NEED FOR CLOUD SEEDING

The key role played by a good water supply as an engine of economic growth and as a yard stick of public welfare and national prosperity has been well recognized by the intellectuals of the developed countries like USA who aptly named water as the "Blue Gold". The more the water wealth of a nation the higher will be the opportunities for achieving high rates of progress in the fields of agriculture production and industrial growth that help in promoting economic wealth, employment opportunities and higher standards of living. Hence the advanced countries are constantly upgrading their water resources by harnessing not only all the ground and surface waters but also by tapping a renewable, virtually unlimited and unexploited sky water resource in the atmosphere in the form of innumerable clouds. Enlightened scientists, bureaucrats, industrialists and statesmen in about 50 countries are frequently using cloud seeding operations for over 40 years for various purposes like

1. Increase of annual rainfall for drinking and agricultural purposes,
2. dispersal of fog in airports and metropolitan city roads
3. Increase of hydro-power generation at the cheapest cost
4. Suppression of hail storms to reduce damage to life, crops and properties
5. mitigation of devastating impacts of recurring droughts
6. mitigation of damaging impacts of global warming and summer temperatures
7. increase of annual rain fall for improving the forests, wildlife and the environment

Several progressive countries like USA, Australia, China, Thailand, European states, former states of USSR, Latin American states, Arab states, Indonesia and Pakistan are getting highly benefited by employing the advanced cloud seeding technologies for the above purposes.. Several Indian states interested in promoting economic growth, agriculture development and public welfare are eager to learn from the successful experiences of other countries like China and USA and adopt those technologies by making necessary modifications to suit the local meteorological, topographical, geographical and other environmental conditions.

Rice is Life — The International Year of Rice (IYR) 2004

The United Nations General Assembly (UNGA) declared 2004 as the International Year of Rice (IYR). The theme of the IYR - "**Rice is life**"- reflects the importance of rice as a primary food source, and is drawn from an understanding that rice-based systems are essential for food security, poverty alleviation and improved livelihood. Rice is the staple food of over half of the world's population.

In Asia alone, it is observed, more than 2 billion people obtain 60 to 70 per cent of their energy intake from rice and its derivatives; it is the most rapidly growing food source in Africa and is of significant importance to food security in an increasing number of low-income food-deficit countries.

Rice-based production systems and their associated post-harvest operations employ nearly 1 billion people in rural areas of developing countries and about four-fifths of the world's rice is grown by small-scale farmers in low-income countries. Efficient and productive rice-based systems are, therefore, essential to economic development and improved quality of life, particularly in rural areas. (http://indiabudget.nic.in)

Refusal of cloud seeding operations means promoting water and food scarcity, diseases, poverty, unemployment and blocking economic prosperity of a nation.

— an environmentalist view

Water scarcity due to population growth :

If water availability in different countries is considered from 1950 it is found that the water availability per person per year is gradually decreasing from the year 1950 and the deficit is getting more and more in African and Asian countries due to the rapid population growth, urbanisation and industrialisation during the recent decades. The water availability is assumed to be the river run-off formed in the territory of a given region and summed up with half the inflow of the river from outside. As the population increases the water consumption also rises and the value of specific water availability in a state gets gradually reduced. The water availability for selected countries for the period from 1950 to 2025 is presented here to show a great unevenness in the distribution of water per capita per year in different countries. For instance Canada has the greatest water availability of about 175,000 cubic meters per capita per annum in the year 2000 but the densely populated countries of Asia, South Europe and Africa get only a moderate quantity of 1200 to 5000 cubic meters per year. But in North Africa and Arabia the water availability is about 200 to 300 cubic meters per person per year but availability at less than 2000 cubic meter per person per year is "low" while less than 1000 cubic meters is "catastrophically low" and consequently such low availability of water unavoidably possess a serious threat to public health, industrial and agricultural development besides causing damage to the environmental assets of a nation. The global charts presented below indicate the specific water availability of every region as designated with a shading colour by the different grades (in 1000 m^3 / person / year of water availability). http://webworld.unesco.org/water/ihp/db/shiklomanov/summary/html/figure_12.html

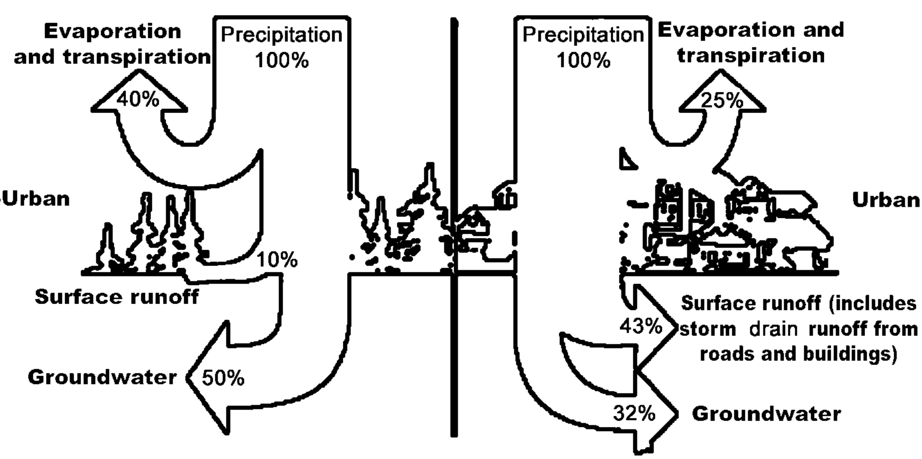
In 1950 specific water availability was generally above average in many countries except North Africa where it was very low. However in Central and South Europe and North China and South Asia including India it was "low" at a level of 2000 to 5000 cubic meters per person per year. The "catastrophically low" water availability was experienced in some regions of the world by the year 2000 particularly in North Africa, Arabian states, "very low" in North China, South and West Asia including India. Presently about 80% of the population in some regions get less than 5000 cubic meters per person per year. About one-third of the earth's population have a very low or catastrophically low levels of water supply and this situation will deteriorate year after year. Scientists warn that by the year 2025 most of the nations have to face very serious water scarcity problems with low and a catastrophically low water supplies. More than one-third of the population may face "catastrophically low" fresh water supplies of less than 1000 cubic meters per person per year. However high levels of water availability will be experienced by the people in North Europe, Canada, Alaska, South America, Central Africa, Siberia and the Far East. Hence most of the countries have to plan for water conservation measures including cloud seeding to tap the abundant sky water in the clouds for protecting public health and promoting economic growth, industrial development and sustainable environment. In fact the intellectuals of China are working to solve the problems of water scarcity, suppress the damage due to hail storms and are reducing the summer temperature by cloud seeding to save electrical power used for air conditioning and thereby improving the water availability for agriculture and economic prosperity of the nation. It is high time that the scientists, the bureaucrats and the political leaders of India should learn from the experiences of China and Texas on how cloud seeding operations can be used to promote public health, economic growth and prosperity of India.

Forests influence rainfall :

Forests protect watersheds and regulate stream flows by retaining some rainwater in the soil by their root network through sponge effect. One million ha forest area is estimated to have a water holding capacity of 300 to 350 TMC of rainwater. Some scientists estimate that about 50% of all rain water evaporates from the leaves of trees and plantations in a forest while the balance feeds the river courses continuously. According to one scientific study made in 1982-83 by Dr.Salati, Professor of Meteorology at Saopaulo University, the water and energy balance, the life support system of a land area depends upon the type of soil cover present in a region. The studies in a Guatemalan Forest show that the water is returned to the air by the trees and help to create the clouds. The release of water through the pores of trees and other plants known as "transpiration" accounts for about half or more of all the moisture returned to the air. Dr.Salati showed that the forest near Manaus in Brazil recycle 75% of the rain back into the atmosphere by evaporation and transpiration and about 25% of the rain was diverted into the river as run-off. About 25% of the rain was evaporated back into the atmosphere from the rain drops that stayed on the leaves while another 50% was returned to the air above the forest by transpiration. In the process of transpiration the moisture absorbed by the tree roots from the soil is carried by the plant's vascular system back up to the leaves and then exuded through the pores of the leaves. Thus a good tropical forest recycles water efficiently because about 50% of the rainfall returns to the atmosphere by transpiration, while about 25% of the rainwater gets evaporated from the leaf surfaces and the remaining 25% of the rainfall appears as ground water run-off in the nearby stream.

Since tropical forests constitute about one half of the world's 48 million sq.miles of wooded land, it is necessary to understand how deforestation in different regions may influence weather and climate patterns and the ability of forests to influence the creation and promotion of clouds and rainfall. Deforestation in the catchment areas of rivers and their tributaries promote higher rates of run-off that result in flooding of low land areas. It is estimated that land covered by tree plantation collects and returns to the air atleast 10 times as much moisture as bare and deforested land and twice as much as the land where grasses or plants, other than trees are predominantly grown. Urbanisation, industrialisation and land development reduce evaporation and percolation into the ground aquifers and increases surface run-off as shown in the following figure.

Development of an area changes the natural flow of water



The total woodlands and forest area of the world was estimated at 7000Mha. in 1900. Due to exploitation of forests for development of roads, railways and housing by the colonial rulers, the forests in several countries were destroyed and by 1975 the forest area stood at about

2900Mha. Unfortunately more than 7.5 Mha. of virgin tropical forests were also destroyed. If the present rate of deforestation at 20ha per minute continues unabated the tropical forests may come down to 500 to 800 Mha. by the year 2050. Most of the tropical countries are likely to face serious problems of deforestation due to population growth and development and consequently there will be a gradual deterioration in the availability of water per person per year. During the past 8000 years the Asian countries had a 70% reduction in forest cover including 95% reduction in the closed forest areas and unless reforestation is taken up on a large scale drought conditions are bound to recur with the growth of population development in many Asian countries.

Water scarcity promotes diseases :

All forms of life need water for their growth and survival. In particular a human being requires about 3 liters per day for his physiological needs. Every individual has a basic human right to have access to adequate, safe and affordable drinking water. An individual needs for his basic needs 20 to 50 liters per day of water free from harmful contaminants. But millions of people in all parts of the world are denied access for adequate and safe water. 2.5 billion people lack access to adequate sanitation. Over 2 million people, mostly children die every year from water-related diseases. At least a million Indians die every year due to pollution of drinking water and another one lakh due to air pollution. Lack of water supplies in sufficient quantities and proper quality results in environmental degradation which again causes large scale morbidity and mortality. A World Bank study estimated the economic cost of environmental degradation in India in 1990s and assessed the costs of environmental damage at about $9.7 billion (about Rs.34,000 crore per year or 4.5% of the gross domestic product (GDP) in 1992. The world Bank study emphasised that the largest share of economic and health costs emerge from the growing pollution of water and air amounting to about 7 billion US dollars (about Rs.24,500 crores per year). Water degradation accounts for health costs estimated at $5.7 billion (Rs.19,950 crores a year or about 60% of the total environmental damage cost). About 75% of the surface water courses except those in the mountainous regions are highly polluted and unfit for human consumption. The natural surface water courses and ground water sources are polluted due to improper disposal of human wastes from rural and urban areas in addition to the highly toxic industrial waste waters and the pesticide and waste contaminated run-off from agricultural fields. Millions of people who depend upon these water sources suffer from water borne diseases like amoebiasis, jaundice, dysentery, diarrhoea, typhoid and intestinal disorders. In order to protect public health and national wealth adequate amounts of safe water must be supplied to the people by the state.

Socio economic damages due to water scarcity :

Although two thirds of the Earth’s surface is covered by water, only approximately 2.5% of this is fresh water. Of this usable fresh water the supply for ecosystems and humans is less than 1%. In 1995 the World Bank Vice President Ismail Serageldin made a much quoted prediction for the new millennium: “If the wars of this century were fought for oil, the wars of the next century will be fought over water”. Serageldin has been proven correct much faster than he or anyone else thought. Five years into the 21st century, the global water wars are upon us. Today about 80 countries and 40% of the world population are facing chronic water shortage problems. Even in India the water disputes between Punjab and Haryana, Karnataka and Tamil Nadu and Andhra Pradesh and Karnataka in the country and between the different regions and districts of Andhra Pradesh are posing a serious threat to public health, food production and economic development.

Water crisis is brewing all over the world including the South Indian states. The United Nations report shows that 31 countries are now facing water scarcity and 100 crores of people do not have access to clean drinking water. Moreover water consumption is doubling once in 20 years while the existing water sources are rapidly getting polluted, depleted, diverted and exploited by the vested interests in the fields of industry, mining, agriculture and hydro-electricity production. The World Bank predicts that by 2025 about two-thirds of the world's population will suffer from scarcity of clean and safe water even for drinking purposes. Rather than taking timely remedial action required to protect the precious water resources, the Governments all over the world are retreating from their responsibilities to promote public health and welfare and economic growth that can wipe out poverty and unemployment. Most of the Governments except China were reluctant to realise that national development plans are intertwined with not only the optimal utilization of the existing surface and ground water resources but also large scale harnessing of the abundant sky water resources in the clouds amounting to about 10 times the water in all the rivers.

Drought as a challenge to tap sky-water in the clouds :

Some countries like China, Pakistan and some states in USA are treating drought as a challenging opportunity to promote cloud seeding operations not only to augment rainfall and snow fall but also to drastically control the damage caused by recurring hailstorms. Moreover they are using cloud seeding technologies to disperse the fog in airports and major cities and are also fighting the adverse effects caused by global warming. Some countries are using cloud seeding operations to produce water at a very inexpensive cost for municipal, industrial and irrigation use and for hydro power generation. But unfortunately Indian intellectuals are not yet ready to learn from the International experts from China, Israel, Australia, Indonesia, Thailand and Texas on how to fight the crucial impacts of droughts, hailstorms, fogs and global warming impacts by cloud seeding. Unfortunately the vagaries of Indian monsoons are very frequently causing floods in the East and North Eastern states while the Peninsular Indian states are facing recurring droughts and famines which are causing water scarcities that are adversely affecting the health of the human and animal populations, food production, hydro power generation and industrial growth. The damaging effects of droughts on food production in recent years are presented here.

Poor Food Grain Output During 2002-2003 : The shadow of drought loomed heavily on 2002-2003 year's outcome of Kharif crops The food grain production in 2002-03 was 174.2 million tones compared to 2001-02 year's production of 212.02 million tones (fall of 18.0 percent). The sharp fall in 2002-03 year's food grain output, which is the lowest since 1996-97 is mainly due to the decline in Kharif production from 111.5 million tones last year to 87.8 million tonnes is the 2002-03 year (fall of 20 percent). The Rabi food grain production is also likely to drop to 86.5 million tonnes compared to 2001-02 year's 100.5 million tonnes – a drop of 14 percent. Rice production in the 2002-03 year is likely to be 72.7 million tonnes (93.1 million tonnes last year) and wheat production is likely to be 65 million tonnes (71.8 million tonnes last year) There is also a large decline likely in production of coarse cereals to 25 million tonnes (34 million tonnes in 2001-02) Pulses production too is likely to drop to 11 million tonnes from 13.2 million tonnes in 2001-02 year.

Kharif output in drought years : Low rainfall years in the past have always adversely affected Kharif crop production. The magnitude of decline in production has varied depending upon the severity of the drought. The 2002-03 year's fall of 19.1 percent in Kharif output compared to earlier poor rainfall years is the highest ever fall since 1972-73. This is explained by the lowest ever rainfall received in July (49 percent fall) which is normally the rainiest month of the season and most crucial month for Kharif crops.

Deficient rainfall years	Monsoon rainfall (% departure from normal)	Rainfall in July (% departure from normal)	Kharif food grain production (% fall)
1972-73	-24	-31	-6.9
1974-75	-12	-4	-12.9
1979-80	-19	-16	-19.0
1982-83	-14	-23	-11.9
1986-87	-13	-14	-5.9
1987-88	-19	-29	-7.0
2002-03	-19	-49	-19.1

The year 2002 was bad monsoon period and the month of July the rainiest month of the year with normal 30% of the monsoon rainfall became the driest month with about 50% shortfall which is a record low in the past 100 years. 18 states in the country including all the southern states suffered drought conditions due to poor rainfall in July.

During 2004, 17 out of 36 meteorological sub-divisions had deficient rainfall. The regions with deficient rainfall include the regions in Gujarat, West Rajasthan, Himachal Pradesh and Telangana. The following table indicates that while some regions received normal and even excess rainfall, some other regions simultaneously experienced water scarcity.

Status of rainfall in 36 sub-divisions in inida

Status	1999	2000	2001	2002	2003	2004
1. Excessive	6	17	17	0	11	4
2. Normal	22	13	11	14	20	15
3. Deficient	8	6	8	18	5	17
4. Scanty	0	0	0	4	0	0

In the last few years India has been experiencing fluctuating food grains production with a steep fall as in 2002-2003 by about 14%. The month of July that normally records highest rainfall received the lowest rainfall in the past 100 years. July normally receives about 30 percent of the monsoon rainfall but the shortfall in 2002 was as high as 49%. Against 75% of the total Full Reservoir Level (FRL) which is the average of last 10 years, the national reservoir storage at the end of the monsoon 2002 stood at 50%. Rainfall during the 2002 monsoon season (June-September) was 19% below the normal, causing disastrous impact on irrigation and agriculture. Drought conditions reigned in 30% of the country and it was severe in South India. http://www.indiaonestop.com/economy-macro-agro.htm. The fallen reservoir levels that reduced food production are presented here.

Reservoir storages at the end of the monsoon season

	Last 10 years Avg.		2003		2002		2001	
	Storage BCM	% of FRL	Storage BCM	% of FRL	Storage BCM	% of FRL	Storage BCM	% of FRL
At the Beginning of Monsoon	23	17	14	11	16	12	17	13
At the end of monsoon	97	74	79	60	69	53	79	60
Storage increase in monsoon	74	--	65	--	53	--	62	--

FRL storage designed utilizable capacity of 70 major reservoirs of 132 BCM capacity.

Cloud seeding cuts down the rising costs of drought relief :

In order to mitigate the impact of drought in several states the Central Government released Rs.1018 crores from NCCF (National Calamity Contingence Fund) and Rs.1227 crores of Central share of CRF (Calamity Relief Fund) for 2002-2003 to the states of Andhra Pradesh, Jammu& Kashmir, Karnataka, Kerala, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttaranchal, Uttar Pradesh and West Bengal. This included advance release of 2nd installment of Central share to 13 states. The eleventh Finance Commission had set aside Rs.11,000 crores for calamity relief through CRF and NCCF. The CRF is shared in the ratio of 75:25 percent between the centre and the states. The State Chief Minister of Andhra Pradesh had demanded Rs.610 crores financial assistance from the centre and one million tonnes of food grain to carry out necessary employment generation program. The other states have also demanded a more or less similar package from the Union Government. If only a small fraction of the CRF and NCCF funds are diverted for cloud seeding operations, weather modification can be undertaken in proper time by adopting proper surface, ground and atmospheric water resources management methods for making available water for drinking and agriculture. Similarly steps can be taken to seed the band clouds to tame the cyclones on the pattern followed in USA for storm-fury experiments.

Limitations of big dams to sustain agriculture :

Although water diversion works like the anicuts across major rivers like Krishna, Godavari, Pennar and Cauvery constructed by the British rulers under the guidance of eminent engineers like Sir Arthor Cotton at an very inexpensive cost have transformed the South Indian river deltas into bread baskets of India several major dams constructed at a huge cost after 1960s have not proved to be successful in producing food grains as anticipated. Even after constructing 8 lakhs of big and small dams around the world the reservoirs are not able to store more than a fifth of the rain water and the bulk of the remaining water is still running wastefully into the oceans. Even though the state and Central Governments in India have built many dams during the last 50 years they are not able to store adequate water for irrigation.(See Table-6)

Consequently lot of water from rivers like Ganges, Brahmaputra, Mahanadi, Godavari and other west flowing rivers is still going into the sea without being sufficiently used for either food production or hydro-power generation. If a small fraction of this rain water can be stored underground by reducing the velocity of the run-off and providing time for recharge of the ground water supplies in many places could be enhanced significantly. But such a task requires an active aquifer management in which planned drawing down of the water table in the pre-monsoon dry months like summer is an important element of the water management strategy for enhancing recharge of such aquifers from monsoon rain water and the irrigation return flows. Such pro-active aquifer management is an established practice in industrialized states like Texas in USA. Similarly in several other industrialized countries the artificial recharge of the ground water is taken up by conducting cloud seeding operations and other methods. The share of artificial ground water recharge to total ground water use is 30% in west Germany, 25% in Switzerland, 22% in the United States, 22% in Holland, 15% in Sweden and 12% in England. Even Israel has taken up ground water recharge by cloud seeding on an extensive scale. Southern Ogallala Aquifer Recharge (SOAR) is carried out by conducting cloud seeding experiments on a regular basis in the southern states in USA at a very inexpensive cost and the cost benefit analysis has been estimated for 2003 at 1:150 for agricultural purposes.

In Southern states the British rulers constructed major dams like Mettur dam on Cauvery river and major irrigation projects like Godavari anicut and Krishna anicut long ago for augmenting water availability for irrigating several lakhs of acres in the delta regions.

Subsequently major dams like Nagarjunasagar, Srisailam and Tungabhadra were constructed to promote large scale irrigation and hydro-power generation. Unfortunately these major projects constructed at a huge cost are not receiving the expected river flows with the result that the agriculture and hydro-power generation is suffering under these projects. In order to improve these conditions cloud seeding operations must be conducted on a large scale by using aeroplanes and ground generators during day and night times for obtaining 20% to 30% additional rainfall in the catchment areas of these reservoirs to restore the agriculture operations and hydro-power generation. The Union Government must cooperate with the Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu to organize cloud seeding operations for augmenting the annual river flows on a substantial scale. Thus major irrigation projects without the aid of the cloud seeding operations may not be always successful in achieving the desired goals of promoting agriculture and economic development.

Desalination is costlier than other options for water supply:

During 1962-77 the ground water level declined by 2meters in most parts of Delhi. During 1977-83 the water table declined by 4 to 6 meters. But in 1983 the depth to water level declined to 10 meters below ground level (BGL) in general with 26 meters BGL at Mehrauli. By 1995 the ground water level was about 35 meters BGL in Mehrauli area of New Delhi. The reasons for this decline are

1. Rapid growth of urbanization and infrastructure development resulting in reduction in green cover and consequential failure to recharge the aquifers.
2. Increased demand for domestic, industrial and agricultural consumption, unplanned withdrawal from sub-soil aquifer of ground water extraction during drought periods.

Several villages in different states across the country are also facing problems of water scarcity even for drinking purposes. In order to meet the growing water scarcity conditions in both urban and rural areas several Governmental Agencies like Baba Atomic Research centre, Central Salt and Marine Chemicals Research Institutes, Jodhpur Research Laboratories and National Chemical Laboratories are engaged in research and development of desalination of water.

Although India with its fortunate location in a tropical region receives abundant rainfall, it is unevenly distributed in time and place and hence many parts of the country face chronic water shortage problems. In some areas extensive exploitation of ground water is causing the ground waters to become saline. Hence some agencies are planning to augment water resources by adopting desalination and water reuse technologies. Thermal membrane desalination, Reverse Osmosis Membrane Technology and Electro-dialysis methods are used for providing good water from saline water and brackish waters. Ultra filtration methods are used for waste water treatment for recycling the industrial effluents. Capital cost per million gallons/day of desalination plant is estimated at Rs.10 crores. Sea water desalination costs Rs.45 per cubic meter. Reverse Osmosis plant produces one cubic meter of water with capital and operations cost estimated at Rs.27/- and Rs.45/- respectively.

Costs of desalination

S.No.	Capacity (m^3/day)	Cost of Plant (Rs.in lakhs)	Cost of O&M/year (Rs.in lakhs)
1.	10	6.0 to 10.0	1.0 to 2.0
2.	20	8.0 to 11.0	2.0 to 2.6
3.	30	9.0 to 14.2	2.6 to 3.4
4.	50	16.0 to 27.3	3.6 to 6.0
5.	100	20.0 to 41.3	7.0 to 11.0

Augmenting drinking water supplies :

In almost all the states even for metropolitan drinking water supplies we need inter basin water transfers. For instance Madras water supply is augmented by transferring water over long distances from Krishna river in the North and Neyveli and Veeranam reservoir sources in the South. New Delhi gets partial water supplies from Bhimgoda on Ganga (200km) and Bhakra on river Sutlej (300km). Even Calcutta, Bombay, Bangalore and Hyderabad get their water supplies from very distant sources. By 2050 the municipal and industrial water supply needs of several state capitals and major industrial cities will have to be met through long distance water transfer which is causing water disputes because the local farmers and villagers are deprived of their conventional water resources on which they depend for their drinking and irrigation needs. The drinking water needs of many other major towns and cities will have to be met by transporting water not only from long distances but also by using ground water supplies which have to be replenished continuously during southwest monsoon and northeast monsoon by taking up cloud seeding operations on an extensive scale because the urban population is also growing very fast as indicated in the following table.

Increase in urban population from 1951-2001 *(in million)*

	1951	1961	1971	1981	1991	2001
Total	361	439	548	683	846	1027
Rural	298	360	439	523	628	720
Urban	62	79	109	160	218	307

Among the several water uses, agriculture at present uses 80 to 85% of the water available as surface flows and under ground water. 80 to 90% of the water is consumed for agriculture operations and the remaining 10 to 20%of the water returns back to rivers as regenerated flow or it recharges the ground water. Low water is consumed in case of navigation and hydro-power generation. The water use in different sectors by 2000AD,2025AD and 2050 AD is estimated as shown in the following table.

Water use for different purposes *(in billion cu.m.)*

S.No.	Purpose	2000 AD		2025 AD		2050 AD	
		Surface water	Groun d water	Surface water	Groun d water	Surface water	Groun d water
1.	Drinking Water	20	20	25	25	35	35
2.	Irrigated Agriculture	420	210	510	260	700	300
3.	Hydro power	20	--	50	--	200	--
4.	Industries	15	15	35	35	75	75
5.	Ecology, Recreation etc.	40	--	80	--	100	--
	TOTAL	515	245	700	320	1110	410

Note : One BCM (billion Cubic meters)=35 TMC(Thousand Million Cubic ft.)

In respect of agriculture development the ultimate irrigation potential is presently estimated at 140 Mha comprising 58 million ha from major and medium irrigation projects, 17 Mha from minor irrigation schemes and 65Mha by ground water schemes. By the end of 1996-97 an irrigation potential of about 92 Mha comprising 34 Mha by major and medium projects, 12 million ha by minor schemes and 46 Mha by ground water schemes has been realised. The ultimate potential is expected to be achieved by 2025 AD. The present irrigation water use is about 660 BCM which will grow upto about 1250 BCM by 2025 AD and to about 1650 BCM by about 2050 AD.

The present population of the country which stands at 1000 million has been projected to reach 1400 million by 2025 AD and 1650 million by 2050 AD. The food requirement is estimated to reach 450 to 500 million tones by 2050 AD. The present productivity is about 2.5 tonnes/ha for irrigated agriculture land and 0.5 tonnes/ha for rain-fed agriculture lands. Assuming that these productivity levels go upto 3.5 tonnes/ha and 1.0 tonne/ha respectively by 2050 AD, it becomes necessary to create an irrigation potential of 160 to 165 Mha to be able to meet the food demands of the country by 2050 AD. Thus 25 Mha in irrigation potential has to be created.

Irrigation by different sources *(in thousand ha)*

State	Canal		Tanks		Wells		Others		Total	
	1981-82	1992-93	1981-82	1992-93	1981-82	1992-93	1981-82	1992-93	1981-82	1992-93
A.P.	1756	1727	1045	729	786	1411	105	162	3692	4029
Karnataka	580	903	321	257	402	725	167	309	1471	2194
Kerala	106	107	57	48	--	66	77	114	240	335
Maharashtra	871	562	--	385	1154	1348	--	175	2025	2470
Tamil Nadu	901	851	739	629	1045	1201	25	17	2709	2698

Source : Amon 1997, Directory of Indian Agriculture, Ministry of Agriculture, Government of India.

The irrigation water requirement by 2050 AD is expected to touch 1070 BCM level. This additional irrigation potential has to be created by non-conventional technologies like inter-basin water transfer by linking the rivers in different regions of the country and also by artificial recharge of ground water by various measures as followed in other developed countries. Similarly water availability in the ground and surface water resources has to be augmented by squeezing the atmospheric water in the form of clouds by following the example set by United States.

The present utilisable surface and ground water is estimated at 1122 BCM. and consequently there is bound to be a water deficit of 126 BCM by 2025 AD and 534 BCM by 2050 AD. The anticipated water deficit can be partially met by purification through recycling of municipal and industrial effluents, ground water recharge, evaporation-suppression and desalination of sea water. However these methods are very costly.

Population, agriculture and irrigation :

In order to understand the causes for the impending water and food famines in India in general and the Southern states in particular by 2025 AD it is necessary to study the gradual changes in land use, cropping pattern, irrigation and food production since 1950 as presented here.

Table - 1 : Land use, cropping pattern and development of irrigation in india

·	Total geographical area	—	328.76	Mha.	
·	Land area as per census	—	306.50	Mha.	
·	Total cultivable area	—	184.376	Mha.	(62%)
·	Forests	—	67.0	Mha	
·	Area under non agricultural use	—	21.8	Mha	
·	Barren and uncultivable land	—	19.4	Mha	
·	Permanent pasture and grazing land	—	12.0	Mha	
·	Fallow lands	—	24.0	Mha	
·	Net cropped sown area	—	118.75	Mha. in 1950-51	
		—	142.5	Mha. (2000-01)	
·	(i) Area under food grain cultivation	—	123.5	Mha	
·	(ii) Out of 123.5 Mha area under Rainfed crops	—	89.0	Mha. in 1990-91	

Since there is substantial waste land it is necessary to bring it under cultivation and grow fruit gardens to make available more nutritious food and minerals by using fruits and better vegetables for human consumption. For this purpose cloud seeding operations can be taken up to provide more water during different seasons to supplement the natural rainfall.

The production of Rice, Wheat, coarse cereals and pulses since 1950 in million tonnes along with the their projections upto 2050 AD are presented in the following table.

Table - 2 : Production of food grains in india

Crop	1950-'51	'60-61	'70-71	'80-81	'90-91	2000-01	2010	2025	2050	Annual growth rate		
										'94-2010	2010-2025	2025-2050
Rice	20	34	42	54	74	85	96	124	200	2.2	1.7	1.6
Wheat	7	11	24	37	55	68	80	100	170	2.6	2.1	1.8
Coarse cereals	15	24	31	29	33	32	32	32	35			
Pulses	8	13	12	11	15	11	12	21	30	3.0	2.6	2.6
Total food grains	50	80	110	130	177	196	220	277	435	2.2	1.8	1.8

All the figures are in Million tons.

The data in these tables clearly indicates that there is an urgent need to provide more food to meet the minimum nutritional requirements of the fast growing population of India. Such an effort will be successful if only more water is made available for agriculture not only by conserving the existing ground and surface water resources but also by tapping the abundant sky water in the clouds through cloud seeding operations.

The land used for different crops and the productive levels in 1996-97 are presented in the following table.

Table - 3 : Cropped area and production in india for 1996-1997

S.No.	Crop	Area(M.ha)	Production (M.tons)	Yield (kg/ha)	Percentage land under Irrigation
1.	Rice	43.3	81.3	1880	50
2.	Wheat	26.0	70.0	2670	85
3.	Coarse cereals	32.1	34.3	1070	10
4.	Pulses	23.2	14.5	623	13
5.	Food grains	124.5	200.0	1600	40
6.	Oil seeds	26.8	25.0	930	25
7.	Cotton	9.0	14.3	266	34
8.	Sugar cane	4.2	277.3	6650	80

Source: Agriculture Statistics. (1998), Government of India.

The above data clearly indicate that the yield of the different crops must be increased and for the purpose better farming methods must be used along with better irrigation facilities.

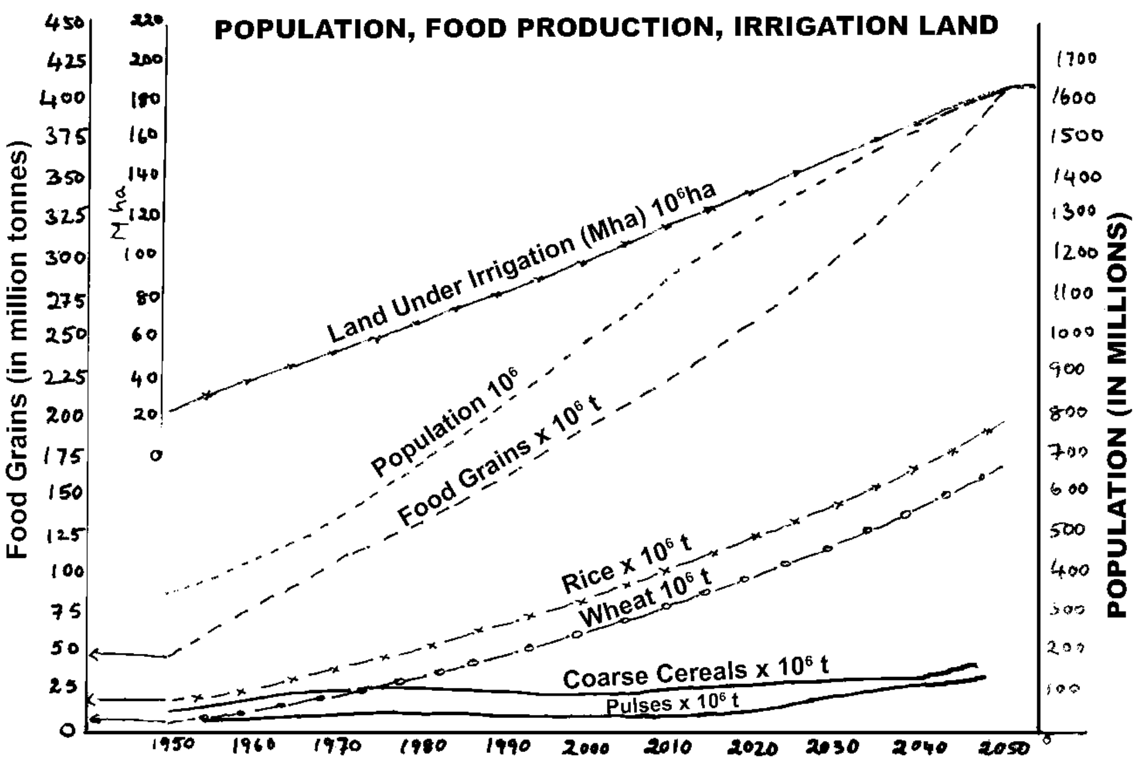
The following table presents the historical growth and the future projections for population, land use and food production for forecasting the potential for food scarcity

Table - 4 : Food-shortage forecast in india for "2025 A.D. and 2050 A.D

S.No.	Particulars	1950	1975	2000	2025	2050
1.	Population,m.	360	640	1000	1350	1650
2.	Land Area, M.ha.	22	55	90	150	200
3.	Food grains, M.t.	50	120	195	325	450
4.	Rice, M.t.	22	50	85	135	200
5.	Wheat,M.t.	7	28	66	110	170
6.	Irrigation water B.cum	100	250	400	640	900

The above statistics indicate the urgent need to bring more land under irrigation for making available more food grains to meet the nutritional requirements of the fast growing population. Unless timely action is taken to make available more water and more land the inevitable scarcity for water and food will cause damage to public health and welfare and national development.

The graphical representation on the population growth, land use and food production is presented below.



The above figure presents the full details on the population growth, food production and land use from 1950 onwards for the projected time period upto 2050 and this clearly must open the eyes of the state and Central Governments to make united efforts to promote irrigation and food production by interlinking of rivers in different stages and also augment water availability by diverting the water from the West flowing rivers into the East flowing rivers like

Godavari, Krishna, Pennar and Cauvery and also to further augment the annual rainfall in these river basins by 25% to 30% by cloud seeding.

The population growth in the Southern states along with the demand, production and scarcity for Rice is presented below for assessing the nature and magnitude of the impending food shortage.

Table - 5 : Food shortage in south indian states (1991-2050)

Population, Rice Demand, Production and Deficit

State	1991				2000				2025				2050			
	Pop	dem	Prod	def	Pop	dem	Prod	def	Pop	dem	Prod	Def	Pop	dem	Prod	def
Andhra Pradesh	66	13	11	2	80	16	13	3	110	22	12	10	140	28	10	18
Tamil Nadu	55	11	5.5	5.5	68	14	6	8	95	19	6	13	120	24	6	18
Karna-taka	49	10	2.5	7.5	60	12	3	9	80	16	5	11	100	20	8	12
Kerala	30	6	1	5	32	6	1	5	35	7	1	6	40	8	1	7
Total	200	40	20	20	240	48	23	25	320	64	24	40	400	80	25	55

NOTE : Population (in Millions)

Rice production, Demand and shortages (in Million tons).

Pop(Population), dem(Demand), Prod(Production), def(Deficit).

The above population and food production statistics in South Indian States point out the urgent need for a meeting of the Chief Ministers of Southern States to put up a united effort to take up extensive cloud seeding operations for making available more water for drinking, irrigation and hydro-power generation in Southern states.

The above tables clearly show that unless timely action is taken to increase food production by providing accelerated irrigation facilities on a war footing the people of South India will have to face mal-nutrition, under nutrition and famine conditions of an irreversible nature. In order to avert this impending crisis of water and food shortages, the central and state governments must plan for optimum utilisation of both the dependable as well as the flood flows of river Godavri and also plan for substantial augmentation of annual flows in the river and its tributaries by conducting cloud seeding experiments in all the river basin states .

The ultimate irrigation potential of India is estimated at 140 million ha. Irrigation under conventional surface and ground water schemes includes 58 million ha. under major and medium projects. 7 million ha. under minor irrigation projects and 65 million ha. under ground water schemes. By 1997 irrigated area covered 92 million ha. including 34 million ha. under major and medium projects, 12 million ha under minor irrigation projects and 46 million ha under ground water schemes. The present population of about 1000 million in India will reach 1400 million by 2025 AD and 1645 million by 2050 AD as per UN projections.

Many environmentalists and economists emphasize that the country is fast moving towards severe food shortage, famine and starvation deaths. About half of the children under 3 years of age are under-weight due to malnutrition and upto 50% women and 74% children are anaemic. The annual rate of growth of food grain production during the 9th plan was low at about 1% per year while the annual population growth was about 2% and per capita food grain availability per day dropped from 5 grams in 1991 down to 4.4 grams in 2001. Crop production growth rate fell from 3.7% per annum during the decade 1979-1980 to 1989-90 down to 2.3% per annum during 1989-90 to 1999-2000. The rate of growth of productivity fell from 3% per annum in 1980s to 1.2% per annum in 1990s. The share of agriculture in GDP during the last 5 decades declined from 61% in 1950-51 to 24% in 2001-2002, even though about 70% of the population still depend upon agriculture for their livelihood. About 100 million ha of land is either drought-prone or flood-prone.

But India has to feed about 16% of the global population although it has only 2.4% of the total land and about 4% of the global water resources. However only about 40% of the net sowing area of about 143 million ha has been brought under irrigation and the remaining extensive land has to depend upon the rainfall. Ground water is fast depleting due to poor water harvesting and poor recharging of ground water. In addition, the scarcity of water in rain fed areas is a serious threat to growth of crops. Out of the total geographical area of 328.7 million ha. an area of about 107.4 million ha is estimated as degraded land. The higher irrigation water charges and electricity bills will adversely effect both the productivity and crop production in agriculture.

By 2050 AD the food grain requirement will be 450 million tonnes per year at the present levels of consumption. Assuming that there will be a moderate rise in consumption the production of food by 2050 must be between 500 to 550 million tonnes per annum If improved technologies raise productivity from 2.5 to 3.5 tons per ha. for irrigated lands and 0.5 to 1.0 ton per ha. for rain-fed irrigation, it is necessary to create additional irrigation potential of 25 million ha, taking the total to 165 million ha. by 2050 AD and this additional potential can be created only by inter-basin water transfer and augmentation of surface and ground water sources by conducting cloud seeding operations on an extensive scale to tap the abundant sky water in the clouds.

Cloud seeding for inexpensive hydro-power generation :

Union Power Minister admitted in the Parliament on 11-3-2005 that there was an overall power shortage in the country and that the surplus Eastern region was supplying the electrical power to the National grid to meet the needs of the deficit regions. On an average the electrical power shortage in the country declined from 8.8% in 2002-2003 to 7.1% in 2003-2004 and 6.8% in 2004-2005. The 10^{th} plan target was expected to generate 41,110 MW . The per capita electrical power consumption increased from 15 units in 1947 to about 600 units in 2005 while the power generation increased from 1362 MW in 1947 to 1,16,000 MW in 2005. During 2004-2005 there was a shortage of 920 MW in the Northern region, 375 MW in the western region, 88 MW in the Southern regions and 1602 MW in the North Eastern region and only the Eastern region met its power generation target of 1210 MW. Hence all the Indian states must make genuine attempts to remove the electrical power shortage by conducting cloud seeding experiments to augment production of hydro-electric power as practised during the last 40 years by Tasmania state in Australia which is producing power at the cheapest rate with a benefit to cost ratio 13:1 as presented in the website elsewhere.

Cloud seeding for water pollution control :

Most of the rivers like Ganges, Yamuna, Krishna, Cauvery and their many tributaries are subject to water pollution due to discharge of untreated and partially treated liquid wastes from many polluting industries and urban settlements located on their banks. Agricultural wastes from farm houses and fertilizer and pesticide residues from agriculture are entering into the natural water courses and are getting concentrated into food chains and food webs of the aquatic eco-systems. The water from these rivers is diverted from various anicuts and reservoirs built across these rivers and their tributaries through irrigation canals into village tanks and agricultural fields. During summer the water flows in these rivers and streams is very much reduced and there is no corresponding reduction in the quantities and quality of the industrial and municipal effluents that are entering into them. Consequently these natural water courses are highly polluted with the result that neither the people nor the animal population can use them for drinking and other purposes. There is a large scale death of fishes in these water courses. Hence there is a need to restore a reasonable degree of purity in these stream waters to protect public health and the environment.

For restoration of stream water quality during the diminished flows of summer season some countries build dams and reserve sufficient water in the reservoirs for maintaining a minimum flow even during the summer season for ecological purposes. In a public interest litigation case on control of pollution in the holy waters of the Ganges and the Yamuna rivers, the Supreme court of India ordered the state and Central Governments that even during the summer season a minimum flow of 10 cumecs (350 cusecs) in Yamuna river and 40 cumecs (1400 cusecs) in Ganga river must be maintained for ecological and environmental purposes for ensuring drinking water for human and animal populations and normal flows with sufficient oxygen for the survival of aquatic flora and fauna including fisheries. The detailed information on this public interest litigation case may be seen from the following websites.

http://www.auburn.edu/~alleykd/yamunacases.htm
http://www.auburn.edu/~alleykd/CPCBaff42699.htm
http://www.auburn.edu/~alleykd/paanimorcha.htm

River water storages must be increased to overcome the difficulties caused by frequent failures of monsoons and also to meet the ever growing demands of summer seasons. The present live storages of about 174 billion cu.m. constitute about 10% of the total water potential available in the country. Even if a low estimate of future water requirements of 1300 billion cu.m. is to be met, a storage of 600 billion cu.m. is required. In order to maintain minimum summer flows to dilute the impact of treated waste water discharges from municipalities and industries, additional storage is needed. Further 50 billion cu.m. is needed to maintain ecological balances in water courses. In addition to the above mentioned live storage the projects under construction and those under consideration envisage additional storages of 75 billion cu.m. and 130 billion cu.m. respectively. Thus there is an urgent need to conserve river waters by transferring the surplus flows from rivers like Ganges, Mahanadi and Godavari to water deficit rivers like Krishna, Pennar and Cauvery and also to augment their yields by cloud seeding.(See the details for Godavari-Cauvery river water-grid elsewhere).

Atmospheric pressure with height

Height	Temperature		Pressure (mb)	Height	Temperature		Pressure(mb)
	°K	°C			°K	°C	
0	288	14.9	1013.2	5.0	256	- 17.1	540.4
0.5	285	11.9	954.6	6.0	249	- 24.1	472.2
1.0	282	8.9	898.8	7.0	243	- 30.1	411.1
1.5	278	4.9	845.6	8.0	236	- 37.1	356.5
2.0	275	1.9	795.0	9.0	230	- 43.1	308.0
2.5	272	- 1.1	746.9	10.0	223	- 50.1	265.0
3.0	269	- 4.1	701.2	12.0	216	- 57.1	194.0
3.5	265	- 8.1	657.8	14.0	216	-57.1	141.7
4.0	262	- 11.1	616.6	16.0	216	- 57.1	103.5

Table – 6 : Some Indian Rivers - Annual Flows and Storages *(in billion cubic meters)*

River Basin	**Annual flow	Completed projects		Ongoing Projects		Total Gross storage	Projects under consideration		
		Gross Storage	Live Storage	Gross Storage	Live Storage		Live Storage	Gross Storage	Live Storage
1. Indus	73.305	17.814	14.515	3.774	2.441	21.588	16.957	0.308	0.050
2. Ganga*	501.643	39.574	33.200	17.644	14.729	57.218	47.930	8.922	6.471
3. Godavari	118.982	22.404	18.553	15.074	11.955	37.478	30.500	8.177	2.763
4. Krishna	67.790	41.007	30.186	7.336	6.099	48.373	36.286	0.576	0.423
5. Cauvery	20.957	8.021	7.181	0.463	0.297	8.485	7.578	0.554	0.482
6. Mahanadi	66.879	10.933	8.310	5.505	4.914	16.439	13.224	17.205	11.665
7. Narmada	40.950	3.216	2.806	20.214	14.106	23.431	16.913	0.551	0.463
8. Tapi	18.000	9.778	8.167	1.200	0.897	10.978	0.906	0.220	0.169
9. West flowing rivers from Tapi to Tadri including Tadri	108.618	0.958	0.856	2.314	2.181	3.272	3.037	0.493	0.476
10. West flowing rivers from Tadri to Kanya-kumari	89.250	10.183	8.895	9.382	7.942	19.566	16.838	0.100	0.100
11. East flowing, Mahanadi to Pennar	23.806	1.191	1.042	4.452	3.659	5.644	4.701	1.345	0.898
12. East flowing, Pennar to Kanyakumari	17.725	1.375	1.329	0.087	0.077	1.463	1.407	0.035	0.023
Total (including other rivers)	1853.494	176.131	143.018	99.817	79.054	275.948	222.072	114.454	82.102

* including tributaries down stream of Farakka

** The figures include the observed flow and corrected for surface utilization and the effect of actual utilization of ground water draft not includes

Source:CWC 1988 P42 **1 Billion Lubic meters = 35 TMC (Thousand Million Cubic Feet)**

Note: As per the existing water use pattern Indian use for agriculture and live stock 80%, for power generation 13.5% for domestic use 3.5% and for industries 3%.

ORIGIN AND DEVELOPMENT - SKY WATER PROJECT

Perhaps a reasonable scientific proposal for rain inducement was for the first time made by James P.Espy the author of the meteorological classic “Philosophy of Storms”.On 5-4-1839 . James P.Espy proposed in the issue of the “National Gazette and literary Register” of Philadelphia that large fires be built to create good updraft in a humid atmosphere to generate Cumulus clouds that cause rain fall. This suggestion made in 1839 that convective rains can be induced by burning large fires was reexamined in 1938, by Gorog and Rovo of Hungary. By observing the fires on the lakes of oil, Gorog and Rovo made calculations and concluded that the method was practical for producing the rain artificially under certain conditions. This concept was put into practice by the Frenchman Henri Dessens of University of Toulouse in 1955 when a Belgian plantation company asked him to study the possibilities of artificial stimulation of rain in Congo region of Africa. Dessens and his son Jean designed a controlled heat generator for burning upto 100 tonnes of fuel in 30 minutes. Trials were conducted in 1961 by using a cluster of oil burners consuming 1000 litres (about one tonne) of fuel per minute in South West France. In one of the trial runs the convection generated was so strong that a small tornado was produced.

In 1875 the Frenchman Coulier experimented to prove that particles floating in air served as nuclei around which condensation of water vapour occurs with little or no super saturation. Scottish physicist John Aitken worked for 35 years with his portable expansion chamber known as Aitken nuclei counter (for particles active at 0.01 mm and 0.1mm radius) demonstrated that there were 2 types of nuclei. Those with an affinity for water vapour on which condensation occurs before water saturation occurs, are called hygroscopic particles and others are non-hygroscopic nuclei which require some degree of supersaturation in order to serve as centres of condensation. In 1919 A.Wigan used balloon flights and measured Aitken nuclei upto about 6km height.

A.Wagner observed liquid droplets at one station (3106 m) at Sonnblick at sub-freezing temperature. A.Wegener in his 1911 book “Thermodynamics of Atmosphere” reported the presence of liquid droplets at minus 20°C to minus 30°C. In this book he described glaciation and propounded the theory of the initiation of precipitation in mixed liquid and ice clouds. He stated that “the vapour tension will adjust itself to a value in between the saturation values over ice and over water. The effect of this must be that condensation will take place continually on the ice, whereas at the same time liquid water evaporates and this process must go on until the liquid phase is entirely consumed”. Under undisturbed conditions, crystallization requires more special properties of the nuclei than condensation (like solid particles showing the angles of the hexagonal crystal system) and so crystallization will not occur due to lack of such nuclei endowed with the said special properties. In the air there will be some such particles that gradually get into action as sublimation nuclei, as the temperature gets reduced. Further disturbed droplets of certain size crystalise easily. Since the crystallization forces grow with falling temperatures the smallest size or disturbance required for crystallization of already formed droplets will get reduced. Within an ascending cold cloud a few scattered elements may spontaneously solidify without any relative velocities of cloud elements at all. By using Wagners diffusion growth theory, Bergeron calculated the time required for the transformation of all liquid into ice. In the case of 4.2×10^{-6} grams of liquid water per cm^3 dispersed in 1000 droplets of 20 microns diameter in the presence of one ice crystal and found that complete diffusion of cloud water into crystal would be achieved in 10 to 20 minutes.

In 1938 W.Findeisen elaborated on Bergeron’s theory and enunciated direct crystallisation from the vapour (sublimation) in preference to the freezing of droplets and considered quartz crystals as the possible nuclei and visualised the possibility of initiating nucleation mechanism by introducing suitable nuclei like silver iodide. Although Bergeron accepted that “warm rains” were common in the tropics, Findeisen emphasised in 1939 that most of the rainfall originates as snow or hail. By 1940 even when scientists found that collision coalescence in “warm clouds” occurs in low latitudes or during summer times Bergeron process remained as the dominant feature of precipitation mechanism. In 1938 Henry G. Houghton emphasised on rain formation by the collision-coalescence mechanism but did not deal with the effects of the breaking of large drops suspended in the “updrafts” to create the “chain-reaction” which later became the foundation for the new theory propounded by Irwing Langmuir.

Langmuir on Warm Clouds : In 1947 Leopold and Halstand of the Pineapple Research Institute told Langmuir that when they dropped dry ice into a cumulus cloud that was everywhere warmer than freezing (warm cloud) rain fell from it and this made Langmuir realise that it was the water which quoted the dry ice pellets that made the cloud rain and then he developed his chain reaction theory of precipitation by the concept of collision-coalescence of raindrops as propounded by Houghton in 1938. Langmuir introduced results on collection efficiencies as calculated by him during the Mount Washington studies. He visualized that as the rain drops grow to an optimum size they would break up and the smaller broken drops get carried upward again by the updrafts to repeat the cycle and this was called (1948) the "chain reaction". Langmuir went to Honduras to work on tropical clouds with Silverthorne who has attempted to stop the blow-downs associated with thunder storms that destroy the fruit gardens. Langmuir advocated use of a single pellet to augment rainfall and stated that large snow flakes will form at all the altitudes above the freezing level, producing cell propagating storms that cause heavy rain. Langmuir advocated introduction of relatively large amounts of dry ice into the clouds to cause over-seeding and thereby dissipate the clouds. He stated that by over seeding the cloud so many nuclei are produced that the snow flakes that form thereby may often outnumber the original droplets and hence they tend not to fall out of the cloud and thereby prevent the cloud from giving even the normal rainfall. Moreover the heat of fusion generated by the conversion to ice-crystal renders the cloud top float away so that it gets separated from the lower part and the cloud gets dissipated. Langmuir stated that one or two pellets of dry ice introduced just above the freezing level are sufficient to transform a cloud into an efficient rain-producer. Langmuir said “the control of a system of cumulus clouds requires knowledge, skill and experience. Failure to consider the importance of the type of seeding, the place and the time, and also the failure to select the best available clouds, explain why the cloud physics project of the US weather Bureau was not able to obtain rainfall of economic importance”.

Scientific Weather Modification (1946) : Scientific weather modification was carried out not by the meteorologists but by others new to the field of meteorology. The leader of this brilliant development was Dr.Irwing Langmuir, a physical chemist and one of America’s foremost Nobel laureate who was helped by his laboratory assistant Vincent J.Schaefer, a skilled mechanic who was working for about 3 years on cloud physics problems including studies on particle sizes, light scattering, precipitation static and icing mechanisms which led them to make a series of observations in the clouds that sweep the summit of Mount Washington in New Hampshire. Schaefer being a good mechanic worked in the machine shop and produced good apparatus for Army research projects undertaken by the General Electric Company under the leadership of Irwing Langmuir. Since Langmuir and Schaefer were lovers of out-door life and mountain climbing, they frequently used to go to the top of Mount Washington to carry out research on glaciation that occurred as a natural development on this mountain. Being unfamiliar with meteorology and the work of Bergeron (1933) on glaciation, Langmuir was surprised that anything exposed to the cold clouds on the summit of Mount Washington immediately gets covered with ice and riming occurred all the time in winter days. They made good progress on icing research and measuring liquid water content of the clouds and collection efficiencies of rain drops. They observed that firstly if there are any snow crystals in the cloud, they will be growing and falling and secondly that if no snow is falling from winter clouds with temperatures below freezing it means that there are no ice crystals in the cloud in adequate number. So Langmuir and Schaefer decided to conduct some laboratory experiments to duplicate these conditions and unfold the mysteries of nature.

Schaefer's Marvellous Discovery : Vincent John Schaefer, a research assistant to Dr.Langmuir, the Associate Director of the Research laboratories of General Electric Company was working on some research programmes related to critical weather conditions for the Government. He was working in a small laboratory on the top of a 6280 foot high mountain known as Mount Washington in the North Eastern state of New Hampshire. Schaefer frequently watched from his windows that the western winds were constantly pushing moist air masses over the sides of the mountain. He noticed that in the colder air masses, at the higher elevation of the mountain, the moisture was getting condensed into cloud droplets and for many days the mountain was covered with super cooled clouds. Because of the low temperatures present over the mountain the super cooled clouds are a normal feature of the region for this latitude and altitude above the mean sea level. Hence, Schaefer concluded that generally the rain and the snow must come from super cooled clouds and that the rain starts as snow. But how this happens is not well understood.

Schaefer knew about the famous Norwegian meteorologist, Tor Bergeron who postulated that if ice crystals somehow got into the supercooled clouds from out side or if they were caused to form within the cloud, the moisture in the cloud might freeze on the ice-crystals and this would lead to the formation of snowflakes which give rain as they melt while falling to the ground. Schaefer also read about German meteorologist, Walter Findeison who expanded the theory of Bergeron. Findeison concluded from his observations that the ice crystals in the cloud were created when the super cooled moisture freezes on some specific dust particles present in the atmosphere. He also predicted that such dust particles (or nuclei) would be provided to the clouds one day or the other by artificial methods. At the end of world war Schaefer and Langmuir reproduced supercooled clouds in their own laboratory for conducting experiments under controlled conditions.

Schaefer obtained a home refrigerator unit used for food storage and modified it to suit to his research work. This refrigerator of about 4 cubic ft capacity was lined with black velvet and provided a small powerful search light in it. He directed a beam of light into the freezer box in order to take observations in the chamber. After bringing the temperature in the box below freezing, Schaefer breathed into the box several times until the air was saturated with the moisture from his lungs. The moisture in the box got condensed and formed fog particles which are like cloud particles. Even at –23^{o}C no ice particles were formed in the dust- free freezer box. Schaefer tried patiently for many weeks by sending air through exhalation into the freezer box to change the fog into snow. To produce ice particles in the box he sprinkled particles of salt, clay minerals and natural dust but practically never got any ice particles.. Nothing happened. He tried to reduce the temperature of the box to below 0^{o}F (equivalent to minus 20^{o}C) at the bottom of the box and 14^{o}F (equivalent to minus10^{o}C) at the top of the box. Still the ice crystals were not produced. It was still too warm. **Natural nuclei do not become fully effective until the temperature is about minus 13^{o}F (equivalent minus 25^{o}C). The experiments continued and still nothing happened.** Then the crucial day arrived on 12-

7-1946 when the day time temperature was fiercely hot. In order to cool the laboratory to some extent Schaefer left the lid of the refrigerator unit open as is done in the super markets. After returning from the lunch he found that the temperature in the refrigerator box had risen very high and it was only a little below freezing level at the top.

For a long time Schaefer used to wonder as to what would happen if something extremely cold was put into the fog of the super cooled cloud in the refrigerator box. The present instant was a good time to put his idea to the test. Schaefer found an 8-inch piece of dry ice (frozen carbon dioxide) with a temperature at minus 109° F (equivalent to minus 79° C) and thrust this dry ice piece into the supercooled box. In an instant the air was just full of ice crystals, millions of them shimmering against the dark velvet background in the search light. Schaefer was very surprised and spell bound. He watched the tiny crystals quickly transformed into snowflakes, growing rapidly larger and larger as they sucked the remaining moisture in the freezer box and the flakes fell to the bottom. Even after removing the dry ice pieces the ice-crystals persisted for some time. Even the tiniest piece of dry ice could fill the super cooled cloud box with crystals.

This experiment indicated firstly that the dry ice had no direct effect on the super cooled cloud but it was rather its temperature that has played the key role in transforming supercooled water into ice crystals. It was found that instead of cooling the freezer box with dry ice any other substance having temperature less than minus 40°C can be used for this purpose. Several experiments showed that there is a critical temperature of about minus 39°C (the freezing temperature of mercury) where a spontaneous reaction occurs in the supercooled water to produce natural nuclei. But if you keep the freezer box at minus 20°C and let in air from laboratory, often you may notice a few crystals, but if a cover is applied they grow and fall down and there will be no more crystals unless you inject some more new air into the box.

Schaefer sent an article on these experiments to the Science magazine and it was published on 15-11-1946 and it contained the following statement. "It is planned to attempt in the near future a large scale conversion of super cooled clouds in the atmosphere to ice crystal clouds, by scattering small fragments of dry ice into the cloud from a plane. It is believed that such an operation is practical and economically feasible and that extensive cloud systems can be modified in this way". This statement was very timely. However nature was too slow to provide the appropriate clouds which Schaefer and Langmuir wanted for their experiments under field conditions. The summer season (June, July, August) was over and autumn season (September, October, November) arrived. On 13-11-1946 a mile long Stratiform cloud at 14,000ft elevation with a temperature at minus 20°C was hanging over Mount Greylock on the East of Schenectady, New York. Schaefer took a small aeroplane with Curtis Talbot as pilot and made his historic flight over this cloud and scattered 3 pounds of dry ice(about 1.5 kg of crushed dry ice) into the supercooled Strato-cumulus clouds over Western Massachusetts(3 miles long over the cloud from the cockpit). Within 5 minutes the whole cloud appeared to have been turned into snow crystals which fell about 2000ft towards the earth before evaporating. So this first field experiment provided the final scientific proof for augmenting precipitation by artificial methods. What was proved in the controlled conditions of the laboratory also seemed to hold true under the field conditions. Once the operation started, the conversion from droplets into ice crystals and then into snow flakes was a fast action. Just like water speeding up as it approaches a narrow path pulling the other water after it, the space vacated by the droplets as they clouded after the growing into flakes, brought other droplets pushing in behind at an accelerating rate. Thus the super cooled water and the water vapour get frozen at a fast rate on the ice nuclei which develop into snow flakes and augment the precipitation either as snowfall or rainfall.

It was considered that dry ice was bulky, perishable and inconvenient to handle for cloud seeding operations. Scientists began to search if there was some other substance without these drawbacks which would do the job just as well. Bernard Vonnegut another research worker with the General Electric Company, began to search for the alternate materials for dry ice. He studied the structure of a number of natural crystals and found that the silver iodide particle, a compound of silver and iodine had almost an identical structure of the ice crystal. He applied vapourised silver iodide to the fog in the freezer box in the laboratory of Schaefer and soon ice crystals were immediately formed. Thus silver iodide proved to be an effective freezing nucleus for ice crystals. Thus Vonnegut found that the particles of silver iodide can also generate many number of ice crystals if the cloud is cold enough. Out of the many natural materials tested such as the smoke from forest fires and factory stacks, volcanic dust, salt powder, soil dust, none was effective until the temperature was far below 0^{o}C. Soil dust began to work as very weak nuclei when the temperature reached 18^{o}F (equivalent minus 8^{o}C) But silver iodide was effective much sooner at 25 to 20^{o}F equivalent to minus 4^{o} C where as other particles just began to work slightly at 14^{o}F (equivalent to minus10^{o}C) At that temperature silver iodide was very active and in full operation. Hence silver iodide is practically the most desirable chemical for cloud seeding operations.

In order to vapourise silver iodide, Irwing P.Krick of California Institute of Technology developed a ground generator consisting of a small fire brick oven inside a steel box (the size of a small Television set). In this oven silver iodide was impregnated in coke and burnt at a white heat of 2500^{o}F (equivalent to 1370^{o}C) impelled by a fan blowing through the fire in the fire brick oven. The vapourised silver iodide rose from the furnace and drifted into the clouds along with the rising air currents feeding the clouds at the rate of millions of particles per second. Thus the scientific basis of rain making was at last established.

Immediately many rain makers came into the field but not all of them were as qualified as Vincent Schaefer. Many people wanted to augment precipitation for many purposes. Farmers wanted rain for their crops. Farmers also wanted cloud seeding operations to stop the hail which was causing serious damage to their crops and properties. Cattle farmers wanted rain for their grass lands for rearing cattle for milk and meat. Electrical Power companies wanted more water in their reservoirs to run their hydro-electric power stations to supply inexpensive electricity to the industries and domestic needs. Municipal Corporations needed water in their reservoirs for domestic and industrial consumption. Mountain resort managers wanted cloud seeding to get more snow for the skii slopes to promote tourism industry. Some Government agencies want cloud seeding operations to augment the ground water supplies and to reduce summer temperatures so as to minimise electrical power use. China and Russian states intend to use cloud seeding operations to prevent unwanted rains during national celebrations and international sports festivals.

Many contractors for rain making came into the field. Some operators used a few buckets of dry ice, dropped from an air craft into the clouds. Many farmers conducted cloud seeding operations by themselves while others used professionals and in the process they covered about one-fourth of the area of the United States. Some charged half to one cent per acre for grasslands and 15 cents per acre for agricultural fields. Some contractors worked on the condition that if there is no rain due to their operations they will not claim for any payment. There were many controversies among the farmers as well as the scientists. The United States Weather Bureau condemned the cloud seeding as "nonsense". Some scientists claimed that it is a new technology that has to be used for the benefit of man-kind.

In order to resolve these controversies and to know the true picture of cloud seeding operations, Senator Francis Case from South Dakota introduced a bill in the US Congress demanding for a President's Advisory Committee on Weather Control. President Eisenhower signed the bill into law on 13-8-1953. On 9-12-1953 a committee was appointed under the Chairmanship of Captain Howard T. Orville, Navy's Chief Weather man and President of American Meteorological Society. The Committee was directed to study and evaluate the cloud seeding experiments carried out by private and Government organizations. On 13-12-1957 this committee concluded that cloud seeding has augmented rainfall by 9% to 17%. If the cloud seeding operations increase rainfall by just one percent during crop growing season, it would pay for the cost of seeding by a good harvest. The National Academy of Sciences was skeptical and it appointed another expert committee which commended cloud seeding as an effective method to improve rainfall and emphasized that rainfall was increased by 10 to 20% rather 9 to 17% as estimated by the Presidents' committee. These findings were upheld by the scientists of Rand Corporation of California and hence the weather bureau finally agreed to uphold cloud seeding and the rain-makers at last earned their credentials!

If silver iodide has become the key to modify these vagaries of weather before one could use this key effectively to modify the weather, one must first know in advance what the weather was going to do?, one must be able to forecast the weather which in turn calls for knowing more about how the weather operates. But, man with all his studies and research on weather finds that he still knows very little about the weather. Thus weather modification always remains a complex problem which for every answer always appears to raise many more questions. Man is still only at the beginning of what he needs to know to tame the vagaries of weather for the benefit of man kind. But with the recent advances in computers, electronic instrumentation, satellites and space explorations, there are more facilities available to study and understand the weather phenomena. Hence the extensive utilisation of the recent advances in science and technology must help man to unravel the mysteries of the weather phenomena and harness the atmospheric resources for the benefit of man and nature.

Why cloud seeding operations should be promoted?

1. The National Research Council prepared a report on **critical issues in weather modification research** and it was published on **13th October, 2003.** This report concluded that there is still no convincing scientific proof of the efficacy of International Weather Modification efforts and that even though there are strong indications of induced changes yet the evidences have not been subjected to tests of significance and reproducibility.

2. This report however does not challenge the scientific basis of weather modification concepts. The definition of scientific proof perhaps involves randomized experiments, statistical support, physical measurement and understanding and replication. But can any scientist demand for similar scientific proof in dealing with crucial environmental problems of climate change, green house effect and ozone depletion?

3. And yet the National Research council emphasises that there is ample evidence that inadvertent weather and global climate modification is a reality, If a certain criteria adopted for pronouncing a judgement on scientific proof for global climate modification is used to establish as a reality, a similar criteria extended to assess planned weather modification would certainly place it on a higher plane of reality.

4. More convincing scientific evidence on the positive effects of cloud seeding operations conducted in different states in USA and in other countries like China, Thailand, Israel,

Australia and other countries are presented to establish the credentials of cloud seeding operations for augmenting precipitation to protect public health and the environment.

5. It is true that the absence of adequate understanding of several critical atmospheric processes have lead to a failure in producing a high degree of precision in ensuring predictable, detectable and verifiable results. But such a situation cannot stop mankind from making use of the best available tools in weather modification technology to fight the recurring damaging impacts of droughts, El Nino impacts and global climate changes. Hence the promotion of further research in critical atmospheric processes can be initiated and continued with vigour if only the cloud seeding operations are also conducted simultaneously.

6. While the water-rich states of USA are taking a tough stand to insist that it is premature to take up cloud seeing operations without conducting more research work on weather modification processes, the water-starved provinces of China are supported by their socially-concerned scientists of the Chinese Academy of Sciences who by their extensive research investigations on cloud seeding operations have endorsed the scientific basis for cloud seeding and are promoting extensive scale of operations in China where more than 35,000 workers are annually engaged in augmenting precipitation from the clouds.

While many scientists attempted to evaluate the scientific basis and the success rates of cloud seeding operations they have resorted to a statistical approach to make further investigations of this technique which meant that there was no real evaluation of the cause and effect of cloud seeding operations. Essentially the most desirable conditions for seedability must be fixed in the first place to prove statistically that cloud seeding operations are effective but such conditions should be necessarily varied to find the optimum method to carry out the seeding operations. Without following this procedure several cloud seeding projects have been evaluated and most of them provided unsatisfactory results or failed to produce an effect that was physically convincing.

Hence managers of cloud seeding operations who are convinced that the theory behind cloud seeding has been already established by the pioneering laboratory and field experiments conducted by Schaefer and Langmuir in 1946 do not expect identical results in terms of economy and success rates for operations conducted under highly varying geographical, topographical and meteorological conditions. Thus the cloud seeding proponents are going ahead with practical methods of cloud seeding as a water management tool that is providing more water for drinking, irrigation, hydro-power generation and environmental improvements for the survival of man and nature.

The Americans being a nation of people with a scientific bent of mind coupled with patriotic fervour always work towards promotion of the living standards of the people and for the purpose seek new methods of augmenting their water wealth. Consequently the Irrigation Department of US Government known as Bureau of Reclamation planned not only to make maximum use of the conventional ground and surface water resources but also to tap the abundant atmospheric water resources in the form of clouds and started for this purpose a scheme in 1962 under the title of “Project Sky Water”. The main objective of this programme is to investigate how cloud seeding operations can be employed efficiently, economically and on a socially acceptable basis for increasing the annual rainfall and snowfall in water deficit regions of the country; in effect to manage the precipitation from the clouds by making use of the science of weather modification for developing the atmospheric precipitation management technology that has wide general applications in water resources management. The applications of this weather Modification technology include fog dispersal, hail suppression and cyclone modification. The field activities of this project involve cloud seeding operations for seeding.

1. Orographic cloud systems (winter storms) that form over mountain range as the air is lifted and cooled by the high mountain barriers.

2. Cumulus clouds that form during the warmer season.

During the winter the cloud seeding programme is used to increase the mountain snow pack so that additional run-off is received during the spring melt season. The seeding of cumulus clouds is to provide increased annual rainfall directly on the land.

Principles Of Cloud Seeding : Clouds are made up of millions and millions of water droplets or tiny ice particles or both which form around microscopic particles of dust, smoke, soil, salt crystal and other chemical aerosols, bacteria and spores that are always present in the atmosphere. These particles are classified as "condensation nuclei" (CCN) on which water vapour condenses to form cloud droplets and a few of them are classified as "Ice Nuclei" (IN) on which condensed water freezes or ice crystals form directly from water vapour. In the normal atmosphere there is an abundance of condensation nuclei while there is a scarcity of ice nuclei.

The types of nuclei and their sizes and concentrations present in the air play a significant role in determining the efficiency with which a cloud system precipitates. Generally tonnes and tonnes of water flow (as rivers of moisture) in the skies over many countries and from these rivers in the sky either little precipitation or not at all falls on the ground because of absence of certain required conditions. Among such important conditions for both initiation of precipitation and the amount of precipitation from a cloud system are;

1. Horizontal and vertical dimensions of cloud
2. Lifetime of the cloud and
3. Sizes and concentrations of cloud droplets and ice crystals.

Under proper conditions one or more of these above 3 factors can be favourably modified by seeding the clouds with appropriate nuclei, mostly by using either common salt or silver iodide particles.

Warm and Cold Cloud Seeding : Precipitation forms in clouds by two mechanisms namely "warm rain" and the "cold rain" processes. The term warm rain was coined by the scientists who found that the rain in tropical countries often fell from clouds whose temperature throughout the clouds was warmer than the freezing level of 0^oC or 32^oF. Rain occurs in these clouds when larger droplets collide with the smaller cloud droplets and absorb them in a process known as "coalescence". The cold rain occurs in clouds whose temperature in all or part is colder than the freezing level of 0^oC or 32^oF . The regions of the cloud below the freezing level are super cooled and contain both water droplets and ice crystals and sometimes only the former. The ice crystals which form in the super cooled regions of the cloud grow very rapidly by means of drawing the moisture from the surrounding cloud droplets and this growth continues until their weight overcomes the gravity forces and causes them to fall to the ground. While falling from cloud these ice crystals coalesce with other smaller droplets and fall from the cloud as snow or rain. The atmospheric nuclei that play a key role in cloud formation exert a strong influence on the efficiency with which the warm and cold rain processes operate.

For example the giant condensation nuclei (GCN) are prevalent in the oceanic atmosphere that allows for larger cloud droplets to form and the coalescence process to initiate rain within the life time of the cloud. But the continental regions are characterized by much smaller and more number of condensation Nuclei(CCN). Hence medium size clouds formed over the continental areas generally dissipate before the coalescence mechanism has had a chance to initiate rain. Similarly many regions have a shortage of Ice Nuclei (IN) which reduces the efficiency of cold rain process.

Reasons for Injecting Chemicals into Clouds : When a scientist detects by scientific measurements the nuclei in the clouds and realises that mother nature has provided very few nuclei to initiate precipitation process in the clouds he helps mother nature by injecting appropriate nuclei in sufficient numbers into the clouds by seeding them at the proper time and place so that the moisture in the clouds falls on the ground as snowfall or rainfall. Seeding the cloud with very large or giant condensation nuclei (GCN) (hygroscopic particles such as sodium chloride, calcium chloride etc) can be done to accelerate the warm rain process and seeding with proper ice nuclei such as silver iodide is done to supply the naturally nuclei-deficient cold clouds with an optimum concentration of ice crystals which will substantially increase rainfall through the cold rain process.

Most often a combination of hygroscopic and also ice nuclei seeding can be done since both warm and cold rain mechanisms operate in the mixed phase cold clouds (practiced in the Thailand by the king). Most important aspect of super cooled cumulus cloud is a dynamic effect caused by ice-phase seeding. It is well known that under favourable natural environmental conditions cumulus clouds can be stimulated to grow larger and also to last longer. The injection of silver iodide particles into the super cooled part of the cloud makes the cloud droplets freeze into ice crystals. This conversion process gets multiplied millions and millions of times within the cloud and releases a large amount of heat, known as the “latent heat of fusion”. This phenomena makes the cloud more buoyant and makes it grow larger in size and thereby makes the cloud process more water longer and more efficiently than would have occurred naturally.

What is Wrong with Natural Clouds? : Chemical seeding of cold clouds which are found as winter Orographic storms is a fairly well established and well understood method. Clouds are formed as the moist air from the oceans, lakes and rivers is lifted and they are cooled as they pass over forests and mountains from West to East during the monsoon. Left to the usual processes and devices of nature most of the clouds are highly inefficient precipitators, content to keep aloft more than 90% of their moisture burden. By seeding some of these cold clouds with silver iodide particles the precipitation efficiency of these clouds can be greatly improved. As already stated the microscopic particles of silver iodide work as artificial ice-nuclei that form ice crystals which attract moisture from the surrounding cloud droplets and grow large enough to fall to the ground as snowfall or rainfall. These large cumulus clouds form when the warm moist air fairly close to the surface of the earth is lifted into the sky where it gets cooled to the point where the water vapour condenses into cloud droplets. The lifting of the moist air can be induced by the heating of the surface of the earth by the Sun or by the passage of a cold front or a warm front through a given area. The life span of most of the cumulus clouds is generally about 20 to 30 minutes and they give very limited snowfall or rainfall because nature provides too little time for the cloud droplets to coalesce into large drops of sufficient weight to fall on earth.

Critical Temperature for Seeding : The two cloud seeding techniques that are generally used to extract more moisture from the cloud in the form of snowfall and rainfall are the hygroscopic seeding of warm clouds and the ice-phase seeding of cold clouds with silver iodide. The silver iodide seeding is used when the cloud top temperature of the cumulus cloud formation is $23^{o}F$

to 26°F (-3°C to –5°C) or colder or when the cloud growth indicates that it will shortly reach that temperature level soon in the atmosphere. The main objective of cold cloud seeding is to initiate the dynamic latent heat release which will stimulate growth of the cloud. If the cloud updrafts are slow the objective then is the same as for orographic cumulus clouds (winter storms) that means the objective is to increase the number of ice crystals in the super cooled part of the cloud to the optimum concentration for the given set of cloud conditions. The ice crystals attract moisture and grow rapidly at the expense of cold clouds because of the special properties of water and the ice crystals grow into ice flakes of sufficient weight to fall through the cloud and melt into rain drops before reaching the earth.

In the warm cloud seeding hygroscopic materials like common salt, calcium chloride or a mixture of Ammonium Nitrate and Urea that absorb water vapour from the surrounding air are used. The hygroscopic substances are finely ground into small particles and released into the updraft beneath the growing cloud. The hygroscopic particles will gradually grow in size by condensation and then by coalescence with cloud droplets that grow into heavy drops that produce rainfall. This process is effective particularly in clouds with strong updrafts which might otherwise remain inefficient precipitators. Left to themselves these clouds would blow much of their water content out of the cloud tops where ice crystal clouds (cirrus) form and hold aloft much of the water that has been processed. Hygroscopic seeding of the clouds generally result in formulation of large drops much lower in the cloud and at warmer temperature levels where there is the greatest supply of moisture and hence more of the water content in the clouds reach the ground as rainfall.

VAGARIES OF MONSOONS AND RAINFALL

Monsoons denote the reversal of seasonal surface winds (Arabic word “Mausam” means “seasonal”) Around 45 AD a Greek mariner discovered that by starting his voyage by ship from the Red Sea port around the summer solstices he could travel across the Arabian sea and arrive at the Kerala coast of India in 40 days and complete his return voyage in the same period, if he commenced his voyage from Kerala coast around the winter solstices and will have favourable winds for his return voyage also. Such periodic reversal of the winds and tides came to be known as the monsoon, derived from the Arabic word “Mausam”, meaning weather or climate that gets reversed. Such alternating winds and tides are of great scientific interest and the associated rains are vital for the life and economy of many regions including India.

Monsoons are classified under secondary circulations, thermal tides, characterized by cyclic reversal of the wind direction. While to a sailor a monsoon means periodic reversal of the winds and waves that influence his voyage, to the farmer it means rains which influence his very survival. In general monsoon means the annual cyclic reversals of pressure and wind systems in association with the consequential changes in the cloud and weather patterns. In the tropical countries, the monsoon regions are generally bounded by the summer and winter positions of the ITCZ (Inter Tropical Convergence Zone) with its maximum oscillation in the Indian ocean. The monsoon flow reversal extends upto 3 to 6km depth based on the strength of the monsoon current.

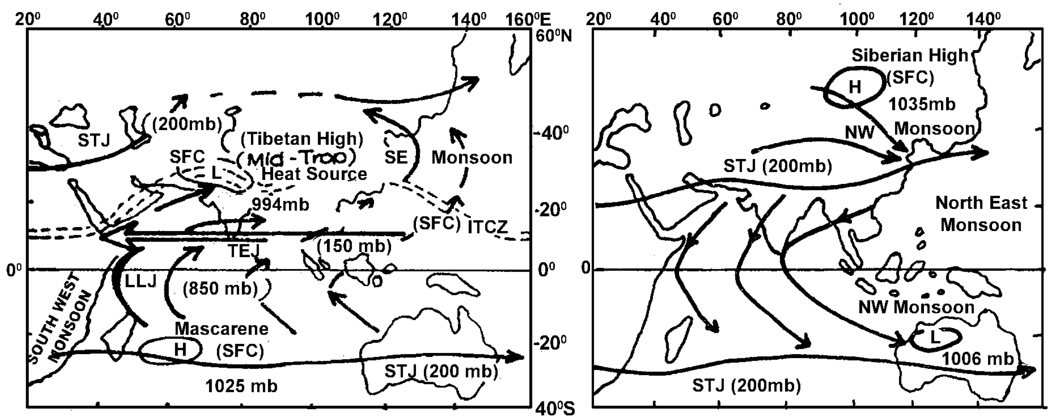
The response of the continents and oceans in the Asia-Australian region to the incoming solar radiation has great differences and the land and sea distribution in the region maximises this contrast. The massive Africa-Europe-Asia land complex has a low heat capacity while the Indian Ocean merging with the Antarctic ocean possess infinite heat capacity and this thermal differential arising from this great land-water contrast provides the driving force for this Asiatic monsoon circulation which may be conceived as a gigantic Land-Sea-breeze circulation.

The Himalayan mountains as a massive barrier obstruct the free meridional flow and separate the Indian monsoon from the Sino-Japanese monsoon system. Himalayas during winter season prevent the entry of cold polar air masses from Siberia to enter into the Indian sub-continent. During summer, Himalayas do not allow the equatorial maritime air masses to cross the mountains and hence force them to turn towards the North West of the Gangetic belt and they produce the hypodynamic effects that influence the type of rainfall or snowfall in India. In the tropical belt the temperature fluctuations in the sea surface vary from 15°C to 30°C while over the continental land masses the temperatures vary from as low as - 5°C to as high as 50°C

Summer Monsoon : The intense heating of land over the Indian subcontinent during summer causes the formation of a permanent thermal induced "heat low" or seasonal "low pressure" (994 mb or h Pa Hectopascals) in North West India and adjoining parts of Pakistan and it extends upto 700m level.

High pressure cells (1025 mb or hPa)build up over the Ocean South of equator around 23°S. These quasi-permanent systems control the "low level" circulation and the "Sub-Tropical Highs" (STH) of Southern hemisphere move Northwards by end of April when South East trades start to cross the equator and temperatures slowly increase and the pressure decreases over India with increasing heat from the Sun. By June the Pakistan "low pressure" zone gets fully established and extends into Bay of Bengal and is known as “monsoon trough”. This monsoon trough can be treated as the "equatorial trough of low pressure" which undergoes seasonal Northward migration and the axis of this trough is called the "Inter Tropical Convergence

Zone" (ITCZ). This cross equatorial transport of air with a reverse flow in the upper troposphere occurs almost all along the equator in the Northern hemisphere summer with the strength of the flow widely varying across the different meridians. The strongest flow is found in the West Indian Ocean along the East African coast. The Southerly flow attains the maximum strength at about 1.5km height (850mb or h.Pa) with core speed of about 80 knots known as the Somali Low Level Jet stream (LLJ). Zonal Easterlies overlie the South westerlies and their strength gradually increases with the height. The Tibetan anti-cyclonic system promotes the Easterly flow. The Easterly Tropical Jet stream (TEJ)at a height of about 15km (150mb or h.Pa) with a main position of 15°N with core speed of about 60 to 100 knots is found over the Indian Ocean from China to Africa crossing over the Indian Peninsula, overlying the Southwest monsoon from June to September and during this period the Westerly Subtropical Jet (STJ) moves towards the pole and does not influence the Indian sub-continent. The synoptic features of the summer and winter monsoon are presented in the figures.



Summer Monsoon **Winter Monsoon**

Active monsoon conditions are associated with strengthening of low level Westerlies which occur with every fresh surge or pulse in the monsoon flow due to increased cross equatorial transport for any reason. During the surges wind speed becomes almost double.

Moreover when the Sun attains the high position in the sky, the Inter Tropical Convergence Zone (ITCZ) (Trough of low pressure) is displaced towards the Gangetic belt, sometimes touching the foot of Himalayas. High pressure cells do form over extensive areas of Indian Ocean and Arabian sea. The South Indian ocean that was generating cyclones from November to April becomes calm with the onset of winter for the Southern Hemisphere. The cold waters cause intense high pressure zones in Southern parts of South Indian Ocean. This “high” generates South East trade winds on the South of the Equator which on crossing the equator get deflected due to the rotation of the earth and become South West monsoon winds.

The warm waters in Arabian sea and South Bay become turbulent due to strong South westerly winds. A pressure gradient of 16 hPa over a radial distance of 100km. (like in a cyclone) generate forceful winds of 60knots. The same pressure gradient now extends over the Indian sub-continent over a distance of 2000km and takes the monsoon air slowly over the country like a giant sea breeze and the monsoon occupies the whole country except Rajasthan in about 30 days and Rajasthan covered in subsequent 15 days.

Normal dates of monsoon are deduced and the southwest monsoon touches Kerala coast by 1st of June. Sometimes the wind pressures rise so much over North India that the seasonal “low” shifts to the foot of the Himalayas and becomes untraceable.

Break-Monsoon :

During July and August the monsoon trough sometime shifts Northwards and its axis lies along Himalayan foothills. There is a general increase of pressure over the country and the isobars show marked refraction along the west coast. The southerlies at the lower levels over North India are replaced by the westerlies since the trough shifts to the Himalayan foothills and heavy rains occur on the Himalayan Southern slopes causing floods in Himalayan rivers. Thus this break-monsoon gets initiated with a warm ridge in the rear of a trough in the upper westerlies. This break sets in when the trough pulls the monsoon trough and the break will get prolonged for 1 or 2 weeks if the Sub-Tropical High (STH) is highly pronounced. Most often westward passage of a number of low pressure systems in the low altitudes in the equatorial trough also occur. The characteristics of the breaks in 80 years (1888-1967) are presented in the following table.

Month	No. of breaks	Duration (No. of days)		
July	53	5.8	17	4
August	55	6.5	20	3

With no mechanism to bring convergence and rain over the Gangetic plains, the condition is known as the “break-monsoon” and this can extend for a week or two and cause drought conditions in Northern parts of India. 2 or 3 breaks in monsoon, each lasting for 4 days upto a week, can occur. If the country receives 85% or less of the long term average rainfall, this Southwest monsoon is considered to be a failure causing a drought year. Prolonged breaks in monsoon is one of the reasons for the drought and absence of cyclone systems, during the Southwest monsoon, may lead to diminished rainfall.

During the southwest monsoon a number of major cyclones in West Pacific ocean around Philippines and China occur and the air masses which rise to very high levels from these areas become Easterly winds around 9 km (150mb) (TEJ)and above in the sky and travel towards India and descend over Pakistan and West Asian countries. In an El Nino year also the Central Pacific becomes as warm as West Pacific and some tropical storms form over the Central Pacific also and the air masses rising from the Central Pacific travel towards India and partly descend over India and reduce the monsoon rains and cause droughts. During April-May months when the temperatures rise the land becomes hot and the pressures over land decrease and consequently the warm moist air from the surrounding oceans starts blowing towards the above low pressure land areas.

By the end of May or first week of June when the low pressure centers are fully developed, the pressure gradient becomes steep and even the trade winds from Australia cross the equator and get deflected to the right due to coriolis force and thus the South East trade winds from southern hemisphere become the South Westerlies of the Indian monsoon and the ITCZ shifts to about 30^{o}N latitude. These winds travel over thousands of miles over the warm tropical oceans and pick up lot of moisture and thus have a great potential for heavy precipitation.

The Southwest monsoon splits into the Arabian sea branch and the Bay of Bengal branch. The Arabian sea branch strikes the western ghats which receive 2500mm of rainfall on their wind ward slopes while their downwind side becomes rain-shadow area. As an example Mahabaleswar on the windward side of Western ghats gets rainfall upto 6500 mm while Pachgani, 16km on the East gets only 1700mm of rainfall. The higher the mountains, larger is the rain shadow effect. The South West monsoon winds pass over Kutch and Thar desert and march upto Kashmir. Since, Aravali hills are parallel to the South West monsoon winds they cannot lift the moist winds to promote precipitation and hence Rajasthan mostly remains as a desert.

The monsoon currents passing over Rajasthan are not only shallow but are also superimposed by stable anti-cyclonic air masses and are not amenable for their uplift and hence cannot give much rain. Moreover the hot continental winds from West and Northwest are drawn towards this thermal 'low' developed in this region and such descent of dry winds are unfavourable conditions for precipitation.

Part of the South West monsoon branch is Bay of Bengal branch and starts around Ceylon and strikes Assam and Burma regions. This branch yields good rainfall and recurves Westward and advances through the Gangetic belt along the "trough of low pressure" around the Gangetic belt and reaches Punjab. The monsoon current blows from the South Easterly direction and the rainfall decreases with increasing distance from the source of moisture and also the Himalayas. While Kolkata on the East receives 1150mm rainfall, Multan on the west of the Gangetic plain receives 125mm of rainfall. When anti-cyclonic conditions develop in Punjab and the North west winds blow into U.P. region drought conditions often occur in this region. Depressions and cyclonic storms originated from Bay of Bengal provide copious rainfall over the states of the Gangetic belt.

Winter Monsoon : During winter season the entire land mass of Asia becomes the centre of a very high pressure and cold waves that travel towards India are stopped by the Himalayan mountains. But a secondary high pressure system that develops over Kashmir and Punjab controls the prevailing winds over the Indian subcontinent. Low pressure belts develop over Indian ocean, Arabian sea and around Australia and hence pressure gradient from land to sea develops and consequently the winds start to move from land to sea and cause the North East monsoon currents. In South India while the wind direction is North Easterly, in North India cold winds in the Gangetic belt are North Westerly. In North India the anti-cyclonic winds are dry; since they originate on land and are off-shore they cause dry and fine weather. Sometimes westerly disturbances provide some rainfall to Punjab and Uttara Pradesh regions. The North East monsoon currents that pass over the Bay of Bengal pick up moisture from the warm sea surface and provide good rainfall over Tamil Nadu and Southern parts of Andhra Pradesh until the middle of December.

The South West monsoon withdraws from Punjab, Uttara Pradesh and Bengal by about September 15^{th}, October 1^{st} and October 15^{th} respectively. The 3 month period from October to December is also known as the post-monsoon period when a seasonal low pressure zone forms off the Tamil Nadu coast and North-Easterlys of about 4.5 km thick strike the southern part of the Coromandal coast . This post-monsoon period becomes North East monsoon period for South India while it is also the main cyclone period for the whole country. During this period 2 to 3 low pressure zones form now and then in the Bay of Bengal. Under favourable atmospheric conditions one of these low pressure cells gets concentrated into a well marked low pressure zone and later into a depression zone that draws all the low level winds around it. With the surface wind reaching 25 knots (1 knot = 1.85kmph) when the depression lies about 300km from the coast the low clouds rapidly move towards depression and Alto-stratus clouds begin to shed moderate rains. If the system continues it will develop into a deep depression (surface winds with 30 knots speed) within 24 hours leading to the start of a cyclone. Thunder clouds in the form of spirals begin to converge towards the depression zone. Thus low pressures, depressions and cyclones are favourable weather systems for providing good clouds that yield good rains and hence cloud seeding operators must take full advantage of such weather systems to get the maximum sky-water. Tamil Nadu receives about 550 mm of rainfall in the months of October and November. During this period some depressions and cyclones develop over the Bay of Bengal and the Arabian sea and produce occasionally heavy rains.

South West Monsoon winds lift over 7,700 billion cubic meters of moisture from the Arabian sea (half the amount comes from the Bay of Bengal) during June to September. Both South-West and North-East monsoons bring over India 11,000 billion cubic meters of moisture of which 2,400 billion cubic meters is released as rain fall. The remaining moisture in the atmosphere is transported by the winds to other countries and if 2% of such moisture is harnessed through artificial rains, the water scarcity problems of South India can be solved.

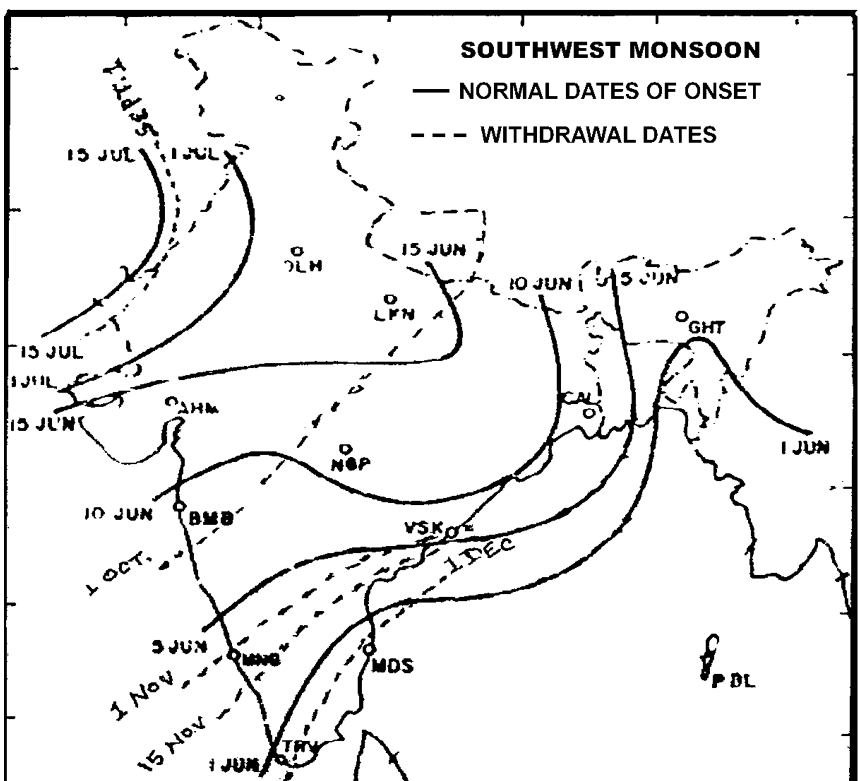
Vagaries of Monsoon Rainfall in 2004-05

S.No	Sub-divisions	01-06-04 to 29-09-04			01-10-04 to 31-12-04		
		Actual	Normal	%	Actual	Normal	%
1.	A&N Islands	1326	1755	-24	431	700	-38
2.	Arunachal	1800	1835	-2	231	244	-5
3.	Assam&Meghlaya	1727	1885	-8	293	191	+54
4.	NG,MN,Tr,Mz	1309	1241	+5	151	195	-23
5.	S.Him, WB, Sik	1897	1955	-3	218	183	+19
6.	GangeticWB	1121	1136	-1	201	159	+26
7.	Orissa	1047	1160	-10	150	153	-2
8.	Jharkhand	890	1105	-19	128	101	+26
9.	Bihar	934	1048	-11	39	78	-50
10.	East UP	714	914	-22	36	62	-41
11.	West UP	501	773	-35	64	51	+26
12.	Uttaranchal	1400	1223	+14	80	87	-8
13.	Delhi, Har, Ch	358	470	-24	60	27	+118
14.	Punjab	278	502	-45	55	41	+32
15.	Himachal Pradesh	423	774	-46	116	111	+4
16.	Jammu & Kashmir	387	514	-25	157	153	+3
17.	West Rajasthan	160	263	-39	22	9	+151
18.	East Rajasthan	570	624	-9	38	26	+45
19.	West Madhya Pradesh	765	904	-15	40	52	-23
20.	East Madhya Pradesh	877	1097	-20	31	59	-48
21.	Gujarat	979	934	+5	23	35	-34
22.	Sau, Kut, Diu	459	486	-6	21	26	-20
23.	Konkan, Goa	2847	2808	+2	44	135	-67
24.	Madhya Maharashtra	810	700	+16	47	105	-55
25.	Marathwada	590	704	-16	63	96	-34
26.	Vidarbha	683	976	-30	40	75	-47
27.	Chhatisgarh	1027	1206	-15	56	82	-32
28.	Coastal AP	531	575	-8	236	326	-28
29.	Telangana	569	767	-26	96	110	-12
30.	Rayalaseema	349	381	-8	127	212	-40
31.	Tamil Nadu, Pondichery	346	316	+9	435	432	+1
32.	Coast Karnataka	2444	3174	-23	183	258	-29
33.	North Interior Karnataka	431	491	-12	71	137	-48
34.	South Interior Karnataka	622	659	-6	138	200	-31
35.	Kerala	1728	2206	-22	438	486	-10
36.	Lakshdweep	902	985	-8	303	329	-8

Note : Excess: +20% or mcre; Normal:+19% to –19%; Deficient: -20% to -59%; Scanty: -60% to –99%.

The Indian Meteorological Department has divided the country into 36 divisions for presenting the rainfall data each week on its website. The rainfall data for these 36 sub-divisions during southwest monsoon period from June to September and Northeast monsoon from October to December 2004 is presented in the table.

It is important to realise that July is the most crucial month for sowing of Kharif crop and in this period the country was receiving deficient rainfall ranging from –20% to –30% and hence the sowing of paddy and other crops have been adversely effected in 2004. But the first two weeks of August have registered excess rainfall while the period between 26th August and 8th September the rainfall was deficient upto about 65%. From 1st June to 30th September 13 sub-divisions received a deficient rainfall in the regions of Andamans, East UP, West UP, Haryana, Punjab, Himachal Pradesh, Jammu and Kashmir, West Rajasthan, East Madhya Pradesh, Vidarbha, Telangana, Coastal Karnataka and Kerala which grow paddy during Kharif. 8 sub-divisions received deficient rainfall upto 20% in Orissa, Jarkhanad, Bihar, East Rajasthan, West Madhya Pradesh, Marathwada, Chhatisgarh and North Interior Karnataka. The remaining 15 sub-divisions received 90% to 120% of the normal monsoon rainfall. Uttar Pradesh reported many drought-effected districts. By receiving 2200 mm rainfall in the monsoon the deficit was –21% and the state suffered a 3rd time in succession due to deficient rainfall. During 2002 and 2003 the rainfall deficits were upto 35% and 32% respectively. Punjab, West UP, Himachal Pradesh, Jammu and Kashmir, Marathwada, Vidarbha and Telangana received in this monsoon the lowest rainfall in the last 6 years while Tamil Nadu received the highest precipitation. Coastal Karnataka, North and South Karnataka and Rayalaseema received the lowest rainfall in 6 years during the post monsoon season. Hence the crops were adversely affected in some areas.



Normal rainfall in a few selected regions *(in mm)*

Region	Jan	Fen	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Coastal A.P.	10	11	12	25	42	685	1106	663	348	113	25	9
Telangana	4	6	11	20	26	135	243	213	188	76	19	6
Rayalaseema	7	5	6	21	53	59	85	98	132	115	71	25
Tamil Nadu	34	15	21	49	71	53	73	98	103	195	194	88
Coastal Karnataka	2	1	5	32	141	868	1161	678	303	184	66	15
North Interior Karnataka	2	3	7	26	48	97	149	129	150	93	27	7
South Interior Karnataka	3	4	7	45	102	149	279	186	138	149	53	12
Kerala	15	17	40	113	257	692	759	435	248	293	164	42
Konkan	1	1	0	5	42	685	1106	663	348	113	25	9
Madhya Maharashstra	4	1	4	12	53	140	271	179	155	71	29	7
Marathwada	3	3	7	10	20	146	206	187	179	57	19	9
Vidarbha	12	10	18	13	14	167	335	277	201	43	15	15

Source : Mausam, Vol.47, IMD, New Delhi, (1996)

Tropical vertical disturbances are classified as follows:

Name	Wind speed
i) Low pressure Area (LPA)	Upto 16knots
ii) Depression (D)	17 – 27 knots
iii) Deep depression (DD)	21 – 33 knots
iv) Cyclonic storm (CS)	34 – 47 knots
v) Severe cyclonic storm (SCS)	47 – 63 knots
vi) severe cyclonic storm with core of hurricane winds	64 knots ore more

Depression and cyclones during 80 years (1891-1970)

Area	June		July		August		September	
	D	C	D	C	D	C	D	C
Bay of Bengal	71	35	107	38	132	26	141	32
Arabian Sea	18	15	9	3	2	2	9	9
Land	12	1	39	1	42	0	21	1

D = Depression - <33 knots **C= Cyclones – 33 knots and more**

Seasonal demarcation : The seasonal demarcation in India is as follows:

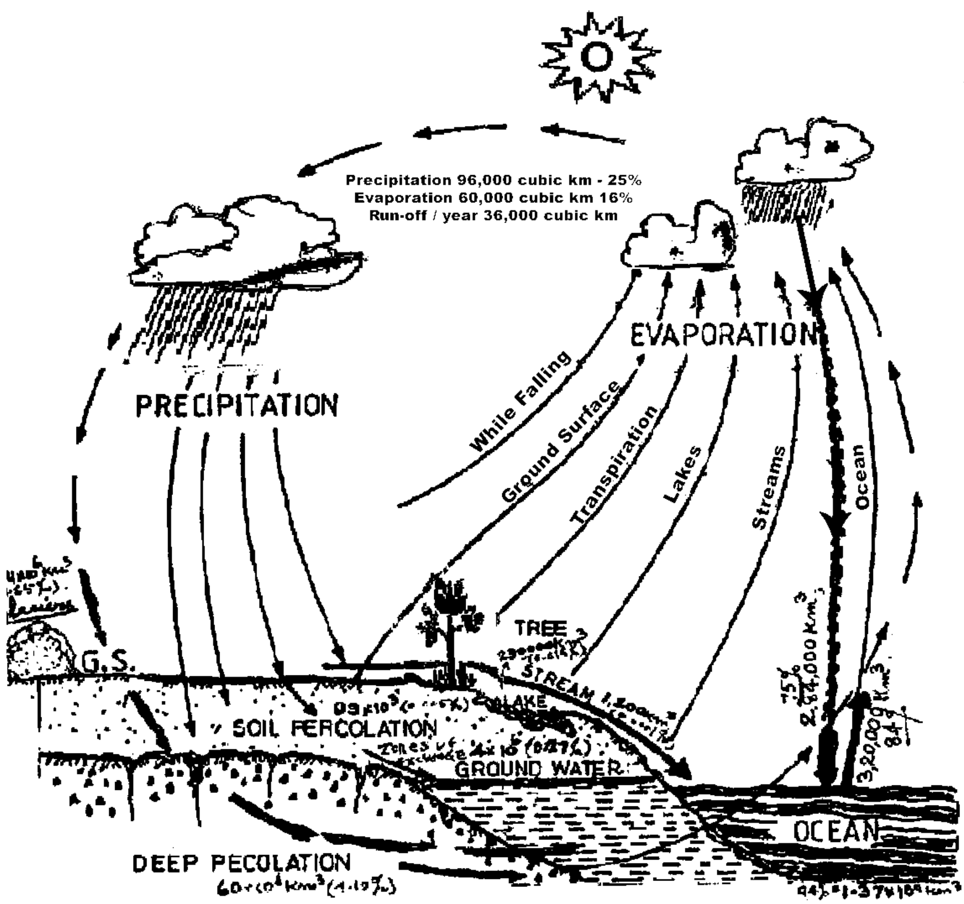
1) Wet season (Varsha) (Southwest monsoon) — June to September
2) Cool season (Sharad) (Retreating monsoon) — October to November
3) Cold Season (Shisira) (Winter) — December to February
4) Hot season (Greeshma) (Summer) — March to May

Hemanth is the early part of winter and
Vasantha is the first part of summer immediately after the winter season.

HYDROLOGICAL CYCLE

In almost all the countries, the people give utmost importance for the use of water which is considered as a basic resource for economic growth and national prosperity. Hence they call it as the "blue gold". It is well known that water exists in the solid, liquid and invisible vapour states. It forms the oceans, lakes, rivers and the underground water found not only in the soil cover but also in the top layers of the earth. In the solid form it is found as ice and snow cover in polar and high mountain regions. Water is so very dynamic that it is always in permanent motion and is constantly changing from liquid to solid or gaseous phases and back again. All the water of the hydrosphere is the free water that exists in the liquid, solid or gaseous states in the atmosphere on the surface of the earth and also in the crest of the earth up to a depth of about 2km.

According to one estimate the total water in the hydrosphere is about 1500 million km^3, 95% of it being contained in the oceans and the remaining 5% is fresh water out of which 4/5th is stored as snow and ice. About half of this frozen water is in Polar ice caps. Hence the fresh and unfrozen water on earth is only 1% of that in the hydrosphere and bulk of it estimated at 99% is ground water and only 1% is in lakes and rivers, soil and atmosphere. Nearly half of the ground water lies 1000 meters below the surface while a good amount is found between 500 to 1000 meters and hence expensive to draw for normal use.



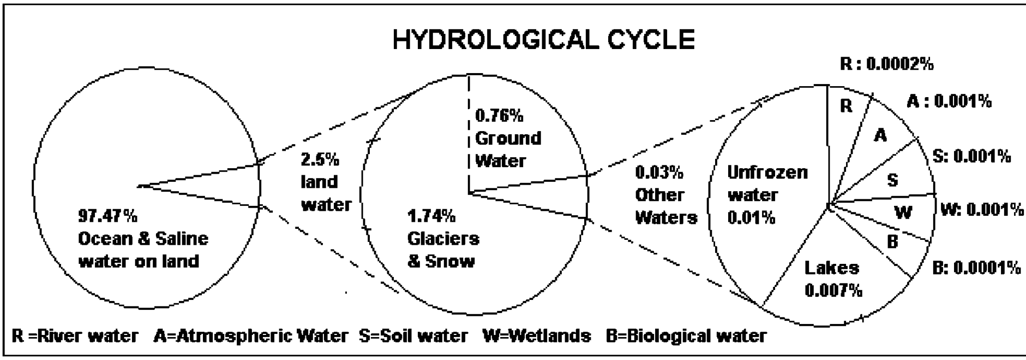
The water in the hydrosphere is distributed to an extent of about 96.5% in the oceans with the remaining 3.5% being distributed over the continents. During the last 2 million years ice caps in polar regions have melted out periodically and then frozen again. If these polar ice caps melt today the sea level would rise by 60 meters and flood many countries. During the greatest icing-up of the oceans the level of the oceans has fallen by about 140 meters. The main water reservoirs on earth namely the oceans, the continental landmasses and the atmosphere are in constant touch with each other through circulation. The moisture in the atmosphere influences the composition of the air masses and energy changes and governs water circulation. While some vapourised water masses remain mostly as atmospheric moisture others are condensed back due to cooling by ascending air streams and become clouds, fog or rain. When the clouds get too heavy, the moisture returns to earth as rain. Part of this rain flows in the streams, some seeps into the soil and replenishes ground water. The upper portion of the ground water sustains growth of trees which absorb water through roots and return it to the atmosphere as water vapour by respiration and transpiration. The motive force for this entire cycle is solar energy. Out of the total solar energy absorbed by the earth about 1/3 is used to maintain the water circulation. Temperature, humidity and wind movement determine the level of evaporation.

Global Water Circulation and Storages : According to some experts, out of nearly 1386 million cubic kilometers of water in the world, 96.5% (1338 million Km^3) is present in the oceans as shown in the following table.

Volume of water in the hydrosphere

Source	Volume in (1000 Km^3)	Percentage of total water	Percentage of total fresh water
World ocean	1,338,000	96.54	--
Saline/brakish ground water	12,870	0.93	--
Saltwater lakes	85	0.006	--
Total salt water stocks	**1,350,955**	**97.476**	
Glaciers, permanent snow cover	24,064	1.74	68.7
Fresh groundwater	10,530	0.76	30.06
Ground ice permafrost	300	0.22	0.86
Total frozen and underground freshwater stocks	**34,894**	**2.522**	**99.62**
Fresh water Lakes	91	0.007	0.26
Soil-moisture	16.5	0.001	0.05
Atmospheric vapour	12.9	0.001	0.04
Marches, wetlands	11.5	0.001	0.05
Rivers	2.12	0.0002	0.006
Incorporated in biota	1.12	0.0001	0.003
Total not frozen or underground freshwater stocks	135	0.0103	0.389
Total freshwater stocks	**35029**	**2.5323**	**100**
Total water on Earth	**1,385,984**	**100.**	

http://www.ec.gc.ca/water/images/nature/prop/a2f23.htm



Fresh water, including 10,530,000 Km^3 of underground water amounts to 24,064,000 Km^3, forming about 2% of the hydrosphere. Since this fresh water includes major portion in the form of ice in polar glaciers, man cannot use it at present. Thus the usable fresh water constituting only 0.3% of the hydrosphere, comprises 0.76% (10.5 million km^3) of underground water in zones of active exchange, 0.007% (91,000 Km^3) in lakes, 0.001% (16,500 Km^3) in soil-moisture, 0.001% (12,900 Km^3) in atmospheric vapour and 0.0002% (2120 Km^3) in the rivers. It is not these small stocks of fresh water that count, but the dynamic reserve that is the water that is in constant circulation that makes or mars the future of man in a given eco-system. The devastating effects of water famine arise from inefficient use of the water resources and from lack of sufficient water in the world. The seas, lakes, streams, ground water, soil moisture and atmospheric vapour are the links in the hydrological cycle, a continuous global process that is sustained by solar energy and gravitation as its motive forces.

Under the influence of the heat from the sun, water evaporates from the seas and the land to form the clouds which float around in gaseous from or in liquid droplet state. Ultimately the water returns to the Earth in the from of snow or rain. Thus the moisture is transported in the process of atmospheric circulation. In the zone of powerful ascending air currents in the equatorial belt, there is an annual rainfall of 1500 mm to 3000 mm. But the polar regions get precipitation of only 100 mm to 300 mm. most of it as snow. In the regions with a marked oceanic influence, the precipitation is high. It is estimated that out of 5,77,000Km^3 of precipitation, 80% falls over the oceans and the remaining 20% falls on the land as shown in the following table.

Annual global circulation of water

Source	Evaporation Quantity (in Km^3)	Percent	Precipitation Quantity	Percent	Difference (in Km^3)
Oceans	5,02,000	87%	4,58,000	80%	- 44,800
Land	74,200	13%	1,19,000	20%	+ 44,800
Total	**5,77,000**	**100%**	**5,77,000**	**100%**	

Such depletion of water vapour in the atmosphere due to precipitation is replenished by the evaporation from the seas, the lakes, rivers and vegetation. Nearly 87% of the moisture that enters the atmosphere evaporates from the oceans and the other 13% from the land areas. In the equatorial zone, evaporation is less than precipitation due to dense cloudiness. While the land shares 20% of the global precipitation, its contribution for global evaporation is only 13%. This difference between the imports and exports of moisture by land amounting to 44,800 km^3 per year is made up by the transfer of atmospheric moisture from the oceans to the land. This unique natural process increases the availability of water on land. As 44,800 Km^3 of water circulates annually round the hydrological cycle, it can provide almost hundred times our present rate of supply. Although there is enough water in the world, it is rarely in the right place at the right time in the right quantity and quality.

River water is of great economic importance in the global hydrological cycle and for the supply of water for the survival of man and all other forms of life. All the different forms of water in the hydrosphere are fully replenished during the hydrological cycle but at very different rates. For example complete recharge of ocean waters occurs in 2500 years, but water storage in lakes gets replenished in 17 years and in rivers in about 16 days. However the atmospheric moisture which is available for cloud formation gets replenished almost once in a week.

The water in the atmosphere mostly in the form of clouds is about 12,900 Km^3 and it is replaced about once in eight days to produce annual precipitation over different parts of the earth. Over the earth out of the annual precipitation of 1,19,000 Km^3 about 74,200 Km^3 gets evaporated making available a daily run-off of 123 Km^3 or 4300 TMC (Thousand Million Cubic ft.) of water per day.

Periods of water resosurces renewal on the earth

Water of Hydrosphere	Period of renewal
World Ocean	2500 years
Ground Water	1400 years
Polar ice	9700 years
Mountain glaciers	1600 years
Ground ice of the permafrost zone	10000 years
Lakes	17 years
Bogs	5 ye3ars
Soil moisture	1 year
Channel network	16 days
Atmospheric moisture	8 days
Biological water	Several hours

http://www.unesco.org/science/waterday/2000/general.htm

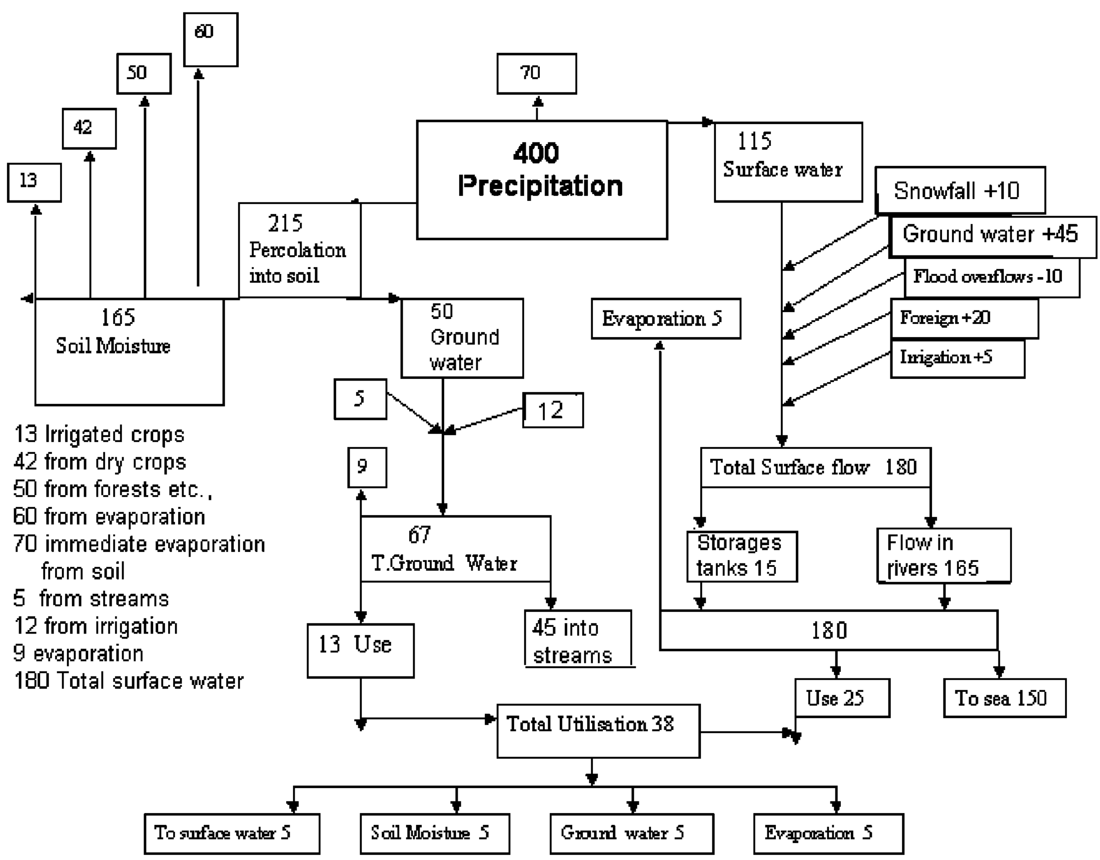
Hydrological cycle for India : In order to quantify hydrological cycle for India the approximate estimates made by the National Commission on agriculture (1974)may be considered to get an idea about the present and future water resources and their utilization patterns. The total surface and ground water resources of India constitute only a small fraction of the total water resources of the earth.

Precipitation in India : The summer monsoon from the South West starts from the equatorial belt and crosses over India in two distinct currents known as the Arabian sea branch and the Bay of Bengal branch. According to National Commission of Agriculture, during the 4 rainy monsoon months of June to September the Arabian branch carries moisture amounting to about 770 Mham (7700 BCM) and the Bay of Bengal branch, about 340 Mham (3400 BCM). Of the monsoon moisture content about 25% to 30% precipitates in the form of rainfall. There is a substantial amount of moisture over the country during the remaining 8 months, contributing a precipitation of about 100 Mham (1000 BCM) a small part being snowfall. About 3000 rain gages are set up for recording the rainfall by the Indian Meteorological Department and the state Governments. The national annual average rainfall of about 120 cm provide annual precipitation of about 390 to 400 Mham (4000 BCM) including snowfall which is not yet fully recorded.

When the clouds give rain a portion of the rain soon evaporates from the ground or the vegetation that intercepts rain, another portion soaks into the ground and the remaining rain water flows away over the land as run off. When the rainfall is a very light shower of about 2.5mm or less it merely moistens the few millimeters of top soil and then evaporates rapidly and hence it does not contribute for the surface water or to ground water. There are about 130 rain days out of 365 days in a year in India and on 75 days the rainfall is of the light showers of the above magnitude. However even during the remaining 55 rainy days there is similar evaporation at the commencement of the rainfall. Ultimately the annual average precipitation occurs in the magnitude of about 400 Mham including 70 Mham lost to the atmosphere. Out of the remaining 330 Mham about 115 Mham flows as surface run-off and the remaining 115 Mham soaks into the ground.

Surface flows : The surface water flows consist of direct run-off from the rainfall, snow melt water and flows in streams, regenerated from ground water. The irrigation commission estimated total annual surface water flows in the country at 180 Mham including about 20 Mham brought by the rivers from catchments lying outside the country. About 45 Mham is the regenerated flow from the ground water as deduced from river flows during non-rainy months. The remaining 115 Mham is a direct contribution from precipitation out of which about 10 Mham is received as snowfall.

Distribution of average annual water resources, 1974 *(Million Hectare Meters)*



Based on artical on water resources India by Nag and Kathpalia, 1975

The surface water gets utilized and disposed of in 3 different ways. A substantial portion of the surface water is stored in reservoirs or used directly by diversion from barrages and anicuts or by pumping. Another portion of the surface water disappears as percolation from streams where ground water table is below the stream surface and the remaining surface water finds its way to sea, a small portion evaporating in the process. A portion of the water stored in reservoirs is lost through evaporation and a small amount through seepage while the remaining major portion is utilized for irrigation and hydropower generation. Out of the 180 Mham of annual surface flow, about 15 Mham is stored in tanks and reservoirs which have 20% evaporation losses from major and medium reservoirs and 40% evaporation loss from the tanks. Such evaporation loss is estimated at 5 Mham per year at present. But with additions to the present projects, the reservoir storage would ultimately be 35 Mham with the losses at about 10 Mham. Out of the 165 Mham of the water that annually flows in the rivers the utilization by diversion works and direct pumping aggregates to 15 Mham which is more than the utilization from storage reservoirs. The remaining river flow of about 150 Mham goes to the sea and some adjoining countries with new developments through diversion works or pumping water, the utilization is expected to touch 45 Mham and consequently the remaining 105 Mham is likely to flow to the sea and to other areas outside the country. The first claim on the rain water is that of the soil to bring the soil moisture to the field capacity. After the soil is saturated then the rain water percolates down to the water table and adds to the ground water reservoir. About 12.5% of the precipitation is estimated to infiltrate to the ground water table. Hence out of 215 Mham that soaks into the ground annually 50 Mham percolates to the water table and the remaining gets retained as soil moisture . In irrigation systems due to seepage losses in field channels and irrigated fields a limited water only is actually utilized by the crops. In alluvial lands about 45% is lost through seepage in the channels and out of the remaining 55% that reaches the field another 17% is lost. In lined canals losses are minimised. About 5 Mham is retained as soil moisture and 12 Mham is added to the ground water. But with more development of irrigation 15 Mham will be soil moisture and 25 Mham will be contributed to ground water. When rivers are in floods the over flow joins the adjoining ground water table. Such additions of about 5 Mham to ground water table may increase to 10 Mham in future.

Ground water : With the addition of 5 Mham from flood over flows and 12Mham from irrigation systems to the 50Mham from precipitation, the ground water excluding the soil moisture comes to 67 Mham and this ground water quantity may increase to 85 Mham in future. Some ground water evaporates through capillary action or is sucked by plants for transpiration in places with high water table. Some ground water evaporates through wells and tube wells and a large part is returned through the surface as regenerated flows in the rivers and the remaining portion that is not disposed of in the above manner adds to ground water and thereby rises the ground water table. With development of water resources the ground water extraction may rise to 35 Mham and evaporation may reduce to 5 Mham due to lowering of water table and the remaining 45 Mham returned to surface of regeneration

Transpiration : Transpiration occurs from crops, forests and other vegetation. Transpiration from irrigated crops is 13 Mham, from unirrigated crops 42 Mham and 55 Mham from forests and other vegetation, aggregating to 110Mham. With further development transpiration increases to 35 Mham from irrigated crops, 35 Mham from unirrigated crops, 55 Mham from forests and other vegetation, making a total of 125Mham.

Evaporation : In the hydrological cycle, evaporation plays a major role. As a rain falls over the land about 70 Mham evaporates out of a total annual precipitation 400 Mham. 5 Mham evaporates from tanks and reservoirs and another 5 Mham from high ground water areas. Out of the total soil moisture of 170 Mham which gets replenished every year about 110 Mham is utilized by the crops, trees and other vegetation and the remaining 60 Mham evaporates. If due to extensive cloud seeding operations if there is increase in precipitation in future the evaporation from it will also increase proportionately.

Out of the annual precipitation of 4,000 BCM(Billion cubic Meters) (1,40,000 Thousand Million Cubic ft) only 380 BCM(13,300 TMC) (9.5%) is utilized presently and by 2025 AD water utilization will go upto 1050 BCM (36,750 TMC) (26%) Out of the total annual rainfall of 4000 BCM, 700 BCM (24,500 TMC) goes for evaporation and 1150 BCM (40,250 TMC) is the runoff into surface water bodies while 2100 BCM percolates into soil. In the subsequent stage, a series of inter changes take place between these 3 sinks and finally almost all the precipitation is returned to the atmosphere. The plants use for transpiration a large part of the water that percolates into the soil and thereby sustain their growth. People use the surface and underground water for domestic agriculture and industrial purposes. The total annual surface water flows from the direct run-off (1150 BCM). Streams entering from neighbouring nations (200 BCM) and underground water courses add upto 1800 BCM. Out of these supplies about 150 BCM is used through diversion works and direct pumping. The remaining 1500 BCM go into the sea or into the neighbouring countries. By the year 2025 it is anticipated that water utilization by the storage (350 BCM) and by direct pumping (450 BCM) will consume 800 BCM out of an increased surface water flow of 1850 BCM. The extra 50 BCM is expected to be the enhanced return water flow from the increased surface irrigation.

Projected Utilisations : According to one group of experts, out of the 2150 BCM that percolates into the soil about 1650 BCM moisten the soil and the remaining 500 BCM will enter into the ground water table. It is expected that river seepage may add about 50 BCM to the ground water supplies. Another 120 BCM will be added from leakage due to irrigation thereby raising the total ground recharge to 670 BCM. The raise in the ground water use in future will cause steeper gradient and also higher seepage from the river beds. Moreover percolation from the irrigated lands will also be more as the irrigation activities grow. The higher water inflows will increase the total annual ground water recharge to 850 BCM. Any soil and water conservation measures and green plantation will also promote infiltration into the ground water table and this will add to regeneration of nearby river flows. However the total ground water recharge often gets dissipated through evapo-transpiration, extraction through dug wells and tube-wells or it may pass through under ground streams into the surface water courses. By 2025AD the amounts of water extraction will increase from the present use of 130 BCM to about 350 BCM. Hence there is a greater need to conserve water by recycling municipal and industrial waste waters and also by tapping the sky water by seeding the warm and cold clouds which contain sky water that is about half a dozen times higher than the water flowing in the rivers.

The Distribution of annual precipitation according to some experts is as follows :

Evaporation and Transpiration loss	— 40% (10,00,000 lakh cubic meters)
Run-off into rivers	— 40% (10,00,000 lakh cubic meters)
Retention as soil moisture	— 10% (2,50,000 lakh cubic meters)
Ground water Recharge	— 10% (2,50,000 lakh cubic meters)

Out of the 40% river flow about 80% is used for irrigation, 3% for domestic use, 4% for industry and 12% for hydro power generation. Out of the available water of 1869 BCM the usable water is about 1122 BCM (690 BCM surface water and 432 BCM ground water) The per capita water availability per year is 1122 cubic meters at present and due to population growth it declines to 748 cubic meters by the year 2050. However countries with per capita water per year of less than 1700 cubic meters are considered as water stressed countries.

CLOUDS AND THEIR CHARACTERISTICS

Introduction : The scientists began to delineate since a long time how the atmosphere is fueled by solar heating which is first absorbed at the surface of the earth. The heat from the Sun falls over the oceans and other water masses. The water thus heated rises into the sky and gets transferred to the atmosphere in the form of latent heat in gaseous water vapour which gets condensed due to adiabatic lapse rate at the dew point level into water droplets that form the clouds. Thus clouds are the converters where by the gaseous water vapour is condensed over dust particles to form into water droplets, thus turning latent heat into sensible heat which can be sensed by thermometer and utilized to drive atmospheric circulations.

The tropical atmospheric circulations operate by means of thermally direct (Hadley) cells with their ascent concentrated in a narrow equatorial "trough zone" and with mean sinking motion outside this zone. At the higher levels in the atmosphere, the tropical cells transport energy and moment towards the poles to make up the radiation deficits in those zones and drive the wind circulations in the temperate and the polar regions.

Cumulus clouds play a vital role as important links in almost every part of this atmospheric heat engine. While the tropical oceans provide the water vapour fuel, the growing cumulus clouds act as fuel pumps that carry the energy upward into the sky and by releasing about 20% though local rainfall to drive the trade wind systems, they are making the rest available for the vast winds of Easterlies to carry equator-ward. In the "equatorial trough" the firebox function of the atmospheric heat engine, is carried out by about 1500 to 5000 giant Cumulo Nimbus clouds concentrated in about 0.1% of the area. These cumulus clouds produce more than 3/4ths of the rain that falls on our planet, dominating in the thirsty tropical and subtropical zones. Since the atmosphere runs an inefficient engine about 2% of the energy drives the planetary wind system while most of the energy is lost to space by radiation. In the temperate latitudes the cyclones draw the energy stored in air mass contrasts and become the driving mechanism in the planet's Westerlies which at high levels snake around the globe in a wave pattern and with their instabilities exert influence over the fluctuating weather. Over the mid latitude oceans cumulus clouds influence the occasional explosive deepening of winter storms that trigger a major readjustment in the wind pattern over the whole hemisphere.

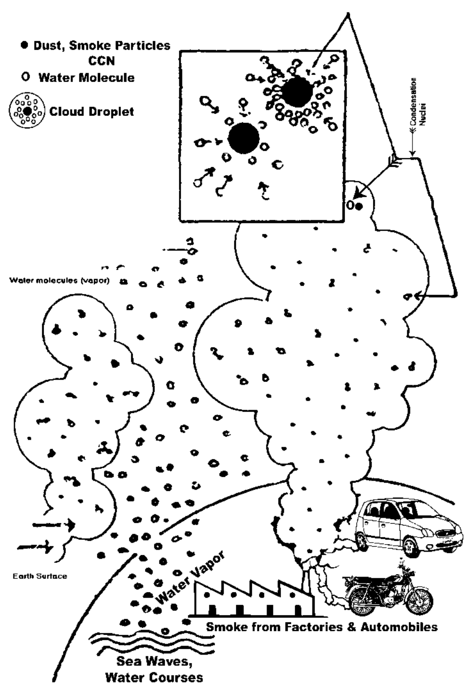
If a number of these cumulus clouds can be modified to some extent a powerful tool would be in the hands of man kind for managing their water resources taming the cyclones and modifying the regional climates. How to explore the different possibilities of modifying the clouds determines the ways in which man can modify cloud systems to tap the abundant sky water to improve the living standards of mankind and conserve nature for sustainable development. In order to provide additional annual precipitation for improving drinking water, agriculture, hydro power generation, fog dispersal in airports and metropolitan cities, forest growth, pollution control, summer heat reduction, flood and cyclone damage reduction and environmental improvement, it is necessary to understand what is already known and what is yet to be known about clouds in general and the large cumulus clouds in particular and how cloud seeding operations are to be conducted and evaluated.

Cloud formation :

A cloud is nothing but a visible conglomeration of very small particles of water or ice or of both in the atmosphere. The moisture that goes into the atmosphere is due to heating of the water from the surface of lakes, streams and oceans by the Sun and it will be in the form of invisible vapour. Like other gases in the atmosphere exert pressure on the earth's surface, the water vapour also exerts pressure on the earth. At any given temperature and pressure, the atmosphere cannot hold unlimited water in the form of water vapour and hence evaporation from any water body comes to an end when the atmospheric air reaches a state of saturation with the water vapour and the partial vapour pressure exerted is called the saturation vapour pressure. More moisture is held by the atmosphere when it is warmer, it means that a warm unsaturated moist air when cooled becomes saturated or even super saturated, that is, the relative humidity exceeds 100% or the dew point equals the atmospheric temperature. The excess water vapour changes into the liquid or solid phase in the form of dew, fog, mist, frost and cloud. Such changes of phase occurs due to condensation , freezing or even sublimation depending upon the temperature. But this process needs the assistance of some surface and this is easily available as dust and other particles from the ground. But in the free atmosphere where suitable surfaces are not readily available super saturation occurs.

In the free atmosphere the temperature of an air parcel as it rises into the sky decreases at the rate of 6^{o}C to 10^{o}C per km due to adiabatic lapse rate. If a parcel of air at the ground level with a temperature of 30^{o}C and relative humidity of 75% contains 20 grams of moisture per cubic meter rises into the sky to a height of 1km. Its temperature becomes 24^{o}C and it can retain about 19 grams of moisture per cubic meter of air and consequently the remaining moisture in the air parcel gets condensed as liquid water over dust particles known as cloud condensation nuclei and the liquid droplets form the clouds. These cloud droplets form in the sizes of 1 to 50 microns in diameter with an average of 10 to 20 microns (a micron is one thousandths of a millimeter and the human hair is 75 microns in thickness)

Cloud droplets of 250 microns provide drizzle while cloud drops between 500 to 5000 microns provide heavy rains. The following figures shows how the formation of clouds occur and the different sizes of cloud droplets and rain drops.

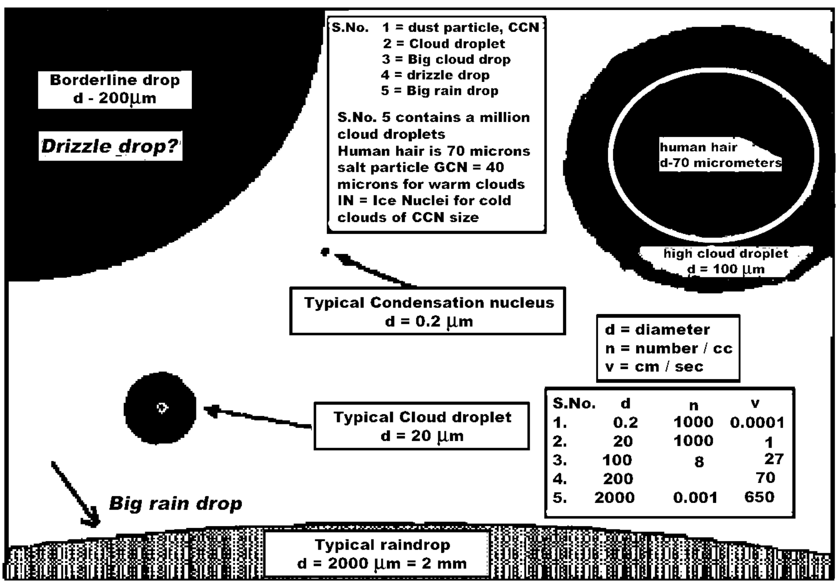


FORMATION OF CLOUDS

The following table gives details about the various sizes of particulates in the atmosphere and the cloud droplets and the rain drops.

Characteristics of particles, cloud drops and rain drops

Particle	Diameter (in μ)	Mass (in gms)	Concentration (No/m^3)	Mass (gm/m^3)
Gas molecule	0.0005	10^{-22}	10^{25}	1000
Medium aerosol(CCN)	0.2 -1.0	10^{-15}	10^{8} – 10^{10}	10^{-6}
Giant Condensation Nuclei (GCN)	10	10^{-9}	10^{3}	10^{-6}
Fog Drops	10-20	10^{-9}	10^{6} – 10^{8}	0.001 – 0.5
Average cloud droplets	10-20	10^{-9}	10^{7} – 10^{9}	0.1 – 5.0
Drizzle drops	400	10^{-6}	10^{5}	0.1 – 5.0
Medium rain drops	2000	10^{-3}	10^{3}	0.1 – 5.0



Fog, dew or mist do not contribute much to the rainfall because the water content is small and the evaporation losses are high. Condensation of moisture occurs when the moist air ascends into the sky and cools adiabatically and the mechanism of ascent may be convection , Orography or frontal uplift. The condensation mechanism in the atmosphere to cool the moisture-laden air is achieved in the following ways.

1. Radiative Cooling: Radiative exchange of heat from the surface of the earth and the tops of clouds
2. Advective Cooling: Passage of warm air over a cold land or sea surface.
3. Convective Cooling: Vertical rise into the sky of air resulting in its expansion due to the decreased atmospheric pressure known as adiabatic cooling. This vertical uplift is caused by mechanism like rising air caused by a mountain barrier known as Orographic lift. The gliding of a mass of warm air over a cold air mass is known as Frontal lift.
4. Mixing of two different air masse with different temperatures often resulting in cooling.

If the air with the moisture is free from impurities even if it expands and cools it remains as vapour even at temperatures below dew point. Fortunately the atmosphere contains many impurities and pollutants as millions of minute particles including hygroscopic aerosols. The water vapour firstly condenses on hygroscopic and other particles and changes into droplets of liquid water and these particles are known as condensation nuclei (CCN). Once the condensation starts the process continues indefinitely and the clouds are formed. The condensation nuclei are of different sizes and originate from the dust, sea spray and the combustion products. Based on the size (diameter) they are known as Aitkeen nuclei (less than 0.1 microns) large nuclei (0.1 to 1.0 microns) and giant nuclei (more than 1 micron). One micron size is one millionth of a meter or 1000th part of a millimeter) Most of these particles are water soluble. In the presence of suitable condensation nuclei which are also known as cloud condensation nuclei (CCN) the condensation of vapour starts when humidity is about 75%. All water vapour does not condense at 0°C and continues to exist in the air as super cooled water without becoming ice crystals upto a temperature of –40°C. But if such super cooled droplets come into contact with ice particles they freeze as ice crystals.

Properties of clouds

Cloud type	Cloud droplet Diameter(microns)	cloud droplets (number per CC)	Water Content (grams per m³)
Continental :			
I) Fog	16.0	15	0.06
II) Stratus	9.5	250	0.30
III) Cumulus	7.0	1300	0.30
IV) Cumulonimbus	14.0	500	1.0 – 3.0
Maritime :			
I) Stratus	13.0	80	0.30
II) Stratocumulus	21.0	65	0.45
III) Cirrus (-25°C)	--	0.10	0.03

Heat is consumed by the water for its evaporation and conversely when water vapour condenses the heat is liberated. For instance the evaporation of one gram of water by boiling requires the consumption of 540 calories of heat and when one gram of water vapour is condensed it releases again the same quantity of heat. This liberated latent heat of condensation is absorbed by the air parcel that becomes warmer and lighter as compared to the surrounding environment and begins to rise. If continued moisture supply is available more and more condensation will occur, resulting in the formation of fog or mist. When this fog is lifted above the ground a sheet like cloud known as **stratus cloud forms**. If this condensation occurs above the ground level after some moist air is forced vertically upwards as updrafts, then small heaps of clouds form and these clouds may not have a growing tendency and hence may dissipate without giving rain.

However when large areas in the sky are covered with streets of puffy **cumulus (heap)** clouds, the larger ones among them with intense updrafts or vertical upward motion of air at a rate of 5 to 10 meters per second, the clouds may grow by as much as 6km in thickness, known as **towering cumulus clouds**. These clouds contain water droplets only in super cooled state. Additional growth of such clouds may result in the freezing of water droplets. If the tops of these clouds grow upto about 16km and may assume anvil shapes indicating outflow of air from the top of the clouds, such clouds are known as **cumulo-nimbus (violent rain) clouds**. The shape of the cloud and its appearance are determined by the nature, number and size of nuclei and droplets and the weather characteristics. The clouds are always in a continuous evolution process and hence display many varieties of forms.

Slow and prolonged ascent of air in a low pressure area or irregular stirring motion produces a layer type clouds known as **“stratiform clouds**”. Convective currents leading to violent ascent of air masses due to insulation caused by heat from the sun create heaps of clouds known as **“cumuliform clouds**”. All the clouds can be divided into four classes based on the thickness and height of the cloud base as shown below

Classification of clouds

Class of Clouds	**Name of Clouds**	**Height of base**	**Temp.at base**	**Main constituent**	**Precipitation**	**Appearance**
High Clouds	Cirrus (Ci)	5-14km	-20°C to – 60°C	Ice	No	White philaments, fibrous
	Cirrocumulus (Cc)	5-14km	-20°C to – 60°C	Ice	No	White patches or layers
	Cirrostratus (Cs)	5-14 km	-20°C to – 60°C	Ice	No	Translucent cloud veil
Medium Clouds	**Altocumulus (Ac)**	**2-7Km**	**+10°C to – 30°C**	**Water with some ice**	**Occasional**	**White grey layers**
	Altostratus (As)	2-7Km	+10°C to – 30°C	Water with some ice	Occasional	Grey sheets with ice in rows
Low Clouds	Nimbostratus (Ns)	1-3 km	+10°C to - 15°C	Water and ice	Good rain	Dark grey layers
	Stratocumulus (Sc)	0.5-2 km	+15°C to – 5°C	Water	Little rain	Grey patchy sheets
	Stratus (St)	0.5km	+20°C to – 5°C	Water	Drizzle	Grey uniform layer
Clouds with vertical growth	Towering cumulus or large cumulus	0.5 - 2km	+15°C to – 5°C	Water	Small showers	Detached clouds grow vertically
	Cumulonimbus(Cb) or Thunderstorm	0.5 – 2km	+15°C to – 5°C	Water	Heavy rain	Huge towering clouds

Clouds play an important role in weather forecasting. Feather like **Cirrus (curl of hair) clouds** in the middle and low latitudes scattered in the sky during summer indicate clearing of the weather.

Rain-clouds :

If **cumulus clouds** are gradually developing into cumulo-nimbus clouds on hot and humid days, they indicate an approaching thunder storm and hence cloud seeding has to be planned in advance to prevent the development of hail storms that cause severe damage to crops and properties. If **stratocumulus clouds** cover the morning sky and the wind is gusty, clouds will develop during the day time. Cloudiness and rainfall are interrelated in the tropical equatorial belt where there will be substantial cloud cover with maximum amount of rainfall. The clouds are localised and have great vertical development. Due to the descending air currents in the subtropical belt, rainfall and cloud cover will be less and deserts are located in such regions.

In the equatorial belt, cloudiness does not vary much from month to month. But the cloud maximum occurs between 10° and 20°North and South latitudes during summer months with substantial rainfall. Daily variations in cloudiness is based on the kind of clouds in the sky. The maximum cumulus or cumuliform clouds occur during the early and middle afternoon periods while stratus and **stratiform clouds** appear to the maximum extent during the morning periods. While **altostratus clouds** give light rain, **towering cumulus clouds** provide short spells of showers. While Nimbostratus clouds give moderate continuous rain, **cumulonimbus clouds** give heavy rain, often accompanied by hail stones. Several other kinds of clouds do not provide rain. Stratus clouds are in the lowest level in the sky.

When there is a depression within 200 to 300 kms from the sea coast stratus clouds in the shape of cotton pieces moving fast, touching the tall trees are found along the seacoast. This cloud is always thin and has a stratiform or horizontal top. If the depression close by is intensifying further, hundreds of these stratus clouds are seen moving like an invading army.

Cumulus clouds are 5000 ft thick and are generated by the summer heat when some moisture is present in the atmosphere. They disappear by night when the convection currents subside. They have rugged or cauliflower shaped tops and are known as fair weather cumulus clouds. During summer when there is moist air and good convection cumulus clouds grow vertically and reach the freezing levels around 6km. Super cooled water often triggers sharp rainfall that lasts upto half an hour.

If there is stable upper air layer, the top of the cumulus cloud gets flattened and the cloud becomes a strato-cumulus cloud. Small strato-cumulus clouds do not shed any rain. Alto-cumulus clouds when closely packed look like a flock of sheep and they do not give any rain. If the sky is covered with alto cumulus clouds for 2 to 3 days it indicates that a low pressure system within 300 km is developing into a depression or a cyclone. Cyclonic storm winds associated with a depression cause a large scale convergence for about 300 kms around the depression at the lower levels of the atmosphere. **Altostratus clouds** then from with a base around 8000 ft and a thickness of 5000 ft to 10,000ft and its spread cloud be around 300 kms around the depression. By its gradual growth and thickness, it provides corresponding increase in rainfall reaching upto heavy downpour which continues until the depression disappears. The rain may last for 2 to 3 days.

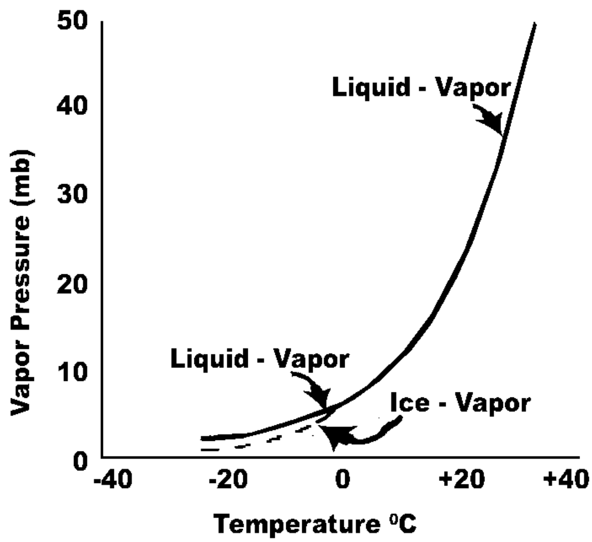
The high clouds that form above 7 km in the sky are known as **cirrus clouds** that are very thin and contain ice-crystals. These clouds do not give any rain. The thunder cloud, the giant king of the sky, is known as **cumulo-nimbus** cloud which is classified as low cloud with its base around 1.5 km and its top reaching 12 km in the sky. They provide rain for about half an hour in dry summer and they dominate the sky during monsoon periods for 2 to 3 hours and produce heavy rains. The **Nimbo-stratus cloud**, a very dark Stratiform cloud gives moderate rainfall for a short time.

Among the clouds the most important ones that provide rainfall are the tall cumulus, the large Strato cumulus, the thick Alto-stratus and the dark Cumulo-nimbus. Since the human eye can observe the horizon upto 40 kms, it is necessary to cultivate sky reading to predict the rain which is influenced both by the vertical extent as well as the horizontal dimensions of the clouds.

COLD CLOUD SEEDING

It is widely known that if most of the super cooled water droplets in the cloud are some how converted into ice crystals then the cloud gives very good rain. The super cooled water is unstable and hence is amenable to freeze upon contact with an ice-nuclei or when it is cooled below its critical temperature. While silver iodide induces contact freezing, the dry ice helps to cool the supercooled water to below its critical temperature, causing it to freeze and any substance that gets frozen always releases latent heat into the surrounding environment and that heat adds energy to the cloud and thereby increases its growth and life span. Seeding for hail suppression involves introduction into the clouds of many ice or AgI crystals for utilizing the available supercooled water vapour so that none of the ice crystals will be able to grow large enough to become big hailstones. Cold cloud seeding is done by using static or dynamic seeding principle.

Static Phase Seeding : One of the two basic principles of cold cloud seeding is the static phase seeding methodology, which is based on cloud micro-physics. It has already been stated that ice particles grow by condensation and subsequent freezing of water vapour (riming) or the direct deposition of water vapour over the ice particle.



As air temperature increases, more water can exist in the gas phase. But as the temperature decreases water molecules slowdown and there is greater chance for them to condense on to the surfaces of other particles. If water has to freeze, the water molecules must become properly aligned to attach to one another and such a chance is less in small amounts of water like cloud droplets and so in clouds below freezing level, both supercooled liquid water and ice particles also coexist. Below 0° C liquid vapour curve splits, one for the saturation point above the liquid surface represented by a curved line and one for the surface of ice represented by the dotted line (See Fig). The saturation vapour pressure at –20°C is lower for ice than for water. Why? One should recall that to convert water into a gas needs 600 calories per gram while to convert water from solid ice to gas requires 680 calories and hence it is naturally more difficult to liberate a molecule of water from ice than from water droplet. Hence when the air is saturated there will be more molecules above water surface (more vapour pressure) than over an ice surface (less vapour pressure).

In other words, if the water vapour in the cloud is to condense over a liquid droplet the surrounding air must be super-saturated with respect to a water droplet surface. So also for condensation or deposition over an ice particle, the surrounding air must be super-saturated with respect to an ice particle surface. Because of the special properties of water, the scientists found that at below-freezing level, the super saturation, with respect to ice particle occurs at lower relative humidities than super saturation with respect to water drops. Hence in the same environment, ice particles will grow very fast than water droplets. As the water vapour gets slowly depleted, the cloud environment becomes sub-saturated with respect to water while it is still super saturated with respected to ice.

The supercooled water tends to freeze when it is disturbed. Icing of the aeroplanes which fly through a cloud with supercooled water is a typical example. Supercooled droplets also freeze when they come into contact with a tiny nucleus of one micron in diameter known as a freezing nucleus. Such freezing nuclei are sparse in the atmosphere. This sudden change from a super cooled water to an ice cloud is caused by the differences in vapour pressures existing over super cooled water droplets and ice crystals both of which remain at the same temperature as shown in the following table.

Comparative Relative Humidity(RH) (with respect to water and ice)

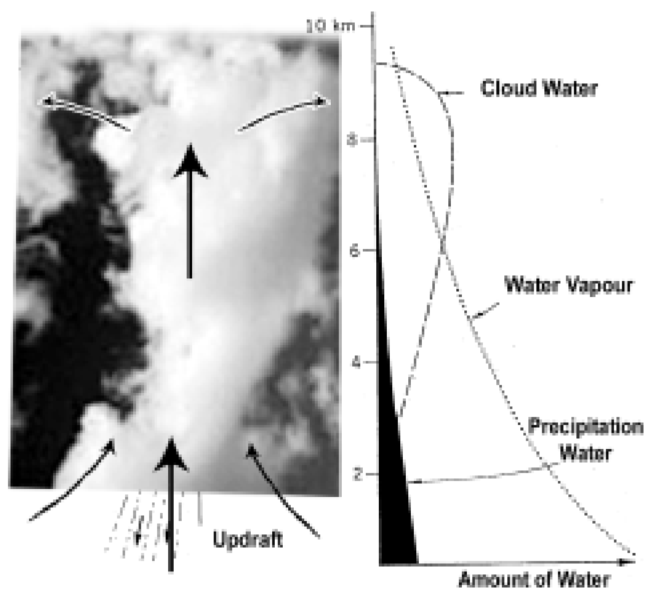
Temperature ($0^{o}C$)	R .H with respect to Water (%)	R.H.With respect to Ice (%)
0	100	100
-5	100	105
-10	100	110
-15	100	115
-20	100	121

From the above table it may be seen that at –15^{o}C the relative humidities are 100% for water, and 115% for ice crystals and so the water vapour diffuses rapidly from air to ice crystals which grow at the expense of the water droplets because the water molecules bind more tightly to ice crystals than to the water droplets. (http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/atmospheric_moisutre/concept_of_saturation.htm)

Dynamic Phase seeding : The second basic principle of cold cloud seeding is a dynamic phase hypothesis that depends upon the dynamics of the cloud. Cumulus and Cumulo-Nimbus clouds depend upon the updraft air movements for their survival. From within the base of the cloud the air in the updraft experiences adiabatic cooling as it rises in the sky and becomes super saturated and condenses into cloud droplets and if it goes to the freezing level ice particles begin to form. While new cloud droplets are generated within the updraft, the existing cloud drops and ice particles are continuously evaporating and sublimating and hence the updrafts must replenish by sucking in more moisture to extend the life of the cloud. The conversion of water vapour into cloud droplets or ice crystals releases latent heat to the surrounding air parcel and increases the temperature difference which in turn increases the buoyancy that accelerates the updrafts and augment the water vapour influx into the cloud. Clouds with weak shear weather conditions grow vertically and the precipitation reaches the ground through the updraft. However the weight of the precipitation and drag created during its fall causes dissipation of the updrafts. Moreover as the precipitation removes large amount of water from the cloud that cannot be easily replenished by the updraft and once the updraft becomes too weak the cloud collapses and evaporates.

Cloud seeding is done to accelerate conversion of water vapour into cloud particles in the form of cloud drops or ice crystals and any increase in this process releases latent heat within the cloud environment which inturn accelerates the updraft that brings more water vapour into the cloud that will again initiate the positive feed back cycle. Hence dynamic seeding of the clouds involves higher rates of seeding than the ordinary doses used for static seeding. While the static seeding aims at mere conversion of the supercooled cloud water into ice particles to fall on earth as precipitation, the dynamic seeding enhances the updrafts and receives increased water vapour influx that will ultimately result in substantially higher rates of precipitation.

Cloud Dynamics : Cloud dynamics is concerned with the relationships between forces and motions in the clouds used for predicting and understanding the structure and functioning of the updrafts and downdrafts in the clouds. When updrafts within a large cumulus cloud of about 10 km height are increased there will be increased suction of inflow of moist air near the base of convection while there will be an increase in the outflow of cloud air near the top as required by mass continuity. Looking from the energy angle the added buoyancy represents the added potential energy that is converted into kinetic energy in the form of horizontal inflow and outflow motion as well as of the updraft motion in the cloud. Hence the dynamic effect of cloud seeding provides this mechanism and it works like a pump which gathers together the moist lower air mass, lifts this air mass up and condenses it and then ejects air from the cloud top somewhat reduced in total water content if precipitation has already taken place.



Graphical representation of cloud water, precipitation water and water vapour

The figure depicts the simple convection cloud without orographic lifting. The dark and shaded lines on the right show the distribution of total water in an air mass and about 90% of the water content is confined to the lower half of the mass of the atmosphere. At the end of one pumping "cycle" the air mass thrown out of the top of the cloud is more moist than the upper atmospheric environment. The air near the base of the cloud remains unchanged in moisture content being replaced by moist air drawn in laterally. Simultaneously the precipitation gets increased. In the seeding of an unstable air mass, the correct analogy to use is a pump which sucks water up from a limitless ocean of moisture in the atmosphere and not a diversion of water from a stream within two confined banks.

Research studies from aeroplanes indicated that cumulus clouds are like buoyant bubbling systems known as “thermals” and when there are vigorous updrafts in these clouds they look like growing plumes or jets with “vortex-like” internal air circulations near the tops of the clouds. The energy for driving the wind motions within the clouds comes from the enormous latent heat released by the condensation of the water vapour carried by the updrafts and subsequently converted into liquid drops in the clouds.

From the CLIMAX project it was found that an excess of ice crystals were thrown out of the top of the seeded cloud which drifted to the East downwind as an artificial cirrus cloud from which a few large crystals might have formed at a great distance down wind in sufficient concentrations to seed the low level cumulus clouds that might have perhaps produced unexpected rain downwind of the seeded area.

The relationships between the vapour and liquid contents of a cumulus cloud in relation to its height are presented in the following table.

Height in Cloud	Temperature	Mass of water per kg of air	
		Vapour	Liquid
Base	10°C	8.7 g	0
1 km	5°C	6.9 g	1.8 g
2 km	- 1°C	5.2 g	3.5 g
3 km	- 7°C	3.6 g	5.1 g

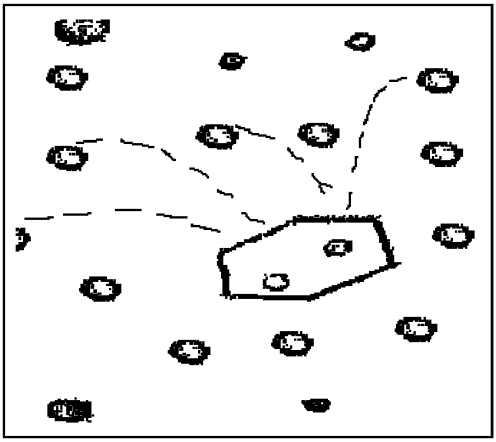
Cloud Condensate : The cloud drops grow to 5 microns and upto 20 microns radius by the condensation process and the growth in radius becomes slow in direct proportion to the increase in the radius of the cloud drop. However for condensation growth a certain degree of super saturation has to be maintained by the expansion cooling of the air parcels in the updraft which serves to sustain the super saturation levels in the wake of removal of vapour by the growing droplets . In the initial stages of the cloud there will be about 20 to 2000 drops/ cm^3 depending upon the effective cloud condensation nuclei (CCN) and the magnitude of the updraft.

Since the lifetime of a cloud may not be long enough to produce a cloud drop of 40 micron size, the production of a much larger raindrop certainly requires some other additional mechanisms to make the cloud give additional rainfall and such processes are (a) the collision and coalescence mechanisms that can produce large rain drops of about 1000 to 5000 microns and (b) the Bergeron ice crystal growth mechanism that produces ice flakes that melt while falling to earth as large raindrops.

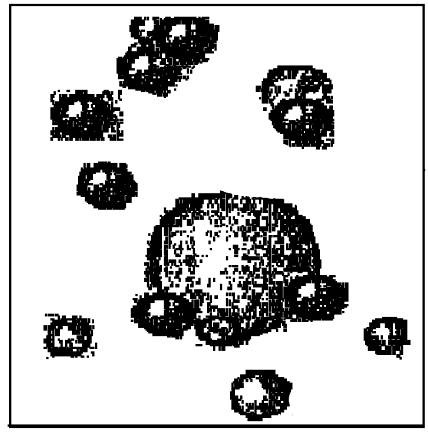
It has been stated that when moist air from the ground is lifted by heating of the earth by the Sun it rises into the sky and gets gradually cooled and condensed. Once the moisture gets condensed within the cloud the condensate may take the form of cloud droplets, rain drops, ice particles, snow or hail. This cloud condensate is controlled by the following factors.

a) The quantity of water vapour in the air parcel being lifted
b) The amount of lifting that influences the depth of the cloud
c) The temperature difference through which condensation will occur
d) The extent of the area over which the cloud forms.

This cloud condensate thus formed becomes the input for determining the precipitation efficiency. If none of the condensate provides precipitation the efficiency will be zero. While if all of the condensate ends up as precipitation, the precipitation efficiency becomes 100%



Growth of Ice crystal in cold clouds



Warm cloud – collision and coalescence

One path taken by the condensate is to get incorporated into the rainfall that reaches the ground. Another path taken by the condensate involves its transport to the cloud boundary where it gets evaporated and thus returns to the atmosphere as water vapour. A third path for the condensate involves its incorporation into precipitation particles or ice crystals that are thrown out of the cloud into the upper outflow cloud region known as the “anvil” from where the particles get evaporated and are sometimes transported and incorporated into other distant clouds. Hence cloud seeding experiments if planned on scientific lines only become successful. It is necessary to realise that some clouds due to low depth will not give rain. Some clouds due to low updrafts and under atmospheric inversion conditions may dissipate before seeding operations attain a maturity stage to make the clouds precipitate. Most cumulus clouds evaporate without producing rain and some convective clouds also just dissipate at about the time good rain emerges from the base of the cloud and scientists found that some clouds are destroyed often by the precipitation forming within them and such a precipitation break has not been fully understood.

Precipitation efficiency :

One important concept relating to shower clouds is the precipitation efficiency which is defined as a ratio of rainfall touching the ground to the total quantity of water vapour going up through the cloud base. For very small non-precipitating clouds precipitation efficiency will be zero. It will be 10% for small shower clouds and 50% for very large thunder clouds. In small unseeded thunder clouds about 80% of the cloud droplets generated ultimately get evaporated and hence its precipitation efficiency is about 20%. However giant thunderstorms in squall lines (violent wind storms) are generally 50% to about 100% efficient in giving precipitation. Over small mountain barriers the clouds have precipitation efficiency of about 20% .

Scientists found that clouds with large updrafts above 25metrs per second (5000 ft per minute) are inefficient. A cumulo-nimbus cloud with a water vapour flux of 5ktons per second in South Dakota recorded only 3 percent precipitation efficiency, perhaps due to moisture loss by evaporation from the edges of such clouds in their downdrafts or due to large outflow of condensate including ice particles through the large anvil at the cloud top.

The physics of clouds began to be studied seriously from 1930 and substantial advances have been made since the Second World War. The cloud physics or micro-physics deals with the particulate matter in the clouds such as cloud condensation nuclei (CCN) freezing ice nuclei (IN) water drops, ice particles, their origin, growth and behaviour.

The predominant cumulus clouds can be classified into 3 types for convenience of our study with their base height of 0.5km from the ground level. The small size cloud is 0.5km in diameter and 2.5km in depth and extends upto +8°C level in the sky. The medium cloud is 1km in diameter and about 5.5 km in depth and extends upto –8°C level. The large cumulus is 4km in diameter and about 12km in height and extends upto –50°C into the sky.

Some of the characteristics of small, medium and large cumulus clouds and their precipitation efficiencies as presented by Simpson and Dennis are as follows:

Rain from some cumulus Clouds and Precipitation Efficiency(Approximate Values)

	Large Cloud	Middle Cloud	Small Cloud
$A(km^2)$ (Cloud base area)	13	0.8	0.20
w(m/sec) Updraft speed	2	1	0.5
Δt (minutes) lifetime	60	30	10
50% efficiency (Kilo-ton)	820	13	0.5
10% efficiency (Kilo ton)	164	2.6	0.1

Just like human beings the clouds have a life cycle and they are born, they grow up, they get aged and ultimately die. Some of the small clouds have a life span of 5 to 10 minutes, the medium sized ones last for 30 minutes and larger ones may live for an hour or more. While a small cloud may contain water vapour passing upward through its base of above 1 kilo tonne, a large Cumulo nimbus may process about 10 kilo-tonnes per second of water vapour, amounting to about 50,000 kilo-tonnes during its life span of about 1.5 hours. Just as in human life, there is a balance to be maintained between the forces of buoyant growth of a cloud and those of its destruction.

Dosage of seeding agents and their properties :

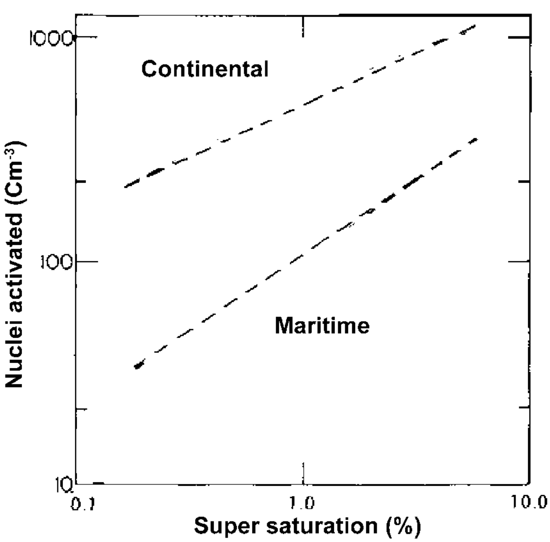
AgI melting point is 552°C and its boiling point is 1506°C. AgI generators work on the principle of vaporizing AgI and allowing it to solidify into particles of diameter less than one micron. one gram of AgI produces 10^{16} particles. One gram of dry ice produces 10^{12} ice crystals in super cooled cloud in the temperature range –2°C to –12°C.

The AgI generators work at about 1000°C so that AgI naturally sublimes from solid to vapour or evaporates from the molten state without ever actually boiling. AgI consumption varied from 5 grams per hour upto 1kg per hour. EW-20 pyrotechnic flare contains 78% $AgIO_3$, 12% Al, 4% Mg and 6% binder and it would yield 20g of AgI upon reduction and hence it is known as a 20g flare.

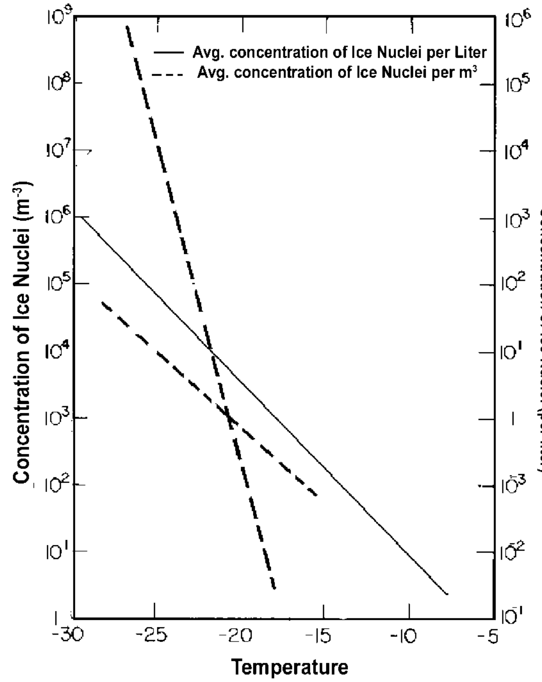
The effectiveness of silver iodide as an ice nucleant is due to its epitaxial nature. The crystalline structure of AgI is almost identical to that of ice. In the hexagonal crystal form of AgI, the silver and iodide ions occupy positions analogous to those of the oxygen atoms in the ice lattice and the spacings are highly similar. The separation between atoms of Oxygen in the C-Plane of an ice lattice is 0.452 nano-meters (nm) and the corresponding spacing of silver ions and of iodide ions in the silver iodide crystal is 0.459nm. This misfit is very little, 0.015 to be exact. Hence, the first layer of molecules of water to be laid down on an silver iodide substrate fits very closely to the silver iodide lattice structure, so the surface energy in the interface is very little. The cubic form of silver iodide is again effective as an ice nucleant. It also has spacings along certain planes which match the 0.452nm ice lattice spacing.

Passarelli et.al (1973, 1974) found that precipitated CuI-3AgI crystals, which have essentially zero misfit, could act as ice nuclei at temperatures of –0.5 to –1.0°C ".

The optimum nuclei required to convert the available super cooled cloud droplets into ice was answered by the scientists of the first experiment "Project Cirrus". In 1949 Tor Bergeron estimated that a ratio of one ice crystal (which could be formed on an artificial nucleus) to 1000 super cooled water droplets was adequate for augmenting precipitation. Since there are about 10^8 cloud droplets/m^3, 10^5 nuclei/m^3 would be required. This causes a 1000-fold growth in mass and 10-fold in radius. Hence a 10 micron cloud droplet becomes a 100 micron ice sphere and the particle terminal velocities would be sufficiently large to ensure their fall out. But one ice crystal for every super cooled cloud droplet would convert the whole cloud into small ice crystals which would stop the natural precipitation and the result would be over- seeding. But Nature under the favourable precipitation conditions, generally supplies nuclei of about $10^3/m^3$ and so theoretically any concentration of nuclei higher than this leads to augmentation of rainfall.



Concentration of CCN activated in continental and Maritime air as a function of Super saturation



It is reported that introduction of 1,00,000 ice particles/litre of cloud air dries up a normal cloud in about 1 or 2 minutes while introduction of 1 to 10 ice particles per litre promotes growth of ice particles for about 20 minutes before the cloud water is completely used up and the ice particles would have grown into snow flakes for precipitation.

But the concentration of effective natural nuclei fluctuates with the temperatures. Generally the nuclei are in a concentration of $10^3/m^3$ at –21°C. But they tend to increase 10 times with a drop of 4°C in temperature and the nuclei decrease by 10 times with every increase of 4°C in temperature and the crucial temperature lies at the coldest part of the cloud which is usually at the top of the cloud. In Australia the favourable cloud top temperature window for augmenting precipitation was found to lie between about –10°C and –23°C

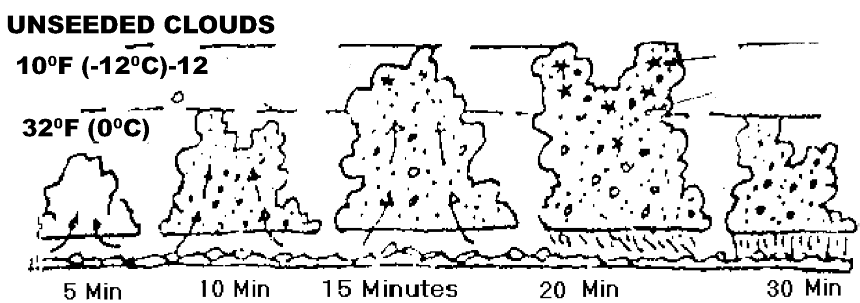
An ice crystal grows to an embryo size(about 250 microns) in less than 10 minutes by deposition of water vapour. In a cold cloud the droplets always evaporate to maintain vapour pressure at saturation level for water surfaces.

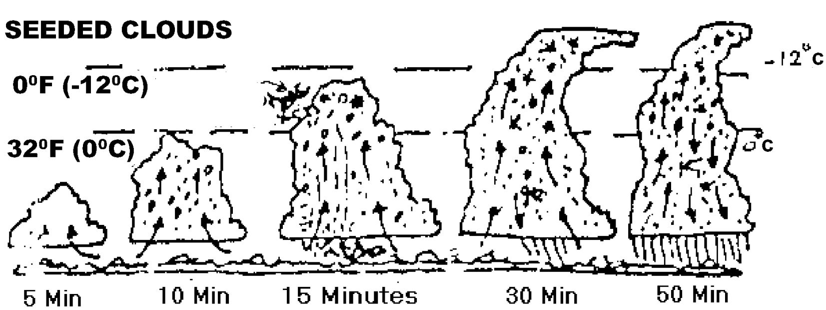
Cloud-seeding experiments :

The augmentation of rain-fall from the cold-clouds is based on the assumption that there is a deficiency of ice-crystals and this deficiency has to be rectified by introducing artificial ice-nuclei like silver-iodide into suitable clouds to produce the required ice-crystals for improving the rainfall.

In the case of ice mechanisms it is mainly the artificial ice nuclei that provide more ice crystals that grow by using the cloud droplets and cloud water within the lifetime of the cloud. Ice particles are formed by ice nucleation, that is, conversion of water vapour or super cooled liquid into ice. An ice nucleus is needed for each ice crystal formed in the cloud. Gradually greater numbers of atmospheric aerosols become effective as ice nuclei as the temperatures fall further below 0°C and when the temperature attains –40°C spontaneous nucleation occurs and all the weak electrolytic water becomes frozen.

Sometimes very strong winds do not provide sufficient time for ice crystals to grow to precipitation sizes before being blown over the mountain tops and then sublimating in the sinking sub-saturated air on the leeward side of the mountains. Often moist-laden wind-flow over a mountain barrier makes the orographic lift to produce the clouds or increase the depth of clouds.





Seeding rates :

1. One nuclei per litre of cloud air is required for an efficient precipitation under the static approach. But the dynamic cloud seeding approach involves the injection of 100 to 1000 nuclei at minus10 degrees Centigrade per litre of cloud air.

In the process the conversion of super cooled liquid water to ice-crystals releases the latent heat of fusion which in turn increases the cloud buoyancy. Such buoyancy invigorates the cloud and extends its life-time, resulting in increased convergence at the base of the cloud. Moreover, such dynamic seeding ultimately results in better collection of the low level in-flow, thereby increasing the probability of merger of several nearby clouds and enhancement of rain-fall.

2. The concentration of ice nuclei that produce ice crystals at a temperature of –12°C will be about one ice nuclei per 100 liters of cloud air. But the active ice nuclei at –20°C will be about one per litre and at minus 28°C it will be about 100 per litre. Ice crystal concentrations of naturally active ice nuclei to produce ice crystals are generally less than the concentrations needed to utilize all the cloud condensate when the cloud temperatures are warmer than –25°C. The static seeding of cold clouds augments precipitation over the natural rate by a few tenths of a millimeter per hour only.
3. Seeding clouds with ice crystals about 10 to 20 per litre of cloudy air promotes precipitation of snowfall of about 1 mm per hour. Actual observations and theoretical calculations show that effective artificial ice nuclei are over 10 per litre for detectable increases in precipitation. (Super 1994, Holroyd, 1998). But Ludlam (1955) suggested 10 to 100 seeding crystals per litre of cloud and higher concentrations may be required for moderate precipitation enhancement. (Super, Holroyd, 1997) However some experts demonstrated AgI seeded snowfall increase of about 1mm per hour with seeded ice crystals of 140 per litre.
4. The cumulus cloud contains 100 cloud droplets per cm^3, one million of them occupying 10 liters of cloud air. One artificial nuclei needed per 10 liters of cloud air or perhaps one nucleus per litre if we assume that the rain embryos reasonably grow further by coalescence as they fall to earth. Assuming 10^{12} active nuclei per gram of seeding agent like dry ice or from AgI generators at temperatures of –6°C to –19°C, the Cumulus clouds which are generally in the range of $1Km^3$ to $10Km^3$ (or 10^{12} to 10^{13} liters) need about 1 gram to 10 grams of seeding material for seeding.

When large amounts of super cooled cloud water is converted into ice particles latent heat is released into the cloud at the rate of 80 calories of heat per gram of water frozen and this causes in-cloud temperature increase of 0.5°C to 1.0°C which causes modest increases in cloud size and provides more buoyancy to make the cloud rise higher into the sky. But if the cloud is embedded in a stable atmosphere the buoyancy might have often little overall effect. But sometimes it may cause “explosive effect” depending upon the other environmental conditions.

A number of practical observational and theoretical studies indicated that there is a cold temperature window of opportunity for cloud seeding. Convective and orographic cloud seeding indicate that clouds colder than –25°C have large number of ice crystals such that seeding becomes ineffective or even may reduce precipitation (Grant 1986, Gagin 1985). The effective temperature range for silver iodide seeding is between –5°C to –25°C and inefficient ice crystal production is found at temperatures greater than –4°C due to slow vapour deposition growth. However dry ice seeding from aeroplanes extends this temperature window to just below 0°C.

Cold cloud seeding was done notably in Australia, USA,USSR, Canada and Israel where convincing and significant increases in rain fall were observed on seeded days.

Cloud seeding experiments in Australia, Texas and Southwest US demonstrated dynamic rise in the cloud tops and extended the rain areas due to seeding of cumulus clouds with dry ice and AgI. Not only updrafts were increasing due to seeding but the added buoyancy was carrying the updrafts through the inhibiting stable layers of atmospheric inversions at the old cloud top levels and the volume of the condensed water within the cloud was thus enhanced. Consequently seeding procedures began to be refined and developed to explain the cloud seeding effects.

Cloud seeding experiments in Australia showed 15% to 20% extra rain-fall in the water storage reservoirs of Tasmania. Similar experiments in Israel indicated extra rain-fall of about 15% over the catchment of Tiberias lake at a highly statistical significance. Dynamic seeding of convective clouds in South Florida indicated 20% extra rainfall over the target area and 50% more in the area defined as the floating target.

A cloud seeding experiment is very inexpensive and highly successful provided if it is undertaken after making the pre-requisite scientific studies including modeling. The rain clouds of Israel are 6 to 9 km high and contain 0.5 million cubic meters of water. By dynamic aerial seeding with silver iodide, the heights of the clouds are raised by 2km and their water content increased to more than 1 million cubic meters. Studies in Ukraine indicate that while seeding a single cloud increases precipitation by about 25% over that of an unseeded cloud, the seeding of multi-cell clouds leads to very high precipitation as compared to single cell clouds. Thus cloud seeding has been successful in several countries including USA, Israel, Russia, Canada, Australia and India.

Successful operations :

1. A number of cloud seeding experiments were conducted on an operational basis mostly in Sierra Nevada of California while other operations for randomising testing and the results provided favourable conclusions for orographic seeding to augment winter snow pack in Western Montana region (Elliot 1986)

2. Tasmania Project with unseeded control areas were operated during even years from 1964 to 1970 and the rainfall increase varied from 15% to 20% during autumn and winter seasons. (Smith 1971, 1974, Dennis 1980)

3. Colorado river basin pilot project was a randomized experiment during the unstable stage of the winter clouds with high liquid water content and comparatively low ice particle concentrations and hence provided good window of opportunity for augmenting the precipitation (Cooper Martwiz, 1980)

4. In mountainous locations the clouds have considerable Supercooled Liquid Water (SLW) and the SLW that crosses over the mountain barrier and often remains unused by nature and hence provides good opportunity for seeding (Super 1990).

5. The stormfury experiment demonstrated that a cloud top height could be substantially increased (Simpson 1965, 67)

6. AgI seeding of cumulus clouds over Texas (Rosenfeld and Woodley,1993) and Thailand (Woodley 1999) augmented precipitation

7. The Western South Dakota experiments conducted from 1966-69 used randomized cross over design, ground generators along with aircraft that sprinkled AgI at cloud top also and this first randomized project demonstrated rainfall augmentation over fixed target areas.

8. Experiments conducted in Israel for several years beginning in the mid 1960s (Gagin and Neunan 1974, 1981) showed increases in rainfall. Experiments on individual clouds resulted in augmentation of rainfall (Dennis 1980, Woodley 1999).

9. Some of the warm cloud seeding experiments in South Africa (Mather, 1987) Thailand (Silverman, 1999) indicated increases in radar estimated precipitation from 30% to 60% from the seeded clouds. Even numerical calculations on the growth of hygroscopic particles into raindrops supported these results on augmentation of precipitation (Cooper 1997).

10. Cloud seeding over Kings river in California conducted for 48 years produced 5.5% additional runoff per year (Henderson 1986-2003). A cloud seeding project run for 25 years in Utah has published results for 19 years indicating 11% to 15% increase in seasonal precipitation (Griffith 1997) Climax Project indicated 10% increase in precipitation while Tasmania experimental results showed 10% increase in seasonal precipitation with cloud tops at minus10^{o}C to minus12^{o}C .

11. Long term cloud seeding operations increased stream flow from 5% to 10% of the natural flow (National Research Council, 1966, 1973) Recent evaluations indicated precipitation enhancement of 10% to 15% (Griffith 1991)and conversion of these increased precipitations resulted in stream flow augmentation by 10% (Stauffer 2001).

12. In cloud seeding experiments in Texas the additional cloud growth resulted from the seeding of turret clusters. Silver iodide seeding of clouds more than doubled the amount of rain (Rosenfeld and Woodley 1989) Further seeded cloud systems lived about 36% longer than their unseeded counterparts, expanded to produce rain over an area 43% larger and merged with the adjacent convective cells about twice as often. Cloud heights increased by 7% more than the unseeded ones and the results were significant at 5% level.

13. Large droplets over 24 microns in diameter in a cloud at the level of –3^{o}C to -8^{o}C may lead to multiplication of existing ice particles.

14. Clouds with substantial cloud condensate become inefficient if appropriate mechanisms for particle growth within the lifetime of the cloud are not available and such clouds are good candidates to augment precipitation by cloud seeding.

15. Continental clouds often have cloud droplets over 500/cm^3 as against 20 to 100/cm^3 in maritime clouds.

WARM CLOUD SEEDING

All air contains moisture. When the warm air rises from the surface of the earth due to the heat from the Sun the air rising into sky begins to cool and some of the moisture condenses on dust particles into small droplets that cause cloud formation. Clouds generally form within about 1 or 2 kms from the ground level depending upon the ambient temperature, water vapour, climatic conditions and topographical features.

It will be interesting to know that more than 99% of the cloud content is the air. Hence clouds contain only an average of one percent of the total atmospheric moisture at any time. So even if cloud seeding doubled the efficiency of a cloud to give rain, the cloud system would perhaps remove only about 2% of the available atmospheric moisture leaving the remaining 98% for other purposes.

The amount of water vapour required for saturation of air at different temperatures is presented in the following table:

Temperature (°C)	-40	-30	-20	-10	0	5	10	15	20	25	30	35	40
g/kg	0.1	0.3	0.75	2	3.5	5	7	10	14	20	26.5	35	47

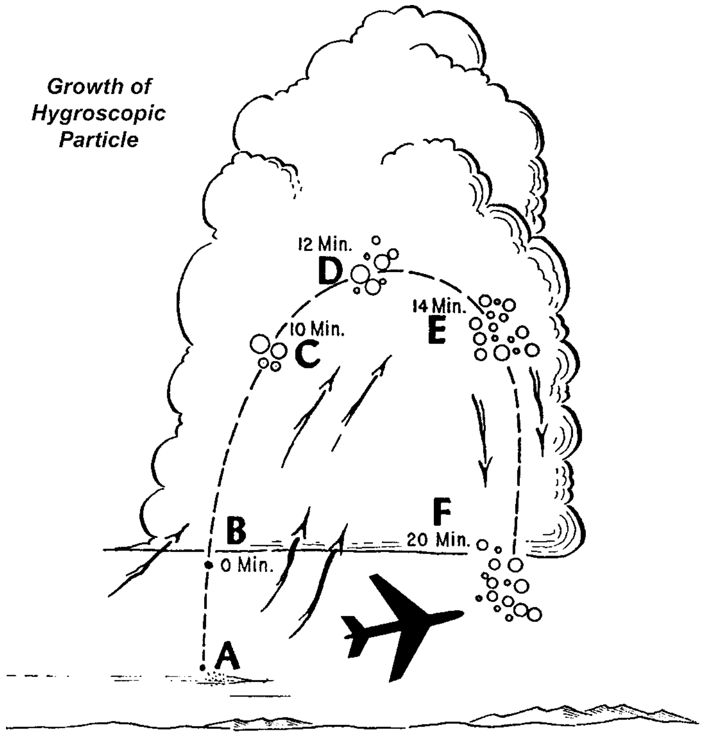
It is well known that clouds begin to form in the sky when the air becomes super saturated and thereby forces the water vapour to condense on particles known as cloud condensation nuclei, (CCN) that grow into cloud drops. Ice crystals also form in those regions of the cloud where temperatures are below freezing levels while liquid droplets also co-exist in such subfreezing environment as Supercooled Liquid Water (SLW) that is the key for cloud seeding. But there is also warm cloud seeding process. Several scientists investigated on the various factors that influenced the formation of clouds and their precipitation. It was found that some clouds give rain when favourable conditions exist.

The water droplets in the clouds are so small (10 micro-meters in radius) that they cannot reach the earth without getting evaporated before touching the ground. Hence if large rain drops (500 to 2000 micro meters in radius) that can reach the earth without evaporating are to be formed, about a million small cloud droplets must join together and for this purpose mere adhesion and condensation are not enough. There are 2 theories about rain-drop formation, each of which is valid under different climatic conditions.

Rain drop formation and theories :

The first theory of rain-drop formation is based on “Langmuir chain-reaction” that mostly occurs in the hot and humid atmosphere of the tropics. The larger droplets fall much faster than the smaller ones such that bigger drops in a cloud overtake and absorb all the smaller drops found in their downward path. In a rising cloud, the up-currents hold the big-drops in suspension while the small ones are caught up and merge with the big ones. If the large drops become too big, they burst into fragments that again collide and coalesce with small droplets and ultimately fall to earth as rain-drops.

The second theory of rain-drop formation is based on “Bergeron chain-reaction” that mostly occurs in the temperate zones. The clouds that precipitate consist at the higher levels, of ice crystals and supercooled water vapour. For the formation of big droplets in the cloud an ice-phase is a precondition and for this transition from the liquid to solid phase a freezing nucleus is essential. The freezing nuclei allow supercooling of water droplets upto -15°C before ice-formation occurs. Infact pure water suspended in air does not freeze until it touches about –40°C temperature. The ice-crystals grow rapidly by absorbing all the super cooled droplets on their way down and large lumps of ice are formed and they melt at about zero degree centigrade level in the sky to become rain-drops that fall on earth.



A - Hygroscopic particle released (.0008 inch diameter)

B - Particle grows by condensation to .003 inch diameter

C - Particle grows by coalescence to .2 inch diameter and breaks up into smaller drops

D & E - Drops formed at C grow and break up again when diameter = .2 inch

F - Drops fall out the base of cloud

In warm clouds to be seeded there is a serious shortage of large water droplets over 20 microns in diameter and this reduces the efficiency of the cloud to give rain. In order to induce such clouds to give rain, the coalescence mechanisms have to be stimulated by injecting the clouds with the hygroscopic particles like sodium or calcium chlorides from an aircraft. The Langmuir chain-reaction gets a boost and the clouds which were formerly unproductive become productive and the clouds which would have given normal rainfall would give some additional rainfall. Similarly the dearth of ice-crystals in cold clouds is removed by seeding them with silver iodide to ensure one nucleus per litre of cloud air so that such seeding generates additional ice-crystals and thereby accelerates the rain-forming processes for providing additional rainfall.

Cloud seeding for artificial rains :

Since salt crystals are abundant in oceanic regions due to wave action and evaporation they favour larger cloud droplets that collide and coalesce to initiate rain fall well within the life time of the clouds. Oceans cover about 70% of the Earth's surface and receive about 80% of the global rainfall. But the atmosphere over continental regions generally contains much smaller and more numerous condensation nuclei without much hygroscopic content like in the marine atmosphere and hence the medium sized clouds formed in such regions usually dissipate before coalescence mechanism has had a chance to initiate rain.

The augmentation of rain-fall from the warm clouds is based on the assumption that there is a deficiency of giant hygroscopic nuclei (GCN) to change cloud-drops into the rain-drops and if salt particles are injected into suitable clouds, they will grow by condensation and then by collision and coalescence mechanisms that initiate rain-fall within the life time of the clouds.

Seeding agents :

Salt particles (NaCl, NH_4NO_3, urea) of about 5 to 20 microns if injected into the clouds grow rapidly due to their hygroscopicity into 40 to 100 microns very quickly and subsequently when these larger grown particles collide and coalesce with smaller cloud droplets precipitation develops. However salt seeding lacks the multiplying effect of silver iodide seeding. Salt particles are million times larger in mass than AgI particles. Salt particles are 100 times lesser in concentration. But in 1948, Langmuir advanced a chain reaction process that could multiply the seeding effect enormously. A rain drop of 5 mm to 10 mm diameter becomes hydro-dynamically unstable and breaks into about 10 droplets. Since the terminal velocity of a large raindrop at break-up point is about 8 meters/second, it gets suspended at about a fixed level in an 8 meter/second updraft. After breakup the little drops move upward towards lower updraft velocities, growing by coalescence while moving up with the updraft until they become large enough to fall back. They stop again at the 8m/second level in the updraft and they breakup again and repeat the cycle. If the salt seeding increases the growth of a few large drops, then under these circumstances the precipitation can be enhanced and the extra rain thus generated reaches the ground when the updraft dies away in about 20 minutes.

Sometimes some cumulus clouds produce precipitation by a mixed phase inclusive of coalescence and ice processes. Hail storms are produced as hail-embryos by the coalescence process and then frozen. Premature seeding might start precipitation but it may reverse or restrict the natural growth of a cloud later in the day and hence premature seeding might advance the time of precipitation without necessarily increasing the total precipitation.

Hygroscopic seeding methods :

For hygroscopic seeding 2 methods are used for enhancing collision –coalescence mechanism.

1. The first method of salt seeding involves application of hundreds of kilograms of salt particles of 10 microns to 30 microns in diameter near the cloud base to produce drizzle sized drops immediately.
2. The second method uses salt flares to disperse about 0.5 to 1 micron size particles into cloud updrafts by releasing one kilogram sized flares from the aircraft from below the cloud base. Many flares are sometimes released per cloud. Coalescence is enhanced and the seeding material eventually spreads throughout the cloud and if the updraft extends high into the sky then the ice process also gets enhanced. Such hygroscopic seeding is used only on continental type clouds because the maritime clouds already contain many hygroscopic embryos.

Sizes of seeding nuclei :

While investigating whether a large water drop in a cloud will collide with another nearby small droplet, it was found that no collisions occur if the drop diameter is less than the Hocking limit of 38 microns in diameter (the so called Hocking limit of 19 microns is the radius of the drop). If the drop size is less than 20 microns any rain by coalescence may not occur in less than 40 to 60 minutes. Langmuir stated that large raindrops of 5 mm diameter become hydro-dynamically unstable and break into smaller drops which serve as raindrop embryos (about 250 microns) to hasten conversion of many other small cloud droplets into raindrops, particularly in clouds with updrafts above 6 to 8 meters per second strong enough to support such rain drops.

Theoretically for changing the micro-physics of a cloud to produce more rain one may add artificial seeding agents (SCCN) of sufficient size and adequate in quantity to prevent the activation of natural dust particles (CCN) so that the moisture in the cloud gets precipitated.

By introducing particles of 1 to 3 microns at the rate of 25 to 100 per cubic centimeter it may be possible to capture almost all the moisture and prevent the innumerable natural dust particles (CCN) from participating in the cloud formation process. To implement this concept, if 2 micron size sodium chloride particles are used at 50 per cubic centimeter, a cumulus cloud by ingesting at the rate of million cubic meters of air per second, requires seeding rate of 30kg of chemical per minute and this heavy operation is almost impossible to execute.

But if one is prepared to assume that **precipitation acts like an infection** one can realise that **once precipitation starts anywhere in the cloud, it spreads as raindrops and the fragments are carried about by the clouds internal circulations and by the turbulence. Hence a single shot seeding of million cubic meters of air, for example might work.** But there is another method of promoting coalescence by the introduction of artificial rain-drop embryos into a cloud by spraying big water droplets into the cloud. Instead of changing all the cloud droplets in the cloud to accelerate coalescence process one can avoid the initial stages of changes in the cloud droplets **we are introducing large particles that work as raindrop embryos straight away**. But this involves use of very large quantities of water to be sprinkled from an aeroplane and this is very costly. In order to reduce this logistical problem one can treat the cloud with hygroscopic agents like calcium chloride or sodium chloride in the form of dry particles or spray droplets which form rain drop embryos by their own hygroscopic action. This procedure is similar to providing the giant CCN that influence the formation of some of the rain showers over the oceans. However if these artificial rain drop embryos are to be effective the giant hygroscopic particles must be some tens of micrometers in diameter and the particles must produce embryos beyond the Hocking limit of 38 microns in diameter. Moreover the seeding agent must start working as rain drop embryo immediately after getting injected into the cloud. One dimensional cloud models suggest that seeding the clouds with sodium chloride particles of over 120 micron diameter produces rain 10 to 12 minutes after cloud-base seeding.

But if smaller particles are used the solution droplets not only will grow very slowly but will also often get ejected from the cloud top without ever growing large enough to start falling back down against the updraft currents. Research studies show that hygroscopic seeding is good for clouds with base temperatures above 0°C in general and 10°C in particular. **The sizes for the hygroscopic nuclei increase in direct proportion to the updraft speed**. **For a 5 km deep cumulus** cloud with a moderate **updraft of 12 meters per second** (2,400ft per minute) Sodium chloride particles injected into the cloud base must be over **40 microns in diameter for the resultant droplets** to avoid **ejection from the top of the cloud.** However the use of hygroscopic nuclei of 50-100 micron diameter poses a serious logistical problem. **If the embryo concentration needed to promote coalescence is estimated at 1000 per cubic meter of cloud,** the number of hygroscopic particles to seed the entire cloud will be **10^{15}** and if the particle diameter is **100 microns a few tonnes of seeding material will be required for the cloud.**

However if this problem has to be overcome one has to assume that the raindrops formed around the artificial embryos would break into fragments which again create more raindrop embryos. For this purpose raindrops of 2 to 3 mm need to be produced and retarded from coming down through the cloud to experience collisions and break up and this requires **updrafts exceeding 5 meters per second** (1000 ft per minute) Each cycle of growth and break up and again growth in the cloud takes about 4 minutes. It is not very clear whether these recycling processes would infect the whole cloud before the natural precipitation processes would obtain the same result. Ultimately one has to decide upon **a reasonable compromise which requires the use of 25 kg to 50 kg of sodium chloride** or other hygroscopic powder like calcium chloride **for a cloud of moderate size. This dosage has been found to be reasonable on the basis of results from various experiments** conducted in different places. It is necessary to remember that once precipitation appeared anywhere in the cloud the raindrops and raindrop fragments would be circulated throughout the cloud by its organized internal motions and by turbulence. **Hence the dosages of chemicals to be used for cloud seeding must be decided on the basis of cloud systems, updrafts, topographical, meteorological parameters etc.**

Successful experiments :

1. The experiments conducted at Baramati in India for 11years indicated the success of warm cloud seeding operations by producing 24% additional annual rainfall, significant at a 4% level at a very inexpensive cost with a benefit to cost ratio of 60:1. The Indian Institute of Tropical Meteorology (IITM), Pune launched a warm cloud seeding experiment using aircraft in the semi-arid region towards East of Pune on the lee-ward side of the Western ghats from 1973 to 1986. A randomized double-area crossover design with a buffer zone was used for the aerial seeding work. The experimental area covering 4800 sq. km. was divided into 3 parts designated as North, Buffer and South sectors in Ahmadnagar, Baramati area . The results of experiments on aerial seeding of warm clouds with common salt mixed with a little soap stone powder for the eleven years are presented in the following table.

Estimates of seeding *(aerial seeding days)*

Year	Cumulative results		
	No. of days of the experiment	Root Double Ratio	Percentage change in rainfall
1973	16	1.119	+11.9
1974	28	1.157	+15.7
1976	52	1.169	+16.9
1979	62	1.219	+21.9
1980	78	1.235	+23.5
1981	98	1.227	+22.7
1982	112	1.235	+23.5
1983	122	1.233	+23.3
1984	132	1.279	+27.9
1985	142	1.235	+23.5
1986	160	1.239	+23.9*

*significant at 4% level (Mann-Whitney test)

The results clearly demonstrate that warm cloud seeding has enhanced the rainfall by about 24% on the basis of experiments conducted for 160 days during the eleven summer monsoon seasons.

The physical changes that occurred in the clouds due to seeding with common salt were also recorded with scientific instruments fitted to the air-craft for more than 100 pairs of seeded (target) and not-seeded (control) clouds to provide scientific evidence as positive proof for the efficiency of cloud seeding technique. The physical changes in the seeded clouds are presented here.

Cloud Physical Responses To Salt Seeding

Microphysical Responses

Parameter	Response	
Cloud Droplet Spectra	Broadening	(300%)
Mean Volume Diameter	Increase	(40%)
Liquid Water Content (Computed)	Increase	(60%)
Liquid Water Content (Meausred)	Increase	(200%)
Concnetration Of Large Size Cloud Drops (Diameter 50 Um)	Increase	(125%)
Concentrtion of Giant Size Condensation Nuclei (Salt Particles)	Increase	(145%)
Dynam Ical Responses		
Vertical Air Velocity	Increase	(200-300%)
Temperature Within Cloud	Increase	(1-2° C)

Electrical Responses

Electric Field	Intestification (200%) Followed By Sign Reversal from the Initial Negative to Positive Following Onset of Rain
Electric Charge Carried by Cloud/Rain Drops	Sign Reversal from the Initial Negative to Positive Following Onset of Rain
Corona Discharge Current	Increase (400%)

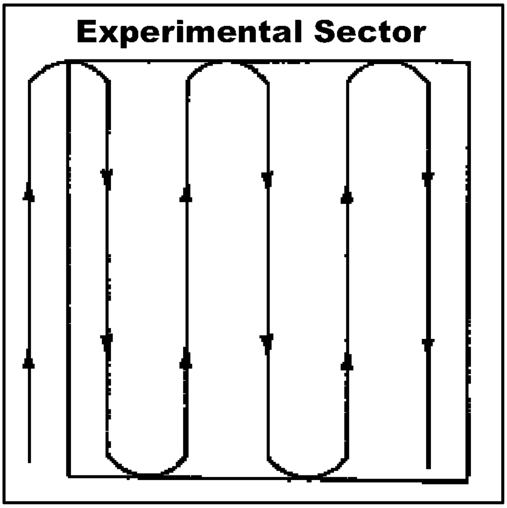
Cride and Sodium Ion Concentrations in Cloud and Rain Water Samples Cloud Cover

Chloride	. .	Increase 140%
Sodium	. .	Increase 110%

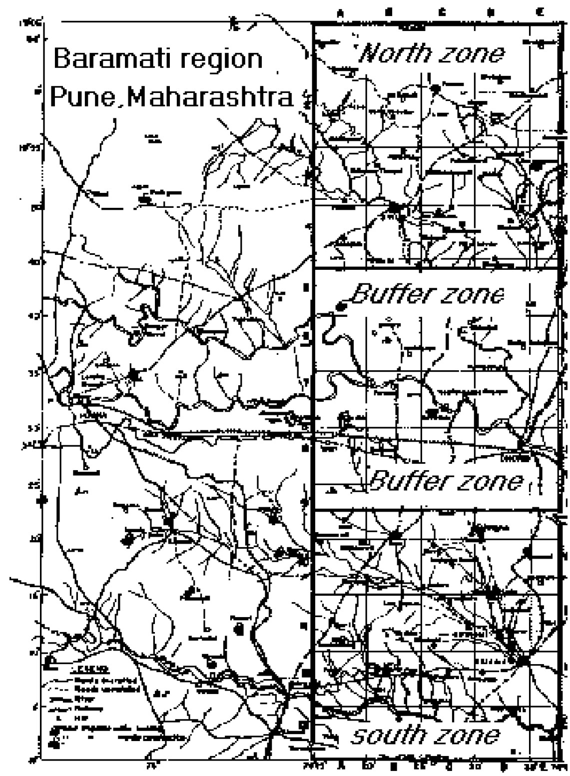
Rain water

Chloride	. .	Increase 156%
Sodium	. .	Increase 165%

The above changes in the micro-physical, dynamical, Electrical characteristics of clouds before seeding and after-seeding along with changes in the concentrations of chlorides and sodium ions in the cloud water and the rain water amply prove that warm-seeding of clouds was mainly responsible for increasing the rainfall by about 24%.



Aircraft flight path for cloud seeding (40kmx40km



Experimental plots each of 40km x 40km

The experiments demonstrated that shallow clouds with vertical thickness of less than 1 km and liquid water content of less than 0.5 grams per cubic meter showed a tendency for dissipation when common salt was sprinkled over the warm clouds from an aeroplane. The clouds developed rain in 20 minutes following seeding. The giant condensation nuclei (SCCN) of common salt powder used for the experiment had a diameter greater than 10 microns. SCCN concentration in the target cloud was higher by about 2 particles per litre. The salt particles in the seeded clouds had a concentration of 1 per litre of cloud air. The median salt particle mass used for seeding is approximately 10^{-9} g corresponding to dry particle diameter of 10 micro meters. The seeding material was released into the clouds during the aircraft penetrations at a height of 200-300 meters above the cloud base. The rate of seeding varied between 0 and 30kg per 3 km aircraft flight path on the basis of density of clouds and their vertical thickness in the target area. On the days of the experiment about **1000 kg of the seeding material was released into the clouds at a slow rate of 10 kg per 3 km** for flight path so as to treat as many clouds as possible. **Concentration of salt particles released into the clouds** were estimated to be **1 to 10 per litre of the cloud air.**

2. Some of the warm cloud seeding experiments in South Africa (Mather, 1987) and Thailand (Silverman, 1999) indicated increases in radar estimated precipitation from 30% to 60% from the seeded clouds. Even numerical calculations on the growth of hygroscopic particles into raindrops supported these results on augmentation of precipitation (Cooper 1997).

3. South Dakota experiments from 41 salt seeded and 38 unseeded cases indicate that first radar echoes appeared closer to cloud base in salt seeded than in unseeded clouds, the average height of the echoes being 1.5km for salt seeded and 3km for unseeded clouds above their bases. Rainfall can be increased from a cloud of about 5km depth by salt seeding but the effect decreases with increasing cloud size.

Points to remember :

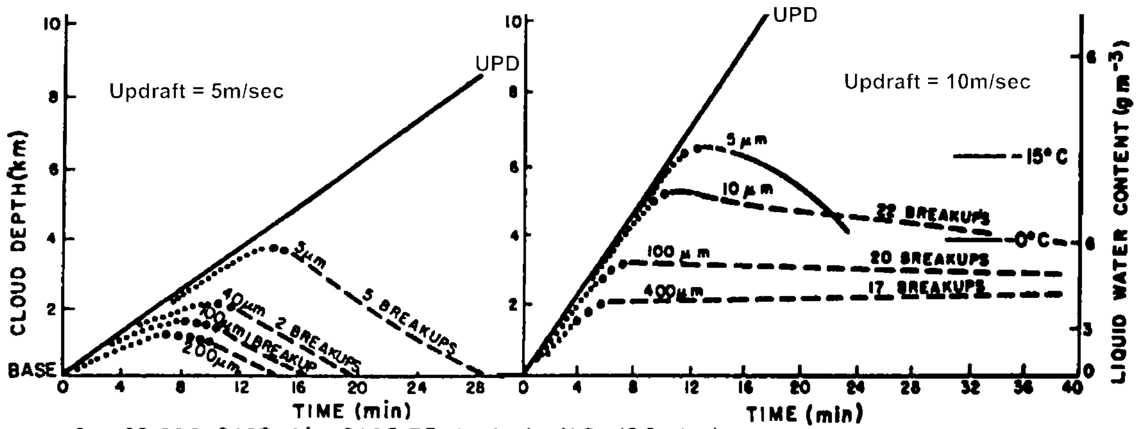
1. Hygroscopic substances are those which attract water or encourage condensation of water vapour into liquid water upon themselves at relative humidities less than 100%. Introduction of artificial embryos into warm clouds include the use of water sprays, hygroscopic powders and hygroscopic solutions.
2. The cloud drops of 5 microns to 20 microns diameter must grow to precipitation size of over 500 microns by coalescence in cumulus clouds, based upon updraft velocities and sizes, water content, lifetime of the cloud and the initial cloud drop size distributions which again are controlled by the size spectrum of condensation nuclei (CCN).
3. Over the oceans the giant sea salt nuclei of 1 micron to 10 microns in radius become the major factors in initiating coalescence, making marine cumulus clouds give rain more readily than their counterpart continental cumulus clouds over the land.
4. According to Langmuir Chain reaction the cloud drops grow by coalescence into raindrops of 6 mm size with velocity of 10 meters per second which break into fragments that again are carried up by the updrafts and again grow to rain drop sizes and fall on earth as rain.
5. Hygroscopic materials of 1kg may result in the collection of 5 to 10 kg of cloud water into artificial rain drop embryos which coalesce with other droplets and give substantial rainfall.
6. When warm cloud is seeded with NaCl at its base to form artificial raindrop embryos in concentrations of $10^3/m^3$ the temperature increases by about 0.05°C.
7. Introduction of artificial embryos of 20 microns to 100 microns in diameter into the lower part of a continental cumulus cloud may result in formation of rain 10 to 15 minutes before natural rain could form.
8. It is said that **seeding agents of about 100 kg per warm cloud are required unless the chain reaction can be initiated.** It means that clouds with updrafts strong enough to support the Langmuir Chain reaction may be taken up for experiments by specifying the conditions favouring chain reaction growth.
9. But modelling studies and field experiments show that dynamic effects of hygroscopic seeding cannot be undertaken intelligently in any programme of cloud seeding operations.

Determining sizes of hygroscopic particles :

Systematic modeling was done to map the growth and trajectory of hygroscopic particles by using particles from 5 microns to 40 microns in diameter, updrafts from 1 to 25 meters per second with cloud base heights of 1 to 3 km and base temperatures upto 20°C. The study was conducted by the experts of the United States Bureau of Reclamation, G.E.Klazura and C.J.Todd (1978). The case study of salt seeding by Biswas and Dennis of July 1970 was also analysed by using this model. This study used a 1-dimensional condensation-coalescence model that follows the growth of a single precipitation particle in a given cloud environment. The process simulated involve release of hygroscopic particles in the updraft region below the cloud and the particles grow by condensation only until they penetrate the cloud base. Later both condensation and coalescence occur until the particle grows to 100 micron diameter at which point growth starts by only coalescence. A drop-frezing temperature of -15°C was selected. When a drop grows to 5mm diameter it breaks into a 2.5mm drop and small fragments. Growth continues only on the 2.5mm drop and not on the fragments. Input to the model are cloud base height, relative humidity, liquid water content and updraft profiles, soundings (height, pressure, mixing ratio and temperature) and initial sizes and physical characteristics of particles like molecular weight, density and van't Hoff factor. The model output presents both trajectories and growth patterns for different size particles. In the graphs, the trajectories of particles with height and time and the liquid water content profile and curves of dotted or solid lines used for different size particles. The curve labeled UPD indicates trajectory of a parcel that would ascend exactly at the speed of the updraft.

Multiple computer runs were made for cloud conditions, characteristic of temperature and warm regions. Relative humidity was 100% at cloud base with a super saturation of 0.1percent at 100 meters above cloud base upto the top. 5 to 400 micron particles were introduced at 0.5km for cloud bases of 1,2 and 3km and in-cloud saturation adiabats (q_m) of 16 and 23.2°C

A 5 micron particle with updraft of 2 meters per second rises to about 2km height above the base grows to 2 to 4 mm diameter and falls from the base of the cloud in 24 minutes while a 40 micron particle goes upto about 0.5 to 1km in height and touches the base in 18 minutes.



θ_m = 23.2°C BASE = 1 km BASE TEMP = 19.4°C M.R. = 16.2 g kg^{-1}

For an updraft of 5 meters per second the 5 micron particle goes upto about 4kms in the cloud and breaks 5 times and the rain drops reach the base in about 20 minutes. In the case of an updraft of 10 meters per second the 5 micron particle gets into the freezing zone and Langmuir chain reactions occur when the drop attains 5mm size and breaks up into fragments which are pushed up the updrafts and grow again to rain drop sizes and fall on earth.. But for updraft of 10meters per second, the 5 micron particle would rise high to freeze before reaching 5mm size and therefore no breakup occurs in it. However the large drops of 10 to 400 microns get into the accumulation zone and migrate towards the periphery of the updraft core and as the updraft becomes less vigorous the drops fall down.

In the case of stronger updrafts the smaller sized particles are all ejected out of the top of the cloud while the large 100 microns and 200 microns grow large enough to fall back through the updrafts as hail stones. Hence parameters like cloud base height and temperature and cloud thickness and diameter, updraft and cloud water contents and cloud droplet-spectra influence the efficiency with which hygroscopic particles act as cloud seeding material to stimulate additional precipitation from a cloud

The numerical simulations demonstrated that for slow updrafts the larger hygroscopic seeding agents travel through the lower trajectories and sweep out lesser water than the small hygroscopic particles grow into raindrops and break up to initiate Langmuir chain reaction while the smaller hygroscopic particles are carried upwards to the cirrus level and get lost before they attain the precipitation sizes. In case of very strong updrafts only the large hygroscopic particles get a chance to reach precipitation size and in this situation hail stones are produced.

The warm cloud seeding experiments are based on static mode seeding concept or seeding for microphysical effects whereby the seeding agents mainly work to improve efficiency of rain formation by accelerating the trinity phenomena of condensation-coalescence-collision process in the cloud. The Indian and Thailand experiments injected into the cloud giant hygroscopic giant CCN of over 10 microns in diameter mainly to jump-start the collision-coalescence process by what is known as "Brute Force" seeding approach which needs very large aircraft that can carry tonnes and tonnes of seeding chemicals. In this process the salt particles are so big that they produce comparatively few rain drops for the large seeding mass employed. Even then the seeding process apparently has produced the desired results in India and Thailand. But the hygroscopic flares based on 0.5 micron diameter CCN aerosols affect the condensation process substantially by broadening the initial cloud drop sizes that promote the competition affect whereby the larger nuclei are activated preferentially over the smaller nuclei. **The flare particles of less than one micron diameter are found by the scientists to have a negative effect on the rain development. Flare technology has 2 major drawbacks** Firstly, the hygroscopic particles produced by the flares being less than one micron in diameter are smaller than the optimal size according to the model studies. Secondly, the quantity of actual material used for seeding is smaller than is required as per the hypothesis of hygroscopic seeding for microphysical effects. But if more flares are needed then it is going to increase the cost of the operations. In order to overcome the short-comings of the hygroscopic flare seeding technology, the experts have to fine tune the flares to produce fewer number of small particles and more number of optimum size particles which should be large than one micron in diameter. Another approach for an alternative flare technology is to produce more hygroscopic CCN particles in the optimum range by using hygroscopic powder sprays into the clouds. Model simulations by scientists indicated the need for hygroscopic particles of 3 to 5 microns diameter and for one of the experiments such salt particles were dispersed into warm clouds from an agricultural sprayer or a duster aircraft. In one of the experiments in Texas **about 20kg of salt** powder was used by the duster aircraft **for about 7 minutes** to seed the cloud at the seeding rate of **3kg per minute and this is a higher seeding rate** than the 0.5kg per minute seeding rate typically **used with flare seeding methodologies.** The experiments indicate microphysical changes in the clouds which are primarily due to the effect of the giant salt nuclei and secondarily through a week competition effect. Some scientists consider that the proper sizes for hygroscopic aerosols are between 2 to 5 microns in diameter. However more research work has to be done to determine the optimum sizes of hygroscopic particles for warm seeding based upon geographical, meteorological and topographical features of a given region.

CLOUD SEEDING IN FOREIGN COUNTRIES

Cloud seeding experiments were conducted during different seasons in about 40 to 50 countries in the world during the last 50 years. Mostly these experiments are frequently conducted in about 25 states of USA and in other countries like Australia, Africa, Israel, Canada, Japan, Soviet Russian states, Latin American states, West Asian, European and Asian countries including China, Thailand, Indonesia, Philippines and Pakistan. A brief review of the experiments conducted in a few select countries along with the results and their costs and benefits are presented here.

China : Several provinces in China including its Northern region have been facing drought conditions frequently. Precipitation in North of China has great variation both in space and time due to the vagaries of its monsoon climate which causes annual rainfall decrease from 1000 mm in the South East to 100 mm in the North West regions. Many provinces have renewable fresh water availability far below 1000 cu.m per capita per year, commonly regarded as a bench mark for water scarcity. While half to two-thirds of the annual rainfall occurs during summer only 15% occurs in the spring. Since 1950 a large part of North China experienced gradual reduction in annual rainfall Population growth, economic development and environmental decay has lead to this water shortage, frequent droughts, ground water depletion and diminution in the annual flows in Huang Ho river. In order to fight the growing water scarcity the Government began to take up cloud seeding experiments since 1958 with the cooperation of the people. Gradually these precipitation enhancement activities have drawn the attention and support from the local provincial and Central Governments and were highly appreciated by the people who have been benefited by the experiments.

During 1997, 18 provinces mostly in North China conducted the cloud seeding operations by using 360 flights of aeroplanes. About 1170 counties (about 40% of the total) have taken up artillery shooting and rocket launching operations for not only augmenting the rainfall but also for suppressing the damage causing hail storms. These experiments are mainly organised and financially supported by the local Governments at different levels in various parts of China. One of the admirable features of the programme activities is that they are managed, conducted and guided on scientific and technical aspects by the local meteorological departmental officers.

National Coordination Committee on Weather Modification : The Chinese Government constituted in 1994 at the National level, this committee which is responsible for organizing, coordinating and guiding all the weather modification activities taken up all over the country. 13 Ministries that reap the benefits of augmentation of snowfall and rainfall actively participate in the meetings of the committee which is attached to the Chinese Meteorological Administration (CMA).

Since North China faces recurring droughts almost every year many provinces of this region conduct cloud seeding operations regularly in the spring seasons. But in South China the droughts occur in a seasonal local manner and hence the cloud seeding operations are carried out at appropriate times. In order to increase the water availability in the reservoirs and rivers like Huanghe Hai river the cloud seeding is done regularly in the Wet seasons when more favourable clouds are available than during the drought conditions. Cloud seeding is also used to prevent forest fires and to protect the crops from severe cold through the increase of snow cover in winter.

Micro Physical Aspects :

Augmentation of precipitation in North China is mainly from Stratiform clouds. Scientific observations of the cloud structure by using the scientific gadgets combined with the radar, satellite, microwave radiometer and dense rawinsonde etc., demonstrated that the cloud droplets are of the continental type, concentration of ice nuclei is large and ranges from 10 to 70 per litre of cloud and the super cooled water content is small, varying from 0.02-0.25g / m^3 and this water content decreases significantly with the decrease of temperature and disappears below minus 20°C. The convective clouds are found to develop during summer season. The scientific observations of these convective clouds indicate that the cloud was continental due to the large concentration of cloud droplets. The cloud base temperature was high and its water content was great. There were many large droplets. Although the vigourous cumulus cloud with top height of 6 to 8kms might produce some rain, its contribution was smaller than that from the cumulo-nimbus cloud. Observed crystalisation of cloud top corresponded to the temperature of minus 16°C to minus 27°C. Due to the high contribution of cumulo-nimbus cloud to the total rainfall and the high efficiency of ice forming technology, the silver iodide sprinkling into the developing cumulo-nimbus cloud mainly by artillery shooting was adopted for augmenting the rainfall through its micro-physical and dynamical effects.

Numerical studies : These studies were made by using 2 and 3 dimensional numerical models of convective clouds and stratiform clouds since 1970s for predicting the water contents and concentrations of different cloud droplets in the clouds. In a number of cases the calculated results were in agreement with the observations in many aspects. Numerical model based experiment on rainfall augmentation in stratiform clouds by adding artificial ice locally in concentrations of one lakh nuclei per cubic meter demonstrated high increase of rainfall for about 2 hours. Moreover small decrease in rainfall was shown before and after this experimental period while the total rainfall increased by about 20%. Moreover the analysis indicated that the increased rainfall came not only from the super cooled water but also from the vapour through the intensified sublimation. The 3 dimensional model demonstrated high dynamical effects of seeding, as local temperature increased for several tenths degree and the updraft increased for more than 10 cm / sec which was favourable for cloud growth. The numerical experiments on convective clouds indicated that the salt seeding gave raise to a lower and an earlier initial radar echo and the increase of rainfall. It was further noticed that the radar echo in warm base convective clouds initiated in the warm region. Further the introduction of artificial ice with concentration 10^5 / $m^3$when echo rose to the cold region might lead to prolonged, widened and increased rainfall and hence ice seeding in the developing stages of cold base convective clouds with top heights varying from 6 to 9 kms gave rise to substantial increase of rainfall.

Seeding technology for cloud seeding operations :

1. Seeding chemicals and equipment : The stratiform clouds were seeded by using the aeroplane to sprinkle dry ice, liquid nitrogen and silver iodide into the clouds. The AgI acetone burner produced more nuclei at faster rate, 10^{13} to 10^{14} IN / gm of AgI at minus 10°C. Artillery shells with AgI were used extensively with increased nucleation rate at 10^{10} / gm to 10^{12} / gm AgI. In the case of AgI pyrotechnics developed for air-borne flares and rockets, the nucleation rate was 10^{14} to 10^{15} IN / gm of AgI according to the tests conducted in a 2m^3 isothermal cloud chamber. For warm cloud seeding the hygroscopic particles like common salt, calcium chloride and urea were sprinkled from the aeroplanes. However this seeding dosage for warm clouds has to be much greater than for ice forming agents. By using various carriers for sprinkling the chemicals into the clouds the maximum heights of delivery followed in China are as follows

a) aeroplane-7km b) artillery of 37mmCaliber –6km c) Rockets of various types–4km to 8km

2. Operation command system : The computer communication system for cloud seeding operation commands was set up in many provinces in 1990s for the purpose of real time data collection and processing and the rainfall augmentation decision making and command. The functions of the system are

a) Collection and display of the meteorological data of various kinds, forecasting and monitoring the weather and cloud conditions for rainfall enhancement.

b) Establishment of the software system for judging the suitability of cloud seeding operation and deciding the place, time and dosage of seeding.

c) Collection of data on rainfall and other observed properties of cloud, seeding parameters, airplane track etc. for evaluating the rainfall enhancement operations effects.

d) Co-ordinating with the air traffic control organisation, communication with all operation points, aeroplanes and observation points for accomplishment of rainfall augmentation by cloud seeding operations.

3. Effects evaluation : The evaluation of the cloud seeding operation programme effects is difficult especially for the operations aimed at reducing drought disasters the users of which cannot accept the randomized design.

a) The aeroplane based cloud seeding operations in North China generally covered large area. The target regions were hardly fixed and therefore the floating target control areas or multi-target control areas had to be used. For instance in Jilin province a 40% increase of the daily rainfall in 62 operations conducted during 1980-87 was shown by using the multi-target control historical regression method, the significant level of which reached 0.01.

b) The ground rainfall enhancement operations had fixed target area, historical regression method being used for evaluation of the rainfall enhancement effect. For instance the cloud seeding operations in Feunghuang province during 75-77 demonstrated an increase of 55% of the daily rainfall as per statistics.

c) A randomized rainfall enhancement experiment was done by using artillery and rockets in Gutian county, Fujian province in rainy season April to June during 1975-86. The target and control areas were 1500km^2 each and the experimental unit was 3 hours. Out of the 244 experiment units 50% units were seeded. According to statistics there was an increase in the average rainfall by 23.8% with significance level of 0.05 . A single station test indicated that the centre of the rainfall enhancement area was at 40km down wind from the seeding point.

d) In the orographic cloud seeding experiment conducted in Baiyang river basin (Xinjiang region) the annual stream flow was used for evaluating the rainfall augmentation effect and the Halayimide river was selected as the control. According to statistics there was an increase by 11.6% of the stream flow during the seeded period 1984-95 in comparison with the unseeded period of 1962-83 at a significance level of 0.025.

e) The physical evidence for cloud seeding impacts were obtained by monitoring the evaluation of cloud micro-structures, radar echo etc. Some of the air borne observations demonstrated a large increase of ice concentration, gradual broadening of the ice particle distribution and significant decrease of Liquid Water Content (LWC) after seeding. In many cases intensification of radar echo in seeded region of the clouds was observed. Further the measurement of the concentration of AgI ion in the precipitation in some experiments provided the required data for evaluating the seeding effects.

Objectives :

1) Future Development in Cloud Seeding : China believes that international cooperation is very important for scientific and technical progress in the field of weather modification. China realized that the cooperative effects between USA and Thailand and Russia and Syria in this field of cloud seeding has yielded good results. Introduction of advanced technology and equipment for monitoring like the multi-functional radars of various wave lengths, air-borne and ground based microwave radiometers, technology of cloud parameter detection by using satellites, physical and chemical methods of tracking the seeding aerosols etc will be very useful for China. Inter comparison and improvement of seeding agents, numerical modelling, consultations on the experiment design and exchange of information on both research and operation will be helpful for making progress in the field of cloud seeding.

China has set the following objectives for long-term development of cloud seeding operations.

a) to strengthen the scientific research and experiments in order to make advance in the following key directions.

   i) to develop and prove the cloud seeding concepts

   ii) to clarify the cloud conditions suitable for cloud seeding and to develop the technology of its real time detection.

   iii) to optimise the cloud seeding method and to develop the technology of its realisation.

   iv) to study the reliable method and technology for evaluating the cloud seeding effect.

b) to improve the operation technology and facilities in order to raise the real efficiency of cloud seeding operation based on the results of scientific research with consideration of the local characteristics.

In order to resolve the key problems in science and technology of cloud seeding a proposal of the national cloud seeding research project for obtaining additional water supply is put forward. By taking advantage of different institutions and through national and international cooperation a long-term well designed cloud seeding experiment is suggested.

2) Achievements in Cloud Seeding : Recently the popular Chinese News paper Peoples Daily in its Publication dt.14-7-2000 announced that the state Government of Shanxi Province has prepared a plan for cloud seeding operations to augment the annual rainfall to relieve its acute water shortage. In fact a group of scientists from the Chinese Academy of Sciences concluded after doing extensive research in Shanxi that exploiting water resources in the air can be a sustainable method to fight the recurring droughts and to solve the water scarcity in North China. Since 1980s Shanxi has been seeding the clouds to increase precipitation by 600 million cu.m. to 800 million cu.m. per year. Based on the latest advice of the scientists the provincial Government prepared a 6 year plan to develop weather modification technologies by cloud seeding to increase its annual rainfall by 2 billion cu.m (75 TMC) to 3 billion cu.m.(105 TMC) per year. It may be pointed out that Shanxi has a population of 30million with a land of 1.5lakh sq.kms (which is perhaps equivalent to Telangana region of A.P. State).

According to the latest reports from China cloud seeding is regularly used to fight the drought conditions in North China. Inspite of the doubts on the feasibility of cloud seeding primarily because of the difficulties faced in implementing the specified standard procedures and in assessing its results, the dominant public opinion is that cloud seeding operations have reached the relatively advanced application stage that they can be considered as one of the technologies capable of providing additional annual rainfall to provide the much needed fresh water supplies for drinking, irrigation and hydro-power generation in arid regions. According to Zhang Qiang a noted Beijing official in the first half of 2004, the meteorologists injected silver iodide particles into the clouds to augment rainfall or snowfall over Beijing. Aeroplanes, rockets, artillery shells, meteorological balloons and "**mountain top based generators**" were employed.

Operational machinery : According to China Meteorological Administration (CMA) from January to end of June (Beijing Time report dt.24-7-2004) China used 227 aircraft putting in 530 hours of flight time in cloud seeding operations in 15 provinces and regions covering an area of about 1.66 million square km and sprinkled chemicals into the clouds by using 12,464 rockets and 66,000 large caliber artillery shells in different provinces and cities, producing 10 billion cubic meters (350 TMC) of water.

According to another report by Qin Dahe of CMA cloud seeding operations were conducted from 1995 to 2003. In 23 out of the country's 34 provinces they have set up weather modification bureau assigned with the regular bombardment of the clouds with chemicals to squeeze out more sky water for the water starving farmers and thirsty city dwellers among China's 130 crore people. Hu Zhijin of the Weather Modification Research center at the Chinese Academy of Meteorological science said official statistics show that 30 modified aircraft, 6900 anti-aircraft guns and 3800 rocket launchers (some mounted on truck) were used repeatedly for cloud seeding in the drought prone areas of China in 2003 and these efforts are still continued under Government sponsored programmes. Ban Xianxiu, Director of Liaoning provinces Weather Modification Bureau states that anti-aircraft guns perform better with small fat clouds, rockets sprinkle chemicals over a wider area and aeroplanes spread cloud seeding chemicals over a much more wider area with clouds in flat layers. Ban Xianxiu stated that they seed the cloud about twice a month when weather cooperates by sending moisture laden-damp clouds over drought prone areas and they cannot create clouds but can only modify the weather to tap the sky water.

Controversy : Regarding a controversy that Ping Ding Shan Weather Modification Officials repeatedly seeded the clouds and squeezed more than 4 inches of rain on 10th July 2004 because the city was in the path of the prevailing winds while the city of Zhoukou downwind received over an inch of rainfall. Ping Ding Shan officials were accused of robbing the clouds that could have given more rainfall to other cities downwind such as Zhoukou. But Wang the Weather Modification Office Director of Ping Ding Shan retorted that they have reported their cloud seeding operation schedule in advance to the provincial Government like other cities and that the water vapour stream flow in the sky is not like liquid water flow within the banks of river on land that could be intercepted at different locations of the stream. It is not like a cake from which if one takes a bite the others get only a smaller piece. Besides clouds change while floating in the sky and so it is quite complicated according to Wang.

Government directive : The Chinese experts spread AgI or liquid Nitrogen in moist clouds to produce additional precipitation. According to Hu although the cloud seeding science is widely known and was practiced in United States and other countries since 1950s, China has put the know-how to practical use more often than other countries in the recent decades because of its severe weather problems. In March 2002 the Chinese Central Government issued a directive regulating the weather Modification operations and it mandated cooperation and information sharing by the various provinces, counties and cities and barred the cloud seeding operations by unofficial groups. The Directors of the Weather Modification Bureau in all the provinces submit annual cloud seeding plans to the Government as per the orders issued for the purpose.

Zhung, Director of weather Modification Bureau in Jilin Province emphasized that cloud seeding will be more effective if several provinces work together when there are huge cloud systems in the sky under favourable weather conditions. According to Baikawa Director of Weather Modification Office of Ziang Su province Nanjing and five other cities organized joint cloud seeding operations in the last week of July to cool down the cities and thereby save electricity used for air conditioners and launch rockets to seed the clouds and the results were satisfactory.

Wonderful works : The cloud seeding operations covered 30 lakh sq.km and precipitation (during 1995-2003) was 2100 billion cu.m (73,500 TMC). During 2003 alone 3,800 rocket launchers, 7000 anti-aircraft guns and many aeroplanes were used in about 1800 counties and employed 35,000 people for the operations. About 413 million Yuan (US $49million) were spent for the operations.

Inexpensive cost : According to Zhang Qiang the cost of 1 cu.m of man made rain water works out to 2 US cents (equivalent to about one Indian rupee). According to Hu Zhijin a cloud expert with Chinese Academy of Sciences Cloud seeding is cheaper than other methods used by Government to solve the water shortage problem such as the South-North water diversion project intended to transport water from Yangtze river basin to Beijing and Northern parts of China. He said that for one dry season only 2 to 3 million Yuan (US $ 24,180 to $ 36,270) was needed to carry out the cloud seeding programmes.

Australia :

Australia consists of extensive desert areas and dry as well as drought prone areas and rainfall is not only low but also unreliable to a large extent. Consequently the aborigines were conducting different kinds of ceremonies to please the rain Gods for getting extra annual rainfall. Subsequently the Australians learnt about the success of the artificial rain making experiments conducted by Vincent Schaefer in the neighbourhood of New York in 1946 by sprinkling ice crystals from an aeroplane into the cold clouds which produced snowfall by artificial means. This successful experiment has raised hopes among the scientists of Australia to conduct similar experiments for producing additional rainfall from the clouds over the local regions. Consequently the Australian scientists selected deep cumulus clouds in the sky over New South Wales and sprinkled dry ice crystals into the clouds on 5-2-1947 and succeeded in squeezing rainfall within a few minutes. Dry ice is frozen carbon-di-oxide with temperature at about minus 80^{o}C. They found that not only the size of the cloud has increased but there was intense rain that continued for more than an hour and provided half an inch rainfall over 50 sq.miles area. Similar clouds in the surrounding area did not give any rain. When the experiments proved that it is possible to produce additional rainfall by artificial cloud seeding methods the state Council of Scientific and Industrial Research (CSIRO) began to conduct scientific studies on artificial rain making experiments.

Several experiments were conducted on cloud seeding from 1947 to 1950 in Sydney region of Australia. The scientists used to sprinkle 100 pounds of dry ice crystals from the aeroplane into the suitable clouds and the consequential rainfall was measured. These early experiments on cloud seeding operations have promoted self-confidence among the scientists. They used to select some clusters of cumulus clouds and sprinkle ice crystals in the chosen clouds while keeping a few similar unseeded clouds as controls and then estimate which of these clouds have given rain and then measure the amount of rainfall yielded by different clouds. After realizing that the cloud top temperatures influence the results of the experiments, they have conducted experiments by sprinkling ice crystals on the tops of the clouds when the tops are just warmer than minus 8^{o}C. They found that only about half of these treated clouds yielded the rain while the remaining half did not. But when they seeded the clouds with ice crystals with tops at minus 10°C and still lower, all the clouds produced rainfall. After sprinkling the ice crystals into the clouds rainfall was produced in 10 minutes from thinner clouds and in 20 to 30 minutes from thicker clouds. When compared with the rain produced from an unseeded cloud a seeded cloud gave additional rainfall amounting to 2 lakh cubic meters or 100 acre ft. It means that cloud seeding experiments have increased additional rainfall from seeded clouds that is several times more than from unseeded clouds.

Cloud seeding experiments were conducted from 1955 to 1963 in 4 regions 1) Warragamba, 2) Snowy Mountains 3) New England and 4) South Australia. The results for autumn and winter were sufficiently encouraging to adopt cloud seeding as a water resources management tool. The second set of experiments were conducted during April upto September from 1979 to 1983 and the experiment was analysed by the CSIRO. Rainfall increases upto 37% were associated with stratiform clouds in south westerly streams. There is no evidence of the effect of cloud seeding over regions downwind of the target area. Silver iodide fumes were introduced into the base of the cumulus clouds while the stratus clouds were seeded with chemicals at temperatures varying from minus 5°C to minus 10°C in the cloud. The experiments were conducted for 3 to 6 years. The prevailing rain bearing winds had different influences. The Snowy Mountains and New England operational areas over the Western slopes of the mountain ranges were influenced mostly by continental (westerly) air masses. South Australian regional operations were influenced by maritime (easterly) air masses while those in Warragamba region experienced weather of both westerly continental and easterly air masses. The first two years experiments over Snowy mountains produced 26% extra rainfall while the first year experiments in New England area produced 30% additional rainfall.

Tasmania results : Having planned to conduct cloud seeding experiments in alternate years in Tasmania region they conducted the experiments in 1964-71 and the results indicate upto 30% increase in rainfall in autumn at significance level of 3%. In other words there was only a 3% chance that the effect was not a result of the seeding. The Government accelerated research activities on cloud seeding operations. Since Tasmania region has hills and mountains, the sprinkling of silver iodide from aeroplanes into stratus clouds subjected to updrafts proved that additional rainfall will be produced., But such positive results were obtained during southwest monsoon clouds when seeded with cloud top temperatures ranging from minus 10 to 12°C. The experiments conducted in Tasmania and Melborne Snowy Mountain regions proved that the additional rainfall of 5% to 10% produced by the cloud seeding experiments are economically beneficial.

The experiments conducted in west Australia for agricultural development proved to be economically beneficial. The experiments conducted in Tasmania produced 37% increase in annual rainfall. However only 18 days in a year were suitable for cloud seeding operations. The benefits obtained by cloud seeding were 13 times the expenditure incurred. The reservoir storage increased from 10% to 20% and the production of hydro power was estimated at US $0.2 cents per KWh. Convective clouds with top temperatures of –10°C to –30°C are more suitable for seeding and the amount of silver iodide is not that important if only a threshold of 5 to 10 gms per cloud is exceeded. However substantial effects were recorded by using 20 gms of AgI per cloud while no worthwhile effects were observed when about 0.2 gms per cloud was used.

Israel :

Cloud seeding experts in Israel began their work in 1948 on individual clouds into which dry ice crystals were sprinkled from the Israel Air Force aeroplane with partial funding from the Ministry of Agriculture. A Rain Committee, an unofficial body composed of scientists and Government officials, planned and supervised these initial experiments. Clouds were seeded by using ground generators which produced silver iodide smoke for precipitation enhancement. It was soon realised that because of the flat terrain selected for the location of ground generators, sufficient concentration of seeding material was unlikely to reach the clouds and increased use of silver iodide was suspected to create environmental problems. In order to inject adequate concentration of silver iodide nuclei in suitable region of the cloud an air craft began to be used in the experiments conducted during 1961-1967. In addition a number of ground generators were also used. In order to make a critical evaluation results of the cloud seeding, the randomization of the experiment was stared in 1952.

When International Conference on science in the advancement of new states was conducted in Israel in 1960, the invited speakers E.G. Bowen of Australia and L.J.Baton of Arizona spoke on the positive results of cold cloud seeding and the water planning authorities got convinced about the key role of cloud seeding in augmenting the water supplies. The 12-year old Rain Committee was made an official organ of the Government and research work funded by the agriculture ministry was to be conducted under the Hebrew University, Department of Meteorology. Cloud seeding by the aircrafts equipped with all the instruments for studying the physics of clouds was done at the cloud base level. The statistical randomized experiment was designated "cross over" and involved two experimental areas by the names "North and Center". Rainfall season for Israel like that of California runs from November to April and the experiments were continued during the rainy season for about 6½ years from February 1961 to spring 1967. For this major experiment a part of the catchment area of lake Tiberius also known as the sea of Galilee in the Bible was selected for seeding by the aircraft, the rest of the catchment being in Lebanon and Syria. Since Tiberius lake and its catchment played a crucial role as a water resource, a second major randomized experiment on cloud seeding was stared in 1969 with two larger experimental areas designated as North and South. Simultaneously a single cloud seeding experiment was conducted for studying the physical properties of cumulus clouds of Israel. The experiments conducted during 1961 –1967 indicated 15% increase in rainfall for the days of seeding. Similarly the experiments conducted during 1969-1975 produced 30% additional rainfall. The rainfall season is the cold season of the year in Israel and the freezing level drops to about 2km on the days of precipitation. The cloud bases were about 700 meters to 800 meters MSL with temperatures of 9°C while the cloud tops extend upto 4km to 6 km above the ground. The cloud top temperatures were at about –16°C in the south and –19.5 °C in the North target areas. The rain bearing clouds are the cumulus clouds associated in bands that move generally from West to East and these bands are embedded in a cyclonic flow having its center in North East Mediterranean.

Assuming updraft velocity of 2.5 meters per second at the cloud base, cloud drops are estimated at about 890 per cm^3. If updraft velocity is 4 meters per second cloud drop concentration works out to about 1010 per cm^3(observed value was 1100 per cm^3). For this cloud with a vertical velocity of 7 meters per second at about 6000 ft above the cloud base, the average works out to 5 meters per second for the whole cloud. At temperatures between –12.5°C to –23°C large water droplets of 250 micron diameter are less than 0.1 per litre.

In the experiments conducted from 1976 onwards the annual rainfall increase ranged from 15% to 18%. WMO declared this experimental programme as the only one worldwide which statistically shows significant success. While the Cumulo Nimbus cloud heights with 6km to 9km contained 5 lakh cubic meters rain the dynamically seeded clouds increased the the height by 2kms and the water content was doubled.

Reference : Meteorological and Geophysical Abstracts, June, 1991, Page 1587.

Pakistan :

In order to protect the withering crops and to quench the thirst of city dwellers the Pakistan Meteorological Department officials recognized that cloud seeding is the only method to promote the health and welfare of the people. They conducted cloud seeding operations successfully from 1953-56 in Beluchisthan, Punjab and North West Frontier provinces. The President of Pakistan carefully observed how the developed countries successfully employed the tool of cloud seeding to fight the recurring droughts and thereby promoted the economic growth and National prosperity and thereby mitigated the impacts of growing poverty and unemployment. He gave directions through the Chief Engineer to conduct cloud seeding operations and assigned this task to the Defence Ministry with the assistance of the Pakistan Meteorological Department. This department has rightly accepted the challenge and took the services of the Army aviation and also the Plant Protection Department of the Agriculture Ministry for conducting the cloud seeding operations Their latest series of experiments were started from the middle of the year 2000 to squeeze additional rainfall from the warm clouds. Out of 48 experiments conducted 30 proved to be highly successful. 4 experiments failed only because of the technical problems with the aircraft. 14 warm cloud seeding experiments had limited success. In the second phase 23 cold cloud seeding operations were conducted while 9 experiments were highly successful, 6 experiments had a limited success while the remaining 8 experiments failed as shown in the following table. These experiments demonstrate a success rate of 65%.

Particulars	Phase-I Warm Cloud Seeding	Phase-II Cold Cloud Seeding
Total experiments conducted	48	23
Highly successful	30	9
Limited Success	14	6
Failure due to technical reasons	4	8

Some details of the methods used and the results achieved are furnished below.

Areas of weather modification

1. Different Areas

(a) Fog dispersion (b) Hail suppression (c) Rain enhancement

2. Different Cloud-Seeding Agents.

(a) Silver Iodide (b) Calcium Chloride (c) Salt (d) Dry Ice (e) Liquid Carbon Dioxide (f) Dust

Rain-Enhancement through CloudSeeding

1. Different Methods of Clouds Seeding

Airborne : By using Aircraft
Ground base : By using Ground Generator or Rocket Technology.

2. Different Categories of Clouds

a. *Warm Clouds:*

- Base warmer than +10 C°
- Top warmer than + 0 C°

b. *Super-Cooled Clouds:*

- Base & Top colder than - 0 C°

3. Types of Super-Cooled Clouds

a. Deep Stratiform Clouds b. Shallow Stratiform Clouds c. Cumuliform Clouds

Methodology for cloud-seeding operation :

- Identification of a suitable situation.
- Arrangement of an appropriate seeding agent.
- Successful transport and diffusion or direct placement of the seeding agent to the super-cooled regions of the clouds.
- Adequate time and super-cooled liquid and vapour must be available to provide precipitation-size particles.

Uses of numerical models in weather modification :

- To estimate the Seedability of the Cloud.
- To identify the optimum location to Seed.
- Quantity of Seeding material required.
- Best time to start Seeding.
- To distinguish operational and non-operational days.

Status of weather-modification experiments in other countries :

- *Japan* conducted Cloud Seeding of snow cloud in Central Japan for enhancing the snowfall in catchment areas of Dams from 1974 to 1997.
- *Mexico* 1997; Program for the Augmentation of rainfall in Coahuila was conducted and initial results were encouraging.
- *China* is successfully using rain enhancement techniques in their arid areas since 1990.
- *Thailand* is successfully using weather modification techniques since 1994.
- *Israel & USA*: They have done lot of research work in the field of weather modification during the last 50 years.

Economic benefits of cloud seeding :

So far, the experiments on warm clouds have given reasonably good results, with 30 successes out of 48 experiments i.e. 63%. The primary motivation for cloud-seeding is the Economic Benefit associated, viz:

i) Increased hydro-Electric power and agriculture production

ii) Salinity reduction

iii) Strengthened tourist industries

A study showed that an additional 10% of precipitation over the growing Season would be expected to increase revenue from $ 10M To $ 43M.

Another study in U.S.A showed that added rainfall of 20mm In June – July and 30 mm for June – August would increase the Economy by over $ 0.5 billion. The other direct benefit is from the augmentation of Snowfall, which results in additional stream-flow for generation of hydro- electric power and increased irrigation water.

USA :

Although research work on clouds and their potential for giving rain started since 1960 the accelerated studies on the problems of cloud physics commenced by the end of second world war. Investigations revealed that the water vapour in the atmosphere condenses over the dust particles and grow into cloud droplets of 5 to 20 microns in diameter and that some water vapour condenses over a few clay particles that are transformed into the ice particles at very low temperatures below freezing levels. Further studies indicated that these cloud droplets gradually increase in size and the cloud grows in height due to the updrafts present in the area.

Operations : The clouds normally shed only about 10% to 15% of the moisture content as rainfall or snowfall mainly due to the deficiency of adequate number of giant hygroscopic nuclei in the warm clouds and ice crystals in the cold clouds. By injecting additional nuclei into these clouds annual precipitation can be increased from 5% to 30% depending upon several favourable conditions. Investigations further revealed that the lifetime of the cloud is found to be about 10 minutes for small 30 minutes for medium and about one hour for large cumulus clouds. Since hygroscopic crystals of 1 to 10 microns in diameter are formed by the Ocean waves, the cumulus clouds give more precipitation on sea than on the land surface. Hygroscopic sodium chloride powder of 100 kg is to be used for obtaining optimum rainfall from a cumulus cloud whose depth may be 2 to 3 kms.

A gram of dry ice produces 10^{12} ice nuclei which work actively from -2^oC to -12^oC. One gram of silver iodide produces silver iodide crystals of about 10^{12} that work actively from -10^oC to -19^oC . Cumulus clouds ranging from $1km^3$ to $10km^3$ have to be seeded with 1 to 10 grams of silver iodide crystals. For ground generators that use hot ovens packed with coaking coal and fitted with a blower, silver iodide powder is sprinkled over the hot coke at about 1200^oC at the rate of 5gm to 30 gms per hour. One gram of dry ice when powdered produces 10^{18} ice nuclei which are sprinkled over cold clouds by using the aeroplanes. Most of the rainfall on the continents occurs in tropical rain forests and other wet regions where the economic incentive to augment rainfall is virtually absent in countries like India.

Results : Cloud seeding operations to augment precipitation from Orographic cloud systems resulted in increases upto 15% of the normal annual rainfall. Stream flow increased due to cloud seeding from 6% on a 10 year project on Kings River in California upto18% on an 8 year project on the Rogue river in Oregon. Stream flow increased upto 8.5% for a 15 year period due to cloud seeding on San Joaquin river in California.

The economic incentive to fog modification by cloud seeding lies in the fact that recurring fog occurrences at several airports becomes an obstacle to the take off and landing of aeroplanes. Cloud seeding operations are conducted to mitigate the disruption of air traffic in the airports in many countries. Such operations are conducted in more than a dozen airports in the Western and North Central United States and about 15 airports in the states of the former Soviet Russia.

The cloud seeding experiments were conducted in South Florida in 1978 under FACE-I programme demonstrated a 25% increase in rainfall on days with seeding compared with the days without seeding. (http://www.fao.org/documents/show_cdr.asp?url_file=docrep/q1093E/q1093e.08htm

The experiments conducted in North Dakota indicate a 15% increase in rainfall and also a 45% reduction in crop hail damage. A winter Orographic cloud seeding programme in Central and Southern regions of Utah yielded about 15% increase in snowfall that resulted in augmenting spring and summer stream flows that are used for irrigation.

The cloud seeding operations in Texas produced 15% to 20% increase in the annual rainfall. A similar 5 year study from 1985-89 for the city of San Angelo recorded a 30% increase in rainfall. The statistical evaluation of Colorado Municipal Water District programmes on cloud seeding recorded increased rainfall by 20% to 30% during the years of seeding in its 25 year programme. The South West cooperative programme from 1983 to 1990 produced increase of rainfall by 130% cloud heights by 7% cloud area by 43% and duration by 36%. It was noticed that the cloud cells which were seeded twice as likely to merge and form rain producing convictive clouds than non-seeded clouds. For more details on US cloud seeding project results the reader may refer to the other relevant chapters in this book.

Japan :

Cloud seeding operations in Japan were started in 1947 immediately following the first US experiment of Vincent Schaefer in the Kyushu district on the South Western Island through an Air borne dry ice seeding. A balloon method of carrying about 1.5kg of dry ice with automatic temperature sensitive release was made in 1952. AgI ground generators employing AgI impregnated charcoal and AgI acetone solution containing alkaline iodide were mostly used. In 1951 Tokyo University experts used balloons that carried a smoke candle with 20 grams of AgI and a self firing device at –5°C. A pyrotechnical generator that used nitro cellulose, Ammonium iodide, silver iodide and a small amount of acetone was developed in 1954 and the ice nuclei produced by this system was 10^9 nuclei per gram. Osaka University experts produced AgI smoke without alkaline iodide by electrically heating an AgI containing ceramic crucibles and quenched the vapour-laden hot air with cold air from a blower. Inspite of other difficulties the simple automation and remote control of this method were the attractive features of the system if only electric power was available. This generator was operated at about 1000°C. 6 major electric power companies helped in the research and operational programmes of cloud seeding and the reports of these activities were presented in Japanese and published in 1954 by the Japanese Rain making committee that was formed in 1952. The operations dealt with the ground based AgI seeding with the visual and the rain gauge evaluation.

Ground generators : A randomized experiment by using ground generators was sponsored by Tokyo Electric Company in 1960 which demonstrated about 20% increase in precipitation during a 5 year experiment. While studying on the background levels of ice nuclei in the atmosphere Tokyo University Scientists found that the natural ice nuclei numbers increased when meteorological conditions over Japan were suitable to get dusty winds from North China and Mangolia. But these ice nuclei were very few in number in an air mass of Oceanic origin. But using an electron micro-diffraction method the scientists while studying about the center nuclei of snow crystals found them to be clay minerals of the Kaolinite type.

Decay of AgI smoke from ground generators during Sunlight when studied by the Meteorological Research Institute (MRI) indicated the decay constant to be about 10^{-3}/hour. When studies on the decay of the smoke kept in a plastic bag was subjected to irradiation from laboratory ultra violet light and the Sun light, the decay constant reported by Tokyo scientists was 0.3/hour while Tohoku University scientists estimated it at about one-tenth per hour and both the results are compatible with Australian results. H.Maruyama of MRI studied AgI nucleated ice crystal at various temperatures and used electron microscope and found that the diameters of effective AgI particles (in micrometers) were 0.82 at –5°C, 0.55 at –10°C and 0.34 at –14°C. He further reported that effective AgI ice nuclei at above –15°C were larger than 0.1micrometers in diameter and they are one-hundredth to thousandth of the total smoke particles present there. Hokkaido University experimented on warm clouds by using a saturated common salt solution droplet generator that produced 10^{11} droplets per second, the droplet being 15 micro meters in diameter. The generators were located on Mt.Asahi at about 500 meters altitude. The results looked promising although definite conclusion could not be drawn. Hygroscopic compounds like $MgCl_2$, $AlCl_3$ and $FeCl_3$ were also studied. During the drought in 1958 in Kyushu district warm cloud seeding was done by using a 40% solution of Calcium Chloride by using the balloon method and the experiment was done for many years by Takeda of Kyushu University.

At the end of 1950s the research schemes and the operational programmes of cloud seeding began to get separated. In 1958, the Tokyo city water supply authority developed a practical cloud seeding operational programme. By them it was felt that further advancement of the cloud seeding technology could be only made by making more scientific clarifications about the various process occurring in the seeding operations and hence the science and technology agency began to sanction grants for research work to be undertaken by the Japanese Artificial Rainfall Corporation (JAARC) which had two independent units, one in Kwanto and the other in Kyushu. Many universities, electric companies also joined in this program.

Research findings : The Kwanto branch research programs had the following points for investigations.

1. To what extent can we expect increased rainfall by cloud seeding? Then what about the reliability?
2. What kind of methods are there for the estimation of the increased amount of rainfall from cloud seeding?
3. What are the suitable cloud structures for cloud seeding? And what are the suitable meteorological conditions for it?
4. Comparison between the effects of ground and airborne AgI seedings and improvement of various seeding methods and the comparison.
5. How does the change of cloud conditions differ depending on seeded and unseeded cases? And what is their relation to the seeding effect?

The final report was published in Japanese. Some of the important points are presented.

The AgI smoke from airborne generator was about 10^{16} nuclei/hour at –15°C. Cloud droplets less than 10 micro meters radius scarcely contain water soluble compounds while droplets of 20 to 40 microns contained sea salt. Number of condensation nuclei at super saturation of 0.05 percent was 40 to 400 per cm^3 at 0.1 percent 100 to 900/cm^3 in Kwanto district at an altitude of 1800 to 2100 meters.

The natural ice nuclei were estimated at 10^{-2} to 10^{-1}/litre at –15°C. But when seeded from an aeroplane the ice nuclei attained a value of 30/litre, at –13°C, after 20 minutes of release. The optimum ice nuclei for seeding depends on cloud temperature, liquid water content, cloud thickness and the amount of cloud glaciation. The liquid water content in the summer medium cumulus clouds was 0.7 to 0.8 grams/m^3 and in the winter cumulus clouds at –7°C the liquid water content was 0.2gms/m^3. In a developing summer cumulus cloud the liquid water content was about one gram per m^3 while the cloud begins to disintegrate it was 0.5gm/m^3. Clouds at –10°C did not possess any electric charge but when the temperature touched –16°C the cloud has considerable charge. When an AgI smoke generator with an output of 10^{16} to 10^{17} nuclei/hour at –15°C was used, the smoke particles at 50kms downwind and at an altitude of 11,000ft (3.4 km) were found in concentrations of 1 to 20 nuclei/litre of air that is sufficient for augmenting the precipitation. When the wind had high or low vertical shear the concentration of nuclei was 5 per litre and when the shear was at an intermediate rate the nuclei were about

10 per litre and hence it may be said that enough ice nuclei will be available for cloud seeding operations. At an altitude of 11,000ft. the highest nuclei concentrations were noticed in places about 25 to 40kms down wind of the generator site. About 100 nuclei per litre were found in summer cumulus cloud at 13,000ft (4km). But outside of the cloud the nuclei numbers were at least a factor of 10 smaller. In a cumulus cloud at 13,000ft. the nuclei were 10/litre for a lapse rate of 6°C/km and 100 nuclei/litre at a lapse rte of 7.5°C/km.

The research results from the Kyushu Branch program are presented below.

The AgI cloud seeding operations were conducted both by air borne seeding and seeding from a mountain top. The AgI seeding rate was 210 to 1200gms/hour for cold clouds and the efficiency of ice nuclei production ranged from 1×10^{8} to 7×10^{11} nuclei per gram at –16.7°C . For warm cloud seeding operations by air borne water spraying from aircraft using 2 tonnes of water at a seeding rate of 60 litres per minute was done and the results were evaluated through air borne visual observations.

Operations-results : When a summer cumulus was thicker than 2.3 km it generally gave natural precipitation until it reached 1km thickness. When the cloud thickness varied from 1.8kms to 2.3kms precipitation formed within 10 minutes after seeding. However seeding did not produce precipitation in a cloud thinner than 0.83kms. When a cumulus cloud which commenced precipitation was seeded it intensified the precipitation and extended the area of precipitation. But seeding the cloud that has already started precipitation resulted in the cloud diminution. Due to over seeding a strong reduction of the precipitation to 40% of the normal level was noticed in winter times. However the 3 year winter experiment over the target forest area in Kyushu district produced 20% increase in precipitation.

The Japanese research has been always proceeding in the direction of advancing our knowledge in micro-physics and dynamics of clouds, instrumentation development, actual field studies as well as laboratory studies with emphasis on weather modification for prevention of hazards and promotion of precipitation for sustainable development.

ECONOMICALLY CHEAPER HYDRO-POWER AND AGRICULTURE

Cloud seeding operations have been successfully conducted by about 40 countries during different periods during the last 50 years. Recently Australia has taken up cloud seeding operations in Snowy Mountains region to augment annual precipitation not only to obtain more snow cover for improving the tourist trade but also for hydropower generation and food production, besides using this technology to fight the emerging impacts of the global warming. China has been extensively using cloud seeding operations by employing more than 35000 people to fight the disastrous consequences of the recurring droughts and also to reduce the summer temperatures and thereby cut down electrical power for air conditioning. Indonesia is conducting cloud seeding operations to store additional water supplies in reservoirs for subsequent use during years of water scarcity and drought. Cloud seeding is used in several places in Russian and American states to eliminate the recurring fog conditions that cause serious traffic disruptions in Airports and major urban settlements. Many countries are extensively using cloud seeding to make drastic reductions in the damages caused to lives and properties due to recurring hail. Presently scientists are considering the revival of cloud seeding experiments to tame the cyclones and thereby mitigate the damage caused by cyclones and hurricanes. Thailand is regularly conducting cloud seeding operations every year to obtain about 2000 mm of annual rainfall not only to meet the municipal, industrial and agricultural needs but also to promote large scale tourist trade by promoting environmental assets like good landscapes, gardens, forests and wild life. In a few places cloud seeding is used to fight the forest fires and to prevent unwanted rainfalls that are likely to disturb the organization of scheduled international celebrations, games and sports.

Cloud seeding is cheaper for water supply than conventional irrigation : A brief review of some of the case studies on cloud seeding experiments conducted in different countries to achieve increased rainfall for municipal water supply, hydropower generation and agricultural production at the cheapest cost are presented here. For more details refer to the relevant websites cited. Further the costs of water supply from various other sources are very high as compared to cloud seeding, which can be seen from the following table.

Water supply costs from different sources (at 1998 dollars)

Water Source	Storage Capital Cost ($/1000m³)			Life time delivery cost ($/1000m³)		
	Low	Medium	High	Low	Medium	High
Big Dams	110	270	1600	2	5	32
Medium Dams	130	320	2200	7	17	110
Small Reservoirs	160	390	2500	7	17	110
Dug Storage	500	800	1200	22	35	60
Ground water recharge				190	210	230
Ground water pumping				20	40	110
Diversion projects				190	200	400
Conservation practices				40	105	300
Recycling of waste water				120	170	220
Reverse Osmosis(brakish)				160	350	540
Recycling waste water				260	460	660
Desalinisation				600	1200	2000
Water from Cloud Seeding**				1	2	3

** This information is added by the authors http://www.cgiar.org/iwmi/pubs/Pub039/Report39.pdf

Is artificial rainwater 150 times cheaper than ground water ...?

Sandy Land Underground Water Conservation District (SLUWCD) has been working day and night in the interests of the farmers to encourage food production to promote the state economy and for this purpose have chosen the most effective method of increasing the water availability by large scale tapping of the sky water and they have succeeded because of their sincere efforts and close rapport between their scientific and technological experts, administrators and the general public. The target area includes Yoakum, Terry and Gaines county regions in West Texas. http://www.sandylandwater.com/cost_benefit.htm

SOAR (Southern Ogallala Aquifer Rainfall) Programme, Texas cloud seeding project covered 5.048 million acres during the operational seasons covering 77 clouds in 2002 and 69 clouds in 2003. Yoakum county for its 5 lakh acres coverage shared the operational costs estimated at $20,000. Two independent reputed weather consultant agencies evaluated the cloud seeding project results. 63 out of 69 clouds seeded during 2003 season produced rainfall increase of about 2,50,000 ac.ft. For the 77 clouds seeded during 2002 season each cloud system produced additional rainfall upto about 5000 Kton making a total increased rainfall of 3,80,000 Kton or 3,06,740 ac.ft. (One Acre feet =1234 Cubic meters)

However the economics of cloud seeding have been estimated for Yoakum county.

1. Cost benefit ratio for Yoakum county for 2002

a) Yield per acre of the total SOAR project area for 2002 =
(3,06,740 ac.ft) ÷ 5048000acres = 0.06 ac.ft per acre

b) Proportion of excess water for Yoakum county for 2002 =
(0.06 ac.ft/acre) X (511808 acres) = 31,100 ac.ft.

c) Cost per acre ft = ($20,000) ÷ (31,100 ac.ft) = $0.64 /ac.ft.

2. Cost benefit ratio for Yoakum county for 2003

d) Yield per acre of the total SOAR project area for 2003 =
(248500 ac.ft) ÷ 5048000acres = 0.05 ac.ft per acre

e) Proportion of excess water for Yoakum county for 2003 =
(0.05 ac.ft/acre) X (511808 acres) = 25,194 ac.ft.

f) Cost per acre ft = ($20,000) ÷ (25,194 ac.ft) = $0.80 /ac.ft.

The above costs for Yoakum county for 2002-2003 represent the purchasing cost of additional water produced by cloud seeding. But the farmers are normally spending $120 per acre foot in pumping costs from underground water wells. So if we compare the costs of pumping incurred by the farmers with the cost of about $0.80 for cloud seeding operation, the cost benefit ratio comes to 1:150. This clearly shows that for every dollar spent by the farmer in Yoakum county the benefits obtained will be 150 times higher.

Hydro-electricity at cheaper cost :

Tasmania produces most inexpensive hydro-electricity : Tasmanian Hydro-Electric Commission is convinced of the economic success of the Tasmanian experiments. This is perhaps best illustrated by the decision of the Hydroelectric Corporation (HEC) to undertake the Tasmania II experiment without any operational assistance from CSIRO. However, the HEC has retained a very pragmatic approach to cloud seeding. McBoyle (1980) quoting from Watson (1976) states “Cloud seeding has emerged as a feasible and economic proposition in Tasmania when the increase in precipitation can be utilized for power generation”. Currently Searle (1994) estimates that each HEC cloud seeding operation costs $645,000 to run and returned an average 55 mm of extra rain during each 6 months experimental season. When the extra water in storage is priced against the energy generated by the only HEC thermal station the real profit from the silver iodide seeding comes to about $14.5 million per annum (Searle, pers. comm.) Seeding of these cloud systems resulted in a 37% increase in rainfall. Suitable days occurred 18 times a year during the experiment and this gave rise to an estimated total increase of 197 mm for seeded days.

Cost-benefit analyses carried out by the Tasmanian Hydro-Electric Commission for the Tasmanian I experiment suggest that the increased rainfall from seeding represents a gain of **13:1**. More recently Searle (1994) argues that the three separate cloud seeding projects sponsored by the Hydro-Electricity Commission of Tasmania spanning 14 years have confirmed that cloud seeding can routinely enhance runoff into Tasmanian storages by 10-20%. Searle estimates that the energy gained by the cloud seeding operation costs **less than 0.2 US cents per kilowatt hour**. http://www.dar.csiro.au/publications/cloud.htm#pt2

Gautemala : The Gautemala cloud seeding evaluation was based upon monthly precipitation data for the period 1980 to 1989. The calculated 17 percent increase for the chosen month of 1992 June precipitation over the Chixoy drainage of Gautimala was equivalent to 1.81 inches. The Chixoy drainage is approximately 2,140 square miles or 1,369,837 acres. INDE officials indicated that the Chixoy watershed converts precipitation to runoff with an efficiency of approximately 30 percent. The additional June stream flow into Chixoy as a result of the cloud seeding program can be estimated as follows:

1,369,837 acres x 1.81 inches = 206,617 acre-feet.

With the 30 percent efficiency factor applied, this equals to 61,985 acre-feet (76,427,505 cubic meters). The cost of this program can be pro-rated to estimate the program costs for June 1992. This cost is $79,700 (U.S.). **C**onsequently, the estimated cost of the additional runoff is **$1.29 (U.S.) per acre-foot or $0.001 (U.S.) per cubic meter.** http://www.nawcinc.com/Summer%20Study.pdf

Honduras : Cloud seeding was conducted over the El Cajon and Lake Yojoa drainage basins in Honduras during 1993, 1994, 1995 and 1997 rainy seasons, to augment natural precipitation in these drainages, which will then augment the amount of inflow into the El Cajon Reservoir. This extra water can then be released to generate additional hydro-electric power. Evaluations of the 1993, 1994 and 1995 cloud seeding programs indicated a 9 to 15 percent increase in precipitation attributed to the cloud seeding.

The June through October 1995 program indicated a 13 percent increase. Additional runoff was estimated as 366,876,000m^3. Calculations of the cost of the program versus the value of the additional inflow from the 1995 program were performed using certain assumptions.

The resultant benefit to cost ratio was calculated to be 23 ½ :1. http://www.nawcinc.com/cseng.PDF

Inexpensive agriculture and drought mitigation :
hina uses cloud seeding for several purposes : The ground precipitation enhancement operations in Feng Huang County of Hunan province during 1975-77 showed an increase of 55% of the daily rainfall by statistics. Experiments in rainy season (April to June) during 1975-86 using rockets in Fujian province showed rainfall increase by 24% with significant level of 0.05. http://www.lanl.gov/chinawater/documents/huzhijing.pdf.

A group of scientists from the Chinese Academy of Sciences concluded after recently doing research in the province that exploiting water resources in the air could be a sustainable way to solve water scarcity in North China. Based on the advice of the scientists, the provincial government of Shanxi has made a six-year plan to develop weather modification technologies, mainly seeding clouds to increase precipitation. The province will strive to increase its annual rainfall by 2 to 3 billion cu m a year. Shanxi is among one of the most arid provinces in China, with about 4 million people and nearly 1 million head of livestock being affected every year. Dry weather also leads to reduced grain harvest, local officials said. Since the late 1980s, Shanxi has been seeding clouds to increase precipitation by 600 million to 800 million cu m a year. http://fpeng.peopledaily.com.cn/200007/14/eng20000714_45496.html.

According to Qin Dahe of China Meteorological Administration (CMA) cloud seeding operations were conducted from 1995 to 2003 in 23 provinces by using 42321 flights of aircraft with a total flight time of 9881 hours and employed artillery and rockets. The cloud seeding operations covered 30 lakh sq.km and precipitation was 2100 billion cu.m (73,500 TMC). During 2003 alone 3,800 rocket launchers, 7000 anti aircraft guns and many aeroplanes were used in about 1800 counties and employed 35,000 people for the operations. About 413 Yuan (US $49million) were spent for the operations.

According to Zhang Qiang a noted Beijing official, in the first half of 2004,the meteorologists injected silver iodide particles into the clouds to augment rainfall or snowfall over Beijing Aeroplanes, rockets, artillery shells, meteorological balloons and mountain top based generators were employed. From January to end of June (Beijing Time report dt.24-7-2004) China used 227 aircraft putting in 530 hours of flight time in cloud seeding operations in 15 provinces and regions covering an area of about 1.66 million square km and sprinkled chemicals into the clouds by using 12,464 rockets and 66,000 large caliber artillery shells in different provinces and cities producing 10 billion cubic meters (350 TMC) of water. Zhang Qiang estimated that the cost of 1 cu.m of man made rain works out to 2 US cents (equivalent to one Indian rupee).

According to Hu Zhijin a cloud expert with Chinese Academy of Sciences Cloud seeding is cheaper than other methods used by Government to solve the water shortage problem such as the South-North water diversion project intended to transport water from Yangtze river basin to Beijing and Northern parts of China. He said that for one dry season about 2 to 3 million Yuan (US $ 24,180 to $ 36,270) was needed to carry out the cloud seeding programmes.

Pakistan : Qamar-uz-Zaman Chaudhry, Director-General of the Pakistan Meteorological Department (PMD), said that the department was conducting cloud seeding experiments in the country with the assistance of the Army Aviation, which was called artificial rain, though it was somewhat misleading. However, he said, these experiments met with considerable success. He said that PMD initiated the experiments from June 2000 to augment rainfall mainly over drought-hit areas of the country. He lamented that at this experimental stage, besides the limitations of resources (equipments, specially equipped aircraft etc) the main reason for limited success in winter was that very weak weather systems were approaching Pakistan. Most of these clouds were lacking the moisture content or these were high clouds it could be developed to a level where drought situations could be averted, he added. He said that among the three experiments -one in Murree area and two in Baluchistan - could achieve some success in the form of rain/ snow. http://lists.isb.sdnpk.org/pipermail/eco-list/2001-February/001017.html

The President of Pakistan, General Musharaff proved his statesmanship as a savior of the people and the environmental assets of Pakistan by directing the Heads of the Pakistan Meteorological Department and the Aviation Department to fight against the recurring droughts by conducting experiments on cloud seeding to promote annual precipitation to augment substantially the snow fall and the rainfall. Pakistan had made a success of the cloud seeding experiments. Out of the 48 warm cloud experiments conducted 30 were highly successful, 14 had a limited success and 4 failed due to technical problems with the aircraft. Out of the 23 cold cloud seeding experiments 9 were highly successful, 6 had limited success and 8 have failed. http://www.comsats.org.pk/latest/anjum_farooqi.pdf.

Wyoming : On March 19,2002 the Governor's Drought Management Task Force met in Cheyenne to discuss and evaluate Wyoming's conditions and drought outlook. During the meeting it was stated that Municipalities, agricultural interests, hydro-electric companies and others that would benefit from additional snow pack that would help cover the costs. Jeri Trebelcock with the Popo Agie Conservation District said the cost of cloud seeding equates to $1 per acre-foot. http://www.uwyo.edu/ces/Drought/Releases/CloudSeed.html. http://www.uwyo.edu/ces/Drought/Releases/statedroughtnews3.html.

Nevada : Benefits vary with the seasonal frequency of suitable weather opportunities. Research results have documented precipitation rate increases of 0.1 - 1.5 millimeters per hour due to ground-based seeding during proper weather conditions. Estimates of augmented water from seeding have varied from 20,000 to 80,000 acre-feet over each of the last ten years. Seasonal percentage increase estimates have varied from 4 to 10%; generally greater in drought years; less in above normal years. **The cost of augmented water, based on the cost of the program, has ranged from $7 to about $18 per acre-foot.** http://cloudseeding.dri.edu/Program/Synopsis.html

Kansas: Brian Vulgamore, who conducted Kansas-State's study, said "Unfortunately, science was unable to separate fact from fiction after that, due to lack of research funding in the 1980s and '90s." That's why his study bypassed the science of modifying the weather. Instead, Vulgamore tried to assess real-life impacts. He examined both rainfall and hail in western Kansas and worked to put their outcomes in dollar terms. "The smallest drought causes economic harm in any semi-arid farming region," Kastens pointed out. "Up to a point, extra rainfall brings extra economic benefits." But equal precipitation losses and gains don't bring equal results. Vulgamore's analyses suggest that an added inch of growing-season rain in western Kansas translates into an economic gain of about $18 million. A 1-inch loss in rainfall translates into economic losses exceeding $19 million. http://www.uswaternews.com/archives/arcsupply/tclosee3.html

North Dakota: Sell and Leistritz (1998) studied the economic impacts of cloud seeding in North Dakota. Eight of North Dakota's most common crops like wheat, barley, sunflower, soybeans, dry edible beans, corn grain, oats, and flax were evaluated for impacts of a statewide cloud seeding program. Results were based on a 45 percent reduction in crop losses (Smith, et al., 1997), and a 15 percent increase in rainfall (Changnon and Huff, 1972). The annual crop production increase was $34.4 million for hail reduction and $52.2 million for rainfall enhancement statewide. This $86.6 million direct impact results in an increase in total business activity of $267 million or an average of $14.52 per planted acre. Additionally, the estimated $3.2 million annual cost of operating a cloud seeding program statewide is more than offset by the $5.1 million in increased tax revenues. Thus, the program more than pays for itself. Additional benefits to other crops, livestock and reduction of property damage were not included in this report, but are also thought to be substantial. http://www.swc.state.nd.us/arb/graphics/QandA.pdf

California : The cost of the annual cloud seeding program is shared among the County and the water districts, which receive a benefit from it. The cost is well justified when compared to its benefits. The average cost of water produced by cloud seeding is less than $100 per acre-foot.

By comparison, the cost of State Water on the South Coast is roughly $1200 per acre-foot. Desalinated seawater costs approximately $1950 per acre-foot. Groundwater and water from Lake Cachuma average between $75 and $250 per acre-foot. Cloud seeding is one of the least expensive sources of water. (Santa Barbara County,USA). http://www.countyofsb.org/pwd/water/cloud.htm.

Municipal water supplies at cheaper cost :

UTAH cloud seeding program : The estimated average annual increase in runoff due to cloud seeding in Utah is 249,600 acre-feet. This is an average annual increase of 13.0 percent. The estimated project cost for the 1999-2000 season is $254,300. The resulting **cost per acre-foot is about one dollar ($1.02).** http://water.utah.gov/cloudseeding/PDF/Utcsprog.pdf. http://water.utah.gov/cloudseeding/CurrentProjects/Default.asp

Syria : Cloud-seeding technology is generally an expensive process, dependent on its efficiency and effectiveness. The equipment used in Jordan included C-B and VRC 74 weather radars, and an aircraft equipped with meteorological recording instruments. The aircraft also contained a computer, satellite station (METEOSAT NOAA), qualified radar technicians, engineers, meteorologists and pilots. In Syria, the cloud-seeding project was initiated in 1992, involving similar equipment and staff. Six aircraft were used for seeding purposes during 1993-1994, with the project costs reaching 156 million Syrian lira. The operation costs reached 25 million Syrian lira (US$ 0.5 million) in 1998. The costs per cubic meter of water for the years 1991-1997 were previously highlighted. Based on the regression method used to estimate the increased rainfall, the costs range between US 0.026-0.181 cents/m^3 of water, and between US 0.016-0.113 cent/m^3 if the ratio method is used. http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8f/B/Cloud.asp

UNEP Programme : It is estimated that the cost of water produced is about **$1.50/m3/season/ha** (United Nations, 1985). This cost is made up of scientific equipment and hardware costs; flying costs for cloud seeding (capital and operational, including maintenance or hire charges); salaries for scientists and pilots; the cost of seeding agents and flares; and, software costs (for experimental and monitoring purposes). http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/cloud.asp

South Africa : Studies by the hydrological community have projected a ~25% increase in annual run off in typical Highveld catchments if the annual rainfall could be increased by 7%. If attainable, this will result in additional water at about 1/5 the cost of the cheapest alternative in South Africa. http://metsys.weathersa.co.za/cloud_detail.htm

Experiments on warm clouds by IITM, Pune (1973-1986) : The Indian Institute of Tropical Meteorology, Pune launched a warm cloud seeding experiment using aircraft in the semi-arid region towards East of Pune on the leeward side of the Western ghats from 1973 to 1986. A randomized double area crossover design with a buffer zone was used for the aerial seeding work. The experimental area covering 4800 sq. km. was divided into 3 parts designated as North, Buffer and South sectors in Ahmadnagar, Baramati area (Hindu dated 18-1-1988). The results of experiments on aerial seeding of warm clouds with common salt and soap stone powder for the eleven years. (Refer Warm Cloud Seeding Chapter)

Cost Benefit Ratio For Warm Cloud Seeding : The cost-benefit Ratio for the warm cloud seeding experiment based upon the data collected by the Institute at Pune for the increase in precipitation of about 20% works out as follows:

i) Total cost of the experiment during the past 11 monsoon seasons (Aircraft changes and cost of seeding material) — Rs.58.0 lakhs

ii) Expenditure incurred during 1986 — Rs. 8.0 lakhs

iii) Cost benefit ratio for a 20% increase in rainfall due to seeding.
Average rainfall in the experimental area during monsoon – 346 mm
Volume of water produced by artificial rain during one monsoon season

Target x Rainfall increase	= $(16000 \times (1000)^2 \times 346 \times 20)/(1000 \times 100)$ = $110720 \times 10^3\ m^3$
Cost of producing 1 m3 (1000 liters) of water	= (Cost of the experiment) / (Volume of the water) produced by artificial rain) = less than 1 paise per 1000 litres of water
Minimum cost of water supplied by Municipal / state Government authorities Cost benefit ratio of artificial rain	= 60 paise per 1000 litres = 1 : 60

http://www.geocities.com/jvmnaidu/actionplan.html

http://arxiv.org/html/physics/9812046

Experiments in Visakhapatnam, 2002 : At the request of the Municipal Corporation of Visakhapatnam Aerial Cloud Seeding was undertaken besides two ground based generators located at Simhachalam hills during 12-14 October 2002. The helicopter used flew for two hours on each day during 1600 to 1800 hours. The seeding was done by sprinkling the Sodium Chloride powder of 200 Kg. on each day manually at heights of about 1 to 1.5 km above the sea level. The results are reproduced in Fig. 1 to 3 clearly demonstrate the increased rainfall. Assuming the area of the district where 42 out of 43 reported rainfall during seeding as 10,000 sq.km. with district average rainfall of 12th as the baseline, the increased water due to seeded rain is estimated at about 15 TMC. The expenditure involved was only about Rs.6 lakhs which clearly demonstrate the cheapest and viable alternative to increase water resources. http://www.geocities.com/jvmnaidu/watershed.html

From the above studies it may be seen that the cost of cloud seeding varies greatly, depending on a large number of factors, such as which seeding methods and materials are appropriate to a specific application, the frequency of seedable conditions, the size of the intended area of effect and the duration of the project. Most cloud seeding projects carry favorable **benefit/cost ratios, ranging over 20:1** in some cases. http://www.nawcinc.com/wmfaq.html.

SOCIAL ISSUES AND FREQUENTLY ASKED QUESTIONS

After the cloud seeding experiments were conducted by Vincent Schaefer near New York in November 1946, many arguments for and against cloud seeding have been advanced by the scientists, social workers and the general public. While some of them are in favour of cloud seeding operations many are strongly against them. However the scientists and technical experts working in the companies associated with cloud seeding operations are arguing that the operations will be highly successful if only they are conducted on scientific lines, the other scientists from the universities and research organizations, government officials and some politicians have been arguing that the cloud seeding operations are not that successful and hence public money should not be misused for the purpose. Moreover they emphasize that the environmental assets will be adversely affected in the long run. Further when cloud seeding experiments are conducted in one region or state the other places downwind will not get their share of normal rainfall. They argue that the eco-systems in nature will be adversely affected and nature's balances will be upset in course of time. Under these adverse conditions cloud seeding operations cannot make a success unless public sympathy and cooperation is obtained. Hence it is necessary for the proponent of cloud seeding operations to analyse the various arguments and doubts raised by the scientists and other people and provide realistic information to clarify the doubts for enlisting their cooperation for the success of the cloud seeding operations. Hence some of these problems are highlighted in the following pages and the necessary scientific information is also furnished to clarify the misgivings on the subject.

Can the clouds belonging to one area be stolen by the others?

There is a feeling among the people that if the cloud seeding operations are conducted in one region or state the other downwind regions or states will be deprived of their share of normal rainfall. This apprehension is not correct because it is not based on true facts. In a typical precipitation cap-cloud ascending over a mountain, if it is assumed that the ascending water vapour mass is cloud-free, about 20% of the water vapour in the ascending air mass condenses and forms a cloud. Out of this about 20% comes down as rainfall from the cloud. Hence only 4% of the atmospheric water vapour amounting to 100(0.20 x 0.20) = 4% is thus removed. If it is assumed that the cloud seeding operations increase the rainfall by 20% then the additional water vapour removed from the ascending cloud vapour in the sky works out to 100 (0.20 x 0.04) =0.8% and this is a relatively insignificant amount and hence only a trivial reduction in the total atmospheric reservoir of water vapour would occur in the region downwind of a target area. According to scientists of South Africa about 6 million cubic meters of moisture passes over the country every day in its sky out of which 5% gets precipitated as rainfall. Out of this rainfall 60% is returning to the sky through evaporation from the rivers, lakes and plants. It means that 40% of the rain amounting to 2% of the atmospheric moisture (1,20,000 m^3) is left in South Africa. But cloud seeding operations produce about 25% additional rainfall. Out of this additional rainfall only 40% remains over land while 60% again returns to the atmosphere due to evaporation. Thus cloud seeding operations are capable of squeezing only a very small fraction of the atmospheric moisture flow in the skies. This inconsequential small fraction of the atmospheric moisture obtained through cloud seeding operations cannot cause adverse impacts on the normal rainfall anticipated in the areas downwind of the target area selected for the operations.

Depending upon its size the life of a cloud may be 30 minutes to 60 minutes. If we are not able to use the cloud in proper time for seeding operations and squeeze its water content in the form of precipitation this cloud may dissipate as moisture. Hence there is no guarantee that this cloud will remain in tact for such a long time beyond its life time to give rain in another region downwind of the target area. Based upon local environmental conditions like meteorology and topography the cloud downwind of a mountain may descend and get dissipated without giving rain in the rain shadow area. However if the area downwind contains good forests or mountains the moisture gets replenished again and the newly formed cloud may provide more rainfall to the areas down wind of the target areas.

Will the chemicals used for cloud seeding cause damage to public health and environment?

Chemicals like Sodium Chloride, Calcium Chloride, Silver Iodide and dry ice are used as nuclei to seed the warm clouds and cold clouds. It is necessary to know what will be their short term and long term effects on the environment. Estimates made in USA indicate that due to the use of silver iodide for cloud seeding operations in 1977 the amount of silver iodide worked out to 1500kgs. According to EPA reports of 1973 about 360mg of silver enters into the atmosphere over USA. In the rain water samples obtained by cloud seeding operations silver concentration is estimated at 10^{-12} that is one part per billion (ppb). Since AgI is not soluble in water it does not readily get into the sea but tends to be deposited in the soil and the bottom of stream beds. The research investigations conducted up to 1977 indicate that this chemical has not posed any threat to the ecological systems. Silver has been detected at 10 nano-grams to less than 0.1 micro grams per litre in the rain water samples collected from the cloud seeding operations. The US authorities specified drinking water standards with the safe concentration of silver at 50 micrograms per litre. The values of silver in the precipitation samples in the Montana project was 1/50 to 1/500 of the limiting values set by the US public health service for silver in drinking water.

Similarly the iodine concentration in the rain water samples collected at the end of cloud seeding operation is found to be far lower in concentration than that found in the common iodized table salt used by the people.

During the experiments conducted for 11 years at Baramati, warm cloud seeding operations were done by sprinkling common salt powder into the clouds from the aeroplanes. The analysis of the rain water samples collected after the experiments indicated the concentration of chloride at 10mg/litre while sodium was present at 4.5 mg/litre. Hence these chemicals are not at all harmful to the public health and the environment.

Scientific investigations indicated that even when the chemicals from the silver contaminated water samples entered into the soil and then into the green vegetation and from there into the insects, birds and animals, it was found that there were not adverse effects in the food chains and food webs of the ecological systems. Moreover the ecological systems in nature are subject to dynamic changes and yet remain in bio-dynamical equilibrium. When compared with the changes that occur in nature, the chemicals used in cloud seeding operations do not cause any changes that upset the ecological balances in nature.

Moreover some states like New South Wales are conducting cloud seeding operation experiments to fight the adverse impacts anticipated due to the global warming. Because of the adverse effects of El Nino several states in South India have been facing drought conditions and the conditions have become so serious that several farmers have been resorting to suicides due to failure of crops. This critical situation calls for remedial action by providing ample supplies of water for drinking, food production, hydropower generation and environmental improvement. Since the river courses, tanks and lake beds have virtually dried up, the only course available to the Government is to make use of the sky water in the form of clouds by resorting to cloud seeding operations on an extensive scale.

Social problems :

Most of the cloud seeding operations have been started with the fond hope of obtaining many economic and social benefits. For instance fog dissipation by cloud seeding is done at several airports to minimize the economic losses to the airline companies and the traveling public, because the interruption to flight schedules causes great inconvenience to the businessmen who travel by air. Since the impacts of these operations are highly localized, there is not a serious debate on the employment of cloud seeding for dissipation of fog in the air ports and on railway tracks and major roads in metropolitan cities like New Delhi. Economic studies made so far demonstrate that augmentation of annual rainfall provides the greatest economic benefits. Additional water from cloud seeding has great economic value for agriculture, hydro-power generation and production of timber and pulp wood, low- flow augmentation for restoring water quality in river courses subjected to domestic and industrial pollution and for sound maintenance of forests, wildlife and eco-systems. Additional rainfall obtained by cloud seeding has a great direct impact upon crops, ground water and environment in arid and semi-arid regions. Irrigation and other water management systems are perhaps the ideal areas for the application of cloud seeding operations.

The seeding of monsoon clouds that pass over the forests and mountains result in precipitation augmentation whose effects can be predicted with great accuracy. In some places the additional water stored in the reservoirs is passed through percolation beds into suitable underground aquifers where the water is not only virtually immune to evaporation losses but also can be subsequently recovered and reused by pumping. Some hydro-power generating firms have found it highly economical to conduct orographic cloud seeding operations only for the sake of producing additional electricity at a very inexpensive cost. Moreover such water used for hydro- power generation in the Snowy mountains of Australia is immediately made available for development of irrigation.

Computer programmes may be run to determine the timings for the commencement of dry crop operations during different seasons and also the periods during which cloud seeding operations have to be planned to obtain specified amounts of rainfall to maintain adequate soil moisture to maximize the crop yields in dry farming areas of Rayalaseema and Telangana districts of Andhra Pradesh and other drought prone areas in different parts of the country. Hail suppression by cloud seeding drastically reduces the costs of damage caused to human and animal population, agriculture crops and other properties.

Social Aspects :

Even where cloud seeding operations confer substantial economic benefits and where there are no over riding ecological and environmental disruptions, the attitudes of people to implement this new technology vary greatly. Among the people perhaps about 10% are innovators who are very receptive to almost any proposed technological changes which in their opinion always provide new opportunities for development. But there are also some persons who would not like to tolerate any technical changes whatever. In between these proponents and opponents of cloud seeding, there is a great majority of people who occupy an intermediate position, neither actively promoting introduction of new technology nor actively opposing it.

Some people who blindly believe in rituals for promoting rainfall do not believe in the scientific experiments on cloud seeding. The opinions of many people about cloud seeding are based on the views of influential people who may be termed as “opinion makers”.

Even among the scientific academies of different countries there is no unanimity about the scientific and economic aspects of cloud seeding. While some scientists of the National

Academy of USA are raising some doubts about cloud seeding operations, many scientists of the Chinese Academy of Sciences are promoting cloud seeding operations on an extensive scale to make available substantial extra water by cloud seeding for mitigating the damage caused to public health, agriculture and the environment. The US Government which used to sanction every year about $20 million as research grants since 1970s has virtually stopped such grants during the recent years. Perhaps the US Government must have felt that adequate research work has already been conducted to transform the science behind cloud seeding into a useful technological tool for conducting cloud seeding operations. In China about 35,000 workers are engaged in cloud seeding operations which are reported to be yielding substantial additional rainfall at an inexpensive cost. The king of Thailand is reported to take personal interest in encouraging cloud seeding operations for promoting public health, economic growth and national prosperity.

The scientists of the Indian Institute of Tropical Meteorology (IITM) conducted warm cloud seeding experiments for a 11-year period during the Southwest monsoons from 1973-1986. The results of these experiments were evaluated by International experts like Dr.P.Koteswaram, former Director General of the Indian Meteorological Department (IMD) and the results demonstrated 24% increase in the annual rainfall. These experiments were conducted in a rain shadow area at Baramati with an annual rainfall of 350mm. The results of this research work were published in the international journal of Weather Modification Association in April 2000.

In the light of the successful results of cloud seeding operations conducted in several countries during the last 4 decades the people of India must come forward to debate on the advantages and disadvantages of cloud seeding operations in the light of their own environmental conditions. The Indian scientific community including the Indian Meteorological Department must come forward to improve the cloud seeding methodologies as adopted by other advanced countries like Australia, USA, Israel, Thailand and China and suggest suitable modifications to make the technology more effective and intune with the local meteorological and topographical features of different regions of the country.

Frequently Asked Questions :

How is cloud seeding used for making artificial rains?

Cloud seeding is a new technique used to treat the natural clouds with chemicals for squeezing more water in the form of rainfall or snowfall. The operation will be highly effective only if suitable clouds are present in the atmosphere during the experiments.

What are clouds?

Clouds contain water droplets and often a few ice crystals. When air filled with moisture is raised by the heat of the Sun into higher elevations in the atmosphere the pressure gradually decreases and the air gets cooled and consequently the water vapour condenses over dust particles to become water droplets which are visible as clouds to the naked eye.

When was this cloud seeding technology discovered by the scientists?

Cloud seeding by injecting artificial substances into the clouds was discovered in the experimental laboratories of General Electric Company on 12-7-1946 by Vincent Schaefer who sprinkled dry ice crystals at –78°C into the super cooled droplets of the artificial clouds produced in his laboratory experimental chamber when the ice crystals were found to transform by freezing the super cooled water droplets into ice crystals that precipitated as snowfall on the bottom of the cloud chamber. Thus the scientific basis for artificial precipitation was established.

Subsequently on 13-11-1946 Schaefer along with his research director Dr.Irwing Langmuir, Nobel Laureate conducted a field experiment over a stratiform cloud above Mount Greylock to the East of Schenectady, New York. The cloud was 14,000ft. high with a temperature of –20°C . He sprinkled 3 pounds of dry ice along a line about 3 miles long over the cloud and within about 5 minutes the whole cloud turned into snow and the snow fell down to about 2000ft below the cloud without touching the ground before evaporating.

By using silver iodide particles which are almost identical to the ice particles the cloud drops were nucleated at a threshold temperature of –4°C unlike the temperature threshold for natural freezing or crystalisation nuclei of –15°C to –20°C. Subsequent researches demonstrated that in nature the predominant natural nuclei for the initial formation of ice nuclei were clay mineral particles active at about -15°C or lower.

After transforming the science of cloud seeding into a new technology for practical applications, Langmuir until his death in 1957 is reported to have been insisting on harnessing this new technology to squeeze more water from the skies for changing the arid and drought-prone areas in the Southwest of United States into green pastures and agricultural fields. The scientific and industrial research organization (Common wealth CSIRO) of Australia also conducted cloud seeding operations in February 1947 and reported that the first case of documented man-made rain occurred near Bathurst in Australia. Due to positive research findings the first cloud seeding experiment in Australia was conducted in 1964 by the Hydro-Tasmania and CSIRO.

What are the principles behind cold cloud seeding operations?

The theory behind cold cloud seeding states that the amount of rain produced by a cold cloud is directly proportional to the number of naturally occurring ice nuclei present in it. The number of ice nuclei naturally available in a cloud is usually far lower than the optimum number needed for effective rain formation. Hence artificial rain making by cloud seeding operations seeks to increase the number of nuclei that are naturally present by injecting into the cloud some artificial cloud condensation nuclei in the form of silver iodide particles.

The concept is that the cloud droplets form small ice crystals on the surface of the natural ice nuclei and also on artificial nuclei like silver iodide particles. Ice crystals falling through the cloud collide and coalesce with more cloud droplets and grow in size. Ultimately when these ice crystals grow into ice flakes and fall from the cloud to the earth they melt as they pass through the melting point and fall as rainfall or snowfall, if the ambient temperature is low enough.

What chemicals are used for cloud seeding operations?

Three types of substances like dry ice, silver iodide and hygroscopic salts are used as seeding agents. Silver iodide is very similar in structure to the naturally occurring ice. Water vapour and droplets in the cloud deposit on the surface of the artificial crystal and the ice crystals continue to grow as if they are the naturally occurring ice crystals. Silver iodide is used to treat the cold clouds. In order to treat the warm clouds hygroscopic salts such as sodium chloride and calcium chloride are used. These giant cloud condensation nuclei attract the water vapour onto themselves and grow larger due to collision and coalescence by a chain reaction known as Langmuir chain reaction and ultimately form into large rain drops that fall on earth. Dry ice (CO_2) acts to cool the water to very low temperatures beyond 0°C and thereby cause the cloud droplets to freeze, thus growing as water freezes on the surface of the ice.

What kinds of clouds and conditions are suitable for seeding operations?

All the clouds are not suitable for the operations. The cloud seeding operations themselves cannot be done if there are no clouds in the atmosphere and hence operators choose Cumulo-Nimbus clouds which are convective in nature with a great deal of vertical mixing. Nimbo stratus clouds and cumulus clouds which are dark grey are also suitable. The cloud must be deep enough with temperatures within a suitable range for seeding. There should be significant levels of super cooled liquid water present in the cloud. The wind also must be below a specified value. Since it takes about half an hour for the artificially injected chemical crystals to grow into raindrops, seeding line must be 30 minutes upwind of the selected target area boundary. If the wind speed is 40 knots the seeding will be done 20 nautical miles or 37km upwind of the target area boundary. If all the criteria are met before launching the operations cloud seeding becomes successful in producing substantial additional rainfall. Cloud seeding operations are conducted during the rainy season in suitable places and the operations take place when it is safe to fly and suitable weather conditions are present, 24 hours a day and 7 days a week. The base of the cloud must be within 1.5km to 2km from the ground. A reasonable degree of local updrafts promote the augmentation of rainfall.

Why are cloud seeding operations conducted?

They are conducted mostly to increase the availability of water in a region by squeezing substantial rainfall in addition to the normal annual rainfall. These operations are used for dissipation of fogs in the airports and for minimizing the adverse impacts of hailstorms. By increasing the annual rainfall from 10% to 20% the additional water will be used for raising the water levels in the rivers and lakes used for drinking, agriculture and hydro-power generation. Cloud seeding is also used to augment the water storage in reservoirs for use in the subsequent years of drought in countries like Indonesia. Cloud seeding is also done for augmenting the snowfall for promoting tourist trade in the Snowy Mountains of Australia and for reducing the summer temperatures in China for reducing the electricity consumption for air conditioning.

Does cloud seeding work economically and effectively?

Cloud seeding experiments were being conducted in about 40 to 50 countries for more than 4 to 5 decades. The additional precipitation obtained from cold clouds by using aeroplanes and ground generators varies from 20% to 30%. In case of warm clouds the sprinkling of hygroscopic particles from the aeroplanes into the warm clouds produced increases of 20% to 25% in the annual rainfalls. On the average the benefits are estimated at about 20 times the cost incurred for the operations. After reviewing the results of cloud seeding operations for several years the world Meteorological Organization (WMO), American Meteorological Society (AMS) and the Weather Modification Association (WMA) issued statements indicating 5% to 20% additional rainfall from clouds over the continents and 30% from the maritime clouds. It was further stated that the hail suppression experiments caused reduction of 20% to 50% in the costs of damage due to hail storms.

How is additional rainfall obtained from the cold clouds?

Cold clouds are those whose tops are at a temperature below the freezing level of 0^oC. These clouds precipitate only about 10% to 15% of their water content as rainfall because of lack of adequate number of ice nuclei in them. In order to obtain additional rainfall, extra ice nuclei or their equivalent in the form of silver iodide particles must be introduced in the clouds by using either ground generators located at suitable places or by using aeroplanes. By this method additional annual rainfall upto about 20% can be obtained.

How is additional annual rainfall obtained from warm clouds?

If the top of the clouds are warmer than the freezing level, the clouds are known as warm clouds. The small cloud droplets numbering about a million have to join together to form a big rain drop to reach the earth. It takes a long time for these warm cloud droplets to join and become a raindrop. The lifetime of the cloud itself may be about half an hour to one hour. In order to promote the transformation of the cloud droplets into rain drops within a reasonable time, additional hygroscopic giant cloud condensation nuclei such as sodium chloride and calcium chloride are injected into these clouds with the help of aeroplanes. In the absence of these giant hygroscopic nuclei, the clouds give only 10% to 20% of their water content as rainfall. By cloud seeding operations which inject the above chemicals into the clouds the annual rainfall upto about 20% may be increased.

Are there any regulations to control cloud seeding operations?

In United States about 32 states have rules, regulations and Laws to control cloud seeding operations. Even in India the State Governments have to obtain permits from the Central Government to conduct cloud seeding operations.

Who conducts the cloud seeding operations?

Most of the cloud seeding operations are conducted by a few specialized commercial companies that work under contract to various kinds of sponsors such as state Governments Irrigation Departments, Metro Water Boards and Hydro-Electric Power generation companies.

Do the cloud seeding chemicals cause any damage to public health and environment?

Research investigations on the damaging impacts of chemicals used for cloud seeding indicated no perceptible damage to public health and the environment. Since the seeding materials are used for the operations are very small in quantities their presence in the precipitation has been detected to be very low in concentration. For instance silver in rain water or snow is found to be in the range of 10 to 100 nano-grams/litre. This low concentration of silver is much below its US Public health Standard of 50 micro-grams per litre. In the case of iodine, its presence in the rain water sample collected at the end of cloud seeding operations is found to be far lower in concentration than that found in the common iodised table salt used by the people.

Does cloud seeding in one region prevent the surrounding regions to get their normal rainfall?

This usual question whether cloud seeding “robs Peter to pay Paul” must be answered with an emphatic “no”. The cloud seeding in one place does not cause any perceptible reduction in rainfall that normally occurs in the neighbouring areas. Out of the total atmospheric moisture continuously flowing over any region the normal condensation removes about 20% of the total moisture to form into clouds. Cloud seeding causes additional precipitation although a cloud normally gives 20% of its moisture as rainfall. Further artificial rain making by cloud seeding causes additional precipitation of 20%. So 100 (0.20 x 0.20 x0.20)=0.8% of the water vapour is removed. Hence the total proportion of atmospheric moisture that gets transformed into artificial rain fall of 20% on earth is very small. Moreover the atmospheric moisture gets continuous replenishment due to transpo-evaporation from the forests, evaporation from the natural water courses and updrafts in the mountainous terrain. Some cloud seeding operations indicated slight increase in precipitation in areas upto 100 miles downwind of the target areas. Thus cloud seeding operations do not rob Peter to Paul.

Can cloud seeding operations prevent or control drought conditions?

Droughts normally occur due to deficiency of rainfall consequent to the absence of suitable clouds in the required places at the proper time. In the absence of clouds one cannot create the suitable clouds and conduct cloud seeding operations to obtain additional precipitation. Hence cloud seeding operations cannot create clouds and stop drought conditions. However cloud seeding operations can be used to substantially increase the annual rainfall in a highly favourable year by seeding the clouds and then store this additional water in the reservoirs for use during the subsequent years when drought conditions may occur. Hence one can use cloud seeding operations as a tool for water resources management which can mitigate to some extent the damaging impacts of a crippling drought.

How does Hydro Tasmania conduct the cloud seeding operations?

Hydro-Tasmania has been successfully conducting the cloud seeding operations in Australia during the last 40 years on scientific lines and at an inexpensive cost. It employs an expert who is independent of cloud seeding operations. He identifies the target areas for cloud seeding operations on the basis of water levels in the reservoirs used for hydro-power generation. The organization employs cloud seeding officers who are trained in weather forecasting.

The decision to fly for cloud seeding operations is made by the duty officer on the basis of all kinds of weather information provided by the satellite images, radars and the Australian Bureau of Meteorology and their own experience in weather forecasting. The organization employs a twin engine air craft (a cessna conquest) which is taken on contract every year for the period of cloud seeding.

This aeroplane is provided with two silver iodide generators or burners containing the silver iodide solution under pressure, one mounted under each wing. Every cloud seeding flight operation is under the control of one pilot and also one cloud seeding meteorologist.

When this aeroplane is conducting the operation the cloud seeding officer advises the pilot on the cloud seeding tract chosen upwind of the target region.

Whenever suitable cloud is encountered on the seeding track, the cloud seeding officer ignites the burner by using the concerned switches provided within the aircraft. The independent expert directs the stoppage of the cloud seeding operations in the areas where the storage reservoirs are attaining their full storage capacity.

LOW-COST GROUND GENERATORS USED BY EXPERTS AND FARMERS

Cloud seeding operations are conducted successfully for almost 50 years in several countries including USA where at present 100 catchments are subjected to cloud seeding to increase winter precipitation and the increased run-off varies from 5% to 15%. 20 years of cloud seeding in Tasmania has been proclaimed as a successful operation by the Australian Council of Scientific and Industrial Research Organization (CSIRO) which confirmed that the rainfall can be increased by 15% to 20% on seeded days. Due to lack of adequate water resources for drinking, agriculture, industry and other needs cloud seeding operations have been taken up in Jordan since 1986 under Precipitation Enhancement Project (PEP). Some of the salient features of this project are:

A special airplane for cloud seeding and 24 ground generators, located at selected sites are used.

- AgI is used with acetone solution
- The average time of cloud seeding by the Airplane is 50-70 hours/season.
- The average of the cloud seeding by the ground generators is 2000 hours/season
- The Doppler C-band weather radar determines the candidate cloud that could be seeded by airplane.
- A special GPS system is used to display the track of the airplane on the radar display.
- Voice communication is available between the radar meteorologist and the airplane to direct the pilot to the candidate clouds.

In China the experts are using not only many aeroplanes but are also using many ground generators including rockets, cartridges and anti-aircraft guns for cloud seeding. However since the use of rockets and anti-aircraft guns pose some problems and since aeroplanes cannot be used in certain special locations like deep valleys surrounded by steep hills **the ground generators become the choicest instruments for cloud seeding to augment precipitation** in some localities.

The latest in ground-based pyrotechnic applications are the ground-based flare-trees offered by the Weather Modification Company of USA . This flare-tree has a tripod base which provides good stability even under the most extreme weather conditions and provides for easy leveling. The flare-tree is provided with 9 racks, each holding upto **12 glaciogenic or hygroscopic flares** and it can be configured for manual or remote controlled operation. Some kinds of ground generators are trailer-mounted so that they can be positioned prior to the operation in the selected locality and removed conveniently after completion of the work. In case these generators are to be used on the mountains, they would be located near the existing roads or access tracks and below ridges to minimise visibility. The trailers are camouflaged steel containers having a gas burner located 3 meters above the ground. Propane gas from an adjacent 2000 litre container vaporizes a mixture of silver iodide and acetone. The combustion and the resultant plumes are generally invisible. Different kinds of ground generators can be developed and used for different localities. Some of the Indian farmers in Kutch region of Gujarat previously used locally developed ground generators and conducted cloud seeding experiments. Many western experts also developed different ground generators for cloud seeding operations. These case studies are presented here.

I. Extensive use of ground generators in USA :

In several states of USA the North American Weather Consultants (NAWC) have conducted cloud seeding operations in several dozens of localities by using not only aeroplanes but also many advanced ground generators as listed at the end of this presentation.

In order to unfold the detailed procedures followed in using ground generators some of the salient features of one of the field projects executed by the North American Weather Consultants (NAWC) under the guidance of the reputed International expert Dr.Don.A.Griffith is presented here with his kind permission.

Gunnison Precipitation project Cloud seeding Operational Plan :

Objectives of the Project : The objective of the proposed project is to augment the precipitation / snow pack that occurs with the passage of late fall, winter and spring cloud formations over the intended target areas in Gunnison river, a tributary of Colorado river in USA;

The primary target area is defined as those mountainous areas above 9000 feet above the mean sea level msl located in southwestern Gunnison County, northern Hinsdale and northern Saguache Counties. The proposed target area constitutes most of the tributaries to the upper Gunnison River Drainage that enter the Gunnison River from the south. Figure 1 provides a map of the proposed primary target area.

There will be some positive (increases in precipitation) effects downwind of this primary target area. These effects will occur primarily on the Eastern slopes of the Sawatch Range and Southern slopes of the La Garita Mountains.

Project Implementation : Operational seeding decisions of when and which ground based generators should be utilized during specific cloud system occurrences will be made by the Company headquarters which is equipped with four personal computers with T-1 access to the internet. A variety of weather products, available through the internet, will be monitored to assist in making these seeding decisions. These products, most of which are provided by the National Weather Service (NWS) will include: weather satellite (IR and visual) photos, surface charts, constant pressure charts (i.e.700,500mb), upper-air rawinsonde observations (weather balloons), NEXRAD weather radar information, surface weather reports (typically available at hourly intervals), NWS weather forecasts and prognostic (forecast) charts of a variety of weather parameters.

NAWC meteorologists will monitor the above information to determine if NAWC's generalized cloud seeding criteria are met and, if so, which generators should be operated. NAWC's generalized seeding criteria developed upon practical considerations plus the results from previous winter orographic weather modification research programs are presented below.

NAWC Winter Cloud Seeding Criteria :

(1) cloud bases are below the mountain barrier crest.

(2) low-level wind directions and speeds that would favor the movement of the silver iodide particles from their release points into the intended target area.

(3) no low level atmospheric inversions or stable layers that would restrict the vertical movement of the silver iodide particles from the surface to at least. The -5°C (23°F) level or colder.

(4) temperature at mountain barrier crest height expected to be -5°C (23°F) or colder

(5) temperature at the 700 mb level (approximately 10,000 feet) expected to be warmer than -15°C (5°F).

A network of 8 to12 ground based silver iodide generators will be used in the conduct of this project. These generators will be sited at private residences or public places of business. The residents or business operators will be trained in the operational procedures to be used in turning the generators on or off.

NAWC meteorologists will contact these operators when conditions have been determined to be favorable for operations and request that the generators be turned on. When conditions are no longer favorable, the operators will be called to turn the generators off.

Figure 1 provides tentative locations of these generators. The project is planned to operate during the period of November 15th – April 15th during the next five winter seasons beginning in the 2003-2004 winter season. This period is the same as that contained in an existing cloud seeding permit covering most of the remainder of the upper Gunnison River Drainage.

Figure 2 provides a photograph of one of NAWC's ground based, manually operated units. Each generator site is equipped with a propane tank. The propane is lit within the generators burn chamber and then the silver iodide (dissolved in acetone) is injected into the propane flame. As the effluent from the generator cools, literally trillions of microscopic sized particles of silver iodide are produced. These particles have the ability to cause water droplets within clouds that are colder than approximately -5^{o}C to freeze. The tiny ice crystal that is produced, if it remains in a favorable environment, will grow into a snow flake. NAWC will use a seeding solution composed of acetone, silver iodide, sodium iodide and paradichlorobenzene. This solution has been shown to produce more effective seeding particles at warmer temperatures (i.e. about -10^{o} to -5^{o}C and to produce these crystals more quickly than pure silver iodide (Finnegan, 1999). Each generator will consume 8-12 grams of silver iodide per hour of operation. Aerial seeding is not proposed for this project.

Project Design for Economic Benefit to the Target Area : The proposed project design is based upon NAWC's significant experience in designing, conducting and evaluating similar winter orographic weather modification projects in the western United States dating back to the 1950's. The design is also based upon the conduct of a number of research programs in weather modification including the Climax Experiments I and II conducted in the Central Rocky Mountains of Colorado (Mielke, *et al*, 1981) and the Colorado River Basin Pilot Project (CRBPP) conducted in the San Juan Mountains of south-western Colorado. NAWC's former affiliate company, Aerometric Research, performed a comprehensive evaluation of the latter program (Elliott, *et al*, 1976).

Evaluations of previous NAWC winter orographic **projects have indicated increases in target area precipitation in the range of 10-20%**. For example, a long term project that began in central and southern Utah in 1974 and continues to the present time has produced approximately a 14% increases in target area precipitation based upon a target and control evaluation (Griffith, *et al*, 1991). Results from other projects conducted in Utah and surrounding Inter-Mountain states are provided in Figures 3 and 4.

Based upon the positive results achieved in these projects and also upon the topography of the target area and the type of storms that frequently impact the area, it is NAWC's expectation that a **10-20% increase in target area precipitation can be produced by this project**.

The predicted 10-20% increases will have a variety of positive impacts within Gunnison County. The additional snow in the winter and spring months will benefit the tourism interests (i.e. skiing, snowmobiling).

A report prepared by the Colorado Department of Natural Resources documents the impact of additional snow on ski area attendance (Sherretz and Loehr, 1983). This report estimated that a 15% in snowfall for hypothetical dry winters at Colorado ski areas are associated with 2-8% increases in total season visits.

Increases in winter snow pack will result in enhanced spring and summer stream flow on the upper Gunnison River and its tributaries. This additional stream flow will provide an economic benefit to a variety of users and consumers. **User groups that may derive benefits will include: hydro-electric generation facilities, fishing,** rafting and general tourism interests. User groups that will benefit from the project will include irrigated **agriculture, livestock** and **municipal water** interests.

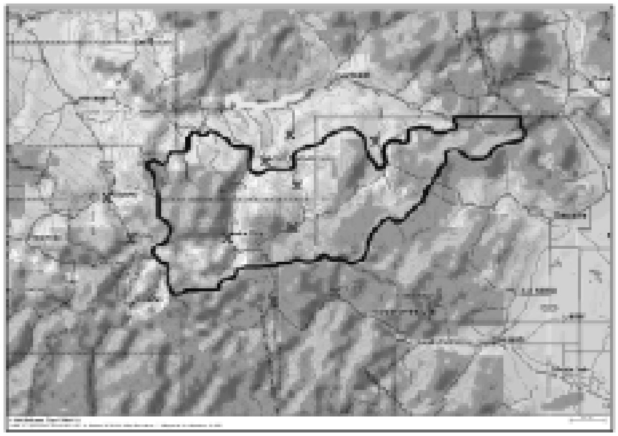


Figure - 1 (a) : Proposed Primary Target Area and Approximate Ground Generator Locations

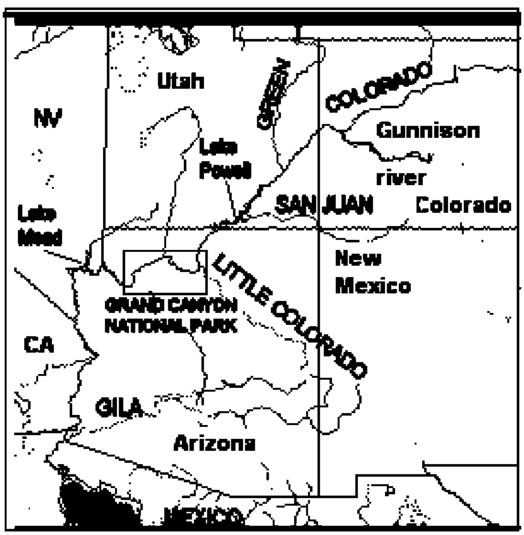


Fig-1b Colorado river with the experimental target area in Gunnison river basin

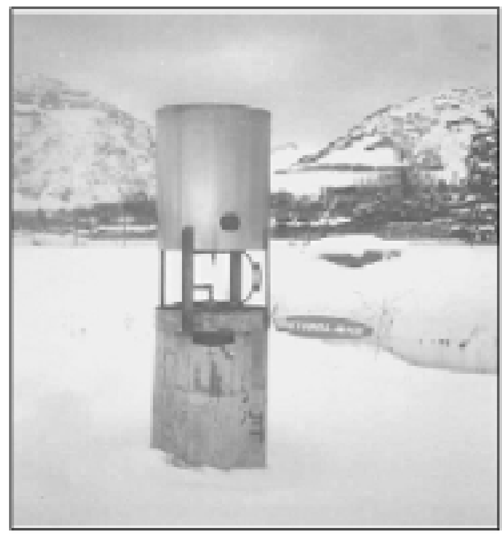


Figure - 2 : NAWC Ground - Based Silver Iodide Seeding Generator

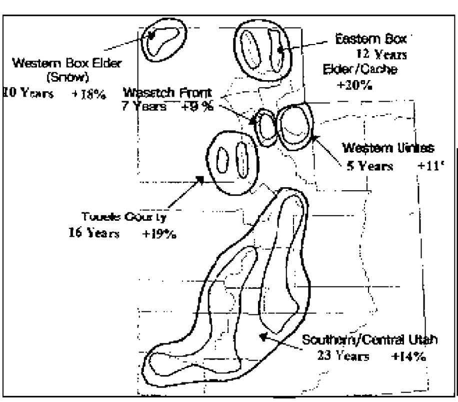


Figure 3. Results from NAWC Winter Cloud Seeding Projects in Utah

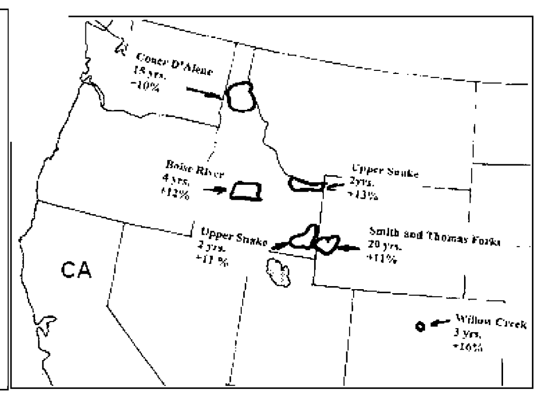


Figure 4. Results from other NAWC Winter Cloud Seeding Programs in the Intermountain West.

A report prepared by the Utah Division of Water Resources estimated that the **additional streamflow** that results from a large winter orographic weather modification program being operated in the State of Utah by NAWC **is being produced for approximately $1.02 per acre foot** (Stauffer, 2001). The value of this water, depending upon its use, is probably in the range of $10-$50 per acre foot in primary benefits. There are a number of secondary benefits as well, for example the impacts on tourism, which increases the value of this water. Increases in tourism also generate additional sales tax revenues which will benefit Gunnison County and the State of Colorado.

Benefit to Both in the Target Area and Colorado Countries : The expected economic benefits to Gunnison County were documented in the previous section. There will be additional general benefits including **increases in timber growth, increases in water stored in under-ground aquifers**, **increased spring flows**, and **carry-over storage in reservoirs from one year to another** which may **lessen the impacts of future droughts in the area.**

Some of the additional water generated by the project will flow downstream into other Colorado counties (e.g. Montrose, Delta, Pitkin, and Chaffee Counties) which will derive economic and general benefits from this additional water (i.e. irrigation, hydro-electric generation, municipal water, tourism). Surrounding counties will also benefit from increased tourism in the area which will generate additional tax revenue for these counties and the State of Colorado.

Project is Scientifically and Technically Feasible : A Policy Statement on Planned and Inadvertent Weather Modification adopted by the American Meteorological Society in 1998 (AMS, 1998) which states in part “There is statistical evidence that precipitation from supercooled orographic clouds (clouds that develop over mountains) has been seasonably increased by about 10%. The physical cause-and-effect relationships, however, have not been fully documented. Nevertheless, the potential for such increases is supported by field measurements and numerical model simulations.” NAWC’s design for this project is directed at winter supercooled orographic clouds. This AMS statement provides scientific support to NAWC’s design. This policy statement was no doubt based in part upon earlier research programs conducted in Colorado that were referenced earlier (Climax I and II and the Colorado River Basin Pilot Project). Another research program of relevance to the design of this project was conducted in the Jemez and Sierra Nacimiento Mountains of northern New Mexico from 1969 to 1972. This project utilized ground based portable silver iodide generators to seed portions of winter orographic storms on a randomized basis. A statistical analysis of the effects of the seeding indicated an increase of 13% during the seeded 24 hour periods (Keyes, *et al*, 1972).

NAWC cites its long history, which dates back to 1951, in conducting successful winter orographic weather modification programs as evidence that the conduct of this project is technically feasible. Attachment provides a summary listing of some of NAWC’s previous operational precipitation enhancement projects. Many of these projects were winter orographic weather modification projects.

NAWC - Operational cloud seeding programmes

http://www.nawcinc.com/Wxmod.pdf **G = Ground Generator**, **A= Aeroplane** , (Silver Iodide and Dry Ice used)

1.	Gunnison County, Colorado (2003)	G	Extra water for Irrigation
2.	Little Cottonwood CanyonUtah(1996-2003)	G	Extra Rainfall
3.	Wellsville and Wasatch Mountains of Northern Utah (1997-2000, 2002-2003)	G	Extra water for Irrigation
4.	Upper Ogden River and Lost Creek Watersheds, Utah, (1991-1993)	G,A	Extra water for irrigation
5.	Upper San Joaquin River Drainage, Southern Sierra Nevada of California (1951-1987,1990-1992)	G,A	Extra water for Hydropower
6.	Mountain Watersheds in Central and Southern Utah(1973-83,1987, 1988-2003)	G,A	Extra water for Irrigation
7.	Bear Lake Drainage, Wyoming and Southeastern Idaho (1954-1970, 1979-1982, 1989-1990)	G	Extra water for Hydropower
8.	Santa Barbara Country, California (1950-1953, 1955,1956-1960, 1978, 1982-1997, 2002-2003)	G,A	Extra for Municipal & Agricultural
9.	Grouse Creek, Raft River, Wellsville and Wasatch Mountains of Northern Utah, (1989-1997, 2001	G	Extra water for Irrigation
10	Provo and Weber River Drainages in Western Uinta Mountains of Utah (1989-1995, 2000-2003)	G	Extra water for Irrigation
11	Wasatch Mountains in Eastern Salk Lake Country, Utah (1989-1996)	G	Extra municipal water supply
12	Upper Kings River Drainage in the Southern Sierra Nevada of California,(1988-1994)	G,A	Extra water for Irrigation/Hydropower
13	Tsengwen Dam Drainage, Taiwan,(1992, 1994)	G	Extra water for Irrigation
14	Grand Mesa and West Elk Mountains of Western Colorado (1990-91)	G	Extra water for irrigation
15	San Gabriel Mountains, California (1959-1973, 1991-93, 1997-2001)	G	Enhance municipal water supply
16	Bannock, Portneuf and Bear River Mountain Ranges of Southeastern Idaho (1988-89, 1992, 1993)	G	Extra water for Irrigation
17	Uinta Mountains of Northeastern Utah(1977, 89, 2003)	G,A	Extra water for Irrigation
18	Boise River Drainage, Idaho (1992-96, 2002-03)	G	Extra water for Irrigation Hydropower
19	Willow Creek Drainage, Colorado, (1992-95)	G	Extra water for Irrigation
20	Higher Elevation Watersheds of Nine Eastern Idaho Countires and One Western Wyoming Country,(93,95)	G	Extra water Irriation
21	Santa Clara Country, California, (1992)	A	Enhance Municipal water
22	Chixoy River Drainage, Guatemala, C.A (91,92,94)	G,A	Extra water for hydropower
23	El Cajon Drainage Basins, Honduras, C.A(93,94,95,97)	G,A	Extra water for hydropower
24	Pine Valley Mountains in Southwestern Utah(1985-87)	G	Extra water for Municipal and Irrigation
25	Deschutes River Drainage, Oregon(64-65, 74-1976)	G	Extra water for hydropower
26	Port Ensenada, Mexico (1970-76)	G	Enhance Municipal water
27	Coeur D'Alene Lake Watershed, Northern Idaho (19950-51, 1952-60,1966-71, 1973-74)	G	Extra water for hydropower
28	Hungry Horse Reservoir Area, Northwestern Montana, (1966-71)	G	Extra water for hydropower
29	San Benito Country, California (1964-1966)	G	Extra water for Irrigation
30	Owyhee Reservoir, Southwestern Idaho(1954-56,59-62	G	Extra water for Irrigation
31	Ventura County, California, 91957-1960)	G	Extra water for Irrigation and Municipal Water supply
32	Santa Ana River Basin, California, (1956-60)	G	Enhance Municipal water
33	Lake Almanor Drainage, Northern Sierra Nevada of California (1952-1960)	G	Extra water for hydropower
34	Mokelumne&Stanislaus Rivers, Central Sierra Nevada of California (1952-1960)	G	Extra water for hydropower
35	Campbell River Drainage, British Columbia (1954-1960)	G	Extra water for hydropower
36	Southern Casacades, Oregon (1951-1960)	G	Extra water for hydropower
37	Crane Valley in the Central Sierra Nevada of California, (1954-1959)	G	Extra water for hydropower
38	San Diego County, California (1950-51, 1956-57)	G	Enhance Municipal water
39	Ocean Falls, British Columbia, (1955-57)	G	Extra water for hydropower
40	Decatur and Clarke Counties, Iowa (1957)	G	Extra water for Agriculture
41	Greene, Boone and Story Counties, Iowa, (1957)	G	Extra water for Agriculture
42	Dallas County, Iowa, (1957)	G	Extra water for Agriculture
43	Southeastern Idaho (1953-1955)	G	Extra water for Irrigation

For more details refer the websites :
http://www.weathermod.com/seeding_equipment.php http://www.jmd.gov.jo/infra6.html

II. Indian farmers seed clouds with ground generators :

As a social worker of Kutch Mr.Shanthilalbhai Meckoni realised that the development of the Kutch region of Gujarat can not be achieved unless the annual rainfall of the region amounting to about 250mm is substantially increased for providing adequate water for drinking and irrigation purposes. In order to conserve water he implemented several water harvesting structures as Vice-President of Vivekananda Research and Training Institute in Kutch region. In the process he realised that the utility of his water harvesting structures becomes more useful if only he can increase the annual rainfall by tapping the sky water from the clouds whenever they appear in the sky over the Kutch region.

He discussed with several foreign experts on how to conduct cloud seeding experiments to make available more water for the domestic and agricultural needs of the people in this region. Among the experts he contacted one professor from Jerusalem University told him how they conducted cloud seeding experiments by using ground generators in Israel for augmenting the annual rainfall. Israel used hot air ovens packed with coke that was heated upto about 1200°C for sprinkling technical grade silver iodide powder in small quantities so that the vaporized fumes directly get into the super cooled regions of the cloud where the silver iodide particles work as ice particles over which the super cooled water and the moisture are precipitated to promote the growth of ice particles into ice crystals and then to ice flakes that fall down to earth due to gravity as snowfall or rainfall.

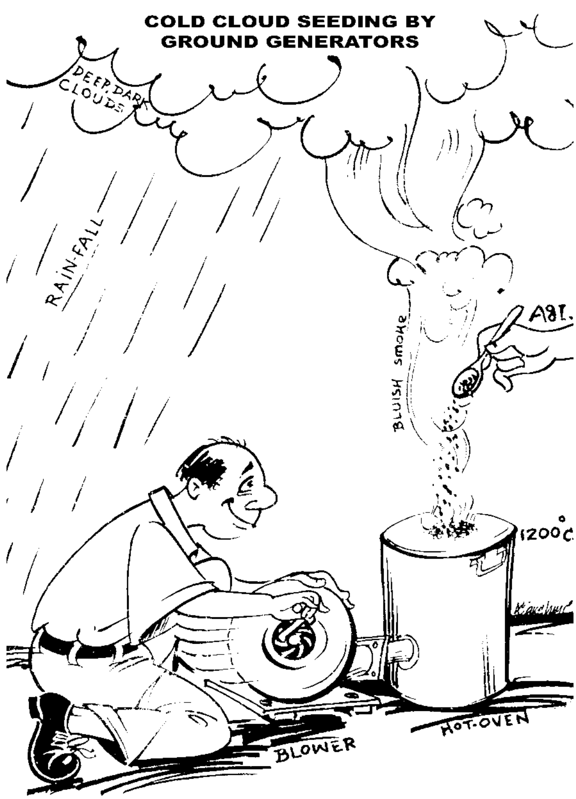
Meckoni considered the special topographical and meteorological features of his region and made suitable modifications in the procedures for conducting the cloud seeding experiments on the lines of the initial cloud seeding experiments conducted in Israel. The farmers in the Kutch region of Gujarat came forward to take advantage of this new technology to improve their lot. Meckoni has supplied the farmers with the ovens fixed with the blowers along with the coke and technical grade silver iodide needed for conducting the experiments. The farmers used to look into the skies for the arrival of dark clouds and cloud clusters and then immediately start the experiments for seeding such suitable clouds. They used to sprinkle 200 gms of silver iodide over hot coke oven with 1200°C at 5 to 8 grams at a time for 40 minutes by using a tea spoon. They used to maintain proper temperature so that the silver iodide sprinkled over the white hot coke in the oven does not get into the liquid state but gets directly into the vapour state so that the vapours directly get carried by the updrafts into the colder regions of the clouds in about half an hour time. Heavy rain used to fall on the ground within 45 minutes. The base of the clouds must be within 1km to 1.5km from the ground level because if the cloud base is far higher from the ground the precipitation from the clouds may not reach the ground as rainfall as the droplets may be carried away again as moisture into the atmosphere.

The farmers received scientific information about the suitability of clouds and the timings when they have to conduct the experiments. The officers of the Indian Meteorological Department who were operating weather radars in Gujarat used to detect the appropriate clouds and pass on the information through the All India Radio station to the farmers who in turn used to take timely action to conduct the experiments. The farmers also used to confirm by local observations about the seedability conditions before launching the experimental operations. The farmers are said to have come forward to collect donations from each village for purchase of chemicals and equipment for the experiments and succeeded in achieving their goals of augmenting the annual rainfall in the drought prone Kutch region. However this good work didnot continue for long for various reasons.

Taking this example the farmers in other states must develop improved ground generators and conduct these cloud seeding experiments to augment their annual rainfall. It must be remembered that ground generators are used in several countries for cloud seeding operations to augment the snowfall or rainfall.

Even if the state Government uses aeroplanes regularly for cloud seeding operations it may not be possible for the aircrafts to seed all the clouds at a time when suitable clouds are likely to be present in distant places in the state under highly favourable weather conditions. For various reasons, the pilots may not be able to reach the target clouds within an hour or the life time of the clouds, making the operations ineffective Thus ground generators, anti-aircraft guns and rockets are still used for cloud seeding operations mostly in several parts of China and Russian states. The Indian farmers also must make genuine attempts to increase the annual rainfall in their respective regions by conducting cloud seeding operations by using suitably modified ground generators.

A smoke generator emits 10^{16} smoke particles per gram of AgI burned and only one in 10 of these particles are effective as ice forming nuclei at –20°C while only one in one lakh at –10°C with a consumption rate of a few grams of AgI per hour. The generator effluent at 10 meters downwind of the generator will have nuclei effective at –20°C of about 3×10^{11} crystals per cubic meter. Of those effective at –10°C the concentration will be 3×10^{7} per m^3. It means the effluent would over-seed the cloud near the generator. But if the generator is located at a point at the base of the mountain slope or in a low flying aeroplane about 1km below the –5°C level entrained within convective updraft, the smoke will be diluted by turbulence by a factor of 100 to one million times. On a complex mountain terrain the generator smoke rises and spreads rapidly and the plume top was found to rise 1.5kms at 5km downwind in the CLIMAX project in wind tunnel modelling.



An English Daily Bombay Times, in its Edition dt.23-6-1995 presented the successful artificial rain making experiments conducted by Shantilal Meckoni who successfully produced additional rainfall in Kutch region of Gujarat and in the Vaitarna and Tansa drinking water lakes of Bombay by sprinkling silver iodide over hot coke oven in ground generators. This rain induction method involves placing silver iodide powder in a furnace to evaporate upwards into supercooled water regions in the clouds where the supercooled water forms into ice crystals that grow into ice flakes which fall down to earth as heavy rainfall.

The parameters required for this experiment are: humidity must be more than 70%, wind velocity about 15kms per hour, cloud thickness must be about 10,000ft. and temperature in the cloud should be minus 5° C. The experiment conducted at Tansa lake produced more than 70mm rain in 2 hours duration. For each experiment just 250gms of silver iodide and a small amount of coke for the furnace is needed to maintain a temperature of about 1200° C and a blower is used for the purpose. Meckoni says that Israil and Russian Governments conduct these experiments even when there is natural rainfall because they want to increase the water availability by making the clouds grow in size by merging with the neighbouring smaller clouds and also by processing more moisture from the updrafts created by the latent heat released during the experiments. There are no side effects as the iodide in the rain water disintegrates and the silver remains only in very miniscule quantities that are within the safe limits. Meckoni learnt this science of rain induction from a visiting professor from Jerusalem University and chose Kutch his homeland for these experiments.

According to a report prepared by Bombay Municipal Corporation from July 16 1992 to August 9, 1992 cloud seeding work was carried out for 9 days at Tansa and Modak Sagar lakes. On these days it was observed that the average rainfall was about 25mm per day at Tansa and about 35mm per day at Modak Sagar while the average rainfall recorded when no cloud seeding was done was about 10mm per day at Tansa and about 13mm per day at Modak Sagar. It means that there was a 200% increase in the rainfall during the cloud seeding days. It is reported that the water level in Vaitarani lake rose by 3 meters in 2 days around 25 July 1992. It is a very inexpensive technique because for one station of 5000 hectares the Bombay Corporation spent Rs.2,250/-

Operational Experimental Conditions : To summarise, the humidity should be over 70%. The cloud should be at a height of 10,000 feet the atmospheric temperature of the cloud should be minus 5°C, 250gms of silver iodide should give best results and the wind velocity should be less than 15km/hour. For more information on warm cloud seeding experiments conducted with the help of the ground generators please see the chapter on "Cloud seeding experiments in India".

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GUIDELINES FOR CLOUD SEEDING IN TEXAS (USA)

A Texas cloud seeding programme, SOAR (Southern Ogallala Aquifer Rainfall Project) uses a specially modified aeroplane and trained pilots and meteorologists to conduct cloud seeding operations to increase annual rainfall by cold cloud seeding. The following guidelines and procedures are followed for cloud seeding operations.

Guidelines :

1. Seedable clouds are those with cloud top heights between minus 5°C to minus 15°C.
2. AgI seeding is done at minus 5°C level (where maximum efficiency for aggregation occurs) in the early stages of cloud development and within the first half lifetime.
3. Seeding should reach dynamic mode when 100 ice nuclei (IN) per litre are present as detected by Radar volume scans.
4. Seeding is done in two ways either at the base or at the cloud top.
5. Seeding at cloud base is done when updrafts of 200ft per minute are present and by injecting 40gram AgI pyrotechnic flares at about 10 to 30 miles upwind of the target area.
6. Seeding at cloud top is done by flying just above the freezing level by dropping two ejectable 20gram AgI pyrotechnic flares at10 to 30 miles upwind of the target area.

Titan Software :

TITAN **(**Thunderstorm Identification Tracking Analysis And Nowcasting) software is used in cloud seeding operation and its processes volume scan data from 5cm radar recording a full volume scan within 3 minutes. It shows the clouds and aircraft flight paths. This data is for analysis of many variables like storm cloud identification, location, area, volume, mass of precipitation, Vertically Integrated Liquid (VIL) and also the rates of variation of all these above parameters. TITAN provides a tool for the skilled meteorologist to quantify a seedable cloud.

Decisions of Meteorologists :

The meteorologist generally takes a series of decisions needed for cloud seeding operations and they are classified as 1)Now casting, 2) Decision Time, 3)Qualification, 4) Treatment, 5) Maintenance and 6) Termination.

Now casting is the procedure by which the meteorologist makes continuous analysis of the atmospheric conditions desirable for deep convection and also for seedable clouds to form. After studying the meteorological output that forecast the prevailing thermodynamic conditions and by making a routine analysis of surface and upper air conditions, the **prediction about** the possibility of **rain bearing clouds** is made and the pilots are briefed accordingly.

Decision Time is the time when the **meteorologist finally decides to start a cloud seeding** operation based on the forecast on atmospheric conditions and after observing cloud echoes on TITAN and also the echo development trends. Quite often a cloud seeding operation is started by visually observing the growth of the clouds or by observing the surface temperature reach a threshold when convection current is expected to initiate or to intensity known as the convective temperature. For a cloud seeding operation with good timing the decision time should be preceded by qualification.

Qualification is the occasion **when a cloud gets qualified to become seedable**. This decision to qualify the cloud is seedable can be made visually by the pilot by observing a cloud before it is detected by the radar. But frequently a cloud is observed on radar before seeding takes place. In the target area a seedable cloud echo generally reaches VIL (Vertically Integrated Liquid of 10kg/m^2) and the cloud continues to rise. Further, the volume of the cloud echo should be about **200km³ with cloud tops at about 8km**. In order to estimate the growth characteristics and lifetime of the target clouds the growth trends of other clouds outside the target area are generally examined. A short lifetime for the cloud does not provide good chances for seeding. A seedable cloud on the TITAN software generally shows a pocket of about 15% of the echo volume with a higher **reflectivity above 40dBZ at an altitude of 6 to 10km.**

Treatment is the time **after the initial seeding of the cloud**. Sometimes treatment may be preceded by qualification in the case of a few clouds. A cloud qualifies as seedable and the meteorologist gives instructions to the pilot to start seeding the cloud. Cloud seeding begins when the pilot encounters, locates or is directed to updraft portion of the cloud where the seeding agent is released. As stated already the updraft shall be over 200ft.per minute.

Maintenance is the time period when **constant rate of seeding** is done with continued observations of growth in the echo volume. During this time cloud echo has not attained its half lifetime. Analysis of the dynamic variables of cloud echo and their trend helps to define the half-life of the cloud. Although the pilot continues to experience the updrafts the meteorologist will be able to locate areas of new growth within the cloud structure.

Termination is the time when the cloud **seeding operation is stopped**. The operation is stopped either due to absence of updrafts in the clouds or when the cloud seeding echo exceeds its half life time.

Procedues for flight operations :

For conducting seeding operations at the cloud top, AgI flares are dispersed where the updrafts are located for these operations. Firstly the cloud top temperatures must be in between minus 5°C and minus 15°C. Secondly, high concentration of super cooled water must be present. Thirdly, the updraft velocities in the cloud must be more than 200ft per minute.

The meteorologist at the radar facility on the ground station must indicate to the pilot the most workable cloud based on the criteria of cloud height and super cooled liquid water concentration.

The pilot will take the aircraft to the altitude where the temperatures of the cloud top are found to lie between minus 5°C and minus 15°C. The air craft makes penetrations into the cloud to detect locations with sufficient super cooled water and then the pilot is satisfied with the liquid water content he measures the updrafts. When the vertical speed indicator shows updraft velocities above 200ft per minute the pilot injects the seeding agents as directed by the meteorologist, generally at the rate of one flare for 200ft per minute.

When the seeding chemical gets properly dispersed in the cloud it would grow as a cauliflower structure and it shows that the seeding agent is working effectively.

When the aircraft makes penetrations into the cloud, it will experience both up and down drafts making control of aircraft difficult sometime. The downdrafts may sometime exceed 200ft. per minute and if the aircraft sprinkles chemical for a few seconds it can make full recovery without experiencing any hazards. But if the aircraft has to go deep into the cloud an out heading previously planned before penetration will have to be used. However an experienced meteorologist will also help the aircraft with any complications of finding clear sky conditions.

For the cloud base seeding operation, the pilot examines the inflow or updraft in areas of new convective development. Aircraft position is important to ensure proper dispersal of the seeding agent from an altitude of 500ft. below the cloud base. The aircraft must be trimmed suitably and the power is set on the basis of the type of aircraft used. Power settings will be different for different air crafts used for seeding operations. After the aircraft is properly set up for seeding from below the cloud base the pilot carefully observes the updrafts. Depending upon the rate of rainfall, the rain shafts are seen from blue to black colours. After locating the rain shaft, the aircraft is directed by the meteorologist to the area of updrafts as the meteorologist has a radar that detects areas with updrafts. Sometimes it may be difficult to locate sustained updrafts. The aircraft underneath the cloud base the overhang must be just outside the area where rainfall is occurring. Downdrafts are experienced when flying close to the rain shaft or through the rain. An aircraft has a vertical speed indicator to enable the pilot become aware of the aircraft climb and descent rates. The meteorologist calculates how much seeding agent should be used for dispersal in a particular cloud. The pilots and meteorologists are regularly sent for weather modification training programmes and workshops in addition to their regular training for the specific purpose of weather modification operations.

SOAR Program :

Agriculturists in some counties of Texas have been over pumping water from Ogalla Aquifer resulting in declines in water table by 3 to 5 ft per year. Since this ground water sustains the livelihood of innumerable farmers this ground water has to be conserved at any cost due to absence of any worthwhile surface water source and for this purpose augmentation of annual rainfall by cloud seeding has become an inevitable remedial measure for sustainable development.

10 cloud seeding projects in different regions of Texas were operational in 2002 and SOAR programme is one of them. It uses 2 pressurised twin engine aircrafts for cloud seeding operations. The meteorologist at the radar ground station forecasts weather daily and directs the cloud seeding operation. The meteorologist gets all the relevant data from the satellite stations and national weather service stations (NWS) and determines the seedability of the clouds. For seeding purposes 20gm ejectable AgI flare (ED) and 40 gram burn-in-place flares (BIP) are used. All the cloud seeding projects in Texas use C-band radar in conjunction with TITAN software which provides 3-dimenstional structure of echoing clouds in real time to the meteorologist for giving directions to the pilot to inject proper quantities of seeding agents into proper locations in the cloud. EMWIN (Emergency Managers Weather Information Network) warnings and alarm signals can be configured and observed on the computer windows machine.

The clouds suitable for seeding must pass the following 3 tests :

The top of the cloud must be colder than about –5^{o}C because the warmer clouds do not develop much ice even though they are slightly super cooled.

The cloud must have a steady updarft speed of atleast 200 ft per minute to provide a continuous supply of moist air that enables the ice particles to keep on growing.

The cloud should not contain much natural ice because if the cloud already developed some ice it need not be seeded since mother nature is already working efficiently.

Hence the cloud must be sufficiently cold, ice-free and must have adequate updraft to become eligible for treatment.

Criteria for seeding the cloud at the top or at the bottom depends upon the cloud top structure, visibility, cloud base height, clearance into military operating areas and the time available to reach the seeding altitude.

In order **to conduct seeding at the base of the cloud** a pilot looks for the inflow or updraft in areas of new convective development. **For seeding at the top of the cloud** the pilot usually has to locate the convective towers with temperatures between –5°C and **-**15°C . Subsequently the pilot drives the aircraft to make penetrations into the cloud to find sufficient super cooled water and when there is sufficient liquid water content the updrafts will be measured and the seeding chemical is dispersed by using one flare (40 grams) for 5km^3 of cloud volume. Cloud top seeding must be done before the first third of the life time of the cloud while at base in the first half of the life time.

A seedable (S) cloud is one that has a large concentration of super cooled water above the freezing level. Using TITAN the meteorologist can cut a cross-section through the cloud to view the vertical extent of the cloud water. Usually, clouds with high convective available potential energy (CAPE) and low cap are seedable. A CAP which is a warm layer above the ground, reduces the buoyancy of the cloud water and acts as a lid precluding any further development. The vertical integrated liquid (VIL) of the cloud is also monitored. VIL is the amount of cloud mass per unit area. Seedable clouds have high VIL. Sometimes the CAP is easily identifiable visually when convection is trying to develop and the cloud structure spreads laterally below the warm layer or lid.

TITAN software is used to compare the characteristics like the lifetime, area and rainfall of seeded clouds and unseeded clouds which serve as controls. A control cloud is an unseeded cloud almost in the same environment as its seeded cloud partner in similar synoptic conditions at similar distance to the radar and from the same time of observation.

Seedable versus Non-seedable Cloud : TITAN software is used to determine whether a cloud is seedable or not? A seedable cloud is one whose cross section is observed by the meteorologist to estimate the vertical extent of the cloud water and clouds that generally contain a high convective energy CAPE (Convective Available Potential Energy, in other words it is the energy available for convection, the updraft and a low CAP (The other factor to determine seedability of a cloud is CAP like a hat) are seedable. When a person wears a hat it shields him from the sunlight. Similarly when there is a CAP in the atmosphere it shields the cloud from growing and one of the factors responsible for the CAP is a warm temperatures aloft. If at the upper level there is a southerly steering wind (called a steering wind because it steers the clouds or a southerly upper level wind) warm air from the lower latitudes will move into the upper latitudes and that is going to warm up the temperatures aloft. But what is required is colder temperature so that the cloud would be warm up than its surrounding environment so that the cloud can be buoyant. But if that buoyancy is killed then there is a CAP. The reason for the CAP is because the Southerly wind brings warmer temperature in Texas region from the lower latitudes for a few days and another reason is the presence of a persistent strong ridge which is a high pressure system and that inhibits convection because high pressure system causes the air masses to descend. In a seedable cloud there must be a strong convective energy with relatively insignificant or no CAP so that the cloud grows to higher altitudes. VIL ,Vertically Integrated Liquid shows how much moisture, how much liquid there is in the clouds. The non-seeded cloud has very low liquid content of 12 while the seeded cloud has **a high liquid content of 22 for seeding** purposes the **meteorologist must look for numbers 13 and 14 and these numbers must increase with the seeding processes.**

Lifetime of Seedable Clouds : The individual localized area of high VIL in a cloud is called a cell. In the second item of the figure at 4.56pm there are 3 to 4 cells and seeding is done to manage the creation of energy to merge the cells to get substantial rain instead of 3 isolated small showers. Dynamic seeding of these clouds leads to release of latent heat from the individual clouds which suck in more moisture through the updrafts from their bases resulting in merger of nearby clouds into massive clouds that provide heavy rainfall.

Seeded versus non-seeded clouds : In the following figure seeded and non-seeded cloud growths are observed at intervals of 20 minutes. In the first bit seeding was started at 5:58pm on 6-12-2002. The flight track can be seen and cloud volume is 1348 km^3 . The unseeded cloud which developed an hour earlier at 4:57 pm has a volume of 1542km^3 and it was not seeded. The unseeded cloud 20 minutes later at 5:19pm attained volume of 2955km^3 and started to dissipate and 40 minutes later at 5:42pm had a diminished volume of 1890km^3. The seeded cloud continues to grow and at 6:21pm had a volume of 1542km^3 and after another 20 minutes at 6:40pm attained a volume of 2444km^3. Hence it is apparent that the lifetime of the cloud is getting increased and the volume is also increasing due to seeding. Thus the seeded cloud is not only increasing in volume but it is also getting its lifetime extended when compared with the unseeded cloud under similar environmental conditions.

After one hour of the case study the seeded clouds have a lifetime and with the stoppage of seeding the volume decreased and after one full hour the volume of seeded cloud was larger than the non-seeded cloud while examining the precipitation a core of rain is present in the seeded case while there are 3 maxima or more of rainfall which shows showers in the non-seeded clouds but large rain in the seeded cloud. A 68% increase in the rainfall rate and a 22% increase in the volume of rainfall is observed. During research studies on 731 seeded clouds and comparable 731 non-non-seeded clouds around Texas and 10 seeding projects in Texas it was found that there was 48% increase in the lifetime and 22% increase in area and the volume without much increase in top height maxima. There was 25% increase in the rain rate known as flux and 79% increase in the precipitation mass. If a cloud moving at 20 miles per hour has 50% increased lifespan, it gives substantial rain. **If a cloud is about 10 miles away one prefers to do base cloud seeding while 60 miles away one may opt for top seeding.**

Rainfall increase :

In Texas state 1031 clouds were seeded during 2001 out of which software analysis was done for 856 clouds. The seeded samples lasted for about 1.50 hours while the unseeded clouds lasted for about 58 minutes. According to Dale Bates cloud seeding requires **updraft of about 800ft. per minute** as against the **conventional updraft velocity in the range 100ft per minute to 200ft per minute**. Cloud seeding caused 131% increase in rainfall in 857 clouds.

TWMA Research (Courtesy of TWMA San Angelo)

Comparison between Seeded and Control Clouds for small cells

Sample size: 731 Seeded and 731 control clouds

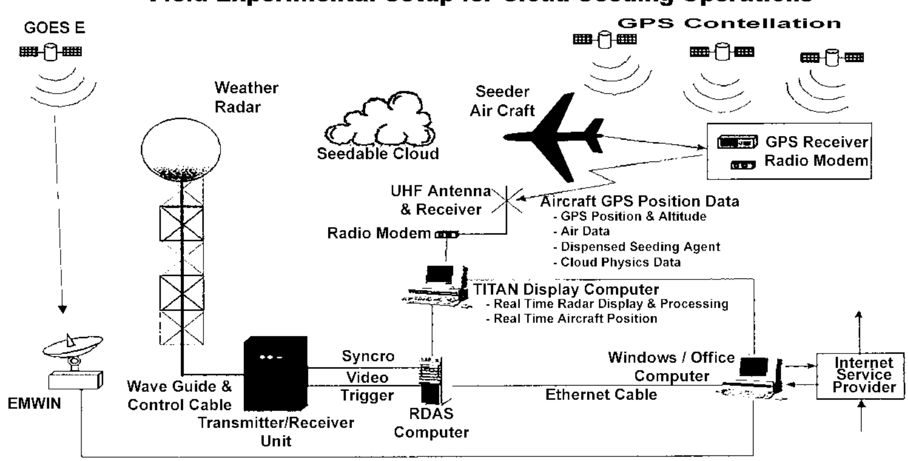
Variable	Seeded	Control	Increase (%)
Lifetime (min)	8.3	5.6	48
Area (Km.Sq.)	54.5	44.6	22
Volume (Km.cu.)	175.3	143.2	22
Top height (km)	8.1	7.9	3
Max dBz	48.7	48.3	1
Top height of max dBZ	4.4	4.4	0
Volume above 7km(km.cu)	54.1	43.1	26
Precipitation Flux (m cu./s)	375.8	300.5	25
Precipitation Mass (kton)	1731	969.7	79

Bigger clouds provide precipitation mass of about 10,000 kilo tons to more than 10 million tones and such clouds constitute only 12% of the clouds in Texas. Out of 857 clouds 731 clouds belong to the super big category. During the 12 years of cloud seeding works in Cuba the average flight time was 2.30 hours. A cloud was seeded for one hour because 30 minutes was spent to reach the cloud and one hour to seed the cloud and one hour to check what is the precipitation and TITAN software was used. But subsequently the duration of the flight has been increased. In Texas they use 80 gram flares for bottom seeding in some places while 40 gram flares are used in some other places.

Significance of TITAN radar image : All the cloud seeding projects numbering about a dozen are using sophisticated interpretative radar system known as TITAN. The radar reflectivity of the cloud gives a 4-dimensional picture of any cloud including the 4th dimension relating to Time. Data on several parameters is provided at the computer system for the meteorologist who directs the pilot to exactly touch the right place at the right time and the exact amount of silver iodide to be released by instructing the burning of a specified number of flares. The TITAN image presented in the following picture shows the reflectivity (dBZ) shown at various intensities. The figure shows the tracking of the aircraft and the places in the clouds where flares were electronically ignited. Each cloud seeding project maintains and pays for its own radar and other staff and aeroplanes.

SOAR Equipment Setup : From the figure of the SOAR cloud seeding operational equipment set up the Geo-stationary Orbit Environmental Satellite (GOES) is seen to provide continental weather information for the over all weather conditions including cloud cover and weather warnings. The meteorologist uses this information and also analysis, the radar signals being interpreted by the TITAN programme. When a potential cloud appears the meteorologist analyses the potential of the cloud by making slices "using the mouse on the screen image to analyse the reflectivity data. Sample slices which provide information on a seedable and unseedable clouds are presented elsewhere.

Field Experimental Setup for Cloud Seeding Operations

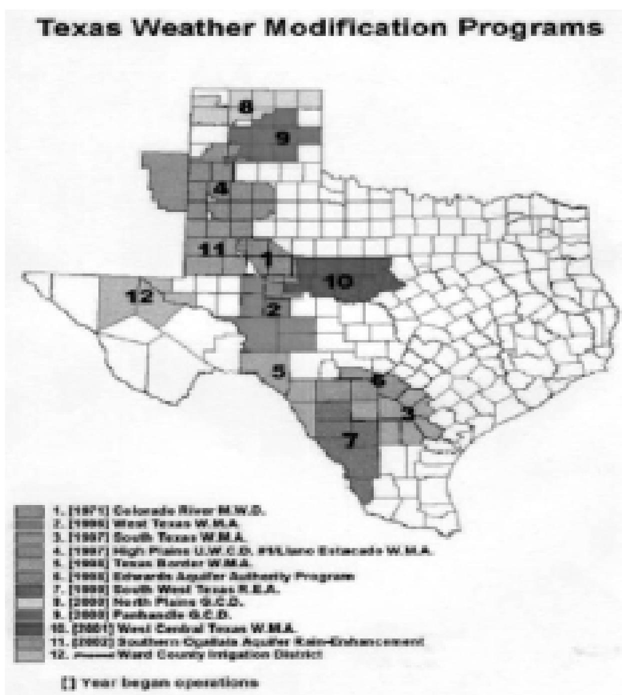


For top seeding it is critical to get to the right place to seed within the first third of the clouds life and for base seeding within the first half life. Bottom seeding can therefore provide more time. The dosage is also different for each method and finding the updraft is critical for bottom seeding. Texas state has the most sophisticated and highly regulated cloud seeding operational activities in the United States and has become a natural choice for visits and detailed study tours by foreign experts interested in cloud seeding. The weather modification activities in different regions of Texas are regulated and controlled by the Texas Department of Licensing Regulation (TDLR)with the full cooperation of the Texas department of Agriculture (TDA). Mr.George Bomar, the Chief Meteorologist is responsible for the grant of licenses for cloud seeding projects in conjunction with Texas department of Agriculture.

The criteria for seeding the cloud on top and at the base is done on the following factors.

On top seeding	Base seeding
First third of cloud life time	First half of cloud life time
Updraft or turrets: Cloud top temps between-5°C and –15°C High concentration of supercooled water droplets Vertical velocity >200ft/min	The inflow of the convective cell: TITAN SSS field identifies weak top structure development within a cell Pilot helps meteorologist "see"
1 flare per updraft or turret	1 flare per 5km³of supercooled volume
Ejectable: 20 gram flare silver iodate	Burn in place: 40 gram flare silver iodate

The following figure provides a list of about a dozen regions interested in cloud seeding operations. Each project is managed by in association of local self Government, water district representatives and others with community and agricultural interests.



Every association employs its own pilots, meteorologists and in most cases owns the aeroplanes. Contractors are avoided so that the focus is always on the rate of success and the results of operations are not merely on hours of flying as contemplated by the commercial firms. Each association gets license to run the programme for 3 years. A statutory Texas Weather Modification Advisory Committee meets quarterly for review of the results of cloud seeding operations to be matched by the funds provided by the local organizations interested in cloud seeding. The state provides about $3million per year towards its half share of contribution. Of the 170 million acres in Texas 52 million acres are targeted for rainfall enhancement by seeding the summer convective clouds between June and November.

Out of the 12 projects taken up for cloud seeding in different regions of the Texas the SOAR project is presented with more details.

The weather modification programme and issue of licenses for the purpose is based on the Texas senate bill 1175 as adopted by the 77th Texas Legislature which transferred the regulations of weather modification and the funding for cloud seeding projects to the state agencies TDLR and TDA agencies (1967)

Some of the cloud seeding projects undertake the following activities:

Colorado River Municipal Water District : This project in Big spring is one of the oldest rain augmentation programmes that has been working for over 33 years. Aircraft treats the growing thunder storms below the cloud base to increase the annual rainfall in the watersheds of Thomas and Spence reservoirs on the upper Colorado river of Texas with its target area of 2.24 million acres.

West Texas Weather Modification Association : After employing contractor to seed the clouds over 6.43 million acres in West Central Texas, the Association removed the contractor and runs its own programme by owning a C-band weather radar and deploying aircraft when seedable cloud conditions are available.

South Texas Weather Modification Association : This programme is in its 9th year of operation and covers 4.4 million acres in 7 counties between San Antonio and Corpus Christi with its head quarters at Pleasanton. The association uses a C-band weather radar and owns 2-aircrafts.

High plains Underground Water Conservation District : This organization based in Lubbock started operations in the spring of 1977 and conducts operations over 6.9 million acres on the Texas high plains. It proposes to augment rain water over the watershed of Ogallala Aquifer.

Texas Border Weather Modification Association : It started operations since 1998 over 3.8 million acres along the Rio Grande basin from the Big bend to Eagle pass.

Edwards Aquifer Authority : The project provides additional rain water on the ground and replenishes the Edwards Aquifer that serves millions of people in South Central Texas and San Antonio and coves 3.1 million acres

Southwest Texas Rainfall Enhancement Association : The project began in 1999 to promote augmentation of rainfall and suppression of hail. But it is the first hail suppression programme using aircraft and established since 1977. The area of operations on year-round basis extends over 5.5 million acres.

North plains Ground water Conservation District : The target area of the programme is 4 million acres in the Panhandle counties and nearby areas and the programme is operational since May 2000.

Panhandle Groundwater Conservation District : This programme started in 2000 intends to augment rainfall to replenish ground water over Ogallala Aquifer and the target area is 3.5 million acres in the Eastern part of the Panhandle.

West Central Texas Weather Modification Association : The project began in the summer of 2001 to cover 4.5 million acres and is dependent upon a private contractor for the cloud seeding operations. http://www.sandylandwater.com/education.htm. http://www.aph.gov.au/house/committee/primind/waterinq/forrest.htm.

CLOUD SEEDING TO STRENGTHEN SOUTHERN WATER GRID (GODAVARI-KRISHNA-PENNAR-CAUVERY LINK)

Water availability in Godavari :

It is estimated that the South West monsoon lifts about 7700 billion m^3 or about 3 lakhs Thousand Million Cubic ft.(TMC) of moisture from the Arabian sea and Bay of Bengal while the North East monsoon lifts another 3300 billion cubic meters of moisture. Of the 11000 billion m^3 of moisture lifted by the monsoon winds about 2400 x 10^9 m^3 (about 85,000 TMC) is released as rain fall over India and the remaining moisture is transported to other countries. 65,000 TMC forms the run-off of Indian rivers and 10% of this flow is planned for storage. Out of the 8000 TMC of rain water in the West flowing rivers, only 500 TMC is stored in reservoirs. Hence there is an urgent need to conserve water resources and plan for optimal utilisation of massive flood waters from Godavari river that join the sea annually to an extent of 2500 TMC.

There are different opinions about the quantity of water available at different places in Godavari basin. According to Krishna-Godavari commission (Gulhati) the annual flow in Godavari is 4167 TMC. Khosla Committee report places the dependable flow in Godavari at 3433 TMC . Dr.K.L.Rao estimated that the annual dependable flow at Dowlaiswaram is 3500 TMC. A study for 66 years (1881 to 1946) estimated the dependable flow at 2500 TMC at 89 percent confidence in the year 1951. The Bachawat Tribunal determined the 75% dependable yield of the river as 2750 TMC out of which 1495 TMC was allotted towards the share of Andhra Pradesh. After utilising the river water for the existing projects the state is dumping into the sea about 1000 TMC in addition to another 1000 TMC from the upper states. During floods about 100 to 150 TMC of water is flowing per day through the river into the sea. During the rainy season (from June to October) every day about 10 to 20 TMC flows for 2 months and 25 to 30 TMC per month flows during the other months, resulting in the wasting of about 2000 to 2500 TMC into the sea per year.

According to late K.Nageswara Rao an eminent Irrigation Engineer the following are the flow particulars for Krishna and Godavari at different stations.

S.No	Name of the River	Site	Max.Flood lakhs cusecs	75% dependable yield (TMC)	50% dependable yield (TMC)	Differe-nce TMC
1.	Godavari	Inchampalli	30	1550	2500	950
2.	Godavari	Dowlaiswaram	33	2860	3730	870
3.	Krishna	Vijayawada	12	2060	2310	250

According to a 75% dependable yield of about 1300 (2860-1550) TMC below Inchampalli is enough to meet the needs of the delta and Polavaram project it is meaningless to propose the production of electricity at Inchampalli by wasting about 1000 TMC of precious water into the sea. In fact the Inchampalli project report of 1970 provides for an out flow of 650 TMC for generation of 500 MW of power. While the 50% dependable yield in Krishna is only 2310 TMC that in Godavari is 3730 (i.e.) about 65% higher. The yield available between 75% and 50% dependable flow is 950 TMC at Inchampalli and it shall be used effectively by using the largest existing reservoirs in the state. With regard to utilisation by upper states, the existing ayacut of 2 lakh acres and the proposed irrigation for about 20 lakh acres requires 250 to 300 TMC and consequently about 1000 TMC of precious water will be flowing into the sea for many decades to come.

Proposal of Late Dr.k.srirama Krishnaiah : Dr.K.Srirama Krishaniah, Member, A.P. State Planning Board proposed Godavari water utilisation of 528 TMC with internal storage of 124 TMC in 23 small reservoirs. The cost is estimated at Rs.12,000 crores and the area for irrigation (in acres) is 8.6 lakhs in Mahaboobnaar, 11.4 lakhs in Nalgonda, 8.3 Lakhs in Medak, 2.3 lakhs in Nizambad, 3.7 lakhs in Karimnagar, 3.7 lakhs in Warangal, 2.8 lakhs in Khammam, 6 lakhs in Adilabad, 4 lakhs in Visakhapatnam, 3 lakhs in East Godavari, 3.5 lakhs in West Godavari and 0.65 lakhs in Krishna district. It is proposed to provide 40 TMC to Rayalaseema, 10 TMC for Hyderabad water supply, 40 TMC for industrial requirements. During rainy season 500 to 600 TMC water can be lifted from a level of 100 meters at Kaleswram to a level of 270 meters at the ridge at Warangal. Similarly water is to be lifted from Godavari from a level of 50 meters at Burgumpahad to a level of 160 meters at the ridge. The water is further passed through existing streams and reservoirs and then again lifted to an elevation of 432 meters and passed over Dindi reservoir, Krishna and Tungabhadra. The scheme is not only cheap but also does not involve submersion of forests and agriculture lands and does not require permission from other states. Several linkages of rivers and canals are proposed for this pumping scheme.

N.W.D.A. Proposal : National Water Development Agency Proposes

1. To provide terminal storages on Mahanadi and Godvari to transfer a surplus water by gravity and lift to the drought-prone areas of Andhra Pradesh, Tamil Nadu and other states.
2. To plan for diversion of water from the West flowing rivers of Kerala and the East flowing rivers of Tamil Nadu.
3. To plan for construction of small storage dams and to inter link the rivers flowing on the West coast for transferring water to the East of the Western ghats through small tunnels or mountain passes and thereby augment the water yield in the rivers of the Southern states.

The peninsular water grid enables additional use of about 8.4 million hectare meters (3000 TMC) to benefit Orissa, Andhra Pradesh, Tamil Nadu and other states and provides additional irrigation to over 13 million hecatres (320 lakh acres). The lift will not exceed 120 meters.

The drinking water needs upto 2025 AD must be assessed by using the standard of 70 and 120 liters per head per day for rural and urban population respectively and 50litres for livestock. Surplus in Mahanadi is 22000 Mm^3 (770 TMC) and in Godavari is 28000 Mm^3 (1000 TMC) as against the present assessment of 11500Mm^3(400 TMC) and 15000 Mm^3 (530 TMC) respectively.

I. From Manibhadra dam on Mahanadi 8000 Mm^3 equivalent to 280 TMC is proposed to be transferred through Mahanadi-Godavari link to deliver 6500 Mm^3 (230TMC) into Godavari at Rajahmundry.

II. **Godavari to Krishna :** Surplus in Godavari is calculated at 21500 Mm^3 (15000+6500) (760 TMC) and this is proposed for transfer into Krishna through 3 links.

(a) 1200 Mm^3 (42 TMC) will be diverted through Polavaram-Vijayawada link to supplement the needs of the delta.

(b) 4370 Mm^3 (154 TMC) is proposed to be transferred through Inchampalli-Pulichintala link to take over part of the command under Nagarjuna Sagar left and right bank canals on exchange basis.

(c) 14000 Mm^3 (500 TMC) of water is proposed to be discharged into Nagarjuna Sagar reservoir after considering needs of enroute irrigation and transmission losses. The electrical power requirements for lifting the water to Pulichintala and Nagarjuna Sagar will be about 110 MW and 1650 MW respectively.

Krishna to Pennar : Out of 14000 Mm^3 discharged into Nagarjuna Sagar 12000 Mm^3 (420 TMC) is proposed for diversion through Nagarjuna Sagar-Somasila link and the balance is utilized under part command of Sagar left canal in exchange. After considering enroute irrigation under Sagar right canal in exchange and irrigation under other canals for about 9800 Mm^3 (346 TMC) reaches Somasila. Since this link provides water on exchange basis to Sagar canals an equivalent quantity of water may be diverted from Srisailam and Alamatti to other needy areas. 2300 Mm^3 (80 TMC) is proposed to be diverted from Srisailam through Srisailam-Proddutur link to reach the barrage at Proddutur. About 2000 Mm^3 (70 TMC) is proposed for diversion from Alamatti through Alamatti-Pennar link to cater for enroute irrigation under Krishna and Pennar basins.

Pennar to Cauvery : About 9500 Mm^3 (335 TMC) of water is proposed to be transferred through Pennar-Cauvery link into Grand Anicut deducting for enroute irrigation and Madras water supply. About 5000 Mm^3 (176 TMC) will reach Grand Anicut and out of this water about 3000 Mm^3 (106 TMC) will be used in Cauvery delta.

Cauvery to Vaigai : Out of 5000 Mm^3 reaching Upper Anicut, about 2000 Mm^3 (70 TMC) is proposed to be diverted through Cauvery-Vaigai link for utilization in Cauvery, Vaigai and other streams in between Vaigai and Vaippar.

Economics : Peninsular link project from Mahanadi to Cauvery costs Rs.50,000 crores for main works and additional amount of Rs.30,000 crores will be needed for branch canals, field channels.

Environment : Out of total forest cover depletion since 1947 about 12% can be attributed to Reservoir projects. About 2.5 Mha. is affected by water-logging 3.0 M.ha by soil salinity and 0.25 Mha. by alkalinity in irrigation command areas in India. For hydro-power storages, evaporation losses amount to1.0m to 1.5m per year and it is estimated at 10 to 15 percent of the storage. For hydro-power projects like Koyna, Sharavathi, Supa etc., there is West-ward diversion of water into sea and such consumptive use presently is 35 billion cum. and it will reach 100 billion cum with further development of hydro-power projects in future. Large reservoirs like Manibhadra on Mahanadi (49 meters high) Inchampalli on Godavari(41 meters high) and Polavaram on Godavari (23 meters high) are essential components and they involve submergence of the following lands:

S.No.	Reservoir	Forests(ha)	Cultivated Land (ha)	Population affected (Nos)
1.	Manibhadra	9,828	9,500	79,000
2.	Inchampalli	21,734	37,742	1,00,000
3.	Polavaram	3,887	43,158	1,10,000

Note : 1. Submersion and Rehabilitation problems can be reduced by lowering the height of the dams and consequently increasing the pumping heads and capacities of the canals.

2. 10% of the 75% dependable yield must be reserved towards maintaining alluvial morphology of rivers and salinity control before diversion of any surpluses can be considered. For Ecology and environment atleast 10% of inflow at diversion structures (average lean season flow) be maintained down stream.

Godavari-Krishna-Pennar-Cauvery Link Canals :

By modifying the Inchampalli project small dams with adequate storage, a link canal to Nagarjuna Sagar can be taken by lifting about 500 TMC of the flood water over 360ft. height in states in the initial reaches along the Salivagu river to cross the Warangal ridge between the

Godavari and Krishna basins. By utilizing the vast coal reserves of over 8,600 million tons in Kottagudem and Ramagundam mines of Andhra Pradesh a few pit-head thermal power plants can be set up by privatization of coal mining and power generation. The electricity thus generated can be used to lift the water from Inchampalli reservoir to cross the ridge at Warangal and discharged into a 250 meter contour canal that empties into Nagarjuna Sagar reservoir. Consequently the Nagarjuna Sagar water used for irrigation becomes surplus for utilization in the upper reaches of Srisailam and other reservoirs. A portion of the water may be given to Karnataka for utilisation under upper Krishna or Bhima projects in exchange for diversion of water from the projects on Bhadra to serve the uplands of Anantapur, Cuddapah and Chittor which cannot be served by the water from Tungabhadra. Some water from Tungabhadra can perhaps be released into Pennar for utilization by minor and medium irrigation projects in Rayalasema. The drinking and irrigation water needs of the drought-prone districts of Bidar and Gulbarga can be met by lifting the water from Godavari river if requested by the Karnataka Government. The implementation of the proposed Godavari-Cauvery link project suggested by NWDA provides adequate water supplies for irrigation both in Tamil Nadu and Karnataka. Thus a permanent solution to the Cauvery water dispute can be struck. One of the major objectives to be achieved by this project is to ensure continuous supply of ample drinking water for major cities like Madras and Hyderabad and several rural and urban areas and industries enroute.

During the 5-year period from 1982-83 to 1986-87 although A.P. State Government sought Central Agency assistance of Rs.1785 crores for flood relief the Central Government sanctioned about Rs.280 crores. Thus the annual loss due to floods may be estimated at Rs.400 crores per year. If Godavari water from Inchampalli is used for irrigating 40 lakhs of acres in the state it will produce food grains worth about Rs.5,000 crores per year. Thus the cost of the project can be recovered within a short-time.

To summarise some of the benefits of the project are:

1. It promotes National integration in its true spirit because the people in the different states gradually develop mutual bonds of love, affection cooperation and understanding as their very survival is linked up with the sharing of the waters from the peninsular water grid.

2. The flood havoc in the Godavari delta will be minimised.

3. The drinking and industrial water needs of Hyderabad will be met

4. The irrigation and drinking water needs of South Telangana, North Karnataka and Rayalaseema districts will be met

5. The irrigation and drinking water problems of North Tamil Nadu districts will be solved

6. Drinking and industrial water needs of Madras city will be met and

7. The Cauvery water dispute problem can be solved.

However, the diversion of 600 TMC of Godavari water by taking up this project is linked up with construction of a super thermal station of 3000 MW in 2 to 3 stages at Singareni for the Projects and work started on them on a war-footing as otherwise food production cannot reach the targets by 2040AD and in such an eventuality poverty, sickness and unemployment grow on a large scale ultimately posing a threat to peaceful life and sustainable development of the country.

Indravati-Waina Ganga-Srisailam Link Canal :

Special priority must be given to an interstate river water diversion project by inter linking Indravati, Wainaganga and Krishna rivers as originally proposed by the National Water Development Agency. This project contemplates diversion of Indravati water from the proposed Duduma project to another project at Garhchiroli project over the Wainagana river. A link canal transfers water from Wainaganga into Srisailam reservoir upto about 500 TMC and this canal involves lifting of water in successive reaches by about 122 meters to cross the Warangal ridge between Godavari and Krishna basins. The project involves tunnels of 95km length in 3 reaches. Water from Srisailam can be supply to Gandikota reservoir on Pennar river, KC canal, Telugu Ganga and other projects proposed to benefit the farmers of Rayalaseema. Some water can be transferred from a barrage proposed at Proddutur on Penna river for diversion to Tamil Nadu through a contour canal that empties into the pond at Upper Anicut on Cauvery river at 76meter level. If this comprehensive scheme is put before the Union Government as integrated project that serves the needs of Andhra Pradesh and its neighbouring southern states. The necessary funding, the required clearances can be easily secure with the cooperation of Tamil Naud and Karnataka Governments. It must be remembered that the surplus flow between the 75% dependable yield and the annual average yield of river Godavari below Inchampally is about 1500 TMC and hence this surplus water can be used by Andhra Pradesh in addition to its own share of about 1500 TMC water allotted by the Bachawat Tribunal. If this link canal project is taken up Godavari water can be definitely taken through the Srisailam Right Branch canal (which is having 2 balancing reservoirs at Gorakallu with FRL at about +856ft. and at Owk with FRL at +746ft.) and then discharged into Mailavaram reservoir at an FRL of +665ft . Thereafter the water can be taken to Cuddapah by a contour canal by crossing Papagni river near Tummalur by forming reservoir. FRL of Papagni reservoir could be fixed between +615ft. and +625ft. to provide a suitable storage capacity. Srisailam Right Bank canal can be continued along the contour and tailed into a reservoir near or below Gandikota with a suitable capacity with its FRL at above +750ft. and the water can be taken to other areas in Rayalaseema and if possible to Tamil Nadu.

Cloud seeding to increase flows in South Indian Rivers :

Since this proposed link canal project with its reservoirs covers extensive length from Dandakaranya forest upto Nallamala forest cloud seeding operations can be done on a large scale to improve the annual rainfall by more than 25% to 30% so that this additional water supply can be used for drinking, irrigation, hydro-power generation and environmental improvements including forests and wild life development. Hence both warm cloud seeding and cold cloud seeding operations during day time and night time must be conducted by using aeroplanes and Ground generators in the catchment areas of the Godavari, Krishna, Pennar and Cauvery rivers in the areas covered by the states of Maharashtra, Karnataka and Andhra Pradesh. For this purpose the Central Government must extend its technical and financial assistance to make the cloud seeding operations successful as in other countries like China and USA.

Table - 3 : Water resources potential of river basins of India

S.No.	River Basin	Average Annual Availability		6Utilizable surface water (km³)	Ground water potential (km³)	Present Diversion	
		Water Resources potential (km³)	Per Capita (m³)			Surface	Ground
1.	Indus	73.3	1757	46.0	25.5	40	17.34
2.	Ganga- Brahmaputra- Meghana (a) Ganga (b) Brahmaputra (c) Barak	1110.6 525.0 537.2 48.4	2833 1473 18417 7646	274.0 250.0 24.0 --	201.4 171.7 27.9 1.8	-- -- -- --	-- 48.64 0.78 --
3.	Godavari	110.5	2026	76.3	46.8	38.0	6.87
4.	Krishna	78.1	1312	58.0	26.6	47.0	6.50
5.	Subernarekha	12.4	1392	6.8	2.2	--	0.13
6.	Cauvery	21.4	666	19.0	13.6	18.0	5.71
7.	Brahmani-Baitarani	28.5	2696	18.3	5.9	--	0.31
8.	Mahanadi	66.9	2546	50.0	21.3	17.0	1.07
9.	Pennar	6.3	648	6.9	5.0	5.0	1.63
10.	Mahi	11.0	1057	3.1	7.9	2.5	--
11.	Sabarmati	3.8	421	1.9	--	1.8	--
12	Narmada	45.6	2855	34.5	11.9	8.0	2.03
13.	Tapi	14.9	1091	14.5	8.2	--	1.96
14.	West Flowing rivers fromTapi to Tadri	87.4	3194	11.9	9.5	--	--
15.	West Flowing rivers from Tadri to Kanyakumari	113.5	3539	24.3	8.8	--	--
16.	East Flowing rivers between Mahanadi and Pennar	22.5	919	13.1	22.8	--	--
17.	East Flowing rivers between Pennar and Kanyakumari	16.5	383	16.7	20.9	--	--
18.	West Flowing rivers of Kutch and Saurashtra includidng Luni	15.1	631	15.0	13.9	--	--
19.	Area of inland drainage in Rajasthan desert	Negl.	--	--	--	--	--
20.	Minor rivers draining into Myanmar (Burma) & Bangladesh	31.0	14616	--	--	--	--
	TOTAL	1869.3	2214	690.3	452.2		

Source : Indian Water Resources Society Theme paper for Water Resources Day 1996.

Table – 4 : Godavari flows at Perur (Kantalapally)

2 reservoirs with combined live capacity of 550 TMC. Storage available for 2nd crop

		To the end of September				To the end of 1st crop		2nd crop		Flow into sea
S.No	Year	Inflow TMC	Utilisation TMC	Balance TMC	Storage TMC	Further Utilisation TMC	Balance TMC	Carry-Over storage TMC	Storage TMC	TMC
1	2	3	4	5	6	7	8	9	10	11
1.	1968	1490	850	640	550	150	400	150	250	90
2.	1969	2900	850	2050	550	150	400	150	250	1500
3.	1970	3370	850	2520	550	150	400	150	250	1970
4.	1971	1020	850	170	170	150	20	--	20	--
5.	1972	1110	850	260	260	150	110	--	110	--
6.	1973	2420	850	1570	550	150	400	150	250	1020
7.	1974	710	710	--	--	--	--	--	--	--
8.	1975	2840	850	1990	550	150	400	150	250	1440
9.	1976	2740	850	1890	550	150	400	150	250	1340
10.	1977	1920	850	1070	550	150	400	150	250	520
11.	1978	3000	850	2150	550	150	400	150	250	1600
12.	1979	1690	850	840	550	150	400	150	250	290
13.	1980	2560	850	1710	550	150	400	150	250	1160
14.	1981	2420	850	1570	550	150	400	150	250	1020
15.	1982	1160	850	310	310	150	160	--	160	--
16.	1983	3220	850	2370	550	150	400	150	250	1820
17.	1984	1050	850	200	200	150	50	--	50	--
18.	1985	1160	850	310	310	150	160	--	160	--
19.	1986	Although a good year detailed flow data was not available							250	1000
20.	1987	680	680	--	--	--	--	--	--	--
21.	1988	3220	850	2370	550	150	400	150	250	1820
22.	1989	1900	850	1050	550	150	400	150	250	500
23.	1990	3530	850	2680	550	150	400	150	250	2130
24.	1991	1390	850	540	540	150	390	150	240	--
25.	1992	1970	850	1120	550	150	400	150	250	570
26.	1993	1050	850	200	200	150	50	--	50	--
27.	1994	3520	850	2670	550	150	400	150	250	2120

Note : i) Godavari flow at Rajahmundry is reported at 3428 TMC in 1995, 2140 in 1996, 1469 in 1997, 2907 in 1998 and 3407 in 1999, 3177 TMC in 2000, 2884 TMC in 2001, 1733 TMC in 2002.

(ii) Inflows from October being meager, are not considered – these inflows are likely to be utilized by the upper states in due course

(iii) Substantial excess flows are let down in 17 out of 27 years – average per year – 1300 TMC

(iv) During the years when southwest monsoon rains are likely to fail as detected by the poor rainfall received during the months of June and July the cloud seeding operations may be undertaken to augment the annual rainfall by using aeroplanes and ground generators to seed both the warm clouds and warm clouds during day time as well as nights.

Water inflows in Godavari at Dhavaleswaram

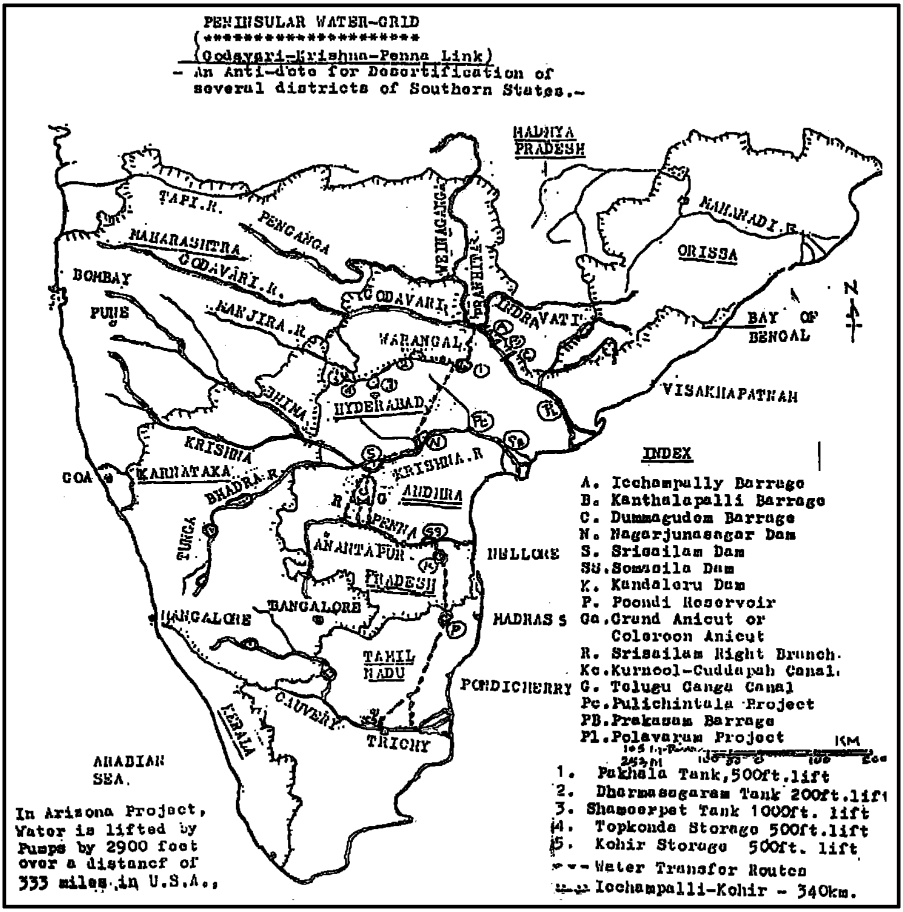
(In TMC, based on 75 percent dependability)(Period 1976-77 to 1983-84)

S.No.	Month	Demand	Inflows	Less
1.	June	13.98	23.14	--
2.	July	9.44	246.19	--
3.	August	32.33	979.92	--
4.	September	35.94	748.76	--
5.	October	22.21	165.60	--
6.	November	8.25	56.44	--
7.	December	19.63	35.14	--
8.	January	39.03	29.49	9.54
9.	February	42.00	24.61	17.39
10.	March	35.99	21.48	14.51
11.	April	6.13	15.06	--
12.	May	3.70	15.19	--
	TOTAL	298.63	2461.02	

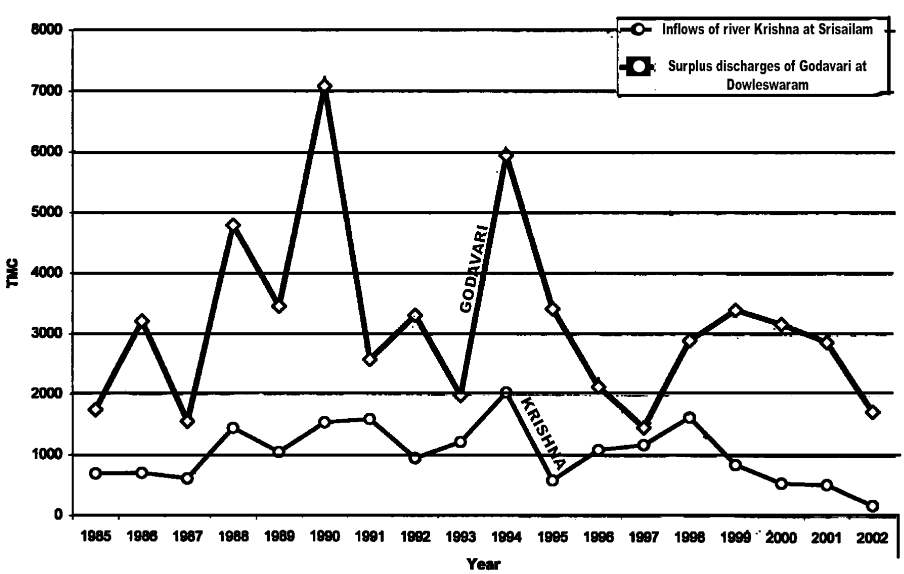
Two Big Reservoirs on Godavari (As proposed byLate K.Nageswara Rao)

S.No	Item	Single Reservoir of 300 TMC			2 Reservoirs of live capacity of 550 TMC		
		Ayacut (lakh Ac)	Utilisation (TMC)	Cost (Rs.crores)	Ayacut (Lakh Ac)	Utiliation (TMC)	Cost (Rs.crores)
1.	Telangana: 1st crop (Paddy) 2nd Crop (ID)	20 15	300 150	15,000 7,000	30 25	450 250	23,000 14,000
2.	Gravity Canal to Krishna Delta	--	200	4,000	--	200	4,000
3.	Rayalaseema 1st crop (paddy) Srisailam	12	--	4,000	12	--	4,000
4.	Hydro-Power	Nil			800 MW		

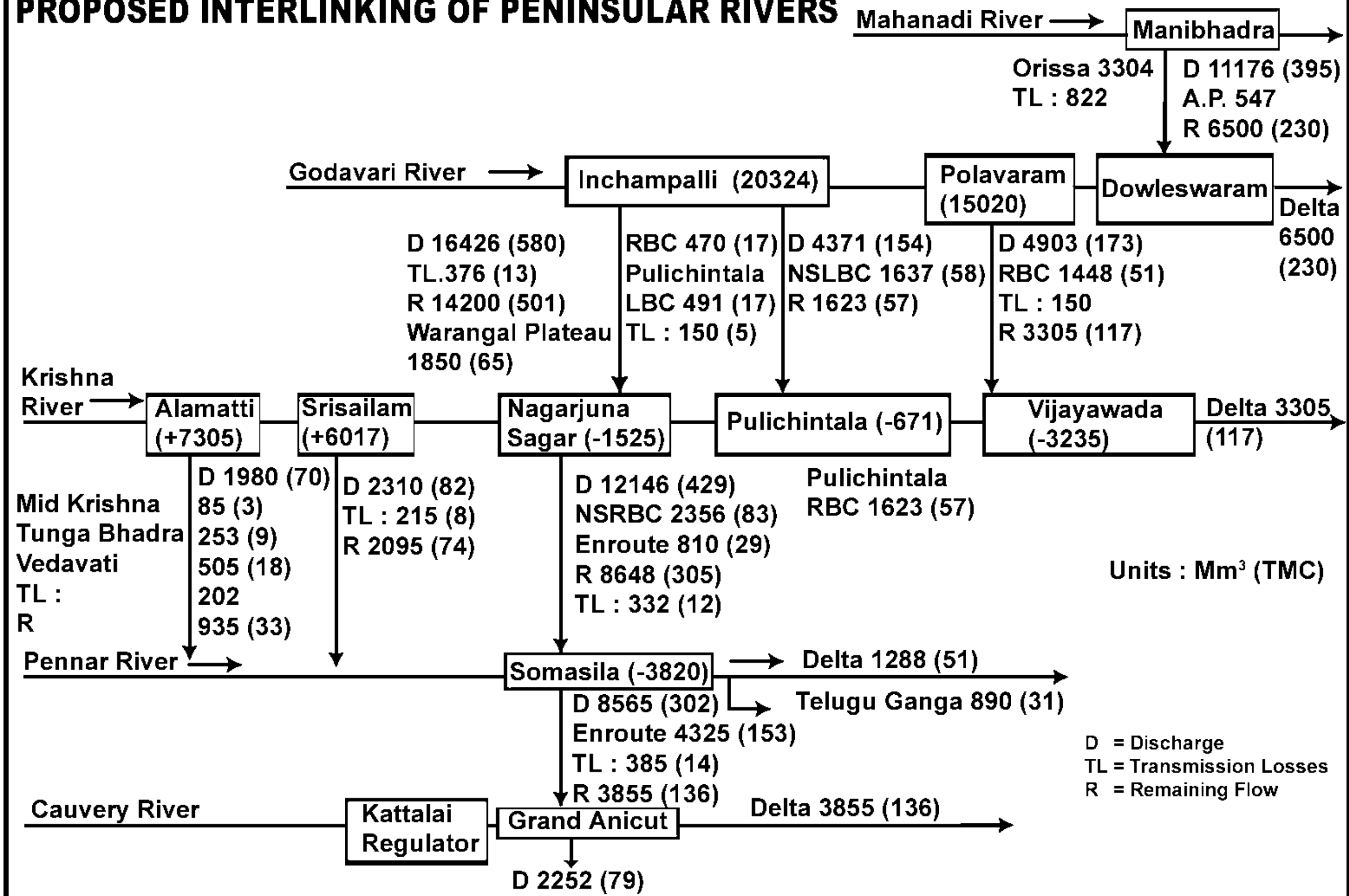
Note : For Nile River flow of 3,000 TMC, Aswan High Dam was built to hold 2 years flow of 6,000 TMC. Hence 3 major reservoirs of 300 TMC capacity must be built one each in Karimnagar, Warangal and West Godavari districts for optimal utilization of Godavari waters including flood flows.



Annual River flows of Godavari and Krishna



NATIONAL WATER DEVELOPMENT AGENCY :
PROPOSED INTERLINKING OF PENINSULAR RIVERS



INTERNATIONAL AGENCIES PROMOTE CLOUD SEEDING

Wmo statement on the weather modification :

Since historical times people began to modify the clouds to augment water resources by increasing the annual rainfall. But the modern technology of cloud seeding began with the discovery in 1946 by Vincent Schaefer that super cooled cloud droplets could be converted into ice crystals by injecting into the suitable clouds a cooling agent such as dry ice or an artificial ice nucleus like silver iodide. About 50 years of subsequent research on cloud seeding vastly increased our knowledge about microphysics, dynamics and precipitation processes of natural clouds and the impacts of human interventions on those processes for increasing the snowfall, rainfall and for decreasing the fog and the hail. Presently about 100 cloud seeding projects are in operation in arid and semi arid regions in about 40 countries where recurring droughts and water shortages limit their ability to produce enough food, clothing and electrical power for the growing needs of population.

The energy involved in regulating weather systems is so large that it is impossible to create the clouds artificially and to modify the wind patterns to get the required water vapor for cloud formation in a given region. Hence we must adopt a more realistic approach to modify the seedable clouds to take advantage of their microphysical responsive characteristics wherein a small man made disturbance in the clouds can substantially change the natural evolution of atmospheric processes for providing more precipitation for improving the quality of life of the suffering millions.

The ability to influence cloud microstructures for augmenting the precipitation has been scientifically demonstrated in the laboratory, simulated in numerical models and verified through physical measurements in modifying the fogs, layer clouds and cumulus clouds. New techniques and equipment like aircraft platforms with microphysical and air motion measuring systems, modern radars, satellites, microwave radiometers, wind profilers, automated rain gauge networks, mesoscale network stations, numerical modeling and computers have recently come to our rescue in improving the cloud seeding operations. Tracer studies are of great help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent.

Randomization methods are adopted for detecting cloud seeding effects. Experiments must be conducted for 5 to 10 years for evaluation of a cloud seeding project. Meteorological parameters like stability, wind direction, pressure gradient or cloud quantities like liquid water content, updraft speed, concentration of large drops, ice crystal concentration or radar reflectivity must be taken into consideration. Ground measurements with rain gauges and remote sensing techniques with radars and satellites must be adopted. Properly designed and conducted operational projects minimize adverse effects like reduction in rainfall due to cloud seeding. Managers must employ scientifically accepted evaluation methodologies to be undertaken by experts independent of the operators.

Different techniques are widely used to disperse warm and cold fogs. To reduce warm fogs seeding with hygroscopic materials must be adopted. This technique can be used in airports and highways in cities like New Delhi. Cold fog is dissipated by growth and sedimentation of ice crystals which can be induced by seeding the fog with artificial ice nuclei from ground based or airborne systems. Glaciogenic seeding of clouds formed by air flowing over mountains provides ideal conditions for increasing precipitation in an economically viable manner. A statistical analysis of precipitation records from long-term projects shows that seasonal increases in rainfall have been realized. Physical studies and numerical modeling indicate that sufficient super cooled water exists in clouds which could be tapped if proper seeding technologies are applied. The present seeding methods should be improved to identify favorable opportunities, thereby optimizing the seeding techniques and quantifying the results by employing properly qualified scientists and operational personnel.

A number of field experiments and numerical simulations have shown the presence of super cooled water in Stratiform clouds and there is ample evidence that precipitation has been increased. During cloud seeding operations the monitoring of possible environmental effects should be undertaken to identify the potential of harmful impacts.

In order to answer the question as to how to produce substantial increases in water availability to fight the recurring droughts in many countries of the world, it will be heartening to know that some progress has been made during the past few years in the science and technology of cloud seeding operations.

According to WMO website: http://www.wmo.int/web/arep/wmp/STATEMENTS/statwme.pdf

"Large numbers of programmes in fog dispersion, rain, snow enhancement and hail suppression are in operation. Several research experimental programmes are supported in some countries and include randomized statistical evaluations. Improved observational facilities, computer capabilities, numerical models and understanding now permit more detailed examination of clouds and precipitation processes than ever before, and significant advances are consequently possible. New technologies and methods are starting to be applied and will help to lead to further understanding and development in this field. In the light of this review of the status of weather modification, the following recommendations are made to interested Members of WMO:

a) Cloud, fog and precipitation climatologies should be established in all countries as vital information for weather modification and water resource studies and operations;

b) Operational cloud-seeding projects should be strengthened by allowing an independent evaluation of the results of seeding. This should include measurements of physical response variables and a randomized statistical component;

c) Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist, advantage should be taken of facilities of other Members;

d) It is essential that basic measurements to support and evaluate the seeding material and seeding hypothesis proposed for any weather modification experiments be conducted before and during the project;

e) Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between Member States (e.g. multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

WMO guidelines on cloud seeding :

1. These WMO guidelines on cloud seeding are intended for those countries that are planning to take up weather modification activities. They include the recommendations formulated on the basis of the results of worldwide theoretical studies as well as laboratory and field experiments. A summary of the main basic concepts and main results obtained from various cloud seeding experiments conducted in several countries for many years is given

in the WMO Statement on the Status of Weather Modification. This Statement was revised thoroughly by the experts and was approved by the Executive Council in June 2001.

2. Since research and operational applications are still under development, under certain conditions, seeding may be ineffective or may even cause reduction in rainfall. But, properly designed and conducted experiments can detect and minimize such adverse effects. The cloud seeding performance level is very high for operational dissipation of super cooled fog and moderate for increasing the precipitation from orographic clouds.

3. The results of cloud seeding shall be through physical measurements of seeding agents and statistical controls including some randomization of the seeding operations. The proponents must engage properly qualified operators and experts. The objective evaluation should be done by an expert group independent of the operational one. Such programmes should be planned for a sufficiently long duration. Experts must use numerical models for reducing the time required to evaluate the project.

4. Suitability of the site for cloud seeding should be carefully determined as per standard procedures. To ensure success in a specific situation, it should be verified through preliminary studies that:

   (a) The climatology of clouds and precipitation at the site indicate favorable conditions for seeding operations;

   (*b*) Conditions are suitable for the proposed seeding techniques;

   (*c*) Modelling studies support the proposed weather modification hypothesis;

   (*d*) For the frequency with which suitable conditions occur, the changes due to seeding technique must be detectable at an acceptable level of statistical significance;

   (*e*) Seeding operations can be carried out at an inexpensive cost.

Besides the expert judgement, the results also depend on the type of site chosen and on the season.

5. There are no quantitative criteria for the acceptance of the results of a cloud seeding experiment except perhaps the cost benefit analysis.

   Acceptance mostly depends on the degree of the scientific objectivity and the consistency with which the operations are carried out and the degree to which this is demonstrated. Better results can be secured by using modern research tools, including advanced radar, new aircraft instruments and powerful numerical models.

6. Cloud seeding should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult because if there are no clouds, precipitation cannot be artificially stimulated. But one has to utilize the opportunities for precipitation enhancement which will be greater during periods of normal or above normal rainfall than during dry periods and then store the additional rain fall for subsequent use in times of water scarcity.

7. The design, conduct or evaluation of cloud seeding programme precludes the WMO Secretariat from giving detailed advice. But the secretary-general may assist any country (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

   a) Costs will have to be met by the requesting country;

   b) WMO can not take any responsibility for the consequences of the advice given by any invited scientist or expert;

   c) WMO accepts no legal responsibility in any dispute that may arise.

UNEP centres promote cloud seeidng for augmenting rainfall :
http://www.unep.or.jp/ietc/publications/techpublications/techpub-8f/b/cloud.asp

The UNEP_DTIE International Environmental Technology Centre (IETC), an integral part of the Division of Technology, Industry and Economics (DTIE) of the United Nations Environmental Programme (UNEP) was established in 1994 with its offices at Osaka and Shiga cities in Japan. To promote the application of Environmentally Sound Technologies (ESTs) in developing countries including the management of fresh water resources.

The Arab countries established the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) in 1971 to promote agricultural and socio-economic development of the drought prone areas including management of water resources. The Arab centre and the UNEP Regional Office for West Asia (ROWA) in their efforts to identify various alternative technologies for augmenting the water availability in different arid-prone areas organized 4-day workshop in April 1999 for augmenting water supplies at Damascus. Several National and International experts presented many papers and reports on the emerging water scarcity scenarios along with appropriate alternate technologies for solving the emerging water crisis. After elaborate discussions and reviews on the various papers presented at the workshop a final report along with their recommendations for tackling the water issues was brought out and the same has been printed as a **source book.** This book provides a comprehensive description of the present technologies in use and the proposed solutions on water issues so that the decision makers, Government and Non-Governmental Organizations can use the book as a reference book to promote the sound planning and management of the fresh water resources.

In this connection it may be recollected that "The Earth Summit (United Nations Conference on Environmental and Development" held in Rio de Janeiro, Brazil in 1992 emphasized the need to balance human needs for natural resources and the ability of nature to provide these recourses in a sustainable manner. It also emphasized the need to develop successful approaches and solutions to address this balance. The "Freshwater" chapter (Chapter 18) of Agenda 21 emphasized the use of environmentally sustainable technologies in the fields of fresh water supply and sanitation. Further it recognized that enhancing access to information on environmentally sound technologies was an important factor in facilitating the development of these technologies and their transfer to and among developing countries. One of the technologies strongly recommended by the experts as presented in the source book is "**cloud seeding technology**" that was already successfully conducted in the Arab nations. The following information on cloud seeding as recommended by the work shop is presented in the above UNEP website and the salient features are presented here.

The technology of cloud seeding is based on the principle of injecting artificial ice nuclei to a few already-existing natural ice nuclei within clouds. Several countries used this technology to increase annual rainfall. Experiments in the states of Soviet Russia, United States, Israel, Australia, China, Morocco, Syria and other countries have demonstrated that cloud seeding increases the amount of rainfall upto 5-20% over large areas and for long durations (during the rainy season).

West Asia could potentially benefit from this technology, including the coastal mountains in the Eastern Mediterranean, Yemen and Saudi Arabia highlands along the Red Sea. **Despite the diversity of opinions on the feasibility of cloud seeding technology, mainly because of the difficulties in assessing its results, the prevailing opinion among most experts is that it has reached a relatively advanced stage of application,** and so it can be considered as one of the technologies capable of contributing to the augmentation of freshwater supplies in semi-arid regions.

Cloud Seeding Technology : Cloud seeding requires advanced scientific equipment, including aircraft, a meteorological station network to monitor the clouds, a rainfall monitoring ground network, a network for data collection and processing, and satellite image transmission networks.

Silver Iodide is used at a concentration of 2%, for seeding at the tops of clouds. Airplanes or ground generators, are used to seed the clouds in regions with supercooled water.

Cloud-seeding projects require (1) a radar and electronic maintenance division, (2) an aviation division, (3) a data collection and processing division, and (4) an education and training division. Cloud-seeding requires coordination between relevant agriculture, electrical power, irrigation, civil aviation and meteorology authorities.

Extent of Use : Cloud-seeding operations were conducted in Arabia, United Arab Emirates, Jordan and Syria. Cloud-seeding operations continued in Syria between 1991 and 1997 (See Table), and the project was conducted by the Ministry of Agriculture and Land Reclamation. The project's objectives included (1) increasing the rainfall in the Balia agricultural regions (2) improving the optimal rainfall availability during different plant growth stages. (3) augemntation of rainfall for charging groundwater aquifers and (4) increasing the rainfall to provide more water for storage in tanks and reservoirs across the rivers. The additional rainfall due to cloud seeding ranged from 6% o 16% of the natural annual rainfall (estimated at about 45 billion m^3). The technology is providing encouraging results.

Results of cloud-seeding operations in Syria (1991-1997)

	Unit	Season 1991-1992	Season 1992-1993	Season 1993-1994	Season 1994-1995	Season 1995-1996	Season 1996-1997	Average
Airplane Meteo Laboratory	airplane	4	6	5	4	3	3	-
Total number of flights	one	93	84	55	40	65	37	63
Total time of flights	hour	360	310	180	101	152	91	199
PV - 50	number	2,964	2,882	2,100	1,391	2,080	1,320	2,112.66
PV - 26	number	6,792	12,380	7,221	8,466	10,292	4,103	8,209
Total cost	US$X1,000	2,560	4,080	1,977	1,662	995.5	736	2,001
Natural rainfall over 4 months	km^3	29.073	24.731	27.077	13.152	34.023	35.150	27.201
Actual rainfall over 4 months	km^3	33.857	28.814	30.246	14.058	36.607	37.769	30.225
Rainfall increase over natural levels, computed by historical series and control stations method	km^3	4.784	4.083	3.169	0.906	2.584	2.618	3.024
Relative increase	%	16.0	16.0	11.7	6.9	7.6	7.4	11.1
Cost per m^3	US cents	0.054	0.100	0.062	0.183	0.039	0.028	0.0777
Natural rainfall over 4 months, using ratio method	km^3	32.1	23.1	26.2	22.7	25.4	34.2	27.28
Actual rainfall over 4 months, using ratio method	km^3	35.3	26.75	28.93	25.7	30.4	38.3	30.90
Rainfall increased on basis of ratio method	km^3	3.2	3.65	2.74	3.0	5.0	4.1	3.62
Relative increase	%	10	15.8	10.5	13.2	19.7	12.0	13.5
Cost per m^3	US cents	0.080	0.112	0.072	0.055	0.020	0.018	0.0595

Source : Abbas A and A. Mustfa (1999)

Operation and Maintenance : This technology requires long-term monitoring of rainfall and other meteorological parameters, based on conventional and satellite meteorological recording networks. As the present prediction methods are inadequate, artificial tracers have to be used to follow the development and motion of clouds. Meteorological radars are used to study cloud micro-structure, cloud heights. Precipitation and cloud development prior to and after the seeding process.

The cloud-seeding plane is usually despatched when seedable clouds are available. It measures meteorological parameters like temperature, humidity, dew point, and wind speed and direction. A radiometer measures supercooled water in the clouds. The operation base on the plane and the radar stations work in cooperation to see that the cloud-seeding operation is based on proper knowledge of the cloud base and height, temperature, uplift currents and humidity. All the navigational, meteorological and seeding operation data is recorded on the plane's computer for subsequent analysis.

When all the physical data on the cloud is obtained, it is seeded with silver iodide pyrotechnics. Regular maintenance work is needed on the mechanical and electronic equipment, which requires skilled staff with multiple specialities.

Involvement of Agencies : Cloud seeding in the West Asia region is organized by Government agencies, with contributions from such executing agencies like civil aviation, meteorology, irrigation and agriculture. The Industries, municipalities, agriculture, irrigation, hydro-power and environmental departments get the benefits due to increases in annual rainfall. The industrial sector has not yet shown significant interest in this technology due to doubts about the high capital costs.

Costs : Cloud-seeding technology is considered as an expensive process, based on its efficiency and effectiveness. The seeding equipment used for the operations included C-B and VRC 74 weather radars, and an aircraft equipped with meteorological recording instruments. The aircraft was provided with a computer, satellite station (METEOSAT NOAA), qualified radar technicians, engineers, meteorologists and pilots. In Syria, the cloud-seeding operations were started in 1992, involving similar equipment and staff. Six aircraft were used for seeding operations during 1993-1994, with the project costs reaching 156 million Syrian lira. The project costs amounting to 25 million Syrian lira (US$ 0.5 million) in 1998. The water costs range between US 0.028-0.183 cents/m^3 of water, and between US 0.018-0.112 cent/m^3 if the ratio method is used.

Effectiveness of cloud seeding operations : Results of cloud seeding experiments in many countries show that natural rainfall can be increased substantially through the use of orographic clouds. Statistical analysis of rainfall records of several projects suggests a rainfall increase of over 10% above the natural level. Nationwide experiments in Syria suggest that the rainfall increase ranged between 7% -16% during 1991-1997. The average increase in rain water was about 3.02 km^3 over a period of 4 months (11.1%) using the regression method, and 3.75 km^3 (12.5%) using the ratio method.

Since cloud-seeding technology is still in a developmental stage, its multiple applications are still limited. Unfortunately the ongoing research currently is concentrated more on the meteorological aspects, while less attention is paid to the hydro-geological aspects that are essential for fighting the recurring droughts and global warming impacts.

This technology is nevertheless considered to be essential under suitable conditions for extracting increased rainfall, resulting in improved water resources and economic development.

Suitability : Cloud seeding operations need certain appropriate conditions, such as (1) suitable sites, (2) suitable cloud-seeding agents, (3) a means of dispensing the seeding agents in the supercooled clouds by aeroplanes and ground generators and (4) sufficient quantities of vapor and supercooled water, and also sufficient time for the rain drops to achieve suitable sizes to cause them to fall to the ground.

Based on current knowledge, cloud seeding gives the best (and most economically-feasible) results when the target cloud systems get lifted and pass over mountains, or the air masses are affected by a series of mountains to form the clouds known as orographic clouds. Most cloud-seeding experiments in many places are conducted under these favourable conditions

Advantages : The advantages of this cloud seeding technology are as follows:

- It contributes to the increase in freshwater resources to meet the growing water demands, particularly in arid and semi-arid areas. Efficiency of the technology can be increased through relevant research, experiments, and a better understanding of precipitation and cloud systems;
- Cloud seeding operations under certain conditions have produced positive results, using either stratus clouds (formed by the collision of moist air masses over high mountain regions) or convective clouds.
- It succeeded in the dissipation of fogs and low stratus clouds that cause obstacles to aviation traffic at airports and automobile traffic in cities
- It improves the productivity in rain-fed agricultural fields, either by increasing the rainfall amounts or sometimes by controlling the spatial and temporal distribution of rainfall.

Disadvantages : The disadvantages of this technology are as follows:

- The success of this technology under drought conditions is very limited, because of the absence of seedable clouds during such periods and hence cloud seeding must be done when favourable clouds are available to store the water for later utilization.
- Cloud seeding requires advanced and costly equipment, and also qualified professional experts like good pilots and skilled meteorologists.

Future Development of the Cloud Seeding Technology : The most important aspect of cloud-seeding technology is its development as a tool to solve the emerging problems of water scarcity in arid and semi-arid regions of the world.

Some of the methods to be adopted to develop and improve the technology are as follows:

- Implementation of joint cloud seeding projects between neighboring states and countries, with the assistance of international organizations in this field and utilizing the results of successful experiments from other countries.
- Conducting cloud surveys for determination of their precipitation potential and analysis of cloud-seeding methods and operations.
- Collection of data on cloud characteristics and cloud seeding operations for publication and distribution among the institutions and countries interested in promoting operations and research in cloud-seeding.
- Promoting the participation of beneficiaries like farmers, and industrialists in cloud seeding to achieve positive results for augmenting water availability required for agriculture and industries. Since cloud seeding results are tangible and multi-facted, attention must be given not only to meteorology and water, but also to the consequential ecological, hydrological, social and economic problems and the project proponents must inform the decision-makers in the Government and the general public of the current weather modification technologies and their impacts on regional and national development.

ACTION PLAN FOR CLOUD SEEDING BY A.P.STATE GOVERNMENT EXPERTS

A seminar on Artificial Rains and aerial seeding, organized by the Andhra Pradesh Forest Development Corporation in collaboration with the Andhra Pradesh Forest Department was inaugurated by the Hon'ble Minister for Forests, Government of Andhra Pradesh on 19-3-1988, at Hyderabad. Various recommendations were made by way of resolutions both for the warm and cold cloud seeding for artificial rains, indicating the programme of action both for short-term and long-term needs of the state. The resolutions include identification of acute rain deficit areas by continuous monitoring of the rainfall of the various parts of the districts and providing necessary equipment and technical man power requirements by the Government of India and taking up cloud seeding experiment by the State Government from the year 1988-89 and establishing an experimental research station(an Institute for Weather Modification) on long term basis for 5 years by Government of India.

At the end of the deliberations at the seminar the Hon'ble Minister for Forests constituted a Working Group for preparation of a report indicating the plan of action for "Artificial Rains" for Andhra Pradesh with Prof.P.Koteshwaram, former Director General, IMD, Sri.J.Raja Rao, Ex.Officio Secretary for Irrigation and Prof.T.Shivaji Rao former Principal of Andhra University Engineering College as Convener. This expert committee report on Cloud seeding was submitted to the Chief Minister, Government of Andhra Pradesh on 23-3-1988. The Salient features of the report are presented here.

Introduction :

The rainfall in India is uneven and undependable ranging from 10 cms in Rajasthan to 1000cms at Chirrapunji in Meghalaya and North Eastern states spread over only about 3 to 4 months in a year carrying large volumes of water into the sea. This uneven and erratic distribution of rainfall in space and time is leaving $1/3^{rd}$ of the country in drought conditions and at the same time another $1/3^{rd}$ of the area is in heavy floods resulting in enormous loss of life. Similar is the situation in Andhra Pradesh also. It is observed for the last 4 years continuous scarcity of the rainfall is occurring in parts of Rayalaseema and Telangana and upland areas of the coastal districts leading to severe drought conditions and shortage of water for drinking, irrigation, power generation and building up of the ground water for agriculture purpose. Deficiency of rainfall is attributed to deforestation and perhaps to probable changes in the climatic conditions in these areas. Review of the rainfall data for the last 100 years shows that continuous drought conditions for 4 years never occurred in succession. Since shortage of drinking water causes large-scale incidence of water borne diseases like dysentery, diarrhoea, typhoid, cholera, jaundice etc., top priority has to be given for drinking water supply not only to the twin cities and urban areas like Warangal, Visakhapatnam and Tirupati but also to the rural areas in the drought prone regions. In the absence of sufficient rainfall the ground water is also very limited and is getting fast depleted that large number of agricultural and garden crops are damaged. Therefore the only way to tackle these problems is to take up the "artificial rain experiments" on a trial basis in the first instance in the catchment areas of the twin-cities water supply reservoirs namely Osman Sagar, Himayatsagar and Miralam tanks.

The next priority must be given for the areas of lowest rainfall in the districts of Anantapur, Mahaboobnagar etc., It is proved beyond doubt that the artificial rain experiments have been successful else where in India and abroad in raising 22% rainfall by cloud seeding. Immediate action is to be taken to start these experiments with necessary equipment and trained personnel from the Indian Weather Modification Organization or other concerned agencies (to be set up) in the areas mentioned above.

A brief outline on the climatological features of Andhra Pradesh, the technology and results of experiments in artificial rain making in India and else where in the world is presented. An approximate estimate for the short and long-term programmes of Action on Artificial Rains are furnished. It may be possible for the Government to provide funds to the tune of Rs. 25 lakhs for the experimental work on cloud seeding for 1988-89 to the Water and Land Management Training and Research Institute (WALAMTARI), which is getting substantial foreign aid for their research and training work. It may be possible for the Andhra Pradesh Council on Science and Technology, Government of Andhra Pradesh to provide funds for the long-term action programme on seeding of cold clouds involving an amount of Rs.7.5 crores for setting up the Experimental Station with the necessary equipment and technical man-power to be secured from the Government of India for the first 5 years (i.e) 1988-89 to 1993-1994.

I. Climatology of Andhra Pradesh :

Andhra Pradesh gets its rainfall from the South West monsoon from June to September: the North East monsoon from October to December and from tropical cyclones., during the pre-monsoon months of April-May and post monsoon months of October-November. Thus, there will be rain– bearing clouds over some part of A.P., or other for nearly 7 months every year. The areas effected by the monsoons and cyclones are also different.(See the maps)

The South West monsoon gives rains in the Northern districts of Coastal Andhra Pradesh (Srikakulam to Krishna) and Telangana mainly from monsoon depression, which travels westward from the North Bay of Bengal across Orissa and Madhya Pradesh. The frequency of the depressions is about one in 7 or 10 days, based on meteorological observations for the past many decades, and they pour heavy-to- very heavy rain in their South Western sectors covering about 250kms inland, flooding the river Godavari and its tributaries from the Vindhyas. In some years when the monsoon depressions are rare or when they move North-West wards over Uttar Pradesh, the Northern districts of Andhra Pradesh suffer scarcity of rainfall as happened in Srikakulam and Vizianagaram districts in 1987. Whenever there is a break in the Southwest monsoon activity over North India, there will be showers all over Andhra Pradesh including Rayalaseema benefiting many of the districts. The activity of the South West monsoon over North India and over Andhra Pradesh have an inverse relation with increases and decreases of rainfall as the monsoon activity shifted North or South.

The Northeast monsoon is confined to the Southern districts of Nellore, Prakasam and Chittoor and occasionally the other coastal districts for a day or two. Tamil Nadu and Nellore districts get most of its rain from this monsoon. This monsoon however is much more erratic than the Southwest monsoon and some times fails in many successive years.

The cyclones that hit the Andhra Pradesh coast are beneficial particularly in the pre-monsoon month of May as they give copious rains in the districts that they hit and also along their path to the West or North West after they have weakened. They are however more numerous in the post monsoon month of October –November, when they destroy standing crops at the harvest stage by strong winds, rains and saline inundations from tidal waves or storm suges from the sea.

Although the Coastal districts and Telangana get rainfall from the monsoons and cyclones, the Rayalaseema districts suffer from lack of rains in most years as they lie in the rain shadow area of the western ghats and the South West monsoon empties its bountiful rain to the West of the ghats. The Northeast monsoon also avoids these districts except Chittoor to some extent, as its rain will be confined to the East of the Eastern Ghats. Climatically Rayalaseema falls in a semi arid belt extending from the arid desert of West Rajasthan to Tamil Nadu. While the annual rainfall is low, the coefficient of variation is high rendering it doubly difficult for crops or even for drinking water. The hard rock area of these districts render availability of ground water also scarce The only hope for these districts is during break monsoon when Rayalaseema and adjoining districts of Mahabubnagar, Nalgonda and Medak get rains.

Monsoon rainfall ceases over the plains of Northern and central India and monsoon disturbances travel westwards from the South and Central Bay over the Peninsula including Rayalaseema and adjoining districts. The only source of water for Rayalaseema lies in the diversion of the water of river Krishna and Tungabhadra over these arid districts for which irrigation channels and reservoirs are being constructed for many years. The Telugu Ganga and Srisailam Right Bank Branch Canal are the latest schemes that will greatly benefit the people of these districts. The Srisailam Left Bank Canal to irrigate 3 lakhs acres of Nalgonda district has already been taken up. **Another reliable method will be to construct a chain of reservoirs over the western ghats to store the copious rains over the westerns ghats and divert the water over the peninsula.** This has to be a joint endeavour by the States of Maharahstra, Karnataka and Andhra Pradesh. A scheme for diversion of rainfall falling on the western ghats to eastwards was suggested to the Government of India some years ago and it is under investigation by the National Water Development Agency of the Government.

II. Clouds and cloud seeding :

As rain has to fall from clouds, there will be some clouds over all the districts of Andhra Pradesh during the monsoon season. The only problem with them is that they develop during day due to the sun’s heat and **dissipate by the evening unless they are influenced by a cyclone or a depression** . Rayalaseema and the Southern districts of Telangana also have such clouds due to depression on some days. It should therefore be possible to use artificial cloud seeding to get some rain from such clouds. The area of formation of **such cloud clusters can be forecast a day or two in advance by the meteorological centers at Hyderabad, Madras, Pune and Visakhapatnam**. The cloud seeding equipment should be rushed to these areas to be in readiness to seed the clouds after they have developed. The seeding agency will be able to determine not only the possibility of development of seedable clouds a few hours before their birth but also the required amount of seeding material to be dropped into them by equipping themselves with a mini computer and using mathematical models. **The clouds building up over the interior peninsula Rayalaseema adjoining Telangana will be mainly of the cold cloud type. Warm clouds will be confined to coastal areas.** Hence, it is essential that cold cloud seeding should be taken up by the Government of India as an urgent measure in order to assist not only Rayalaseema and Telangana, but the large arid and semi-arid belt of India extending southward from Rajasthan to Tamil Nadu. Till suitable techniques are developed by the Government of India, it should be possible for the Andhra Pradesh Government to fund experiments using competent scientists in universities in the state and on loan from the central Government. **Till dynamical cloud seeding techniques are developed** by the IWMO it may **utilize the warm cloud seeding techniques** whenever possible **in the area of lowest rainfall such as Anantapur and neighbouring pockets of Mahaboobnagar districts to start with**.

Scientific and technical aspects of artificial rainfall :

The Expert Committee examined the evidence presented by the scientists on various experiments conducted on warm-cloud seeding at Poona and the cold-cloud seeding in Israel.

They have also noted grave concern expressed by various speakers at the Technical Session on Artificial rains about devastating impact of recurring droughts on public health, drinking water supplies, power generation, agriculture, forests and wild-life and the human environment. Most of the speakers emphasized on the urgent need to tackle the problem by using the latest technology on cloud-seeding.

The experiments conducted by the Rain and cloud physics Research Unit on cloud modification by means of salt seeding ground based generator during 1957-1966 indicated a statistically significant increase of rain by about 20% on seeded days (Ramana Murthy, 1968).

The Institute of Tropical Meteorology at Poona in collaboration with the Indian Meteorological Department conducted air-craft salt seeding of clouds over the catchment of Rehand reservoir in U.P. during the monsoon seasons of 1973 and 1974. Although the experiment was not randomized, the data from the limited number of rain-gauges in the catchment area showed an increase of rain-fall by 17% to 28% (Kapoor etal.1976).

Again aerial cloud seeding with common salt was done over the catchment of the Linganmakki river in Karnataka during the monsoon of 1975 when the water level in the reservoir showed an increase upto 73.25 level. This increase was about 26% more than the highest increase recorded due to the natural rains in the preceding ten years when no cloud-seeding operations were done.

The Tamil Nadu Government with the assistance of Atmospheric Incorporated, U.S.A., undertook cloud seeding through Silver Iodide pyrotechnics during the summer monsoon season of 1975. Based on the Radar observations, the American firm claimed extra rain-fall increase of 20% to 25% due to cloud seeding.

With the discovery that the deficiency of ice crystals in cold clouds prevent them from giving normal rain-fall, attempts are made to correct that deficiency through the introduction of artificial ice nuclei like Silver Iodide at a concentration of about one nuclei per liter of cloud so that precipitation occurs by ice-crystal chain reaction mechanism. This method was widely used in Australia, U.S.A. and Israel where convincing and significant increase in rain-fall on seeded days was noticed. The cloud-seeding experiments in Tasmania showed a 15% to 20% extra rain-fall in the water storage reservoirs (target area) which are highly significant (warner 1973 b). The results of the work on cold-cloud seeding in Israel showed extra rain-fall by 15% over the catchment of Tiberias lake at a highly statistical significance (Gagin 1981)

Cold Cloud Seeding : But introduction of massive dosages of silver iodide into the clouds at minus 10^{o}C at the rate of 100 to 1000 nuclei per liter of cloud air is known as dynamic seeding. In this process the conversion of super-cooled water in the cloud into ice-crystals (through Bergson-Findesen reaction mechanism) releases latent heat that increases buoyancy, thereby increasing the size of the cloud with the probability of cloud merger and area-wise enhancement of rain-fall (Woodley and Sax 1976). Dynamic seeding of individual clouds on a random basis in USA indicated significant increase in rain-fall by a factor of three (simpson et.al;1973)

The dynamic seeding of convective clouds in South Florida indicated 20% additional rain-fall over the 13000 Sq. km total target area and nearly 50% more in the area defined as he floating target (Woodley et al 1977).

Warm cloud seeding : (Refer to the Chapter on Warm Cloud Seeding)

Experiments on cold-cloud seeding :

The cold clouds contain both super cooled water droplets and ice-crystals. Just as there are cloud condensation nuclei in warm-clouds in the form of dust, smoke, salt crystals and other materials, cold clouds contain ice nuclei on which cloud droplets freeze or ice-crystals form directly from water vapour. The ice-crystals grow rapidly drawing moisture from the surrounding super cooled cloud droplets due to the difference in saturation vapour pressure over the super-cooled water droplets and the ice-crystals by what is knows is Bergeron Findesen mechanism. When the ice-crystals grow to a few millimeters in size they fall to the ground under the influence of gravity as rain. The National Academy of Sciences of USA apparently regarded 10% to 20% precipitation increases due to weather modification as modest once. Various experimental programs concluded that ice-nuclei seeding of cold clouds have increased precipitation at the ground. A project in Switzerland and another in Israel gave positive results. The first Israeli experiments (1961-1967) indicated an increase by 15% in rainfall through seeding of cold-clouds with silver iodide in the target area as a whole with the interior sub-continent recording an increase of 22%.

The second Israeli experiment of 6 rainfall seasons (1969-1975) proved that rain-fall can be increased upto 27%.

The results of these experiments show that Israel's water supply could be increased by about 25% and that too at about 1/30 to 1/60 of the next cheapest method for developing new water sources.

Unfortunately no worthwhile research and development work has been done in India on cold-cloud seeding and hence, there is an urgent need to undertake scientific investigations at the National and state levels. For this purpose, a long-term programme of action for cold cloud seeding experiments must be taken up with the assistance of the Central Government, the Universities and other concerned agencies.

For more details on the experimental data of the Israeli experiments of 1961-1967 please see the article "cloud seeding for improved water and power supples and environment" by Prof.T.Shivaji Rao presented elsewhere.

IV. Program of action on artificial rains

The program of action is divided into two parts, namely, the short-term program on warm cloud seeding for a period of one year (1988-89) and the long-term program on cold cloud seeding for a duration of 5 years (1988-89 to 1993-94).

(i) **Short-term program: (1988-89) :** The short term program on warm cloud seeding experiments envisages that all the required equipment and the technical personnel will be provided by the Indian Weather Modification Organization at Pune (to be started). The necessary funds of Rs.25 lakhs will be provided by the state Government (WALAMTARI) or other Government departments like Energy, Environment, Science & Technology or Andhra Pradesh Council on Science and Technology. These proposals were discussed with the concerned officers of the Weather Modification Organisation, IITM at Pune and the WALAMTARI at Hyderabad. It is desirable that the Government should initiate immediate action on this proposal.

(ii) **Long-term program (1988-89 to 1992-93) :** The long term program on cold cloud seeding experiments contemplates original research and development work by establishing Experimental Research Station at Hyderabad. (Himayat Sagar Dam) The station is to be headed by the project Director and manned by other scientists and technologists. The

Director will be a senior scientist with adequate experience in methods of weather modification and organization of field experiments. The other staff, equipment and financial requirements for the program are presented in the Appendix. (See Table)

Appendix – I

Table-1 : In addition to one Project Director, the staff structure will be as follows:

Group	AD	SSO	JSO	JSA	TOTAL
1. Seeding Group	1	2	1	2	6
2. Cloud Physics Group	1	2	1	1	5
3. Radar Group	1	2	2	2	7
4. Statistical Group	--	1	1	1	3
5. Modelling Group	1	1	1	1	4
6. Aircraft Group	1	1	1	1	4
7.Maintenance Group	1	1	1	2	5
8.Administration Group	1	1	2	2	6

Seeding Group is responsible for taking decisions regarding the seeding flights based on the results of the cloud model runs, weather conditions, conduct of the seeding operations and other organizational duties.

Cloud Physics Group is responsible for cloud physics studies and physical testing of the seeding hypotheses.

Radar Group is responsible for radar study of convective rainfall and radar evaluation of the experiment.

Statistical Group is responsible for pilot studies during Phase-I and development of suitable evaluation techniques and statistical analysis of rainfall.

Modelling Group is responsible for the development of cumulus models and updating them from time to time using the cloud micro-physical data for making the model results more realistic. Also, this group handles the daily computations of the seedabilities based on daily radiosonde data in coordination with the seeding group.

Aircraft Instrumentation Group holds the key for the success of the experiment, the main responsibilities of the group are:

(i) design and development of new instruments

(ii) Servicing of Radars, Laboratory and field instrumentation etc.

The personnel of the group should have sound knowledge of the latest solid state instrumentation. Also, the senior engineers should be able to fly in turbulent weather conditions in the seeder aircraft. The instruments fitted to the aircraft often time require checks and minor repairs because of their operations in turbulent conditions. Up-keep of the cloud physics instrumentation is essential during all the flights for the microphysical data collection at the appropriate time without losing any opportunity.

Maintenance Group is responsible for general technical and maintenance work.

Administration Group is responsible for Administration, accounts work.

Table - 2 : Year wise break-up of Budget *(Rs. in lakhs)*

Year	Equipment	Recurring	Capital works	Fellowship Foreign	Total
Ist year (1988-89)	5.00	10.00	--	--	15.00
IInd Year(1989-90)	200.00 (F.E.150.00)	40.00	30.00	5.00 (4 Fellowships)	275.00
IIIrd year (1990-91)	100.00 (F.E.75.00)	70.00	--	--	170.00
IV Year(1991-92)	100.00 (F.E. 15.00)	80.00	--	--	180.00
V Year (1992-93)	30.00 (F.E. 15.00)	80.00	--	--	110.00
	435.00	280.00	30.00	5.00	750.00

Total Rs.7.50 crores F.E. Rs. 2.55 crores

Approximate cost estimate for 5 years period — **Rs. In lakhs**

1. Salaries (41 posts)	120.00
2. Equipment and Ground support	300.00
3. Cloud Physics Instruments	110.00
4. Maintenance of 100 rain gauges and cost of surface observations	25.00
5. Cost of 20000 silver iodide pyrotechnics and 2000 hours of of aircraft flying time (3 aircraft)	160.00
6. Capital works	30.00
7. Miscellaneous items	5.00
Total	750.00
	Rs.7.50 crores

Appendix – II

Table - 3 : Equipment–Ground Support

S.No.	Equipment	No.	Cost Rs. in lakhs
1.	10 cm radar with quantitative rainfall measurement capability (DVIP)	One	50.00
2.	Mobile C-band radar with accessories	One	70.00
3.	Aerosol measuring equipment consisting of CCN, Aitken and ice nucleus counters	Two each total 6	10.00
4.	Mobile radiosonde stations	Two	5.00
5.	Mobile pilot balloon stations	Two	2.00
6.	Self recording raingauges	100 gauges	10.00
7.	Time lapse cameras for cloud photography	Two	6.00
8.	Walkie Talkie set	Five	2.00
9.	Xerox, photography and drafting equipment		5.00
10.	Mobile meteorological observatories for field work	Four	10.00
11.	Micrometeorological field station		10.00
	Total		Rs.300.00lakhs

Appendix – III

Table - 4 : Instruments for measurement of cloud physical parameters

S.No.	Instrument	No.	Cost Rs. in lakhs
1.	Total water content probe	One	5.00
2.	JW hot wire meter	Two	1.00
3.	Airborne hydrometer sampler	Two	2.00
4.	Continuous Formvar replicator	Two	10.00
5.	Mee Ice particle counter	Two	4.00
6.	Aircraft dew point sensor	Two	2.00
7.	Temperature probe	Four	2.00
8.	CCN counter	Two	2.00
9.	Ice nucleus counter	One	2.00
10.	Time Lapse Camera System	Three	6.00
11.	Knollenberg cloud and rain drop 20 spectrometer	One	10.00
12.	Aitken nucleus counter	Two	2.00
13.	Rain Water scoop, air samplers	Six	2.00
14.	Data logger system for the aircraft	Two	10.00
15.	Multi-channel strip chart recorders	Five	8.00
16.	Inertial navigation system	One	20.00
17.	Turbogenerator for aircraft	One	5.00
18.	Multi-channel strip chart recorders	Five	8.00
19.	Densitometer	Two	10.00
		Total Rs.	110.00 lakhs

Appendix – IV

SPECIFICATIONS FOR SEEDER AND RESEARCH AIRCRAFT

Seeder Aircraft:

1.Normal speed true	500km/hr
2.Maximum usable fuel	65,000 pounds
3.Fuel reserve time	2.0 hours
4.Enroute time	10.0 hours
5.Maximum range	5000km
6. Maximum flying altitude	25,000 to 30,000 ft
7.Maximum pay load	20,000 pounds
8.Maximum take-off weight	1,35,000 lbs
9. Maximum capacity	12 scientists plus crew

Research Aircraft

1. Normal speed true	200 km/hr
2.Maximum Endurance	6.5 hours
3.Maximum cruising range	1800 kms
4.Maximum flying altitude	30,000ft
5.Maximum capacity	4 scientists plus crew
6.Maximum gross weight	8500 lbs
7.Maximum pay load weight	2400 lbs
8.Fuel capacity	1564 lbs

Appendix – V

DETAILS OF AIRCRAFT FLYING TIME AND SILVER IODIDE PYROTECHNICS ETC. FOR 5 YEARS OF EXPERIMENTATION

	Cost Rs. in lakhs
1. *Cost of flying 2000 hours for 5 seasons (3 aircraft @Rs.10,000/- per flying hour based on estimates in USA in 1975)	100.00
2. *Cost of 20000 NEW-TB-1 70 gm flares	50.00
3. * Flare racks of capacity 300 pyrotechnics delivery systems etc	10.00
Total	260.00

*The flying time and number of silver iodide flares required for one seasons experiment depends on the size of the experimental area and the number of seeding opportunities. Generally 10 to 20 flares are required for seeding one cloud. The output of the silver iodide flares for the dynamic cloud seeding experiment should not be less than 10^{13} nuclei per gram of silver iodide at –8°C.

Composition of TB-1 Flares Material	Percent by weight
Silver iodate ($Ag10_3$)	78.3
Magnesium (Mg)	5.2
Sluminium (Al)	10.2
Binder	5.8

Expected exhaust products of TB-1 flares:

Compound	Percent (per gm of mix*)
Silver iodide (AgI)	64.9
Aluminium oxide (Al_2O_3)	20.4
Magnesium oxide (Mgo)	8.6
Carbon dioxide (CO_2)	18.2
Water (H_2O)	7.4

* Total exhaust products add up to more than 100 percent because some oxygen to burn the metal fuels is incorporated form the surrounding atmosphere.

References :

1. Ramana Murthy, Bl.V. and K.R.Biswas, J.Meteor.Soc.Japan 46, 160-165(1986)

2. Kapoor et.al, Pune and Applied Geophysics, 114, 379-392 (1976)

3. Kapoor et.al, Proc.Int.Conf.on Cloud physics, Boulder, USA, 145-156 (1976)

4. Warner,J. Proc.W.M.O / AIMAP Scientific Conference on Weather Modification,Tashkent, 43-50 (1973)

5. Gagin et.al, Second Israeli Randomised cloud seeding Experiment J.App.Meteorology, Sept.1981

6. WoodleyW.L. et.al.,NOAA Tech.Report ERL-354,WMPO-6, 206 PP.

Seminar on artificial rain and aerial seeding held on 19-3-1988at Hyderabad
Session - 1 : Artificial Rains

Resolutions :

Having considered the various views presented by the expert scientists and Engineers in the Seminar on “artificial rain and aerial seeding and spraying” organized by Andhra Pradesh Forest Development Corporation at Jubilee Hall in Hyderabad on 19-3-1988 in its first session on Artificial rain the participants discussed the possibilities of cloud seeding both warm and cold clouds in trying to mitigate droughts in many districts every year and make the following recommendations to the state and central Governments.

1. The Government of Andhra Pradesh should identify periodically acute rain deficit areas prone to drought conditions and intimate their requirements for cloud seeding as early as possible to Central Government (Department of Science and Technology)

2. The Government of Andhra Pradesh should continuously monitor the rainfall from various parts of each district by organizing a net work of rain gauges and getting reliable data by fast telecommunications system, to assess the deficit of rainfall for maturity of crops and also building up the storage in the reservoirs for drinking water, irrigation, hydro power etc. This work should be done in collaboration with IMD., Offices at Hyderabad and Visakhapatnam and ICRISAT at Hyderabad. This work may be entrusted to the Hydrology wing of the Engineer in Chief, Irrigation Department.

3. The Central Government should provide additional ground facilities like mobile radars and other instruments to Indian Weather Modification Organisation to fulfill these requirements in order to alleviate the drought conditions in areas identified by the State Government.

4. The Central Government should provide the facilities for cloud seeding including the equipment, man power etc., and the State Government should provide the necessary infrastructure facilities after due discussions well before the commencement of the monsoon season. For this purpose the IWMO will provide to the State Government an approximate estimate depending upon the climatological conditions in the State.

5. Active investigation shall be undertaken by the IWMO for the cold cloud seeding in the State using the latest techniques. For this purpose aircrafts may be hired from Indian Airforce, NRSA and any other sources. After the results of the cold cloud seeding experiment are evaluated, they should be brought to an operational stage within a period of 5 years for which the entire funding should be provided by the Central Government.

6. In order to get the maximum benefit for Andhra Pradesh and the adjoining states, the National Water Development Agency, under the Union Ministry of Water Resources may be approached to undertake this project in addition to the other distress alleviation measures over the peninsula.

7. The cold cloud seeding experiments should be aimed at shifting the rainfall maximum on the Western ghats to the East of the ghats so that the rain shadow areas are benefited.

8. The R & D particularly mathematical modeling work relating to further development of technology in the state for the cold and warm cloud operations should be undertaken by APERL, WALAMTARI and the interested universities in Andhra Pradesh and necessary funds shall be provided by the Government, the UGC, CSIR, DST, D.O En.

9. A technical advisory committee on weather modification may be constituted by Government of Andhra Pradesh to implement the above resolutions.

10. Water and Land Management Training and Research Institute, Hyderabad will be the nodal agency for planning, co-ordination and implementation of the Pilot Projects in areas with lowest rainfall and conduct research and development studies. For this purpose the necessary infrastructure and financial support shall be provided by the State Government.

11. Soil and Water Conservation including aforestation schemes should be intensified by Government of Andhra Pradesh in drought prone districts of the state to avail the full benefits of artificial rains.

12. A Committee with the Hon'ble Minister for Forests as Chairman and including the following members

1.	**Prof.P.Koteswaram**	**2.**	**Prof.T.Shivaji Rao**	**3.**	**Mr.D.V.Rao, I.F.S.,**
4.	**Mr. J.Raja Rao,**	**5.**	**Mr.V.Subbaramayya**	**6.**	**Mr.P.Narayanappa**
7.	**Mr. T.Hanumantha Rao**	**8.**	**Mr.Pushp Kumar** (Convenor)		

be constituted for working out an action plan and contacting various organizations and draw up a future course of action on weather modification programmes of the state.

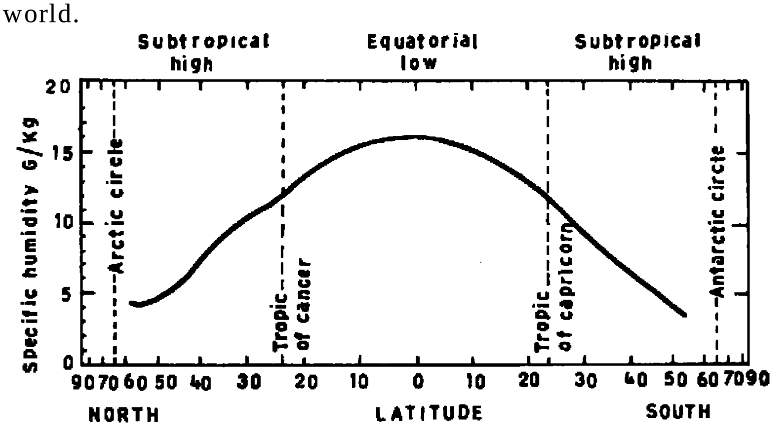
Extract from the minutes of the seminar :

After the inaugural function the technical session commenced with **Prof.T.Shivaji Rao** in the Chair, who initiating the discussion, explained how this programme was started in the USA. After the initial experiments, a survey was conducted by sending questionnaire in USA and 60% of the people gave a positive response. A large number of the people conveyed their consent that the programme was successful. We have been contemplating projects with huge investments to bring drinking water from far-off places, as for example, to Hyderabad city from Godavari or Krishna rivers at cost of several hundred crore rupees. The cloud seeding project will be a much less expensive proposition. In Gujarat sea water is proposed to be converted into fresh water at a cost of Rs.40/- to 45/- per unit (one cubic meter or 1000 liters) while the same quantity can be obtained by cloud seeding at a cost of about 1 paise.

Prof. P. Koteswaram (Former Director General, Indian Meteorological Department) said that we as scientists have to see whether we can use available technology to increase the water resources of the country. In India the average precipitation is quite high, about 117 gms/sq.cm but is not evenly distributed. There are places like Cheerapunji in Meghalaya which get rainfall of about 1000cms in a period of 3 months and rest of the year is dry. There are places in West Rajasthan which get only 5 to 10cms of rain in a year. We see clouds many times in the rainy season, but they do not rain. We should try to induce them to rain.

Experiments began in 1947 in the USA. Rain making experiments were organized in India from 1957 to increase rain from clouds. Cloud seeding was attempted over Rihand reservoir in 1974 and it was found that efforts at increasing the precipitation and filling the reservoir were successful. Similar experiments were done in Karnataka over the Linganmakki Reservoir in 1975 successfully. But efforts at rain making made by some US companies in the month of February in Bihar failed as there were no clouds there in the winter season.

In the monsoon season, cold clouds are found above 6 km and hence we have to go above that level. Such seeding can be tried with silver iodide whose crystals have a dendrite structure like ice crystals. In our clouds water content is about 5 gms/kg and is one of the highest in the world.



Zonal distribution of specific humidity

The other places where tropical clouds were available is in Florida (USA). It was possible to induce the clouds to cluster together. It was found such a group of clouds was capable of dropping 4 times more rain than all the individual clouds put together. We have been dropping powered common salt (Na Cl) over warm clouds and the precipitation was found to be about 10% higher.

A single experiment cannot give a solution to our problems such experiments have to be repeated under different conditions and periods. They were started in India East of the Western ghats since 1973 and the results were evaluated in 1987. It was found that dropping of common salt over clouds can increase the rain upto about 24%.

Two points emerge for consideration.

1. Cloud seeding is a proven technique. Warm cloud seeding technology has been tried in India which has acquired a lead in the world in this technique. The earlier experiments were done near Pune subject to sinking air East of the ghats and hence even the success of 24% is an under estimate for Rayalaseema which is away from the Ghats.
2. A scheme was drawn up in 1974 and again in 1980 at a cost of Rs.10 crores to conduct experiments in cold cloud seeding in India. This needs to be implemented. May be it will cost more now due to rise of prices.

Dr.A.S.R.Murthy, Asst. Director of the Institute of Tropical Meteorology Pune showed slides and transparencies about experiments done and results obtained and sequence of various events in the development history and application of cloud seeding. It started in 1946-47 in USA WHEN Schaefer and Vonnegut demonstrated the possibilities of rain making. Then Langmuir explained the coalescence mechanism in warm clouds. Randomised field experiments were conducted from 1962-70. This was followed by dynamic seeding technique from 1973-80. The Rain and Cloud Physics Research Institute was set up in India in 1955-60. Then in between 1975-86 salt spray by aircraft was done. Rain can be triggered by injecting the cloud. The chemical used is silver iodide and only a small quantity of it i.e 1 gm costing about Rs.3/- can generate about 1 million drops of rain. However the cost of injecting is enormous. Most of the experiments done however lack statistical acceptance.

This was studied by the world Meteorological Organisation a UN body which observed that:

1. Rain fall effect can be modified locally.
2. Weather modification it still largely in the research stage.

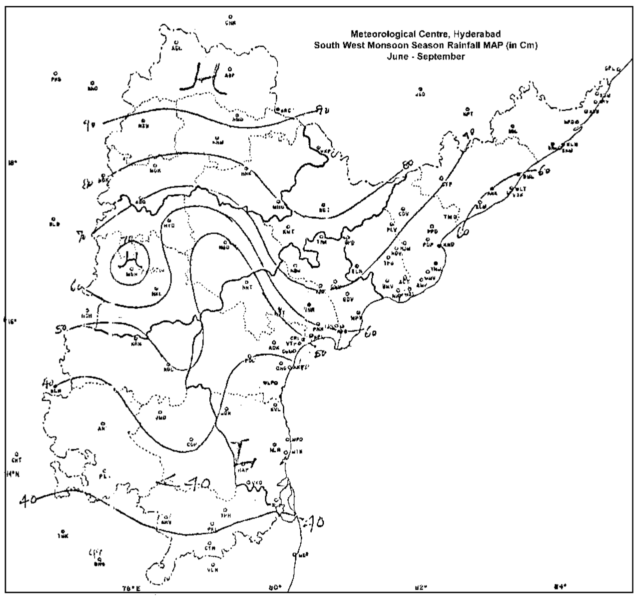
In India experiments have been conducted at Pune over 11 monsoon seasons and it was found that about 25% increase in precipitation can be obtained by cloud seeding. Dr.Murthy also observed that the life of a cloud is about ½ to 1 hour in which time, it can travel about 20kms the apprehension that inter state or international problems can arise is not justified if we could seed a cloud that remain in our state.

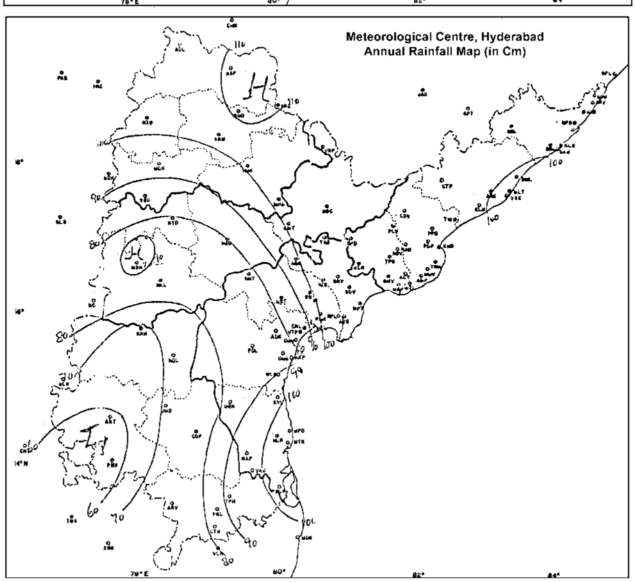
In the Indian experiments pulverized salt and soapstone as injected. The Dakota plane used to carry 150 kgs of salt at a time. Seedable density was found to be 0.5gm/cum and amount of low clouds should 3 Oktas. The initial results of 1973showed 11.9% change in precipitation and it later stabilized between 22-24%. If the clouds are small, there will even be reduction in rain fall. Massive seeding was also tried. Under optimum conditions possibility exists for augmentation. Positive results are possible only if seedable clouds exist. Persistant drought conditions are some times accompanied with minimum seedable clouds. Such experiments have been done in U.P. during 1973-74, in Haryana during 1971-1974 in Karnataka during 1975, 1981 and 1982 in Tamilnadu during 1963 and in Gujarat during 1974, 1981 and 1987 and in Kerala during 1987.

Sri Purushotham Reddy suggested that the efforts at getting more rain can be called an eco-development plan. The droughts and water reduction are the results of depletion of forests which are the natural cooling zones for clouds to shed the rain. He referred to the International problem that can result by cloud seeding citing the example of Cuba. He suggested that cloud physics be introduced as a subject in the universities. To start with this may be done in Osmania University and the Hyderabad University. He also suggested that an Environment committee be constituted in A.P.

Prof.Shivaji Rao in his concluding comments suggested that we should go on doing cloud seeding regularly over a long period so that it can mitigate the drought effects. A dedicated effort is required.

At the conclusion of the discussions, the draft resolutions were discussed and adopted with few minor amendments.





APPENDIX-I : AUTHORS LETTER ON CLOUD SEEDING TO PRESIDENT OF INDIA

The President of India,
Rashtrapati Bhawan,
New Delhi.

Sir,

I am herewith sending you an Extract of a News Report from PEOPLES DAILY of China dt. 14-7-2000 on how the patriotic scientists of Chinese Academy of Sciences had been promoting CLOUD SEEDING operations to fight the DROUGHTS in the arid Northen provinces since 1980s .The enormous quantities of rain they are getting per year is about 30 TMC and they are now planning to produce about 100 TMC of water for the Northern Province by using advanced technologies by making use of the services of scientists including the experts of the Meteorological department who are willing to serve the cause of the people as per the advise tendered to all the countires to take up cloud seeding to fight the droughts as per the guidelines formulated by the world Meteorological Organisation and the United Nations Environmental Programme.

The intelligent scientists of both the progressive countries like United States and China conducting cloud seedingoperations for the last 40 years while the Indian Government virtually stopped this scientifically proved technology being continued by the Indian Institute of Tropical Meteorology, Pune which successfully conducted the warm cloud seeding for 11 years during 1973-1986 and subsequently stopped the work due to lack of encouragement from the Union Ministry of Science and Technology and the Indian Meteorological Department (IMD) which are vested with the basic task of promoting proven scientific technologies for promoting public health and National prosperity.

The political leaders of all parties should be educated on the urgent need to use this technology on a large scale to fight the droughts at a very inexpensive cost of less than Rs. 10 crores per state instead of meeting the demands of atleast a 1000 crores being demanded by each state from the Prime Minister and the Union Government towards drought relief.

I appeal to you to use your scientific skills and diplomacy to inspire both the heads of political parties in different states and heads of National scientific laboratories and science departments in central and state Govenrments to promote research and development and cloud seeding operations to ensure sustainable development in the fields of health, agriculture, forests, hydro-power generation and economic growth of the various states in particular and the country in general.

I have also enclosed the relevant website from the People's daily of China to get more information on this subject from Chinese authorities.

Website : http://fpeng.peopledaily.com.cn/200007/14/eng20000714_45496.html

Yours sicnerely,
PROF.T.SHIVAJI RAO,
Director, CEntre for Environmental Studies,
GITAM Engineering College, Visakhapatnam

APPENDIX-II
REPLY BY IMD ON CLOUD SEEDING

एस० के० सुब्रमण्यन
मौसम-विज्ञान के उप-महानिदेशक
(चक्रवात चेतावनी)

भारत सरकार
भारत मौसम-विज्ञान विभाग
मौसम-विज्ञान के महानिदेशक का कार्यालय
मौसम भवन, लोदी रोड,
नई दिल्ली-११०००३ (भारत)

S. K. SUBRAMANIAN
Deputy Director General of Meteorology (Cyclone Warning)

GOVERNMENT OF INDIA
India Meteorological Department
Office of the Director General of Meteorology Mausam Bhavan, Lodi Road, New Delhi - 110003 (INDIA)

D.O. No. F.12016/1/00-NA

February, 2004

Dear Prof. Rao,

Kindly refer to your e-mail dated 9.10.2003 addressed to the Hon'ble President of India regarding suggestions about cloud seeding to combat droughts.

Cloud seeding activities taken-up earlier in India were discontinued about a decade back as the period of experiment was felt to be of sufficient duration. In spite of more than 50 years of intensive research in the field of weather modification, the efforts have not produced definite results. W.M.O. guidelines state that those willing to develop activities in the field of weather modification should be aware that under certain conditions seeding may be ineffective or may enhance undesirable effects (increase in hail, reduction in rain, etc.). In particular, if there are no clouds, precipitation cannot be artificially stimulated. Precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry spells.

Your appeal to the President of India to urge to Indian scientists to follow the line of cloud seeding operations as being followed in China deserves appreciation.

With kind regards,

Yours sincerely,

S.K. Subramanian
25/2/04

(S.K. Subramanian)

Prof. T. Shivaji Rao
Director,
Centre for Environmental Studies,
GITAM Engineering College,
Visakhapatnam, Andhra Pradesh

Tel. : (91) -(11)- 24611068; Telex : 231-66494; MDGM-IN or 231-66412 MDGM-IN;
Telefax : (91) - (11) - 24643128, 24699216; E-mail : subramanian@imd.ernet.in

APPENDIX-III : Dr. K.L. RAO'S SUGGESTIONS ON CLOUD SEEDING

The eminent Irrigation Engineer and a former Union Minister for Irrigation Dr.K.L.Rao in his treatise on "India's Water Wealth"(1979) strongly appealed to all the Irrigation Engineers in different states to realise that water is the basic foundation not only for the economic growth of a nation but also for the very survival of man. He emphasized that due to rapid growth of population and increased needs of agriculture and industries, water in many areas of the country has become a critical factor for development.

He recalled that the hydrological cycle clearly shows that rainfall occurs mostly over the oceans while the vast stretches of land in different states are starved of water and that many regions are designated as "drought-prone" areas. He reminded the engineers that intensive research studies have been taken up to increase the size of the clouds and make them shed more water at the required places.

He recalled that a number of cloud seeding experiments have been conducted in many countries like Australia, USA, Russian states, France, Canada and Israel where positive results are obtained to substantially increase the annual rainfall.

He stated that many countries have been using cold cloud seeding operations while India has attempted warm cloud seeding. He commended the Indian warm cloud seeding experiments that used common salt and obtained increase of 20% rainfall during the monsoon season.

He suggested that cloud seeding has reached an important threshold for large scale applications for water resources development. In the light of the positive attitude of Dr.K.L.Rao to augment water availability by cloud seeding operations, the Irrigation Engineers of the Union and State Governments and the Ministries of Water Resources and Power development must realise that in addition to the utilization of ground and surface waters, sincere attempts must be made to harness the abundant sky water available in the clouds at about half a dozen times more than the fresh water in all the rivers on earth.

APPENDIX-IV : RAINY DAYS IN SELECT REGIONS

Rainy Days in A.P. State

Month	Anantapur		Kurnool		Hyderabad		Gannavaram		Ongole		Visakhapatnam	
	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD
Jan	0.2	0.0	0.7	0.1	3.2	0.3	0.9	0.1	3.0	0.3	11.4	0.5
Feb	1.4	0.1	2.6	0.3	5.2	0.4	5.3	0.4	9.1	0.5	7.7	0.5
Mar	3.4	0.3	7.9	0.6	12.0	0.9	9.6	0.5	5.5	0.2	7.5	0.5
Apr	16.2	1.2	19.5	1.7	21.0	1.8	14.3	1.0	11.6	0.7	27.6	1.2
May	65.4	3.5	60.5	2.9	37.3	2.7	51.3	3.1	53.2	2.2	57.8	3.0
June	57.8	3.6	90.9	5.6	96.1	7.6	131.9	7.6	65.7	4.9	105.6	6.4
July	60.9	4.4	138.3	9.4	163.9	10.6	218.4	12.6	102.5	6.5	134.6	8.7
Aug	62.0	4.5	141.2	9.1	171.1	10.1	185.6	11.5	102.2	6.9	141.2	9.3
Sep	134.8	7.2	148.1	8.2	181.5	8.9	163.5	8.8	121.3	7.8	174.8	9.9
Oct	117.2	6.3	90.2	5.6	90.9	5.7	142.6	7.1	218.9	9.2	204.3	8.7
Nov	31.0	2.1	20.3	1.9	16.2	1.6	51.3	2.8	143.2	5.1	65.3	2.7
Dec	10.7	0.9	5.7	0.4	6.1	0.4	6.7	0.6	36.5	1.7	7.9	0.6

RAINY DAYS IN SELECT METROPOLITAN CITIES

Month	New Delhi		Mumbai		Kolkata		Bangalore		Chennai		Hyderabad	
	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD
Jan	20.3	1.7	0.6	0.1	16.8	0.9	2.7	0.2	16.2	1.0	3.2	0.3
Feb	15.0	1.3	1.5	0.1	22.9	1.5	7.2	0.5	3.7	0.3	5.2	0.4
Mar	15.8	1.2	0.1	0.0	32.8	2.3	4.4	0.4	3.0	0.2	12.0	0.9
Apr	6.7	0.9	0.6	0.1	47.7	3.0	46.3	3.0	13.6	0.7	21.0	1.8
May	17.5	1.4	13.2	1.0	101.7	5.9	119.6	7.0	48.9	1.6	37.3	2.7
June	54.9	3.6	574.1	14.9	259.9	12.3	80.6	6.4	53.7	4.1	96.1	7.6
July	231.5	10.0	868.3	24.0	331.8	16.8	110.2	8.3	97.8	7.3	163.9	10.6
Aug	258.7	11.3	553.0	22.0	328.8	17.2	137.0	10.0	149.7	8.5	171.1	10.1
Sep	127.8	5.4	306.4	13.7	295.9	13.4	194.8	9.3	109.1	6.6	181.5	8.9
Oct	36.3	1.6	62.9	3.2	151.3	7.4	180.4	9.0	282.7	10.2	90.9	5.7
Nov	5.0	0.1	14.9	1.1	17.2	1.1	64.5	4.0	350.3	10.1	16.2	1.6
Dec	7.8	0.6	5.6	0.4	7.4	0.4	22.1	1.7	138.2	5.5	6.1	0.4

Month	Ahmedabad		Bhopal		Bhubaneswar		Chandigarh		Goa		Guwahati	
	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD
Jan	2.6	0.3	12.9	1.3	12.4	0.7	33.1	2.6	0.2	0.0	11.4	1.2
Feb	1.1	0.2	7.8	0.7	24.2	1.6	38.9	2.8	0.1	0.0	12.8	1.3
Mar	1.0	0.1	7.2	0.7	24.2	1.5	30.4	2.6	1.2	0.1	57.7	4.6
Apr	0.9	0.1	4.5	0.4	21.8	1.6	8.5	1.1	11.8	0.8	142.3	9.0
May	6.0	0.4	8.0	0.8	55.5	3.0	28.4	2.1	112.7	4.2	248.0	14.3
June	108.7	5.0	114.0	6.7	196.4	10.3	145.2	6.3	868.2	21.9	350.1	16.1
July	265.3	11.3	355.8	14.5	325.3	15.3	280.4	12.3	994.8	27.2	353.6	16.8
Aug	219.8	10.7	388.4	14.9	329.5	15.4	307.5	11.4	518.7	23.3	269.9	13.9
Sep	171.9	6.2	195.8	8.2	287.6	13.0	133.0	5.0	251.9	13.5	166.2	10.3
Oct	10.8	0.7	26.2	1.7	208.0	8.6	21.9	1.4	124.8	6.2	79.2	5.3
Nov	8.9	0.6	13.7	0.8	37.4	1.7	9.4	0.8	30.9	2.5	19.4	1.5
Dec	2.6	0.2	12.4	0.7	5.5	0.3	21.9	1.4	16.7	0.4	5.1	0.4

Month	Jaipur		Lucknow		Nagpur		Patna		Pune		Trivandram	
	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD	RF	RD
Jan	7.9	0.6	21.9	1.6	10.2	1.0	18.9	1.3	0.0	0.0	22.7	1.6
Feb	11.7	0.9	11.2	1.1	12.3	1.1	10.7	1.1	0.5	0.1	24.4	1.6
Mar	6.1	0.7	7.7	0.7	17.8	1.5	11.4	1.0	5.3	0.6	40.4	2.9
Apr	4.1	0.5	4.9	0.5	13.2	1.4	7.6	0.9	16.6	1.1	117.4	6.9
May	16.2	1.1	16.5	1.0	16.3	1.2	33.3	2.0	40.6	2.8	230.4	11.3
June	66.0	3.6	107.4	4.2	172.2	9.0	134.2	6.4	116.1	7.5	320.8	16.3
July	216.3	10.8	294.3	11.6	304.3	15.0	305.8	13.2	187.2	12.8	226.8	14.6
Aug	231.2	11.6	313.9	13.1	291.6	14.4	274.4	12.8	122.3	10.6	138.1	11.0
Sep	80.3	5.1	180.6	7.4	194.4	9.4	226.9	9.8	120.1	7.4	174.6	8.9
Oct	22.6	1.2	45.2	2.0	51.4	2.8	93.8	3.3	77.9	4.6	281.7	11.9
Nov	3.2	0.3	3.8	0.3	11.8	0.7	8.9	0.4	30.2	2.0	184.5	8.6
Dec	3.3	0.4	7.3	0.7	17.2	0.8	4.1	0.5	4.8	0.4	65.9	4.1

(From IMD Publication, based on Observations from 1951-1980)   RF =Rainfall (mm)   RD = Rainy Days

APPENDIX-V : HOW READERS ESTIMATE DAILY RAINFALL

How to estimate clouds and rains once in 3 hours per day :

People mostly rely on the TV, Radio and News papers to know about the changes in weather conditions to plan their day to day activities. With the latest satellite images people can use the internet and make their own judgements about the possible changes in clouds and rains at a given point of time by browsing through the following websites which present the continuous changes in weather conditions like winds, clouds and rains once every 3 hours per day.

http://grads.iges.org/pix/prec6.html : This COLA website gives an idea about the short-term rainfall forecast for the coming 5 to 10 days in a general way.

http://www.sat.dundee.ac.uk/pdus.html : When you click on the above web site, the page opens with title "DSRS" and at the end one finds a table " IODC [........Indian Ocean}and click on the word "medium" found in the third column and the first row under the channel "IR". After your click, a menu opens asking you to register .In my case I will insert my I.D ,"SHIVAJI" and password "hyx564" to open the image. Kindly request the web authorities for a free I.D. and pass-word.

http://cimss.ssec.wisc.edu/tropic/tropic.html http://cimss.ssec.wisc.edu/tropic/other/faq_enhance.html [indicate cloud top temperatures] http://www.desktopdoppler.com/help/nws-nexrad.htm (colour charts for rainfall intensity] : Click on this web site and when it opens click on left side menu for "Indian Ocean[Met-5]" on the "IMages & Movies" and when it opens,again click on the last coloured image to get its magnified version and you can see cloud cover in colours over India;the green stands for clouds of 4 to 5 km.height,the red colour indiates clouds of 8km depth and white cement colour stands for 12 km deep clouds..For more details click on the second web site .Next click on the third web site to know the intensities of rainfall for the different classifications given

http://www.eumetsat.de/en/index.html?area=left2b.html&body=http://eumits.eumetsat.de/&a=296&b=1&c=290&d=290&e=0 (European website with animation indicating cloud movements): Click on the website and look into the Menu bar in left side and click on the last item of the menu "Meteosat Images. Then you will get two pictures, the one on right side is "Indian Ocean Data Coverage Service" then click on the Indian Ocean Data picture and you will get the required imagery with black panel with different operational titles and a large picture with Indian Ocean. First click on the word "Play" on the black menu panel. Wait for 1 or 2 minutes to see the clouds moving all over India and Africa. Click on the time panel and fix any particular time of the day. For details read instructions on static image controls and Animation controls etc.

APPENDIX-VI : SHANXI PROVINCE PLANS FOR 100 TMC EXTRA RAINFALL PER YEAR

The moisture in the air may help the arid North China's Shanxi province relieve its acute water shortage by augmenting annual rainfall by cloud seeding, experts said.

A group of scientists from the Chinese Academy of Sciences concluded after recently doing research in the province that exploiting water resources in the air can be a sustainable way to solve water scarcity in north China.

Based on advice of the scientists, the provincial government has made a six-year plan to develop weather modification technologies, mainly seeding clouds to increase precipitation. The province will strive increase its annual rainfall by 2 to 3 billion cu m a year.

Shanxi is among one of the most arid provinces in China, with about 4 million people and nearly 1 million head of livestock being affected every year. Dry weather also leads reduced grain harvest, local officials said.

Since the late 1980s, Shanxi has been seeding clouds to increase precipitation by 600 million to 800 million cu m a year. http://fpeng.peopledaily.com.cn/200007/14/eng20000714_45496.html (Friday, July 14, 2000)

Shanxi Province:

i) Area : 1,50,000 sq.km

ii) Population: 30,000,000

iii) Forests in 20% of area, 3.44M.ha.

iv) Yellow River Drainage : 97,500 sq.km

v) Haihe River Drainage : 60,000 sq.km

vi) 8 rivers, each with a length of 150km

vii) Total water resources: 15,240M.cum (540 TMC)

viii) River Water run-off : 11,400 M.cum (400TMC)

ix) Under ground water : Only 45 percent recoverable

x) Semi-dry continental monsoon climate in the temperature zone

Taiyuan,Capital of Shanxi, Latitude: 37° 47'N : Latitude 112° 33' E Elevation :2552 ft

Month	Temperature (0°C)		Rainfall (mm)	Humidity (%)	Snowy cover No. of days
	Max	Min			
January	1.1	- 12.8	2.5	50	5
February	4.4	- 9.4	5.0	49	5
March	11.1	- 2.8	10.0	51	2
April	19.4	4.4	22.5	48	0
May	25.0	10.0	35.0	51	0
June	28.9	14.4	55.0	58	0
July	29.4	18.3	112.50	72	0
August	27.8	16.7	97.50	76	0
September	23.3	10.6	60.0	73	0
October	17.8	3.9	27.50	67	0
November	8.9	- 3.3	12.50	63	2
December	2.2	- 10.6	2.50	57	6

APPENDIX-VII : THAILAND USES 45 AEROPLANES FOR CLOUD SEEDING

The cloud seeding operations started on Tuesday, 22-3-2005 in Thailand, spearheaded by the King Bhumibol Adulyadej were successful with additional rainfall recorded in 10 provinces across the drought stricken country. The heaviest rainfall of 46 mm occurred in 3 provinces. By using 45 aircrafts Thailand Government launched a massive cloud campaign under the personal supervision of the King in a bid to open the heavens over the drought-hit areas. 71 out of 76 provinces have been suffering from the worst drought in Thailand, the world's top rice exporter.

11 million people in about 44,500 villages amounting to 60% of the rural population have been affected by the drought. Agriculture Minister Newin stated that more than 60 pilots and scientists would be trained in cloud seeding operations beginning on Tuesday, 22nd March 2005 by using 45 aircrafts carrying 37,000 tonnes of chemicals. 10 areas have been declared as disaster zones and 63 out of 76 provinces are experiencing the drought which cost the economy $364 million. Cloud seeding operations use chemicals including Sodium Chloride or Calcium Chloride to generate rainfall in the clouds. Cloud seeding is expected to continue throughout the year except during the rainy season which normally comes in late May or June.

According to Taipei Times News paper from Bangkok dt.15-4-05, the propeller aeroplanes take-off almost every day over the rice fields of Thailand squeezing in around large containers of chemical cocktail ranging from silver iodide to ordinary salt and dry ice. These planes fly at about 3km over the parched agricultural fields, dried up dams and thirsty rivers and enter directly into clouds that most pilots normally avoid but the scientists can avail the opportunity to dump their cloud seeding chemical loads in the cloud and wait for the rainfall. The agricultural officials confirmed that the cloud seeding operations have worked with success and eased the toughest drought in 7 years by 80%. This success has made the countries from Oman to Cambodia to request Thailand Government if the cloud seeding method followed in Thailand could ease periodic droughts in their countries.

Thailand has used cloud seeding operations for almost 30 years under the guidance of King Bhumibol who has his own patented rain making technique. Rain making begins when the relative humidity exceeds 60% and lower humidity makes the seeding efforts difficult to succeed. The technique used by the King Bhumibol uses 2 aeroplanes to seed warm and cold clouds which are at different altitudes to make rain over a wider area than other methods. The aeroplanes that fly almost daily work for 2 hours at a time depending on the size of the aircraft and the target area.

Due to the pinching drought the airforce, the police and the Navy gave on loan to the Agricultural Ministry additional aeroplanes, giving the scientists a total of 45 aircrafts for cloud seeding. The rain making bureau has 600 staff and a budget of US $25 million though expanded operations this year and the increasing fuel costs could force the authorities to demand for more money from the Government. Thailand receives plenty of rain, more than 1200 mm per year in most of the areas and even 4,000 mm in some coastal provinces. But the rain does not occur evenly through out the year, causing a cycle of droughts and floods and this year was made worse by the exceptionally harsh dry season ahead of the rains that normally begin by the middle of May 2005. This cloud seeding technique tries to help distribute the rain for the whole season so that water is available to mitigate the damaging impacts of droughts.

http://science.news.designerz.com/deforestation-blamed-for-worsening-thailand-drought.html?d20050317.

http://science.news.designerz.com/thai-cloud-seeding-yields-results-as-rains-hit-drought-plagued-provinces.html?d20050323

http://www.taipeitimes.com/News/world/archives/2005/04/15/2003250531.

APPENDIX-VIII : MODELLING

The usefulness of a cloud seeding experiment is improved in several ways when a model exists for indicating the quantitative relationships for the modified versus unmodified cloud system. When we develop a model we assure a community that we understand the physical parameters of the system and the causality of how the modification works. Moreover the working model predicts the effect of the cloud modification exercise on several relevant measurable quantities and thereby increases our power to test the validity of the modification hypothesis. Cumulus cloud processes can be modeled by analogy with the laboratory models or by mathematically solving a set of differential equations describing the behaviour of the cloud processes so that the solutions make sound predictions about the cloud properties as a function of time and space, given the specified initial and boundary conditions. The equations along with their physical background and their solutions are known as cloud models.

Numerical models began to be used to predict from the balloon sounding data what increase in updraft and raise in height can be anticipated through cloud seeding and the consequential augmentation in precipitation. The models indicated that under typical conditions the seeding may raise the temperature of the updraft by about 0.3°C and yet the updraft can be doubled and the top raised by more than 1km. Some working numerical models of cloud seeding were developed by Dr.Joanne Simpson and her colleagues at the National Oceanographic and Atmospheric Administration (NOAA)

But all the models of atmospheric processes are subject to various limitations such as formulation of correct equation governing the cloud processes, inadequacy of computer systems, lack of precision about the initial conditions etc. Thus the models remain only as approximations and simplifications and hence the predictions must be always checked by ground truth verification measurements which again are never perfect.

Non-linear differential equations describing the cumulus cloud processes cannot be easily solved analytically by formal mathematics and hence we have to take resort to “numerical” solutions in specific cases by feeding the equations into a computer which solves them by successive approximations, completing the work in a few seconds which might generally take months to perform by hand.

Ideally the scientists visualized a stability criteria known as the “parcel theory” for cloud growth that is influenced by the “adiabatic lapse rate” and according to this theory all tropical clouds rise from the troposphere and penetrate into the stratosphere, topping at the level of 100mb atmospheric pressure or 54,000ft. But in reality most tropical clouds develop upto about 3 to 6 km in the sky where the parcel buoyancy is greatest and this shows that some amount of drag or friction force strikes a balance with the forces of buoyancy. After the Second World War, Henry Stommel stated that Cumulus clouds were “entraining” or mixing into themselves by receiving the air from their immediate drier surrounding environment. Stommel found a mathematical and a graphical method of calculating the rate of entrainment which is mathematically expressed as $(1/M)dM/dz$ where M = mass in the cloud element and z = vertical coordinate. For small clouds $(1/M)dM/dz$ is 10^{-5} /cm or 1 km. It means that in a rise of 1km the cloud entrains into itself as much outside environmental air as it originally contained and such large dilution reduces the moisture, life-blood of the cloud and thus reduces its latent heat release and its consequential buoyancy. Thus the cloud gives its heat, moisture and momentum to its surroundings through a vital important “exchange mechanism”. A cumulus cloud is a dynamic balance between its rapid growth and its equally rapid destruction and thus a component of its motion is sometimes caused by growth on one side and the dissipation on the other. Cumulus clouds also get destroyed if their source of moist low level air is exhausted or cut off.

To simulate cumulus dynamics, 2 types of numerical models have been developed and they are known as "**entity models"** and the "**field of motion models"**. In the entity model the cloud is likened to a jet or a plume, a buoyant bubble or some other physical entity that can be observed and recognized. The forms were suggested by time-lapse motion pictures of real clouds by laboratory experiments and by the results of numerical experiments. (See the article by Arneson G; R.S.Greenfield and E.A.Newburg - A numerical experiment in dry and moist convection including the rain stage. J.Atmos.Sci.25, 404-415, 1968). Saunders developed laboratory tank "cloud" as a function of time. A blob of salt solution was released into a water tank. The "cloud" being denser than its surroundings moves downward and its "vortex-like circulation" is rendered visible by neutral density, white painted particles (See the article by Saunders P.M – Penetrative convection in stably stratified fluids, Tellus 14, Pages 177-194, 1962)

The entity model has a highly reduced number of differential equations and the primary equation to be solved is generally for the rise-rate of the entity or the updraft at its core. The important characteristics of the model are the semi-empirical laws deduced from the measurements or theories relating to the entities. The model permits the complete specifications of all parameters in the equations except for the cloud properties which have to be predicted. The models are based on the "inverse radius entrainment law". Scientists recognized that the strength, size and duration of the updrafts or vertical air currents, namely the cloud dynamics has a stronger influence on cloud precipitation than the cloud particles or the microphysics. In order to understand the importance of the dynamic control on rainfall enhancement, it is desirable to compare the processes in the small cumulus, intermediate cumulus and large cumulus clouds as presented.

The upward flux of the water vapour passing through the updraft from the cloud base is calculated from the formula

Flux (vapor) = $pq\ AwDt$,

Where p	=	air density in grams per cubic centimeter
q	=	specific humidity of water vapour in grams per gram of moist air
A	=	is the cloud base-area
w	=	average updraft velocity through cloud base and
Dt	=	lifetime of the updraft

Typical values of the small, medium and large size cumulus cloud properties and the resulting fluxes and rainfall with their efficiencies are presented in the table (See Chapter-6).

The entity model treats the growing cumulus cloud as a bubble or as an entraining jet and will obey the laws that are applicable to such entities in fluid mechanics. Some scientists attempted to fit observations of convective cloud into this conceptual frame work of the entity model. Simulation of convection in laboratory tanks that used liquid of different densities helped in selecting the relationship that applies to convective clouds. In the models the cloud is treated as a succession of bubbles, each of which rises to the same height in the atmosphere. In a one-dimensional or "stick" model the variations in temperature, humidity etc; within the bubbles are ignored.

To run the cloud model assume a bubble of air of specified radius with a small upward speed at the height calculated for the cloud base. After calculating the upward acceleration the bubble is moved upward by about 50 meters per each height-step. The processes affecting the buoyancy are estimated and a new velocity is calculated that is assumed to apply through the next height-step. This process is to be repeated several times until the bubble reaches a stable layer where its buoyancy becomes negative and the upward speed becomes zero.

Each bubble develops positive buoyancy so long as its virtual temperature continues to be more than that in the ambient air but gets slowed down through mixing with the surrounding environmental air.

Mathematically the equation may be written as follows.

Vertical acceleration = (Buoyancy-Drag)

$$\frac{dw}{dt} = w\frac{dw}{dz} = gB - \left(\frac{1}{m}\frac{dm}{dz}\right)w^2 = gB - (2\mu / r_u)w^2$$

where w = upward speed of the bubble

z = height of the bubble

g = acceleration due to gravity

B = buoyancy of the bubble

m = mass of the bubble

μ = empirical constant from laboratory measurements

r_u = radius of the updraft (tower radius)

$\frac{1}{m}\frac{dm}{dz}$ = entrainment rate or the dilution rate of the cloud mass with its outside air as it rises.

Buoyancy is reduced and drag is created by entrainment. Buoyancy dilution is maximum at low levels in the warm air masses. If the entrainment rate is specified the above equation can be solved for the rate of rise of the updraft and other cloud properties as functions of the height "Z" . Cloud buoyancy is reduced not only by entrainment but also by the weight of liquid or solid particles like cloud drops or ice crystals. A water content of $1gm/m^3$ may subtract more than the equivalent of 0.5°C from the buoyancy. The buoyancy, being given by

$B = (DT_v / T_v) = (T_v - T_{ve}) / T_v$

Where T_v = virtual temperature of the bubble and T_{ve} is the virtual temperature of the environment.

The temperature of the bubble as it goes up is controlled firstly by the expansion of the bubble as it ascends and secondly by the latent heat released and thirdly by the entrainment of air surrounding the bubble. Since the ambient air is not saturated the cloud water of the bubble evaporates to make the relative humidity of the entrained ambient air upto 100% and this causes further cooling. Experiments proved that entrainment changes inversely with the radius of the bubble and fluctuations in the rate of entrainment are controlled by an empirical constant μ which is taken as 0.20. In some cloud models all condensed water is considered to fall out immediately as otherwise buoyancy must be adjusted with respect to downward drag exerted by the cloud water. In such a situation the buoyancy is given by

$B = (DT_v / T_v) - w$

Where 'w' is the cloud water mixing ratio (grams of water per gram of air) For practical purposes this one dimensional steady state cloud model is adequate because it is considered that the models can never simulate the actual behaviour of cloud in nature except in a general way. These models were found to be useful in predicting the heights to which different cumulus clouds with different updraft sizes rise into the sky under different lapse rates and moisture conditions.

To simulate seeding effects cloud water is assumed to be glaciated, based on non-linear freezing curves which show that cloud water gets frozen between –5°C and - 25°C in seeded clouds and between –20°C and –40°C in unseeded natural clouds with sudden temperature increases of about 1°C in the updrafts due to freezing. Some of the latent heat is used for expanding the updraft air, performing work against the pressure exerted by the ambient air. The entity models show that cloud heights will not rise by seeding the clouds under very stable conditions. Similarly if extreme unstable conditions enable the convective clouds rise quickly into the tropopause the entity models again predict insignificant rise in the cloud heights due to seeding.

Hence where a natural cloud is capped by inversion the entity model shows that artificial glaciation by cloud seeding releases adequate latent heat to the cloud towers to penetrate through the inversion and rise above the unstable layer above in the inversion and this development is known as the “explosive growth” of the cloud. Some scientists predict that merger of a number of nearby clouds may produce a large cumulo-nimbus that may provide rain at the rate of 5 x 10^7 m^3 per hour even though the individual clouds left to themselves might produce rain at the rate of $10^6 m^3$ per hour.

APPENDIX-IX : CONCEPT OF SATURATION IN COLD CLOUDS

When the heat from the Sun produces high temperatures the liquid water readily evaporates and the ice readily sublimates to the gas phase. Over the equatorial waters the temperatures being high, evaporation from the oceans readily occurs and the local atmosphere contains upto 4% or more of water vapour by volume. Water vapour gets into the air firstly by evaporation from soils, rivers and ocean surfaces and secondly by sublimation from ice masses in the glaciers and thirdly by transpiration from plant leaves mostly from forest cover. About 85% of the water in the atmosphere originates from the evaporation from the oceans. The mixing ratio of water vapour with the air in the atmosphere varies with the location and it is almost zero over the North and South poles and it is 4% in the hot tropical zones.

The temperature of a parcel of air decreases with increasing altitude in the troposphere because the pressure in this region decreases with increasing height and the air expands with the decreasing pressure. For example if a parcel of air rising into the sky is to expand, the kinetic energy must be converted to work and the resulting loss of kinetic energy causes the air temperature to decrease upto tropopause level of about 12kms with about 250mb pressure. (tropopause height decreases from about 15 to 18km near the equator to 8km near the poles.

The saturation vapour pressure of water over an ice surface is always lower than that over a liquid water surface at the same sub-freezing temperature for the simple reason that the ice molecules require more energy to sublimate than liquid molecules require to evaporate at that same temperature. (273^{o} K = 0^{o}C)

Saturation vapour pressures and the partial pressure of water determine whether the water vapour in the cloud gets condensed as liquid or gets deposited as ice. When the ambient temperature is above freezing level like +2^{o}C and if the **partial pressure of water (*Pv*) is greater than** the **saturation vapour pressure of water** over a liquid surface (*Pvs*) then water vapour condenses as a liquid (*Pv >Pvs*). But the liquid water evaporates when the saturation vapour pressure exceeds the partial pressure of the water vapour ((*Pv <Pvs*). In the case of sub-freezing temperatures of the air at about –2^{o}C and if *Pv* is greater than *PvI* when water vapour gets deposited as Ice. But if *Pv* is less than *PvI* ice sublimate to water vapour.

But when liquid water and ice co-exist in the same air parcel and *PvI* is less than *Pvs* is less than *Pv* deposition over ice particles is favoured in preference to condensation into liquid water drops because *PvI* is less than *Pvs* at the same subfreezing level of temperature. But if *PvI* is less than *Pv* is less than *Pvs* then water evaporates from the liquid water surfaces and gets deposited over ice particle surfaces. This is the fundamental assumption under the Wegener-Bergeron-Findeison(Bergeron) theory of ice crystal growth in cold clouds in which super cooled liquid water cloud droplets also co-exist along with ice crystals.

Whenever the ratio of cloud drops to ice particles is les than 1,00,000:1 then each ice crystal receives water from les than 1,00,000 cloud drops and hence ice crystals cannot grow large enough to fall from the clouds to the earth. But if this ratio is greater than 10,00,000:1 then the ice crystals grow large enough to fall from the cloud before all the liquid water gets depleted, resulting in less-than-the optimal precipitation from the cloud. But if the ratio lies between 1,00,000:1 and 10,00,000:1 then each ice particle receives the liquid water from 1,00,000 to 10,00,000 droplets and these ice crystals that fall from the cloud to earth contribute for maximizing the precipitation. The greatest difference between the saturation vapour pressures over liquid water and ice according to the graph (Chapter-6) occurs at –15^{o}C and at this temperature ice crystals in the form of the snow flake shaped crystals known as dendrites grow most favourably at the fastest rate.

APPENDIX – X : CLOUD SEEDING FOR CONTROL OF HAIL STORMS

Hailstorms unlike cyclones are highly localized weather phenomena and are randomly distributed. These violent storms are extreme events and often become atmospheric hazards due to discharge of a large amount of energy in a short time, the sudden impact perhaps resulting in a disaster. Hail storms due to cumulo-nimbus clouds, often lasting for about 2 hours are produced under atmospheric conditions favouring the release of considerable instability and are always accompanied by lightening and thunder. They are also accompanied by strong winds, heavy rain and sometime hailstones. A Hailstorm is like a thermo dynamic machine in which the potential energy of the latent heat of condensation is quickly converted into kinetic energy of rising air currents for updrafts. The basic pre-requisites for hailstorm are (a) the presence of warm and humid air in the lower layers of the atmosphere, (b) atmospheric instability and (c) intense convective activity, which often causes lightening discharge due to warm and moist air. A Hailstorm is like a weather factory with a combination of strong wind gusts, thunder, lightening, torrential rains and cumulo-nimbus clouds with a diameter upto about 50 kms with a lifespan of several hours. They contain a few convective cells with updrafts and downdrafts joined together and go through a life cycle in 3 stages.

(i) The first stage of the cell is a cumulus cloud stage with updrafts upto 160kms per hour to be able to uphold the large hailstones aloft along with the co-existing ice crystals and liquid water.

(ii) In the second mature stage updrafts coexist, heavy precipitation falls on the ground. The friction drag exerted by the precipitation changes the updraft into a downdraft. Lightening and thunder and hailstones are seen in the stage. Heavy rain, high cool downdrafts with greatest contrasts of temperature are found at the base of the cloud and weather hazards may be experienced by the aeroplanes.

(iii) The final dissipating stage is characterized by downdrafts only coupled with light rains, providing welcome cooling effect on hot summer days.

Electricity generated in these clouds through the friction of freezing water drops and ice crystals. There is a clustering of positive charges in the upper portion and negative charges in the lower portion of the cloud. Often a secondary positive discharge centre is found at the base of the cloud, the value of the discharges being 20 to 30 coulombs with 1km distance between the above discharge centers. Lightening discharge may occur within a cloud itself, from one cloud to another cloud or between the cloud and the earth. Lightening discharge occurs between positively and negatively charged centers within a cloud. Lightening strokes carry negative discharges from the clouds to the ground. A series of strokes produce the flash of lightening which influences the rainfall. Some experts find that lightening discharge is generated from the ions produced by cosmic rays. A falling rain drop plays a crucial role in charge separation. It is said that when a falling drop is broken, part of the negatively charged outer layer escapes into the surrounding air while the remaining part is left with a positive charge. Similar charge separation may also occur during the freezing of water or melting of ice. A thunder is produced when intense sound is emitted by rapidly expanding gases along the channel of a lightening discharge. A lightening stroke generates tremendous heat along its path and the air is heated to 10,000°C which causes rapid expansion of the air column. Such tremendous expansion of air sends vibrating pressure wave outward that moves at the speed of sound (3kms per second). The noise caused by such a wave is called as **thunder.**

Hailstones : A Cumulo-nimbus cloud in a severe thunder storm often produces hailstones due to the co-existence of ice crystals and water particles and other favourable conditions such as high temperature lapse rate so that the buoyancy of cumulus updrafts provide the opportunity for hailstones to grow aloft. Maximum ground heating during summer afternoon provide ideal conditions for rain formation. Topographical features such as hills and forests provide additional favourable conditions. Hailstorms occur in North Indian states like Bihar, Madhya Pradesh and Assam and in the Telangana and Rayalaseema districts of Andhra Pradesh.

The High Mountain Geophysical Institute of Russia (VGI) conducted research on hail formation and hail prediction and identified a few atmospheric conditions necessary for hail formation. The maximum updraft speed just below the top of the cloud must be 15 meters per second and lessen towards the top of the cloud. The water content in the accumulation zone above the level of maximum updraft velocity may be 20 grams per cubic meter or more. The accumulation zone must have a temperature between 0°C and minus 20° C at the height of the lower boundary. The concentration of crystalisation nuclei active at the given temperature must be atleast 1 million to 10 million per cubic meter. Hailstone diameter can be decreased by a factor of 4 by using a chemical reagent dosage of 50 to 100 grams per cubic km. in the hail growth zone. Natural concentration of hailstone embryos of 1 to 10 per cubic meter must be increased by 2 orders of magnitude. In order to obtain positives results 1 lakh per cubic meter of crystalisation nuclei are needed and this means use of chemical dosage of 0.1 to 2 kg of reagent per cubic kilometer at an ice forming activity of about 10^{12} particles from 1 gram of the reagent. However VGI recommends lower reagent dispersing rates at 0.1 to 0.5 kg per cubic kilometer for a reagent with the same activity characteristic. Russians increased use of seeding agent from 1kg in 1963 experiments to as much as 75kg on a large cloud formation during 1970s. US scientists feel that enough competing embryos to suppress hailstones can be produced by seeding with 1kg of silver iodide per hour if the cloud contains considerable supercooled rainwater. Sometimes the consumption of silver iodide averaged about 2kgs per hour in some experiments.

Hail suppression attempts were made since 1965 with mixed success rates. First of all hail suppression control is crucial because hailstorms cause billion of dollars of crop and property damage around the world every year. In many countries like Canada, Argentina, several states of USA, Europe and China regular cloud seeding operations are conducted to suppress the hailstorms. In most of these countries the benefits of cloud seeding operations are far higher than the costs involved. The procedures for cloud seeding operations for augmentation of rainfall are used with necessary modifications for prevention, control and management of the hailstorms. The meteorological departments in all countries must take a positive role in forecasting the favourable weather conditions and in predicting the formation of thunder clouds so that timely action can be taken to suppress the hailstorms and the consequential damage to life and properties to the maximum extent.

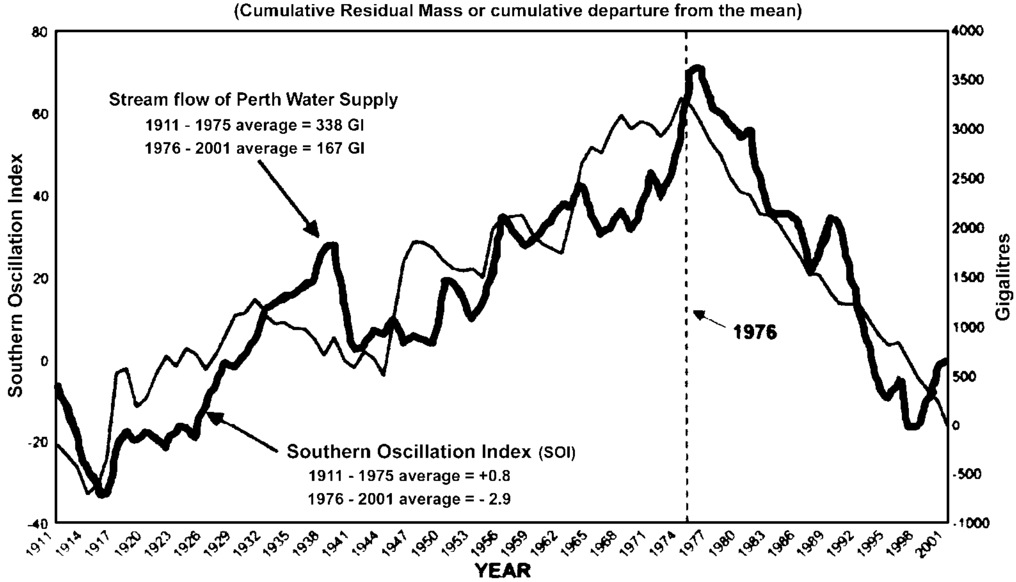
Silver iodide used for hail supression projects (Approx.)

Year	Place	Area (in sq.km)	Per season (kg)	Average per day(kg)
1962	Caucas Mountain	300	6.5	1
1968	North Dakota	8000	90	3.0
1968	Alberta	6,000	260	16
1971	France	70,000	4,500	50
1972	Alberta	14,000	140	6
1974	South Dakota	1,20,000	220	3.0
1974	Colorado	1,500	130	10

APPENDIX – XI : AUSTRALIA : GROUND GENERATORS WITH A TRACER

Annual Rainfall and snowfall activities in Australia have undergone considerable change during the last 25 years. Scientific discussions are still going on to find out the fundamental causes including global climate change, El Nino and the impacts of local industrial pollution and urban heat and dust pollution impacts on the clouds. Although the causes are yet to be identified the impacts of urbanisation and industrialisation and their effects on precipitation have resulted in adverse impacts on agriculture and domestic water supplies in southern parts of Australia. Dr. Bryson Bates of Scientific and Industrial Research organisation (CSIRO) warned on 14-3-2002 that low rainfall during the post 3 decades are perhaps the results of changes in atmospheric pressure patterns of the Antarctic rather than the Indian ocean. He said that the natural precipitation is missing the Australian continent due to recent changes in pressure cells in the South and the dry spell followed a natural shift since 1970. The water supply storage deterioration has the same trend as the Southern oscillation index. In a distinct change in the Southern index in 1976 from an average of + 0.8 to an average of minus 2.9 is very clear as can be seen from the following figure.

Perth Water Supply Inflows - Southern Oscillation Index
(Cumulative Residual Mass or cumulative departure from the mean)



A 5-year research project of winter cloud seeding to increase snow precipitation in the Snowy mountains in the Southeast region of Australia has been taken up after making environmental impact assessment. The method involves the use of silver iodide as the seeding agent with Indium Sesquioxide as a tracer dispensed from ground based aerosol generator. The project is using trace chemistry and a statistical design to evaluate the effectiveness of snow enhancement. The post frontal winter cloud systems over Snowy Mountains contain super cooled water and water vapour for producing ice-phase precipitation (snow). The silver iodide particles injected into the cloud nucleate new ice particle embryos that grow naturally to form snow flakes and so the technology is to create now from the post frontal clouds that might otherwise dissipate . The target area is the National Park with high snow fall winter precipitation and it excludes wilderness areas. 10% annual increase in snow pack is expected and it gives annual additional water of 70 giga liters (2.5 TMC) for the hydro-power station. The earlier proposal of 1993 had a target area of 2000sq.m including the wilderness as to produce increased water yield of 150 giga liters (5TMC). Originally the proposed target area was excised due to possible impact of cloud seeding in the wilderness area. This present project was specially taken up on a priority basis because the inter Governmental panel on climate change warned that human activities have been proved to cause changes to global climate and these changes will continue due to increased emissions of carbon-di-oxide and other green house gases. Further the green house effect is going to have an adverse impact on the operation of the Snowy Hydro project and evidence is building up to show that climate change is damaging the alpine regions of New South Wales as evidenced by the increases in the winter temperatures since 1962 with a decline in maximum sow depths and a number of snow days. Cloud seeding is consequently viewed as an opportunity for local mitigation of global climate change and to save the endangered flora and fauna whose survival is depended upon making available a more reliable snow cover. Moreover cloud seeding is an instrument for obtaining more water for electricity generation and thereby offsetting increasing demand on carbon based electricity production as well as providing additional annual rainwater for release to the Murray River flows. The snowfall enhancement is expected to be more than 10% of the long-term average value. Silver and Indium are expected to be well below the levels of eco-toxicological significance to the biological life. Doubts were raised whether cloud seeding in one area will effect precipitation in another area on the downwind side. This is not correct. A common misconception regarding cloud seeding is to consider the atmosphere a static pool of cloud water passing over the earth which is a limited steady state supply of water. With this conceptual model people argue that because this supply is limited and we remove some percentage of water in the form of rain from the atmosphere through cloud seeding in one area, there will be less rain water available to fall in other down wind areas because a larger fraction of this fixed supply of water was already removed in the upwind target location. But the atmosphere does not behave in this simple manner. Clouds are systems that continuously process moist air. Clouds are created when tiny water droplets form when cooling rising air goes up into the sky. Experiments in USA proved that areas down wind of the target location get a little additional rain.

The seeding agents include dry ice pellets, silver iodide, liquid propane and some bacteria. The winter clouds passing over snowy mountains contain sufficient below freezing water droplets and either precipitate naturally because they are cold with abundant ice particles or otherwise they will pass over the mountains where they evaporate or pass out to the sea because the natural precipitation process are inefficient. Hence attempts are made to act extra artificial ice nucleating particles to the clouds to improve the efficiency of the ice nucleation process.

12 automatically control ground based generators are used to discharge the seeding agent into the appropriate cloud systems. Besides silver iodide to seed the clouds trace amounts of Indium sesquioxide is used as a monitoring tool to measure the cloud seeding efficacy. These chemicals are not water soluble and will not be avail readily bio-available and thus the likelihood of adverse environmental impact is negligible even in potential zones of accumulation. Two-thirds of the snow storms will be seeded while the other one-third will not be seeded to provide for statistical analysis of the seeding results. The seeding operations are limited to in altitude of 1400 meters when rainfall is occurring at the 1400 meter level no seeding is done to ensure that there is no adverse impact on the snow pack over the sky resort areas.

APPENDIX - XII : RAIN BEARING POTENTIAL OF SHALLOW WARM CLOUDS WITH LOWER REFLECTIVITY, dBZ VALUES

http://www.desktopdoppler.com/help/nws-nexrad.htm

The following table linking reflectivity of the clouds and the rainfall potential both in inches per hour and mm/hour clearly indicate that the clouds of reflectivity less than 33dBZ also provide sufficiently reasonable rainfall rates per hour which should be harnessed for making available even the minimum possible quantities of extra rainfall to save the withering agriculture crops in the districts of Andhra Pradesh and Rayalaseema which are suffering from serious drought during the last 3 years. Hence we ventured to suggest to the contractors that they should not avoid seeding such shallow warm clouds by using hygros with higher sizes of Calcium Chloride particles by getting them manufactured immediately by their suppliers in USA who also stated in their web site that they manufacture flares depending upon the customers needs and the different geographical regions of the world. This is a new suggestion made by us in the light of our own expertise in economic and research fields and cloud seeding operations conducted in different places in Andhra Pradesh including Visakhapatnam.

Reflectivity (dBz)	Rainfall Rate ($^{mm}/_{hr}$)	Rainfall Rate ($^{inches}/_{hr}$)
5	0.0749	0.0029
10	0.1538	0.0059
15	0.3158	0.0123
20	0.6484	0.0253
25	1.332	0.0519
30	2.734	0.1066
35	5.615	0.2190
40	11.53	0.4497
45	23.68	0.9235
50	48.62	1.8963
55	99.85	3.8949
60	205.05	7.9975
65	401.07	15.6424
70	864.68	33.723
75	1775.65	69.252
80	3646.33	142.21
85	7487.83	292.03
90	15376.51	599.69
95	31575.91	1231.46
100	64841.98	2528.84
105	133154.6	5193.03
110	273436.4	10664.02

APPENDIX - XIII : CLOUD SEEDING EXPERIMENTS IN INDIA

In India, notable experiments on warm-cloud salt-seeding, using ground-based generators, were conducted by the Rain and cloud physics Research Unit of the National Physical Laboratory during 1957-1966 in North India and the results indicated about 20% increase in rain-fall. The salt-seeding of warm clouds from an air-craft over the catchment of Rihand reservoir in Uttar Pradesh was executed by the Indian Institute of Tropical Meteorology (IITM) during the monsoons of 1973 and 1974 and the results showed an increase of rain-fall by 17% to 28%. Similar experiments conducted during the monsoon of 1975 over the catchment of the Linganmakki reservoir in Karnataka registered 20% additional rainfall. When Tamil Nadu Government, with the assistance of Atmospherics Incorporated, USA, used silver iodide for seeding the cold-clouds during the monsoon of 1975 the Radar observations are reported to have indicated 20% to 25% additional rainfall. These experiments were not conducted for a sufficiently long period by using standard methods based on good scientific principles and hence they did not provide adequate scientific criteria for promoting cloud seeding operations to augment rainfall for various purposes. However IITM Pune conducted warm cloud seeding experiments for 11 seasons during the period 1973 to 1986.

Pune Experiment : The Institute of Tropical Meteorology, Pune, conducted for 11 years a warm cloud seeding experiment by using an air-craft in the semi-arid region towards East of Pune on the lee-ward side of the Western ghats during the period 1973 to 1986. A randomised double-area cross-ver design with a buffer zone was used for the aerial seeding work. The experimental area covering 4,800 sq.kms. was divided into 3 parts designated as North, Buffer and South sectors in Ahmednagar-Baramati region. The results of the experiments conducted for 160 days during the eleven summer monsoons indicated enhancement of rain-fall by about 24%. The physical changes in the clouds due to seeding were recorded with scientific instruments fitted to the air-craft to provide scientific evidence as the positive proof for the success of the warm cloud seeding technique. (Refer Warm Cloud Seeding Chapter)

Cold cloud seeding experiments in Hyderabad(1993) :

Subsequently under the supervision of the Government of Andhra Pradesh some trial experiments were conducted on cloud seeding using silver iodide (AgI) . In the ground based generators the coke was burnt to reach a temperature about 1200^{o} C where the silver iodide is burnt in small quantities of 5 to10 gm so that it becomes vapour and gets into the developing cumulus cloud. Along with S.Meckoni of Mumbai, the author was closely associated with the experiment while the necessary meteorological information was supplied by an officer of Meteorological Centre, Hyderabad.

The experiments were conducted over Osman Sagar in the catchment area of the twin lakes of Hyderabad. The results showed an increase of 2ft water level in Osman Sagar where 5 ground generators were located on the southwest/western side about 5 to 10km away on the windward side of the catchment area. Silver was detected in traces in the samples of rainwater collected from the rain gauge stations in the catchment area. Conspicuously the Himayat sagar lake which is part of the twin lakes located on the other side of the ridge line did not report any increase in the water levels. These two criteria indicated the first success of the experiment conducted in July 1993.

Second experiment on cold cloud seeding at anantapur(1995) :

The second trial experiment was conducted in Anantapur, the drought prone district of Andhra Pradesh under the instructions of the then Chief Minister, Government of Andhra

Pradesh.. The experiments were conducted in a similar way by using several ground based generators by sprinkling silver iodide over hot coke ovens at 1200^{o} degrees centigrade at different stations as shown in the following table. The experiment conducted in July 1995 for 16 days, yielded some interesting results with a record rainfalls of 95mm reported at 0830 hrs IST of the next day of seeding at Anantapur on 27th July 1995 shown in Table. The meteorological information was provided by the officer of from Meteorological office, Bangalore.

For all the above experiments the following criteria was adopted

1) The relative humidity at ground level shall be greater than 75%,
2) The base of the cloud shall be within 1 to 1.5 km from the ground,
3) The height of the cloud has to be more than 5 km.
4) The surface wind speed shall be less than 15 kmph. The generators were located 15 to 20 km apart in the West or Southwest sectors of the target area.

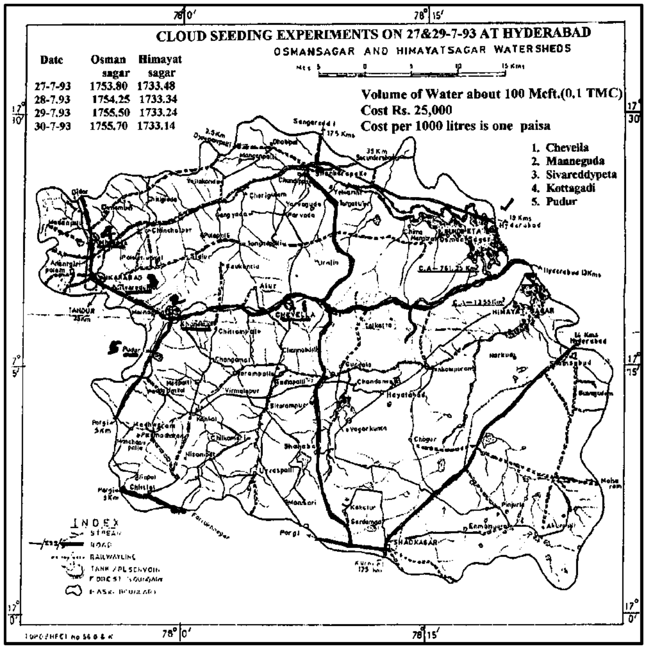
Details of rainfall received during the experiments conducted for artificial rians in Anantapur in July and August 1995

Date	Name of station	Time & Duration	Quantity of AgI used	Quantity of coke used	Rainfall on the next day in mm
26.7.95	Anantapur	7.30 to 8.30PM	200 gm	2 kg	Anantapur 15mm Raptadu 7.8mm, B.K.S 15.4mm
27.7.95	Anantapur	6.30 to 7.30PM	200 gm	2 kg	Anantapur 95mm
28.7.95	Kothigutta(Raydurg)	3.00 to 7.00PM	100gm	2 kg	26mm
1.8.95	-do-	4.30 to 7.30PM	100 gm	5 kg	1.8mm
2.8.95	-do-	-do	100 gm	5 kg	--
28.7.95	Kalyandurg	5.30 to 6.30PM	200 gm	5 kg	--
29.7.95	-do-	-do-	-do-	-do-	--
1.8.95	-do-	-do-	-do-	-do-	--
9.8.95	Marketyard(Raydurg)	4.00 to 7.30PM	100 gm	3 kg	Drizzle
10.8.95	- do-	-do-	-do-	2 kg	3.4mm
27.7.95	Penukonda	3.30 to 5.00PM	50 gm	5 kg	56.4mm
28.7.95	- do-	-do-	-do-	6 kg	17.8mm
4.8.95	- do-	-do-	-do-	5 kg	10.2mm
10.8.95	- do-	-do-	-do-	-do-	19 mm
14.8.95	- do-	-do-	-do-	-do-	11.8mm

The following table indicates that the rainfall received in the district during the time of cloud seeding for the months of July and August 1995 has doubled when compared with the rainfall received during the previous and the subsequent months of the cloud seeding operations. Although success was reported, the experiments were not continued as the South West Monsoon was normal for subsequent years since 1988 . Obviously this weakened the interest of officials in the project of cloud seeding as most of the reservoirs continued to maintain reasonable levels for some years. Unlike other countries, Central Government did not encourage cloud seeding operations in India.

Monthly rainfall data during SW Monsoon Months (1995)

Month	Normal Rainfall	Actual Rainfall in 1995
June	47 mm	33 mm
July	56 mm	112 mm
August	72 mm	153 mm
September	121 mm	97 mm

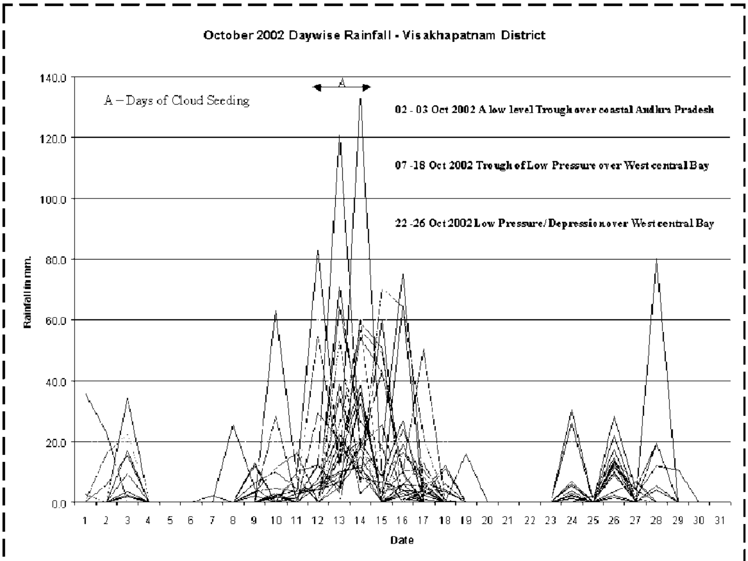


Warm and cold cloud seeding experiments at Visakhapatnam(2002) :

The 2002 southwest monsoon rainfall had been below normal, leaving vast areas of Andhra Pradesh under deficit rainfall category. Most of the reservoirs under river Krishna in Andhra Pradesh were nearly at the dead storage levels by September 2002. The Cuddapah district recorded the lowest level of 53% of the rainfall while Anantapur and East and West Godavari districts of Andhra Pradesh recorded 57% of the rainfall for the monsoon season. As the rainfalls in Krishna river catchment were also around 70% of the normal rainfall, the water was not released to Andhra Pradesh from Karnataka. This created wide spread wilting of the already transplanted paddy in many of the fields.

By the middle of October 2002 the water availability for the city of Visakhapatnam at the storage reservoirs was available for 100 days while the requirement was for 260 days till the next Monsoon. Consequently under the direction of the authorities of Visakhapatnam Municipal Corporation, the author has conducted both warm and cold cloud seeding in the catchment areas of the reservoirs on a trial basis on 12, 13 and 14th October 2002. The ground generators were used, burning silver iodide of about 500 grams per day on Simhachalam hills at a substantial height above the sea level on 12th ,13th and 14th during the afternoon hours from 3 to 5 p.m. On 14th at 08.30 hrs observation of Visakhapatnam air port recorded a rainfall of 37 mm and at Waltair it was 30.6 mm. The rainfalls on 13th and 15th were of a few millimeters in the city.

The rainfall collected from Mandal Headquarters in the district showed good rainfalls ranging up to 133 mm with in about 40 km from the seeded area where sodium chloride of 200 kg was sprinkled at 2 to 3 km height using helicopters. The aerial spraying was done up to 40 km distance from Visakhapatnam in the west and southwest sectors. The rain falls in several places ranged from a few mm to 133 mm. At Nathavaram, located at about 80 km southwest from Visakhapatnam and 40 km from warm cloud seeded area the highest rainfall of 133 mm was recorded on 14th. This is also the highest Rainfall recorded in the district during the month. The rainwater samples collected at various sites in the seeded areas showed silver up to 1.06 micrograms/liter, which is well below the safe limit of 50 micrograms/liter as specified in USA.



The following are the results of analysis for silver iodide in the rain water samples collected after the experiments and sent to National Geophysical Research Institute at Hyderabad.

राष्ट्रीय भूभौतिकीय अनुसंधान संस्थान

NATIONAL GEOPHYSICAL RESEARCH INSTITUTE

वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद्

COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH

TÜV CERT EN ISO 9001 Certificate : 04100 10950

ICP-MS data for water samples from GITAM college of Engineering, Visakhapatnam

Sl. No.	Sample Identification	Ag concentration in ng/ml (ppb)
1.	Simhachalam 14-10	0.31
2.	Sudivalasa Canal Water	0.24
3.	Sudivalasa Rain Water	1.06
4.	Malkapuram	0.44
5.	RR Peta 14-10	0.19
6.	NIST 1643d	1.276 (1.270)*
7.	NIST 1643d	1.263 (1.270)*

- **The values in brackets are certified values.**

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The weather conditions that prevailed on this day were a trough of low pressure area over Bay of Bengal off coastal Andhra Pradesh. The Precipitable water content on these days ranged from 4 to 6 cm in unit area. The conditions were favourable with good updraft and with overcast skies. The surface winds were also less than 20 kmph during most of the times at Visakhapatnam.

All these trial experiments indicate an augmentation in the rainfall due to cloud seeding which need to be exploited. The experiments conducted by IITM, near Pune showed an increase of rainfall of 24% in the semi-arid areas near western ghats. Such experiments in the coastal areas may yield better rainfall in view of the high moisture content and frequent conditions of updraft associated with low pressures/depressions. Although the number of days, that are favorable for cloud seeding in a drought year are low one has to explore this possibility of augmenting the rainfall so as to protect the wilting crops and to increase water resources.

APPENDIX - XIV : CLOUD SEEDING TO IMPROVE GROUND WATER

Cloud seeding for inexpensive agriculture :

Based on their work in Ganga-Yamuna basin, the U.P. Irrigation Research Institute, Roorkee, derived an empirical relationship to arrive at the ground water recharge as a function of precipitation.

$$R = 1.35(P-14)^{0.5}$$

Where R = net recharge due to precipitation during the year (inches)

P = annual precipitation (inches)

However, there is a lower limit to the rainfall below which the recharge due to rainfall is zero and the recharge commences from zero at P=14 inches (35 mm) and it increases upto 18% at P=28 inches (70 mm) and again decreases. This lower limit accounts for the surface run-off, soil moisture deficit, interception and evaporation losses. Recharge is about 15% of the yearly rainfall.

Ground water in India :

Ground water is a source of about 90% of the countries drinking water. In rural areas almost all the water supply comes from ground water while one-third of our 100 largest cities depend upon ground water for atleast a part of their water supply. Moreover ground water is considered to be safe for drinking purposes as compared with surface water which is generally contaminated during the recent decades. Ground water is also getting contaminated with septic effluents in some residential areas and also with industrial effluents in some of the industrial townships. If ground water is contaminated it is difficult to restore the quality of water except through extensive cloud seeding operations for a considerable period.

The total ground water reserves of India upto a depth of 300 meters is estimated at 3700 Mham almost 10 times the annual rainfall, the usable ground water is about 42 Mham per year. Out of this 28% only amounting to 12 Mham at present is exploited. The bulk of ground water is non-replenishable like Coal. It is estimated that the total annual recharge from rainfall and seepage is estimated at 67 Mham and this may increase with the development of water resources. The hardrock formations of South India forming about 70% of countries land mass is said to have more ground water than was assumed earlier. The usable potential ground water per year is estimated at 9.27 Mham in U.P., 5.95 Mham in Madhya Pradesh, 2.21 Mham in Andhra Pradesh and 2.03 Mham in Gujarat (See Table). The ground water table is declining rapidly due to intensive tube well irrigation in states like Punjab, Haryana, Uttara Pradesh, Maharashtra and Andhra Pradesh .

Tube well irrigation in India started with developments in Meerut of U.P. during 1935. There were 5000 tube wells in India in 1950-51 as opposed to 4 million dug wells. The famine conditions of 1960’s boosted tube well development with the result that the private tube wells grew by about 1,70,000 per year during 1970s as compared to 50,000 per year in 1960s and 2000 per year in 1950s. Tube well development helped farmers to exploit the ground water and supply adequate amounts at the right time to the crops as opposed to canal irrigation where the water supply was in the hands of inefficient bureaucratic officials. 90% of the tube wells in 1971 were located in Punjab, Haryana, U.P., Bihar and Bengal.

The total cost of a private tube well was Rs.10,000/- during 1975 compared to the cost of a deep bore well in hard rock of 1000 ft depth costing Rs. 1 lakh and it meant such tube wells had to be financed by the state or the banks. In 1961 tube wells irrigated 2.6 lakh ha or

1% of the national net irrigated area and by 1974 the tube wells irrigated 5.6 million ha. Unfortunately with the increasing use of this tube well the ground water table began to get depleted and the poor farmers who could not dig their wells deeper began to suffer. The water table declined from a depth of about 12ft to more than 30ft and consequently the traditional farmer who depended upon the Persian wheels and animal operated water lift systems suffered a great deal. The withdrawal of ground water in excess of annual recharge by the rainfall began to cause serious drinking water shortage and food production suffered in the hands of the poor farmer who could not use mechanized pumpsets. The shift in cultivation from rain fed crops to sugar cane in states like Maharashtra also created local shortages of ground water. In many states the over-use of ground water led to the intrusion of saline water resulted in ground water pollution. In addition the aqua-culture has ruined the ground water resources in the coastal belts of several districts on the Coromandal coast. Hence these ground water sources have to be reclaimed only by making available more water by conducting regular cloud seeding operations.

In India about 60% of the total agricultural water comes from ground water which accounts for about half of the total irrigated area. In India the mechanized and tube wells rose from about 10 lakhs in 1960 to about 20 lakhs in 2004. During 50 years while the Government in India spent about $20 billion (Rs.80,000 crores) on Irrigation development, the rich private farmers have invested about $12 billion (Rs.50,000 crores) and it is found that the private investments contributed for greater financial and economic benefits.

In Pakistan, ground water irrigation in Punjab is found to be cheaper than government sponsored irrigation projects in terms of both capital costs and operational costs (See table below) (http://www.water.2001.de/supporting/Asia_GroundWater_Boom.pdf).

Irrigation System	Cost in Rupees per Acre-foot of water	
	Capital Cost	Annual Operation Cost
Surface Storage (Dams)	15,000	1800
Canal extension	5,800	720
Canal Lining	10,000	1320
Water course improvement	4,600	720
Electrical Tube well		
1 cusec capacity	900	340
0.5 cusec capacity	1550	450
Diesel Tube well		
1 Cusec capacity	1100	720
0.5 Cusec capacity	1750	850

Ground water in A.P. :

According to latest estimates the net annual availability of ground water is 30.41 BCM (1074 TMC) out of which 13 BCM (460TMC) is used. The area surveyed for estimating the ground water potential in Andhra Pradesh is 22.8 million ha. and it is found that ground water is presently used in 2.6 million ha for irrigating and in areas covering 26,586 villages and 117 urban areas for drinking water. Thus ground water exploitation is occurring in about 5 million ha. If ground water utilization is considered in the entire net sown area of about 45%, the state ground water potential of about 50% of the 30.41 BCM can be taken as the most probable utilizable ground water potential. The ground water well-potential increased from 8 lakhs in 1975 to 22 lakhs in 2001 and the corresponding area irrigated with the ground water rose from

10 lakh ha to 26 lakh ha in that period. Presently the ground water development is estimated at 43% but not uniformly distributed throughout the state and hence in certain pockets intensive ground water development has created critical situations in the form of high ground water depletion, water scarcity and saline water encroachment in coastal areas and increased incidence of fluoride, iron and other salts in drought prone districts of Rayalaseema. In Andhra Pradesh the total surface and ground water resources are estimated at 3820 TMC (108 BCM)out of which 2000 TMC (62.3 BCM) is used for agriculture, industry, power generation and drinking purposes. The per capita annual water resources are estimated at 1400 cubic meters which places Andhra Pradesh as a water scarce area (as per UN criteria water availability at less than 1200 cubic meters makes an area water scarce while 1700 cubic meters makes it water stressed). The present withdrawal of water is about 60% for various purposes.

Present and projected water requirements in Andhra Pradesh state are presented in the following table.

S.No.	Description	Present Utilisation		Needed by 2025		Increase %
		TMC	MCM	TMC	MCM	
1.	Drinking water	21	601	122	3468	581
2.	Irrigation	2268	64,252	3,814	1,08,050	168
3.	Industries	10	288	51	1445	510
4.	Power generation (consumptive use)	1	28	2	56	200
5.	Total	2300	65169	3989	113019	173

The surface water sources in Andhra Pradesh amount to 2746 TMC Central Ground Water Board estimated the annual replenishable ground water in the state at 1074 TMC making a total of both surface and ground waters of 3820 TMC equivalent to 10.82 Mham.

Ground water potential assessment for the 3 region of A.P.

Region	Area considered for recharge(Km²)		Net annual groundwater availability (mcm)		Current gross annual ground water draft for all uses (mcm)		Current draft for irrigation (mcm)		Stage[a] of ground water develop-ment %	
	C[b]	NC	C	NC	C	NC	C	NC	C	NC
Coastal Andhra	20793	47896	7404	5233	949	2621	766	2383	13	50
Rayalaseema	4351	53822	817	4106	139	2962	127	2848	17	72
Telangana	9833	91080	3008	9834	659	5641	615	5222	22	57
Total for A.P	34978	192760	11232 (397)[c]	19173 (677)	1744 (62)	11223 (396)	150 6	10392 (367)	16	56
Total of command and non-command	227,738		30,405 (1,074)		12,967 (458)		11,897 (420)		43	

[a]Stage of ground water development (SGD) = ground water utilization (draft) divided by groundwater potential (availability)
[b]C = canal command area; NC = non-command area.
[c]Values in parentheses are TMC
Source: Groundwater Department 2002.

Ground water resource of Indian States (1998)

Sl. No.	States	Total Replenishable Ground Water Resource	Provision for Domestic Industrial & Other uses	Available Ground Water Resource for Irrigation in Net terms	Utilizable Ground Water Resource for Irrigation in Net terms	Gross draft Estimated on Prorata basis	Net Draft	Balance Ground Water Resource for future use in net terms	Level of Ground Water Development
		MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	[%]
	States								
1	Andhra Pradesh	3.52909	0.52936	2.99973	2.69975	1.11863	0.78304	2.21668	26.10
2	Arunachal Pradesh	0.14385	0.02158	0.12227	0.11005	-	-	0.12227	-
3	Assam	2.24786	0.33718	1.91068	1.71962	0.20356	0.14249	1.76819	7.46
4	Bihar	2.69796	0.4047	2.29327	2.06394	1.17895	0.82527	1.46800	35.99
5	Chattisgarh	1.60705	0.24106	1.36599	1.22939	0.10925	0.07647	1.28952	5.60
6	Goa	0.02182	0.00327	0.01855	0.01669	0.00219	0.00154	0.01701	8.30
7	Gujarat	2.03767	0.30566	1.73199	1.55881	1.21895	0.85327	0.87872	49.27
8	Haryana	1.11794	0.16769	0.95025	0.85523	1.02637	0.71846	0.23179	75.61
9	Himachal Pradesh	0.02926	0.00439	0.02487	0.02238	0.00591	0.00413	0.02073	16.63
10	Jammu & Kashmir	0.44257	0.06640	0.37620	0.33860	0.00586	0.00403	0.37217	1.07
11	Jharkhand	0.66045	0.09907	0.56138	0.50525	0.17352	0.12146	0.43992	21.64
12	Karnataka	1.61750	0.24186	1.37564	1.23665	0.64973	0.45481	0.92083	33.06
13	Kerala	0.79003	0.13135	0.65869	0.59281	0.17887	0.12509	0.53360	18.99
14	Madhya Pradesh	3.48186	0.52228	2.95958	2.66362	1.05494	0.73846	2.22112	24.95
15	Maharashtra	3.78677	1.23973	2.54704	2.29233	1.26243	0.8837	1.66334	34.70
16	Manipur	0.31540	0.04730	0.26810	0.24129	Neg.	Neg.	0.26810	Neg.
17	Meghalaya	0.05397	0.00810	0.04587	0.04128	0.00260	0.00182	0.04405	Neg.
18	Mizoram			Not Assessed					
19	Nagaland	0.07240	0.01090	0.06150	0.05535	Neg.	Neg.	0.06150	Neg.
20	Orissa	2.01287	0.30193	1.71094	1.53984	0.37196	0.26037	1.45057	15.22
21	Punjab	1.81923	0.18192	1.63730	1.47357	2.30028	1.61020	0.02710	98.34
22	Rajasthan	1.26021	0.19977	1.06044	0.95440	1.10350	0.77245	0.28799	72.84
23	Sikkim			Not Assessed					
24	Tamil Nadu	2.64069	0.39610	2.24458	2.02013	2.00569	1.40398	0.84060	62.55
25	Tripura	0.06634	0.00995	0.05639	0.05075	0.02692	0.01885	0.03754	33.43
26	Uttar Pradesh	8.25459	1.23819	7.01640	6.31476	4.25171	2.97619	4.04021	42.42
27	Uttaranchal	0.28411	0.04262	0.24149	0.21734	0.09776	0.06843	0.17306	28.34
28	West Bengal	2.30914	0.34637	1.96277	1.76649	0.9025	0.63175	1.33102	32.19
	Total States	43.30063	7.09873	36.20191	32.58033	19.25207	13.47627	22.72564	37.23

Note : 1 Mhm = 353 TMC; 1BCM = 1Km^3 = 35TMC http://wrmin.nic.in/publication/ar2002/ch11-13.pdf

Ground water pollution :

There are serious water scarcity and drinking water pollution problems in almost all the industrial townships including the metropolitan cities like New Delhi, Mumbai, Chennai, Bangalore, Hyderabad and Kolkata where ground water pollution is rampant..

Modern urbanisation, industrialisation as well as agricultural activities have made water pollution a growing concern in both surface and ground water resources. But ground water has received little attention in the past because of the common belief that ground water was pristine. Ground Water Pollution is usually traced back to four main origins industrial, domestic, agricultural and over exploitation. Industrialisation without provision of proper treatment and disposal of wastes and liquid effluents is a major source of ground water pollution. Excessive application of fertilizers and pesticides for agricultural development coupled with over-irrigation are responsible for surface and ground water pollution.

The generation of wastewater in India by 1980 was estimated at 75,000 million liters day i.e. about $27km^3$ annually, which poses a perennial danger to the potable ground water resources. Inspite of sewage treatment plant at Delhi, the city discharged 100 million gallon of untreated sewage into the Yamuna river. Wastewater generation was estimated at about $40km^3$ (110,000 million litre/day) annually by 2000 when the population was estimated at about one million. Solid waste disposal is also not lagging behind in adding to ground water pollution problem.

Industrial effluents in many places are discharged into pits, open ground, or open unlined drains near the factories, thus allowing it to move to low lying depressions resulting in ground water pollution. The industries daily produce about 55000 million M^3 of wastewater per day, out of which 68.5 million M^3 is discharged into rivers and streams and hence about 70% of our rivers and streams contain polluted water and are rendered unfit for drinking and irrigation.

Among the states identified as endemic to fluorosis are: Nalgonda and Rangareddy districts in A.P., Banskatha, Kutch and Amroli in Gujarat, Hissar, Kaithal and Gurgaon in Haryana, Augul Bolengir, Phulbani in Orissa, Bhatinda, Sangrur in Punjab, Ajmer, Bikaner, Pali, Nagur and Sirohi in Rajasthan, Chengalpattu and Madurai in Tamilnadu, Unnao in U.P., Some places in Karnataka, Madhya Pradesh, Maharastra, Bihar and Delhi are also effected Half million people are suffering from ailments due to excess of fluoride in drinking water up to 11.0 mg/lit. Arsenic in ground water has been reported in a range (0.05-3.2) mg/l in shallow aquifers from 61 blocks in 8 districts of West Bengal namely Malda, Mushirbad, Nadia, North and South 24 Pargana, Bardharnan, Howrah and Hugli due to excessive exploitation of ground water for irrigation.

Cloud seeding for managing ground water resources :

During the past few decades several industries have been located on the banks of major rivers and their tributaries in different states. Moreover several cities and towns are also located on the banks of the rivers. With the accelerated growth of urbanisation and industrialisation the municipal and industrial effluents are finding their way into the natural streams and rivers. With the result that the water which was previously used for drinking, fishing , bathing, agriculture and recreational purposes has become highly polluted and unfit for many uses. During summer the stream flows dwindle to a trickle and consequently most of the streams used by the public for beneficial uses have become virtually the sewers of the neighboring cities and industries. 90% of the water courses are highly polluted. For instance even major rivers like Ganges, Yamuna, Krishna, Cauvery, Damodar and Hoogly have become so polluted that public interest litigation cases have been filed against the industries and the state and the central pollution control authorities to restore the quality of waters in these river courses to protect public health and environment.

Ground water pollution in India

Pollutant	State	Place of occurrences
Salinity (Inland)	Maharashtra	Amravati, Akola
	Bihar	Begusarai
	Haryana	Karnal
	Rajasthan	Barmer, Jaisalmer, Bharatpur, Jaipur, Nagaur, Jalore & Sirohi
	U.P.	Mathura
Salinity (Coastal)	Andhra Pradesh	Vishakapatnam
	Orissa	Puri, Cuttak, Balasore
	West Bengal	Haldai & 24 Pargana
	Gujarat	Junagarh, Kachch, Varahi, Banskanta & Surat
Flouride	Kerala	Palaghat
	Andhra Pradesh	Cuddapah, Guntur and Nalgonda, Krishna, Ananipur, Nellor, Chittoor.
	Gujarat	Banskanta, Kachch & Amreli
	Haryana	Hissar, Kaithal & Gurgaon
	Orissa	Bolangir, Bijapur, Bhubaneshwar and Kalahandi
	Punjab	Amritsar, Bhatinda, Faridkot, Ludhiana & Sangrur
	Rajasthan	Nagaur, Pali, Sirohi, Ajmer & Bikaner
	Tamil Nadu	Chengalput, Madurai
	U.P.	Unnao, Agra, Aligarh, Mathura, Ghaziabad, Meerut & Rai Baraili
Sulphide	Orissa	Balasore, Cuttak & Puri
Iron	U.P.	Mirjapur
	Assam	Darrang, Jorhat, Kamrup
	Orissa	Bhubaneshwar
	Bihar	E. Champaran, Muzaffarpur, Gaya, Manger, Deoghar & Madubani
	Rajasthan	Bikaner, Alwar, Bharatpur
	Tripura	Dharmnagar, Kailasanar, Ambasa, Amarpur & Agartala
	West Bengal	Madnipur, Howrah, Hoogly and Bankura
Maganese	Orissa	Bhubaneshwar, Athgaon
	U.P	Muradabad, Basti, Rampur & Unnao
Arsenic	West Bengal	Malda, Murshidabad, Nadia, 24 Pargana
Nitrate	Bihar	Patna, East Champaran, Palamu, Gaya, Nalanda, Nawada and Banka
	Andhra Pradesh	Vishakapatnam, East Godvari, Krishna, Prakasam, Nellor, Chittoor, Anantpur, Cuddapah, Kurnool, Khamam and Nalgonda
	Delhi	Naraina, Shehadr (Blocks)
	Haryana	Ambala, Sonepat, Jind, Gurgaon, Faridabad & Hissar
	Himachal Pradesh	Kulu, Solan, Una
	Karnataka	Bidar, Gulbarge and Bijapur
	Madhya Pradesh	Sehore, Bhopal & (West & Central Part of state)
	Maharashtra	Jalna, Beed Nanded, Latur, Osmanabad, Solapur Satara, Sangli and Kolhapur
	Punjab	Patiala, Faridkot, Firozpur, Sangrur & Bhatinda
	Rajasthan	Jaipur, Churu, Ganganagar, Bikaner, Jalore, Barmer, Bundi and Sawaimadhopur
	Tamil Nadu	Coimbatore, Penyar and Salem
	West Bengal	Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura and Purulia.
Chloride	Karnataka	Dharwad, Belgaum
	Madhya Pradesh	Bhind, Shagapur and Sehore
	Maharashtra	Solapur, Satara, Amravati, Akola & Buldana
	Rajasthan	Barmer, Jaisalmer, Jodhpur & Jalore
	West Bengal	Contai, Digha, Haldia
Zinc	Andhra Pradesh	Hyderabad, Osmania University campus
	Delhi	R.K. Puram
	Rajasthan	Udaipur
Chromium	Punjab	Ludhiana

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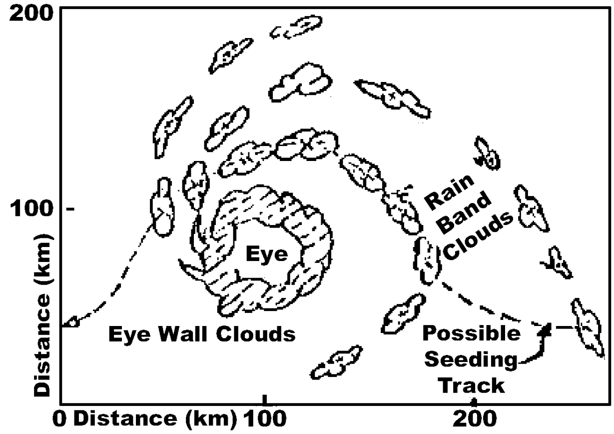
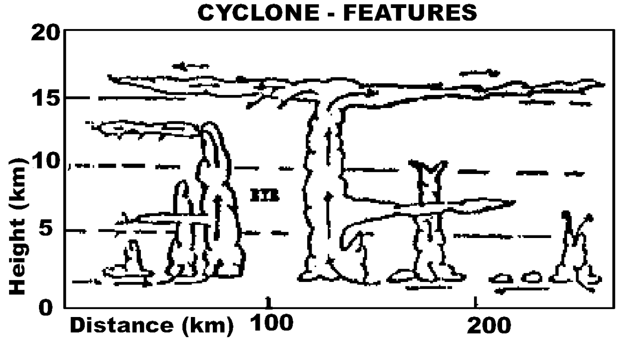
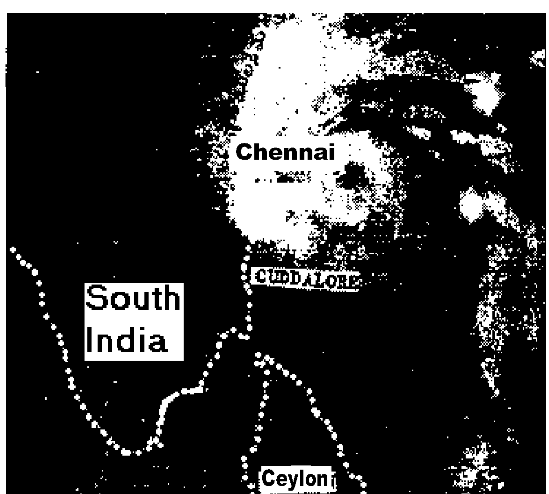
CAN SEEDING OF BAND CLOUDS OF THE CYCLONE AUGMENT RAINFALL IN DISTANT PLACES?



CYCLONE - FEATURES





Cloud Cover over Rayalaseema during cyclone on 8-5-1990

Seeding of Band Clouds helps augmentation of Rainfall at many distant places