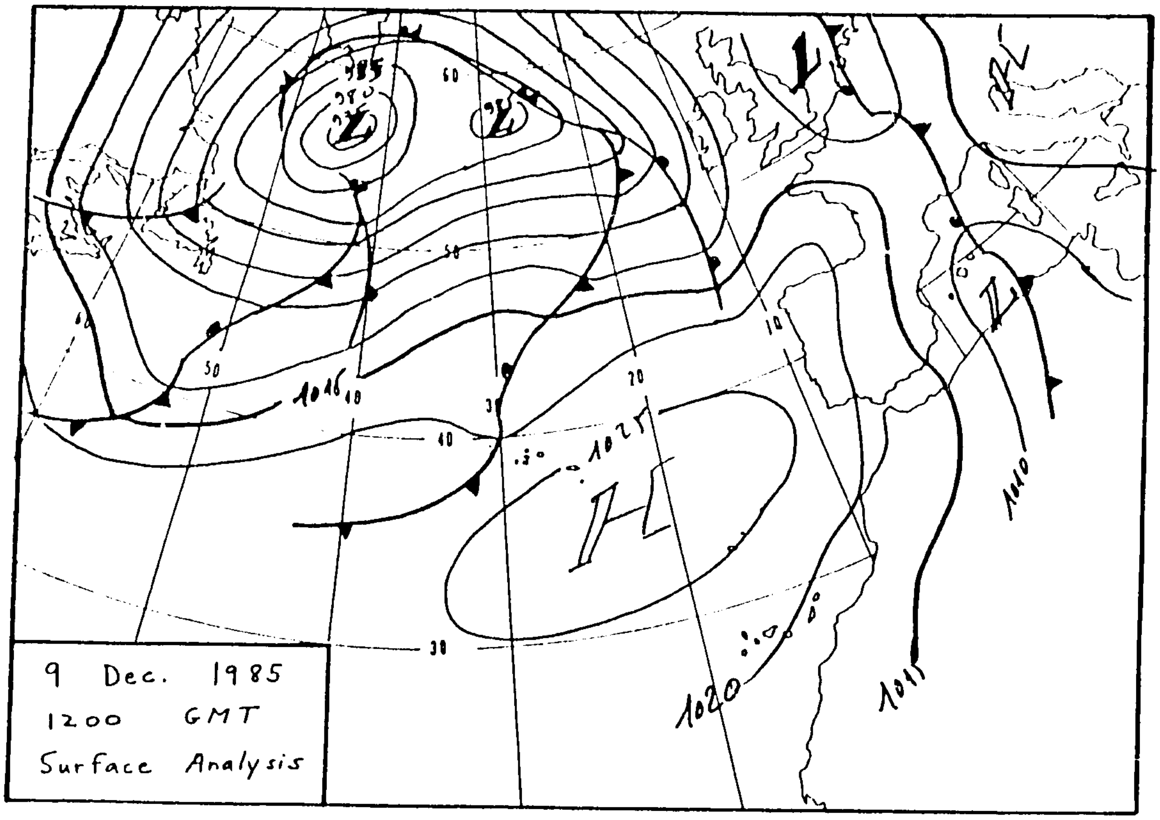


(a)



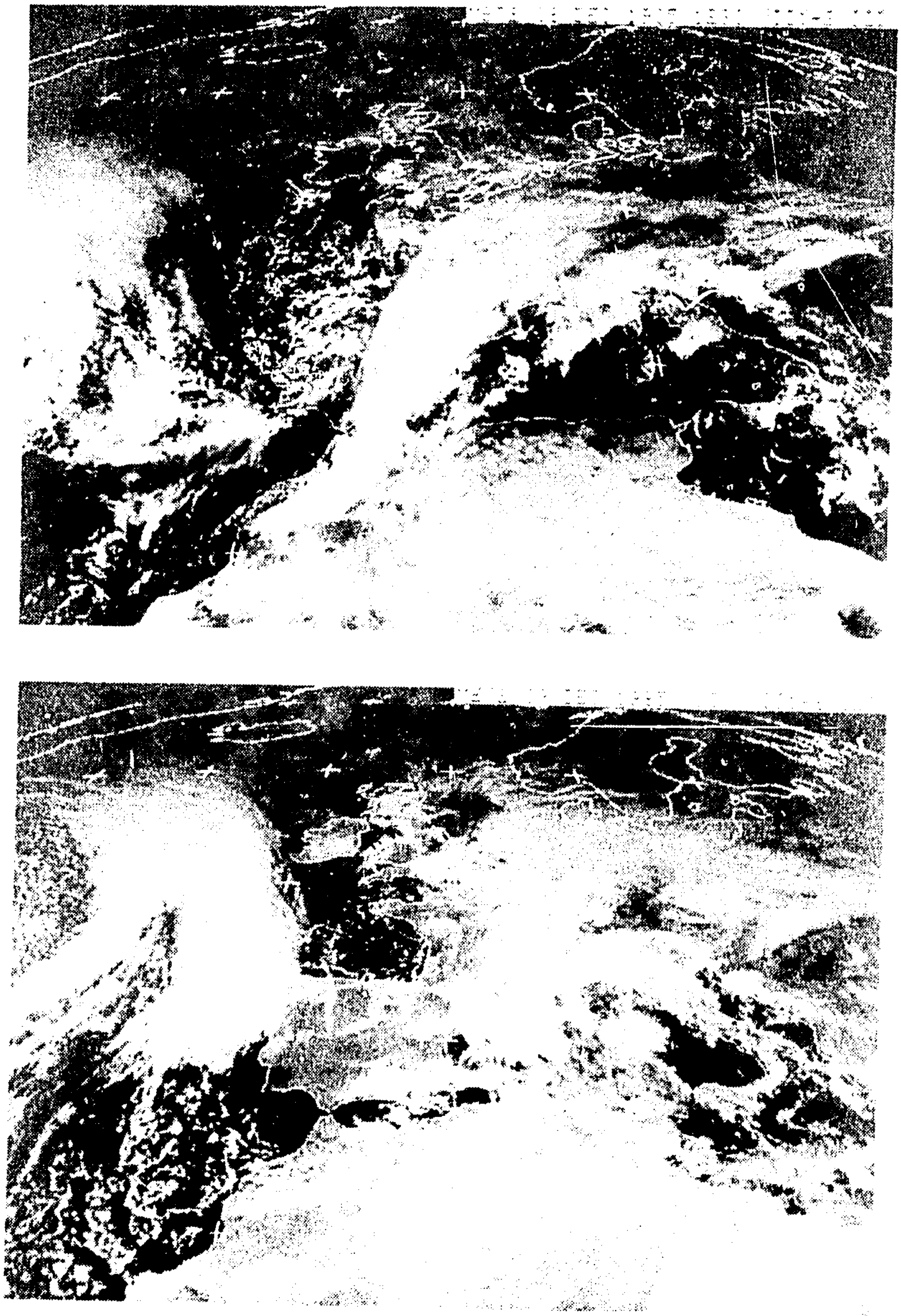
(b)

Figure 8.1. - Synoptic surface analysis for December 7, 1985 (a), December 8, 1985 (b), and December 9, 1985 (c) at 1200 CUT.



(c)

Figure 8.1. - Synoptic surface analysis for December 7, 1985 (a), December 8, 1985 (b), and December 9, 1985 (c) at 1200 CUT - continued.



(a)

(b)

Figure 8.2. - Visible satellite photographs at 1230 CUT on December 8, 1985 (a) and on December 9, 1985 (b).

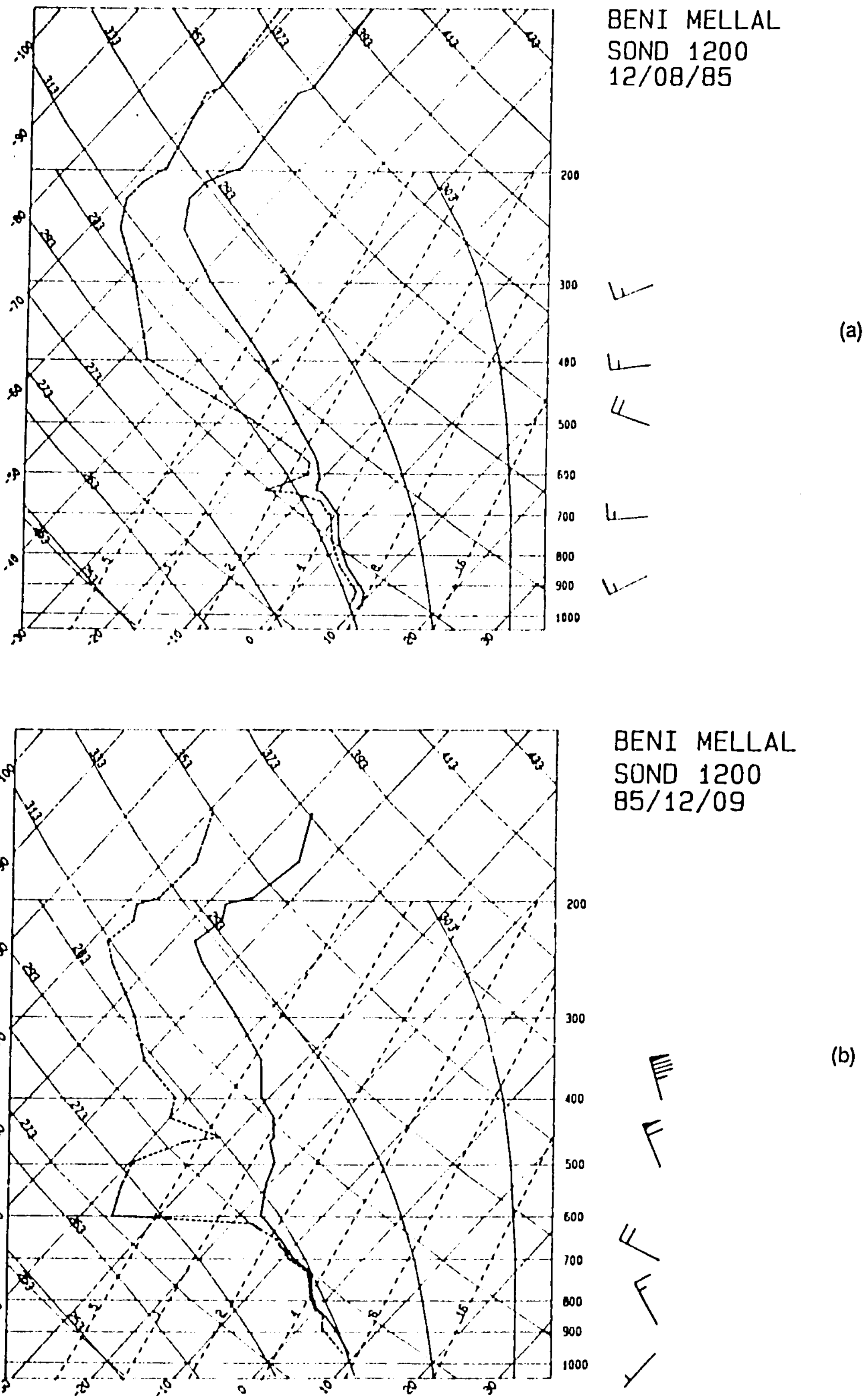


Figure 8.3. - Soundings from Beni Mellal on December 8, 1985 (a) and December 9, 1985 (b) at 1200 CUT.

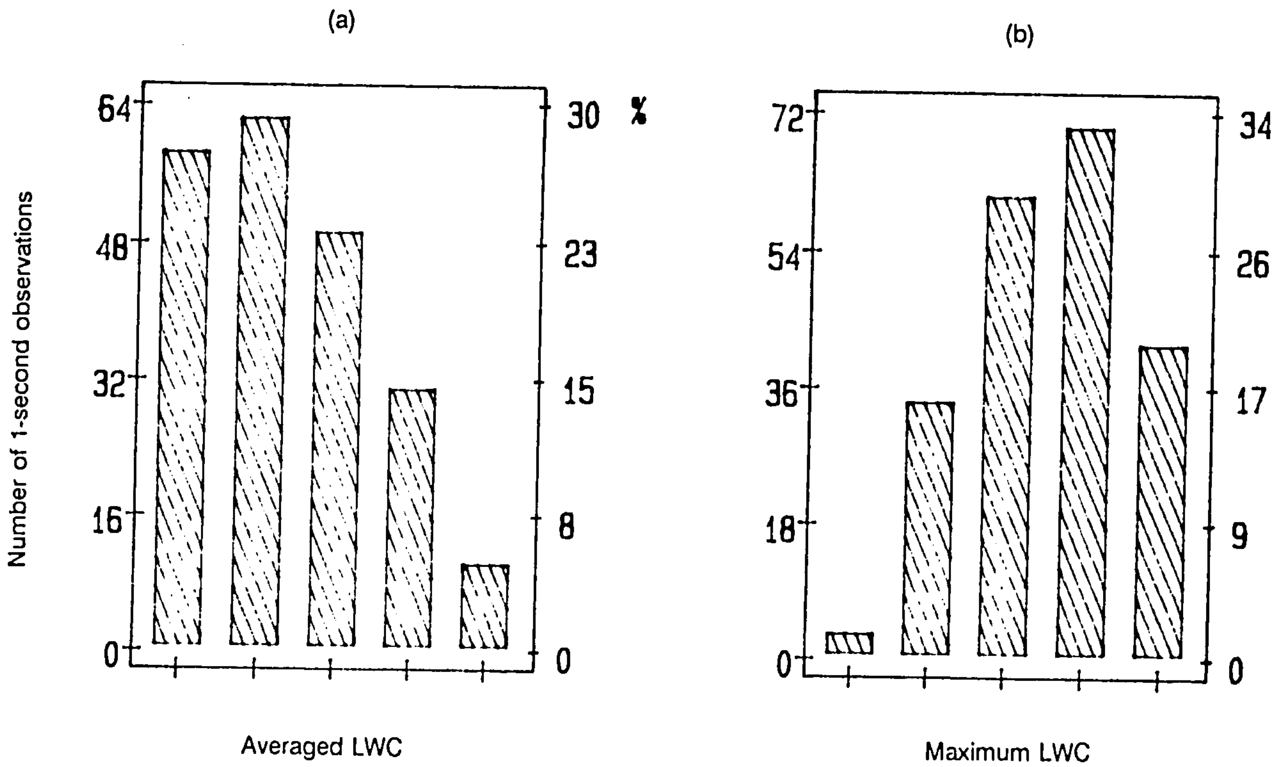


Figure 8.4. - Distribution of average (a) and maximum (b) SLW concentration from aircraft observations made from 1985-89.

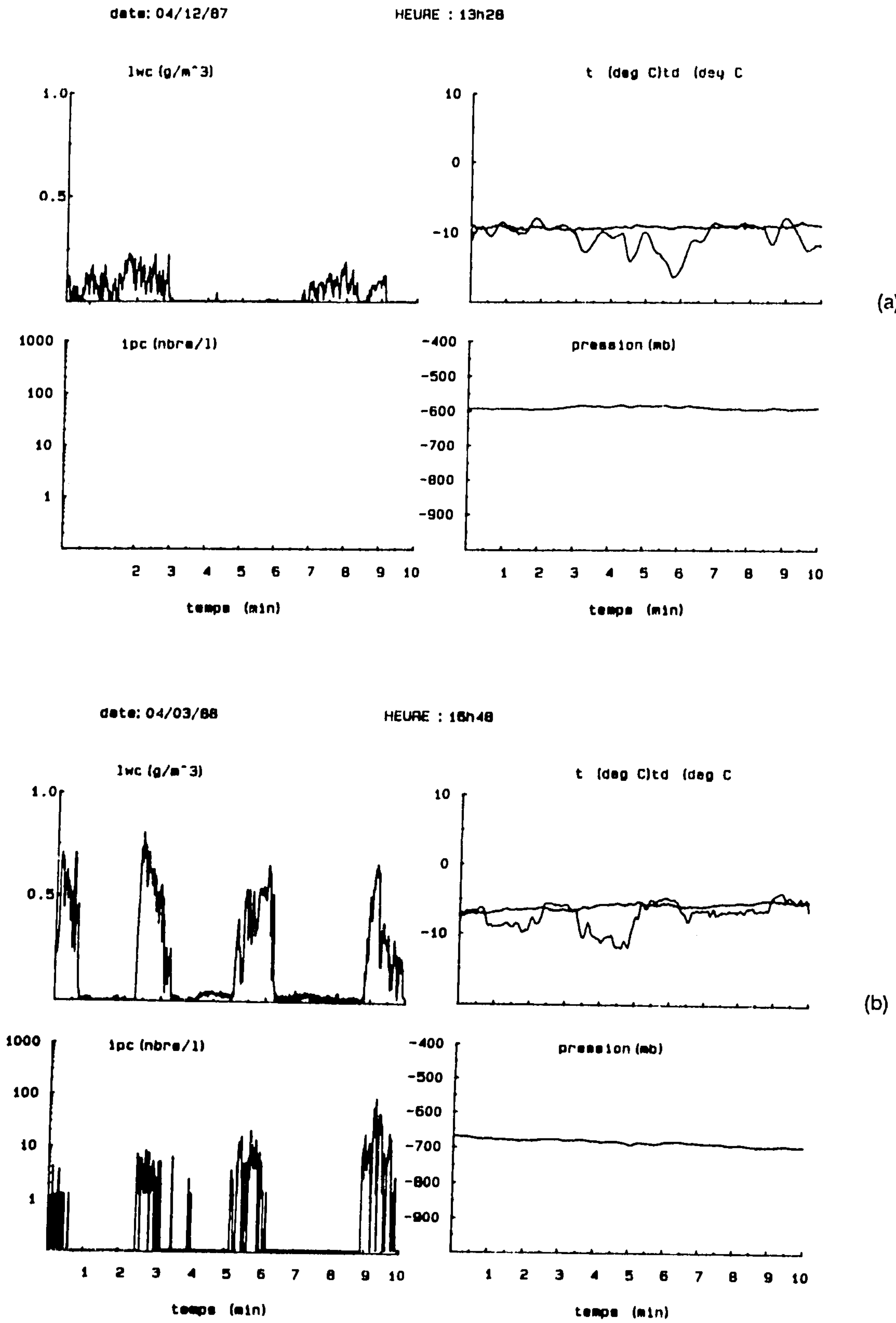
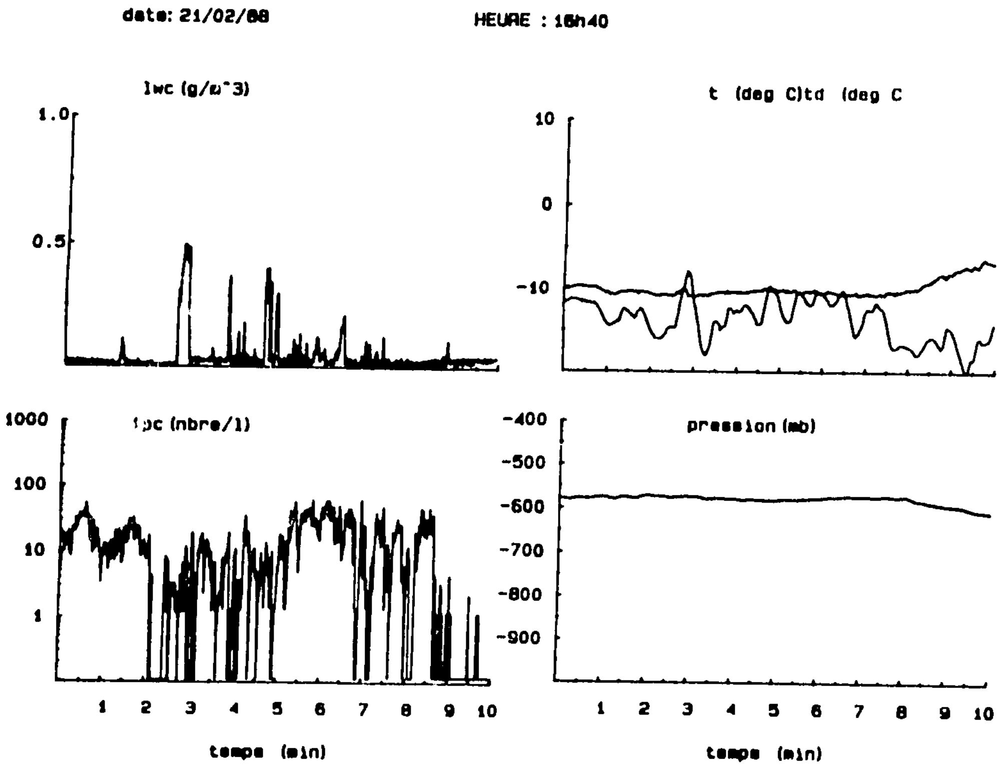


Figure 8.5. - Typical microphysical and thermodynamic characteristics of the C1 (a), C2 (b), and C3 (c) cloud categories observed by the King Air cloud physics data acquisition system in 1987-88.



(c)

Figure 8.5. - Typical microphysical and thermodynamic characteristics of the C1 (a), C2 (b), and C3 (c) cloud categories observed by the King Air cloud physics data acquisition system in 1987-88 - continued.

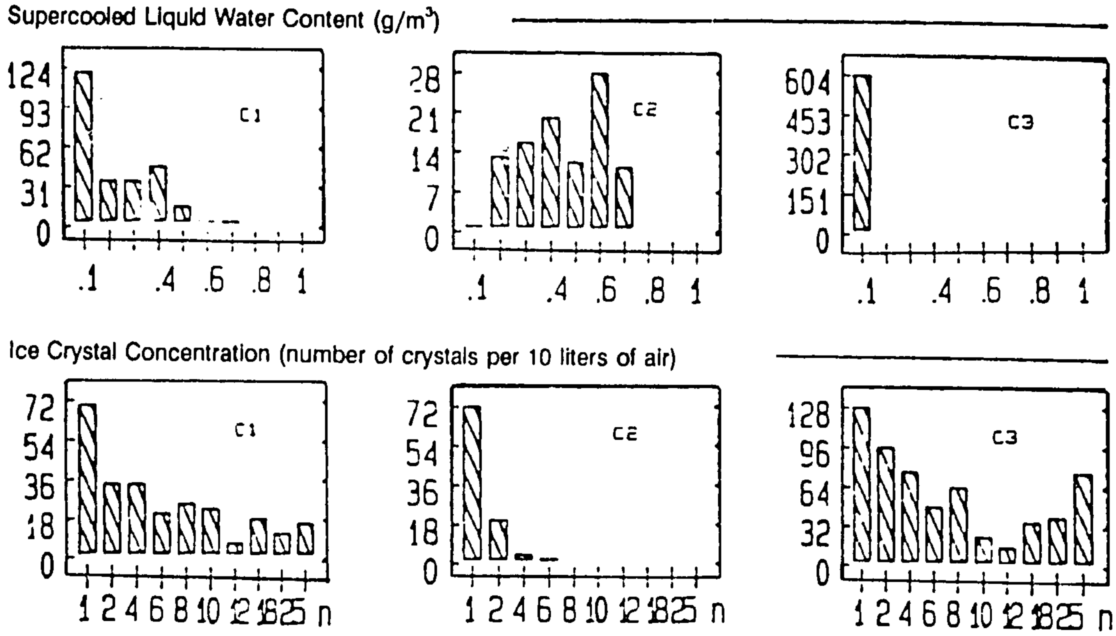


Figure 8.6. - Histograms showing the frequency of observed SLW contents and ice crystal concentrations by cloud classifications (C1, C2, or C3) over the High Atlas from 1985-88.

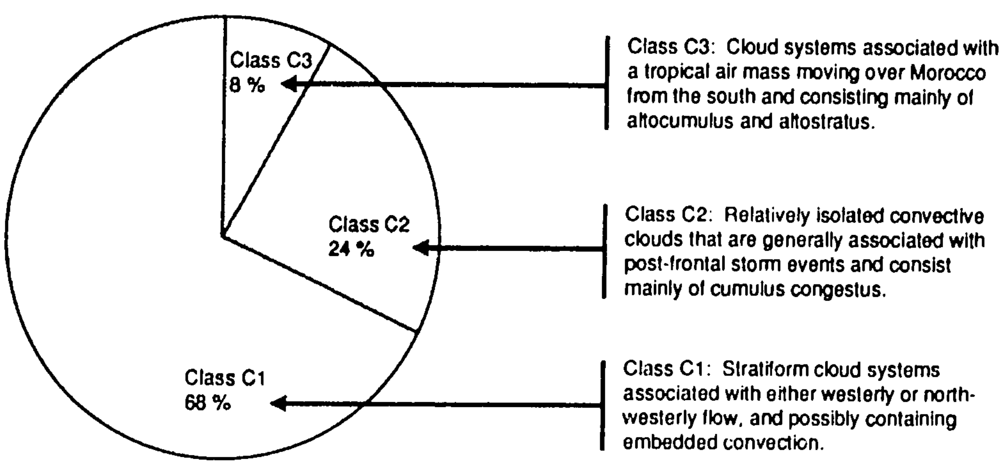


Figure 8.7. - Frequency of occurrence of the three cloud classifications (C1, C2, and C3).

8.2 Airflow and Cloud Physics Modeling Studies

Numerical modeling studies are one of the most important scientific activities of Programme Al Ghait. These studies are designed to simulate the evolution of different physical variables at each point of a grid covering the domain of interest. The phenomena modeled include general airflow, dispersion of seeding nuclei, effects of seeding on precipitation microphysics, and targeting of precipitation to desired locations.

The first model used in the project was the GUIDE model, which was two dimensional and included simple microphysical parameterizations. Loukah (1986) adapted the GUIDE model to Morocco and tested various parameterizations as part of his M.S. thesis work. Later, Deshler and Benassi adapted a similar model – the SCPP version of the GUIDE model (Rauber et al, 1987, 1988) – to Morocco. The resulting ATLAS model is currently the operational model of the project. The ATLAS model grid extends over the entire target area and beyond, covering an area exceeding 6500 km^2. The grid is 160 by 100 kilometers horizontally and extends from the surface to 600 millibars.

8.2.1 Objectives. - The primary objectives of the ATLAS model in Programme Al Ghait are to:

- Aid in real-time decisionmaking for operations direction.
- Improve real-time decisions as to type of seeding system to be used (aircraft vs. ground delivery).
- Select specific ground-based generators for operations depending on wind direction.
- Simulate precipitation processes from initiation to fallout.
- Estimate the areal coverage by seeding plumes.

In order to meet these objectives the model must:

- Simulate the major characteristics of the airflow in the target area.
- Simulate the growth and trajectories of the particles created by seeding, covering the chain of events and different processes involved from nucleation to evaporation or the impact of precipitation on the ground.

The model can be initialized with observational data in real-time for operational decisionmaking or operated in a research mode.

8.2.2 General description. - The model contains three parts:

1. Thermodynamic analysis routine. - This routine reads the initial sounding file with thermodynamic and wind data, decodes the data, and interpolates the information to a standard grid for analysis.

2. Kinematic analysis routine. - This routine calculates temperature and wind components at the grid points. It assumes steady-state flow and accounts for orographic lifting by the Atlas Mountains, which is assumed to be adiabatic. The most critical region for model simulations is from Beni Mellal downwind to the Atlas crest, which usually means about 100 kilometers southeast of Beni Mellal.

3. Microphysics routines. - These routines simulate the microphysics of precipitation growth from nucleation to fallout of precipitation on the ground. Ice crystal growth and terminal velocities are affected by the airflow over the model domain.

During the first two seasons, Programme Al Ghait used a simple parameterization based on laboratory and experimental observations to obtain fast real-time operational results. In order to improve the microphysics, a more complex subroutine was added to the ATLAS model based on the work of Rasmussen and Heymsfield (1987). The revised model is more precise and complete because the detailed transformations during different phases of crystal growth are computed as a function of time. The model now has a variable time step to compute the more complex processes.

In the model, horizontal and vertical dispersion are functions of the airflow and stability. Nucleation occurs in that part of a seeding plume where the temperature is below -6 °C, which is the threshold temperature for activation of typical silver iodide crystals. To estimate the fallout area, the model computes the nucleation and growth of ice crystals under five different assumptions about terminal velocities. The latest microphysical improvements to the model permit one to judge the phase of precipitation particles and consider evaporation as well as growth. Examples of the results from model computations are shown in the next section.

8.2.3 Simulation of aircraft seeding. - The model is used to choose the seeding location and determine the region of fallout of precipitation from aircraft seeding. The calculations take into account wind velocities from the surface to seeding levels. The altitude for seeding is determined from the rawinsonde data. Nucleation occurs in the model generally within 20 minutes of seeding and is simulated for each 5-minute interval after the aircraft releases the seeding agent. The first nucleation occurs at the point where burners should be turned on. The simulated processes include deposition, aggregation, and riming, followed by melting and evaporation, depending upon the thermodynamic conditions. Fallout trajectories are simulated for particles nucleated at 5-minute intervals until 20 minutes after initial seeding. For each group of crystals, the trajectories are calculated for crystals with fall speeds of 0.7, 0.8, 0.9, 1.0, and 1.2 times that of the expected or "theoretical" crystal. The results from the model runs are given to the operations coordinator.

Figure 8.8 shows the results of model predictions for March 5, 1988, at 0000 CUT. The seedline selected was 72 kilometers long at an altitude of 3350 meters m.s.l., with an LWC of 0.4 g/m^3 inside the cloud. Seeding along this line was determined by the model to yield precipitation near the target point chosen by the operator, near Bin El Ouidane reservoir. The + symbol shows the nucleation point, and the * indicates the fallout point of precipitation on the ground. For this case the fallout area was 760 km^2, or about 11.8 percent of the primary target area. This fallout area was 15 kilometers downwind of the seedline.

Figure 8.9 shows an atmospheric sounding from the surface to 100 millibars on March 5, 1988. The sounding was moist in the lower levels, indicating a cloud layer extending from 1000 to 4200 meters. The indicated cloud base and top temperatures were 8 °C and -13 °C, respectively.

Figure 8.10a shows the simulated evolution of an ice particle created by seeding at 3350 meters in the March 5 case. The solid line shows the change in particle diameter with altitude. The dashed line shows the ice crystal diameter. The separation of the two curves indicates the region of change from solid to liquid. Dry growth occurs between 4200 and 1800 meters, as shown by the superimposed curves from -8.3 to -0.5 °C. From 1900 meters (temperature = 0.9 °C), the ice content decreases but the particle continues to grow until it is completely melted at 1700 meters. This wet growth includes the coalescence process, which continues until the droplet reaches the surface at 1200 meters, where the temperature is 4 °C. Figure 8.10b shows the diameter with time, and the corresponding change of diameter with temperature is shown in figure 8.10c.

8.2.4 Simulation of ground-based seeding. - The locations of all seeding generators are shown in figure 8.11 by their three-letter identifiers. Ground-based seeding is simulated for routine operational decisionmaking each morning on Programme Al Ghait.

The results of a simulation of the case of January 27, 1989 are shown on figure 8.11. The notations used in figure 8.8 nucleation point and fallout points are used in figure 8.11 also. The seeding plume, which indicates the area seeded by each generator, is shown by the lines extending from the generator sites. The * symbol shows the precipitation fallout points, all of which were within the target area.

The vertical dispersion of a seeding plume on January 12, 1989, is shown in figure 8.12a. In this simulation the new version of the model with detailed microphysics illustrates the effect of evaporation on crystal growth and fallout into regions of dry air below cloud base. In this case nucleation occurred at 3100 meters. However, the ice crystal evaporated after falling below cloud base at 2700 meters, resulting in no surface precipitation (fig. 8.12b). The new model provides a more accurate simulation of the particle microphysics and is being developed as a research tool to improve the operational model.

8.2.5 Comparison of model predictions with aircraft measurements. - Wind and temperature fields from the model were compared with measurements by the King Air cloud physics aircraft on February 24, 1988. The sounding used to initialize the targeting model was made at 1200 CUT, and the aircraft flight was made 2 hours later. The aircraft climbed over the valley east of Beni Mellal, crossed the Atlas Mountains proceeding southeastward at 5000 meters, then turned back toward Beni Mellal at 4100 meters. Aircraft measurements of windspeed, wind direction, temperature, and u and v wind components were compared with the values calculated by the model along the aircraft track. The aircraft data were collected at a level slightly above the seeding level. Wind direction and temperature as simulated by the model were in close agreement with observations. The errors were smallest in the 100-kilometer domain upwind from the crest of the mountain. The largest errors were downwind of the crest, which is outside the area of interest for seeding effects. Further detailed aircraft and model comparisons are needed in a variety of conditions to confirm the reliability of the model simulations over complex terrain.

8.2.6 Conclusions. - The airflow and microphysical models are useful tools for operational decisionmaking. Models that were originally developed and used operationally in the Sierra Nevada of California have been successfully adapted for the High Atlas. They have been used operationally and are being verified with observations to determine their reliability over the High Atlas of Morocco. Seeding plume transport and diffusion simulations are needed for daily operational decisionmaking and for the evaluation of the relative efficiency of seeding during operations. These simple airflow models are contributing to a better understanding of the seeding plume characteristics and targeting of seeding material in Programme Al Ghait.

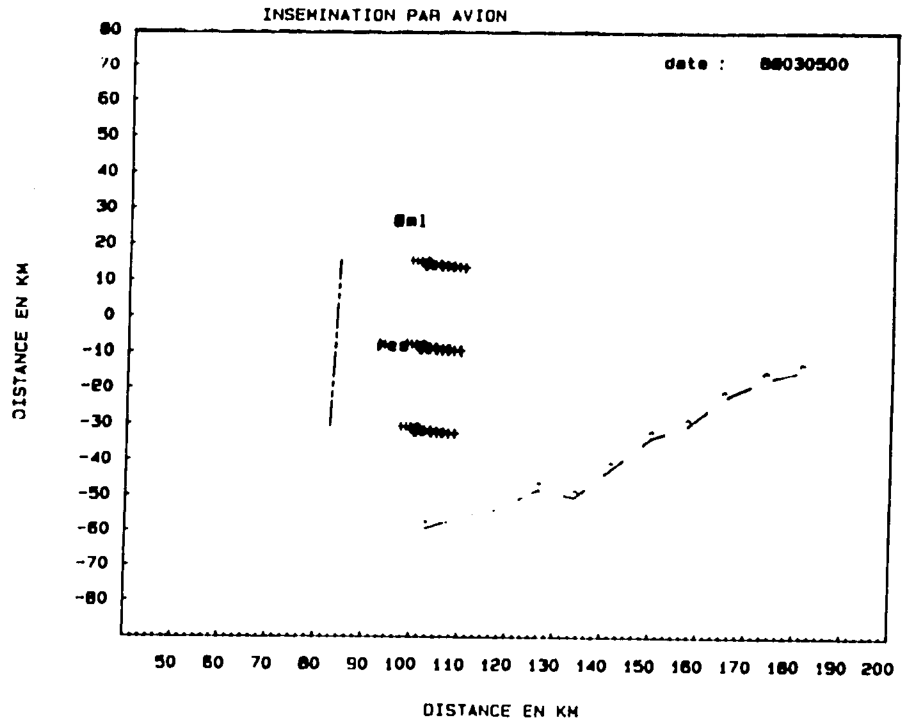


Figure 8.8. - Calculated seedline and fallout area of crystals for an aircraft seeding at 3350 meters m.s.l. on March 5, 1988, at 0000 CUT. The dashed line indicates the aircraft seedline, and the + indicates the fallout points of precipitation on the ground.

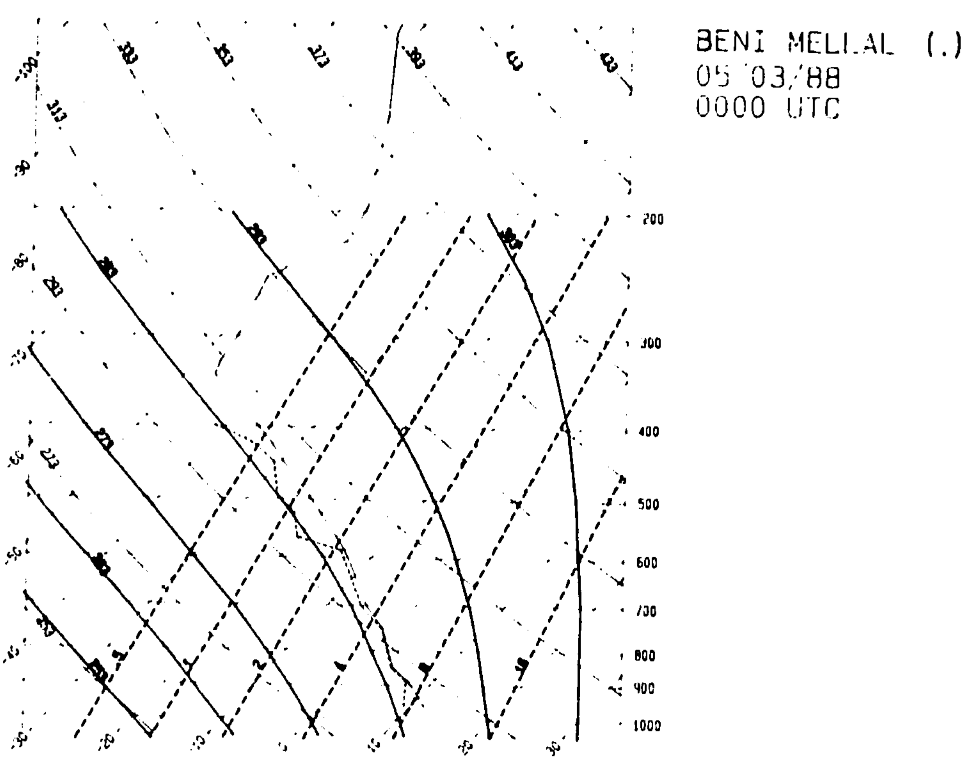
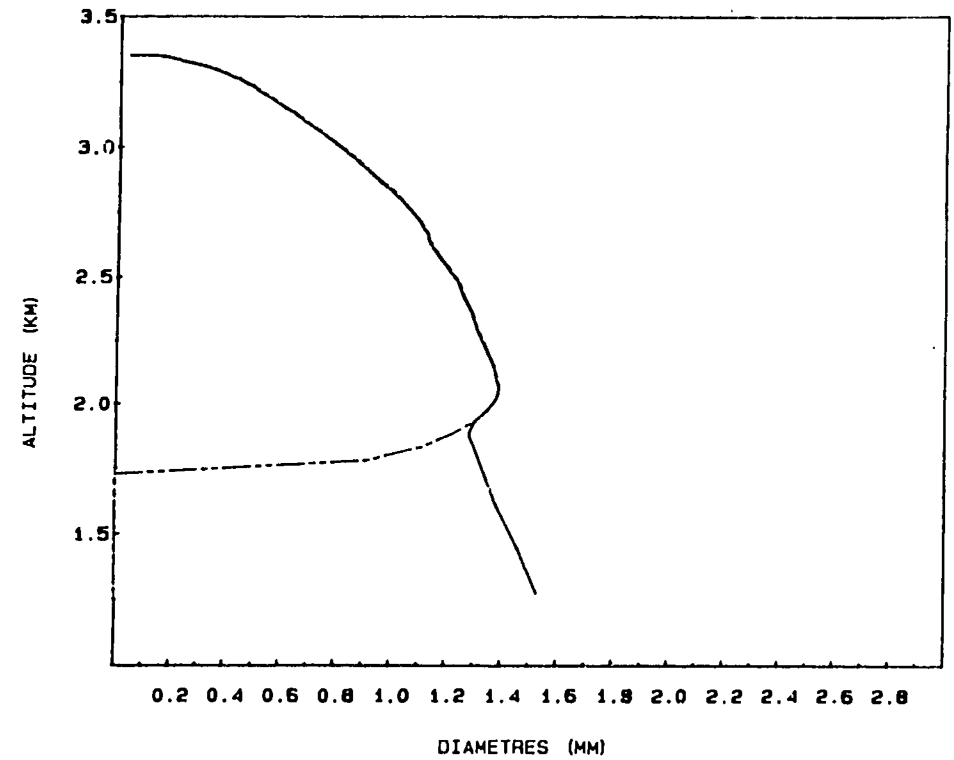
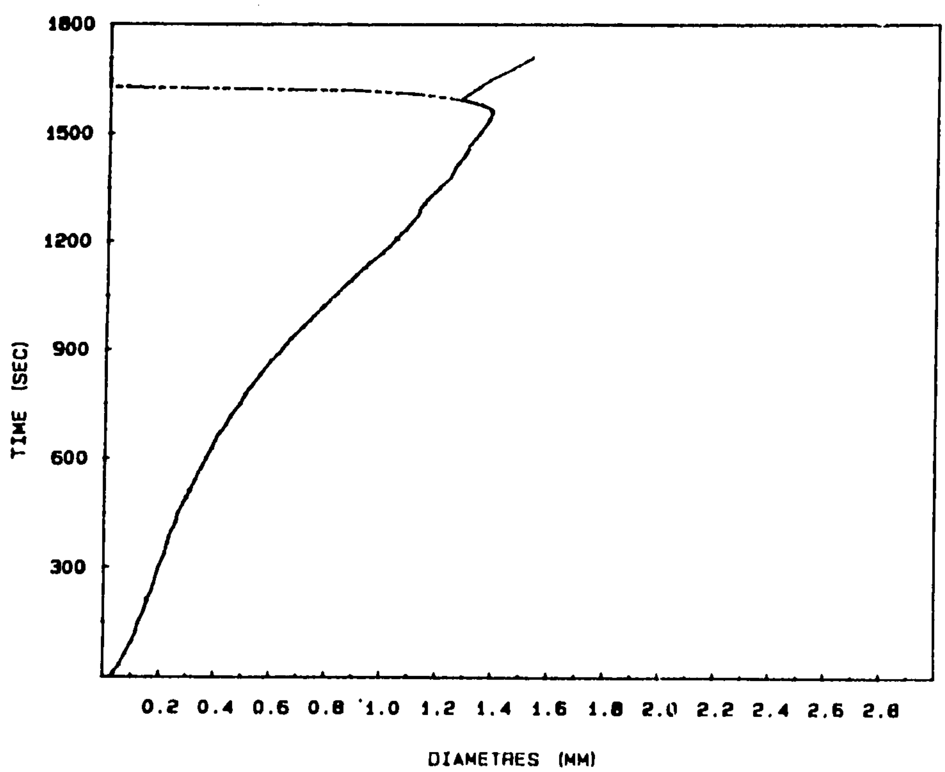


Figure 8.9. - Thermodynamic diagram showing the temperature (solid line) and the dewpoint (dashed line) from the surface to 100 millibars on March 5, 1988.

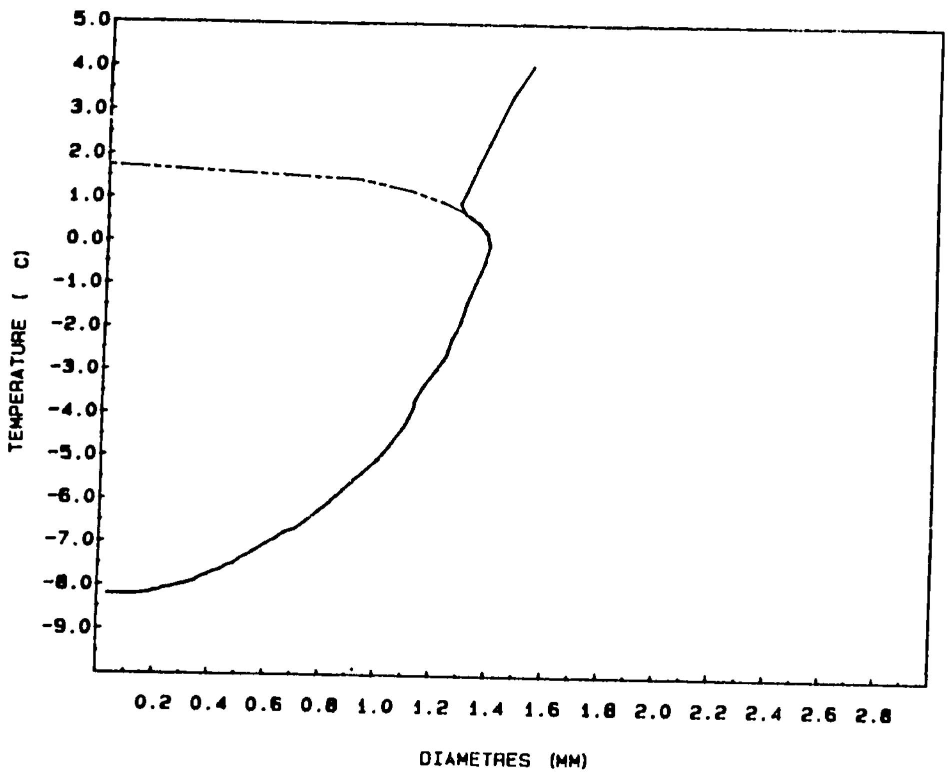


(a)



(b)

Figure 8.10. - Evolution of a particle created by seeding at 3350 meters m.s.l. as it falls to the surface. Solid line represents the change in particle diameter with altitude, and line segments represent the change in ice particle diameter with altitude (a), time (b), and temperature (c).



(c)

Figure 8.10. - Evolution of a particle created by seeding at 3350 meters m.s.l. as it falls to the surface. Solid line represents the change in particle diameter with altitude, and line segments represent the change in ice particle diameter with altitude (a), time (b), and temperature (c) - continued.

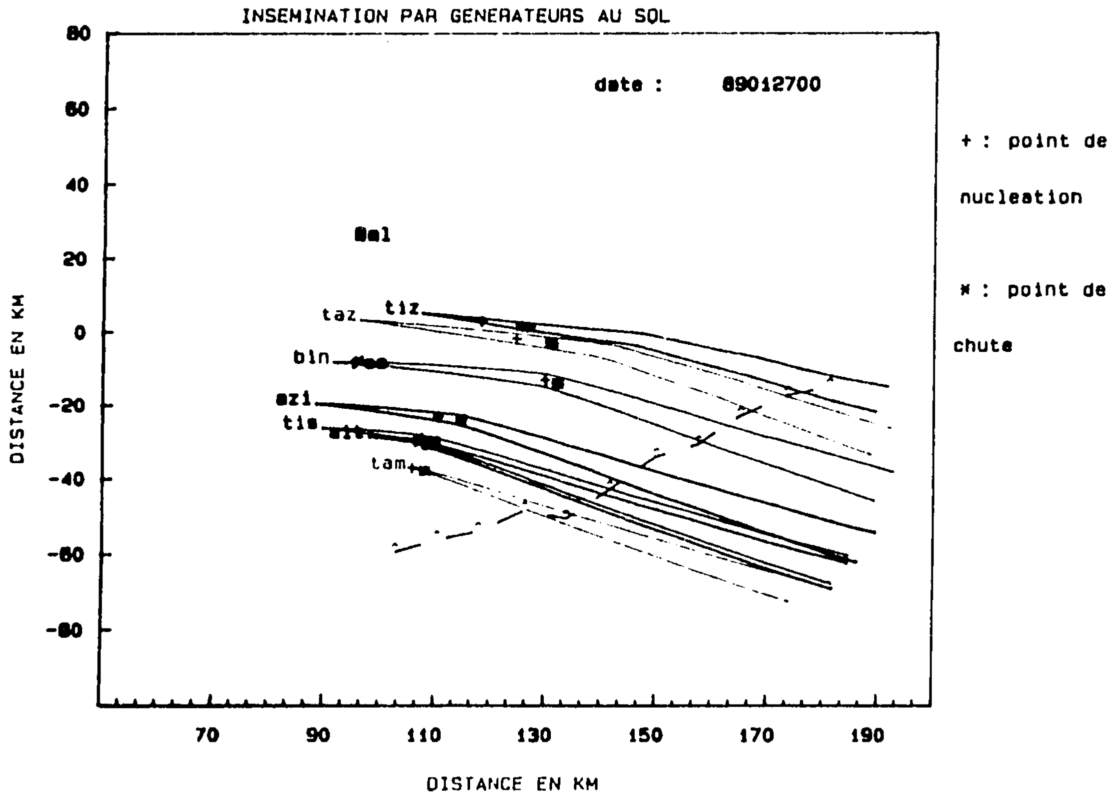
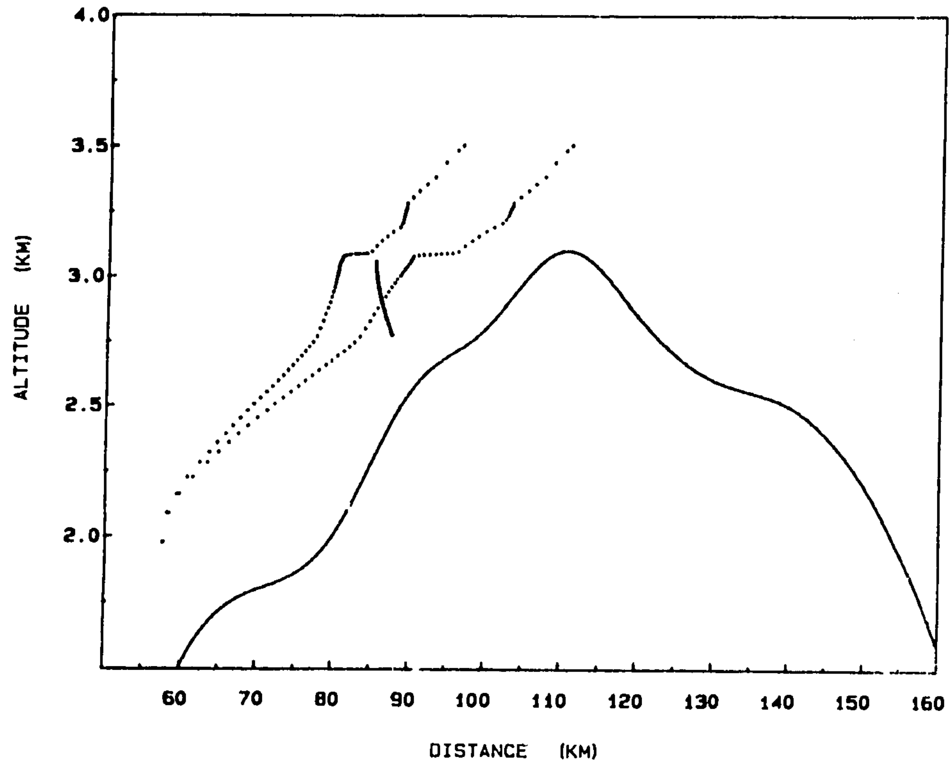
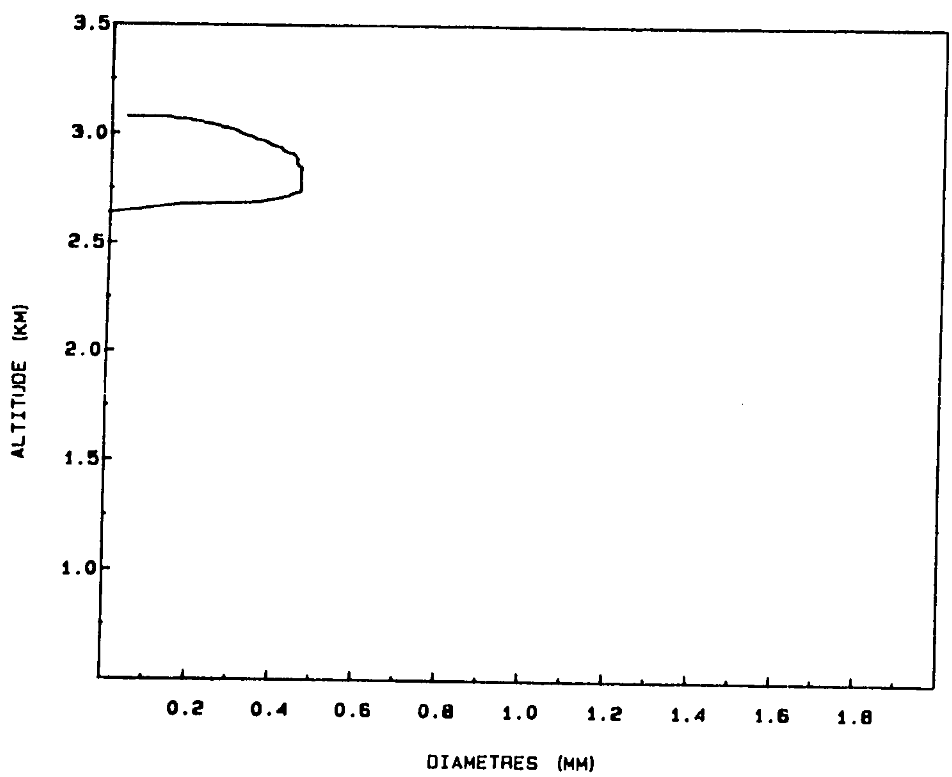


Figure 8.11. - Plumes of nuclei originating from each ground generator on January 27, 1989, at 0000 CUT. The + indicates the nucleation point, and the * indicates fallout point on the ground.



(a)



(b)

Figure 8.12. - Plume of nuclei showing the vertical dispersion (a) of AgI crystals from a ground generator and the trajectory of a particle created by seeding on January 12, 1988, at 0000 CUT. Evolution of particle size (b) created by ground seeding from nucleation to evaporation on January 12, 1988, at 0000 CUT.

8.3 Orographic Precipitation Modeling

8.3.1 Introduction. - The Atlas Mountains of Morocco consist of a barrier oriented southwest-northeast that, during most winter storm events, forces moist air to rise and condense a portion of its moisture, some eventually falling as precipitation. This natural process, known as an orographic precipitation process, is generally well known and has long been observed over other mountainous areas of the world. Knowledge of the distribution in space and time of winter precipitation over mountainous areas is of considerable value to societies for establishing their water consumption strategies. These societal needs and recognition by scientists of the orographic precipitation processes have led to the development of mathematical models that simulate orographic precipitation over mountain barriers.

Programme Al Ghait requires daily weather forecasts during the operational season. It also requires a capable and efficient statistical evaluation of cloud seeding effects. Because of previous success in the use of an orographic precipitation model for the purposes of weather forecasting and weather modification evaluation (Rhea, 1978; Armstrong and Williams, 1981; Medina et al., 1979), it was decided to adapt a model for use in Morocco. Specifically, an orographic precipitation model would be adapted for (a) daily operational use in the development of a quantitative precipitation forecast, and (b) development of an additional statistical covariate or explanatory variable to help forecast what the target streamflow would be without seeding.

Some very complex models are currently available, known as orographic cloud models, that attempt to simulate complex cloud processes in substantial detail. These models require considerable computer resources and are mostly used for research purposes. Orographic precipitation models are less complex; they simulate fewer cloud processes but attempt to include the most important ones that account for much of the mountain winter precipitation. Orographic precipitation models are fast-running on microcomputers and require only routine sounding data as input. Therefore, they can be employed operationally.

The adaptation of an existing orographic precipitation model to Morocco required substantial analysis and computer programming. The opportunity to accomplish the adaptation arose when Mr. El Majdoub, who was pursuing an M.S. degree in Meteorology at the South Dakota School of Mines and Technology, decided to adapt the Rhea model as part of his research (El Majdoub, 1989).

8.3.2 The Rhea orographic precipitation model. - The Rhea orographic precipitation model (Rhea, 1978) has been employed in the United States with good success. It is an empirical model that uses the 700-millibar wind to predict orographic effects. (The 700-millibar level is approximately 3 kilometers above mean sea level.) Details about the original model and its adaptation to Morocco are given by Rhea (1978) and El Majdoub (1989), respectively. Only a brief description of the model is included here.

The Rhea model is two dimensional, steady state, and multilayer. It accounts for moisture flow from any direction and terrain effects such as rate of rise and "shadowing" by upstream mountain barriers. The desire to simulate shadowing and some restrictions, such as operating in two dimensions, imposes the requirement for a topographic grid unique to each wind direction. Rhea (1978) indicates that a terrain elevation grid for each 10° in azimuth is sufficient. Since the model is steady state, it requires upper air information valid for a specified duration.

The requirement to simulate shadowing suggested a coordinate framework that follows air parcels. In this Lagrangian coordinate system, the model keeps track of condensate formation or evaporation as air layers experience vertical displacements in interaction with the underlying topography. In sinking, part or all of an air parcel's cloud water may evaporate. Because the model is multilayer, precipitation falling into a subsaturated layer will partially or totally evaporate. In time, precipitation developed at higher layers reaches the ground, provided it is not fully consumed by evaporation.

The 700-millibar wind direction must be specified as falling into one of thirty-six 10° sectors. The model employs 36 separate gridded arrays of topography, one for each wind direction class, at a selected grid spacing that for Morocco was set at 10 kilometers. The 700-millibar wind direction estimated at the center of the area of interest determines which of the 36 arrays is to be used for model computations.

A spatially constant precipitation efficiency is used in the model. A functional relationship, $E = -kT_c$, where E is the precipitation efficiency, k is a positive constant, and T_c is the temperature in degrees Celsius of the highest layer with relative humidity equal to or greater than 65 percent, gives satisfactory results provided E is not allowed to exceed 25 percent.

The model employs simple formulations in accounting for blocking at low layers and for streamline vertical displacement. Enhanced streamline displacement over the highest terrain is used to simulate the effects of convection. When atmospheric sounding data are available for three or more locations, the model can include some effects of large-scale vertical motion.

The model requires as minimum inputs estimates of the vertical profiles of wind, temperature, and humidity at the upwind edges of the area of interest. When available, estimates of the large-scale vertical motion are inserted in the model. If the latter estimates cannot be obtained from weather maps or computed from input data, then this feature is turned off in computations. Since the model is steady state, frequent updating of the input information will improve model performance.

8.3.3 Adaptation of model to Morocco. - Although the Rhea model can be used with a 5-kilometer grid spacing, it was decided to adapt a 10-kilometer version for use in Morocco. A 10-kilometer elevation grid, in the 270° azimuth orientation, was developed by averaging elevations read every 5 kilometers from topographic maps for the geographical area of interest shown in figure 8.13. The resulting grid contained 35 columns and 45 rows of grid points, and thus was 340 kilometers wide (east/west) by 440 kilometers long (north/south). The resulting smoothed model topography is given in figure 8.14.

The model produces integrated precipitation at each 10-kilometer grid point of a selected 450- by 350-point grid array. To estimate precipitation at locations of interest, such as Azilal or Bin El Ouidane reservoir, an interpolation scheme using surrounding grid point values is employed. The model also produces integrated volume precipitation for designated watersheds for periods of choice. Watersheds are described by demarcation of grid points representing the area partially or wholly contained within watershed boundaries. The volume precipitation can be quickly estimated by the model for a given day, month, or months for a drainage such as the program's target area.

A schematic of inputs to and outputs from the model is given in figure 8.15. It was found that use of input soundings from Beni Mellal gave better results than the use of soundings from Casablanca and Agadir, so discussion in this chapter is limited to results using Beni Mellal soundings. Interpolated soundings contain the input wind, temperature, and humidity data in a special format required by the model. The input "stations' coordinates" refers to locations on the 270° grid of sites for which point precipitation amounts are desired. On the output section of the schematic, "gridded precipitation patterns" refers to grid arrays of precipitation values computed by the model for each input sounding, or grid arrays of sums computed from a specified group of soundings.

Table 8.1 is a list of sites for which the model calculates precipitation (El Majdoub, 1989). The table also shows station elevations and coordinates on the 270° grid.

Table 8.1. - Stations used for "point estimation" calibration of the Rhea model, with their elevations in feet (m) and x-y coordinates in tens of kilometers (from El Majdoub, 1989).

No.	Station	Height		x	y
		ft	m	(dkm)	(dkm)
0001	Azilal*	4690	1430	22.10	22.20
0002	Khenifra*	2788	850	30.17	33.15
0003	Azrou*	4100	1250	34.20	38.80
0004	Beni Mellal	1548	472	24.00	26.40
0005	Demnate*	3572	1089	17.95	19.90
0006	Amizmiz	3280	1000	6.20	13.90
0007	Bin El Ouidane*	2657	810	25.00	24.40
0008	Agaiouar	5925	1806	10.35	14.50
0009	Asloun	3789	1155	13.20	15.55
0010	Asni	3939	1201	8.50	14.13
0011	Ijoukak	4593	1400	6.90	11.40
0012	Toufliht	4806	1465	14.85	16.40

*These stations are downwind of seeding locations, so the observed precipitation used in this study might have been partly seeded precipitation. This will introduce additional noise into the data. This should be kept in mind when interpreting the results.

The model adaptation process involved sensitivity analyses to determine the preferred settings for several important model parameters. Final settings yielded estimates of precipitation that were closer to actual measurements. El Majdoub (1989) studied the effect on precipitation measurements primarily of different settings of (a) relative humidity thresholds, and (b) parameters controlling the extent of air layer streamline vertical displacement. Model outputs obtained with systematic changes in parameter values were compared with observed values for the 12 stations given in table 8.1, and correlation values were calculated to better determine model parameter performance.

The input data set employed by El Majdoub (1989) consisted of the project soundings taken at Beni Mellal and daily precipitation for the 12 stations listed in table 8.1. Analyses were conducted with daily information and monthly sums. In the daily analyses El Majdoub employed a model input data set consisting of soundings for 40 days from January through April and November and December 1987 and precipitation measurements that were properly synchronized in time with the soundings. The 40 days included only those where either the computed or the observed precipitation, or both, was nonzero. For the monthly analyses, the input data consisted of monthly sums obtained from the daily results. However, with monthly data, the soundings and precipitation measurements were not limited to 1987 as all other data (from Beni Mellal soundings) were employed when periods contained few missing cases.

Tables 8.2 and 8.3, from El Majdoub et al. (1989), show the correlation coefficients for 12 runs representing 12 different parameter settings with monthly data and correlation coefficients for daily data cases with a single setting of model parameters, respectively. The fraction of the variance in monthly precipitation explained by the model for Azilal and Bin El Ouidane is 0.85 and 0.69, respectively, both quite respectable values.

In the daily data analyses, three stations were employed due to their superior data quality and better synchronization in time with the soundings. Also, only one setting of parameter values was employed because the results of the monthly analyses indicated that no noticeable improvement in the correlation coefficients could be expected from adjustments to the parameters.

Table 8.2 shows that the correlation between predicted and observed precipitation is insensitive to parameter settings when monthly data are employed. In the case of Azilal, for example, the correlation between computed and measured precipitation varied between 0.898 and 0.918 for different parameter settings. Larger variations than that occurred from station to station, reflecting variations in the model's ability to forecast for specific sites. Variation in model capability among sites is likely due to differences in, for example, the relative importance of orographic and convective precipitation and "shadowing" by upwind ridges (El Majdoub, 1989). Stations at lower elevations typically receive less orographic precipitation, which the model was designed to simulate. Station location with respect to Beni Mellal, where the soundings are taken, is also important since the representativeness of the sounding data for each station is a function of distance from Beni Mellal.

The model's inability to simulate convective cloud processes accurately is an important deficiency. The model employs a simple adjustment of the streamline vertical displacement over the highest barriers to simulate convection. Other potential negative influences include inferior data quality and effects of the relatively coarse 10-kilometer grid spacing.

Tables 8.2 and 8.3 show that the correlation values for Azilal drop from about 0.91 with monthly sums to 0.76 with daily data. A similar drop occurs for Bin El Ouidane, from 0.82 to 0.73. This is not surprising, as some smoothing takes place in the computing of monthly sums.

Note that the regression line, which was derived by the least-squares method, has a negative intercept. This fact indicates that the model is somewhat underestimating the daily precipitation.

Table 8.2. - Correlation coefficients obtained for 12 runs for 12 stations
(from El Majdoub, 1989).

Station	El. (m)	1	2	3	4	5	6	7	8	9	10	11	12
Azilal	4690	0.911	0.916	0.910	0.915	0.910	0.898	0.916	0.918	0.910	0.907	0.911	0.911
Khenifra	2788	0.457	0.460	0.455	0.459	0.438	0.441	0.459	0.473	0.469	0.468	0.458	0.457
Azrou	4100	0.614	0.619	0.615	0.619	0.637	0.593	0.606	0.595	0.603	0.603	0.615	0.624
Beni Mellal	1548	0.577	0.577	0.583	0.583	0.580	0.572	0.584	0.597	0.570	0.574	0.578	0.576
Demnate	3572	0.675	0.680	0.670	0.676	0.670	0.663	0.679	0.675	0.676	0.680	0.675	0.673
Amizmiz	3280	0.317	0.312	0.313	0.320	0.314	0.321	0.312	0.308	0.325	0.333	0.317	0.315
Bin El Ouidane	2657	0.825	0.833	0.820	0.829	0.823	0.802	0.828	0.828	0.821	0.826	0.825	0.807
Agaiouar	5925	0.596	0.583	0.600	0.600	0.599	0.592	0.592	0.592	0.592	0.606	0.597	0.595
Asloun	3789	0.836	0.842	0.838	0.838	0.852	0.827	0.837	0.828	0.839	0.841	0.836	0.833
Asni	3939	0.748	0.747	0.750	0.750	0.747	0.743	0.747	0.548	0.747	0.744	0.744	0.748
Ijoukak	4593	0.508	0.536	0.524	0.553	0.503	0.506	0.499	0.502	0.503	0.556	0.514	0.507
Toufliht	4806	0.510	0.511	0.511	0.510	0.511	0.516	0.498	0.490	0.513	0.474	0.504	0.506

Table 8.3. - Some statistical parameters for the daily run
(from El Majdoub, 1989).

Station	Elevation (ft)	Regression correlation	Regression intercept (mm)	Regression slope
Azilal	4690	0.764	-3.9	0.98
Bin El Ouidane	2657	0.725	-2.3	0.94
Khenifra	2788	0.353	0.3	0.12

Scatter plots of computed versus observed precipitation for Bin El Ouidane on a monthly and daily basis are given in figures 8.16 and 8.17, respectively. These figures express the linear relationship between model-computed and observed precipitation. A feature of note in the daily analysis is the rather large number of zero precipitation events computed by the model that are actually nonzero. This result warrants some additional exploratory work, as there may be some resolvable systematic effects not currently properly accounted by the model.

8.3.4 Summary of model results. - Analyses during the adaptation of the model to Morocco indicated that correlation values were largely unaffected by altering model parameter values, suggesting that settings are close to their optimum value in the current version of the model. High correlations were obtained for some stations, indicating the prominence of winter orographic precipitation at those sites and ample model ability for its determination. For some stations, particularly those at low elevations, the model estimated precipitation poorly. Additional exploratory analyses with the model should lead to some improvement in estimates for stations at middle elevations.

The model also produced estimates of precipitation volumes for the project's target and control areas for each sounding and for desired groups of soundings (time periods). The correlations between the predicted precipitation volumes and actual streamflow measurements for the periods of interest were calculated. Some results of this process are given in chapter 9. The correlations obtained for monthly data were about 0.4. The low correlation reflects, in part, water storage processes in the snowpack at high elevations. The model estimates current precipitation that may not run off for several months. This suggests that the model's ability should improve substantially with seasonal data.

A seasonal analysis requires preproject, historical sounding information, which is available only from Casablanca and Agadir. It was recognized that soundings at those two stations would not represent conditions over the Atlas Mountains as well as soundings from Beni Mellal. In addition, a review of the Casablanca and Agadir data indicated that about 25 percent of the soundings were missing. Nevertheless, model runs with the available data produced estimates of seasonal volume precipitation which were correlated with seasonal streamflow, the correlation coefficients being around 0.4. Predictions of volume precipitation for shorter time periods based on Casablanca/Agadir soundings showed no significant correlation with streamflow. The model prediction of seasonal volume precipitation was found to be a useful covariate for the statistical evaluation. The results of the analyses using the additional covariate are given in chapter 9.

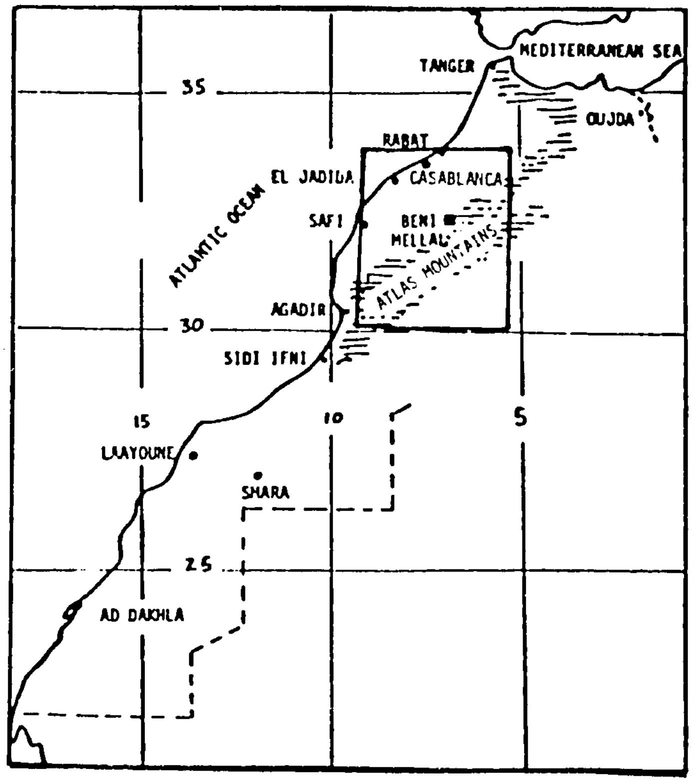


Figure 8.13. - Model domain (heavy line rectangle) in Morocco (figure from El Majdoub, 1989).

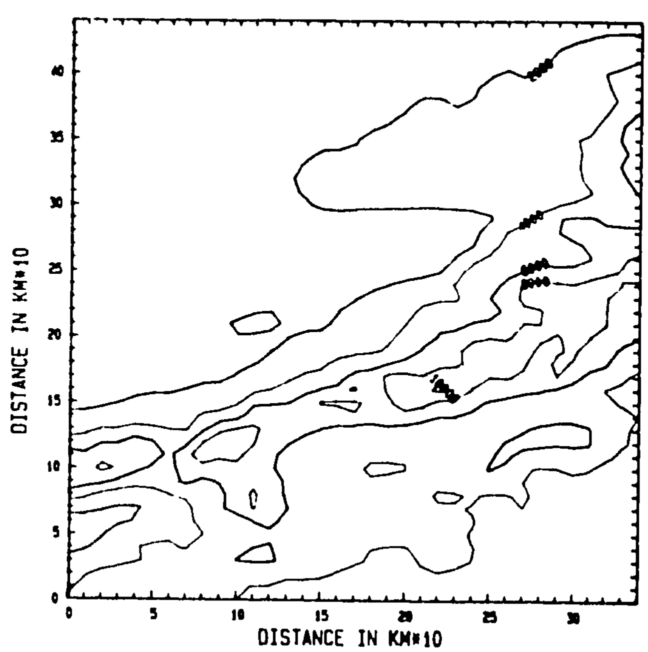


Figure 8.14. - Model topography obtained using a 10-kilometer grid interval. Elevation contours are in feet (from El Majdoub, 1989).

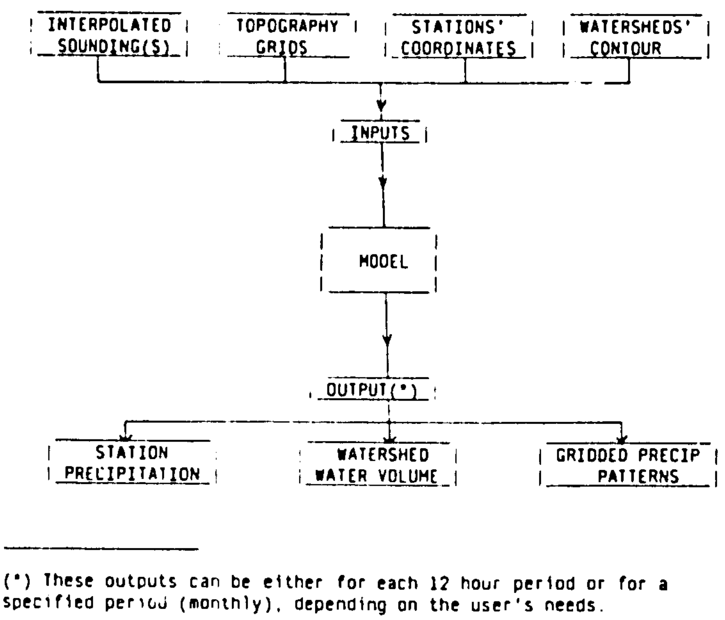


Figure 8.15. - Diagram showing model inputs and outputs (from El Majdoub, 1989).

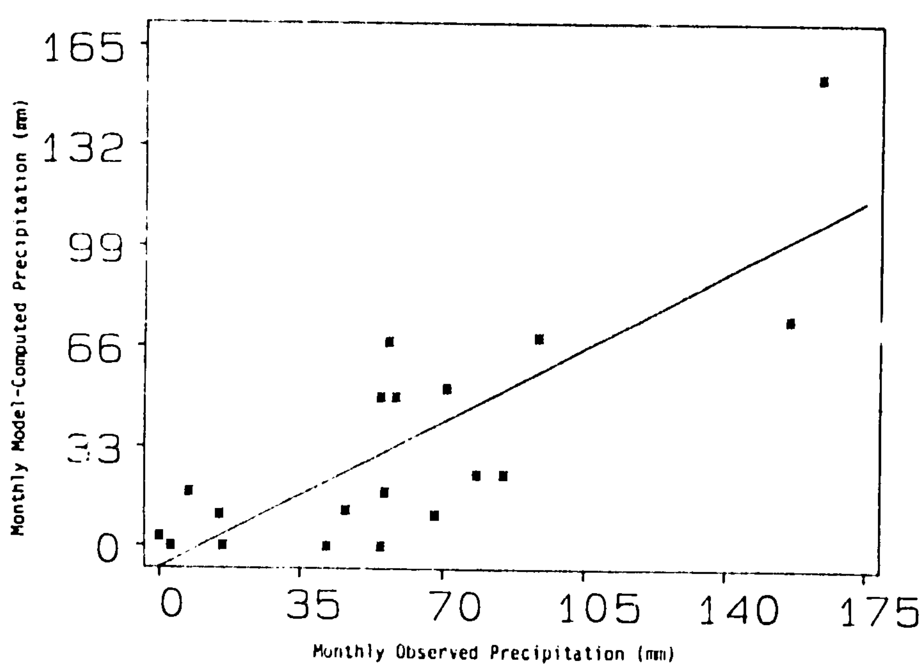


Figure 8.16. - Scatter plot of model-computed versus observed monthly precipitation for Bin El Ouidane (El. = 2657 ft; correlation = 0.83) (from El Majdoub, 1989).

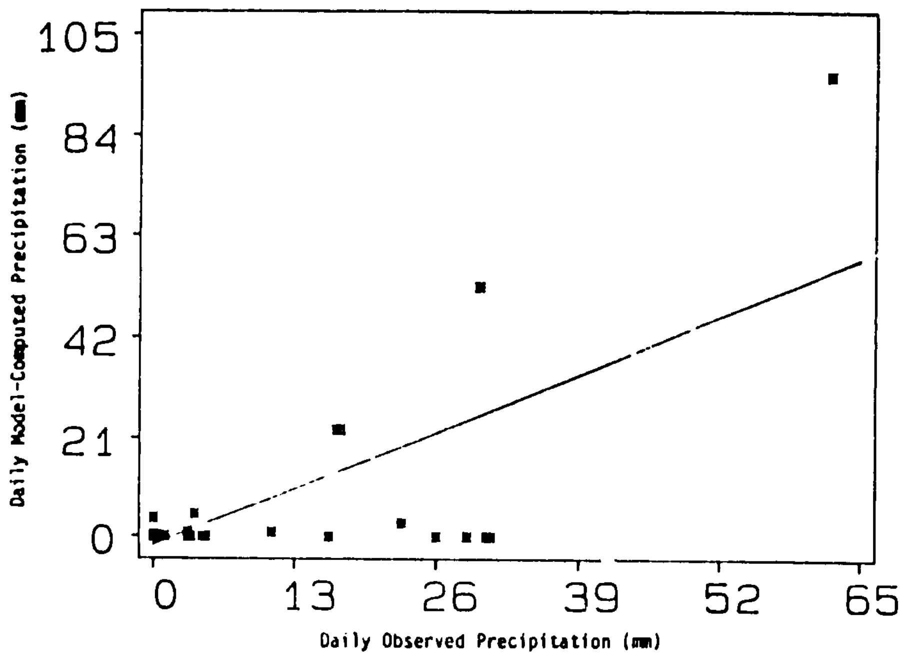


Figure 8.17. - Scatter plot of model-computed versus observed daily precipitation for Bin El Ouidane (correlation = 0.73) (from El Majdoub, 1989).

8.4 Radar Echo Studies

8.4.1 Radar description and capabilities. - As previously noted, one of the principal items of equipment provided to Morocco through Programme Al Ghait was the first meteorological radar system ever used in Morocco. The radar is a 5-centimeter wavelength 1.6° beam radar, transmitting a peak power of 250 kilowatts. The characteristics of the radar are described in section 4.6.2.

The radar, located on a shallow plateau near the town of Khouribga at an elevation of 778 meters, midway between the Atlantic coast and the Atlas Mountains (figs. 8.18 and 8.19), is well positioned to observe storms approaching from the west or northwest, as well as to command a clear view of the target area. At low elevation angles, however, the ground return from the Atlas Mountains limits quantitative analyses of the radar echoes in the target area.

The primary purpose of the radar is to support project operations. In particular, it is critical to synoptic analysis of the current weather, short-range forecasting (nowcasting), and operational decisionmaking. The radar is also used to advise the aircraft crews of hazardous weather to be avoided and promising areas for seeding. The radar has an IFF system to track project aircraft, which aids greatly in coordinating aircraft movements.

8.4.2 Data collection procedures. - In addition to its operational uses, the radar records digital data on 8-inch floppy diskettes for subsequent archival or analysis. During radar operations, the operator takes a regular sequence of PPI and RHI scans every 15 minutes to document the storm history.

Each scan recorded must be specifically requested by the radar operator. To record data, the operator must select either a PPI or an RHI scan and manually initiate the recording sequence. PPI scans are usually made at an elevation angle of 0.5° to permit surveillance of approaching storms. At this elevation, however, the ground return from the Atlas Mountains is quite large. To minimize the ground return, PPI scans intended for quantitative analyses are usually recorded at an elevation angle of 1.8°. In addition to the PPI scans, individual RHI scans are also recorded to document the vertical structure and extent of the precipitation being recorded.

Figure 8.20 shows a black-and-white grey shade reproduction of the digital radar PPI data for the region from Casablanca to the High Atlas Mountains on January 17, 1988 (fig. 8.20a) and a convective band in the southeast quadrant of the radar on February 21, 1989 (fig. 8.20b). Note the effect of ground clutter from the Middle Atlas Mountains between 50 and 100 kilometers from the radar in the southeast quadrant.

8.4.3 Quality control and data management. - As recorded on diskette, the radar data can only be played back on the Z-80 microcomputer system and display device provided by CIC, which is usually located at the radar site in Khouribga. In addition, the data files are relatively large and rapidly fill the 8-inch diskettes. To solve these difficulties, Mr. Nhou developed a data compression routine that reads the binary data and radar calibration files from the 8-inch diskette, writes a summary of the housekeeping data for that file (for example, if the file is a PPI, the housekeeping information would include the time, date, and elevation angle of the radar and the total number of range bins that contain echo), applies the correct calibration for that day's data, and prepares a compressed ASCII-format data file of the calibrated radar data. This compressed data file is more efficient in storing the data than the original binary data on the 8-inch diskettes. Using this more efficient method of data storage, a single diskette can usually hold all the radar data recorded on a single day.

By running the data compression program, the radar technician or data analyst verifies the accuracy of the data collected, generates a summary file that serves as the primary data management information for the radar data, and stores the data in its archive format, all in a single operation. If difficulties are subsequently identified in the condensed ASCII data archives, the data can be easily read using a standard text editor and usually can be corrected without loss of data.

In addition, a separate program has been written to display graphically the calibrated radar data as a function of range (a pseudo A-scope display). This display allows easy monitoring of many of the factors affecting the overall calibration of the radar data and can give a rapid quality control check of the collected data.

8.4.4 Display and analysis of data. - As part of the scientific collaboration between the American and Moroccan scientists, Mr. Nbou and Dr. Johnson have developed software to analyze and display the compressed ASCII data. This program was developed to operate on any of the project IBM PC/AT personal computers. Separate programs were written for PPI and RHI data. The color display can be centered on any interesting portion of the radar echo and can be enlarged as much as necessary to show all the relevant details of the echo structure. In addition, the display can be combined with other available software to produce time animations, animated loops of the echo evolution, or both.

Such displays can be used to view the echo growth and evolution as a storm approaches Morocco and moves into the project area. When the PPI and RHI views of the storm and its evolution are combined, the scientist has a good overall view of the storm structure that augments the information available from other data sources – an important part of any storm case study. In addition, by monitoring the storm as it moves through the project area, it is possible to obtain estimates of the area coverage and duration of the storm in the target area. These estimates form an important part of the regions-of-potential approach for estimating the magnitude of possible seeding effects.

8.4.5 Target-control analyses. - An alternative analysis offers the possibility of me quantitative evaluation of the seeding effects on echo structure. For this analysis, three areas w[illegible] designated. These areas (figs. 8.18 and 8.19) are all identical in size and in distance from the radar. The northern and southern areas are termed the north and south control areas, respectively; the central region (which includes most of the area in which seeding is concentrated) is termed the target area. While all three areas have terrain features that can provide orographic lifting, it is apparent that the terrain in the target area is more mountainous and will have greater likelihood of an orographic effect, as well as greater amounts of ground return. The most direct comparison between the target and control areas would be a simple intercomparison of the area covered by radar echoes and their magnitude (a measure of precipitation intensity). This approach, however, is suspect since the ground return is likely to be different in the three areas, and it would be impossible to guarantee that the differences in echo properties actually represent a real difference in the falling precipitation. Limiting the analysis to elevation angles of 1.8° or greater will help, but does not completely solve this difficulty.

A better approach is to examine the time evolution of the echoes properties in target and control areas. Figure 8.21, for example, shows the evolution with time of the areas filled by radar echoes in the target area and in the northern control area. Only data collected at an elevation angle of 1.8° have been included in this analysis. In this case (March 4-5, 1988), the storm moved in from the southwest, as evidenced by the earlier onset of precipitation in the target area as compared to the northern control area. Seeding generators were turned on well in advance of the storm's arrival. Before the storm reached the mountains, neither the target nor the control area contained any significant radar echoes. As the storm passed, both the target and control areas showed significant areas of precipitation. Precipitation in the target area, however, was uniformly more intense (by a factor or 2 to 3).

8.4.6 Radar-rain gauge comparison. - If the radar is to be used for quantitative measurements of precipitation, it must be carefully calibrated. As a check of the radar calibration, a detailed examination was conducted of the precipitation over Beni Mellal during two storms in February 1989, as measured by a recording rain gauge at Beni Mellal and by the project radar at Khouribga (about 75 km from Beni Mellal).

Data from the recording rain gauge were analyzed in 15-minute intervals during the storm passage. The radar estimate of the precipitation was made using the standard Marshall-Palmer relation:

$$Z = 200\ R^{1.6}$$

where Z is the radar reflectivity factor in mm^6 per cubic meter, and R is the rainfall rate in millimeters per hour. Reflectivity factors for the nine range bins closest to the rain gauge location were averaged, and the average was used to estimate the precipitation intensity. The radar estimates of precipitation intensity were converted into the same 15-minute time intervals that were used in the rain gauge analysis. The results for the storm of 10 February are shown in figure 8.22. For this case, there was a correlation coefficient of 0.81 between the two estimates of precipitation. The correlation coefficient increased to 0.90 when data from both storms were used.

8.4.7 Radar echo characteristics. - A number of different studies of the properties and characteristics of the precipitation echoes have been performed by Mr. Nhou. In one analysis, he classified the radar echoes as band, cell, or multicell. Band echoes were identified by the presence of a single elongated echo or a group of echoes orientated along a common linear axis and having a common history. Cellular echoes were individual echoes having maximum reflectivity factors of 20 dBZ or greater and lifetimes of 30 minutes or more. Multicellular storms were more complex systems formed by the merger of individual cells, in which the constituent cells maintained a separate identify. Band echoes were often associated with either westerly or northwesterly flow and seem to be associated with clouds of class C1 (sec. 8.1.3). In every case examined, the passage of a cold front was marked by a single radar band. The cellular echoes were generally associated with postfrontal convection (class C2). In general, postfrontal echoes were of moderate intensity with rather low echo top heights.

Figure 8.23 shows the distribution of echo types by synoptic situation. Four different synoptic classifications were used, based on an analysis of the synoptic data and satellite imagery:

postfrontal, frontal, prefrontal, and airmass. Figure 8.24 shows the distribution of rain areas and water volume as a function of the radar reflectivity factor for one case exhibiting a banded echo structure.

Figure 8.20b shows an example of a moderately intense convective band located about 40 kilometers east to south of the radar along a northeast-southwest axis on February 21, 1989. The line of echoes farther southeast at 80 to 100 kilometers is the front ridge of the Middle Atlas Mountains.

8.4.8 Summary. - The radar has been a valuable addition to Programme Al Ghait. The main role of the radar is to support project operations; but data from the radar have also been used to assist in case studies, define storm areas and duration for ROP analysis, and perform quantitative analyses of echo differences in carefully selected target and control areas.

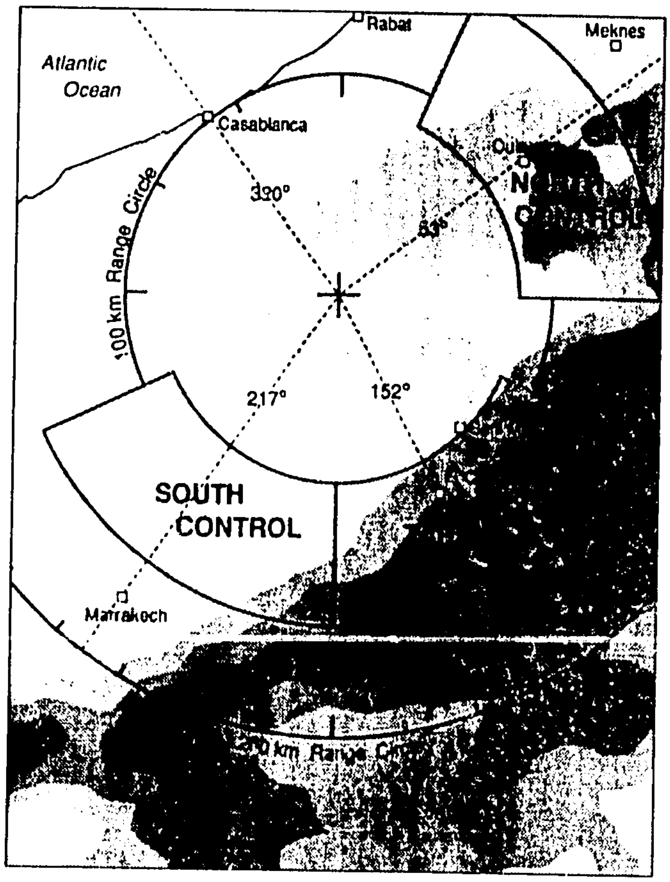


Figure 8.18. - Map showing terrain, radar location, and target and control areas used in the radar analyses. The elevation contours are shaded in 500-meter intervals.

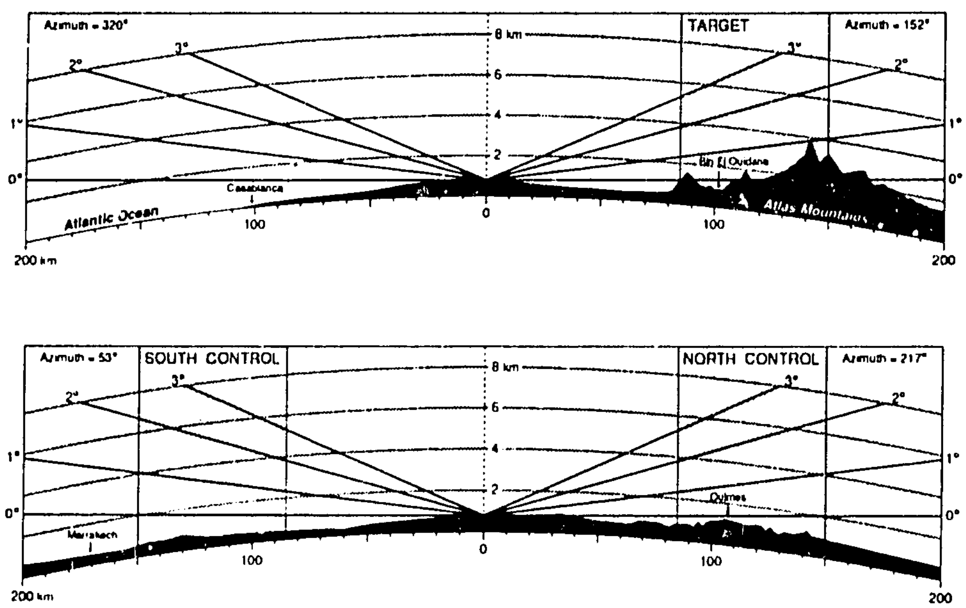
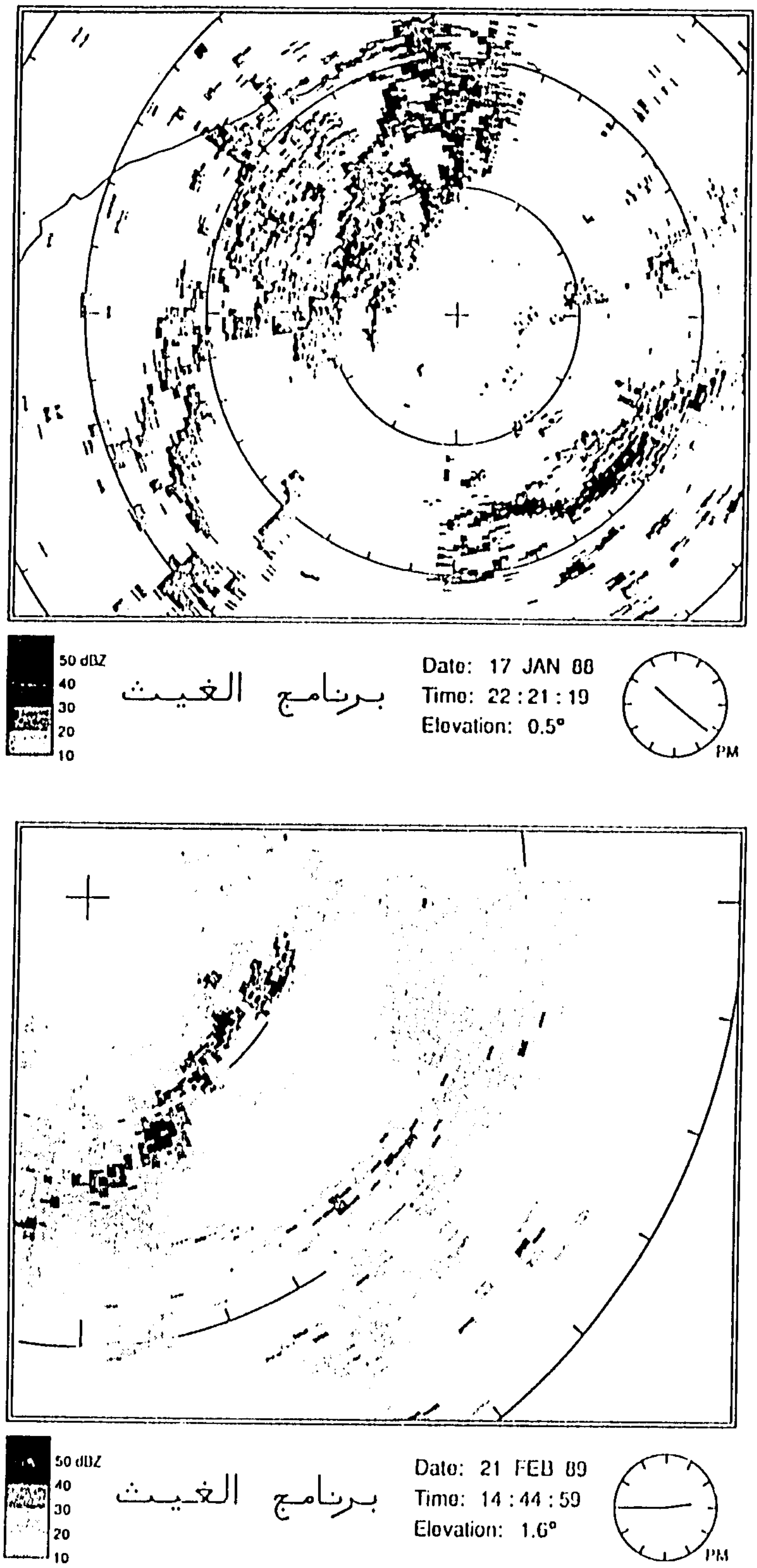


Figure 8.19. - Terrain cross sections along the 53°, 152°, 217°, and 320° radials from the radar site at Khouribga. The curvature of the base line and lines of constant elevation represent the effective curvature of the earth (assuming standard refraction of the radar beam). Solid lines radiating out from the center illustrate the field of view along the 0°, 1°, 2°, and 3° elevation angles.



(a)

(b)

Figure 8.20. - (a) Sample PPI from a storm on January 17, 1988. Range circles are drawn at 50-kilometer intervals. At this elevation angle (0.5°), ground return from the Atlas Mountains southeast of the radar is prominent. (b) A zoomed PPI of a convective echo band in the southeast quadrant of the radar on February 21, 1989, viewed with an elevation angle of 1.6°.

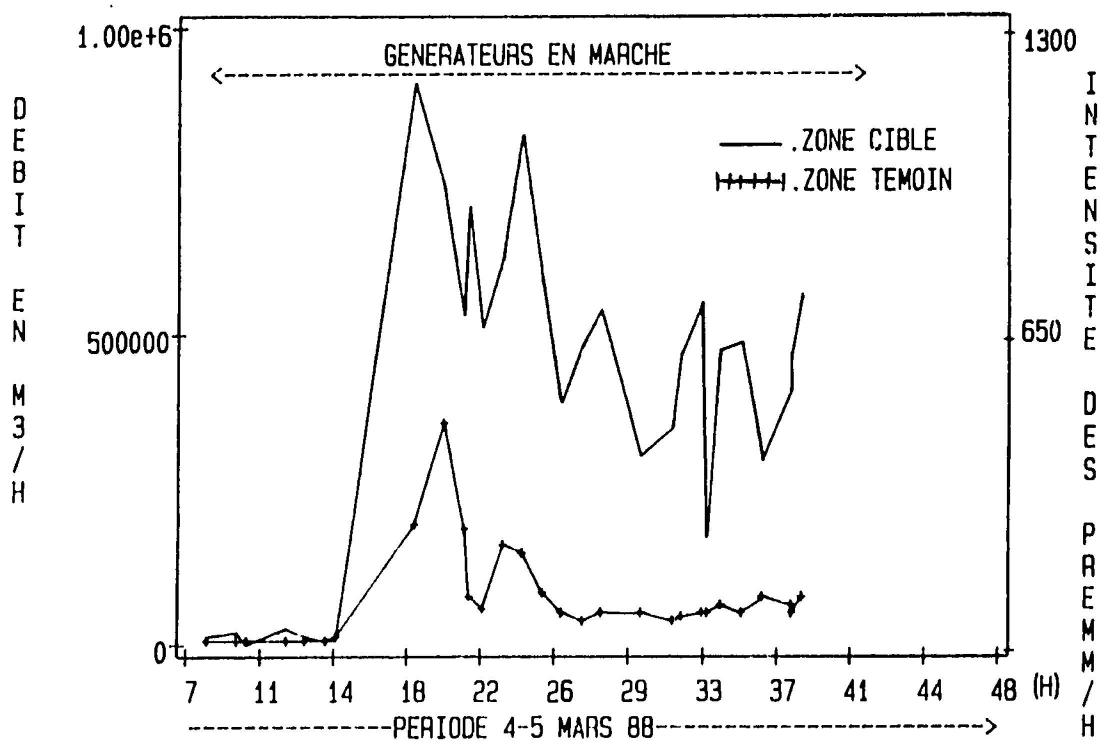


Figure 8.21. - Time evolution of the radar return in the northern control area (ZONE TEMOIN) and in the target area (ZONE CIBLE).

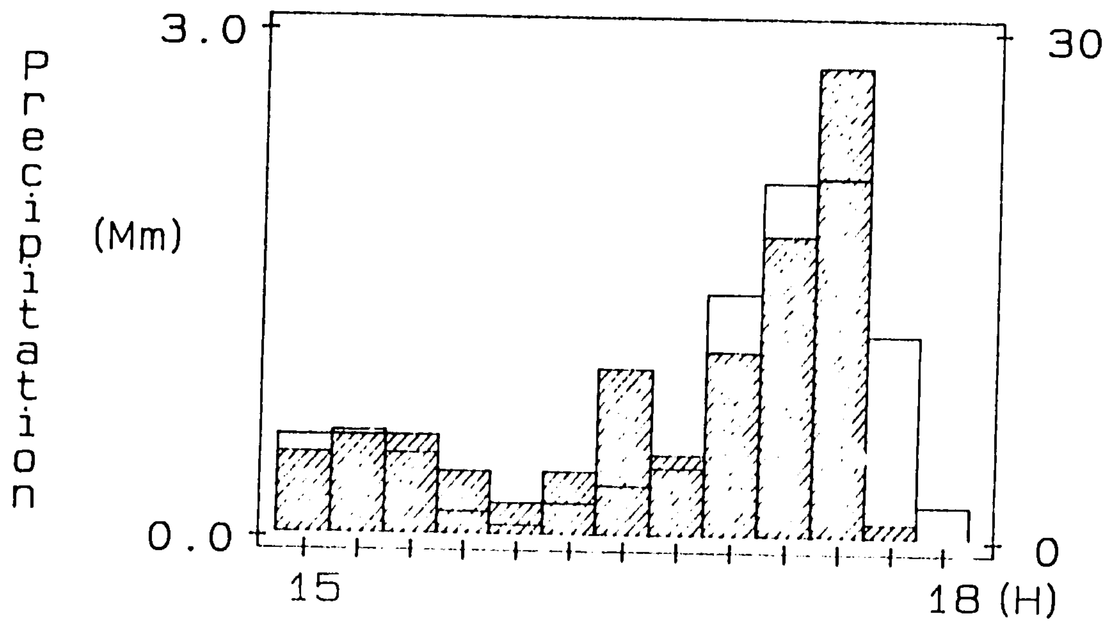


Figure 8.22. - Time evolution of precipitation over Beni Mellal as measured by radar and rain gauge (February 10, 1989).

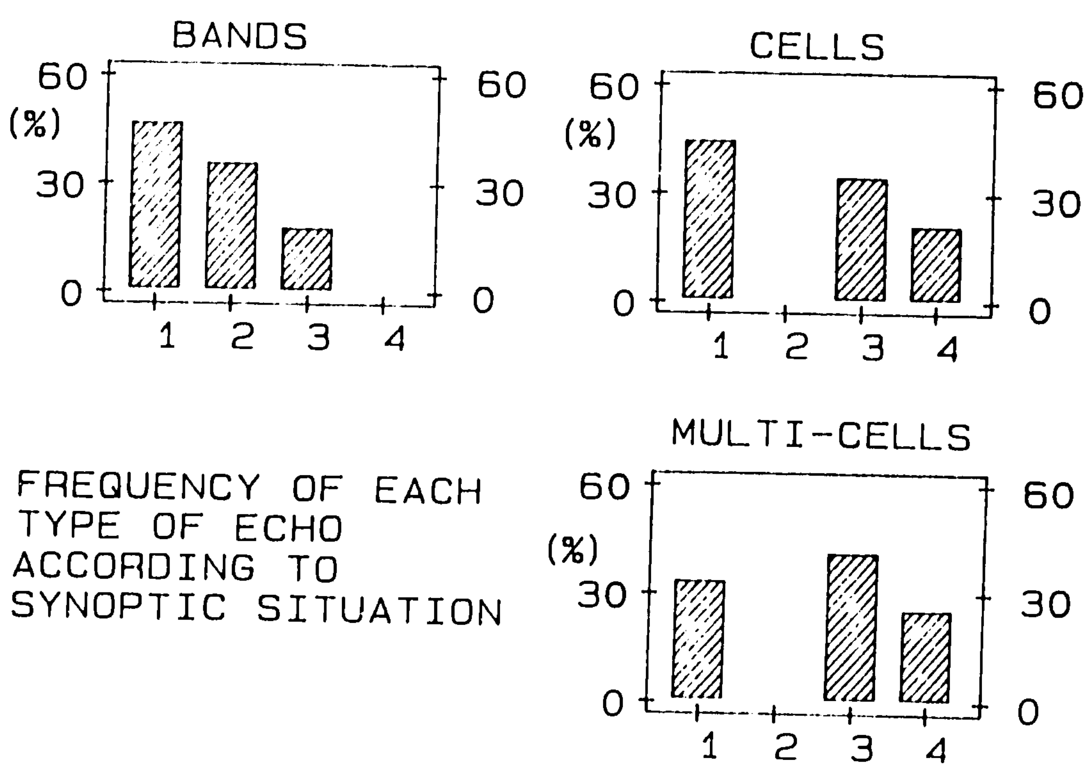


Figure 8.23. - Echo type by synoptic situation. The four types of synoptic situations are (1) postfrontal, (2) frontal, (3) prefrontal, and (4) airmass convection.

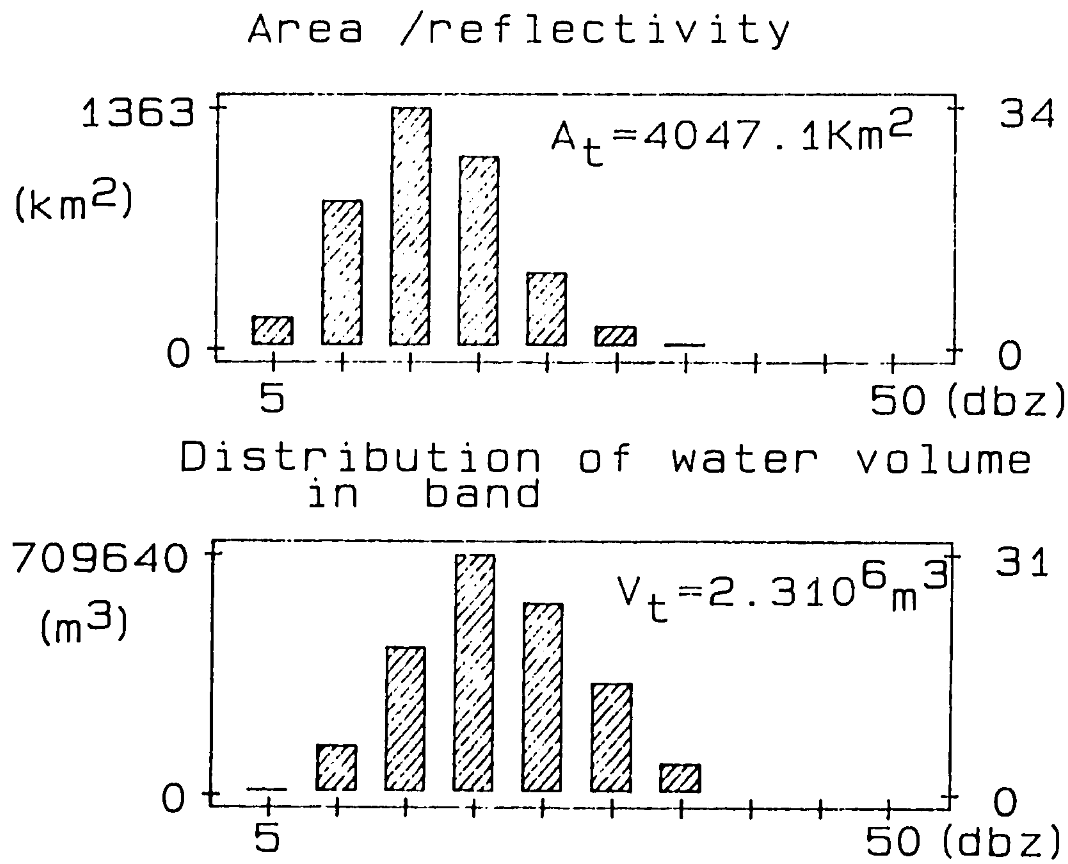


Figure 8.24. - Rain areas (km^2) and water volume (m^3) as a function of radar reflectivity in a banded echo.

8.5 Snow Cover Mapping and Snowmelt Runoff Studies

Use of satellite imagery for mapping of snow cover in the Atlas Mountains was undertaken to support Programme Al Ghait in two instances. In the first case, a retrospective study of a drought year and a year of normal precipitation was undertaken in the Remote Sensing Section of Reclamation's Denver Office. In the second case, follow-on work involving snowmelt and runoff modeling was performed by Mr. Abidi in preparation of an M.S. thesis at the South Dakota School of Mines and Technology.

8.5.1 Objectives of the retrospective snow cover study. - The retrospective snow cover study had two objectives. First, documentation of areas of seasonal snowpack accumulation was desired, since limited snowcourse data were available at the outset of the project. Second, examination of the temporal variation of snow-covered area was undertaken as a possible variable for use in evaluating results of weather modification activities.

8.5.2 Description of the retrospective snow cover study. - A study of satellite images showing snow cover in the Atlas Mountains was undertaken for the winters of 1978-79, a year of normal precipitation, and 1981-82, a drought year. Landsat Multispectral Scanner (MSS) image data of the area were purchased from the Earthnet Programme Office of the European Space Agency in Frascati, Italy. Additional coverage obtained by the Advanced Very High Resolution Radiometer (AVHRR) instruments on board the NOAA and TIROS satellites was bought from the Centre de Meteorologie Spatiale in Lannion, France.

The study area consisted of 15 gauged basins in the Atlas Mountains tributary to the Oum Er Rbia and Tensift Rivers. The basins range in size from 200 to nearly 2500 km^2 and in elevation from 400 to over 4000 meters. They are depicted in figure 8.25. Due to the high cost of digital data in the case of Landsat and limited availability in the case of AVHRR, snow mapping was performed through manual photointerpretation from hard copy image products. Landsat positive transparencies of band 2 (0.6 to 0.7 μm) were interpreted at a scale of 1:500,000. AVHRR visible--band black-and-white prints of scale 1:3,500,000 were interpreted with the assistance of a zoom transfer scope to produce delineations of snow-covered area at 1:1,000,000 scale. Figure 8.26 presents a sample Landsat image. Figure 8.27 presents a sample AVHRR scene of Morocco. The resolution of the original digital Landsat MSS data is 80 meters, and for the AVHRR data it is 1 kilometer. Snow-covered area was interpreted from Landsat images for 16 dates and from AVHRR images for 13 more, for a total of 29 mapping dates over the two winter seasons.

Geographic information system (GIS) software was used to digitize the snow cover interpretations and the basin boundaries and to calculate the proportion of snow-covered area within the basins for each date with available coverage. These proportions were plotted against time for each basin, as shown in figure 8.28. The areas under the curves were also calculated, by simple trapezoid rule, to give a time-integrated measure of snow cover in units of total snow cover days. These results were analyzed statistically to explore differences in snow cover within basins and the correlations in snow cover among the basins under drought and normal conditions.

8.5.3 Results of the retrospective snow cover study. - A series of custom color maps of snow-covered area, in the context of basin boundaries, major rivers, and cities, was produced at 1:600,000 scale for all available dates in the two winters under study. This provided the necessary documentation of the location and extent of seasonal snowpack under drought and normal conditions.

Statistical tests showed that, within basins, the differences in total snow cover days for drought and normal conditions are as significant as those for total streamflow for the same periods. The correlation coefficient between total seasonal runoff and total snow cover days was 0.82. Furthermore, strong correlations between basins were seen for the temporal variation of proportion of snow-covered area. This suggests that target-control pairs might be identified and snow cover differences tracked in the same way that streamflow data are analyzed for evaluation purposes. Snow cover for the basins would have to be performed over a long historical period, however. This would provide the necessary strong correlation between basins prior to the period of weather modification activities. Then, decreases in correlation during the seeding period could be statistically evaluated to assess the impact of those activities.

A more complete discussion of the retrospective snow cover study and its results is provided by Verdin (1986).

8.5.4 Objectives of the snowmelt runoff modeling studies. - The overall objective of these studies was to develop a tool for modeling flows yielded by snowmelt in major river basins of the Atlas Mountains. Such a tool could be used in simulation mode for a variety of studies related to engineering and economic impacts associated with annual fluctuations in quantity of snowpack. In forecast mode, it could be a useful indicator for the development of suspension criteria for weather modification activities and a general tool to support water management decisionmaking related to reservoir operations, irrigation scheduling, and municipal water supplies.

Specific objectives of Mr. Abidi's thesis work were (a) adaptation of the Martinec-Rango Snowmelt Runoff Model (SRM) to the Tillouguit basin of the Atlas Mountains, (b) development of a digital snow mapping procedure using AVHRR imagery collected over Morocco during 1986, and (c) simulation of 1986 flows in the Tillouguit basin as a test of the model.

8.5.5 Description of the snowmelt runoff modeling studies. - The SRM is based on the degree-day approach for modeling the snowmelt process, wherein the melt water released from the seasonal snowpack is assumed to be proportional to air temperature in the basin. The advantage of such an approach lies in its simplicity, since air temperature is a practical index of the complex set of thermodynamic processes making up the snowpack energy balance. Daily air temperature data are ordinarily available in or near almost any basin of interest. The SRM requires only these data, precipitation data, and snow-covered area estimates on a daily basis to generate mean daily flows for a basin, once it has been set up for that specific basin. Setup involves the determination of basin parameters based on its physical characteristics. These include identification of runoff coefficients and melt rate factors for each elevation band into which the basin is divided, an air temperature lapse rate for extrapolation of data to higher elevations, a critical air temperature for classifying precipitation as rain or snow, and a lag time and recession coefficient to describe the manner in which melt water reaches the mouth of the basin. Division of the basin into elevation bands is accomplished through examination of area-elevation curves prepared from topographic data, such as that presented in figure 8.29. Historic streamflow data are used to determine runoff coefficients, the lag time, and the recession coefficients. Figure 8.30 offers a schematic of the SRM and the input it requires to be set up and generate streamflows.

The Tillouguit basin (basin 12 of fig. 8.25) was selected for simulation due to its location in the target area of Programme Al Ghait and its importance to the operation of the Bin El Ouidane reservoir. It is over 2500 km^2 in area and has elevations ranging from 1050 to 3400 meters above sea level. The SRM was set up for the Tillouguit basin using available streamflow, air temperature, and snow cover data for 1979. Air temperature data from the station at Bin El Ouidane were extrapolated to mean hypsometric elevations of elevation bands in the basin using a lapse rate determined from sounding data from Beni Mellal. Melt rate factors and runoff coefficients were allowed to vary until there was acceptable agreement between observed and simulated streamflows.

Digital snow mapping procedures were developed on the IBM PC/AT using the EASI/PACE image processing software of PCI, Inc., of Toronto, Canada. Seven cloud-free digital AVHRR scenes of the Atlas Mountains were available for the February-April 1986 period. Also available was one 80-meter resolution Landsat MSS scene acquired within 24 hours of the February 12, 1986, AVHRR scene. This scene was used to calibrate a histogram cutoff threshold for discriminating between snow-covered and snow-free pixels in the coarse-resolution AVHRR data set. The threshold was extrapolated to AVHRR data sets on other dates by a simple normalization calculation based on solar zenith angle.

Snow cover depletion curves for March 1986 were developed from the results of the digital snow cover mapping just described, and temperature and precipitation data for that month were obtained from Morocco. Using the setup established with 1979 data for the Tillouguit basin, streamflows were simulated with the SRM for March 1986. Measured streamflows for that month were then obtained to evaluate the performance of the model.

8.5.6 Results of the snowmelt runoff modeling studies. - Agreement between measured and simulated flows for the Tillouguit basin in 1979 is presented in figure 8.31. The match is characterized by a seasonal volumetric difference of only 0.5 percent and an accounting for 84 percent of the variation in measured mean daily discharge by the SRM. This is good agreement. The real test of the model, however, is found in the results for March 1986. They are presented in figure 8.32. Here the volumetric difference was 6 percent, and the SRM accounted for 72 percent of the daily variation in discharge. This is a good result, considering that the observed streamflows for March 1986 had no influence on the modeled discharge.

8.5.7 Conclusions. - The SRM has been shown to be a practical tool for modeling streamflows in the basins of the Atlas Mountains. While it may not be sufficiently sensitive to evaluate weather modification, it can produce results of significant utility for engineering and economic studies. Reservoir operations at major facilities, like Bin El Ouidane reservoir, might derive important benefits through its use. If up-to-date AVHRR image data can be provided, then all necessary tools will be present for use of the model in forecast mode. This is because the image processing software and the SRM both reside on the same IBM PC/AT. Full realization of the benefits that might be provided by use of the model now awaits only its refinement for the Tillouguit basin and expansion of its application to other important basins of the Atlas Mountains.

The SRM may provide useful covariates for statistical analyses and evaluation studies. Data sets for extended periods are needed for these studies to develop a sample size large enough to provide historic and seeded information for the period of statistical analysis. The model should be extended to more basins in the target and control areas for more comprehensive coverage of important basins in the High Atlas that provide water to the Oued Oum Er Rbia and the Oued Tensift Rivers.

8.6 Summary of Scientific Analyses

The preceding sections have presented the important initial results from studies that are in progress. While they are preliminary, they indicate the capabilities of the SAET and initial physical results of important studies. These studies should be continued to build larger samples of cases and to broaden the generalizations for the entire 5-year period of the project. This suggestion is expanded in chapters 11 and 12.

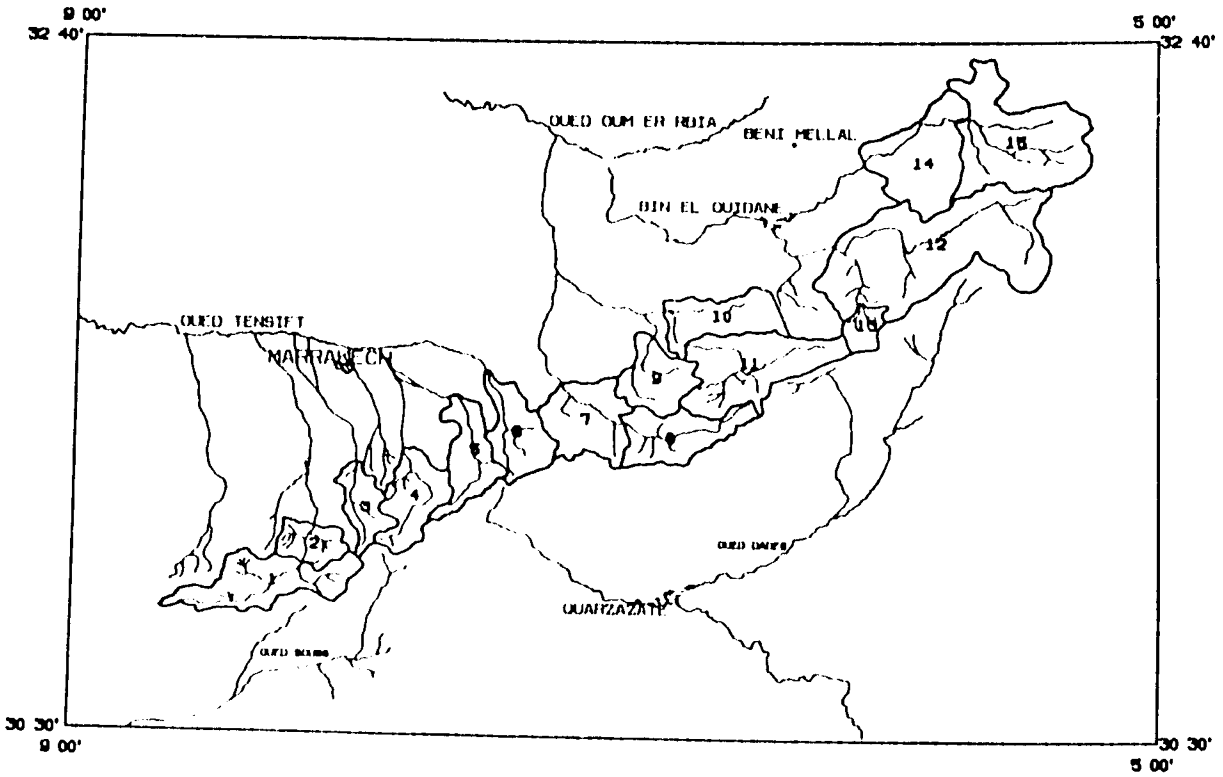


Figure 8.25. - The 15 gauged basins of the Atlas Mountains for which snow cover was mapped in the retrospective study.

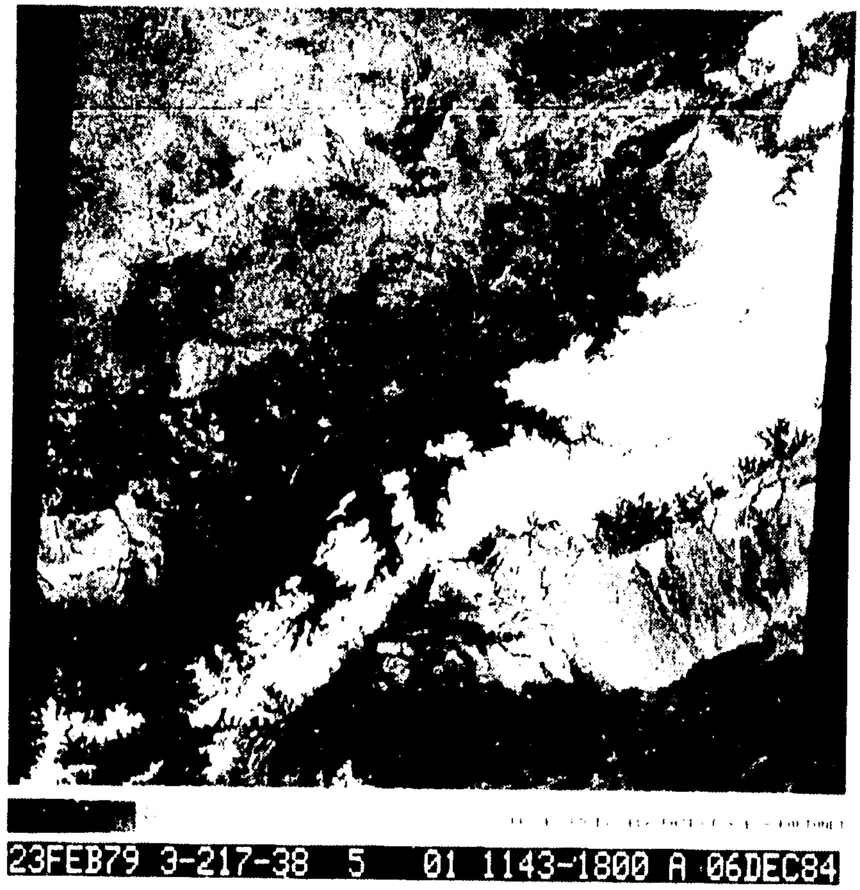


Figure 8.26. - Example Landsat band 2 image of the Atlas Mountains for February 23, 1979, covering basins 2 through 11 of figure 8.25.

Figure 8.27. - Example AVHRR visible band image of Morocco for February 23, 1979.

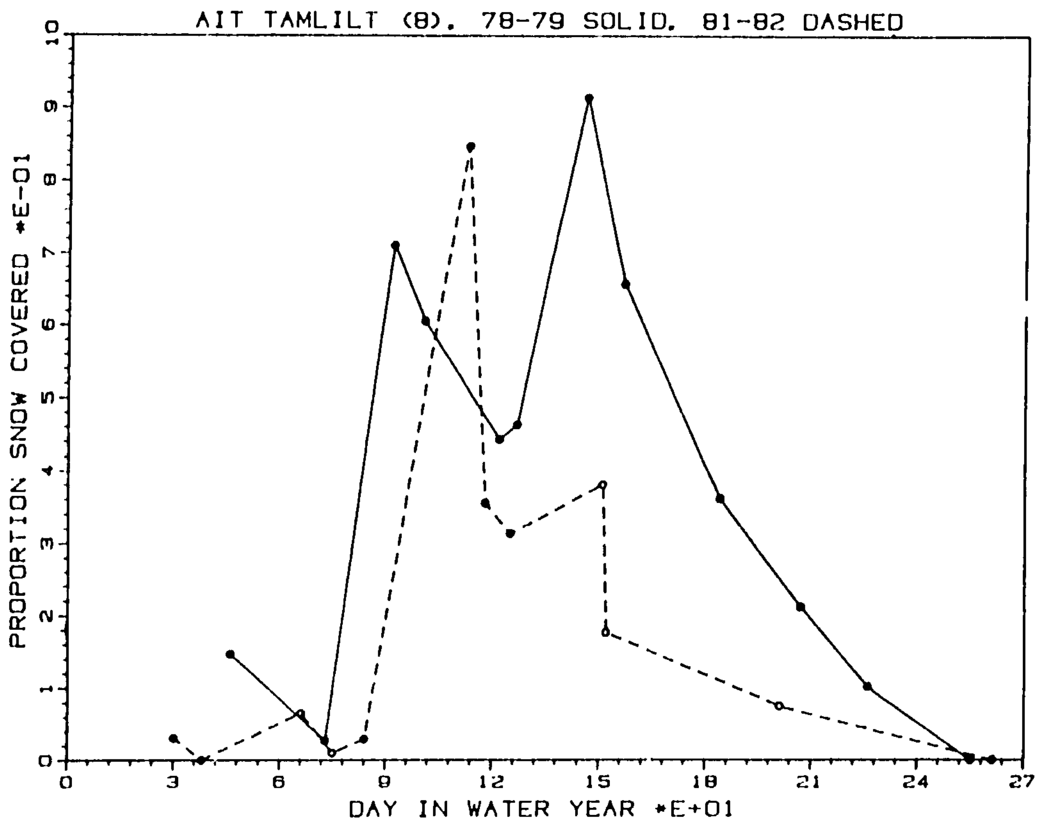


Figure 8.28. - Plot of proportion snow-covered area versus time for basin 8 of figure 8.25, Ait Tamlilt, for the 1978-79 and 1981-82 seasons.

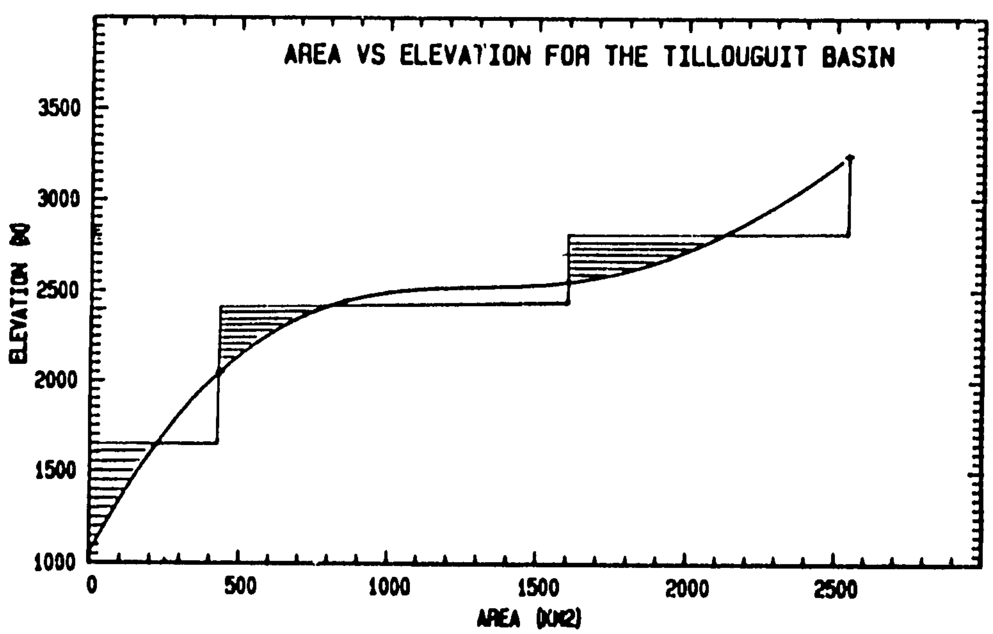


Figure 8.29. - Area-elevation curve for the Tillouguit basin, showing determination of mean hypsometric elevations for each of the three elevation bands used to model snowmelt runoff.

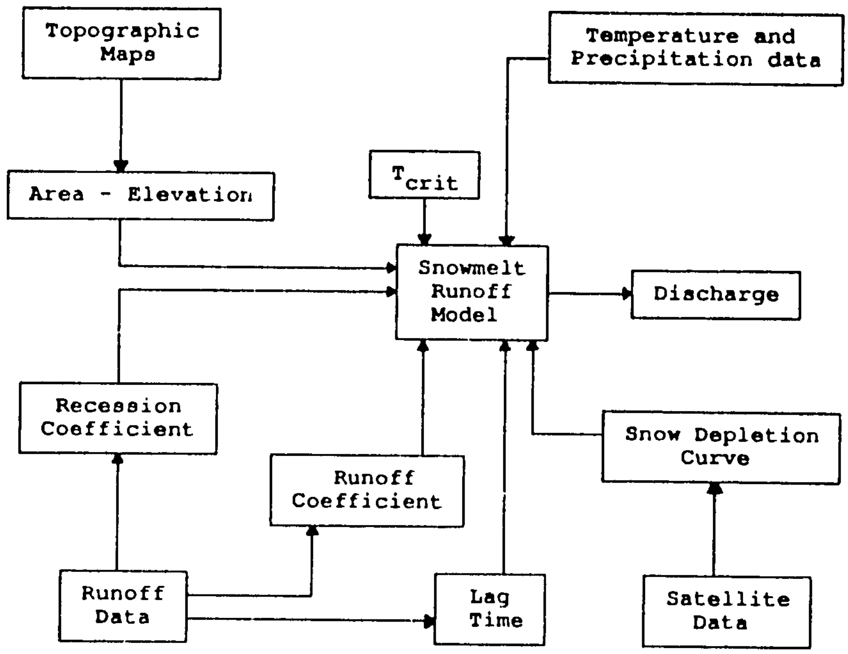


Figure 8.30. - Schematic of the Martinec-Rango Snowmelt Runoff Model.

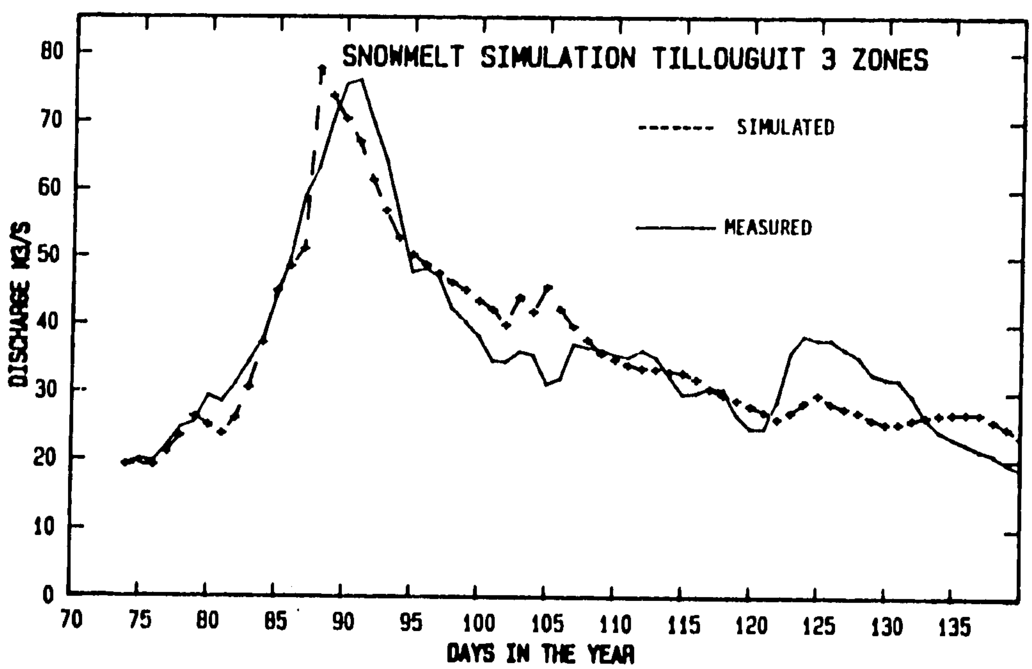


Figure 8.31. - Plot of simulated and measured streamflows for the Tillouguit basin in the 1979 snowmelt season.

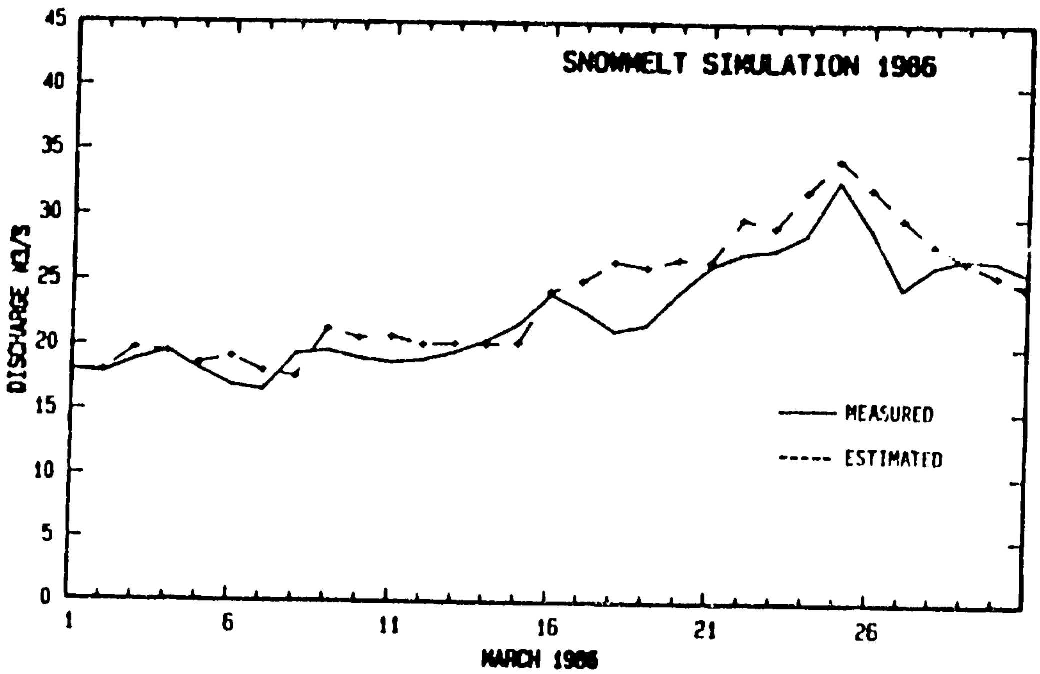


Figure 8.32. - Plot of simulated and measured streamflows for the Tillouguit basin for March 1986.

9. STATISTICAL EVALUATION OF CLOUD TREATMENT EFFECTS ON STREAMFLOW

9.1 Introduction

The principal goals of the Moroccan demonstration cloud seeding program are to provide some alleviation of the ongoing drought and to establish the basis for a long-term program. Cloud seeding, which commences on about November 1 and terminates at the end of April, is primarily intended to increase precipitation over a portion of the Oum Er Rbia basin that feeds the Bin El Ouidane reservoir (fig. 2.2). This target area receives precipitation from clouds that develop over the Middle and High Atlas Mountains.

Operational seeding procedures employed in Morocco call for the treatment of all potential cases expected to affect the target area. Consequently, the program is known as an operational program as opposed to an experiment with randomization where cases for seeding are selected according to a random procedure and some proportion (usually one-half) of all cases is not seeded, but measurements are taken for making comparisons.

Evaluation of seeding effects in operational programs, as well as in randomized experiments, requires comparisons of seeded data with similar nonseeded data. Experiments provide nonseeded experimental units along with the seeded ones. Operational programs do not provide nonseeded units since all potential units are supposed to be treated. This makes it essential to obtain historical data for the basis of comparison in operational programs. The type of cloud seeding program, operational or experimental, and the type of data available, such as streamflow or rainfall, affect the statistical evaluation performed.

Section 9.2 includes some background material and philosophy on statistical evaluation of cloud seeding programs. Section 9.3 covers the statistical design developed for Programme Al Ghait. Target and control data available for the evaluation are discussed in section 9.4. Estimation of the amount of time the project must be operated to achieve a selected confidence in the results is covered in section 9.5. Section 9.6 covers the use of the Rhea orographic precipitation model (Rhea, 1978) in the evaluation. Section 9.7 discusses the status of the evaluation given available seeding information.

9.2 Background and Philosophy of Statistical Evaluations

To evaluate the results of cloud seeding, the sampling of some selected variables such as streamflow or precipitation is necessary. Two types of errors normally occur in sampling a variable: random and systematic. An example of a systematic error is the underestimation by rain gauges of precipitation from snowstorms with substantial wind. Some random errors occur due to the random behavior of weather. Systematic errors, better known as bias, should be reduced or avoided only to the level of random noise since additional benefits cannot be obtained by further reduction unless the random noise is also reduced.

Necessary conditions for unbiased comparisons of seeded and nonseeded measurements, such as streamflow from operational programs, are that the selection of seeded units be objective and that the method of selection be applicable retrospectively to historical data to select comparable units. The validity of historical comparisons is substantially improved, in the sense of less bias, if long-term units such as entire months or seasons are employed and all such units during the program's duration are included as seeded regardless of seeding amount (Gabriel, 1979). However, this means seeding effects can be greatly diluted if weather forecasts are poor and heavily relied upon, equipment fails frequently, or the operational design is inadequate to allow treatment of important potential cases (such as may occur during night hours).

Once a seeding program is fully operational, the dilution of results by inclusion of, for example, a month when little seeding took place due to equipment failure is the price that must be paid for a more unbiased analysis of such programs. The gain is permitting a more valid evaluation. Whatever the time units used, analysis can be unbiased only if it compares all such units that occurred during the seeding program with all similar historical units. Once the program is deemed fully operational, analysts must not omit any nonseeded eligible units to compare with nonseeded units only those actually seeded in an attempt to avoid dilution. However, early trial seeding units (see the last paragraph of section 9.3.1 for the definition of seeding unit) obtained during program initiation can be eliminated provided that it is clear that the required full operational status and procedures had not yet been established.

Cloud seeding evaluations that involve comparisons of seeded information with historical hydrometeorological data assume two important premises: (a) streamflow, or precipitation in some analyses, is independent of historical like data, and (b) detected changes in the distribution of the selected response variable, such as streamflow, are due to cloud seeding. The first assumption is likely, particularly if drought years that have caused the decision to seed can be eliminated. In the second assumption, for successive seasons as seeding units, no clear indications of dependence (serial correlation) or nonstationarity (probability structure changes with time) are documented, so historical comparisons of seasons would seem to have useful validity.

The statistical design for evaluation of cloud seeding effects in Morocco by Mielke and Medina (1987), proposed, as part of a group of analysis procedures, the application of historical regression where one or more control variables are employed to adjust for natural variability in the data. This adjustment will generally reduce the number of seeding units necessary for achieving a desired probability of detection (probability of correctly rejecting the null hypothesis for the selected alternative hypothesis). The primary argument against the use of historical regression is that the degree of applicability of regression expressions, particularly those built on small samples or "snap-shots" of the data, into the future is unknown. Consequently, the use of regressions to forecast meteorological results well into the future is discouraged. In the manner in which regression is applied in the Moroccan seeding program evaluation (Mielke and Medina, 1987), the potentially detrimental effects of historical regression are substantially reduced.

Others have been concerned about the use of historical comparisons in the evaluation of operational cloud seeding programs. Gabriel and Petrondas (1983) claim that operational-historical comparisons on precipitation data by standard statistical methods produce appreciably more significant results than should properly occur. They employed extensive worldwide precipitation records in pseudo-experiments where at least five different statistical tests were applied.

Recognizing the various problems with historical comparisons, the statistical techniques employed in evaluating the Moroccan project have been selected to lessen these difficulties. For example, the use of pooled samples of the historical and seeded units (e.g., historical years plus seeded years) in the application of regression lessens the potential detrimental effects of substantial natural differences between the historical and seeded samples. The use of permutation procedures (Mielke and Medina, 1987), with their minimal assumptions and their character to compare the actual outcome with those from all possible permutations of like samples, is less likely to produce overly optimistic results, as Gabriel and Petrondas (1983) discuss.

9.3 Project Design

9.3.1 Available data. - Typical hydrometeorological data available from mountainous terrain consist of measurements of streamflow, point precipitation at a number of locations, and snowpack water content at some snowcourse sites. Shown in figure 2.2 are the locations of available streamflow and precipitation gauge sites in Morocco of potential use in the statistical evaluation of cloud seeding results. A survey of available Moroccan data indicated that the best historical information in quantity and quality consisted of streamflow. Monthly measurements were available from 30 stream gauges in 8 watersheds, including the Oum Er Rbia basin, of most interest for the conduct of the cloud seeding.

Streamflow has several desirable qualities for evaluation of cloud seeding effects. In particular, it sums (integrates) water in space and time. This reduces the variability of measurements, an item of importance to a statistical evaluation since it may lead to a shorter period for determination of seeding effects. Integration in space yields estimates that include water produced at all elevations above the gauge, including the higher areas where most heavy precipitation occurs. Additionally, evaluation of streamflow is appealing because estimates are on the principal variable of interest, that is, water in the rivers.

Precipitation data were available for a few sites as indicated in figure 2.2. However, only a couple of locations are in the selected target area, and these are at middle and lower elevations, too low to produce a useful (to the evaluation) indication of precipitation at high elevations. A few point measurements generally are not adequate to describe the precipitation over a watershed at an accuracy adequate for evaluation of cloud seeding.

Some historical data were available for several snowcourses located above Bin El Ouidane reservoir (fig. 2.2). Again, the data set was not adequate in quantity or quality for statistical evaluation of the cloud seeding.

After a thorough consideration of the type, quantity, and quality of the historical data available for the Moroccan project evaluation, it was clear that a statistical evaluation design was required that focused on techniques for the detection of small differences in streamflow. Consequently, streamflow became the primary response variable of measurement for the cloud seeding project.

The evaluation requires that a seeding unit be selected for which measurements of the response variable are obtainable for all the seeding and, retrospectively, in the historical period. In Morocco, the seeding unit of preference is the assemblage of all the clouds affecting the target area during a selected time period, such as a month or a season, in which some or all of the clouds are selected for treatment. The two time periods of most interest were months and seasons because less response variable noise and other complications mentioned in section 9.2 were likely with their use.

9.3.2 Selection of the target-control design. - Two designs have been used in the past to evaluate effects of cloud seeding over an area. The first one, which is now rarely used, is known as single target and involves treating seeding units associated with a single area. In this case the evaluation of seeding results from an operational program would be based on differences between target measurements for treated and historical seeding units, for example, monthly streamflow measurements for the response variable for the treated period versus like data for the available historical period.

The second design is the target-control design. It also involves the treating of seeding units associated with a single target area. However, measurements are also taken at a nearby control area that is selected so that response variable measurements are well correlated with those of the target area, but are not contaminated by the cloud treatment in most seeding units. The control data are carefully paired with those of the target area which then allows the application of statistical techniques to compensate for extraneous natural variability. As a consequence, the target-control design is more efficient than the single target design, and, therefore, fewer seeding units are required to detect differences in the response variable due to cloud treatment. Thus, because of its greater efficiency and the type and quality of data available, the target control design was selected for use in Morocco.

9.3.3 Statistical techniques. - Precipitation and streamflow, like many other geophysical measurements, are statistically distributed in complex ways that defy simple analytical characterizations. The statistical techniques selected for application to Moroccan streamflow depend on permutations of the available data. With these methods there are no questionable assumptions about the statistical distribution of the response variable. The inferences of the selected procedures depend strictly on the data available.

Specifically, the techniques selected consist of least-absolute-deviations (LAD) regression and the multiresponse permutation procedures (MRPP) employed within the framework of the target control design to estimate the P-value, the probability that differences in the data samples in question are due to chance. These procedures are discussed in detail in the statistical design document by Mielke and Medina (1987). The procedures are applied to data through fast-running computer programs that can be run on microcomputers such as the IBM PC/AT or equivalent.

The combination of LAD regression and MRPP yields a P-value in the testing of null hypotheses (hypotheses of no effect). A different method is necessary to estimate the actual treatment effect. The technique selected for Morocco is the double ratio. It has been described in section 2.5 and is also discussed in Mielke and Medina (1987). The double ratio is frequently employed in quoting estimates of results of cloud seeding. Essentially, the double ratio adjusts the ratio of the target-seeded streamflow to historical streamflow by the ratio of the control streamflow for the seeded period to control streamflow for the historical period. Wide use in other winter seeding projects, thus furnishing a good basis for making comparisons, and ease of application contribute to the double ratio's utility for estimation of seeding effects on streamflow.

9.4 Target and Control Data

The target stream gauge selected was that at Bin El Ouidane reservoir (fig. 2.2). It integrates runoff from the Oued El Abid and Oued Assif Melloul, the two principal rivers feeding the reservoir. Daily flow measurements were available for the Bin El Ouidane gauge for September 1953 through April 1989.

As indicated by Mielke and Medina (1987), the Tensift basin was selected as the primary control area because it is more frequently upwind during important precipitation events than other nearby nonseeded areas and, due to the southwest-northeast orientation of the Atlas Mountains, is less susceptible to contamination under northwesterly flow of moist air. Flow from this direction is considered more likely to lead to contamination problems; contamination diminishes the control's usefulness.

The survey of historical data for quantity and quality indicated that four control stream gauges in the Tensift basin produced useful records of streamflow for the statistical evaluation. These are listed below along with the record length available for each.

Control stream gauge	Record available
Aghbalou	1964 - August 1988
Jmim El Hamam	1970 - June 1988
Sidi Rahal	1964 - August 1986
Taferiat	1954 - May 1988

Data quality for the four control stream gauges was examined and considered preliminarily acceptable for inclusion in the evaluation [see Mielke and Medina (1987) for a discussion of data quality]. The final selection of control gauges awaits the results of further data quality checks. The collection, preparation, and quality control processing through removal of provisional status on some streamflow data may require up to 2 years after collection.

Correlations with monthly streamflow for November through July of the historical period prior to 1984, for the control gauges with Bin El Ouidane, are given in table 9.1. Mean monthly flows in millions of cubic meters are also given.

Table 9.1. - Correlations of control gauge streamflows with flows into Bin El Ouidane.

Control gauge	Mean monthly flows (M m^3)	Correlation with Bin El Ouidane
Taferiat	13.35	0.78 (202 months)
Sidi Rahal	8.66	0.75 (188 months)
Jmim El Hamam	17.15	0.39 (162 months)
Aghbalou	13.07	0.81 (135 months)
Bin El Ouidane	126.49	(279 months)

All correlations are significant at < 0.0001. From mean monthly flows it is observed that flow into Bin El Ouidane reservoir well exceeds the sum for all the control gauges. Jmim El Hamam produces the lowest correlation at 0.39 with Bin El Ouidane, in part because it is the most distant from the reservoir.

The control streamflow selected by Mielke and Medina (1987) to be employed in the evaluation of seeding effects on Bin El Ouidane consists of the mean, for each time unit selected (like months), of the four control gauges listed above. At this time, it appears that all four gauges will be included in the development of the mean. However, there are some remaining data quality questions that need to be resolved.

Using the historical data set for the individual control gauges, the correlation for the computed (perhaps temporary) control developed from the four gauges with Bin El Ouidane was 0.66. When the streamflow values are summed (integrated) to form seasonal totals, the correlation between the computed control and Bin El Ouidane increases to 0.73. These values are a bit lower than those reported by Mielke and Medina (1987). This is due to changes in the data as a result of quality checks since their work.

9.5 Estimation of Project Length

A quantity that is useful for planning and designing a cloud seeding program is the probability of detection. This quantity, generally known as the power of a statistical test, is the probability of correctly rejecting the null hypothesis in favor of the alternative hypothesis. The concept and methods for its estimation are covered by Mielke and Medina (1987) and are not repeated here. However, some discussion follows regarding how this quantity derives its usefulness.

A data set collected in the conduct of an experiment is, in reality, a small "snapshot" of the universe that consists of all possible outcomes. Geophysical data include possible outcomes that are aberrations and not representative of the typical behavior of the phenomenon under study. Consequently, if a conducted experiment draws a sample containing even a few outliers, or aberrations, an actual treatment effect may go undetected (known as a type II error in statistics) due to the requirement for a larger sample than project plans allow to overcome the effect of the outliers.

Estimation of the probability of detection from large historical samples will enable the development of project designs that better allow for the potential detrimental effects of the "snapshot" view of the phenomenon. For example, in using a historical data set that well exceeds typical sample sizes for the variable under study, 100 "snapshots" (samples) are drawn at random from the historical data and are analyzed as though 100 experiments were conducted; that is, one-half of each of the 100 drawn samples are adjusted by insertion of a treatment effect, and then a P-value is obtained for the subsample pair for each of the 100 samples. The 100 P-values can then be employed to estimate the probability of detection. This process can be used to estimate the number of seeding cases required for a desired probability of detection, at a selected significance level, for each of the inserted simulated increases in the response variable (such as streamflow). More than 100 samples may be studied to ensure more stable results.

Estimates of the probability of detection were developed by Mielke and Medina (1987) for use in designing the Moroccan cloud seeding program. Given in table 9.2 are their estimates for selected treated durations, significance levels, and simulated increases of the response variable, streamflow. Useful historical data commenced in 1962 and ended in July 1984. November through July were included in the analysis, as the cloud seeding generally starts in November and the streamflow recession does not usually reach the base flow level until July.

Table 9.2. - Estimates of probability of detection (power) by significance level, treatment period, and simulated monthly streamflow increases (values from Mielke and Medina, 1987).

Increase (%)	Treated period (months)	Significance level	Power
10	54	0.1	0.54
10	54	0.05	0.39
10	72	0.1	0.65
10	72	0.05	0.48
15	36	0.1	0.80
15	36	0.05	0.69
15	54	0.1	0.90
15	54	0.05	0.76

Values from table 9.2 indicate that with a significance level of 0.05 and a simulated 10 percent increase, a probability of detection of 0.39 is attained with a treated sample of 54 months. The result improves to 0.54 if a significance level of 0.1 is acceptable. The results improve substantially if simulated increases are 15 percent. Since increases in streamflow due to cloud seeding are expected to be about 10 percent, results given in the table suggest that at least 54 months with treatment effects are required to achieve the 50-percent probability of detection (with a significance level of 0.1). This suggests that, at a minimum, 6 full seasons of cloud seeding are required where the treatment efficiency of seedable clouds is near 100 percent (see chapter 7 for a discussion of treatment efficiency).

The issue of treatment efficiency is an important one. If, for example, only half of the seedable cases are treated, then the required number of seeding units (months in the current discussion) will approximately double (108 months in the example given above) to achieve the same probability of detection. This shows the substantial importance of keeping vital equipment and personnel on line for the treatment of all storms that may have seeding potential.

From the purely scientific point of view, the 0.05 significance level is much more desirable than the 0.1 level. Additionally, some scientific experiments require that sample sizes be large enough that the 90-percent probability of detection is achieved. The determination of what values to employ and design into a program depends on costs and benefits involved and the desires of decisionmakers regarding risk.

9.6 Rhea Model Capability in the Evaluation of Streamflow

The Rhea orographic precipitation model has been employed in other orographic precipitation studies (Medina et al., 1979) to forecast winter precipitation and, consequently, the seasonal streamflow. Estimation of Moroccan target area volume precipitation by a properly adapted version of the Rhea model was considered to have good potential for development of a useful objective covariate for use in the statistical evaluation. The model configuration and adaptation processes are discussed in section 8.3.

Results from runs of the model, which estimates the natural (nonseeded) precipitation over the target area in a fully objective manner, indicate that during the winters of 1984-85 and 1985-86 the target and control areas should have received approximately the same amount of areal mean precipitation. This is indicated by the target/control ratio

$$T / C = 44.70 / 46.01 = 0.97$$

where T and C are the model estimates of areal mean precipitation for the target and control areas, respectively, for the seasons indicated. Months included in each season are November through April, as precipitation after April is likely to be mostly convective in nature, and the Rhea model was not designed to handle convection. Rawinsonde data employed in the runs are those taken at Beni Mellal as part of Programme Al Ghait and are considered to be of high quality.

According to the model, during the two winter seasons of 1986-87 and 1987-88, about 53 percent more precipitation should have occurred without seeding in both areas than during the previous two seasons and with approximately equal amounts occurring per area. This can be seen from the target/control ratio

$$T_s / C_s = 69.72 / 68.72 = 1.01$$

where T_s and C_s are the respective model target and control areal mean precipitation estimates for the winters indicated (the subscript denotes a seeded period). The ratio of 1.01 obtained here is comparable to the previous one at 0.97.

Companion values for the historical winter seasons prior to 1984-85 are not given because the quality of the rawinsonde data during those periods is not considered adequate for this purpose. Atmospheric soundings (rawinsonde) from Casablanca and Agadir were employed in model runs for the historical period to 1984-85; thereafter, project soundings taken at Beni Mellal were used because these were considered more applicable and of vastly superior data quality.

Model runs with the Casablanca-Agadir soundings may produce volume precipitation estimates for the target area that are useful as an additional independent variable in multiple regression. Consequently, model runs were made and results used in multiple regression computations. For historical seasons to 1984-85 (the start of program), the variance explained (R^2) in least squares multiple regression for the dependent variable, target streamflow, with the two explanatory (independent) variables, control streamflow and Rhea model volume precipitation for the target, indicates the model does not improve results unless seasonal time units are employed. The variance explained in the monthly analysis is 0.51 with only the control streamflow passing the statistical F-test for entry as a covariate and 0.79 when seasonal time units are employed and model values for the target qualify for entry. With seasonal units and only the control streamflow as an independent variable, the variance explained is 0.62. Apparently, the smoothing process in seasonal sums removes some noise in the data, and seasonal amounts remove the mismatch that occurs in monthly data when winter snowfall runs off later during springtime (the mismatch decreases the correlation with model estimates) to enable the model to supply useful explanatory information.

Least squares regression will not be employed in the formal evaluation but is used here only for its utility in testing the capability of the model. Since the data set has not yet been finalized, results obtained for these types of analyses may change.

9.7 Cloud Seeding Effects on Streamflow through 1987-88

As indicated in chapter 7, cloud seeding efficiency records are available through the 1988-89 operational season. The cloud seeding efficiency of potential cases did not exceed 20 percent until January 1987. This presents a major problem for the statistical evaluation because inclusion of results for the initial period with cloud seeding that commenced in November 1984 and ended in December 1986 will certainly dilute seeding effects of the eventual overall sample. As stated in section 9.2, trial seeding performed as part of program startup should be eliminated from any consideration. In the Moroccan program the urgency for additional water due to a severe ongoing drought led to early initiation of the seeding despite the lack of adequate equipment and trained personnel to fully cover the geographical area desired.

An important aspect of the evaluation is whether the initial seeding results (first 2 years plus 2 months) should be included in the streamflow evaluation, given that, generally, the seeding efficiency was 10 to 15 percent. The best course of action appears to be deletion of the indicated early seeding period from any consideration either as treated or nontreated since the program had not yet reached its intended capability and any seeding accomplished was more in the nature of trial seeding.

The overall treatment sample is far from completion (at least 54 months are needed) as streamflow for the control gauges is available only through June 1988 for a total of 13 nonmissing months, given the elimination of the early seeding results. Some of the control values are still listed as missing and are being reviewed by Moroccan hydrologists. Any results based on a sample this size would be virtually meaningless because they would be very unstable. Therefore, preliminary results with streamflow from the 13 months with potential treatment effects will not be computed until more data are obtained.

The development of new probability of detection values where streamflow for the 13 months available is taken into account is also not warranted at this time due to unresolved missing data and the brevity of the record available. The brief data set could easily give a wrong impression of seeding results if streamflow values logged are an aberration from the average state.

More exploratory analysis should be conducted once the data are cleared of provisional status. Preliminary analysis with the Rhea model results looks encouraging and needs more exploration when additional data become available. Further exploratory analysis could lead to stronger explanatory variables (covariates) and, consequently, more confidence in the eventual results.

10. HYDROLOGIC AND ECONOMIC STUDIES

10.1 Design and Objectives

The hydrologic and economic studies were designed to determine the technical and economic feasibility of cloud seeding technology as a water resources management tool. The project design included this study to provide a basis for rational decisionmaking on the use of this technology.

Three major parts of the study were as follows:

1. Hydrologic evaluation. - The primary purpose for the hydrologic study was to evaluate the distribution and use patterns of the added streamflow that might be produced from the Moroccan Winter Snowpack Augmentation Project. The objective of this study was to determine quantitative differences in hydrologic parameters measured from a "preproject" (natural flow) condition versus a "project" (enhanced flow) condition. The hydrologic impacts, as estimated by the river simulation model, were used in the economic evaluation.

2. Economic evaluation. - The purpose of the econom evaluation was to provide a benefit-cost analysis of the value of the additional streamflow that might be produced as the result of cloud seeding versus the total cost of cloud seeding operations. The assessment of benefits was based upon hydrologic impacts from augmented precipitation estimated by the river model. The intermediate objectives for the economic evaluation were to:

   - Identify benefits of incremental economic values for uses of the additional water supply from winter cloud seeding operations over the Oued Oum Er Rbia (OER) basin terrain for hydroelectric power generation, domestic and industrial uses, and irrigation for crop production.

   - Identify costs related to capital investments and annual operating expenses for Programme Al Ghait.

   - Sum the benefits and costs to determine the benefit-cost ratios for assumed percentage increases in streamflow.

   The economic evaluation includes the hydrologic evaluation – that is, the use of Morocco's computer model for the Oued Oum Er Rbia basin and the data as applied to the snowpack augmentation project. Since actual streamflow increases are not yet available from the statistical evaluation, the economic evaluation is based on assumed percentage increases.

3. Applications activities. - Studies and training that apply the findings and recommendations of the physical and economic evaluations to practical issues in water resources management.

In May 1986 a three-member Reclamation economic evaluation team was formed. Mr. Patrick A. Hurley of DARR was selected as the team leader. The other team members were Mr. R. Wayne Cheney, Hydraulic Engineer, and Mr. Kent D. Shuyler, Economist. This team of experts traveled to Morocco during June 1986 to visit Moroccan Government agencies, meet with Moroccan professionals, and visit agricultural and other water resource facilities concerning the management of the Oued Oum Er Rbia basin. The primary purpose of this visit was to start the process of gathering data that the team would need for the hydrologic and economic evaluations.

Early in 1987, as previously noted, the Government of Morocco (GOM) established the Scientific Analysis and Evaluation Team (SAET) for Programme Al Ghait and assigned GOM team members specific areas of responsibility. This initiative evolved into a joint Reclamation/GOM effort, where Reclamation counterparts were identified to collaborate with the GOM scientists. The individuals identified for the hydrologic and economic evaluations were as follows:

Task	Responsible GOM person	Responsible Reclamation person
RIVER model/hydrologic evaluation	Abderrahman Mrabet Boutayeb Mohamed Oubalkace	R. Wayne Cheney
Economic evaluation	El Bachir Loukah Smouni	Kent D. Shuyler

In the spring of 1987, Mr. Cheney returned to Morocco to obtain additional hydrologic data and to collaborate on modeling procedures that would be acceptable to the different Moroccan agencies as well as project staff. In October 1987 Mr. Cheney and Mr. Shuyler again traveled to Morocco to obtain additional economic data and to present the analytical methods to be used in the hydrologic and economic evaluations. During these visits to Morocco, they worked with their GOM counterparts, Mr. Mrabet and Mr. Loukah, on these tasks. The GOM scientists are pivotal in the successful completion of the evaluations, as they provide liaison with the various GOM agencies in the collection and development of the data. They also provide consultation to their Reclamation counterparts to ensure that technical data are properly interpreted for the purposes of these evaluations.

10.2 Hydrologic Studies

10.2.1 Hydrologic data requirements. - The most important aspect of a hydrologic evaluation is obtaining enough hydrologic data that are sufficiently free of manmade trends or biases. River flows free of such influences are known as virgin or natural flows. Natural flows are free of upstream regulation, diversions or exports, or any other manmade phenomena. If the flow record is not free of such phenomena, then it must be adjusted to offset them.

The length of record is also very important because all records used in the simulation must have a common length. Desirable record lengths are 30 years or greater.

Table 10.1 shows a list of streamflow records in the Oued Oum Er Rbia basin taken from a summary of streamflow records maintained by Hydraulique.

Table 10.1. - Stream gauging stations in the Oued Oum Er Rbia basin.

Stream/river	Station name	Station number	Date in service
Oum Er Rbia	Khenifra	2901001	1927
Oum Er Rbia	Sidi Maachou	2700118	1929
Lakhdar	Assaka	4500038	1930
Oum Er Rbia	Kasba Tadla	3701476	1935
Oum Er Rbia	Kasba Zidania	3701477	1938
Oum Er Rbia	Imfout	2700035	1941
Oum Er Rbia	Daourat	2700048	1950
Oum Er Rbia	Dechra El Oued	3701475	1953
El Abid	Bin El Ouidane	4600004	1953
Lakhdar	Sidi Driss	4500830	1962
Tessaout	Bissis Bissa	3601534	1963
Oum Er Rbia	Mechra Ed Dahk	3701478	1963
Tessaout	Ait Tamlilt	5400045	1964
El Abid	Ouaouirinth	4500522	1967
Derna	Moulay Bouzekri	3701481	1967
Derna	Taghzirt	3701480	1967
Oum Er Rbia	Ouled Sidi Driss	3602408	1968
Tessaout	Moulay Youssef	5400068	1970
Lakhdar	Ait Chouarit	4501215	1970
Ghzef	Ait Sigmine	4501214	1970
Lakhdar	Addemaghne	4501215	1973
Faregh	Arba Aounat	2701778	1974
Srou	Chacha Nl'AellahH	2901378	1974
Nourine	Tizi Nisly	3702605	1975
Chbouka	El Herri	2901377	1975
Oum Er Rbia	Tarhat	2901376	1975
Tessaout	Tamesmate	5400069	1975
El Abid	Ait Ouchene	3700649	1975
Ouaomana	Taghzoute	3702604	1975
Amangous	Tamchachat	3000564	1975
Ahancal	Zawya Ahancal	4600137	1976
Oum Er Rbia	Al Massira	3501174	1977
Oum Er Rbia	Merija	3500853	1977
Ahancal	Tillouquit	4600138	1978

In order to calibrate the simulation model accurately, computed reservoir inflow under natural conditions was obtained for the following facilities:

Table 10.2. - Water management facilities - Reservoirs and irrigation diversions within the Oued Oum Er Rbia basin used in RIVER Model simulations.

Dechra El Oued (proposed)	Moulay Youssef
Kasba Tadla	Al Massira
Bin El Ouidane	Imfout
Ait Ouarda	Daourat
Hassan I	Said Maachou
Sidi Driss (proposed)	

In addition to the considerable amount of hydrologic data gathered and analyzed, substantial amounts of data were assembled that describe the physical characteristics of hydropower and storage facilities that exist in the Oued Oum Er Rbia basin.

The physical characteristics obtained for the above-listed facilities include (a) minimum reservoir operating level, (b) maximum reservoir operating level, (c) initial reservoir level, (d) initial reservoir inflow, (e) initial reservoir discharge, (f) reservoir precipitation characteristics, (g) reservoir evaporation characteristics, (h) reservoir area-elevation-capacity interpolation tables, (i) tailrace discharge versus reservoir elevation curves, (j) powerplant discharge versus reservoir elevation curves, (k) minimum downstream flow requirement, (l) river outlet discharge versus reservoir elevation curves, and (m) reservoir operating rule curves.

Data to describe powerplant characteristics include (a) maximum powerplant capacity, (b) monthly load factors, and (c) generation versus discharge interpolation tables. Diversions and projected demands for irrigation, domestic, and industrial uses (including monthly patterns) were obtained for locations shown in figure 10.1, which shows the watersheds, stream gauges, and dam locations within the Oued Oum Er Rbia basin. The type of diversion, whether before or after the turbine, or for irrigation, municipal, or industrial use, is noted in figure 10.2, which is a schematic representation of the Oued Oum Er Rbia system needed to perform a suitable hydrologic evaluation. The annual demand for each type of diversion is shown, followed by the percentage of return flow to the river, percentage delivered for agricultural use, and percentage delivered for domestic (municipal and industrial) use.

The evaluation team has reviewed the natural reservoir inflow data, dam and reservoir characteristics, powerplant characteristics, and diversion and return flow requirements that have been prepared by Hydraulique for planning and modeling purposes. This collection of data has been reviewed by the DMN and ONE staffs as well. These reviews have resulted in complete data sets that have reasonable acceptance among several Moroccan national water resource management agencies and are well suited for the hydrologic evaluation.

10.2.2 Model design, basin configuration, and modeling assumptions. - The evaluation team has reviewed the river/reservoir model (RIVER) currently being used by Hydraulique and has found it to be a satisfactory tool for the evaluation of enhanced streamflow in the Oued Oum Er Rbia basin. The evaluation team sought and obtained permission from Hydraulique to use RIVER and the physical characteristics of the basin as assembled by Hydraulique for evaluating enhanced streamflow assumptions. (Refer to RIVER Program Operating Manual for complete model documentation). RIVER is a generalized simulation model designed to simulate river and reservoir effects based on changing conditions or alternative operating rules. This is ideal for the needs of the evaluation study. Because RIVER is a general model, it must be configured specifically for the Oued Oum Er Rbia system.

It should be noted that RIVER is not an optimization tool. The hydrologic evaluation will therefore make no effort to optimize reservoir operations or optimize the use of water in the Oued Oum Er Rbia system. Reservoir operating rules used by Hydraulique in RIVER were employed unchanged in this study. Since the objective of this study is to measure effects of increased flows in the basin as it currently exists, improvements to facilities or operating procedures that may be justified because of increased streamflow are not yet considered. Revised operating procedures or improvements/expansion of facilities should be considered under recommended future studies.

The procedures used for the hydrologic evaluation are designed to reduce the effects of errors that normally exist in the basic data, the model used, and the operating rules followed. The effects of most of these errors are mitigated by evaluating relative differences rather than focusing on absolute values. Therefore, the hydrologic evaluation is based on the differences between a preproject (natural flow condition) and a project (enhanced flow) condition.

As stated earlier, the physical evaluation of the project has not been completed. Several additional years of cloud seeding operations will be necessary to produce statistically significant results. Therefore, the evaluation process began with assumed modifications of the natural inflows to the reservoirs. Data from other similar weather modification projects in the United States and around the world indicate that a reasonable range of increased streamflow is between 5 and 10 percent.

This hydrologic evaluation assumed two cases of increased reservoir inflow: 5 percent and 10 percent. The natural inflow at each of the reservoirs was enhanced by approximately 5 percent and 10 percent, but only during the 7-month period of enhanced streamflow resulting from cloud seeding operations (December through June). This arrangement allowed 2 months following the end of cloud seeding operations in April for augmented mountain snowpack to melt and flow into the reservoirs. Streamflow during the remainder of the year was not modified.

It is expected that the reservoir inflow pattern will not change due to cloud seeding operations; therefore, the pattern of natural inflow to Bin El Ouidane reservoir was used as the pattern for the modified flows throughout the basin. A modification factor was designed to preserve the pattern and modify the natural annual streamflows by 5 percent and 10 percent, respectively, using the following equation:

$$Y = A - (X-B)**2$$

where:

- Y = the percent increase applied to monthly flow values
- A = a constant to control the increase in streamflow
  - A = 12 for about 5 percent annual increase
  - A = 20 for about 10 percent annual increase
- X = the number of the month being modified (1 = September)
- B = a lagging factor adjusted for the desired pattern
  - B = 7 to follow the pattern of natural inflow to Bin El Ouidane

The equation was further limited so that Y was set to zero for July through November. (See figure 10.3 for an analysis of the flow modification equation.) It is important to note that this procedure for modifying streamflow is an assumption. Once the physical evaluation of the project has been completed, this procedure for modification should be revised to more closely represent actual enhanced mountain snowpack and the resulting runoff.

10.2.3 Hydroelectric power production. - Basinwide hydroelectric power production was constructed by creating annual totals from monthly production at each powerplant. Annual production values were summed for each plant, creating a basin total for each year of the study. Differences between the natural flow case and the augmented flow cases were tabulated.

Figure 10.4 is a bar chart of those differences for each year of the study and shows that some increase can be expected in every year of the study for both assumptions of increased streamflow. The average annual increase in power production is 46 gigawatt hours (GWh) and 89 GWh for the 5-percent case and the 10-percent case, respectively.

Figure 10.5 is a frequency analysis of the difference between the natural flow case and the natural flow plus 5 percent case, as well as the difference between the natural flow case and the natural flow plus 10 percent case. This shows the maximum difference to be about 250 GWh and the minimum difference to be about 10 GWh. It is particularly important that more than 30 GWh annually can be expected for 50 percent of the years for the 5-percent increase, and more than 70 GWh can be expected on 50 percent of the years for the 10-percent increase. Figure 10.5 allows the analyst to quantify the benefits of this increased hydropower resource at any desired confidence level.

Furthermore, it is clear that the hydroelectric facilities that currently exist in the Oum Er Rbia basin have sufficient capacity to handle a considerable increase in streamflow. Any increase in streamflow will produce an increase in hydroelectric production without physical modification or additional costs. Since neither assumption of increased streamflow is limited by powerplant capacity in any year, future studies should consider an assumption of greater increased streamflows in order to assess the system's full hydropower capability. Also, as soon as the physical evaluation can be completed, this analysis should be redone with a better estimate of increased streamflow and a consideration for changed operating rules designed for increased power production.

10.2.4 Reservoir storage. - Basinwide reservoir contents were assembled by adding the end-of-year contents of each reservoir, repeated for each year of the study. Figure 10.6 is a time series plot of the basin's reservoir contents for each streamflow assumption, namely, natural flow, natural flow plus 5 percent, and natural flow plus 10 percent. When the reservoirs are full or nearly full, the differences among the three cases are small or zero, as expected. The largest differences occur when the reservoirs are in some stage of reduced capacity. This indicates that the reservoirs have sufficient capacity to provide some measure of carryover regulation with increased streamflow. This analysis does not explore those limits, which should be considered in any future studies.

The differences in reservoir content between the natural flow case and the augmented flow cases are illustrated in figure 10.7. During times of low reservoir storage, differences in reservoir contents can be as high as 380 millions of cubic meters (M m^3). The average annual increase in reservoir contents is 59 M m^3 and 114 M m^3 for the plus 5 percent case and the plus 10 percent case, respectively.

Figure 10.8 is a frequency analysis of the increased reservoir contents under both assumptions of augmented streamflow. The analysis shows that some increase in reservoir contents can be expected at least 85 percent of the time. Equally important, more than 60 M m^3 annually can be expected 50 percent of the time for the 5-percent increase, and more than 100 M m^3 annually can be expected 50 percent of the time for the 10-percent increase.

About 15 percent of the time, the increases in reservoir contents are near zero, and for about 3 percent of the time they are slightly negative. This result arises during times when the reservoirs are full under the natural flow case and any increase in streamflow cannot be retained. Slight decreases in reservoir storage can occur with increased streamflow because the contents are distributed differently among the several reservoirs. If the operating rules were changed to favor increased reservoir storage, the storage decreases would probably disappear and additional increases in reservoir contents would be likely. Changes in operating rules to enhance reservoir storage should be considered in any future studies.

10.2.5 Agriculture and domestic water deliveries. - Agriculture and domestic water demands and deliveries under the two water supply assumptions were summarized in two areas because the uses are somewhat different in each area. Under the natural flow case, about 80 percent of the demands in the upper basin (Tadla area) are met nearly all the time (except for the extreme drought in 1983 and 1984) as shown in figure 10.9. Under both assumptions of enhanced water supply, the reductions in shortages are significant.

Figure 10.10 shows the increased deliveries in the upper basin for both the natural flow plus 5 percent case and the natural flow plus 10 percent case. Occasionally, increases of more than 200 M m^3 can be observed. Average annual increased deliveries over the study period are 25.8 M m^3 and 53.0 M m^3 for the natural flow plus 5 percent case and the natural flow plus 10 percent case, respectively.

Figure 10.11 is a frequency analysis of the increased water deliveries in the upper basin for both water supply assumptions. Some increase is indicated about 80 percent of the time, while significant increases can be expected at least 20 percent of the time.

Water demands in the lower basin (Doukkala area) are less than in the upper basin and are never completely met by the natural flow or either of the enhanced flow assumptions. Figure 10.12 shows that only about half of the demands are met with any consistency. During the extreme drought periods, the lower basin deliveries are sometimes as low as 200 M m^3.

Figure 10.13 shows the increased deliveries in the lower basin for both the natural flow plus 5 percent case and the natural flow plus 10 percent case. These increases are less than in the upper basin, but are nevertheless very significant. During some of the water shortage years, increases of 100 M m^3 are expected. It should be noted that some of the increased deliveries are partially offset by occasional decreased deliveries. These are due to the different distribution of available storage in the several basin reservoirs. Also, the reservoir operating rules are not tuned to specifically promote increased water deliveries. As mentioned earlier, some of the enhanced flow is consumed in increased reservoir storage. Future studies should consider the relative advantages of using the enhanced flow for increased reservoir storage or for increased water deliveries.

Figure 10.14 is a frequency analysis of the increased water deliveries in the lower basin for both water supply assumptions. Some increase is indicated about 75 percent of the time, and significant increases are expected at least 20 percent of the time.

10.2.6 Recommendations for further hydrologic investigation. - One of the deficiencies of this study is that it did not consider the effects of anticipated future water demands, water resource development, or hydropower requirements. This study considered only the near-future case. Further work on model configuration, operating rules to more prudently balance reservoir storage in extreme water supply events, and the allocation of water supply among reservoir storage, power releases, and releases for consumptive uses is also desirable. It is suggested that these additional investigations be pursued in concert with the ongoing snowpack enhancement demonstration project. Certainly these more detailed investigations should be completed before any operational snowpack enhancement activities are initiated.

10.3 Economic Studies

10.3.1 Economic analysis procedures. -

10.3.1.1 General principles. - The economic analysis of the Al Ghait Winter Snowpack Augmentation Project consisted of determining benefits from irrigation, domestic water, and hydropower generation; determining the sum of annual equivalent benefits; and comparing this sum to annual equivalent costs. In this analysis, the economic value of additional water supplies that might result from Programme Al Ghait is based on historic water use, as demonstrated in the RIVER program. The methods used for this type of incremental analysis, based on additional supplies of water and additional hydropower production, are in use worldwide in economic analysis of water and land resource projects.

Computations are based on discussions, agreements, and data obtained from numerous sources in Morocco, including 18 Moroccan Government sources, USAID, the World Bank, and several sources in the U.S. Department of Agriculture (USDA). For cross-checking statistics, data from the following sources were used: the Morocco Energy Model-POWER spreadsheet, the Doukkala, Tadla, and Settat farm budgets, and the Economic Intelligence Unit. The Doukkala and Tadla irrigation areas are only partially irrigated, with their distribution and delivery systems not fully utilized. However, the determination of project benefits considers full water supply under project development conditions.

10.3.1.2 Hydropower benefits. - Hydropower benefits are calculated by multiplying the amount of additional hydropower expected to be produced by the project by the unit cost of power from alternate sources. The calculated cost is considered the equivalent hydropower benefit since the project would replace a like amount of power which otherwise would have to be produced by the national system using fossil fuels. The quantity of additional hydropower that might be produced is determined by averaging the results of power generation simulations for the 46 years from 1940 through 1985. The POWER spreadsheet, which is a subprogram of the Morocco Energy Model (MEM), is used to determine the unit cost of power from the alternate sources.

10.3.1.3 Irrigation benefits. - It is expected that the principal impact of a cloud seeding project upon irrigation in Morocco would be to increase the area supplied with irrigation water, with a corresponding decrease in the area where dryland farming is practiced. Therefore, irrigation benefits are calculated by multiplying the increment in return per unit area from irrigated land as compared to nonirrigated (rain-fed) land by the area expected to convert to irrigation as a result of the project. Three levels of benefits are calculated based on (a) GOM support prices, (b) free-market prices, and (c) blended prices based on the proportion of each crop subject to support and free marketing. The analyses based on support and free-market prices are presented as sensitivity analyses.

10.3.1.4 Domestic water supply benefits. - Domestic water supply benefits are estimated by calculating the incremental cost to supply an equal quantity of domestic water from alternate sources for distribution in Moroccan cities. The cost of water from the Barrage de Sidi Mohammed Ben Abdellah extension is used in the calculations. Costs of domestic water from the Ouljet Beni Khmis Sur L'Oued Grou Dam and the Tiddas Sur l'Oued Bou Regreg Dam are based on full costs rather than incremental costs and cannot be used for sensitivity analysis.

10.3.1.5 Relationship of benefits to costs. - The economic valuation, or relationship of benefits to costs, is presented in the main analysis using the enumerated methods of determining benefits for irrigation, domestic water supply, and hydropower production.

Due to the complex price structure within Morocco, significant differences between the World free-market values and the domestic prices exist. Therefore, in order to account for the "true values" of water that is consumed for hydroelectric power, irrigation, and domestic uses, a comprehensive analysis of shadow prices is required. This analysis is beyond the scope of this project; hence a simple analysis of known values in the free market and in Morocco is presented as a sensitivity analysis. This sensitivity analysis provides insight as to the range of prices and effects on the benefit-to-cost ratio. The detailed analysis is presented in the report by Goorian et al. (1989). Section 10.3.5 presents the summary of the sensitivity analysis in terms of benefit-to-cost ratios and total benefits to costs.

10.3.2 Benefit determination. -

10.3.2.1 Hydropower benefits. - Several incremental analyses were performed to determine the enhanced hydropower production derived from the project. Additional hydropower generation within the OER basin was calculated based on the 5- and 10-percent precipitation augmentation situations. Estimates of increased energy production were obtained from the hydrologic river model (RIVER) simulations using streamflow data for the 46-year period of record from 1940 through 1985 for dams located in and near the Doukkala and Tadla areas.

The average annual power generation from the Doukkala and Tadla area dams for the 46-year period of record has been determined from existing data. Plant energy consumption and electric system losses from the plant to the final wholesale point where the energy is transformed for distribution to retail users are determined. The net available energy multiplied by the unit cost of thermal power yields total energy value.

Two dams produce hydropower in the lower OER basin: Al Massira and Imfout. No dams produce energy directly at Tadla, but six nearby dams – the Bin El Ouidane, Afourer (Ait Ouarda), Dechra El Oued, Kasba Tadla, Hassan I, and Moulay Youssef – produce hydroenergy that enters the national grid. These dams, which would be impacted by increased precipitation, and estimates of additional annual average hydropower generation simulated in RIVER are listed in table 10.3.

Table 10.3. - Average annual changes in hydropower generation (GWh/yr).

Hydropowerplants	5% precipitation augmentation 1940-85		10% precipitation augmentation 1940-85	
	Total GWh	Average GWh/yr	Total GWh	Average GWh/yr
Doukkala area				
Al Massira	531.30	11.55	1,047.88	22.78
Imfout	37.26	0.81	66.24	1.44
Tadla area				
Bin El Ouidane	481.16	10.46	980.72	21.32
Afourer (Ait Ouarda)	396.52	8.62	709.78	15.43
Dechra El Oued	302.22	6.57	601.68	13.08
Kasba Tadla	20.70	0.45	40.48	0.88
Hassan I (Ammougez)	231.88	5.03	471.96	10.26
Moulay Youssef	98.82	2.17	184.92	4.02
Total		45.67		89.21

As noted in section 10.3.1.2, hydropower benefits are calculated as the cost of alternate energy production displaced from the national power system. Assuming no load changes, the impact of increased hydropower production from the project will displace an equivalent amount of power generation from more costly oil- and gas-fired thermal plants that would have been produced in the absence of the project. This incremental method of analysis considers costs saved by displacing such thermal power at midlevel fossil fuel prices to be a measure of equivalent power benefits.

Several methods are available to estimate these hydropower benefits. The MEM developed by Meir et al. (1987) was used. This model, which incorporates several programs and Lotus 123 spreadsheet software, simulates the institutional structure of energy planning in Morocco. For this study, the electric capacity expansion module, or POWER spreadsheet, was used to estimate incremental hydropower benefits. POWER estimates the optimal electrical capacity for the Moroccan national power grid, given certain assumptions, and calculates capital investments for new plants, foreign debt, imported and domestic fuel costs, and energy generation and consumption. POWER also estimates the difference in fuel costs due to additional hydropower generation incurred by increased precipitation in the OER basin, including the Doukkala and Tadla areas.

Assumptions for all runs in this optimization analysis include a 16-year period from 1985 to 2000 for el ctrical expansion and fuel cost calculations, a 5-percent annual increase in power demand, a 20-percent reserve margin, a project exchange rate of DH 8 = $1, a constant installed capacity for the national power grid, and a midlevel oil price projection for the project period. For the two optimization runs under project conditions, the average annual power estimates for the hydropowerplants were added to the POWER data base. The first run increases hydropower at the identified dams based on 5 percent precipitation augmentation, and the second increases hydropower at the same dams under 10 percent precipitation augmentation. Average annual imported fuel costs were calculated for each run and compared to average imported fuel costs for the baseline optimization run. The differences in average annual costs between runs following project development and the baseline run represent the potential hydropower benefits associated with this project. Hydropower production in each case is reduced by 15 percent to allow for transmission, transformation and distribution losses, and plant losses.

Annual hydropower cost savings and equivalent benefits are shown in table 10.4.

Table 10.4. - Annual cost savings and benefits for baseline analysis.

Costs and benefits	5% precipitation enhancement	10% precipitation enhancement
Baseline analysis		
Average annual fuel costs	2,001.47	2,001.47
Additional hydropower runs	5% increase	10% increase
Average annual fuel costs	1,992.38	1,980.73
Difference in fuel cost	9.09	20.74
Average annual benefit	9.09	20.74
Average additional hydropower, kWh/yr	45,670,000	89,210,000
System losses, 15%	-6,850,500	-13,381,500
Net additional hydropower, kWh/yr	38,800,000	75,800,000
Benefit per unit, DH/kWh	0.2342	0.2735
Total annual benefit, DH	9,087,000	20,731,000
Total annual benefit, $	1,136,000	2,591,000

10.3.2.2 Irrigation benefits. - As previously noted, the principal change in farming due to augmented streamflow in the OER basin would be the conversion of some dryland farms to irrigated land. The difference in net farm income between irrigated farms and nonirrigated farms – that is, the incremental net farm income due to implementation of irrigation – is therefore the controlling factor in calculations of irrigation benefits. Incremental irrigated land is determined on the basis of total augmented water supply for the upper and lower OER basin at the point of diversion for each dam that serves the irrigation systems, less delivery losses. The augmented irrigation water supply is applied to newly irrigated land on the basis of water demand per hectare in each irrigation project, as indicated in the farm budgets.

Irrigation benefits are based on the budgets for irrigated and rain-fed farms in the OER basin (fig. 10.1). The Doukkala[1] budget fairly represents the lower OER basin, and the Tadla[2] budget fairly represents the upper OER basin, both under irrigated conditions. The Settat[3] rain-fed budget represents nonirrigated farms in the entire OER basin.

Finalized farm budgets in this report are based on original budgets supplied by Dr. W. Tyner of USDA and USAID. These budgets included definitive data on cropping and livestock cultural practices; crop, byproduct, livestock, and livestock product yields; farm inputs; and prices for goods bought and sold. Changes were made on the basis of data in the extensive list of background material on Morocco referenced in footnotes and in the Bibliography. The three budgets for the Doukkala, Tadla, and Settat areas are discussed in detail by Goorian et al. (1989).

Changes in the cropping patterns were required by foreseeable agricultural policy changes by the European Common Market. Those changes will reduce current levels of Moroccan vegetable exports to Europe, which in turn will reduce the area planted to market vegetables. The expected changes were reflected in the revised farm budgets used in the model runs. In addition, the low profitability of beet sugar refining removed sugar beets from the budgets, and grain, pulse, and forage crops were increased proportionally. Additional detailed changes were mandated for various crop yields, crop prices, and prices paid. No new orchards were added because permanent plantations command higher on-farm irrigation priority, and orchards would probably neither increase nor decrease in number under future conditions. Livestock patterns were adjusted to correspond to background data. No sheep or goats were originally included for the Doukkala area, although GOM sources indicate large ovine populations for Doukkala and Tadla.[4] Therefore, appropriate herds and flocks were added for the modeling study.

Three levels of prices received were used, as noted.[5, 6, 7, 8, 9] The indicated blended prices create a median level of irrigation benefits. GOM support prices tend to be higher and therefore create a higher level of benefits; free-market prices are lower and produce a correspondingly lower benefit level. Prices for livestock and livestock products[10] are essentially local and, therefore, are not

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[1] Doukkala Irrigated Farm Budget, Model Number 2, 1985-86, amended.

[2] Tadla Irrigated Farm Budget, Model Number 1, 1985-86, amended.

[3] Settat Rain-fed Farm Budget, Model Number 4, 1985-86, amended.

[4] Office Regional de Mise en Valeur Agricole des Doukkala, 1985.

[5] Conseil D'Administration, Office Regional De Mise En Valeur, Agricole Des Doukkala, Royaume Du Maroc, 1985.

[6] Statistiques Agricoles, Principales Productions Vegetales, Campagne 1975-76, Royaume de Maroc, 1976.

[7] Country Development Strategy Statement, Morocco, Annex C, FY 1988, Agency for International Development, 1986.

[8] La Politique de Prix et D'Incitations Dans le Secteur Agricole, Annexe Statistique, Royaume de Maroc, 1986.

[9] ORMVA Studies, Tadla and Doukkala, 1985-86.

[10] Morocco: Agricultural Prices and Incentives Study, The World Bank, 1976.

subject to price change in the analyses. Table 10.5 shows blended prices, GOM support prices, and free-market prices for all crops produced in the project area.

Table 10.5. - Agricultural support, free-market, and blended prices.

Crop	GOM		Free market		Blended
	DH/MT	% of crop	DH/MT	% of crop	DH/MT
Soft wheat	1,803	56	1,472	44	1,657
Hard wheat	2,000	100	n.s.	n.s.	2,000
Barley	1,500	100	1,380	n.s.	1,380
Maize	1,800	100	1,270	n.s.	1,800
Lentils	none	-	4,200	100	4,200
Chick peas	none	-	4,200	100	4,200
Tomatoes	none	-	1,000	100	1,000
Watermelons	none	-	900	100	900
Green peas	none	-	400	100	400
Seed cotton	5,500	100	n.a.	-	5,500
Alfalfa	none	-	1.43/f.u.	100	1.43
Berseem clover	none	-	1.67/f.u.	100	1.67

n.a. = not applicable
n.s. = not significant
f.u. = forage unit
MT = metric tonne

The basis for irrigation benefits is net annual incremental farm income in the Doukkala irrigation perimeter and the Tadla irrigation perimeter. Budgets also were supplied for the Moulouya irrigated area and the rain-fed Haouz and Gharb areas, but are considered less representative of future potential project areas.

With the various adjustments made, net income per hectare was calculated for irrigated farms in the Doukkala and Settat projects. Net farm income per hectare from nonirrigated land was determined for the Settat perimeter, reduced to 1 hectare, and subtracted from future irrigated income in Doukkala and Tadla to calculate incremental net farm income per irrigated hectare. The incremental net farm income was applied to all land projected to receive irrigation water as a result of cloud seeding under assumptions of 5 and 10 percent increases in seasonal precipitation.

Net farm income for the Doukkala and Tadla irrigation areas, net farm income for the Settat rain-fed area, incremental net farm income due to irrigation for the Doukkala and Tadla irrigation areas, and irrigation benefits, using blended prices, are summarized in table 10.6.

Table 10.6. - Summarized net irrigation farm income, blended prices, by project area.

	Net income/hectare			Consump. (m³/ha)	Water supply (M m³)	New land equiv. (ha)	Benefits	
	Irrigation	Rain-fed	Increment				DH 000	$ 000
10% precipitation enhancement								
Doukkala	5,067	2,462	2,605	4,913	13.709	2,790	7,269	909
Tadla	6,036	2,462	3,575	5,176	20.856	4,029	14,403	1,800
Total							21,672	2,709
5% precipitation enhancement								
Doukkala	5,067	2,462	2,605	4,913	7.934	1,615	4,207	526
Tadla	6,036	2,462	3,575	5,176	10.156	1,962	7,015	877
Total							11,222	1,403

Annual irrigation benefits for the 10-percent precipitation enhancement situation are DH 7,269,000 ($909,000) for the Doukkala area and DH 14,403,000 ($1,800,000) for the Tadla area. For the 5-percent situation, irrigation benefits are DH 4,207,000 ($526,000) for the Doukkala area and DH 7,015,000 ($877,000) for the Tadla area.

10.3.2.3 Domestic water supply benefits. - Domestic water supply, as defined in this study, is raw water available at a river diversion point, subject to the same level of system losses used for irrigation water diversion. Costs of delivery to downstream treatment facilities, treatment, and storage and distribution of treated water are not considered.

The domestic water supply benefits are derived from the cost of producing an equivalent quantity of raw water at point of diversion to wholesale distributors for domestic use. This incremental method is similar to the determination of hydropower benefits. Hydraulique[11] has presented cost and water delivery figures for three alternatives, one involving an extension of an existing dam and two involving new dams. The cost of water from the dam extension is calculated to be less than the cost of water from new storage facilities. Therefore, the dam extension, at Barrage de Sidi Mohammed Ben Abdullah, is accepted by Hydraulique as a measure of the value of domestic water from other sources.

For the Sidi Mohammed extension, Hydraulique has projected 1985 project costs in economic prices with a 40-percent increase from 1982 to 1984 and a 12-percent increase from 1984 to 1985. A 12-percent inflation increase has been projected for the Tiddas Sur L'Oued Bou Regreg and Ouljet Beni Khmis Dams and is applied to Sidi Mohammed extension costs to 1986 for common time correspondence to irrigation benefits. The base-indexed construction cost is increased by 30 percent for contingencies and by 25 percent for overhead. Interest during construction (IDC)

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[11] Barrage De Sidi Mohammed Ben Abdullah; Barrage De Tiddas Sur L'Oued Bou Regreg; Barrage De Ouljet Khmis Sur L'Oued Bou, Hydraulique, 1985.

and operation, maintenance, and replacement (OM&R) are estimated and included. Sidi Mohammed extension costs are detailed in table 10.7.

Table 10.7. - Single-purpose alternative costs for domestic water benefits (000 DH) - Sidi Mohammed Ben Abdellah Barrage Extension (annual yield = 178 M m^3).

Construction, 1985	349,960
Construction, 1986	391,955
Contingency 30%	117,587
Overhead, base cost, + contingency	127,385
Construction, total	636,927
IDC	280,568
Capital costs	917,495
Annual equivalent	139,735
OM&R	1,960
Total economic costs (DH)	141,695
$ equivalent	17,712
Value/m^3 (DH)	0.796
$ equivalent	0.100

The annual cost of DH 141,695,000 divided by the annual controlled released flow of 178,000,000 m^3 from Sidi Mohammed extension dam yields a unit cost of DH 0.796/m^3. This value is assigned to additional water produced in the Doukkala and Tadla areas.

For the Doukkala area, water from the Al Massira and Imfout Dams serves major downstream cities, including Casablanca, as well as local domestic usage. For the Tadla area, allocations are made for domestic water from Tassaout and Sidi Driss, but all flows from the Mouley Youssef, Ait Ouarda (Afoura), Kasba Tadla, Hassan I, Sidi Driss, and Tassaout reservoirs are allocated to irrigation.

Determined water storage release data were obtained for the 46 years from 1940 through 1985. Allocation of releases between irrigation and domestic purposes and system losses between points of diversion and use were provided by GOM.

The data on past water deliveries were used to estimate the additional deliveries that would be made with a cloud seeding program in effect. The domestic water supply deliveries and calculated benefits with a project operating are detailed in table 10.8.

Table 10.8. - Domestic water deliveries and calculated benefits.

	Average year (M m³)	System efficiency (%)	Domestic use (%)	Irrigation use (%)	M m³	Benefits	
						DH 000	$ 000
10% precipitation augmentation							
Doukkala area dams							
Al Massira	22.45	76.90	6.00	72.00	1.036	825	103
Imfout	2.31	76.90	100.00	0.00	1.776	1,414	177
Tadla area dams							
Tassaout	3.02	71.50	20.00	40.00	0.432	344	43
Sidi Driss	9.27	71.50	20.00	40.00	1.326	1,055	132
Total					4.570	3,638	455
5% precipitation augmentation							
Doukkala area dams							
Al Massira	13.100	76.90	6.00	72.00	0.604	481	60
Imfout	1.23	76.90	100.00	0.00	0.946	753	94
Tadla area dams							
Tassaout	1.45	71.50	20.00	40.00	0.207	165	21
Sidi Driss	5.21	71.50	20.00	40.00	0.745	593	74
Total					2.502	1,992	249

The derived value of DH 0.796/m³ for Sidi Mohammed extension is applied as an equivalent benefit figure for OER dams. With annual domestic usage of 4,570,000 m³/yr for 10 percent precipitation augmentation, annual equivalent domestic water benefits are DH 3,638,000, or $455,000. For 5 percent precipitation augmentation, comparable figures are 2,502,000 m³ and DH 1,992,000, or $249,000.

10.3.2.4 Total project benefits. - Total project benefits are the sum of hydropower, irrigation, and domestic water benefits, as summarized in table 10.9.

Table 10.9. - Summary of hydropower, irrigation, and domestic water supply benefits (DH).

Benefits	10% precipitation enhancement	5% precipitation enhancement
Hydropower		
National power grid	20,731,000	9,087,000
$ equivalent	2,591,000	1,136,000
Irrigation		
Doukkala, Lower OER	7,269,000	4,207,000
Tadla, Upper OER	14,403,000	7,015,000
Subtotal	21,672,000	11,222,000
$ equivalent	2,709,000	1,403,000
Domestic water supply		
Doukkala, Lower OER	2,239,000	1,234,000
Tadla, Upper OER	1,399,000	758,000
Subtotal, OER basin	3,638,000	1,992,000
$ equivalent	455,000	249,000
Total	46,041,000	22,301,000
$ equivalent	5,755,000	2,788,000

For the project area, benefits are DH 46,041,000, or $5,755,000, for the 10-percent precipitation enhancement situation, and DH 22,301,000, or $2,788,000, for the 5-percent precipitation enhancement. The proportional distribution of benefits is illustrated in figure 10.15.

10.3.3 Costs. - Project costs are those capital, annual, and periodic replacement expenses, including capital equipment, scientific support, and training by USG and GOM, required to operate a cloud seeding project. A cloud seeding project is nonstructural and requires no dams or other major structures. The water conveyance systems are considered to have ample capacity to deliver the augmented diversion that would be created by the project. New irrigation or drainage systems or on-farm development will not be required. Costs are confined to capital equipment for cloud seeding, including radar, computer, and communications facilities, ground-based generators, meteorological and measurement equipment, spare parts, and vehicles.

Capital costs are reduced to annual equivalent values over 30 years of useful life at 15 percent interest and replaced at intervals corresponding to end of useful life by sinking fund factors.

Annual or recurring costs include salary and labor; training; aircraft rental; chemicals and other supplies; equipment operation, maintenance, and repair; and administration and overhead. Some expenses would be incurred in dirhams and some in dollars, as shown in table 10.10.

Table 10.10. - Summary of project costs.

Capital, equipment, scientific support, and technology transfer	
USA ($)	
Equipment	1,144,413
Scientific support	3,450,996
Training	832,769
Subtotal	5,428,177
GOM ($)	
Equipment	94,298
Total ($)	5,522,475
DH equivalent	44,179,798
Operation, maintenance, and repairs, GOM (DH)	
Operation and maintenance	
Salary	2,204,500
Rawinsonde	637,500
Equipment, aircraft, and chemical usage	2,194,370
Supplies	249,630
Subtotal, operation and maintenance	5,286,000
Replacement ($)	208,263
Replacement (DH)	1,666,104
Total, OM&R (DH)	6,952,104

Total project costs are determined as the annual equivalent of capital costs and annual OM&R costs. OM&R exceeds the annual equivalent of capital costs since the project is nonstructural and, therefore, interest during construction is not applicable. Total annual equivalent project costs are summarized in table 10.11, and their proportional distribution is shown in figure 10.16.

Table 10.11. - Summarized project costs (DH).

Capital: Total project investment	44,180,000
Annual equivalent	6,729,000
Annual equivalent OM&R	6,952,000
Total annual equivalent	13,681,000
$ equivalent	1,710,000

10.3.4 Benefit-to-cost analysis. - Benefit-to-cost ratios, calculated by comparing the sum of annual benefits to the sum of annual costs over the expected 30-year period of project operations, are shown in table 10.12.

Table 10.12. - Calculation of benefit-to-cost ratio.

Benefits and costs	10% precipitation enhancement	5% precipitation enhancement
Annual benefits (DH)		
Hydropower, POWER, midlevel fuel prices	20,731,000	9,087,000
Irrigation, blended prices	21,672,000	11,222,000
Domestic water,		
Sidi Mohammed Ben Abdullah extension	3,638,000	1,992,000
Total annual benefits	46,041,000	22,301,000
$ equivalent	5,755,000	2,788,000
Costs (DH)		
Capital: Total 5-year project investment	44,180,000	44,180,000
Annual equivalent	6,729,000	6,729,000
Annual equivalent OM&R	6,952,000	6,952,000
Total annual costs	13,681,000	13,681,000
$ equivalent	1,710,000	1,710,000
Benefit-to-cost ratio	3.37	1.63

The numbers developed for the benefits show that each kilowatt hour of electricity produced has a benefit value of 0.274 DH for the case of a 10-percent increase in precipitation and 0.234 DH for the 5-percent case. The numbers also show that each cubic meter of water produced has a benefit value of 0.796 DH for the case of 10 percent and 5 percent precipitation enhancement.

The excess of benefits over costs on an annualized basis is shown in table 10.13.

Table 10.13. - Annualized excess of benefits over costs (DH).

	10% precipitation enhancement	5% precipitation enhancement
Annual benefits	46,041,000	22,301,000
Annual costs	13,681,000	13,681,000
Benefits minus costs	32,360,000	8,620,000
$ equivalent	4,045,000	1,078,000

The various analyses presented in this chapter combine to show that a cloud-seeding program to increase runoff from the High Atlas would be economically feasible, provided that it produced increases in precipitation and streamflow comparable to those reported for orographic cloud-seeding projects in other countries.

10.3.5 Sensitivity analysis. -

10.3.5.1 Hydropower benefits. - Three sensitivity analyses apply to the hydropower benefit determinations. One is based on POWER and uses hydropower generation assumptions and high-level, rather than midlevel, fuel costs. A second uses POWER hydropower generation and blended variable costs of energy produced from oil-fired plants and coal-fired plants in Morocco in 1985, based on ONE data. The third combines POWER generation costs per kilowatt hour and Office National L'Electricite (ONE) power generation figures. This analysis is presented in detail in the report on Hydrologic and Economic Studies for the Moroccan Winter Snowpack Augmentation Project by Goorian et al. (1989).

- High-level fuel costs. - This sensitivity analysis uses POWER hydropower production and MEM high-level fossil fuel costs.

  The MEM is capable of simulating the national power grid at different oil price projections. The analysis in section 10.3.4 was based on a midlevel oil price projection to identify fuel cost savings incurred by the 5-percent and 10-percent precipitation enhancement situations. This sensitivity analysis substitutes the high oil price projection option in the POWER spreadsheet for the baseline, 5-percent increase, and 10-percent increase runs to determine the impact of high oil prices on the national power grid optimization.

  Assuming high-level oil projections, benefits increase from the midlevel oil projections. Under the 5-percent seeding increase situation, total hydropower benefits are DH 11,568,000, equivalent to $1,446,000, or a 27-percent increase from the midlevel oil projections of DH 9,092,000 ($1,136,500). For the 10-percent situation, hydropower benefits are DH 26,707,000, or $3,338,000, an increase of 29 percent from the midlevel oil price analysis of DH 20,731,000 ($2,591,000).

- Blended variable energy costs. - This sensitivity analysis uses POWER hydropower production, as above, plus blended oil and coal-fired plant costs.[12] Hydropower benefits are DH 33,320,000 ($4,165,000) for the 10-percent situation and DH 16,828,000 ($2,104,000) for the 5-percent situation.

A special river modeling simulation was made by Mr. Smouni and Mr. Lahbi of ONE for comparison with the RIVER Model simulation. The ONE simulation studied the natural streamflow and augmented streamflows with 5 and 10 percent increases to the natural flow for monthly average flows from 1940 to 1985. The only difference in the simulations was the use of the calendar year for ONE, whereas Hydraulique RIVER Model analyses were based on the agricultural year of September to August. Results were averaged over the 46-year period; therefore, they are comparable.

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[12] Country Report, Morocco, The Economic Intelligence Unit, No. 2-1986.

Note that the 10-percent enhanced streamflow results from the ONE model were 51 GWh/yr higher than the same simulation using the RIVER Model. This represents a 57-percent increase in total hydroelectric power which produced a set annual benefit of 25.1 million dirhams (MDH) in comparison to 20.7 MDH for the RIVER Model (about 30 percent higher). Table 10.14 summarizes the results from the ONE model simulations.

The ONE analysis uses 1989 power production figures, midlevel prices, and the POWER format. Benefits are DH 25,061,000 ($3,133,000) for the 10-percent situation. No simulation run was available for the 5-percent ONE analysis.

10.3.5.2 Domestic water supply. - The domestic water supply analysis does not require a sensitivity analysis. The Sidi Mohammed Ben Abdellah Dam extension cost is considered the equivalent single-purpose alternative benefit, since it includes only incremental costs of the dam extension. Base costs are considered to be sunk, corresponding to Al Ghait sunk base facility costs. The costs of the Tiddas and Ouljet Dams include installation and do not correspond to project costs that were incurred previously. The analogy is similar to single-purpose hydropower benefits, where only variable, or operational, costs are included and installation, or capacity, costs are excluded. Values are summarized below.

Summary of values of domestic water, by facility	DH/m^3
Sidi Mohammed extension	0.796
Tiddas sur L'Oued Bor Regreg	2.644
Ouljet Beni Khmis	2.584

10.3.5.3 Irrigation. - Two sensitivity analyses were required for irrigation, involving the price levels received by farmers. The indicated blended prices create a median level of irrigation benefits used in the full analysis. The sensitivity analyses involve GOM support prices, which tend to be higher and therefore create a higher level of benefits, and the free-market prices, which tend to be lower and produce a correspondingly lower benefit level. Prices for livestock and livestock products are essentially local and therefore not subject to price change in the analyses. Table 10.5 showed blended prices, GOM support prices, and free-market prices for all crops produced in the project area.

For the free-market prices, irrigation benefits are DH 18,394,000 ($2,299,000) for the 10-percent situation and DH 9,477,000 ($1,185,000) for the 5-percent situation.

For the GOM prices, irrigation benefits are DH 23,332,000 ($2,916,000) for the 10-percent situation and DH 12,085,000 ($1,511,000) for the 5-percent situation.

10.3.5.4 Summary of sensitivity analyses. - Results of the six sensitivity analyses of various agricultural and hydropower prices are presented in tables 10.15 and 10.16.

The total sensitivity analyses, as shown in table 10.15, demonstrate the range of benefits and costs that occurs in the various combinations of project input. The base figures for hydropower, domestic water supply, and irrigation are shown in table 10.15, "Baseline analysis." These figures are POWER midlevel oil prices for hydropower, Sidi Mohammed Dam extension costs for domestic water supply, and blended agricultural prices for irrigation. The variables are agricultural blended prices, GOM support prices, and free-market prices for irrigation; and POWER hydroelectric generation with projected high-level and midlevel fuel prices, ONE blended variable energy costs from oil-fired and coal-fired plants, and POWER generation costs plus ONE power generation levels, for hydropower. No sensitivity analysis is used for domestic water, since the Sidi Mohammed Ben Abdullah Dam extension is the only facility with data available for an incremental analysis.

Sensitivity analyses 1, 2, and 3 use blended agricultural crop prices, 4 and 5 use free-market prices, and 6 uses GOM support prices. Sensitivity analysis 1 uses POWER high fuel prices, 2 and 5 use ONE power production and midlevel fuel costs, 3 uses blended fuel prices, and 4 and 6 use POWER midlevel fuel prices. The highest benefits occur in the blended fuel prices for hydropower, which has the highest hydropower values, and the lowest ratio occurs in the combination of free-market agricultural prices and POWER midlevel fuel prices. Median levels of benefits to costs occur in the sensitivity analyses that use ONE and POWER midlevel fuel costs.

Table 10.14. - Summary of ONE RIVER Model results for the Oued Oum Er Rbia basin. Average values for 1940-1985 period with monthly runs.

	Normal	5% enhanced	10% enhanced
Bin El Ouidane + Afourer			
Hydroelectric power generated (GWh)	731.4	756.0	779.8
Volume of inflow (M m^3)	1154.0	1211.7	1269.4
Flow through turbines (M m^3)	1098.0	1143.8	1189.6
Diversions (M m^3)	19.0	29.3	40.2
Evaporation (M m^3)	44.5		
Storage (final-initial) (M m^3)	240.0	271.2	297.6
Irrigation demands (M m^3)	944.7		
Unsatisfied irrigation demands (M m^3)	73.3	64.4	55.9
Hassan 1er + Sidi Driss			
Hydroelectric power generated (GWh)	144.2	152.6	158.9
Volume of inflow (M m^3)	296.8	311.7	326.5
Flow through turbines (M m^3)	287.9	303.1	315.9
Diversions (M m^3)	1.8	1.5	3.5
Evaporation (M m^3)	9.0		
Storage (final-initial) (M m^3)	25.9	25.4	28.2
Irrigation demands (M m^3)	259.0		
Unsatisfied irrigation demands (M m^3)	11.4	10.5	9.6
Dechra El Oued + Kasba Tadla			
Hydroelectric power generated (GWh)	210.4	219.5	228.7
Volume of inflow (M m^3)	962.0	1010.0	1058.0
Flow through turbines (M m^3)	915.2	959.6	1004.5
Diversions (M m^3)	14.9	18.8	22.1
Evaporation (M m^3)	37.1		
Storage (final-initial) (M m^3)	-15.5	-13.3	-10.0
Irrigation demands (M m^3)	407.8		
Unsatisfied irrigation demands (M m^3)	7.6	7.5	7.0
Moulay Yousef			
Hydroelectric power generated (GWh)	57.5	60.3	63.1
Volume of inflow (M m^3)	331.4	348.0	364.5
Flow through turbines (M m^3)	315.3	329.4	342.5
Diversions (M m^3)	9.8	12.1	15.4
Evaporation (M m^3)	7.0		
Storage (final-initial) (M m^3)	46.2	48.3	51.4
Irrigation demands (M m^3)	206.1		
Unsatisfied irrigation demands (M m^3)	11.7	10.4	9.2
Lower Oued Oum Er Rbia			
Al Massira + Imfout + Daourat + Maacho			
Hydroelectric power generated (GWh)	422.4	448.2	475.4
Volume of inflow (M m^3)	712.3	712.3	712.3
Flow through turbines (M m^3)	1960.4	2052.5	2140.5
Diversions (M m^3)	87.7	104.7	125.5
Evaporation (M m^3)	57.8		
Storage (final-initial) (M m^3)	-190.7	-160.2	-139.7
Irrigation demands (M m^3)	1253.2		
Unsatisfied irrigation demands (M m^3)	17.9	14.9	12

Table 10.15. - Sensitivity analysis for benefit-to-cost ratios.

Condition			Benefit-to-cost ratio	
Irrigation	Hydropower	Domestic	10% precipitation enhancement	5% precipitation enhancement
Baseline analysis				
Blended prices	POWER midlevel oil prices	Sidi Mohammed (S.M.) generation extension	3.37	1.63
Sensitivity analyses				
1. Blended prices	POWER high fuel prices	S.M. extension	3.80	1.81
2. Blended prices	ONE power production midlevel fuel costs	S.M. extension	3.68	NA
3. Blended prices	blended fuel costs	S.M. extension	4.29	2.20
4. Free market	POWER midlevel fuel prices	S.M. extension	3.13	1.50
5. Free market	ONE power production midlevel fuel costs	S.M. extension	3.44	NA
6. GOM support	POWER midlevel fuel prices	S.M. extension	3.49	1.69

The average annual benefits and costs of each method are:

Table 10.16. - Sensitivity analysis, benefits and costs (000 DH).

	Irrigation benefits		Hydropower benefits		Domestic benefits		Costs
	Precipitation enhancement situation						
	10%	5%	10%	5%	10%	5%	
Full analysis							
	21,672	11,222	20,731	9,087	3,638	1,992	13,681
Sensitivity analyses							
1.	21,672	11,222	26,707	11,568	3,638	1,992	13,681
2.	21,672	11,222	25,061	NA	3,638	1,992	13,681
3.	21,672	11,222	33,320	16,828	3,638	1,992	13,681
4.	18,394	9,477	20,731	9,087	3,638	1,992	13,681
5.	18,394	9,477	25,061	NA	3,638	1,992	13,681
6.	23,332	12,085	20,731	9,087	3,638	1,992	13,681

10.3.6 Shadow prices. - The blended agricultural price analysis is a partial use of shadowing in this analysis. The concept of shadow pricing is the conversion of market prices by shadow factors, based on real opportunity costs, to provide a supplemental economic analysis. Shadow factors that would be required for a complete analysis include the standard conversion factor, which will provide accounting values for nontraded goods, such as locally consumed livestock, livestock products, and vegetables; the shadow wage rate, based on productivity of family agricultural labor; the shadow exchange rate, based on freely exchangeable currency at all levels in the analysis; and other shadow factors which will remove the effect of taxes, insurance, or other imposed charges.

A detailed analysis of shadow prices was not available from USAID at the time of this writing, and funding levels do not permit more detailed analysis by Reclamation. Such analysis is recommended for the future, to evaluate the full effect of the project, including farm production which remains outside the free-market economy.

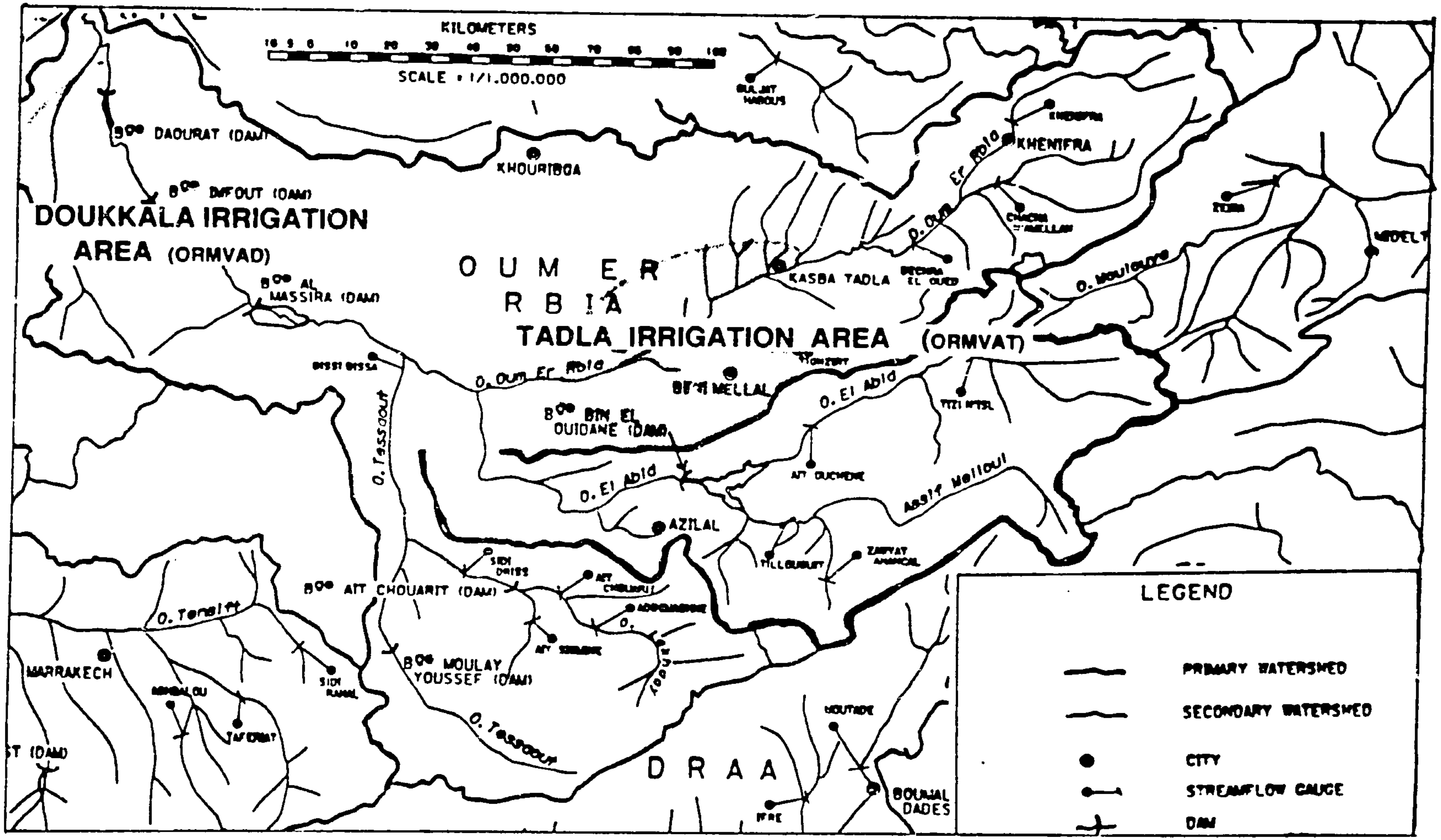

Figure 10.1. - Map of watershed, stream gauges, and dam locations within the Oum Er Rbia River basin.

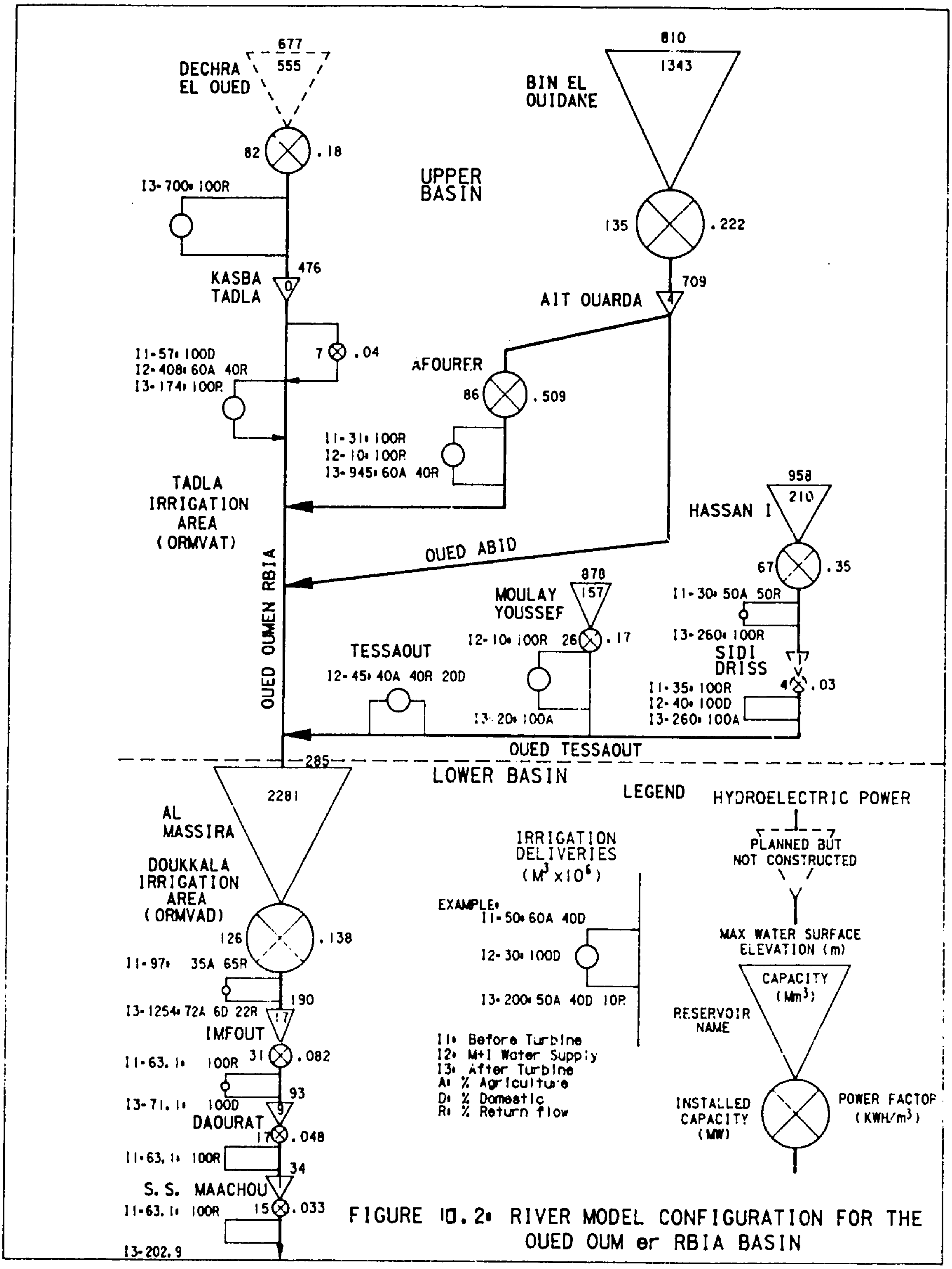

Figure 10.2. - Schematic representation of the Oum Er Rbia water management system showing diversions for turbines, irrigation, and municipal industrial water. Quantities of installed hydroelectric capacity (MW), reservoir elevation, and capacity (m^3) are shown at each diversion.

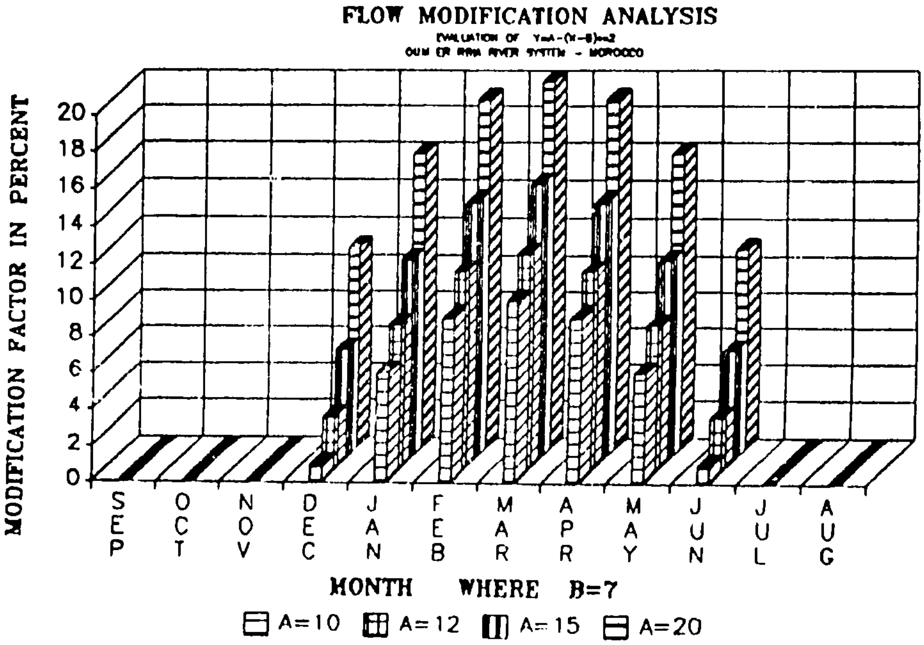

Figure 10.3. - Flow modification showing percent changes from the natural flow for each month, where A = 12 for 5 percent increases and A = 20 for 10 percent increases in annual flow.

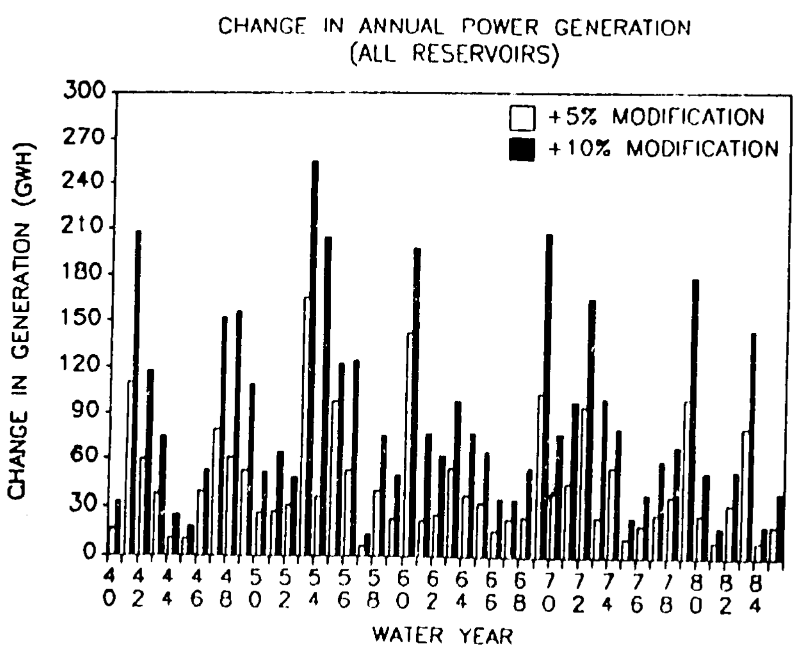

Figure 10.4. - Changes in the annual power generation (GWh) for all reservoirs in the Oum Er Rbia basin each year from 1946 to 1985. These changes represent results for the 5- and 10-percent increases above normal streamflow simulated by the RIVER Model.

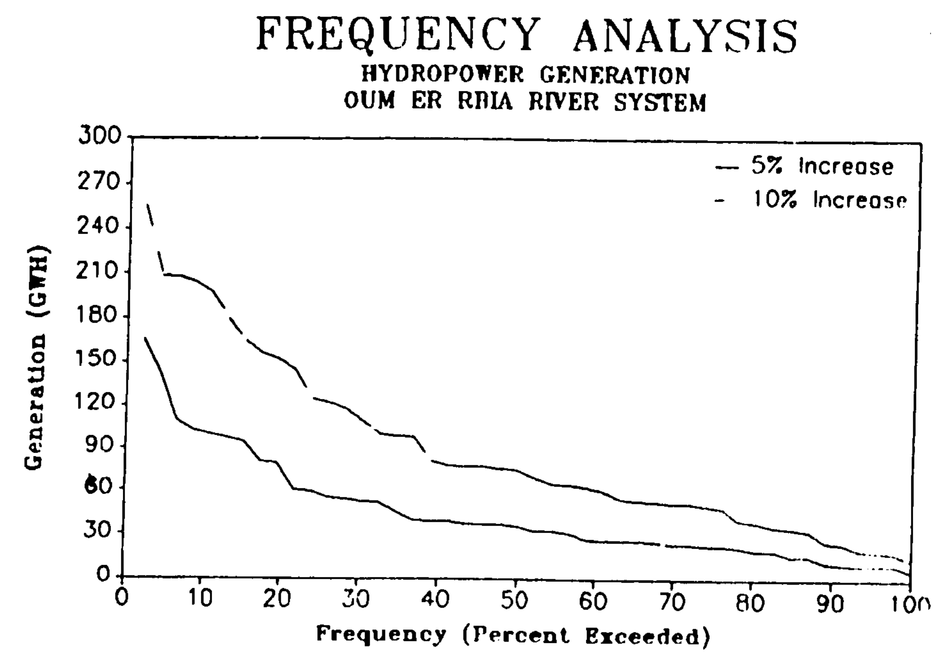

Figure 10.5. - Frequency of changes in hydroelectric power generation (GWh) from the natural level for increased streamflow for RIVER Model simulation as described in figure 10.4.

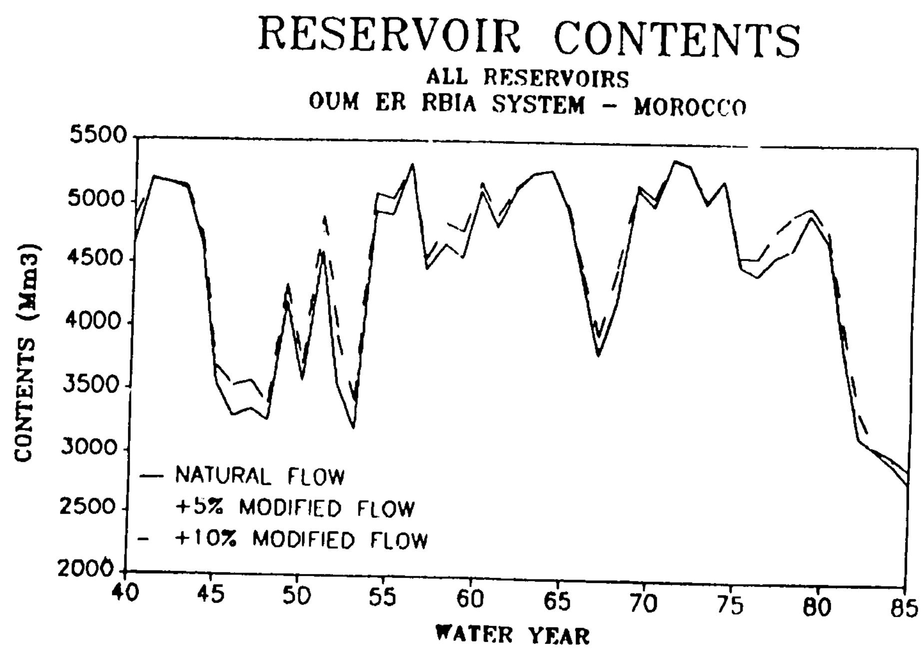

Figure 10.6. - Reservoir contents (M m^3) for all reservoirs within the Oum Er Rbia basin simulated by the RIVER Model for natural and 5 and 10 percent increases in annual streamflow.

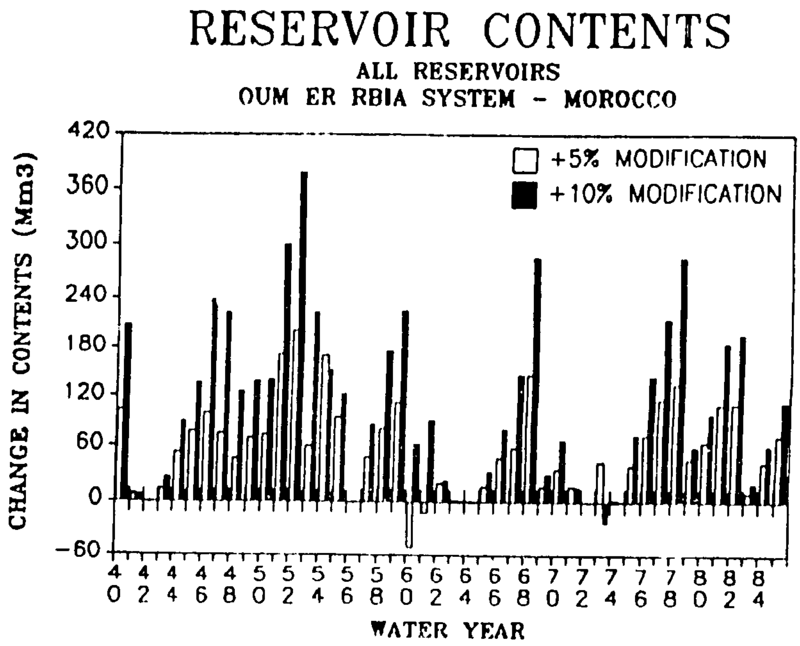

Figure 10.7. - Changes in reservoir contents (M m^3) for each year from 1940 to 1985 for all reservoirs in the Oum Er Rbia basin. Changes represent RIVER Model results of deviations from the natural volumes due to 5 and 10 percent simulated increases in streamflow.

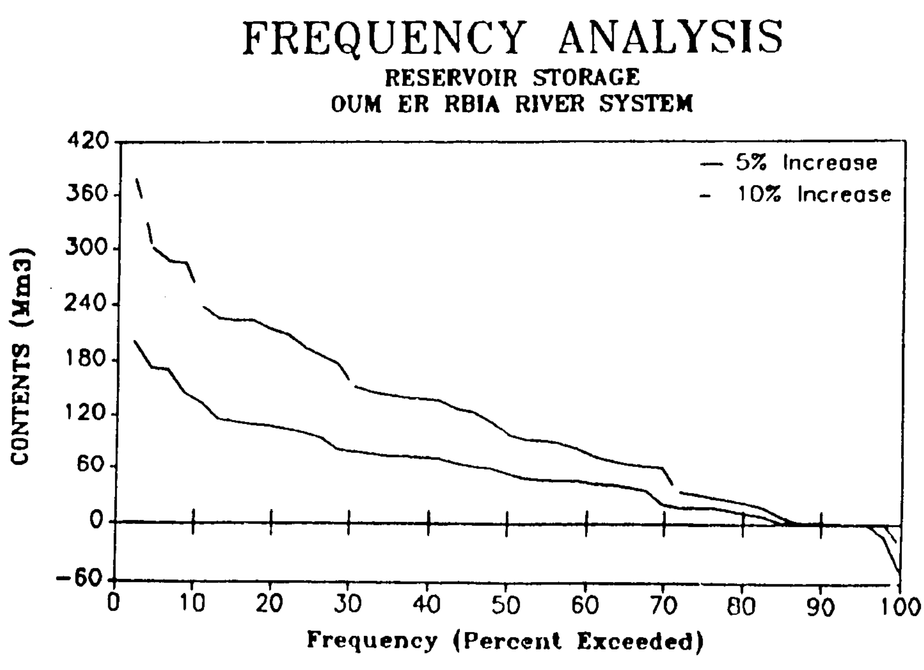

Figure 10.8. - Frequency of changes in reservoir contents (M m^3) for each year from 1940 to 1985. Scheduled deliveries are shown with actual normal streamflow simulation and augmented flows as described in figure 10.3.

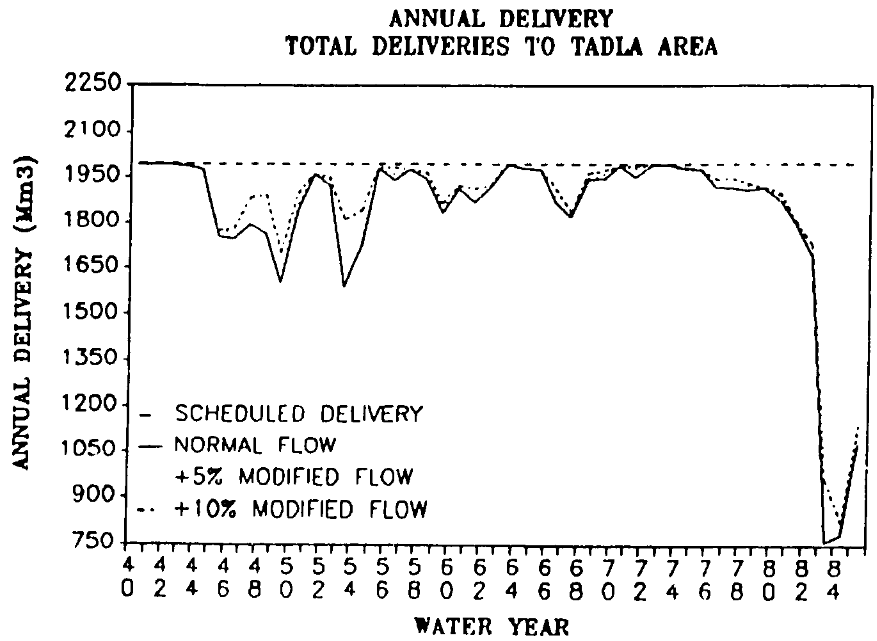

Figure 10.9. - Annual delivery of irrigation water (M m^3) to the Tadla area from 1940 to 1985. Scheduled deliveries are shown with actual normal streamflow simulation and augmented flows as described in figure 10.3.

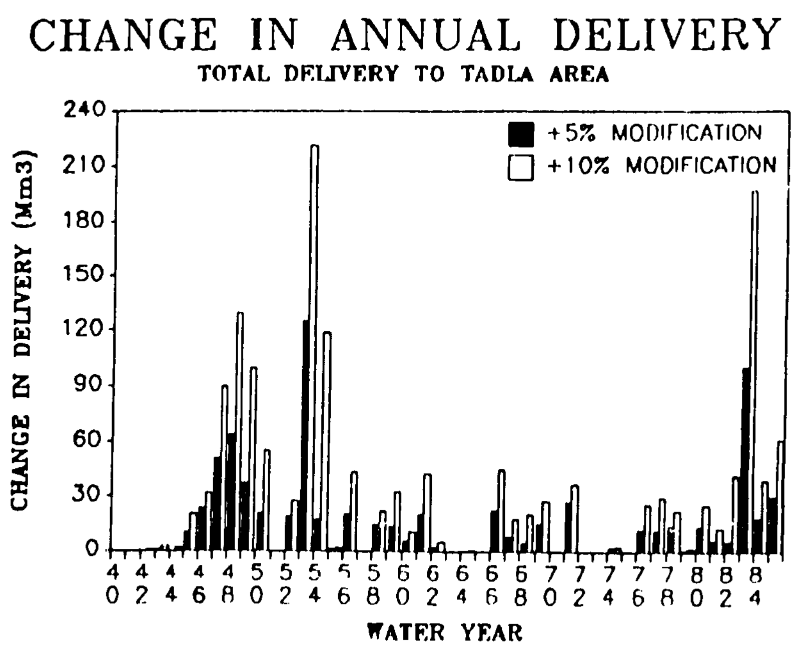

Figure 10.10. - Changes in irrigation water delivery (M m^3) to the Tadla area irrigation system for 5 and 10 percent simulated increases in streamflow as described in figure 10.3.

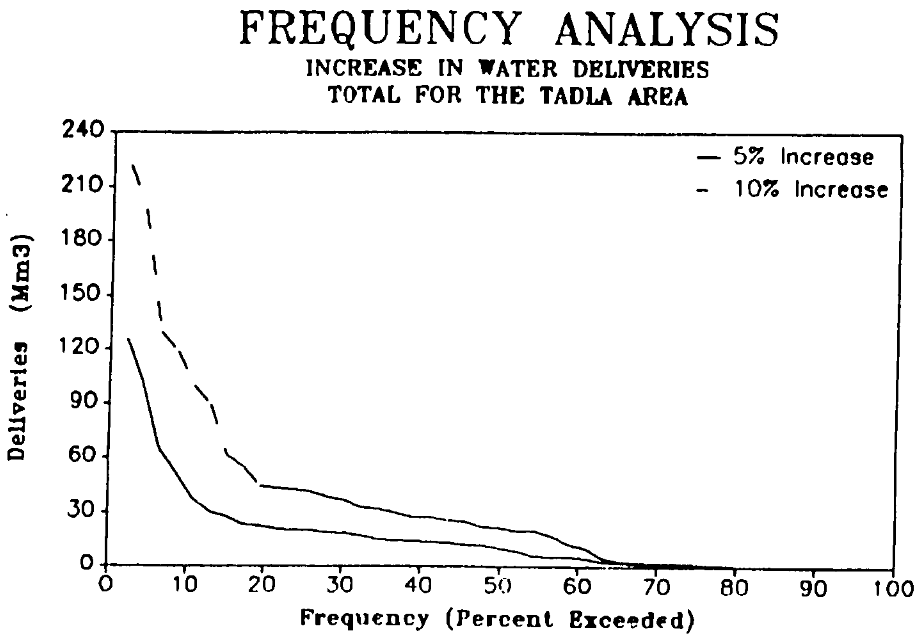

Figure 10.11. - Frequency of increases in irrigation water deliveries for the Tadla area for RIVER Model simulation described in figure 10.8.

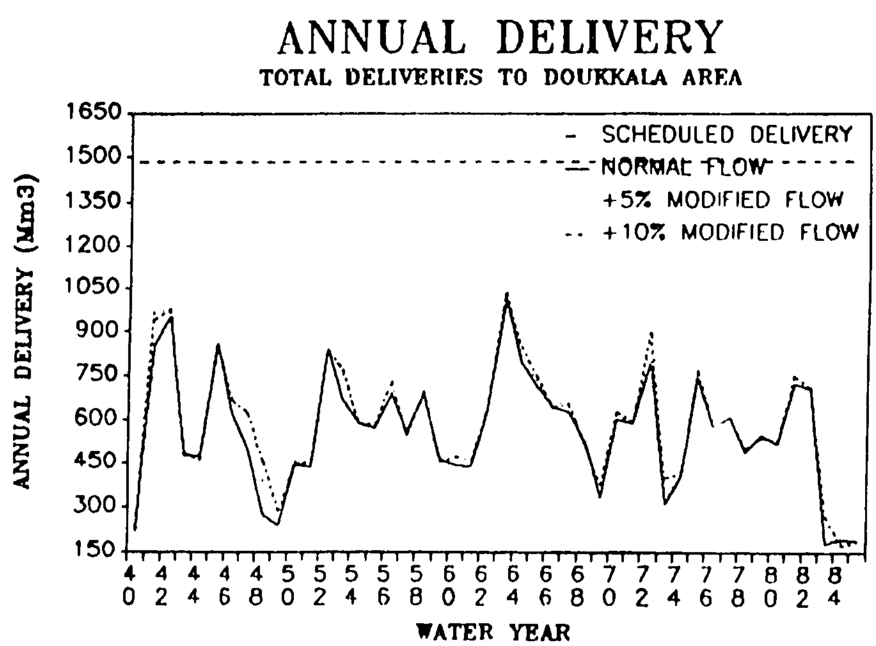

Figure 10.12. - Annual delivery of irrigation water to Doukkala area system (same as described in fig. 10.9).

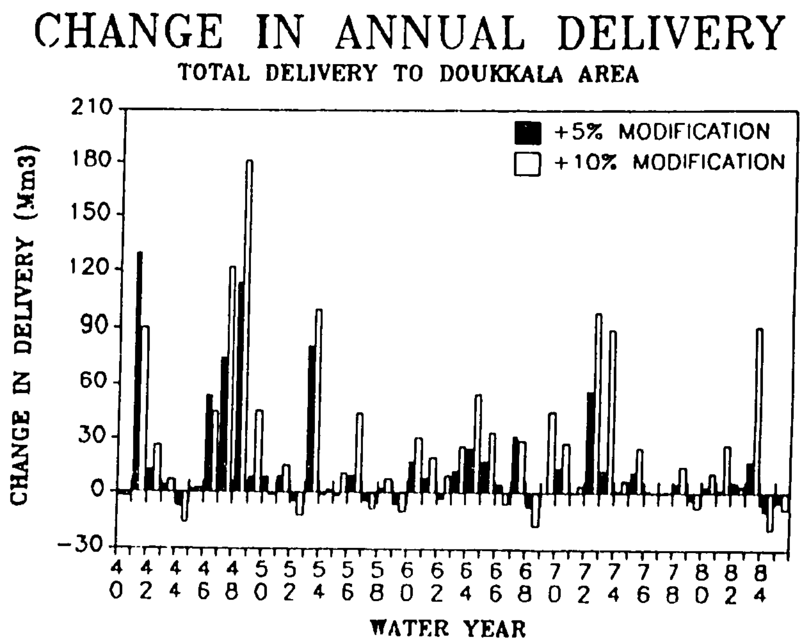

Figure 10.13. - Changes in irrigation water delivery to the Doukkala area system (same as described in fig. 10.10).

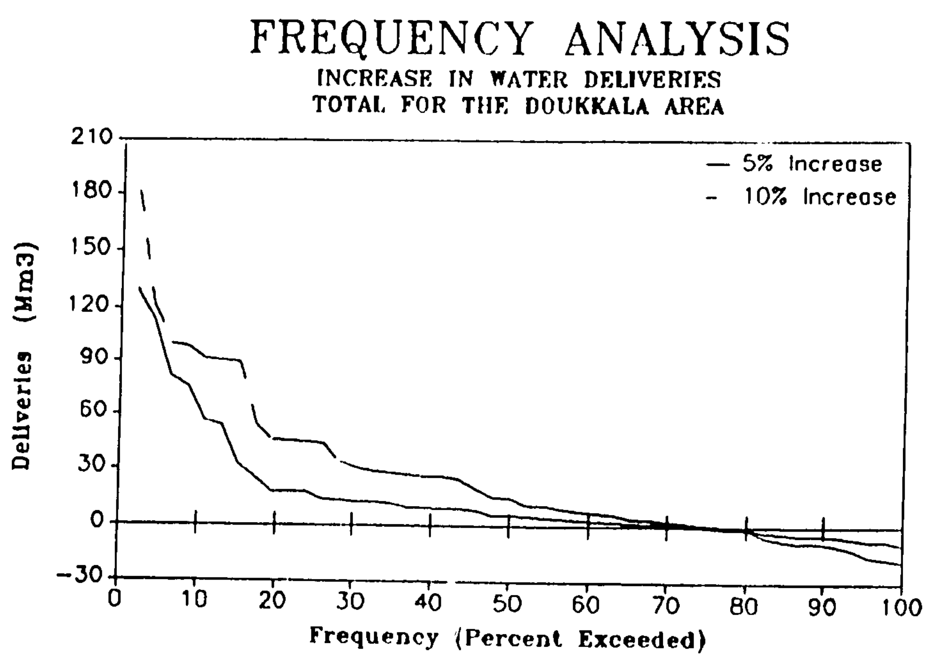

Figure 10.14. - Frequency analysis for Doukkala area (same as described in fig. 10.11).

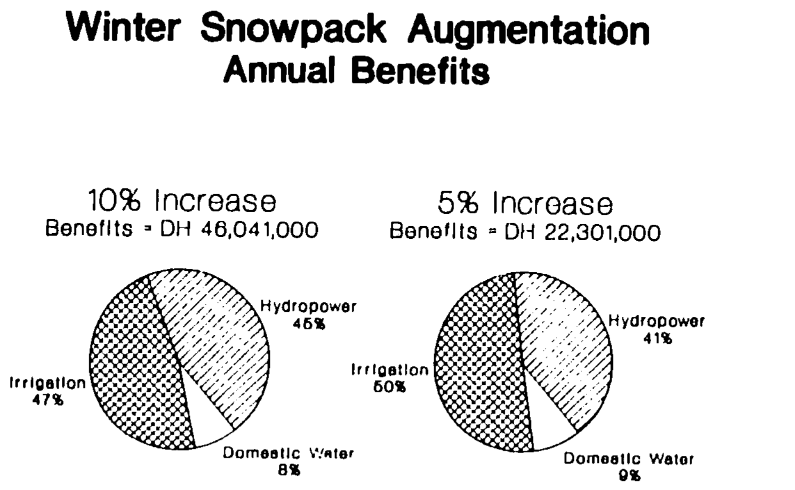

Figure 10.15. - Distribution of annual benefits due to 5 and 10 percent increases in streamflow simulations by the RIVER Model, and blended agricultural prices.

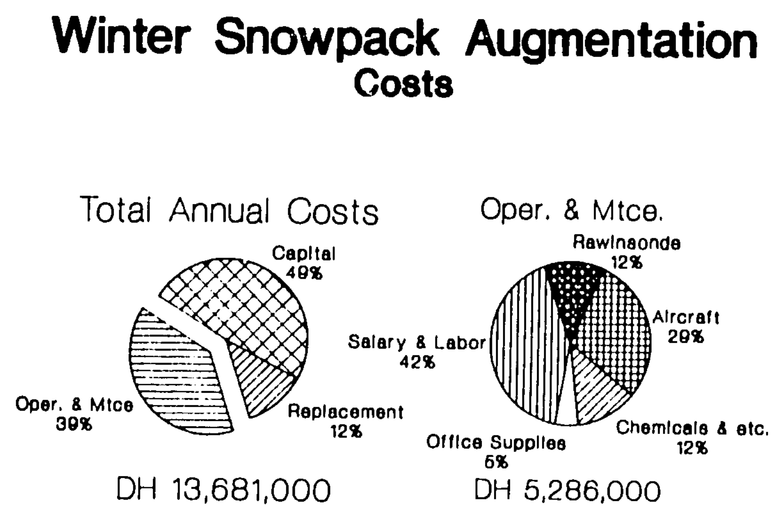

Figure 10.16. - Distribution of annual costs by type of investment: (a) capital equipment, replacement parts, and operational maintenance costs; and (b) distribution of specific operation and maintenance costs by major categories.

11. PROBLEMS ENCOUNTERED AND LESSONS LEARNED

This chapter reviews problems encountered and lessons learned during the past 5 years so that future projects may benefit from Reclamation's experience. Issues addressed include program management, operational planning, equipment, logistics, and training. The problems that arose ranged from minor annoyances to major delays in operations.

11.1 Program Management

11.1.1 Organization. - Programme Al Ghait is a complex project with several levels of management and numerous interactions among persons from different agencies. The project was designed as an emergency response to a severe drought that was affecting the water supplies and hydroelectric power of Morocco. The first management decisions, including some on procurements, were made to expedite the initiation of operations within 6 months of the signing of the project agreement in 1984. As a result, the project's management structure evolved with time, rather than being completely defined from the outset.

Initially, an organization chart and specific position descriptions were prepared and presented to the Direction de la Meteorologie Nationale (DMN) for review and implementation. During the first year the organization chart was modified several times, which led to uncertainty among the staff. Furthermore, there was a reluctance to put names with the team leader positions and establish their specific responsibilities and authority to direct their subordinates. No middle managers were formally designated within the official GOM personnel management system until 1989. As a result, an informal management system evolved with somewhat unclear lines of intermediate authority below the project director. Although this system worked, it was awkward and less effective than a formally recognized organizational plan would have been.

Future projects should implement formally, within the first 6 months, an organization chart with clearly defined functions and lines of control. The organizational structure should be carefully reviewed with all members of the team so that everyone clearly understands his role and its relationship to the others within the project.

Detailed position descriptions should be written and discussed with each staff member. Once the position descriptions are agreed upon by the workers and managers, more detailed work plans should be completed by managers and subordinates. **Once the work plans** are accepted, the managers and workers can set **realistic objectives**, with **schedules for specific work products**, and monitor their progress toward those objectives.

11.1.2 Resident scientists. - The Reclamation support in Morocco was provided through the Resident Scientific Advisor (RSA) and through Reclamation and contractor experts who visited Morocco to perform specific tasks. One permanent scientific advisor was insufficient for the large quantity of work involved in starting the project. During the first 6 months, his duties included program management, coordination with USAID and the Project Steering Committee (PSC), development of the Operations Plan, training of scientific and technical personnel, and monitoring of contractors during the installation of complex data collection systems. In lieu of a complete project implementation team stationed in Morocco, a number of Reclamation and contractor experts were stationed on temporary duty in Morocco at various periods for 2 to 12 weeks at a time to assist the RSA in the project implementation. Their dedication and expertise led to a successful start of the project.

Future projects should provide more time for project implementation and more personnel to handle its multidisciplined training and equipment issues. An American project implementation team of three people should be assigned as residents in the host country during the first 12 to 18 months, when equipment is installed and scientific data collection and operations are initiated in a very intensive period of management and training. **The three experts should include a scientific advisor and team leader, a field operations and scientific analysis expert, and an electronics expert.** The project implementation team should be responsible for initial program management, scientific operations training, equipment installation and maintenance training, and operations monitoring.

GOM counterparts should be assigned to work closely with the individual implementation team experts so that the team's expertise is transferred to counterpart scientists and engineers. Office space and facilities for each of the team members and his/her counterpart should be provided at the appropriate site. The implementation team and their counterparts would form the nucleus for the project management team, which would consist of the project director, scientific team leader, operations coordinator, and equipment maintenance coordinator. The host country management team should continue to consult with their U.S. counterparts after the latter's return to the United States. The RSA should remain in-country until the conclusion of the intensive technology transfer phase of the project. In Programme Al Ghait 4 years was appropriate for this phase.

11.1.3 Mission project officer. - During the past 5 years, this project has had four excellent USAID Mission project officers (sec. 1.5). While they provided excellent management to the project, the changes during the project have resulted in lack of continuity and some loss of time and effort as each new person became familiar with the project and its personnel. Future projects should attempt to maintain the same individuals for extended periods, preferably a minimum of 3 years each. The project has benefited from the skills of each person: Mr. John Giusti for his excellent orientation and management assistance to the neophyte RSA; Dr. Samir Zoghby for his superb language skills and diplomacy; Mr. Robert Kahn for his technical interest and expertise; and Mr. Eric Loken for his environmental expertise which led to close monitoring and technical understanding of the project. Mr. Loken's support of the scientific aspects of the project has contributed to the motivation of the scientific team and led to their participation in international scientific meetings and enhanced scientific collaboration. This type of expertise and level of interest are recommended for future projects due to the technical nature of the scientific studies.

One lesson learned from the project management perspective is the need for close coordination and cooperation between the Mission and the RSA in maintaining open communications and developing strategies for the project monitoring and management of various issues. While the RSA was stationed in Casablanca, 100 km from the Mission, frequent telephone conversations and personal visits provided a mechanism to exchange information and obtain guidance on delicate issues. Meetings and discussions of issues and agendas before each PSC meeting led to more effective meetings and resolution of issues. These types of frequent exchanges are recommended for future project managers and RSA's.

Similar exchanges were helpful in maintaining the information flow between the RSA and the other PSC leaders in Rabat. Frequent meetings with Mr. Bensari and Colonel Bamaarouf led to frank and open discussions of issues and resolution of problems before they became critical. This type of management is needed to gain confidence with host country leaders and counterparts, thereby developing strong relationships that result in effective decisions based on thorough understanding of often complex technical issues.

11.1.4 Interministerial coordination and cooperation. - The National Steering Committee (NSC) was established to coordinate interministerial activities and information transfer. It met once a year to review the scientific progress of the project. Details of project management issues and problems were not discussed at the annual meetings.

The NSC played a critical role in the initiation of the project through its direct involvement in the project and provision of assistance from different ministries for specific ministry-related issues. The NSC could have been more effective if it had met more frequently and the PSC had briefed it more often on project status and needs. An example is the provision of a site for the radio repeater station by the Ministry of Agriculture and the sites for seeding generators from Eaux et Forets and the Radio Television system of Morocco (RTM). These issues were resolved over a period of several months. If the NSC had been more closely involved in the planning stage, the issues might have been resolved faster.

Future projects should have regularly scheduled quarterly briefings and additional meetings to deal with specific issues. The briefings would provide a status review of project activities, scientific findings, and problems appropriate for resolution at the NSC level.

11.1.5 Annual monitoring reviews. - The annual monitoring reviews contributed significantly to the project. These onsite reviews by two experts in environmental, diplomatic, scientific and technical, and management aspects of the project contributed to the identification and resolution of specific issues that the PSC had failed to resolve. The annual monitoring review team was comprised of the USAID Washington's Environmental Coordinator for Asia and the Near East and Dr. Bernard Silverman. Their intimate knowledge of the project and people involved in the program from its inception enabled the team to evaluate the project critically and make important policy and technical recommendations to the PSC and the USAID Mission in Rabat.

Each annual onsite review lasted for about 2 weeks. The reviews provided an intensive evaluation of the status of implementation, administrative, programmatic, and technical issues. The review team assisted the project management team at USAID and the GOM in their management of difficult issues. Through their assessments and experience, they were able to suggest new ideas that often led to improvements of the project.

Future projects should retain the annual monitoring review process and, whenever possible, use similarly qualified experts who have intimate knowledge of the project and its personnel from its inception. The combination of one high-level USAID official and a Reclamation scientific manager is highly recommended.

11.1.6 External evaluation review. - This project also benefited from the USAID requirement for an independent team of experts selected to provide an external evaluation of the project every other year. This External Evaluation Team (EET) is discussed in section 1.5. It examined the project implementation, technology transfer and institutional development, scientific analysis and evaluation, and program management. The EET's critical review of the project contributed to the scientific management and operational development of the project. The EET provided an independent source of new ideas and expertise which identified problems and suggested solutions. Their reviews assisted the project management and gave an independent expert assessment of the project to the USAID Mission. However, the 2-week period allocated for the in-country review and reporting was too short for such a complex and extensive project.

The EET report was translated and given to the project management staff in USAID and the GOM, generally within 1 month of the review. The report was then discussed by the PSC and appropriate action taken. In the EET review years, the annual monitoring review was scheduled following the EET review, so that the monitoring team could discuss the EET's general recommendations and provide specific implementation recommendations that were within the scope of the project budget and policy. This provided a balance between the sometimes idealistic recommendations of the EET and the realities of the project budget.

The Mission's requirement for such an external team of experts was wise and should be continued in future projects. Future projects should schedule the reviews of the EET so that they have a maximum impact on the Mission and project staff and meet the technical need to review the project during field operations. Sufficient time should be scheduled for briefings and debriefings of the Mission staff, with time to review the final draft of the EET report before its publication and distribution. Generally, a 3-week period within the host country will provide sufficient time for the information gathering and report writing phases of the review. Scheduling the monitoring team's annual visit after the completion of the EET's final report is recommended to give the appropriate balance in the implementation of recommendations.

11.2 Operations Plan

In the early stages of the project, the Operations Plan was not complete. It lacked several important components on personnel management, data forms, and data management procedures which would have improved the early scientific analyses. The Operations Plan (Hartzell et al., 1986) continued to evolve as the project expanded. Each year required detailed reviews and updates of the plan, followed by education of the staff on the revisions and how they affected their roles.

Future projects should establish a firm schedule for development and implementation of the Operations Plan. Annual reviews of the plan are needed to update it to represent all changes in project operations and additions to the equipment, data collection and management, communications, etc. A procedure should be established to ensure that all staff are aware of all changes to the plan prior to each new field season.

Selection of sites for ground-based cloud-seeding generators posed a special problem for the project design and for rewrites of the Operations Plan. The need for ground-based generators was determined after the first year, during which only aircraft seeding was done. Possible sites were studied by Reclamation and DMN experts, and suitable locations were identified in November 1985. Generators were shipped to Morocco in October 1985; however, they were not installed until January 1987.

The principal cause for the delay was excessive scientific studies for siting generators prior to committing resources and personnel to the ground seeding network, although logistics also played a part. The logistical problems involved the transportation and housing of personnel in a mountainous region in the vicinity of Azilal. Field surveys of the selected sites were conducted by the DMN staff during the summer of 1986, and generators were installed at 7 of the 14 recommended sites in January 1987. At present, seven additional sites have been selected and visited, and personnel are available to operate generators. However, due to resource limitations and higher priorities assigned to other project activities, these generators have not been installed. The current network of seven generators does not adequately cover the target area, especially in northwesterly and westerly flow conditions. Only about half of the target area is seeded in these conditions.

Future projects should allow for changes in their design, so that new operational requirements that may arise can be met quickly. However, any proposed changes must be considered in light of their impact on the project's evaluation.

In siting seeding generators in Morocco, the experts' preliminary recommendations for seeding generator sites should have been followed initially in order to meet critical project needs. Had these initial recommendations been executed in 1985, an additional year of more efficient seeding operations would have been completed. Initial deployment of the generators could have been followed by more detailed studies of airflow and modeling to determine better locations. It should be noted that subsequent modeling studies did not significantly change the original recommendations for sites.

11.3 Logistics

11.3.1 Facilities. - The original plan called for the co-location of all operational facilities. Ideally, the operations center, scientific analysis facilities, and operational support facilities would be co-located with the aircraft operations center so that all teams could interact throughout the field season. Khouribga was selected as the operations center for a number of reasons. It is located near the target area at a site providing good radar coverage of the target. Runways at the Khouribga airfield are adequate for effective aircraft operations. The operations center building had an abandoned control tower and a briefing room. Much of the original planning revolved around Khouribga as a complete operations center. Special radio equipment for air-to-ground communications and an automatic weather station were purchased for use at Khouribga. The automatic weather station was planned to be installed there to provide weather observations, including the altimeter setting, for aircraft operations. Unfortunately, a power line that had been installed over the west end of the Khouribga runways prevented aircraft operations. A plan to place the power line underground was found too expensive and disruptive for the Office Cherifien des Phosphates' (OCP) phosphate mining operations in Khouribga. Therefore, all aircraft operations were based from Meknes, the Kenitra Air Force Base, and the Marrakech Air Force Base, which resulted in the deployment of the operational and scientific staff over a large region of Morocco.

Issues of local housing, transportation, and working facilities presented difficult problems for the project management and hindered effective operations from 1984 to 1986. Efficient buildings and facilities were provided in Casablanca, Khouribga, and Beni Mellal in accordance with the original plan. These included a large three-story building at Khouribga, which was remodeled especially for the project. However, few personnel were willing to work at the more remote sites such as

Khouribga and Azilal. This was due in part to lack of office furniture, living space, and cooking facilities. The facilities were adequate for the operations team on temporary duty at Khouribga.

Lack of transportation also contributed to the problem of staffing remote sites. Scientists and operations directors in Casablanca often were unable to travel to Khouribga during storms because no vehicles were available. As a result, Khouribga was often understaffed during operations. Khouribga was understaffed with operations directors; however, there were enough technicians. Lack of adequate transportation for the Scientific Analysis and Evaluation Team (SAET) and operations personnel also limited the scientific interaction among personnel in Casablanca and those at the outlying sites.

The team of radar operators and electronics technicians stationed at Khouribga performed well 24 hours a day, although operations direction was often limited to daytime hours due to lack of adequate staffing for 24-hour operations. The project succeeded because of the efforts of a few excellent, dedicated individuals.

The housing problem at Khouribga was eliminated in 1989 when five excellent apartments were completed in a major remodeling of the second floor. The new facilities are very attractive and should be more than adequate to persuade operations directors and staff to move to Khouribga for extended periods. The Khouribga center is an ideal location for radar research and other scientific studies, in addition to a base for operations. The microcomputers provided with the radar and an IBM PC/AT should provide a means for more complete data management and associated scientific studies.

At Azilal in 1987, transportation again was a critical issue, which has not been resolved. The staff of over 15 meteorologists and technicians has only one vehicle with which to maintain four precipitation gauges and seven seeding generators and collect snowcourse data over a large area.

Lack of transportation also limited the effectiveness of cloud physics data collection and aircraft seeding operations. The aircraft operations were based at Kenitra, where excellent hangar space and other operational facilities were provided for the aircraft team. However, the distance from Kenitra to Casablanca, about 180 km, limited the ability of the SAET and operations coordinators to interact with the air crews, especially during flight operations.

Future projects should plan carefully for the project operations center and the transportation and housing of personnel so that an adequate staff is provided at all critical locations. Plans for centralized facilities should be coordinated with all responsible authorities so that they can be implemented without major disruptions. Sufficient resources for the purchase of vehicles and their maintenance should be available from the start of the project. Costs of facilities and transportation should be evaluated with adequate consideration of the needs of the affected personnel for housing, recreation, and education of dependents. **The provision of adequate housing and transportation will ensure more effective operations.**

11.3.2 Equipment. - The management of the initial procurement of equipment was performed under extremely short lead times to meet the emergency needs imposed by the severe drought conditions. Many decisions were made during the survey trips to Morocco in early 1984 based upon the best available information and limited interaction with the GOM officials. Under these circumstances, the GOM felt that they did not have time to review many items adequately before approving them. After the arrival of the RSA, the procurement process improved; however, due to the lead times needed to send documents from Denver to Casablanca, the interactions were still somewhat limited. As a result, the GOM criticized the procurement process as not having given them adequate input to the equipment specifications.

One of the basic equipment issues involved differences in commercial electric power between Morocco and the United States. In order to meet the emergency procurement schedule, many items were purchased in the United States, some of them without the 220-volt or 50-hertz options required for Morocco. However, the long lead times required to purchase equipment with European (Moroccan) specifications from overseas subsidiaries of United States companies ruled out that option for all practical purposes. Current inverters and transformers were required to convert from 50 to 60 hertz and from 220 to 110 volts, respectively, in order to power the U.S. devices, which increased the maintenance burden. **Future projects should provide more time for coordination with the host country's electronics experts on procurement of equipment that meets the host country's specifications.**

Power stabilizers were required for all equipment. While the original plan provided power stabilizers for major pieces of equipment, not all systems were covered adequately. Power stabilizers are generally recommended for all delicate electronic equipment. They are especially needed in developing and rural areas where electrical power is subject to surges. A more complete initial plan of all equipment requirements might have resolved this issue. Reclamation had several experts involved in this process. One of them was in Morocco for 3 weeks before completion of the project's final Participating Agency Service Agreement (PASA) with Reclamation, but his visit was inadequate to check all aspects of equipment specifications, power supplies, and telecommunications. **The project required a more complete equipment plan, with one individual assigned to the planning, procurement, and installation of all the systems required.**

An electrical engineer should be assigned to the project implementation team, and sufficient time should be provided for this person to deal with the equipment issues. Adequate time should be allowed for this person to visit the host country and discuss equipment needs with USAID Mission and American Embassy officials experienced in the installation of electronic equipment, computers, and communications systems in the host country. **The assigned engineer should work closely with the host country experts, visit proposed field sites, and follow up on the equipment installation. He/she should also arrange for training.**

Mr. Louaked served as the equipment and maintenance coordinator. His excellent knowledge of the Moroccan systems and management skills were needed full time to manage the large number of equipment and electronics technicians located at five sites in Morocco. **Future projects should assign a host country engineer full time to this critically important position.** One problem that was never resolved was the transmission of satellite imagery to Khouribga for use by the operations director. This situation illustrates the type of coordination needed to handle equipment in a complex project. A specially conditioned line was required for transmission of high-resolution satellite imagery from Casablanca to Khouribga. This line and a line for radar data transmission were originally requested in 1984 from Post, Telephone, and Telegraph (PTT). The Alden Electronics Corporation provided the GOM with specifications for the line and signal quality. The radar line produced excellent radar relays; however, the satellite line was never operational. When the line failed to support image transmission, no Reclamation experts were available to help resolve the problem. A number of checks were made from 1984 to 1988 by the DMN electronics coordinator, the satellite system electronics expert, and the PTT staff in Casablanca and Khouribga. The problem was determined to be lack of a good line from the National Meteorological Forecasting Center (NMFC) at the Casablanca Anfa airport to the downtown PTT center and from the PTT center in Khouribga to the operations center building. If PTT had worked closely with DMN, the line would have been installed 3 years earlier, in 1985.

Close coordination is essential in following a problem from its detection to its resolution. Specific electronics technicians should be assigned to particular pieces of equipment and given full responsibility and authority to resolve problems in a timely manner. When problems involve different organizations, coordination through the NSC may be required to expedite solutions and resolve problems in a timely manner. A U.S. electronics expert on the project implementation team could assist his/her host country counterparts in the timely resolution of such an issue.

When local solutions to a problem are not possible, alternative solutions may be available. In the case of the satellite system, installation of another direct-readout ground station at Khouribga would have been an alternative. However, the cost of such a system was beyond the scope of the project budget in 1984. Today a simple, less expensive system, such as that provided in 1989 by Great Britain's Overseas Assistance Project, could be purchased by the GOM and installed at Khouribga and might be more cost effective than the land line installation. An alternative solution is to move the original project Secondary Data Users Station (SDUS) to Khouribga and use the British system in Casablanca.

11.3.3 Shipping and supply. - The shipping of goods to foreign countries from the United States poses special problems in project management. To minimize these problems on Programme Al Ghait, local suppliers should be used for items available in Morocco, such as batteries and paper products. In order to minimize project delays due to shortages, procedures were devised for inventorying more than 200 different electronic components that were stocked in Morocco.

Careful planning can help to smooth customs formalities, which often cause significant delays. The first procedures for shipments from the United States to Morocco were not well coordinated with GOM officials. This situation led to delays. Finally, the Forces Royales Air (FRA) designated the Ateliers Mecaniques Generales (AMG) base of logistical support as the official receiving agent for all project equipment, supplies, and parts. Once implemented, this system led to very efficient receipt and delivery in Morocco. All shipments were assigned to Royal Air Maroc commercial flights and shipped by one knowledgeable American freight handler. Once the shipping procedures were specified clearly, from the preparation of inventory through crating and packing to the exact route and delivery point specification, the trans-Atlantic shipments went smoothly.

While project personnel were able to meet most needs in a timely manner, several critical items were not handled efficiently. Several critical installations were delayed when, due to unexpectedly long shipping times, personnel who were to install equipment arrived in Morocco before the equipment did. This situation led to increased travel costs and disruptions of training schedules.

Future projects should have an automated procedure to track all equipment requests and follow their delivery to the requester. Tracking and reporting procedures must be clearly defined so that the English part names, part numbers, serial numbers, and sources are identified. With such a system in place, parts can be ordered and tracked to final delivery in the host country. In future projects, the arrival and status of each item of equipment should be confirmed before any personnel undertake travel for its installation or to train others in its use.

11.3.4 Maintenance of equipment. - The management of equipment maintenance is a major task when a project covers hundreds of kilometers and dozens of personnel are involved in its maintenance and operation. The inventory of spare parts and supplies has been mentioned above. Adequate schematics and documentation of operational and repair procedures were found to be very important. Logs with calibration data and equipment status reports were required for all equipment.

Future projects should provide training on computer-aided management of equipment maintenance and spare parts supply. Detailed procedures for recording equipment status, including repairs, and inventories are needed to ensure timely equipment maintenance and repair.

11.4 Data Collection and Management

Some problems were encountered in both data collection and data management. Some specific problems in data collection are presented below as examples of what can happen on a large field project.

11.4.1 Data collection. - Observations from the mountain precipitation gauges are not forwarded to Casablanca each month as they should be. The recording gauges serviced from Azilal are in remote locations that require off-road vehicles for access. As noted in section 11.3, the 15 people at Azilal have only one vehicle for all of their transportation needs. Consequently, gauges do not receive the required monthly maintenance. Currently, data are sent to Casablanca only at the end of each season.

Future projects should provide sufficient vehicles to meet reasonable transportation needs. Serious data losses occur when equipment is not maintained in a timely manner (at least once a month for recording precipitation gauges). A schedule should be arranged to provide maintenance during extended periods of fair weather each month. (Experience from the past 5 years suggests that at least one 1-week period of fair weather occurs each month.)

Snowcourse observations have not yet been made on a regular basis. These sites have been selected at excellent locations in the High Atlas; however, the logistics of making the observations using personnel from Casablanca or Azilal have prevented data collection. All sites are located above 2400 meters, so access to them is difficult. It was planned that Gendarmerie Royale helicopters would provide transportation on a monthly schedule for DMN experts trained in snowcourse measurements. However, the helicopters were often unavailable during the periods of good weather when the measurements could be made. Only two sets of data were obtained, and that was done with great difficulty.

An alternative source of snowcourse data collection was identified during a tour by the RSA and the equipment coordinator in December 1986. A French team working in Tabant on a mountain development project sponsored by the French Embassy offered to make observations near Tabant at the Jebel Couchet (No. 3), Lac Izoura (No. 5), and Jebel Rat (No. 6) snowcourse sites (fig. 2.2) described in the Operations Plan. Similar observations were discussed with members of the Club Alpine Francais (CAF) in Casablanca and at their alpine chalet in the Oukaimedan ski area. The members of the CAF offered to make observations for the project if the measuring system was left at their facility in Oukaimeden. They would make observations, record the data, and bring them to the DMN facilities in Casablanca each month. In addition, they could make observations after each storm. The individuals at the Tabant and Oukaimedan sites appeared reliable and would provide the required measurements at no cost to the project.

Future project operations should use such means of data collection when more directly controlled measurements are not practical. Individuals or groups who can provide data should be contacted and regular observations requested. These data should be used for the 1989-1993 data collection period. When unusual opportunities for data collection occur, they should be investigated thoroughly and used, if feasible.

Timely collection of streamflow data is essential to the statistical evaluation of results from cloud seeding. This allows scientists to promptly identify measurement equipment problems that, left unresolved and unrectified, could negatively impact the evaluation and, in extreme cases, disable an adequate assessment of results. **It is imperative that project managers and scientists realize the importance of superior data quality to evaluation analyses that ultimately will determine the success of their entire program.**

Future programs that deal with streamflow should, immediately upon selection of this variable for analyses and prior to the beginning of operations, ensure that timely, consistent, and proper collection procedures are employed by the group collecting the data. This should be followed by timely, consistent, and proper reduction of the raw data, either by the collection agency such as Hydraulique or by Programme Al Ghait scientists. Finally, reduced data should be submitted to quality control tests and then properly archived.

Currently, the acquisition of reduced streamflow data for the four control gauges selected for the statistical evaluation is running about 2 years after measurements are taken. This lessens the value of the quality control program because equipment repairs or other necessary changes cannot be made in a timely manner, which could lead to important data losses. Additional efforts should be made to expedite the acquisition of the reduced data.

11.4.2 Data management. - Data management procedures were specified in the Operations Plan. Detailed forms for data tabulation and entry into the project's microcomputer data bank were provided by the RSA to the scientific and operations teams.

The automated data collection systems provided with the radar, rawinsonde, and cloud physics data collection systems functioned well and provided an excellent data base which the individual responsible scientists have managed capably. However, the routine meteorological and operations information, which was not automated, has not been entered into the data base.

In future years on Programme Al Ghait, the entire system for data management outlined in the Operations Plan should be followed. The data manager should request all operations directors to provide operations summaries for each day, which would include the status of operations; the number of generators turned on, with their start and stop times; the mountain observations; and other information needed for project evaluation. These data and summaries of the mesoscale structure and cloud characteristics observed each day by satellite should be entered daily into the data base by the respective specialists.

Any future project should establish data management procedures and assign overall responsibility for data collection, quality control, inventory, and archival to one individual as his/her only job. The person assigned to the data management position should have a thorough knowledge of data base management and have training in quality control procedures, data inventory preparation, and data archival, as well as meteorology.

11.5 Training and Scientific Collaboration

Training was the most important and successful part of Programme Al Ghait; however, it was not without problems.

The educational aspects of the project are, without a doubt, the most important and successful part of the project. Training was divided into three types: short-term, long-term, and scientific collaboration. The training plan and results of the technology transfer were presented in chapter 6. This section focuses on the problems and lessons learned from the experience of the past 5 years.

11.5.1 Long-term training. - The long-term training program was established to provide scientific expertise at the Master of Science level in Meteorology and in Remote Sensing. The long-term training program was also designed to accomplish specific research objectives such as developing numerical airflow and orographic precipitation modeling capabilities and expertise in remote sensing within the scientific team. **Long-term training where trainees used project data for their degree theses work was suggested by the Moroccan project management as an alternative to specific contract work. This was a very successful approach and is highly recommended for future projects. When feasible, substitution of educating a graduate student for the use of services of a contractor is recommended because it provides lasting expertise for the host country and achieves the technology transfer objectives.**

The graduate students selected for this program chose research topics having direct applications to advance the project's operations and analysis capabilities in Morocco. They were selected during the first and third years of the project, and their studies in the United States took from 17 to 24 months. All students successfully completed their university programs. The initial two students completed their studies in late 1986 and late 1987 and returned to Morocco to resume their duties in the project. Mr. Loukah's return to the deputy director position contributed significantly to the progress of the project and its operational effectiveness. His airflow modeling work resulted in a model of direct application to the operational decision process. The two students who started studies in 1987 did not return until the late spring of 1989. This was at the end of the project, and their research will largely provide future benefits for the project operations and scientific analysis.

In a future program, the long-term training should begin at the earliest possible time so that students may return to the project and apply their new knowledge to the project's goals. Selection of the most capable and motivated trainees is important to the success of this training. Careful scheduling for the English language training and the Graduate Records Examinations (GRE) and the Test of English as a Foreign Language (TOEFL) is needed so that the students can enter universities at the earliest time.

In the selection of research topics, we found that a collaborating scientist from Reclamation who closely followed the student's research and participated on his graduate committee was most helpful in focusing the efforts on practical applications. **Future long-term students should have an independent scientist or engineer with practical experience and knowledge of specific project needs on the committee.** Mr. Medina worked closely with Mr. El Majdoub in developing the Rhea model studies for Morocco and in the use of the model for quantitative precipitation forecasting and the statistical evaluation. Mr. Verdin's close collaboration with Mr. Abidi resulted in a very capable model of snow cover runoff for the High Atlas. This type of applied research and educational experience significantly improved the capabilities of the DMN and will lead to long-term benefits for the project.

11.5.2 Short-term training. - A significant number of the project's scientists, engineers, and technicians participated in the short-term training program in the United States and Morocco. Training in the United States required proficiency in the English language at a level of 70 on the American Language Institute, Georgetown University (ALIGU) examination prior to completion of the USAID Mission approval. This often created problems due to the long lead time required to reach a sufficient understanding of English. Future projects should anticipate a minimum of 2 to 4 months of intensive English studies prior to the departure of students.

Details of orientation for living in the United States and preparations for travel were provided by Reclamation's Foreign Activities Division. These experts provided assistance from Washington and Denver. It is necessary to prepare candidates thoroughly for the training programs. Early in the project, arrangements were not clearly defined; this led to misunderstandings which could have been avoided. All details and procedures should be explained in advance while in the host country, so that the candidates know what to expect and can focus on the technology transfer and training when they arrive in the United States. The procedures and conditions of training should be discussed and documented prior to the candidate's acceptance in the program. The documentation should include the complete process: initial applications within the host country, English requirements, technical proficiency, financial obligations, visa and passport requirements, travel arrangements from the host country to the United States, travel advance procedures, and financial support while in the United States. International travel arrangements by the host country were the responsibility of the DMN. These arrangements were often not completed until the last day before scheduled departure. This led to great uncertainty and lack of airline reservations for trainees who had connecting flights from New York to Denver. The host country should make arrangements several weeks in advance of the travel so that reservations are available and travel plans are finalized at least 1 week prior to travel. A formal agreement between the host country airline and the project to provide reserved airline tickets is recommended for future projects.

Training in Morocco was conducted by American experts who did not generally speak French. In the early stages of the project, this training required simultaneous translation so that the DMN personnel could understand the training. Prior training in French for the American experts and in English for the DMN personnel would have significantly improved the exchange of information. The Peace Corps program of English training was quite helpful during the first 2 years; however, intensive English training should have been required for all key Programme Al Ghait staff. A 6-month training period prior to the start of the project would have significantly improved the initial transfer of technology. **The Peace Corp's training was very successful in the first year when Dr. Janet Hajjar and Ms. Laura Wagner, two experienced English teachers, conducted formal classes each day, ranging from beginner to advanced levels, for more than 100 students. This type of cooperation between USAID and Peace Corps programs is highly recommended for future projects.**

One problem that arose in the early stages of the training was that insufficient time had been allocated for in-country training. **Periods of less than 3 weeks were found to be generally too short for extensive training of personnel at various sites in Morocco.** In-country adjustment to the effects of jet lag required several days, thus limiting the initial efficiency of training personnel from the United States. Future training should provide 3 to 4 weeks of time in the host country to permit completion of required work. Travel arrangements should be flexible so that when tasks are completed in advance, the trainer may return ahead of schedule. Likewise, should additional time be required to solve difficult problems or meet unexpected priorities, the trainer may extend his/her visit. All training contracts and schedules should provide sufficient time for American experts to plan detailed courses and activity schedules and prepare appropriate handouts for all students.

Technical scientific seminars and workshops were very successful when presented in a formal classroom environment. One early training problem was the lack of visual aids and a good classroom for training. Lectures required a room with visual aids and a blackboard and screen for presentation of technical viewgraphs using an overhead projector or slide projector. Reclamation purchased special training equipment including a 35-millimeter slide projector, an overhead projector, and a video camera recorder (VCR) video tape system with color monitors. These visual aids systems are highly recommended for future projects. In addition, supplies of transparency film for viewgraphs and 35-millimeter slide film are required for development of scientific presentations by DMN scientists and use by visiting experts. All students requested written notes from their instructors for lectures and informal workshops. Advance preparation of these materials including appropriate reference lists and excerpts from or copies of technical publications is recommended for all training programs.

Reclamation purchased a video camera system to record the training lectures and informal on-the-job training (OJT) sessions with American experts. This record was then available for students' reviews of courses and for teaching new students. This procedure for reinforcing the initial training is recommended for future projects. An individual from the host country who participated in most training should be assigned to operate the equipment and assist with the use of visual aid equipment so that the host country personnel can conduct the required seminars without the RSA. Initially, the RSA operated the equipment and was responsible for its safekeeping; this function should have been promptly transferred to a full-time project person from the host country.

All project equipment should be used principally in the project so that it is available for project needs and should be stored in a project office that is accessible during training periods. Equipment was sometimes locked in a room, and the responsible person was unavailable when the equipment was needed for training.

Electronics technician training required special planning by host country electronics personnel to ensure the most efficient use of the American experts' time. One problem that occurred due to the complicated scheduling at four field sites was wasted time due to lack of advance planning and preparation within Morocco. Upon arrival of instructors, extra time was required to establish detailed schedules that met local needs, assign DMN personnel, and plan for specific electronics maintenance and OJT. Often, time was spent searching for local suppliers and parts that were not available in the project stock. A request for specific items prior to the American experts' departure may save time. Two requirements for electronics training and maintenance were (a) detailed information from the host country technicians regarding specific equipment problems, and (b) the associated parts or supplies needed for performing repairs.

Future projects should provide for direct communication between the host country electronics technicians in the central headquarters and the field sites of Morocco and the American experts in the United States to eliminate wasted time upon arrival. **A special predeparture conference call among all involved technicians and their American counterparts, 2 weeks prior to the Americans' departure, would permit purchase of the necessary parts and preparation for specific problems.**

11.6 Hydroeconomic Studies and Application Activities

The hydrologic and economic studies were designed to determine water resources assessment and management and economic feasibility of cloud seeding, and then develop strategies for their application as an enhancement or alternative for current water resources management in the host country. These studies were originally conceived as significant efforts which had a budget of $720,000. During the first 2 years, the level of emphasis dropped as more pressing operational issues and more fundamental scientific studies took priority. The USAID Mission determined that these economic studies were less important than the statistical evaluation and physical studies; hence, their budget was reduced from the original level to $80,000. As a result, only a preliminary assessment of the impacts of seeding on the hydrology and the resulting economic value of increased water was possible. It is felt that this effort has laid the foundation for further study; however, it is limited at present by incomplete and insufficient data. This problem is largely due to the lack of resources required to complete the scientific and economic collaboration with Moroccan counterparts at the level required. More comprehensive checks of the modeling study's configuration of the Oum Er Rbia River basin and simulations of streamflow are needed for comparisons with the ONE model. In addition the economic analysis lacks detailed information on shadow prices and hidden subsidies of various agricultural and domestic water practices in Morocco. Further development of farm budgets for the irrigated areas in Tadla and Doukkala is needed for irrigated versus rain-fed farms in the same precipitation zones.

Sufficient time and resources are needed to conduct complex hydrologic and economic evaluation studies which can lead to the development of better water management strategies. In the hydrologic studies conducted, the American expert should have spent more time in Morocco working closely with his counterpart for a month or more until all aspects of the river model configuration and the resulting simulations were thoroughly understood. One problem that hindered quick resolution of the river simulation questions was short trips to Morocco in which partial information was obtained with the expectation that the remaining information could be obtained by mail or telephone. The necessary information often involved several different agencies and, consequently, travel between Casablanca and Rabat. This resulted in extended delays and failure to complete tasks in a timely manner.

Experience has shown that the best way to resolve issues and problems and to gather information was for the American expert to complete the job personally while in the host country. In all cases when problems were not resolved on the spot, many months passed before their resolution. Seemingly trivial issues often went unresolved. This was due to several factors: lack of sufficient immediate need to solve the problems once the U.S. expert departed, lack of understanding of the exact question or issue posed, and lack of counterpart interest and items of higher priority upon the departure of the expert.

The economic analysis for the benefit-cost study required a significant amount of research within Morocco because these types of studies had never been done for Morocco. Hence, significant amounts of time in the country should have been allocated by the American experts to data gathering at a number of different locations and from different agencies, and then to developing the analysis with resident American experts at USAID, the Embassy, and in the GOM. The nature of these data required a good understanding of technical French so that various subtle issues could be understood and thorough information and data obtained. In the economic data gathering trips, insufficient time was allocated and much difficulty arose due to language issues. More time and an American expert who was fluent in French would have been helpful. The need for a host country counterpart who understood the economic issues and English was essential. Upon Mr. Loukah's return from his master's-level education in the United States, he was able to expedite the data collection and information gathering for the economic studies. English training for Mr. Mrabet, the hydrologic modeling counterpart, led to a significant improvement in his effectiveness in the hydrologic studies. In future studies of this type, language proficiency should be ensured, or a counterpart who already thoroughly understands English and the technical issues should be assigned.

12. SUMMARY AND RECOMMENDATIONS

12.1 Summary of Achievements

12.1.1 Project implementation. - The original project design was implemented successfully in a demonstration weather modification project for winter snowpack augmentation in the central High Atlas Mountains of Morocco. Institutions for the management and execution of a scientifically based demonstration project were developed and are being used by the DMN to conduct operations and evaluate the results. The required equipment, including Morocco's first weather radar and airborne cloud physics data acquisition system, was obtained and installed and is currently operated by DMN. The first project objective – to alleviate drought conditions – was met by the commencement of cloud seeding operations by a well-trained team in November 1984. The project is being analyzed and evaluated by a team of Moroccan meteorologists who have been trained in techniques for cloud physics research and statistical evaluation of weather modification projects. The successful implementation of an efficient, soundly based field operation is a major achievement of the project.

12.1.2 Scientific analyses and evaluation. - The second objective of the project was to examine the cloud and precipitation processes to improve the scientific basis of the demonstration project and obtain evidence of its physical plausibility. Ongoing scientific analyses are providing convincing evidence of the seedability of Moroccan clouds and indicate significant potential for beneficial seeding effects. The conditions required for cold-orographic cloud seeding occur frequently during winter storms and extend over large areas in the Atlas Mountains. Preliminary studies by the Moroccan scientific team indicate high concentrations of supercooled liquid water (0.2 to 3.0 g/m^3) in cloud types associated with specific parts of the storms. The types of clouds that often have seedable conditions occurred in 92 percent of the storms observed during the 1985-89 period. This is an encouraging result. The physical conditions in Morocco's winter clouds are similar to those observed in clouds over mountains in the Western United States, where some cloud seeding operations have been conducted with apparent success.

Statistical analyses of historical streamflow data used in developing the target-control evaluation design for Programme Al Ghait indicated that at least 6 years of efficient seeding would be required to achieve a 50-percent probability of detecting a 10-percent increase in streamflow. Such a long time is required, in part, because of the high variability of precipitation in the Atlas Mountains. Efficient seeding operations on Programme Al Ghait commenced in January 1987 with the installation of the ground-based silver iodide generators. Because the 1988-89 streamflow data are not yet available, the data sample for efficiently seeded storms that is available for evaluation covers only about 1.5 years, or one-fourth of the 6-year record required. There are also some remaining questions on the historical streamflow data for some of the control stations. Consequently, a preliminary estimate of the effects of Programme Al Ghait on streamflow to date has not been made. The decision not to make a preliminary evaluation at this time is not indicative of negative results; it is simply based on the recognition that statistical analysis of small samples of data can yield apparent "results" far different from the true seeding effects.

12.1.3 Transfer of winter precipitation augmentation technology. - Formal and informal training of the project scientists and technicians has been the most important and successful achievement of the project. The scientific and operations teams had extensive training in the United States and in Morocco on weather modification research and operational methods. Four

DMN scientists attended American universities and earned their M.S. degrees in Meteorology. In their research studies, they focused on topics related to weather modification, using data collected on Programme Al Ghait. They completed research having direct application to Mo occan issues. Their success is evidenced by the routine application in daily operational decisions of numerical models that they developed for Morocco and in their exercise of project leadership and management. Training of electronics technicians on the operation and maintenance of complex modern equipment has led to the successful maintenance and repair of the radar, cloud physics data acquisition system, and other complex equipment. The introduction of scientifically based operational decisionmaking in the direction of the field project has resulted in a steady improvement in the project's operational efficiency. The new satellite, radar, and rawinsonde data systems are providing improved analysis and forecast capabilities for the project and the entire country. Those capabilities have generally enhanced DMN's contribution to Morocco and Morocco's contribution to the world's meteorological data base.

Evidence of the successful transfer of technology was provided in the 1988-89 season, after the RSA had departed Morocco. GOM managers and scientific and technical personnel conducted the seeding operations and scientific analyses very efficiently. They also designed and implemented a new field project in the Oulmed Plateau.

12.1.4 Increased awareness of weather modification as a water resources management option. - The hydrologic and economic studies in the project were performed to determine effects of enhanced water supplies from cloud seeding on the hydrology and national economy, and to increase awareness of the need for improved water management within the OER river basin – management that would consider weather modification as a water resources option. The studies resulted in increased interaction between the DMN scientific team and the water resources management agencies of ONE and Hydraulique. Direct contact among the DMN, Reclamation hydroeconomic experts, and the GOM experts in ONE and Hydraulique resulted in the establishment of a hydrologic modeling team and an economic evaluation team that were aware of weather modification options. These teams contributed to the river modeling study that examined weather modification's potential contribution to hydroelectric power, agricultural irrigation water, and domestic water supplies within the OER basin. Annual NSC meetings and meetings of water resources experts from Morocco and the United States led to increased awareness of weather modification as an alternative in water resources management. A workshop was conducted in 1987, where GOM leaders and Reclamation experts discussed current water resources management alternatives. The workshop discussions led to a better understanding of how successful weather modification may be applied to improve water management.

Hydrologic and economic studies performed indicated benefit-to-cost ratios exceeding 1.0 when 5 and 10 percent streamflow increases were inserted into analyses. These preliminary results with a limited data set suggest significant potential benefits for Morocco. Additional studies utilizing more data and more scenarios with the input variables will enable more comprehensive and better descriptions of the impacts on the hydrology and the Moroccan economy. These studies are needed to meet the original objectives of developing more comprehensive water management strategies that may include weather modification as an option.

12.2 Recommendations on Programme Al Ghait

12.2.1 The Government of Morocco should continue the project to reach scientifically sound results. - The current project should be continued at least four more years. Calculations made at the end of that period would determine the apparent treatment effect and the confidence to be placed in the results obtained. In order to obtain the necessary sample of effectively seeded seasons, the project should continue to follow the existing management plan, scientific design, and Operations Plan, using the existing facilities and well-trained personnel already on the project, to conduct operations, collect data, and perform scientific analyses. It is recommended that the GOM take the following steps in order to fully accomplish the goals of Programme Al Ghait:

- Fund an annual budget in both dirhams and foreign exchange, as appropriate, to support the continued execution of Programme Al Ghait, including its personnel, equipment, parts, and supplies, including seeding materials.

- Install additional ground-based generators to provide for full coverage of the target under all seedable conditions.

- Establish an autonomous, officially constituted organization whose mission is to carry out Programme Al Ghait.

- Execute a formal agreement between the Programme Al Ghait organization and the FRA whereby the FRA continues to provide the aircraft, seeding generators, and seeding materials required to carry out aircraft seeding operations and collect cloud physics data.

- Execute a formal agreement among Programme Al Ghait and ONE and Hydraulique whereby ONE and Hydraulique provide, on a timely basis, the streamflow data needed for evaluating the program.

12.2.2 The scientific research capabilities should be enhanced. - The scientific team has begun a series of interesting and useful studies which should be completed. Larger samples of cases and more comprehensive stratification of events into homogeneous samples are needed for sound scientific conclusions to be drawn. Completion of this work will require more time for data quality control and completion of computerized data bases, development of software for the display and processing of information, and detailed scientific analyses.

Expanded studies of the radar and satellite data should be performed to describe the mesoscale and synoptic characteristics of precipitation events in Morocco. Such studies from the Programme Al Ghait data sets may improve understanding of the mesoscale structure of storms in this region and thereby lead to better weather forecasts. Results of the mesoscale studies should be combined with the cloud microphysical observations and numerical modeling simulations to improve understanding of the physical mechanisms that lead to precipitation. Combining these physical studies with statistical studies that include the use of covariates will lead to better cloud seeding results and improved project evaluations.

The presentation of scientific results from Programme Al Ghait to the Moroccan and international scientific communities should be continued. These presentations will help other Moroccan water resources experts understand the cloud seeding program and its possibilities for improvements in water resources. Presentations to the international community will improve the general understanding of precipitation mechanisms active in northwestern Africa and of Moroccan attempts at weather modification. Publication of scientific papers in refereed journals is strongly recommended.

12.2.3 The United States should continue to be involved in the project. - Continued U.S. participation in the project was recommended by the final EET report and the annual monitoring report of 1989. Both reports recommended continued U.S. involvement for the next 4 years, at the end of which a sound scientific result may be obtained. The support should focus on ensuring sound operations and data collection each year with quality control of data collected, and the completion of scientific analyses and the statistical evaluation of the project. Continued U.S. assistance would build on the transfer of science and technology already accomplished, through continued scientific collaboration and more advanced training.

The United States should continue to monitor Programme Al Ghait's progress and look for ways to support continued scientific collaboration after the end of the current USAID project to ensure that a sound scientific result can be obtained over the next 4 years.

- Monitoring of the GOM progress in successfully implementing recommendations 12.2.1 and 12.2.2 above should continue.

- If the GOM successfully continues Programme Al Ghait, the United States should consider limited strategic assistance in the most critical areas of:

    - Improvement of the statistical evaluation of the cloud seeding effects on streamflow through (1) the performance of additional exploratory analyses to develop the best covariates as soon as the historical data set is finalized, and (2) the performance of a final statistical evaluation and interpretation of results through collaborative efforts that will answer the important questions and avoid pitfalls that may occur if the final seeded data sample is a substantial aberration from the norm.

    - Improvement of the usefulness of numerical models by (1) additional refinements in the Atlas airflow model and Rhea orographic precipitation model, (2) enhanced use of the models in daily operations and in project evaluation studies, and (3) more thorough interpretation of model results.

    - Improvement in the aircraft data analysis by (1) continued emphasis on cloud physics data collection, (2) selection of a representative data sample for expansion of the current analysis, and (3) interpretation of results for the physical evaluation of the project.

    - Improvement in radar data analysis by (1) support of continued quality control of all data collected, (2) development of a radar data climatology of all storms for which data were collected, and (3) interpretation of results of radar data analyses.

    - Mesoscale studies to improve understanding of Moroccan winter storms and their seedability.

Continued U.S. participation may also enable further development of the hydrologic and economic studies. Their completion will produce (a) a better assessment of the economic benefits of the cloud seeding to the various Moroccan economies, and (b) new scenarios that utilize the additional water that may occur from cloud seeding for the improvement of Morocco's water resources management.

12.3 Long-term Strategy

The potential importance of additional water supplies that might be obtained through weather modification and the complexity of the issues involved argue that some group within GOM should be assigned to continue studying the issues after Programme Al Ghait is finished. In the meantime, it appears premature to launch additional projects until Programme Al Ghait is completed and its results evaluated, a process that will take several more years. If the final results of Al Ghait suggest economically feasible precipitation increases, then the launching of additional operational projects would be warranted, assuming environmental issues can be handled satisfactorily. On the other hand, if there is still no statistically significant evidence of an increase in streamflow, it would be unwise to launch any additional operational projects. If the trend in results is for an increase in streamflow, continuing the seeding to expand the data sample to strengthen the evaluation seems prudent. Continued scientific study to determine weaknesses in current seeding strategies and procedures and implement improvements is important and should be pursued.

Rational decisions on future applications of weather modification technology in Morocco will be possible only if its advantages and disadvantages are well understood and it is considered as one of many options in water management. Weather modification is not a substitute for water storage systems, conveyance systems, or water conservation. On the contrary, the introduction of weather modification to enhance precipitation is an added reason for constructing storage and conveyance systems. Since cloud seeding requires special weather conditions that may not be present in the locations or times of greatest need, the benefits of weather modification are enhanced by the availability of structures to transport water and store it for later use. Furthermore, use of successful weather modification in conjunction with water storage and conveyance facilities can increase the cost effectiveness of those facilities by spreading their fixed costs over a larger volume of water.

Proper integration of weather modification into a water management system requires a clear understanding of the limitations of weather modification. It is effective only on certain types of clouds, which may or may not be found in a proposed target area. In areas where suitable clouds occur, the amount of additional precipitation produced is usually quite limited, perhaps to 5 to 15 percent of the naturally occurring precipitation over a season. Its effects vary from season to season depending upon the frequency with which the various types of favorable storms traverse the intended target area.

Weather conditions in Morocco vary widely from year to year, so the number of opportunities for cloud seeding to enhance rainfall also varies widely. There is no generally accepted method for making long-term weather forecasts for a year or more ahead, so one must resort to climatological statistics in order to estimate the average number of opportunities that future years will bring.

In spite of the points just made, weather modification has several important advantages, which account for its extensive application in many countries. It is relatively inexpensive; it can be implemented without building additional fixed structures; and it can easily be stopped or temporarily suspended at any time. Benefit-cost studies in this report show that it could be an economically feasible way to enhance the water supplies of Morocco provided that 5 to 15 percent increases in streamflow are obtained. Long-range planning for management of Morocco's water resources will not be complete without considering the weather modification option.

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APPENDIX

List of Project Reports and Publications

This appendix lists the reports, publications, and documents which led to the design and implementation of the agreement between the Government of Morocco and the United States and the subsequent technical assistance project. The technical reports represent various scientific contributions of the project.

Project Design and Implementation

The following documents and reports led to the initial feasibility assessment and development of the project design and eventual agreements between the GOM and the USG.

Lintner, S. F., and B. A. Silverman, *Project Paper - Morocco Winter Snowpack Augmentation Project (608-0190)*, Bureau for the Near East, USAID, 81 pp., February 1984.

Silverman, B. A., S. A. Changnon, A. S. Dennis, and S. F. Lintner, *Weather Modification Assessment - Kingdom of Morocco*, Bureau of Reclamation, 53 pp., Denver, Colorado, November 1983.

USAID, *Participating Agency Service Agreement (PASA IMA-0190-p-iw-4093)*, Washington, D.C., 20 pp., May 1984.

USAID Mission, *Project Grant Agreement between the Kingdom of Morocco and the United States of America for Snowpack Augmentation Project 608-0190*, 53 pp., Rabat, Morocco, April 1984.

Project Review and Evaluation

A series of annual monitoring reviews were designed to provide project oversight and scientific quality of the project and verification of implementation of suspension criteria. These annual reviews were summarized in *Annual Monitoring Review Reports*. In order to ensure scientific quality of the project, an independent external evaluation team provided three reviews which focused on the project's scientific design and evaluation, implementation, management, institutional development, transfer of technology and training, and water resources planning and management. The following reports document the various reviews.

Changnon, S. A., R. L. Rose, and J. A. Warburton, *An Evaluation of the Winter Snowpack Augmentation Project in Morocco, April-May 1985*, 43 pp., May 1985.

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Lintner, S. F., and B. A. Silverman, *Third Annual Monitoring Report, Winter Snowpack Augmentation Project*, Bureau of Reclamation, 56 pp., Denver, Colorado, May 1987.

Silverman, B. A., and G. L. Whaley, *Fourth Annual Monitoring Report, Winter Snowpack Augmentation Project*, Bureau of Reclamation, 55 pp., Denver, Colorado, June 1988.

Silverman, B. A., D. A. Matthews, and J. C. Lease, *Fifth Annual Monitoring Report, Winter Snowpack Augmentation Project*, Bureau of Reclamation, 55 pp., Denver, Colorado, June 1989.

Progress Reports

A series of monthly and annual progress reports were written to document the significant events, progress toward objectives, problems, cost accounting, and operational status. The *Monthly Project Status Reports* provide a daily summary of meteorological conditions affecting operations and operational status with summaries of precipitation, streamflow, and reservoir levels. Annual summaries of project operations and technology transfer provided a comprehensive review of the project each year from 1985 to 1988.

Hartzell, C. L., *February 1985 Project Status Report - Winter Snowpack Augmentation Project: Programme Al Ghait*, Bureau of Reclamation, 6 pp., Denver, Colorado, March 1985.

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Matthews, D. A., *July-September 1986 Project Status Report - Winter Snowpack Augmentation Project: Programme Al Ghait,* Bureau of Reclamation, 27 pp., Denver, Colorado, October 1986.

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The Government of Morocco reported a summary of progress each year to the National Steering Committee. These reports were prepared by the project operations and scientific analysis teams. They provided an overview of the progress and summary of field operations and scientific analyses.

Programme Al Ghait, *Programme Al Ghait - Projet Maroco-Americain*, Direction de la Meteorologie Nationale, 16 pp., Casablanca, Morocco, May 1985.

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Other Scientific Reports and Papers

Technical and scientific reports were developed from the scientific research studies and as part of the technology transfer process. The Operations Plan (Hartzell et al., 1986) provided the scientific design for the conduct of seeding operations and the data collection and analysis. Other technical reports and collections of information that resulted from the project are listed below.

Baddour, O., *Aspects Generaux sur la Physique des Nuages et L'insemination Artificielle pour Augmenter les Precipitations*, DMN, 19 pp., Casablanca, Morocco, January 1987.

Baddour, O., and R. M. Rasmussen, "Microphysical Observations in Winter Storms over the Atlas Mountains in Morocco" (accepted for publication in *Atmospheric Research*), 1989.

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Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic Institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.