जलाशयों में वाष्पन नियंत्रण

Evaporation Control in Reservoirs

भारत सरकार
केन्द्रीय जल आयोग
बेसिन आयोजन एवं प्रबंध संगठन
नई दिल्ली

Government of India
Central Water Commission
Basin Planning and Management Organisation
New Delhi

2006

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Table of Contents

1.0 INTRODUCTION

Water is one of the nature's precious gifts, which sustains life on earth. Civilizations over the world have prospered or perished depending upon the availability of this vital resource. Water has been worshiped for life nourishing properties in all the scriptures. Vedas have unequivocally eulogized water in all its virtuous properties.

The total water resources on earth are estimated to be around 1360 Million cubic km. Out of which only about (33.5 Million cubic km) is fresh water. India possesses only 4% of total average runoff of the rivers of the world although it sustains 16% of the world's population. The per capita availability of water in the country is only 1820 m^3/year, compared to 40855 m^3/year in Brazil, 8902 m^3/year in USA, 2215 m^3/year in China, 2808 m^3/year in Spain, 18162 m^3/year in Australia, 3351 m^3/year in France, 3614 m^3/year in Mexico, and 3393 m^3/year in Japan. The total water resources of India are estimated to be around 1,869 BCM. Due to topographic, hydrological and other constraints, only about 690 BCM of total surface water is considered as utilizable.

In the earlier days availability of water was taken for granted. It is now being realized that water, though replenishable, is not an unlimited resource and cannot be produced or added as and when required, by any known technological means. The other important limitation is that the availability of water over the years depends upon the spatial and temporal variation of precipitation. Thus water may be abundant during monsoon season and scarce in non-monsoon season, when most needed. The ingenuity of man, therefore, lies in his ability to modify the pattern of availability of water to suit needs. One of the commonest forms of such modification is storage of water during monsoon season for eventual use in lean season. The traditional methods are big storage in natural or artificial ranks. Lately a large number of storages have been constructed. Due to high temperatures and arid conditions in about one third of the country, the evaporation losses have been found to be substantial. Therefore, it is imperative to minimise evaporation losses in the storages/water bodies.

The need for prevention of enormous evaporation losses assumes greater significance, in view of the predictable scarcity of water; the country will be facing in future. It has been assessed that against the utilizable water resources of the order of 1123 BCM, the requirement by 2025 AD to be met from surface water resources will be around 1093 BCM, thereby surplus by just 30 BCM.

Due to intense agricultural practices, rapid increase in population, industrialization and urbanization etc., scarcity of water is being increasingly felt. The situation becomes grave in the arid and semi-arid regions especially during droughts, when general scarcity of water is compounded by high evaporation losses from open water surfaces of lakes and reservoirs. During severe drought conditions of 1987, the water scarcity in Gujarat and some other parts of the country was so severe that even drinking water had to be carried by trains to the affected areas. In the present scenario of utmost strain on the water resources, of the country, it becomes necessary to conserve water by reducing evaporation losses. National Water Policy-2002 under para 19.1 emphasises that evaporation losses should be minimised in Drought-prone areas.

Basin Planning and Management Organisation (BPMO), CWC had earlier published a Status Report on "Evaporation Control in Reservoirs" in December-1990. As sixteen years had passed it was felt necessary to update the report, in case there have been new researches in this field and new chemicals (Water Evaporation Retarders) or new techniques have been evolved since then. Accordingly, the request letter was sent to all the State Governments and various Institutions involved in the water resources research field to send us the feedback of various researches on Evaporation Control. However, all the responses received, indicate that no new researches have been conducted by the State Govts or Central / State agencies. The earlier publication contained the monthly and annual evaporation maps of the country. In this regard, IMD was also approached so that the updated evaporation maps could be included in this publication. Asstt Meteorologist, IMD Pune also informed that the evaporation maps were last published in 1991. There is no difference in the evaporation maps in the earlier publication and the photocopies of the maps supplied by IMD.

The internet was also browsed to search the information on any new researches or identification of any new technology / chemicals to retard the evaporation rate. The search on internet, resulted in finding some case studies done in this field in other countries, however, the chemicals / technology used is the same as covered in the earlier publication. Some websites are from the manufacturers of WER chemicals such as Hexadecanol or Octadecanol or Acilol claiming to have conducted experiments in other countries towards evaporation control.

These case studies have been added as Chapter-8 “Case Studies of Evaporation Control in other Countries” in this publication.

2.0 ASSESSMENT OF EVAPORATION LOSSES IN INDIA

As per available records, assessment of evaporation losses in the country was first made by L.A. Ramdas and presented in Symposium of Evaporation control in 1966. The assessment was based on the following assumptions:

Area of arid, Semi arid and long dry spell regions of India	2,000,000 Sq.Km..
Estimated water area in this region(1%)	20,000 Sq.Km..
Estimated area where film application may be feasible	2,000 Sq.Km..
The evaporation loss from the above area	6,000 MCM

The National Commission on Agriculture (1976) had estimated that the annual evaporation losses from reservoir surfaces will be of the order of 50,000 MCM.

Central Water Commission in their publication "Status Report on Evaporation Control in Reservoirs, 1988" had indicated that on an average there is a loss of about 450 MCM of water every month from an area of 2,000 Sq.Km.. which amounts to an annual loss of 5,400 MCM.

The Water Management Forum (WMF), a national body of the Institution of Engineers (India), in their publication "Water Conservation by Evaporation Control, 1988" had indicated that on the Indian sub-continent the estimate total loss of water from large, medium and small storages will be to the tune of 60,000 MCM, which according to WMF would be adequate to meet the entire municipal and rural water needs of India by 2000 AD.

The assessment of evaporation losses had been reviewed by CWC in 1990. Average annual evaporation from reservoirs/water bodies in India varies from 150 cm to 300 cm. The total surface area of existing large and medium storages, tanks and lakes in the country is of the order of 12,000 Sq.Km.. This is likely to increase to about 25,000 Sq.Km. at the ultimate stage of development. Assuming annual evaporation loss rate of 225 cm, the evaporation loss from existing water bodies works out to 27,000 MCM. In the ultimate stage, the evaporation losses may be of the order of 56,000 MCM. Thus, likely evaporation losses appear to be high, considering capital costs involved in creation of storages.

It may not, however, be possible to take remedial measures of evapo-retardation on all storages/water bodies. Assuming even 20% of the above area falls in scarcity and drought areas, it may be necessary to tackle around 2,400 Sq.Km. of surface area in the present stage and about 5,000 Sq.Km.. at the ultimate stage. It is further seen that about 30% of evaporation retardation may be achieved by known evapo-retardation methods. Thus it may perhaps be possible to effect a saving to the extent of 1,620 MCM at present and 3,375 MCM at the ultimate stage. Further reduction in evaporation losses may be possible with development of cost effective and economic methods of evapo-retardation.

3.0 FACTORS AFFECTING EVAPORATION

Evaporation is a process by which a liquid changes into vapour form. Water molecules are in constant motion and some have the energy to break through water surface and escape into air as vapour. Evaporation in general is a beneficial phenomenon in regulating global water balance through the hydrological cycle and it is the same phenomenon contributing to massive losses from water bodies. Control of evaporation from land based water bodies, has thus remained one of the main planks of water conservation strategies. This assumes greater significance in arid regions, where water scarcities are already a common problem.

A number of factors affect the evaporation of water from open water surface, of which the major are:

3.1 Water Surface Area

Evaporation is a surface phenomenon and the quantity lost through evaporation from water stored, therefore, depends directly on the extent of its surface exposed to the atmosphere.

3.2 Temperature

The temperature of water and the air above it affect the rate of evaporation. The rate of emission of molecules from liquid water is a function of temperature. The higher the temperature, greater is the rate of evaporation.

3.3 Vapour Pressure Difference

The rate at which molecules leave the surface depends on the vapour pressure of the liquid. Similarly, the rate at which molecules enter the water depends on the vapour pressure of the air. The rate of evaporation therefore depends on the difference between saturation vapour pressure at the water temperature and at the dew point of the air. Higher the difference, more the evaporation.

3.4 Wind Effect

The greater the movement of air above the water, greater is the loss of water vapour. Experimental studies on the relationship between wind speed and evaporation show direct relationship upto a certain value of wind velocity beyond which perhaps the relationship does not hold good. Factors like surface roughness and dimension of the water body are reported to have an important role to play.

3.5 Atmospheric Pressure

Atmospheric pressure is very much related to other factors affecting evaporation. It is, therefore, difficult to assess its effect separately. The number of air molecules per unit volume increases with pressure. Consequently with high pressure, there is more chance that vapour molecules escaping from the water surface will collide with an air molecule and rebound into the liquid. Hence evaporation is likely to decrease with increasing pressure.

3.6 Quality of Water

The salt content in water affects the rate of evaporation. Experimental studies show that the rate of evaporation decreases with increase in salt content in water. In the case of sea water, the evaporation is 2 to 3% less as compared to fresh water, when other conditions are same.

4.0 METHODS OF DETERMINING EVAPORATION

Evaporation can be determined by several methods. The following methods and their modifications are generally used by different scientists:

i) The Water Budget or Storage Equation
ii) Measurement in an Auxiliary Pan
iii) The Evaporation Formulae or the Empirical Formulae
iv) Mass Transfer Method or the Humidity and Wind Velocity Gradient Method
v) Energy Budget Method or Insolation Method

4.1 Water Budget / Storage Equation Method

In this method the evaporation is determined by the equation :

E = $P+I-O\pm U\pm S$, where,
E = evaporation
P = precipitation on the water surface
I = surface inflow
O = surface outflow
U = underground inflow or outflow and
S = change in storage.

S is (-)ve for any increase and (+)ve for any decrease in storage. The quantities are usually expressed as millimeter depth in the water area for some convenient time interval.

For correct assessment of evaporation by the above method, loss of water due to seepage, which may be significant, is to be determined. Some work has been done in this field in our country. Two research stations, namely Irrigation Research Institute, Poondi, Chennai and Irrigation Research Institute, Roorkee, Uttaranchal have made attempts to develop methods of measuring seepage. The technique developed by the former involves the measurement of seepage of water through the bed. The device as shown in Fig 4.1 is used for measuring the seepage loss. The apparatus consists of 2 cylindrical pans, 1.23 m diameter and 0.43 m high with a hole of 38 mm diameter in the center and short metal pipes of about 102 mm in length are welded to the holes to project outside from the bottom. These metal pipes serve to connect the pans to each other with the help of a rubber hose. One of the pans is inverted and rammed into the bed such that at least 229 mm of its sides penetrate into the soil; the other pan with its open end facing upwards is supported on a frame-work above the first with its bottom at least 229 mm below the water surface of the tank.

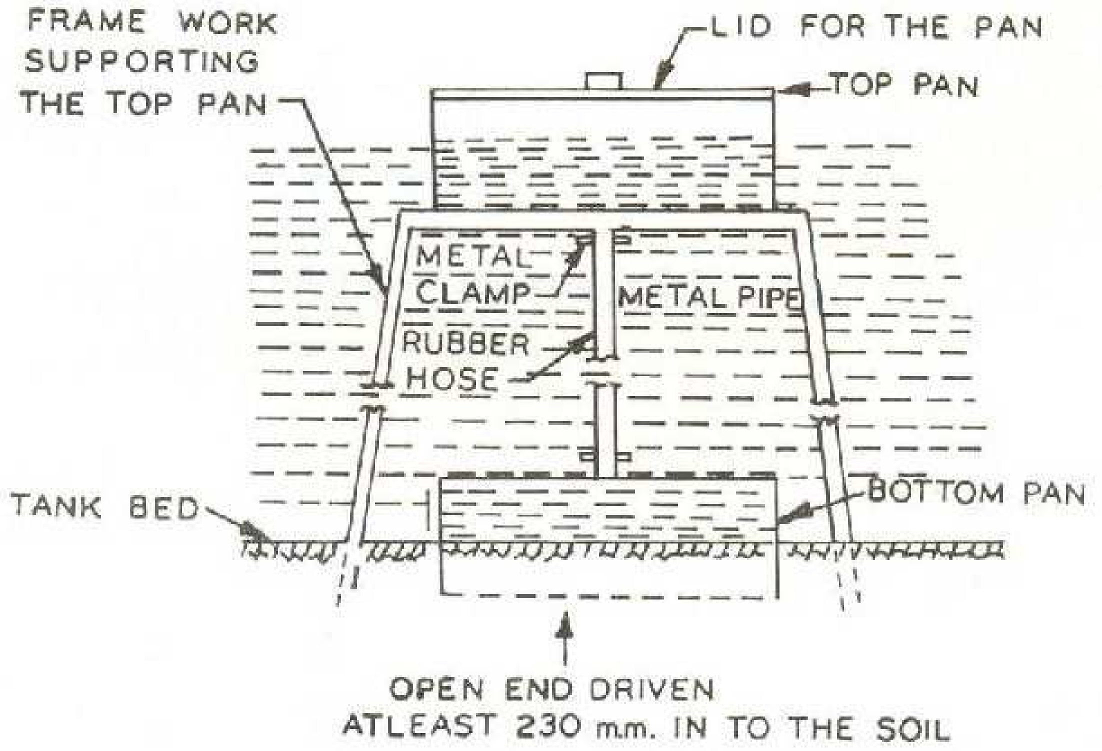


Fig- 4.1 Seepage Meter developed by Irrigation Research Institute, Poondi

The top pan is covered by a lid to prevent loss of water due to evaporation and water is poured into it to the same level as that in the tank on the outside of it. The loss of water level in the top pan indicates directly the loss of water due to seepage from the tank bed. It has been reported that consistent values could not be obtained.

At the Irrigation Research Institute, Roorkee, Uttaranchal attempts were made to improve the seepage meter developed by Regional Salinity Laboratory, Soil Conservation Service, River site, California, by replacing the plastic bag by a constant head vessel (Fig 4.2) to measure seepage in channels. The seepage meter essentially consists of a seepage cup, constant head vessel and the swivel head joint. The seepage meter is standardized before use. The value obtained by a seepage meter is to be multiplied by a coefficient greater than one for less previous soils and less than one for more previous soils.

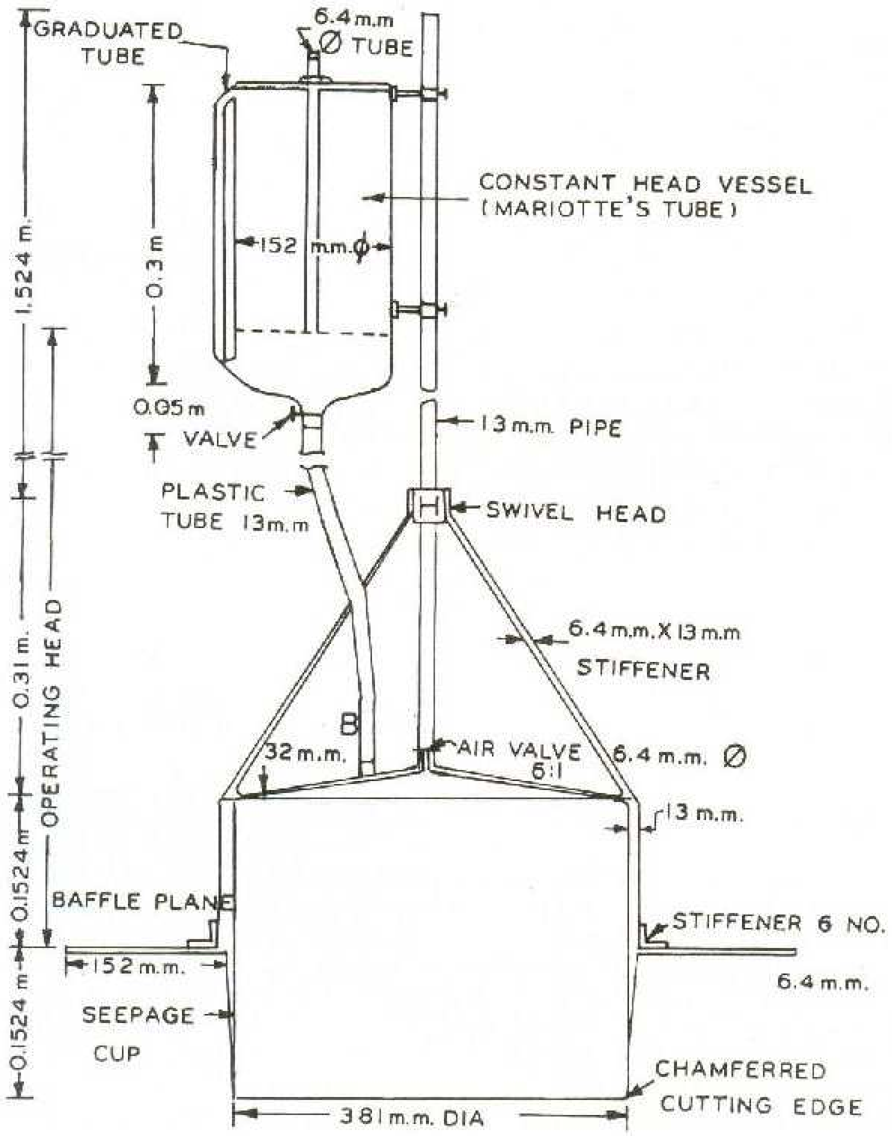


Fig- 4.2 Seepage Meter developed by Irrigation Research Institute, Roorkee

The main disadvantage of the water budget or storage equation method is the varying degrees of accuracy of the quantities measured. This equation may not hold good where large springs occur in the lake beds or where large underground seepage losses occur.

4.2 Measurement in an Auxiliary Pan

Kohler and others had calculated evaporation from lakes by converting measured evaporation from pans to lake evaporation by applying a coefficient. Bleney had studied the effects of high altitude on evaporation from pans and determined suitable coefficient. Studies by Bigelow had shown that the location of pans relative to the water of a reservoir has significant effect on the calculated evaporation. He concluded that evaporation from natural lakes or reservoirs is about five-eighth as fast from an isolated pan placed outside the vapour blanket. Further studies by Rohwer, Kohler, and Mansfield showed that the evaporation coefficient ranges anywhere between 0.2 to 1.5 and this factor is dependent upon size, depth and location. With this kind of evaporation measurement, it is essential that the coefficient of evaporation be measured under all different conditions, which is not practically feasible in large water storage systems.

The present practice is to estimate evaporation loss from land pan evaporimeter. In the studies being done at IHH, Poondi a floating evaporimeter is used for the experiments. A floating evaporimeter made of GI sheet was initially used. Later on it was found that the stored energy inside the water body has a significant effect on the evaporation loss. To have this effect truly reflected, IHH found it necessary to have a suitable material for manufacturing floating evaporimeter. An ideal material to achieve this objective should perhaps be the one which will have a thermal conductivity equivalent to that of water, but at the same time non-leaky. With this in mind, a study of the thermal conductivity of some materials was made. Thermal conductivity of water is 0.556 W/m ^{o}C. It is 0.75 for iron, 0.60 for brick, 0.78 for window glass, 0.1 for concrete and 0.02 for plastics. It shows that plastics and concrete have low values and the metals have high values. Ideally brick or glass should be made use of for making floating evaporimeter. But the brick is heavy and leaky and the glass is brittle. Hence a new material, Perspex sheet, which is akin to glass but at the same time non-brittle and workable, was chosen as an alternative material for the fabrication of floating evaporimeter installed at Poondi reservoir.

From the experience so far gained in the installation of a floating evaporimeter, an arrangement that might perhaps sub-serve the objective of rational determination of evaporation loss and the seepage loss as a by-product, as devised by IHH, Poondi is shown in Figure 4.3. The arrangement consists of an evaporimeter (made up of Perspex sheet) which is enclosed by a sliding type of wave arrester (again made up of Perspex sheet). This sliding unit slides on the supporting les of the stand which carried the evaporimeter with a wire rope and a pulley. Equipment like wind anemometer, thermometers etc., can be mounted on the outer sliding frame work. The main advantage of this system is that the sliding arrangement follows the water surface and could be fixed at the desired location. Further, the unit remains at a fixed location. A graduated gauge of requisite least count when fixed to the frame work shall enable the observation of water level fluctuations at the site of evaporation through the transparent perspex sheets.

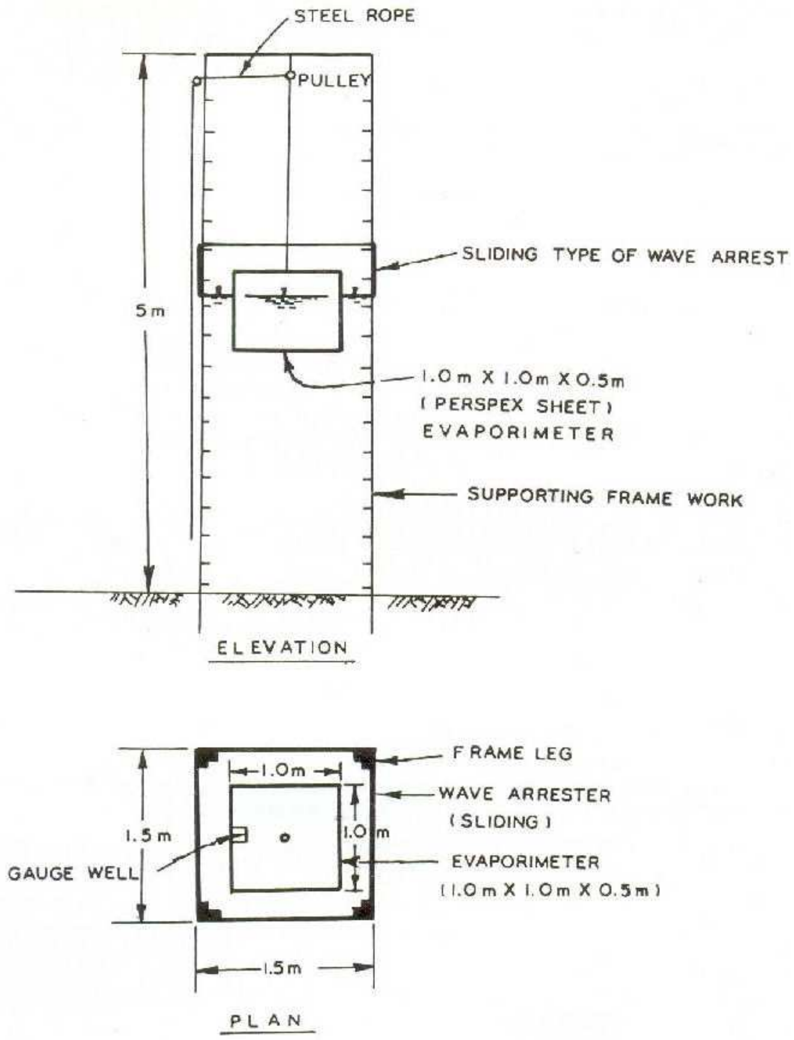


Fig- 4.3 Floating Pan arrangement developed by Institute of Hydraulics and Hydrology (IHH), Poondi.

Since the Meteorological factors affecting hydrological processes including evaporation vary over the year, IHH plans to obtain data for a few years for deriving reliable results for possible use in reservoir analysis problems.

4.3 Empirical Formulae

The rate of evaporation at a given location depends upon a number of parameters as explained earlier. Dalton was one of the first scientists to have expounded an empirical formula for evaporation loss, which states that:

$E = C(P_w - P_a)$, where

E= Rate of evaporation in inches per day of the exposed surface;

P_w=vapour pressure in the film of air next to water surface
P_a=vapour pressure in the air above the film; and
C= coefficient dependent upon barometric pressure, wind velocity and other variables

Many other scientists have proposed different modifications of this evaporation equation by taking into account various related factors. Fitzgerald modified the Dalton's equation by taking into account the effect of wind velocity on evaporation. Carpenter subsequently further modified the Fitzgerald equation by taking modified coefficient factor for wind velocity and his equation was found applicable to the conditions in western United States. Research scientists, Boelter Hickox, Thomas and Ferguson have later significantly contributed in the development of evaporation equations and removal of doubts and confusion of terms adopted by different authors.

However, as can be seen from the equation, some parameters like temperature conditions, wind velocity etc. have not been separately considered, but their effect is lumped in the form of coefficient C.

In India S.P. Ghosh and S.K. Sarkar, River Research Institute, West Bengal had made attempts to develop equations, correlating evaporation with meteorological factors like temperature, degree of saturation of water vapour, wind velocity and atmospheric pressure. The following equation for calculation of Pan-evaporation from meteorological factors as suggested by them is:

$E = (1.3684-0.0189B)(0.41+0.136W)(e_s-e_d)$, where
E= daily evaporation in inches
B= mean barometric pressure in inches of mercury,
W=mean velocity of ground wind in miles per hour,
e_s= Mean vapour pressure of saturated air at the temperature of water surface in inches of mercury.
e_d= mean vapour pressure actually present in the air in inches of mercury.

The pan evaporation as calculated can be converted into reservoir evaporation by multiplying with standard pan coefficient. The accepted standard coefficient for 1.22m (4') dia US Class A land pan is 0.70.

The above equation has been developed based on the limited years of meteorological data of four stations, having evaporation ranges from 1.04 mm to 9.88 mm (0.041 inch to 0.389 inch), barometric pressure ranges from 648.72 mm to 763.78 mm (25.54 inches to 30.07 inches) of mercury, ground wind velocity ranges from 0.48 to 9.30 km/hr (0.30 to 5.78 miles per hour) and temperature ranges from 10.97 ^oC to 36.23 ^oC (51.75 ^oF to 97.22 ^oF). In view of this, the equation suggested can be considered as a generalized equation for regions having meteorological values within the range indicated.

G.B.Pant University of Agriculture and Technology, Pantnagar, U.P. had conducted experiments to determine the effect of application of chemical films namely Hexadecanol and Octadecanol in reduction of evaporation from free water surface at different wind velocities by use of wind tunnel. Based on these studies, the following equations were suggested for predicting evaporation rate from free water surface with and without use of chemical films:

i) free water surface:
$E= (0.1184+0.0025 W) (e_s-e_a)$

ii) with the application of Hexadecanol:
$E= (0.0014 + 0.044W) (e_s-e_a)$

iii) with the application of Octadecanol:
$E= (0.0039 + 0.0057 W) (e_s-e_a)$.

where E is evaporation rate in mm per hour, W is wind velocity in km per hour, e_s and e_a are the saturation and actual vapour pressure respectively in millibars. The values of vapour pressure deficit (e_s-e_a) have been calculated by the following relationship:

$(e_s-e_a) = 0.644 (T_d-T_w)$, where T_d and T_w are the dry bulb and wet bulb temperatures (^oC) respectively.

4.4 Mass Transfer or Humidity and Wind Velocity Gradient Method

As the name suggests two important factors (i) humidity and (ii) wind velocity form the basis of calculating the evaporation. The basic assumptions involved in this method are:

i) If the moisture gradient exists in air, water vapours will move towards points of lower moisture content.
ii) The rate of movement of water vapour is accentuated by the intensity of turbulence in the air.

The method is applicable to both land and water surfaces. However, relatively expensive and highly sensitive hygrometers and wind velocity meters are required to measure the corresponding factors simultaneously at two different elevations above the ground.

4.5 Energy Budget / Insolation Method

This method was suggested by Angstorm in 1920 and is based on the conservation of heat within the body. For any given body of water, a balance must exist between heat gains and losses. Heat is normally gained by long and short-wave radiation, conduction and condensation. Heat loses result from direct land reflected radiation, conduction convection and evaporation. Radiation conduction, convection and changes in the energy storage in water may be measured and the evaporation or condensation may be computed. In this type of calculation some factors, such as heating due to chemical and biological processes, conduction of beat through the lake bottom and transformation of kinetic energy into thermal energy are considered insignificant. Different equations relating each of the parameters mentioned have been developed by various research workers in the field. This method suffers from the main draw back of measuring various parameters accurately with the help of sensitive and costly equipment.

5.0 MONTHLY AND ANNUAL EVAPORATION

Evaporation data were published by India Meteorological Department in 1970. The publication entitled “Evaporation data (India)” contains evaporation data of 30 departmental observatories for the period 1959 to 1968 and 42 agro-meteorological observatories for the period 1961 to 1968.

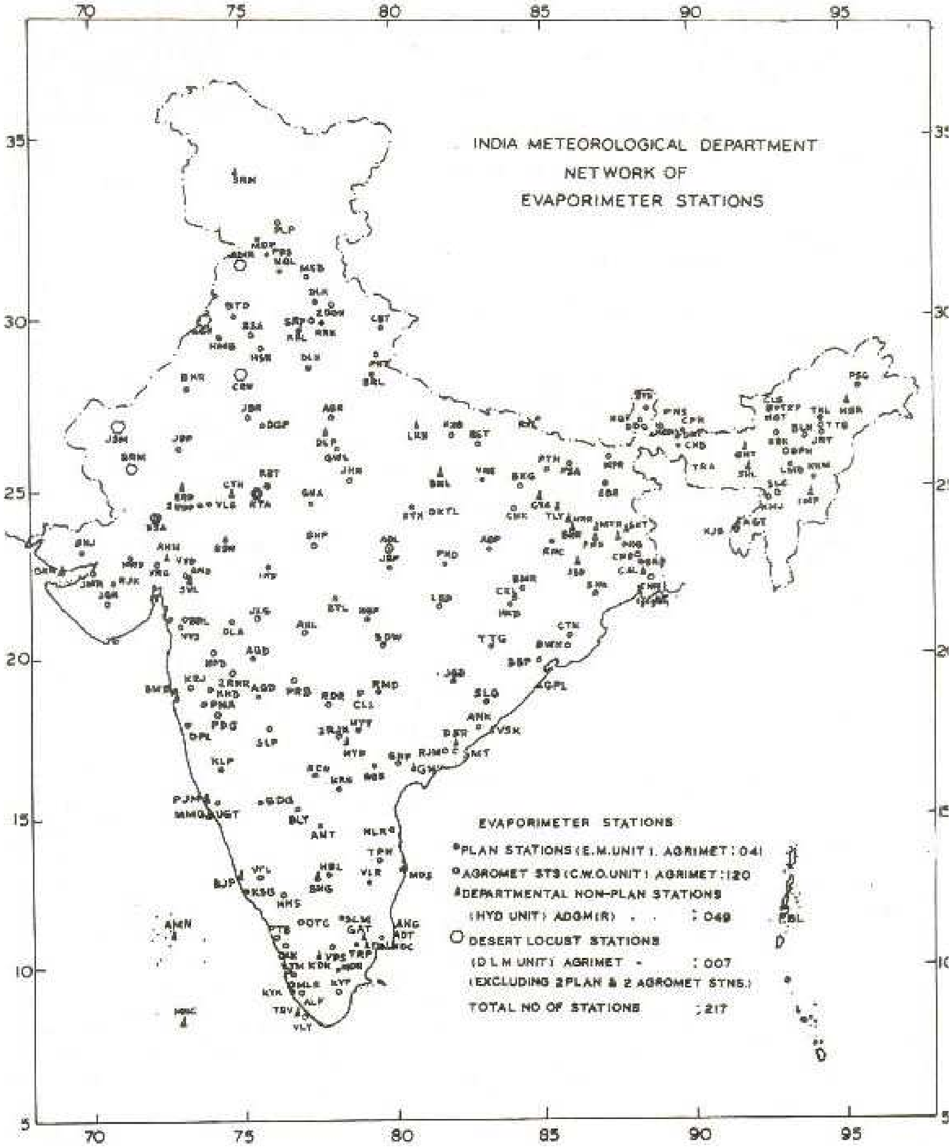


Fig- 5.1 Network of IMD Evaporimeter stations in India

Rao et al had presented (1971) distribution of evaporation over India using these data. Their analysis is based on short period averages (5-10years) from a thin network of 72 stations. Subsequently, in 1980, evaporation data of 40 departmental observatories for the period 1965 to 1975 and 72 agro-meteorological observatories for the period 1966 to 1975 were published.

The number of agro-meteorological observatories have now been considerably increased. The network IMD Evaporimeter stations existing in India is shown in Figure 5.1. With the availability of evaporation data of large number of stations, L.S. Rathore and B.C.Biswas of the Division of Agricultural Meteorology, Pune had prepared climatological maps based on the evaporation data of 176 observatories. Apart from data input from a large number of observatories, these maps are based on fairly long period of evaporation data of periods varying from 12-16 years. The basic data used are daily evaporation of 24 hours observed at 08.30 hrs. The monthly and annual evaporation isohyets are shown in Figures 5.2 to 5.14 at the end of this chapter.

As can be seen from the evaporation maps, the annual evaporation varies from as low as 50-75 cm over parts of Himalayan regions to as high as 325 cm over West Rajasthan and Jalgaon-Akola region. The region east of 87^{o} E longitude, including parts of West Bengal and entire NE India, register evaporation is 175 cm. The evaporation values for West coast, south of 20^{o} N latitude is about 150 cm, which is lower than the evaporation over the east coast. Over most of the east coast, the evaporation is 175 cm. However, the southern coast in Tamil Nadu registers comparatively very high evaporation. Annual evaporation of the order of 300 cm, though over a small portion, is also seen.

Saurashtra is another area where evaporation is fairly high (275-300 cm). The Deccan Plateau also exhibits high evaporation values ranging between 250-325 cm. Evaporation over the Himalayan region and its foot is low (60-150 cm).

The island stations register evaporation in the range of 131 cm to 201 cm and the monthly variation is very little. Similarly Himalayan regions, North Eastern States and coastal regions also exhibit less monthly variations. During summer, Rajasthan, interior peninsular India, Gujarat and parts of Central India register a sharp increase in evaporation rates. Though this is the belt of high evaporation in winter months too, the magnitude of increase in rate during summer months is quite high. Hence the region experiences wide variations in the evaporation rates.

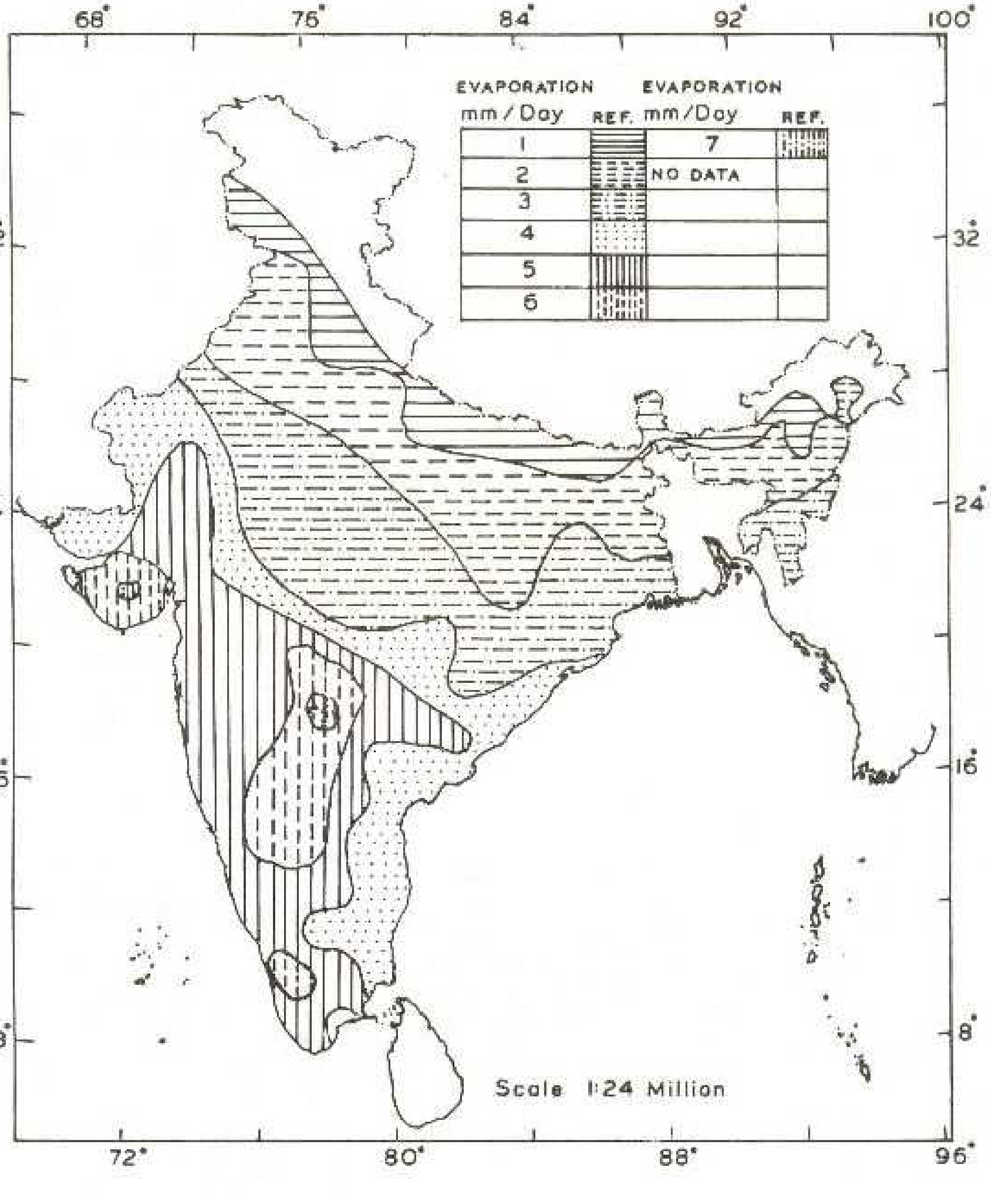


Fig- 5.2 Mean Daily Evaporation (mm) for January month

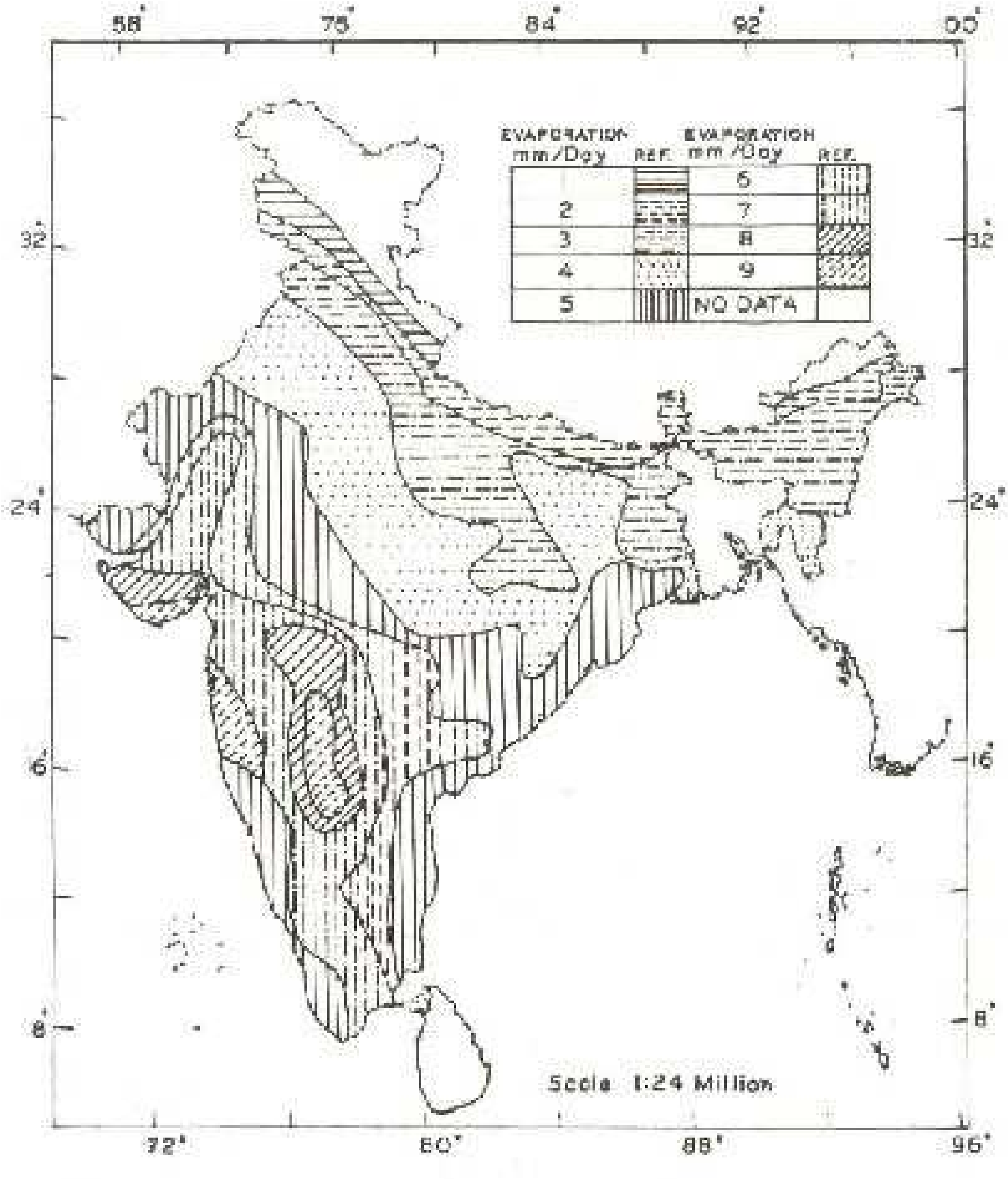


Fig- 5.3 Mean Daily Evaporation (mm) for February month

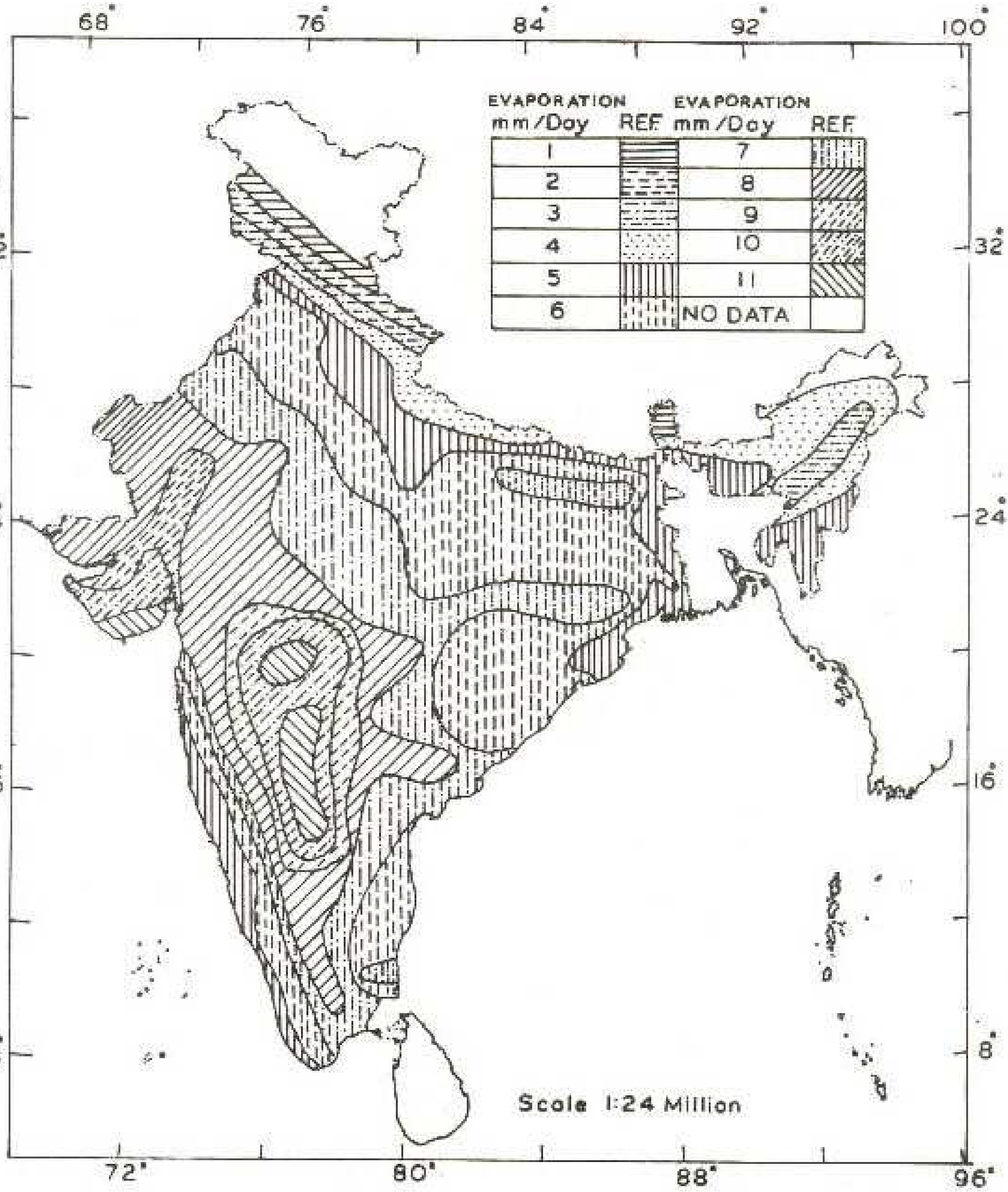


Fig- 5.4 Mean Daily Evaporation (mm) for March month

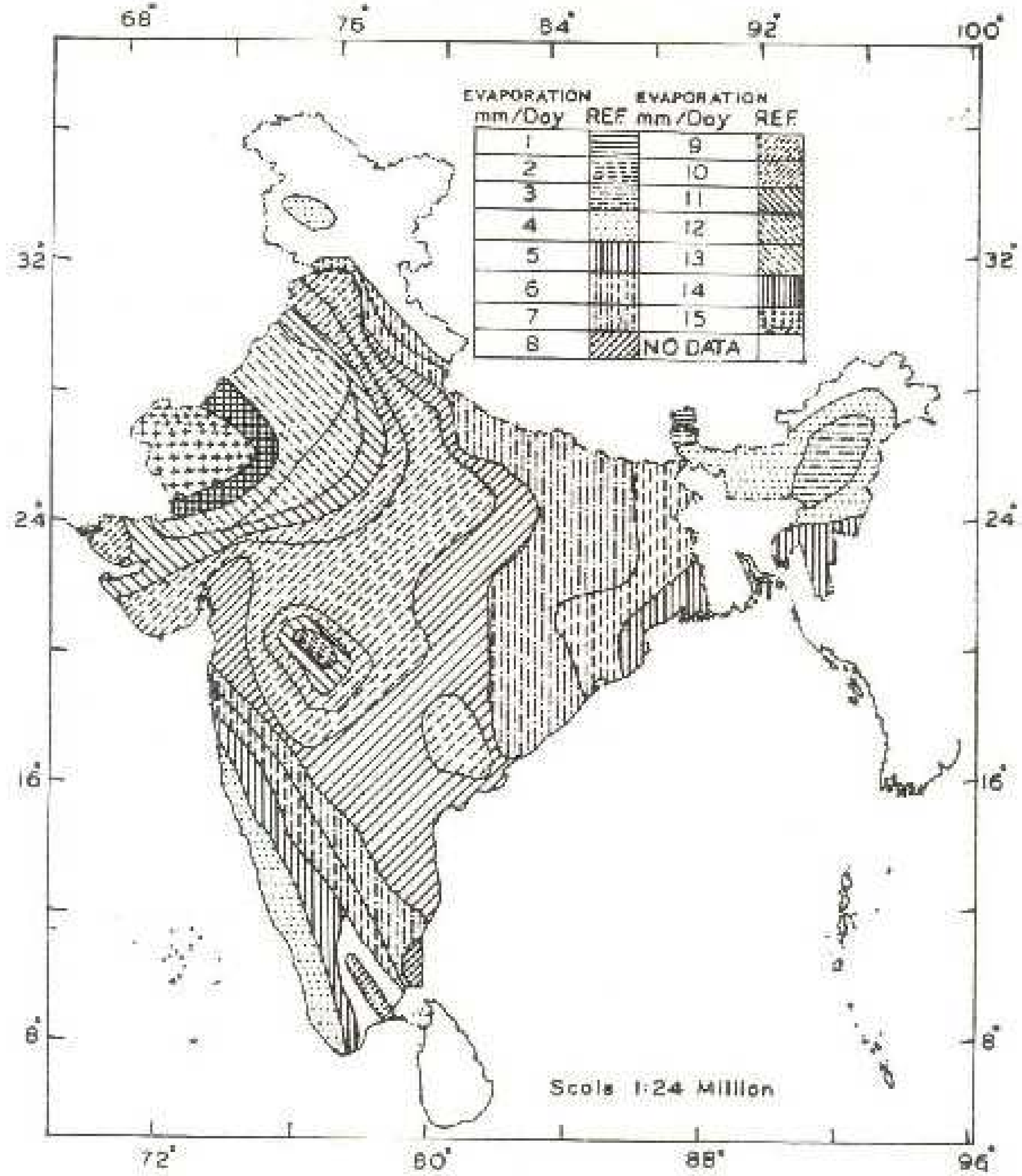


Fig- 5.5 Mean Daily Evaporation (mm) for April month

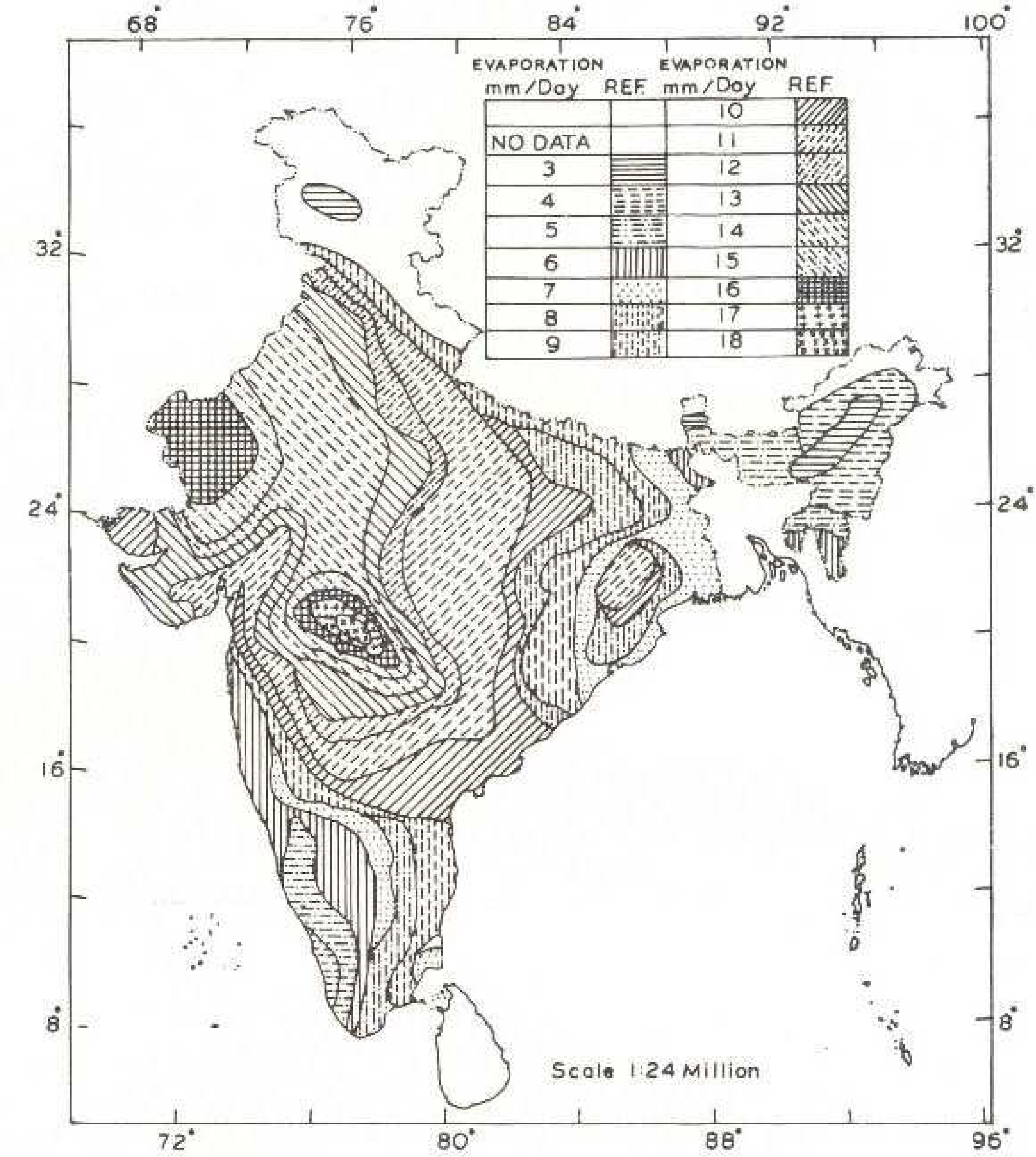


Fig- 5.6 Mean Daily Evaporation (mm) for May month

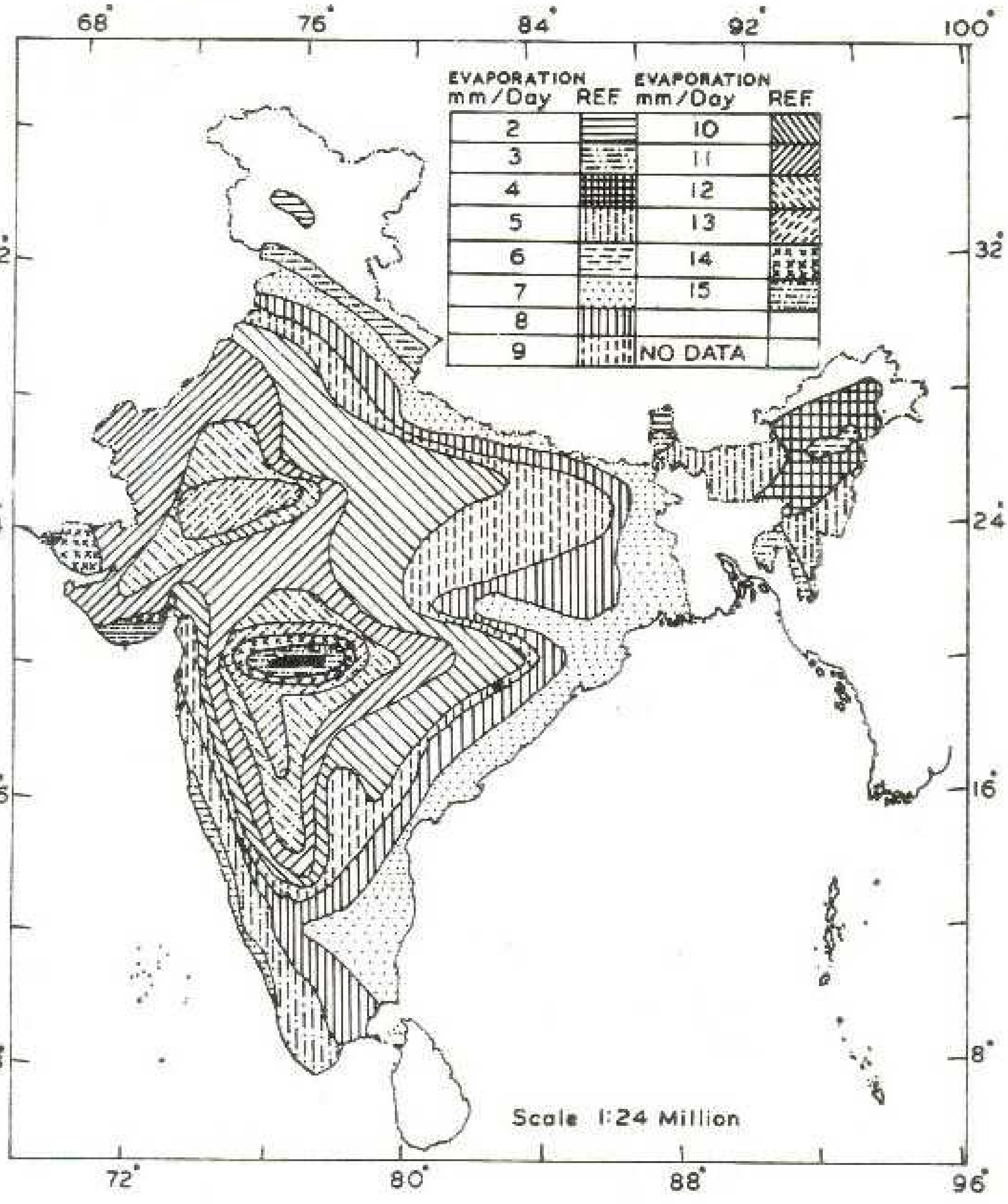


Fig- 5.7 Mean Daily Evaporation (mm) for June month

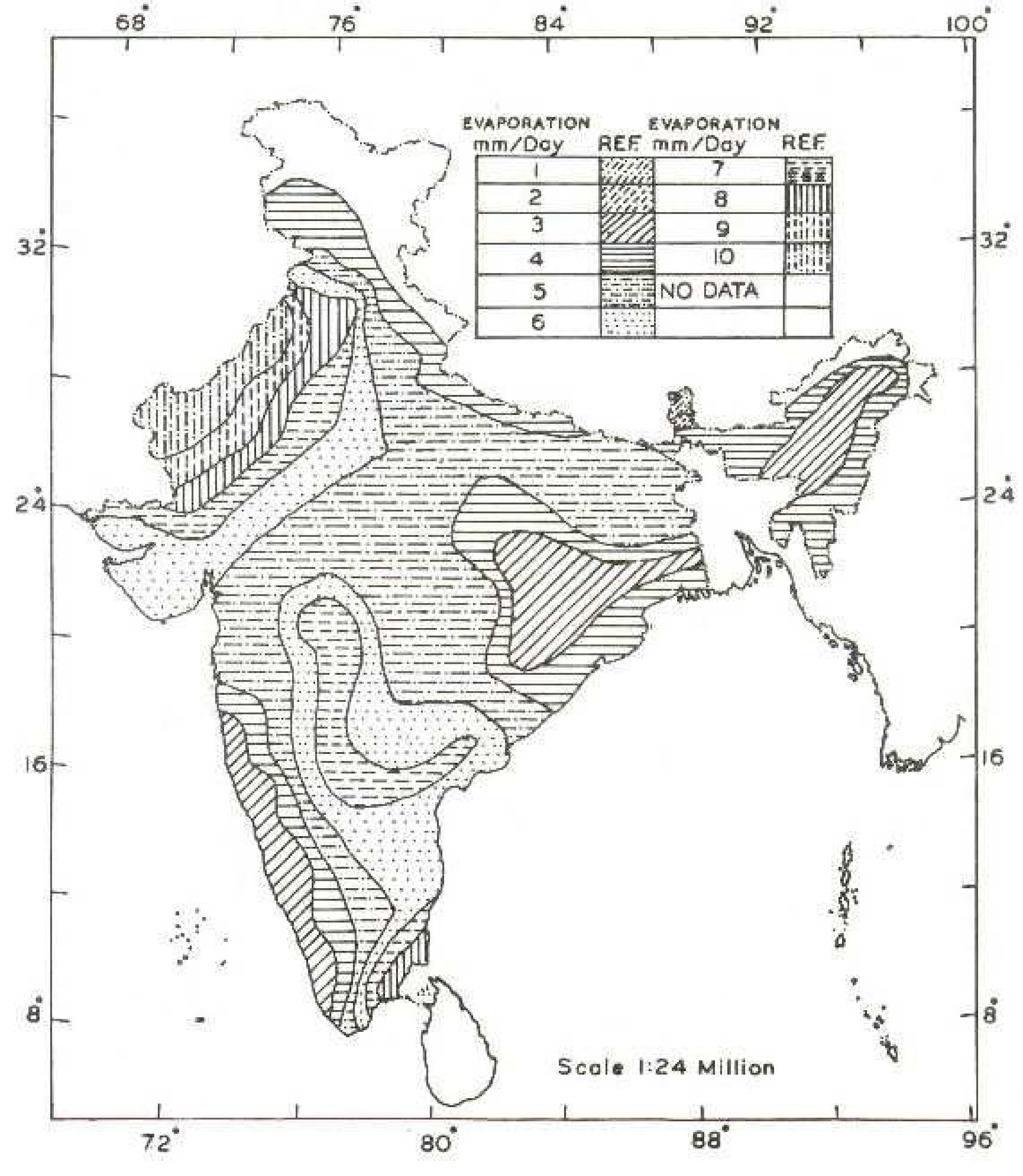


Fig- 5.8 Mean Daily Evaporation (mm) for July month

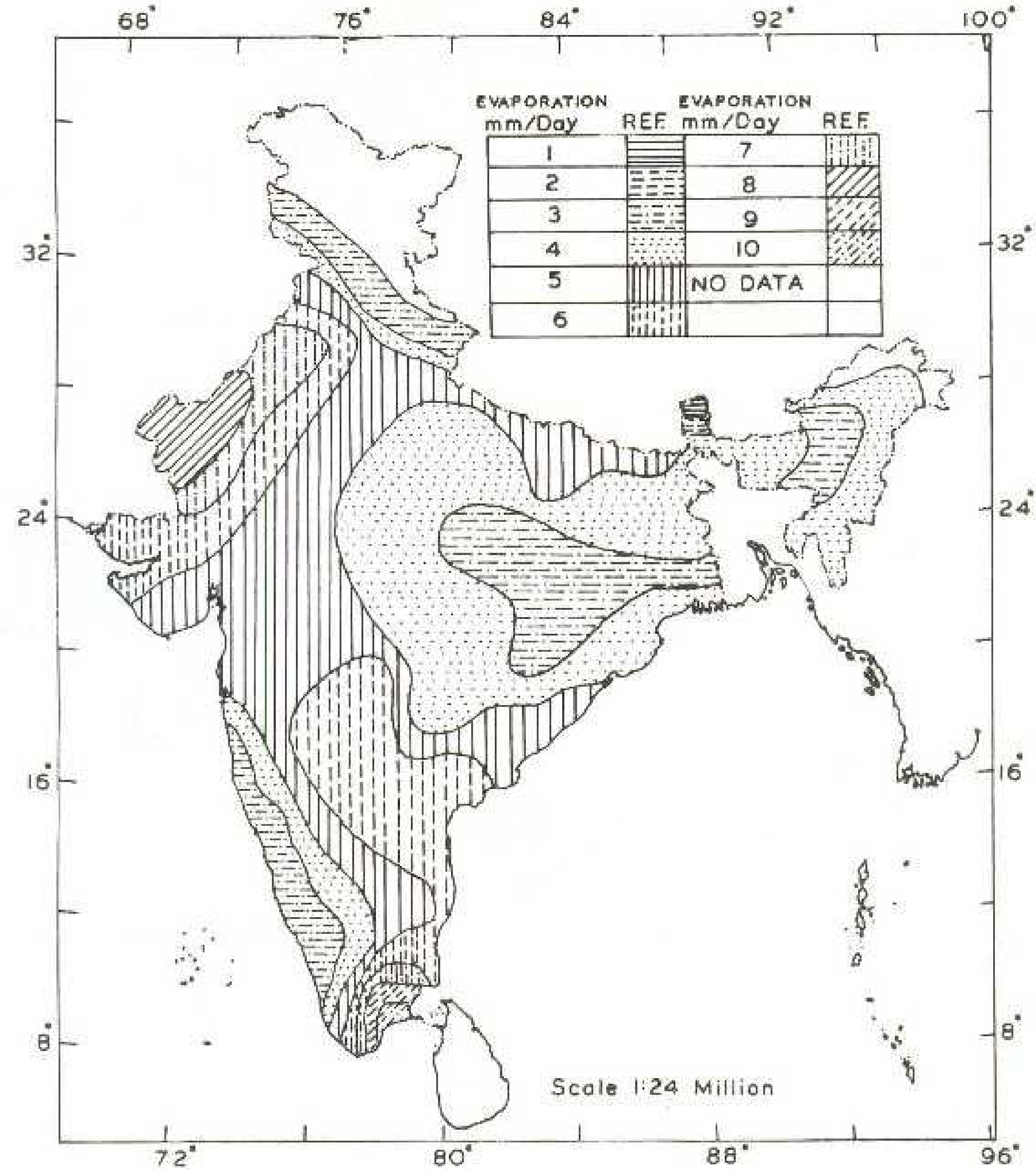


Fig- 5.9 Mean Daily Evaporation (mm) for August month

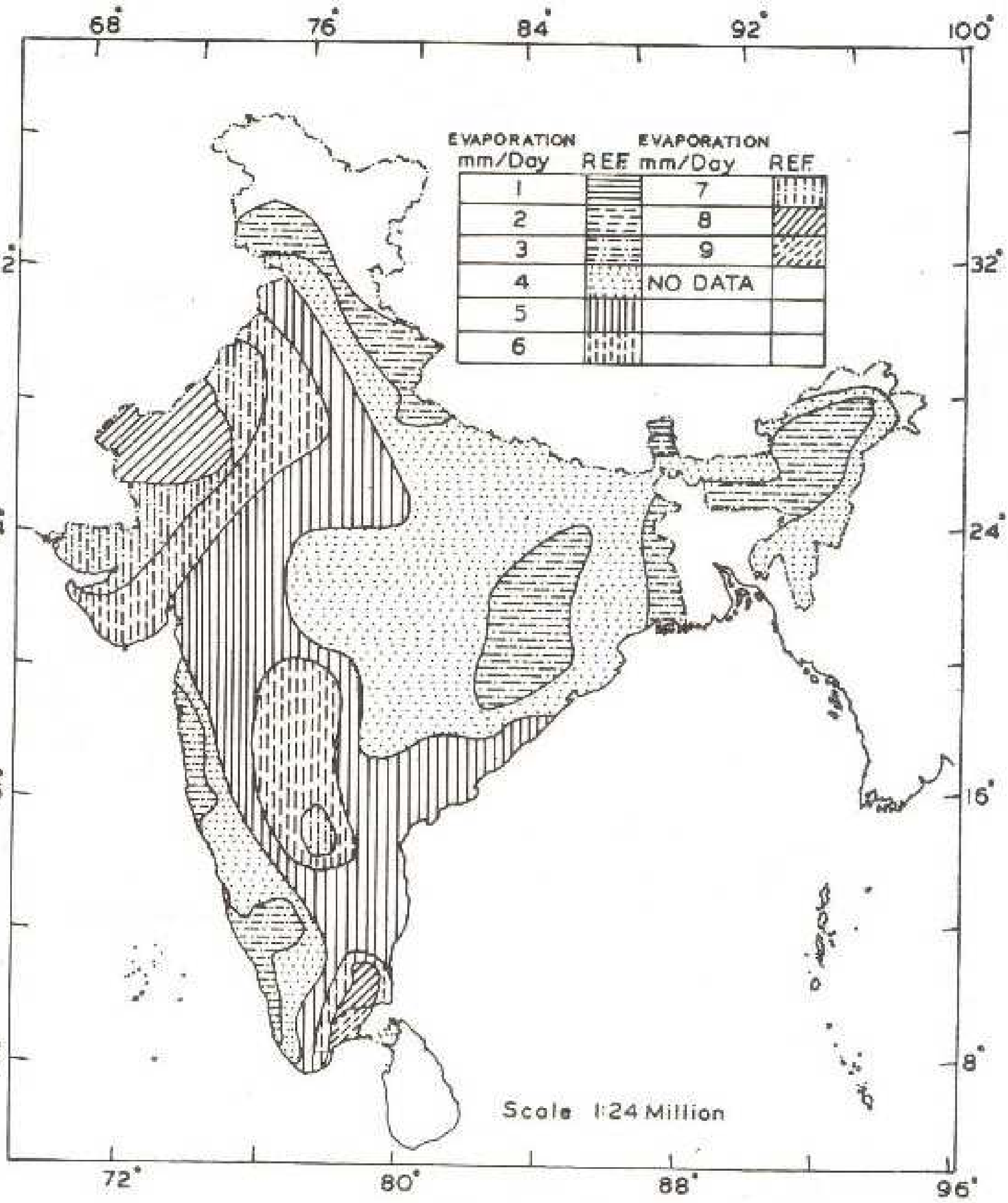


Fig- 5.10 Mean Daily Evaporation (mm) for September month

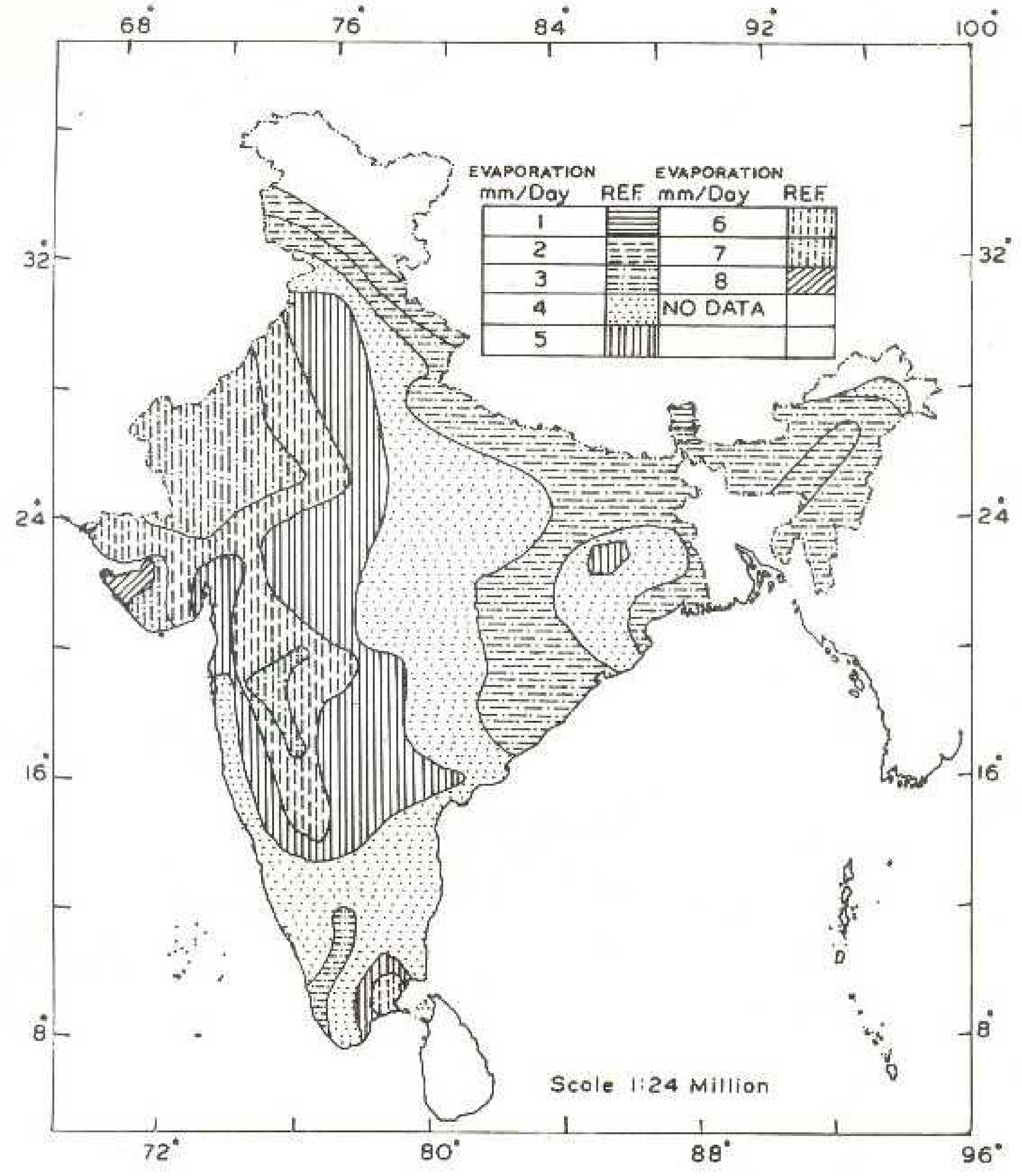


Fig- 5.11 Mean Daily Evaporation (mm) for October month

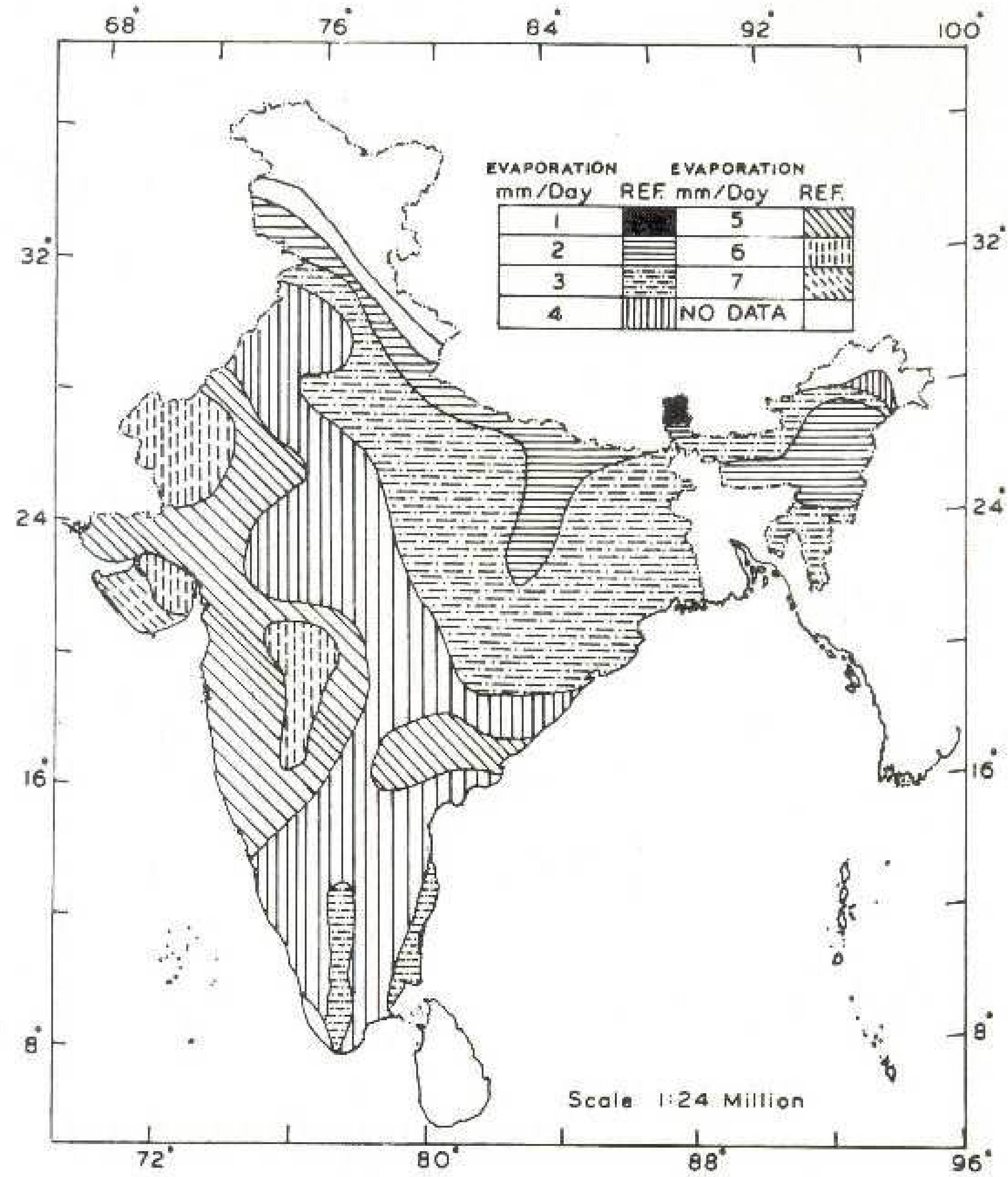


Fig- 5.12 Mean Daily Evaporation (mm) for November month

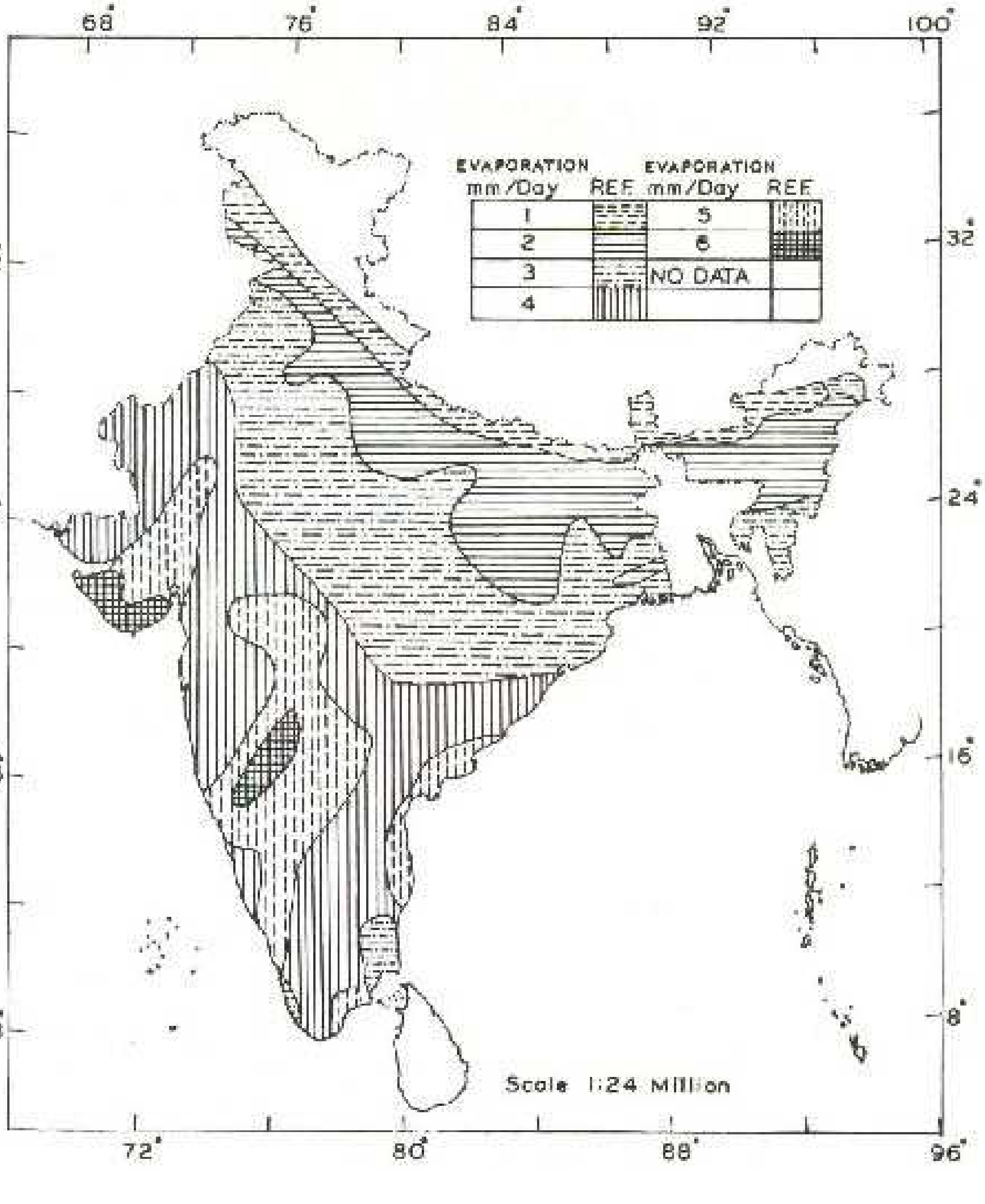


Fig- 5.13 Mean Daily Evaporation (mm) for December month

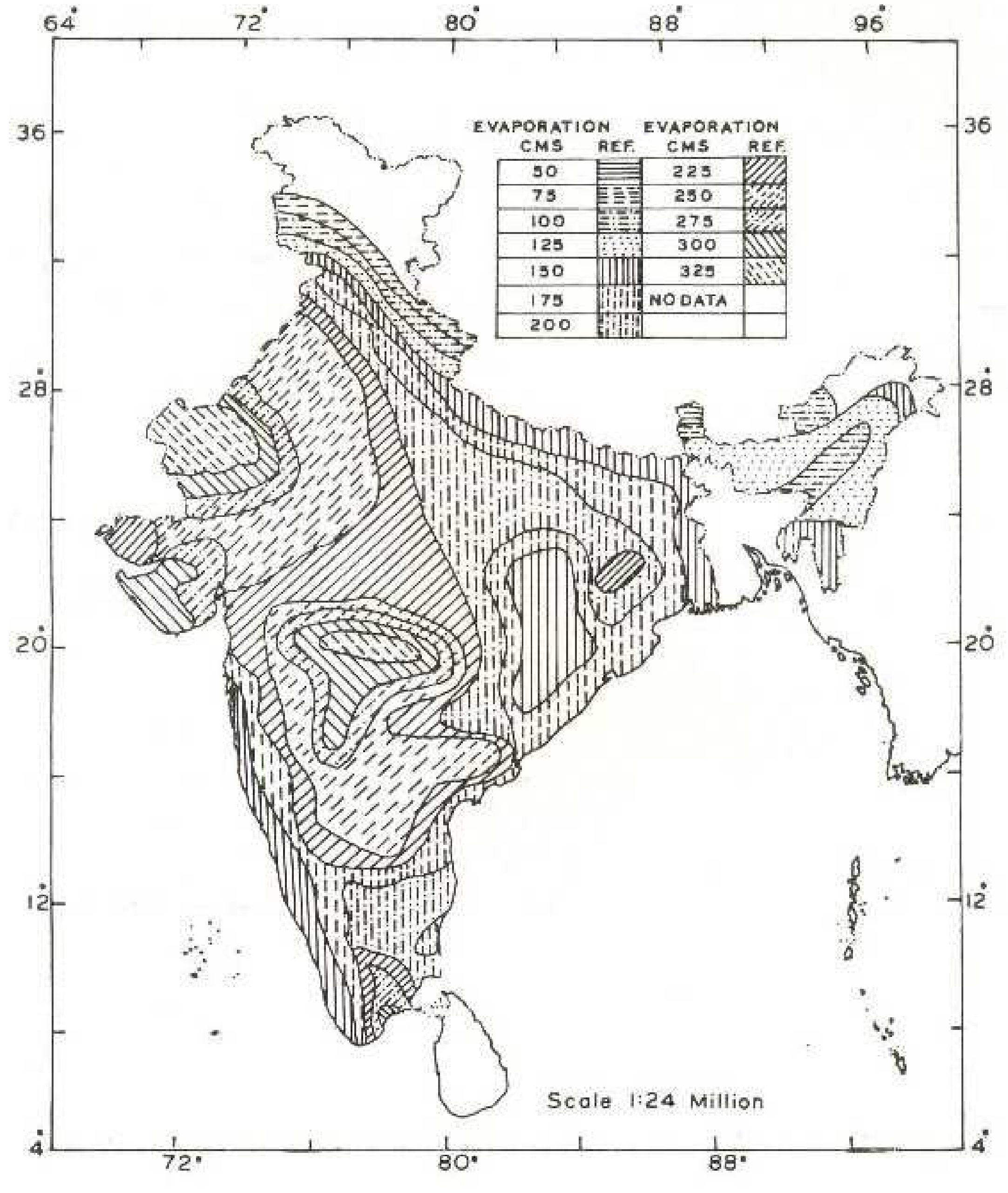


Fig- 5.14 Average Annual Evaporation (cm) in India

6.0 METHODS TO REDUCE EVAPORATION

Although evaporation losses in the country are quite substantial, the evaporation retardant methods perhaps cannot be employed to all open surface water bodies, irrespective of their size and shape. In view of this, water conservation management by control of evaporation has so far been limited generally to drought prone and scarcity areas under specified wind speed and temperature conditions of the water bodies.

The methods of evaporation control can be grouped under two broad categories :

(i) Short term measures and
(ii) Long term measures.

A number of approaches have either been applied or considered by Engineers and Scientists in their attempt to reduce evaporation losses from surface of water bodies. Since the basic meteorological factors affecting evaporation cannot be controlled under normal conditions, efforts have so far been restricted to managing the suppression or inhibition of evaporation from water surfaces by physical or chemical means. The methods generally used or being tried are broadly listed below:

i) wind breakers
ii) covering the water surface
iii) reduction of exposed water surface
iv) underground storage of water
v) integrated operation of reservoirs
vi) treatment with chemical Water Evapo Retardants (WER).

6.1 Wind Breakers

Wind is one of the most important factors which affect rate of evaporation loss from water surface. The greater the movement of air over the water surface, greater is the evaporation loss. Planting of trees normal to windward direction is found to be an effective measure for checking of evaporation loss. Plants (trees, shrubs or grass) should be grown around the rim of tanks in a row or rows to act as wind breaker. These wind breakers are found to influence the temperature, atmospheric humidity, soil moisture, evaporation and transpiration of the area protected.

Plants to act as wind breakers are usually arranged in rows, with tallest plants in the middle and the smallest along the end rows, so that more or less conical formation is formed.

Trees grown as wind breakers are constantly subjected to usual stress of wind, temperature, moisture, evaporation, insects and diseases. Thus, plants selected as wind breakers should be capable of resisting these stresses. The list of vegetation recommended by Indian Council for Agricultural Research, New Delhi (Technical Bulletin No. 22) for planting as wind breakers in different regions of India is given in Table 6.1. The spacing between plants varies from place to place, depending upon the climate and type of soil.

In general, the following spacings are recommended:

a) Shrubs	0.60 to 1.00 m
b) Medium height broad leaved trees	1.50 to 2.00 m
c) Medium to tall evergreen trees	2.10 to 2.40 m
d) Tall broad leaved trees with conical crown	2.40 to 3.00 m

Spacing of plants at 3 m is found to have little effect in reduction of wind velocity over the protected area.

TABLE 6.1 Recommended Tree, Shrub And Grass Species For Different Regions Of India

Northern Region (plains of Punjab, Haryana, UP, Delhi and parts of Gujarat and M.P.)

Botanical Names	**Vernacular Names**	**Habit**
Acacia nilotica	Babool	T
A. Jacquemontii	Bouli	ST
Albizia lebbeck	Kala siris	T .
Aroundo donax	Baranal	S
Agave americana	Grit kumari	S
Capparis decidua	Kair	S
Dalbergia sissoo	Shisham	T
Euphorbia royleana	Thar	S
Impomoea crassicaulis	Besharam	S
Jatropha curcas	Ratan jyoti	S
Lawsonia inermis	Mehandi	S
Parlinsonia aculeata	Vilayati keekar	ST
Saccharum bengnalensis	Munj	G
Syzygiu cumini	Jamun	I
Sesbania sesban	Jayanti	S
Tecoma stans	Sonnapatti	S
Tamarix aphylla	Farash or Jhau	T
Thevetia peruviana	Kaner	S
Vitex negundo	Nirgandi	S
Ziziphus nummularia	Ber	S

Central Region (Parts of Gujarat, MP, Andhra Pradesh and Maharashtra)

Acacia nilotica	Babool	T
A. Catechu	Khair	T
Agave sislana	Grit kumari	S
Boswellia serrata	Salai	T
Cassia siamea	Siamea	T
Dalbergia latifolia	Sitsal	T
Gliricida maculata	Madre	ST
Hardwickia binata	Anjan	T
Jatropha curcas	Ratan jyoti	S
Leucaena leucocephola	Ipil-ipil	ST
Melia azadirachta	Bakain	T
Pithecellobium dulcis	Jangal jalebi	ST
Pongamia pinnata	Karanj	T
Ricinus communis	Arand	ST
Sesbania grandiflora	Basna	ST

Southern Region (Chennai, parts of Andhra Pradesh, Mysore and Kerala)

Acacia nilotica	Babool	T
A. Auriculiformis	Wattle	T
A. Decurrens	Blackwattle	T
Agave sp.	Grit kumari	S
Anacardium occidentale	Kolamavu	T
Albizia lebbeck	Magei	T
Bambusa sp.	Mungli	G
Borassus flabellifer	Panei	T
Casuarina equisitifolia	Chauku	T
Erythrina spp.	Mulu moduyu	T
Eucalyptus spp.	Eucalyptus	T
Gliricida maculata	—	ST
Grevillea robusta	Silveroak	ST
Jatropha curcas	Nepalam	S
Pueraria javanica	—	S
Sesbania sesban	Chittikatti	S
S. Bispinosa	Jayanti	S
Telphrosia candida	Lashtia	S

Eastern Region (W. Bengal, Assam, Orissa and Bihar)
(a) inland areas

Acacia catechu	Khair	T
Agave sislana	Kantala	S
Anacardium occidentale	Kaju	T
Artoarphus heterophyllus	Kathal	T
Arundo donax	Gaba nal	S
Bambusa sp.	Bans	G
Borassus flabellifer	Tal	T
Casuarina equisetifolia	Janguli saru	T
Cocos-nucifera	Narial	T
Dalbergia sissoo	Shisham	T
Imperata cylindrica	Ulu	G
Lannea caromandelica	Jhingal	T
Musa paradisiaca	Kela	ST
Syzygium cumini	Jamun	ST
Tephrosia candida	Lashtia	S
Vitex negundo	Nirgandi	S

(b) Coastal areas

Acacia auricuiformes	Sonejhur	T
Anacardium occidentale	Kaju	T
Borassus flabellifer	Tar	T
Casuarina equisitifolia	Janglisaru	T .
Cocos nucifera	Narial	T
Delonix elata	Gulmohar	T
Erythrina indica	Polita mandas	T
Buphurbia tirucalli	Sehund	S
Bicus spp.	Gad gubar	T
Indiqofera aspalathoides	Sivanimba	S
Ipomoea biloba	Natilata	T
Pongamia pinnata	Karanj	T
Prosopis juliflora	Vilayati babool	T
Inifex littorcus	Rawn moonch	G
Tamarix aphyila	Farash	T
Thespsia populnea	Paras pipal	S

Arid-Region
(Western Rajasthan, Part of Andhra Pradesh and Mysore)

Acacia nilotica	Babool	T
A. Leucophloea	Reonja	T
A. Planifrons	Godugh thumba	T
A. Senegal	Kummet	T
A. Tortilis	Israeli babool	T
Balanites aegyptiaca	Hingot	S'T
Calligonurn polygonoides	Phog	S
Capparis decidua	Kair	S
Clerodendrum phlomoides	Arni	S
Saccharum munja	Munj	G
Eucalyptus camaldulensis	Eucalyptus	T
Euphoribia caducifolia	Thor	S
Lasiurus sindicus	Sewan	G
Panicum turgidum	Murat	G
Tamarix aphyilla	Farash	T
Zizyphus numrnularia	Jharber	S

T = Tree, ST = Small Tree, S = Shrub, G = Grass
Source : Technical Bulletin (AGRIC) No. 22, ICAR, New Delhi (1969) by J.K. Ganguly and R.N. Kaul.

Some scientists had also advocated use of synthetic polytrees and poly shrubs in place of vegetative trees, keeping in view the vast availability and economy of this product in the country. According to them these synthetic plants can be raised as barriers against the hazardous wind in minimum possible time, particularly in arid areas, where it is otherwise difficult to grow vegetation. However, no experimental data to substantiate the effectiveness of these synthetic plants and its economy in conservation of water is available.

Wind breakers are found to be useful under limited conditions for small reservoirs. In large reservoirs, wind breakers are not effective, as their effect is limited to a short distance from the rim of the reservoir, thereby exposing the inner water spread area to the hazards of wind. Another disadvantage of this method is that large quantity of water can be lost due to transpiration by the trees planted. Considering these effects, the wind breakers are commonly employed for specific high wind locations. In such locations, chemical method of evapo-retardation may not be feasible as the monolayers of Water Evapo Retardants (WER) are found to break at wind velocities from 10-16 km. per hour.

6.2 Covering the Water Surface

By Covering the surface of water bodies with fixed or floating covers considerably retards evaporation loss. These covers reflect energy inputs from atmosphere, as a result of which evaporation loss is reduced. The covers literally trap the air and prevent transfer of water vapour to outer atmosphere.

Fixed covers are suitable only for relatively small storages. For large storages, floating covers or mat or spheres may be useful and effective. However, for large water surfaces the cost of covering the surface with floats is prohibitive. Further in case of reservoirs with flood outlets, there is also the danger of floats being lost over spillway or through outlets. The floating covers are thus of limited utility to larger water bodies.

Genet and Rohner had reported that floating spheres of a polystyrol reduced evaporation to 80% in small experimental tanks. The white spheres have the added advantage of reflecting solar energy and thus influencing evaporation.

Department of Soil and Water Conservation Engineering, College of Technology and Agriculture Engineering, Rajasthan Agriculture University has done experiments with other floating bodies as vegetable oils, wax, wheat husk, paddy husk, wooden blocks, saw dust and thermocol boards. According to these studies, conducted for a limited period of 15 days, the most effective evapo-retardant is mustard oil, which resulted in 46% saving in water. The next in the order of effectiveness was found to be thermocol, followed by wax, Paddy straw, wheat straw, saw dust and wooden blocks were found to have less effect on reducing the evaporation. However, mass scale and economic use of these materials were not recommended, till conclusive results providing their economics and utility are available, based on some more experiments under varying conditions and on varying sizes of water bodies.

6.3 Reduction of Exposed Water Surface

In this method shallow portions of the reservoirs are isolated or curtailed by construction of dykes or bunds at suitable locations. Water accumulated during the monsoon season in such shallow portions is diverted or pumped to appropriate deeper pocket in summer months, so that the shallow water surface area exposed to evaporation is effectively reduced. This method is one of the recognized methods of conservation in drought areas and has been successfully tried for lake Worth in Texas, USA. In India, this method has been tried for Nayka reservoir, supplying water to Surendranagar in Gujarat, which yielded good results. The compartmentalisation work in the lakes supplying water to Chennai city has indicated that this method is more economical and effective than chemical WER method.

6.4 Underground Storage

This is a radically different approach for control of evaporation losses, which comprises storage of water in underground cavities or aquifers. This can certainly be done with great advantage in specific cases, where aquifers for such storages are available and do not entail higher lateral dispersion losses. Sub-surface dams can also be constructed in such schemes to prepare limited aquifers and thereby raise the level of storage, reducing subsequent pumping. Sub-surface dams or underground check dams have been constructed in Maharashtra, Andhra Pradesh, Gujarat and some other States across streams or rivulets in water deficient areas to hold groundwater and recharge the adjoining limited aquifers. They can be of masonry on rolled imperious fill depending on the rocky or alluvial strata. Problems of water supply by raising of groundwater, thus have been mitigated for many settlements. One outstanding application of this method was recharge of the aquifer adjoining Talaji rivulet near the town of Talaja in Bhavnagar District of Gujarat where significant water level rise was registered, after the limited monsoon. The main advantage of this method is that loss of valuable lands and forest areas due to surface submergence can be altogether avoided. The method has a great future all over India in view of the environmental advantage.

6.5 Integrated Operation of Reservoirs

This method is suitable for a system of reservoirs which can be operated in an integrated way. The method consists of operating the reservoirs in such a way that total exposed water surface area is kept minimum for the system as a whole. Consequently evaporation loss gets minimized. For achieving this objective water use should be planned in such a way that shallow reservoirs with large water spread area are depleted first. This method has been successfully practiced by Mumbai Municipal Corporation in their water supply scheme. Such techniques were also tried in the Hiran dam 1 & 2 in Junagarh district of Saurashtra region of Gujarat. The Chennai Metropolitan Water Supply and Sewerage Board has also been practicing integrated operation of Red Hills, Cholavaram and Poondi reservoirs, which supply water to Chennai City, so that the exposed water surface is kept minimum.

6.6 Treatment with Chemical Water Evapo-Retarders (WER)

Chemicals capable of forming a thin mono-molecular film have been found to be effective for reducing evaporation loss from water surface. The film so formed reflects energy inputs from atmosphere, as a result of which evaporation loss is reduced. The film allows enough passage of air through it and hence, aquatic life is not affected. The film developed by using fatty alcohols of different grades has been found most useful for control of evaporation. These materials form a film of mono-molecular layer when applied on water surface which works as a barrier between water body and the atmospheric conditions. These fatty alcohols used for evaporation control are generally termed as chemical water evapo-retardants (WERs) and these are available in the form of powder, solution or emulsion.

These chemical water evapo-retardants have the disadvantage of high cost of application. However, when adopted in scarcity period, drought, etc. the quantity of water saved by this method would work out cheaper than alternate means of bringing water from far off places by manual or mechanical transport. The economics of WERs application may however vary from site to site depending on local factors. The chemical water evapo-retardants have another limitation of the mono-layer breaking at high wind velocities. Following chemicals are generally used for water evaporation retardation:

- Cetyl Alcohol (Hexadecanol) $C_{16}H_{33}OH$
- Stearyl Alcohol (Octadecanol) $C_{18}H_{37}OH$
- Ethoxylated Alcohols and Linear Alcohols
- Linoxyd CS-40
- Acilol TA 1618 (Cetyl Stearyl Alcohol)

6.7 Short Term Measures

Short-term measures are employed in the drought and scarcity conditions especially for crisis management. Since these are cost prohibitive, the use of chemical retardants can be restricted to crisis management to tide over the periodic and acute shortages of water when even drinking water may not be adequately available. This method, however, is not cost effective for mass scale use. This method is also not suitable under following conditions :

(i) When the wind velocities are more than 10-16 km/hr.

(ii) When the temperature rises above 40-42^{o} C.

(iii) The size of reservoir/ water body is relatively large.

Fatty alcohols can be used for the purpose having following properties :

(i) The chemical selected should have cohesive property which can maintain the monolayer on the surface of the body irrespective of the effect of wind. Even if the layer is broken due to occasional high wind velocities, the material should have the property of reuniting and forming the layer.

(ii) The chemical selected for use should have no effect on the quality of water , especially no toxic effect on aquatic and human life.

(iii) The chemical should also be such that the film should allow enough passage of air through it so that the aquatic life is not affected.

6.7.1 Merits of Chemical WERs

Use of evaporation control techniques requires a small capital investment. Locally constructed rafts can be used in its application, and skilled labour is not required, except for operation of motorized boats. Fatty alcohols cause no hazards in handling, and are non-inflammable, non-toxic, and non-irritating. There perhaps may be no known harmful effects, making this technology safe for application on drinking water lakes and reservoirs. There are also no known ecological ramifications, as the alcohols contain straight chain carbon compounds, which are biodegradable and permeable to oxygen.

6.7.2 Demerits of Chemical WERs

The fatty alcohols used as WERs are not readily available and are costly. Historically, fatty alcohols were produced only by sperm whales or by sodium reduction of animal oils and fats. It was only after the development of high-pressure hydrogenation process that good quality fatty alcohols are now commercially available. However, this is a very advanced technology, and requires trained and skilled staff to operate.

The other short-term method for control of evaporation is by covering the water surface for protection against rise in temperature of water surface and effects of air currents. This method cannot, however, be employed on large storage bodies. The use of plastic floating materials has been found to be quite effective and useful, although this method is also cost prohibitive. Floating spheres of poly-steryl can be effectively employed. White colour spheres have the added advantage of reflecting solar energy, thus reducing the evaporation in a more effective manner. Floating covers constructed of low density (110-130 kg/m^3) closed cell synthetic rubber sheeting (EFDM) can also be used. The covers can be fabricated from 6.4 mm thick sheeting bonded together with contact adhesive. The life of such covers may be around 8 years, if the material and methodology as adopted by Dean (1930) and Dedrick (1976) is used. The size of covers should be slightly larger to accommodate shrinkage. These methods can be used to cover water storage tanks. The other floating materials tried are wheat husk, paddy husk, wooden blocks, thermocol boards etc. Thermocol board has been found to be more effective than straw, dust and wooden blocks. However, mass scale use of these materials is not recommended till results providing their economic and utility are available.

6.8 Long Term Measures

Although some long-term measures like wind breakers, reduction of exposed water surface, storing water in underground storages etc. have been employed in some or the other parts of the country, their economics and long term utility effectiveness have yet to be established. Nevertheless, these methods are in use and continue to be employed reportedly with some success.

Reduction of exposed water surface: This method is useful if some shallow portions in reservoirs are available, which can be isolated by constructing dykes and water diverted or pumped to the deeper pockets so that the exposed surface is effectively reduced. This is a recognized method of evaporation control for water conservation management in drought areas. The reduction in exposed water surface can also be achieved with integrated operation of reservoirs. In this case the reduction is achieved by storage management in reservoirs, so that shallow reservoirs are utilized first and deeper reservoirs later.

Underground storages of water: The water can be stored underground in cavities and aquifers, where available, which do not entail higher lateral dispersion losses. This method has the advantage of saving valuable lands on the ground, since there is no surface submergence involved. However, areas where this method can be employed will need to be identified by geological investigations prior to resorting to this method. The advantage of this method is that the surface water can be used as and when required. However, the disadvantage is that the water needs to be pumped for use, which entails additional pumping costs and energy consumption. This method may therefore be suitable only when the economics of valuable land saved compares well with additional expenditure on pumping and energy is generally available.

Wind breakers: This method can also be employed only in small reservoirs/ water bodies. In involves planting of trees normally to wind ward direction around rim of tank in a row or a number of rows. These wind breakers greatly influence/ reduce the temperature, humidity, soil moisture, evaporation and transpiration of the area protected. The plants to serve as windbreaker are to be arranged in such a way that the tallest form the middle rows and the smallest the end rows, so that more or less a conical section is formed. The types of trees, shrubs and grass for planting as recommended by ICAR need to be used to serve as wind breakers. The spacing between the trees varies from place to place depending upon the climate and type of the soil. The most commonly followed spacing is indicated below:

Shrubs	0.60 m to 1.00 m
Medium height broad leaved trees	1.50 m to 2.00 m
Medium to tall evergreen trees	2.10 m to 2.40 m
Conical crown	2.40 m to 3.00 m

Spacing of 3 m and above is reportedly found to have little effect on overall wind velocity of the protected areas.

7.0 CASE STUDIES OF EVAPORATION RETARDATION–MEASURES IN INDIA

7.1 Chemical Water Evaporation Retarders (WER)

Experiments using various chemical Water Evapo Retardants (WER) were in practice all over the world from the year 1957 onwards. A review of these studies shows a variation of percentage of savings in evaporation loss from as low as 8% for a long duration study to as high as 64% for short duration period (Table 7.1).

In India also, many leading research stations and State Govt. agencies were engaged in conducting laboratory and field experiments in controlling evaporation from water bodies. The agencies which have contributed significantly in experimentation of evaporation control and the salient features of the work carried out by them are enumerated in the following paragraphs and also abstracted in Table 7.13

7.1.1 Irrigation Development Division, Mumbai

This Division is one of the first few premier organizations in India to carry out investigations during end of 1957 with Cetyl alcohol. The experiments were carried out in Kasurdi Tank (capacity 0.42 MCM) and Bhandgaon Tank (capacity 0.32 MCM) both situated near Pune. Cetyl alcohol was used for evaporation suppression studies and was dispensed on water surface in a powder form by a hand-operated duster, mounted on a boat. A quantity of 0.91 kg of Cetyl alcohol was spread in four rows in each of the two tanks covering the entire area of the tanks. The following data were collected during the field experiments:

i) water level of the tank
ii) inflow into the tank
iii) outflow by way of seepage and for irrigation
iv) evaporation with and without Cetyl alcohol from pan evaporimeter of 3m dia kept by the side of the tank and
v) wind velocity, air and water temperature in different periods of the day.

The saving in water due to the application of Cetyl alcohol was found as 30% in Bhandgaon Tank and 14% in Kasurdi Tank.

TABLE 7.1 : Evaporation retardation work carried out in foreign countries

SI. No	Location	Organisation	Duration of the work	Chemical used	% Saving in evaporation	Reference/ Publication	Basis for results
1.	Lake Hefner, Oklahoma City, USA	Reported by NEERI, Nagpur	1958 (Summer)	Hexadecanol (emulsion form)	9	Evaporation control as a measure of conservation of water by S.R. Kshirsagar, presented at the 15th Annual convention of IWWA.	Results computed on the basis of energy balance approach combined with mass transfer theory.
2.	Field trials in . 274 cm diameter outdoor steel tanks, USA.	ASCE, USA	March 63	Alkanol	30	Stable Alkanol Dispersion to reduce evaporation by Gary W. Frasier et al, Jrnl. of Irrigation and Drainage Division, ASCE, March, 1968.	Tank data (1% alkanol concentration)
3.	— do—	— do—	March 64 (7 days)	— do—	64	— do—	— do—
4.	—do—	— do—	Sep. 66 (30 days)	Alkanol dispersion	26	—do—	— do— (3% alkanol concentration)
5.	—do—	— do—	Feb. 67 (7 days)	— do—	28	— do—	Tank data (1% alkanol concentration)
6.	—do—	ASCE, USA	March 67 (10 days)	—do-	27	--do—	—do—

7.	— do—	— do—	March 67 (10 days)	Powdered alkanol	15	—do-	—do—
8.	Boulder Basin in Lake Mead, USA	USBE Denver, USA	June to Sept. (4 months) year not known	Ethoxylated Alcohols and Linear Alcohols.	8-20	Evaluation by the bureau of Reclamation's Evaporation Reduction Research Program by Darid C. Bomberger & Paul V. Roberts, A revision of final report - March 1970 Revised October 1980.	Wind speeds used in the calculation exceeded 9 MPH in 50% of the time.
9.	—do-	—do-	All year application	—do—	18-41	—do-	Wind speeds exceeded 15 MPH in 70% of the time.

7.1.2 Central Soil & Materials Research Station, New Delhi

This Research Station, earlier known as Central Soil Mechanics and Concrete Research Station had conducted studies with chemical WER for a period about eight years from 1958 to 1966 on Badkhal Tank, Haryana; Takhat Sagar Maota and Sagar tanks, Rajasthan and Mir Alam tank, A.P. The chemicals used were mostly Cetyl or Cetyl Stearyl alcohol and were dispense in the solution or emulsion form. As a trial, powder form of WER was also used. Mineral turpentine as a solvent and indicator oils having film pressure in the range of 11 to 40 dyne/cm were used. A film pressure of 24 dyne/cm is reported to have been maintained at these sites. Meteorological observations like temperature, wind direction, wind velocity were regularly observed during the studies. A contour survey of the tanks was also undertaken to know the quantity of stored water. Besides, gauges were fixed in different parts of the tank to record water level. Pan evaporimeters were also installed at the site.

The details of water spread area, period of study, methodology of application and percentage evaporation reduction achieved in each study are given in Table 7.2.

TABLE 7.2 Studies conducted by Central Soil and Materials Research Station, New Delhi

S. No	Name of Reservoir	Average water spread area in ha.	Period of study	Method of Application	Evaporation Reduction Percentage	Retardant used per ha. per month in Kg
1	2	3	4	5	6	7
1.	Badkhal Tank, Faridabad, Haryana	50.59	Nov. 58 - June 59	Solution with mineral turpentine	37.8	0.34
2.	— do—	25.90	Nov. 58 - June 59	—do—	21.0	0.82
3.	— do—	46.95	Nov. 61 - June 62	Emulsion with water	32.4	2.0
4.	— do—	30.35	Nov. 62 - April 63	Solution with mineral turpentine	30.0	0.75
5.	Mir Alam Tank, Hyderabad, A. P.	145.69	Mar. 64-- May 64	—do—	41.3	0.39
6.	Takhat SagarTank, Jodhpur, Rajasthan	43.31	June 64 - Oct. 64	Emulsion with water	48.2	1.30
7-	Maota & Sagar Tank, Jaipur Rajasthan.	10.12	April 65 - Dec. 65	—do—	---	2.70

The inference drawn from these studies were as under:-

i) evaporation reduction achieved was in the range of 21 to 48%
ii) an effective film pressure of 24 dyne/cm can be achieved at a lower cost in the solution form as compared to emulsion form.
iii) Cetyl Stearyl alcohol is harmless to aquatic and plant life.

7.1.3 Institute of Hydraulics and Hydrology, Poondi, Chennai

The studies on evaporation control with chemical WER were conducted from 1959 to 1965 in Buderi tank situated near the institute. The tank had a water spread area of about 11.34 ha and depth of 3.66 metres. There were no withdrawals from this tank for irrigation or for other purposes. The inflows into the tank were only from monsoon rains. Regular meteorological observations and pan evaporimeters studies were conducted at the location of study. Cetyl Stearyl alcohol was used for the study. Cetyl Stearyl alcohol was applied on water surface at the rate of 0.05 kg to 0.25 kg in the form of solution and emulsion and at the rate of 0.36 kg in the powder form. Applications were made during the daylight hours for short periods ranging from 7 to 10 days.

Film pressure was tested by indicator oils of standard strength. It was maintained at 40 dyne/cm, which is the equilibrium value at which the film was found to offer maximum resistance to the escape of water molecules.

The inference drawn on the basis of the study were:

i) From economic considerations and facility of operation, application in the form of emulsion appeared to be the best, under local conditions.
ii) Layer is found to break due to wind velocity above 8-16 km per hour and also due the presence of bacteria and protein in water.
iii) The efficiency of the layer decreases with increase in temperature
iv) The saving in water was to the tune of 20%

7.1.4 Karnataka Engineering Research Station, Krishnaraja Sagar

This Research Station, then known as Mysore Engineering Research Station, had conducted evaporation control studies on field and semifield scales in four tanks during 1962. The salient features of these tanks and the details of the studies conducted are given in Table 7.3. The studies conducted in each tank are discussed below:

TABLE 7.3 Details of Studies Conducted by Karnataka Engineering Research Station, Krishnaraja Sagar

S. No	Name of Reservoir	Average water spread area in Ha	Maximum depth in m	Meteorological observations	Method of application	Surface film pressure maintained
1.	Kukkarahalli Tank, Mysore.	66.77	10.67	Temperature, wind direction, its velocity & rainfall	Solution, emulsion & powder form	24-40 dyne/cm
2.	VarunaTank, Mysore.	69.61	3.66	—do—	—do—	—do—
3.	Kadavinahosahalli Tank,, Hassan Distt. Karnataka	0.4	—do—	—do—	Emulsion & solution form	40 dyne/cm
4.	Lingambudhi Tank, Mysore.	67.99	5.61	—do—	Solution, emulsion & powder form	—do—

a) **Kukkarahalli Tank :** This tank had a limited catchment and the main source of water supply to the tank was from a feeder channel and had two draw-off points. Cetyl alcohol was mainly used as evaporation retardant. Water level recording was done by means of Hook-Gauge. Contour survey was done as and when the water level got depleted. Seepage meters were also used to measure seepage losses. Cetyl alcohol in the solution form was dispensed either by the shore dispenser or by raft dispenser. Semi-field studies using pan evaporimeters were also done. The studies indicated saving in evaporation loss varying from 5.7 to 24%.

b) **Varuna Tank:** The methodology adopted for studies in this tank is similar to the methodology adopted for Kukkarahalli Tank. Semi-field studies using CS pan evaporimeter deploying all the 3 methods (emulsion, solution and powder form) at various film pressure were undertaken. It was observed that an appreciable savings could be achieved by an increase in surface film pressure using solution and emulsion techniques. The saving in water achieved was found to be varying from 8.9 to 36.91%.

c) **Kadavinahosahalli Tank:** The studies done in this tank are similar to Kukkarhalli Tank. Cetyl alcohol was spread both in emulsion and solution form. It was observed that the factors such as concentration of the retardant, temperature, rate of spreading and rate of evaporation have an important role to play in maintaining the optimum surface pressure of 40 dyne/cm. Emulsion technique was found to be more economical than the solution technique.

d) **Lingambudhi Tank :** Field and semi-field studies using all the three techniques are reported to have been conducted. Studies on correlation of evaporation observed in different evaporimeters namely Piche Evaporimeters, CS Pan, USWB Land Pan and two floating pans have also been reported. The percentage of saving in evaporation loss varied from 8.50 to 35.24%.

The inferences drawn from the study were:-

i) The quantity of chemical required to maintain a surface pressure of 40 dyne/cm would be much more than to maintain 16 dyne/cm, but the cost of additional chemical is offset by the increase in the quantity of water saved.

ii) Percentage saving is nearly the same at 40 dyne/cm by either of the techniques namely solution or emulsion.

iii) For corresponding concentrations of the chemical, emulsion techniques is found to be more effective than solution technique. The percentage of savings ranges from 9.5% to 28% in case of emulsion,19% to 34% in case of solution and 8.5% to 35% in case of powder.

iv) Optimum surface pressure of 40 dyne/cm lead to maximum evaporation reduction

7.1.5 Central Public Health Engineering Institute, Nagpur

This Institute had conducted studies on three lakes namely Walwhan, Vihar and Gorawara as per suggestions from Australian experts and guidance from C.S.I.R. in the mid-sixties. The Walwhan Lake had a water spread area of 0.22 Sq.Km.. at FRL Meteorological data such as maximum and minimum temperature, wind direction, wind velocity, rainfall were reported to have been recorded daily at fixed interval of time. Besides, gauges were fixed in different parts of the tank.

Cetyl alcohol as evaporation retardant and indicator oils from M/s Shell Company having surface pressure in the range of 16-40 dyne/cm were used. While the Cetyl alcohol was dispensed in the form of emulsion in the Walwhan and Vihar lakes, powder technique was used in the Gorawara Tank. The powder was dispensed by means of a duster fitted on the boat.

The inflow and outflow characteristics of the lakes were regularly recorded by measuring the water level differences.

Inferences drawn from the studies are given below:

i) The chemical required ranged between 0.02 to 0.05 kg/hectare/day to maintain the film pressure of 21 dyne/cm in Walwhan and Vihar lakes, while in Gorawara tank it was 0.05 kg/hectare/day.
ii) The evaporation saving ranged from 3.7 to 17.8% for the period of study in Walwhan Lake, 0.25 to 20% in Vihar lake and 8-16% in Gorawara Tank.

7.1.6 Central Salt and Marine Chemicals Research Institute, Gujarat

This Institute conducted evaporation control studies using Cetyl Stearyl alcohol in sixties at Khodiyar lake, Bhavnagar. The Khodiyar Lake has a maximum water spread area of 1.90 ha and storage capacity of 6.3 MCM. Both the powder and emulsion techniques were used. The data were collected for a period of 2 to 5 years. The film pressure was maintained at less than 24 dyne/cm. Its presence was detected by the absence of any movement of particles of antipyrine and camphor when dusted on the water surface and also with the help of indicator oils. The record of weather data were also maintained during the study. Studies by the institute showed lake evaporation (E) to be 0.65 times the standards pan evaporation (E_s).

The evaporation data assessed theoretically and as observed are presented in Table 7.4. The inference drawn from the studies showed that the saving in evaporation loss was comparatively higher by using powder form than by emulsion form. But the consumption of the chemical in the former was almost double. An optimum wind velocity of 6.4 km/hour (4 miles/hour) was found to be conducive for spreading the layer. Savings of the tune of 10-33% by way of reduction in evaporation loss have been reported.

TABLE 7.4 : Studies Conducted By Central Salt And Marine Chemical Research Institute, Bhavnagar At Khodiyar Lake

Method of application	Evaporation Data (mm per day) (Average of the months)							
	Months	Penman's Aerodynamic formula	Penman's Sink-strength formula	Rowher's formula	Standard pan Evaporation Es	Lake Evaporation 0.65 x Es	Actual observed Evaporation	Percentage saving
Aqueous Suspension	Dec. '62	3.5	5.1	5.5	11.7	7.6	6	20.0
	Jan. 63	6	6.2	6.4	10.4	6.8	5	23.0
	Feb. 63	4	10.5	10.7	13	8.2	6.4	24.2
	Mar. 63	11.3	20.4	21.6	11.5	7.4	6.1	17.4
	Apr. 63	6.2	14.6	13.2	13	8.4	6.8	18.2
	May 63	6	21.4	20.5	17.4	11.3	9.6	13.6
	June 63	6.3	20.4	18.5	18.5	12	10.6	10.6
No treatment period	Dec. 63	2.7	3	2.9	--	--	--	--
	Jan. 64	3	10.4	10.7	5.3	3.4	--	--
Powder technique	Feb. 64	3.1	4.6	4.5	7.8	5	3.3	35.0
	Mar. 64	9.7	16.7	16.6	10.9	7.1	4.8	32.2
	Apr 64	8.9	22.6	23	14.7	9.5	6.8	27.1
	May 64	7.4	28.4	27.2	13.6	8.9	7.6	14.3
	June 64	4.5	21.2	19.5	11.8	7.7	6.9	10.0

7.1.7 National Environmental engineering Research Institute, Nagpur

This Institute had conducted evaporation control studies on three lakes namely Sagar lake (Jaipur) and Jawai lake (Pali) in Rajasthan and Vehar lake (Thane) in Maharashtra. The salient features of these lakes details of experiments conducted, methodology followed, observations carried out and percentage of reduction in evaporation achieved are detailed in Table 7.5

The studies had shown that the optimum pressure of 16-25 dyne/cm of Cetyl alcohol lead to a saving of 48.2% to 57.9% in evaporation loss in Sagar lake. In Jawai lake, an optimum pressure of 16-40 dyne/cm lead to 23-29% reduction in evaporation loss. The studies at Vehar lake showed a percentage reduction of 0.25-20% at an optimum pressure of 40 dyne/cm. Other inference drawn from the studies was that the evaporation control technique should be useful in small lakes having low wind velocity during summer months when water is scarce and costly.

TABLE 7.5 : Studies Conducted By NEERI, Nagpur, Maharashtra

SI. no	Experimental Details	Name of the Lakes		
		Sagar Lake (Jaipur)l	Jawai Lake (Pali)	Vihar Lake (Thane)
1.	Gross area at FRL	2.25 ha	2600 ha	370 ha
2.	Gross Capacity	—	210 MCM	—
3.	Period of study	April-June 1968	June & July in 1966, 67	Jan. - June 1965
4.	Chemical used	Cetyl alcohol	Cetyl alcohol	Cetyl alcohol
5.	Measurement of rate of evaporation	Field — Standard evaporation pan	Field — Standard evaporation pan	Field — Standard evaporation pan
6.	Area covered	2.25 ha	246 ha in 1966 and 451 ha in 1967	370 ha
7.	Rate of application	0.24 kg/ha	0.24 Kg/ha	0.12 Kg/ha
8.	Optimum pressure	16-25 dyne/cm	16-40 dyne/cm	40 dyne/cm
9.	Meteorological data Temperature	Min. 28°C-33°C Max. 39°C-40°C	1966 1967 22-24°C 22-24°C 41-37°C 41-46°C	22°C-24°C 29°C-41°C
	Relative Humidity	Min. — Max. —	30-48% 11-40% 97-98% 90-95%	54.25-75.2% (mean)
	Wind Velocity	10 km/hr	4-6 km/hr (Min) 2-3 km/hr 16km/hr (Max) 6.5-8.5 km/hr	6 km/hr -8 km/hr

TABLE 7.5 (CONTD.)

1	2	3	4	5
	Rainfall	—	812mm 812mm	—
	Lake Temperature	Min. — Max. —	27-30°C 26-28°C 33-35°C 32-36°C	24°C-30°C
10.	Wind effect on layer	drifting of the layer to the shore	drifting of the layer to the shore	drifting of the layer to the shore
11.	Permeability to CO_2 & 0_2	Good	Good	Good
12.	Frequency of reapplication	Once in a day	Twice in a day	Once in a day
13.	Hazard to public health	Nil	Nil	Nil
14.	Methodology adopted for calculating evaporation loss	Water Budget	Water Budget	Water Budget
15	% saving in evaporation Losses	48.2 % to 57.9 %	23 to 29 %	0.25 to 20 %

7.1.8 A.P. Engineering Research Laboratories, Himayatsagar, Hyderabad

Studies were conducted by this Institute in Himayatsagar reservoir in the Ranga Reddy District of Andhra Pradesh during the period from April, 1983 to June 1983. Cetyl alcohol dissolved in mineral turpentine oil was spread over an area of 697 ha at the rate of 0.125 kg of chemical per hectare per day. The chemical was sprayed by petrol driven automatic sprayer and an optimum pressure of 18-24 dyne/cm was maintained. Meteorological data such as temperature, wind velocity, humidity, rainfall were recorded. Daily application of the chemical was found necessary to maintain the required film pressure. The study for this small period of time indicated evaporation reduction of 38%.

7.1.9 Directorate of Irrigation Research and Development, Pune

During 1976-77 to 1979-80, a number of experiments were carried out by this Directorate for conservation of water by evaporation control. These experiments were conducted in collaboration with National Chemical Laboratory (NCL), Pune. Three minor irrigation tanks and two percolation tanks were selected for this purpose. The salient features of these tanks are given in Table 7.6. A chemical “Linoxyd CS-40” developed by NCL and commercially manufactured by M/s HICO Products, Mumbai was used for the study. This chemical is an Ethylene Oxide condensate of long chain fatty Alcohol called Alkoxy Ethanol and is reported to be an effective water evaporation retardant.

TABLE 7.6 : Studies by Directorate of Irrigation Research and Development, Pune

Sl. No	Particulars	Kondhapuri M.I. Tank	Aundhengnath M. I. Tank	Baradhari M.I. Tank	Kedarpur percolation tank	Indira percolation tank
1.	Village	Kondhapuri	Aundha	Mahektri	Ladgaon	Rajgurunagar
2.	District	Pune	Parbhani	Ahmednagar	Nagpur	Pune
3.	Average monsoon rainfall (mm)	480	800	500	890	600
4.	Gross storage at FRL (MCM)	2.51	2.81	1.87	0.40	0.57
5.	Full Tank level (m)	136.22	554.62	109.06	997.14	62.18
6.	Water spread area (ha)	66.52	45.00	38.00	13.70	14.18
7.	Gross command area (ha)	580.00	590.00	360.00	131.00	188.00
8.	Percentage evaporation retardation compared with Pan Evaporation					
	i) 1976-77	—	—	—	—	35
	ii) 1977-78	19.50	37.00	—	34.78	39.19
	iii) 1978-79	—	—	11.17	—	35.20
	iv) 1979-80	—	—	15.12	—	—

The basic compound Linoxyd CS-40 was used for preparing the emulsion. The composition of the emulsion was 40% original compound and 60% other material. The emulsion was stabilized by surface active reagents like detergents. The required quantity of the emulsion at 650 gm/ha/day was taken and mixed with a little quantity of water manually. The diluted paste was then sieved through a thick cloth to act as a filter. This was then re-diluted to about 15 times by adding adequate quantity of water. The diluted Linoxyd CS-40 was then spread over the water surface to form a thin film. For this purpose, the water surface was divided into a number of bays by using floats. One float was covering approximately 0.8 to 1.0 ha. Each float had one container with a pinchcock. The container had a capacity of 18 liters and was mounted on a platform of 1.2 m X 1.2 m. The pinchcock ensured regular dripping of the diluted emulsion. The wooden platform had 4 sealed empty tins (2 litres) at the four corners to enable the platform to float on the surface. The floats were anchored with nylon chords and heavy weights to keep them stationary. A manually operated boat was used for carrying the emulsion to the containers. There were about 20 floats placed in different bays in the reservoir. The rate of drip was one litre / hr for 10 hours day. SAE-40 indicator oil was used to test the existence of the film.

The lake levels and therefore the contents were monitored through gauge data. Visible seepage was measured through a V-notch. Outflow into the canals is measured through a V-notch coupled with an automatic stage recorder. Pan Evaporimeter was established and observations were taken twice a day (08.30 and 17.30 hrs). Maximum and minimum temperature and relative humidity were recorded at 0830 hrs. Wind speed and direction were measured every 2 hours and rainfall once a day. About 6 workers were required for 20 ha. of water surface.

The Pan coefficient for the Pan evaporimeter established near the lake was found to be 0.9 and was so adopted in the analysis.

The Linoxyd CS-40 was also thoroughly checked from the angle of toxicity, at two laboratories namely Haffkins Institute and Hindustan Lever Research Laboratory. The report says that the compound is neither toxic nor harmful to human beings, animals and aquatic life. The film was found allowing oxygen to pass through and hence the percentage of dissolved oxygen remained unaffected.

An analysis of the cost per unit of water saved was also carried out. The cost was considered to include equipment, material and labour. The conclusions drawn from the experiments were :

(i) The percentage of reduction in evaporation losses varied from 11.17 to 39.19%. The lower value was attributed to the higher wind speed and increased area of water surface.

(ii) When the wind velocity was more than 10 km/ hour, the film was found to break and the chemical got accumulated at the periphery.

(iii) The method of evaporation retardation was not cost effective especially for conservation of water for irrigation purposes. The

Directorate however concluded that during drought conditions and in the years of scarcity this method of water conservation may be viable proposition on small tanks (water spread areas 20-50 ha) which supply water for domestic purpose.

The firm had used their chemical Acilol TA 1618 for control of evaporation in Ramgarh Lake (Jaipur), Foy Sagar (Ajmer) and Maja Dam (Bhilwara) in Rajasthan State, Nyari (Rajkot) and Sasoi Dam,Jamnagar in Gujarat state and Hyderabad Metro Water Works, Andhra Pradesh. The details of the studies are given in Table 7.7. Some of the inferences drawn from these studies are (i) no toxic effect on aquatic life (ii) no change in water quality and permeability to gases like oxygen and carbon dioxide (iii) monolayer breaks if wind velocity is greater than 16 km/ hr and (iv) percentage reduction in loss is of the order of 23.4 to 35%.

TABLE 7.7 : Studies Conducted by M/S Aegis Chemical Industries Limited, Mumbai

S. No	Details	Name of Reservoir/lake/tank etc.					
		Ramgarh Lake	Foy sagar	Meja Dam	Nyari Dam	Sasoi Dam	Osman Sagar
1	Location	Jaipur, Rajasthan .	Ajmer, Rajasthan	Bhilwara, Rajasthan	Rajkot, Gujarat	Jamnagar, Gujarat	Hyderabad, A.P.
2	Purpose (Hydel, Irrigation, Drinking, Industrial etc.)	Drinking Water	Drinking Water	Drinking Water	Drinking Water	Drinking Water	Drinking Water
3	Period of study	April 85-July85	Jan. 86-June 86	Jan. 86-July86	Jan. 86-June86	Jan. 86-June86	April 86-June 86
4	Measures adopted	---------------------------------Chemical treatment -------------------------------					
5	Experimental a) Equipments used for measuring rate of evaporation (both in the field and lab- scale)	---------------Pan evaporimeter and other meteorological instruments---------------					
	b) Area covered (ha)	102	6	144	92	164	410
	c) Name of the chemical used	------------------Cetyl Stearyl Alcohol Emulsion--------------------------------					
	d) Thickness of the monolayer applied	---------------------------------------0.015 micron---------------------------------					
	e) Optimum pressure of layer	---------------------------------------35 dyne / cm----------------------------------					
	f) Mode of application of the layer	Dispensing the diluted emulsion by dripping from a barrel kept on rafts.					

TABLE 7.7 (CONTD.)

6.	Observations during the study :						
	a) Meteorological observations: Average Temp. — Max. — Min. . Average Humidity Average Wind Velocity Rainfall	 37°C 21 °C 62% 14 km/hr Nil	 36° C 18°C 60% 8 km/hr Nil	 38°C 21 °C 59% 10 km/hr Nil	 35°C 19°C 72% 12 km/hr Nil	 36° C 29°C 76% 11 km/hr Nil	 37°C 26°C 55% 14 km/hr Nil
	b) Temperature of water Max. Min. c) Water quality changes before and after application	 35°C 19°C None	 34°C 16°C None	 36°C 19°C None	 33°C 17°C None	 34° C 18°C None	 35°C 24°C None
	d) Wind effect on the layers e) Breaking up of layer due to any other factors	The monolayer breaks when the wind velocity is higher than 16 kmph --No---------------------------------------					
	f) Effect on aquatic life g) Permeability of the layer for gases like Oxygen, Carbon dioxide etc.	--No toxic effect---------------------------- --Permeable ---------------------------------					
	h) Frequency of reapplication of layer	A dosage of 500gms/ha/day daily for initial 30 days and thereafter 250gms/ha/day. The monolayer was tested by indicator oil like castor oil to check whether dosage was effective.					
	i) Hazard to public health, if any	----------------------------------No hazards --					

7	Methodology adopted for calculating evaporation loss	--Water Budget ------------------------------------					
8	Evaporation Control a) % reduction in loss due to evaporation	23.4 (from May, June it was 29%)	35	30	30	32	33

7.1.10 G.B.Pant University of Agriculture and Technology, Pantnagar

This University had conducted experiments to evaluate the performance of chemical films in evaporation retardation by using wind tunnel. The wind tunnel used is a closed type open circuit aerodynamic tunnel in which provision for controlling wind velocity exists. It consists of three sections (i) a honey combed screen protected square entrance (ii) a square section test chamber (61 cm X 61 cm) and (iii) a diffuser.

The honey combed square entrance has contraction ratio of nine to one, which converges to the test section. The square section test chamber gradually diverges to the circular diffuser section. At the end of the diffuser a fixed pitch four blade propeller operated by a 20 H.P. motor is fitted, which sucks air through the tunnel. The speed of the propeller is controlled with the help of an electric resistance regulator. A pair of adjustable flap gate is provided at the end of the test section and at the beginning of the diffuser section to control the wind velocity. These gates are operated from outside to adjust a part of the air to be sucked from the side windows and partly through the test chamber to maintain the desired wind velocity in the test chamber.

The test tank was made of 6 mm mild steel sheet having an area of 1568 square cm. The test tank was fixed at the bottom of the opening of the test chamber in such a way that the top edge of the tank was just at the floor elevation of the test chamber. A layer of thick paper was pasted around the test tank to eliminate chances of air leakage.

The chemicals Hexadecanol and Octadecanol were used for the study and were applied over the water surface in a fine power form with a hand dust sprayer. Care was taken to maintain a uniform thickness of the film. Measurements of loss of water due to evaporation from the test tank were made with the help of a calibrated inclined manometer. Evaporation data from free water surface were recorded with and without application of chemicals.

A vane type sensitive anemometer was used to measure the wind velocity in the test chamber. Calibration of opening of flap gate for maintaining the required wind velocity in the test chamber was made with the help of a micro manometer. Wet bulb and dry bulb thermometers were used to determine vapour pressure deficit in the test chamber.

Table 7.8 shows the variation of evaporation of free water surface without chemical films. The value of vapour pressure deficit (e_s-e_a) were calculated by the following relationship.

$(e_s-e_a) – 0.644\ (T_d-T_w)$.

Where e_s and e_a are the saturated and actual vapour pressure respectively and T_d and T_w are the dry bulb and wet bulb temperature respectively. It is evident from Table 7.8 that with increase in wind velocity, the rate of evaporation and vapour pressure deficit increased. This may be due to heat ingress from outside in wind tunnel through the incoming air at higher wind velocity.

Table 7.8 : Variation of Evaporation on Water Surface Without chemicals

Wind Velocity (Km/hr)	Vapour pressure deficit (e_s-e_a) (mb)	Evaporation (mm/hr)
3.1	5.73	0.7
5.8	5.54	0.8
10.4	7.34	1.1
16.6	7.82	1.3
20.5	8.09	1.4

Table 7.9 and 7.10 give a comparison of measured evaporation from free water surface to that with the use of Hexadecanol and Octadecanol respectively. With the use of Hexadecanol, there was practically no evaporation at wind velocities upto 3.1 km/ hr. Upto wind velocity of 16.65 km/ hr an evaporation rate of 0.6mm per hour was observed while a moisture loss of 1.3 mm per hour was found when no chemical treatment was given. Thus, there seems to be a possibility of nearly 50 per cent reduction in evaporation by use of Hexadecanol. It is clear from Tables 7.9 and 7.10 that the performance of hexadecanol is better than octadecanol for reduction of evaporation losses from open water surface.

Table 7.9 Variation of Evaporation on Water surface with Application of Hexadecanol

Wind Velocity (Km/hr)	Vapour pressure deficit (e_s-e_a) (mb)	Evaporation (mm/hr)
3.1	5.36	0.0
5.8	6.44	0.2
10.4	7.46	1.3
16.6	7.46	1.6
20.5	8.56	0.8

Table 7.10 Variation of Evaporation on Water surface with Application of Octadecanol

Wind Velocity (Km/hr)	Vapour pressure deficit (e_s-e_a) (mb)	Evaporation (mm/hr)
3.1	4.98	0.2
5.8	5.38	0.3
10.4	6.10	0.5
16.6	6.75	0.8

The inference drawn from the experiment is that persistence of an established film is very important for evaporation reduction The wind velocity had a pronounced effect on the established film. At wind velocities greater that 10.5 km/ hr, it was observed that the chemical film breaks and its effectiveness starts decreasing.

7.1.11 Gujarat Engineering Research Institute, Vadodara

This Institute had conducted field experiments in a small irrigation tank namely Jambuvai in the Vadodara District of Gujarat State. The studies were carried out during the period from 2/86 to 5/86 and 12/86 to 2/87 by using the chemical Acilol TA 1618 (Cetyl Stearyl Alcohol), which is manufactured by M/s AEGIS Chemical Industries, Mumbai.

A meteorological station with pan evaporimeter, anemometer, windvanes and thermometer screen was erected at the site and observations were taken. .

The Acilol TA 1618 was used in emulsion as well as powder form. The emulsion was spread at 300 gm/day-hectare for the initial 15 days and reduced to 250 gm per day per hectare during subsequent period. The emulsion was diluted with water 20 to 25 times by volume for ease of application. Application of the solution was done by dripping from a storage drum fitted on floating raft. A drum of 30 litres capacity was found to cover a water surface area of about one hectare. Presence and continuity of the film was ascertained by putting a drop of indicator oil like castor oil on treated water surface. If the drop of indicator oil maintains its shape, it was considered that the film is intact on the water surface.

The chemical in powder form was spread at a rate of about 75 gm/ha per day. The powder was dispersed from a boat by means of two manually operated dusters placed on both sides of the boat. About 10-15% of the daily dose was kept in reserve for use whenever film gets broken.

The details of the equipment used for the experiment alongwith their costs are given in Table 7.11. The percentage of savings in evaporation loss achieved and other details of the experiment are indicated in Table 7.12. The conclusions drawn from the experiments were :

i) The percentage of savings in evaporation losses were to the tune of 23.6% to 26.2%.
ii) The site conditions play an important role in control of evaporation loss. In general where wind speed is high the percentage of savings is low.

7.1.12 Review of Studies Carried out in India by Various Agencies

A review of the details of the studies carried out by various agencies indicates that:

i) Cetyl alcohol was used in the earlier stages of experiments (1957). Later on Cetyl Stearyl alcohol was the most commonly used WER. A mixture of alcohols and Alkoxy Ethanols (ethylene oxide condensate) was also used in the experiments.

ii) All three modes of application of WER viz. powder, emulsion and solution form were tried by various agencies. The consumption of solution is, however, found to be higher than powder form.

iii) The water budget equation and pan evaporation equations were the most commonly used methods for determining rate of evaporation.

iv) The extent of saving by way of evaporation reduction assessed by various agencies varied from 5 to 48%. However, an average value in the range of 20-30% can be considered as the possible saving in evaporation losses.

v) Meteorological conditions prevailing over the location of water bodies were found to be the main guiding factor in the rate of application of chemical WER. The application was effective upto wind velocity of about 15 to 20 km/ hr. beyond which the layer was found to break, making it less effective.

vi) The evaporation reduction was also found to be directly related to the surface pressure of the monomolecular layer formed. Individual research stations have adopted surface film pressures in the range of 20-40 dyne/ cm, with maximum evaporation saving was found attainable at 40 dyne/ cm.

vii) Very few research stations have studied the effect of the chemical monolayer on the quality of water and on the aquatic life. These few studies however, indicated no adverse effect. Further extensive studies to substantiate the effect of WER on the quality of water and aquatic life need to be carried out.

Table 7.11 Equipment used for Application of chemical WER and for assessment of their efficiency in Jambuvai Tank

SI. No	Equipment	Name of Manufacturer supplier	Approximate cost (Rs)	Purpose
1	2	3	4	5
1.	Motorised boat	FIBROFORM, Pune N.M. WADIA, BALLIMORA	60,000/- each	Spraying WER
2.	Dusters/Pulverisers	—	5.000/- each	Pulverising WER
3.	Floating raft & drum	Locally made	2,000/- each	Drip arrangement
4.	Anchors/Chains	—	1,000/-each	Anchoring of rafts
5.	Pan evaporimeter (Land type) (IS 5973-1970)	M/s Associated Manufacturers and suppliers, 1, Panchayat Building, Lai Darwaja, Ahmedabad.	7.500/- each	Measurement of evaporation-2 Nos. (1 in chemically treated condition and second in untreated condition)
6.	Anemometer	—do—	1,500/- each	Measurement of wind velocity (1 No)
7.	Wind Vane (IS 5799-1970)	M/s Prakash Industries, Vithal Kanya Vidyalaya, Nadiad	1,000/- each	Observation of wind direction (1 No)
8.	Thermometer Screen (IS 5968-1970)	M/s National Industrial Designers 2, Union Co., Opp. Industrial Estate Ltd. Rakhial, Ahmedabad.	600/- each	Fixing and protecting thermometer (1 No)
9.	Dry Wet bulb	M/s National Instruments, Jadavpur, Kolkata.	500/- per set	Measurement of humidity (1 set)
10	Min. & Max. thermometers (IS 5681 -1970)	----do-----	400/- per set	Measurement of minimum & maximum temperature during a day (1 set)
11	Automatic Raingauge (IS 5235-1969)	M/s Lawrence & Mayo (India) Pvt. Ltd., 274, Dr. Dadabhai Nauroji Road, Mumbai-400001	3,000/- each	Measurement of rainfall (1 No.)
12	Sunshine Recorder (IS 7243-1974)	M/s Associated Manufacturers & suppliers, 1, Panchayat Building, Lai Darwaja, Ahmedabad.	900/- each	Measurement of total sunshine hours during a day (1 No.)
13	Barometer	Institute of Tropical Meteorology (ITM), Ramdurg House, Poona University Road, Pune-5.	-----------------	Measurement of atmospheric pressure (1 No.)

TABLE 7.12 Studies By Gujarat Engineering Research Institute, Vadodara

SI. No.	Reservoir	Period of water spreading in days	Evaporation losses in Pan Evaporimeter in metre		% saving in pan - col. 4- col. 5	Total depletion in reservoir in m.	Drawal in m	Absorption losses in m (0.12"/day)
			Without W.E.R	With W.E.R	Col. 4 x 100			
1	2	3	4	5	6	7	8	9
1,	Jambuvai Irrigation Tank-	24-2-86 to 1 -5-86 (66 days)	0.611	0.309	49.4	0.719	0.157	0.201
2	— do—	24-12-86 to 21-2-87 (60 days)	0.339	0.171	49.6	0.510	0.120	0.183

Average water spread area of reservoir in m^2	Net evaporation losses in m columns (7)-(8+9)	Loss in reservoir without W.E.R. (4) x 0.8	Actual saving in evaporation in m (12) - (14)	Saving in m (13) x (10)	% Saving in reservoir (13)/(12) x100	Total cost of spreading (material and labour charges) in Rs	Spreading cost of WER Rs/m^3
10	11	12	13	14	15	16	17
24949	0.361	0.489	0.128	3193.50	26.2	Mat. 3780 Lab. 1980 Total 5760	1.80
9350	0.207	0.271	0.064	598.40	23.6	Mat. 1200 Lab. 600 Total 1800	3.00

Note :

1. The absorption losses have been assumed at 3 mm / day (0.12" / day) on the basis of conclusion drawn in Aji-1 experiment in 1966.

2. The other losses are assumed on the basis of site observation.

TABLE 7.13 Abstract of Results of Evaporation Retardation Studies by Use of Chemical Retardants Carried out by Various Agencies in India

SI.	Name of organisation	Location of Study	Period of Study	Chemical used	rate of application of chemical	% saving in evaporation	Cost per m^3 of water saved (Rs)
1	2	3	4	5	6	7	8
1	Irrigation Development Division, Mumbai	Kasurdi Tank and Bhandgaon Tank near, Pune	End.of 1957	Cetyl alcohol in powder form	—	14% in Kasurdi 30% in Bhandgaon Tank	—
2	Central Soil & Material Research Station, New Delhi	Badkhal Tank Faridabad	Nov. 1958 to April 1963.	Cetyl or Cetyl-Stearyl alcohol in emulsion form	0.34 to 2.00 kg per ha. per month	21% to 37.8%	0.38
		Mir Alam Tank Hyderabad.	March 1964 to May 1964	— do—	0.39 kg per ha per month	41.30%	— do—
		Takhat Sagar Tank, Jodhpur	June 1964 to Oct. 1964	— do—	1.30kg per ha per month	48.20%	— do—
		Maota & Saga Lake, Jaipur.	April 1965 to Dec. 1965	— do—	2.70 kg per ha per month	_	—do—
3	Institute of Hydraulic and Hydrology, Poondi	Buderi Tank, Poondi	1959 to 1965	Cetyl Stearyl alcohol in the form of emulsion as well as powder form	_	20%	_
4	Karnataka Engineering Research Station, Krishnaraja Sagar	Kukkarahalli Tank, Mysore.	Feb. 62 to May 62	Cetyl alcohol in solution, emulsion and powder form	—	5.7% to 24%	0.09
		Varuna Tank, Mysore	Aug. 1964 and Jan, 65 to April, 65	—do-	_	8.9 to 36.91%	—do—

TABLE 7.13 (CONTD).

1	2	3	4	5	6	7	8
		Kadavinahosa halli Tank, Hassan, Distt.	June & July'1962	Cetyl alcohol emulsion and solution form	—	-	
		Lingambudhi, Mysore		Cetyl alcohol solution	0.05 to 0.07 kg/ha/day	19 to 34.29%	0.12
				Emulsion form	0.12 to 0.30 kg/ha/day	9.57 to 28.00%	0.12
				Powder form	0.34 to 3.99 kg/ha/day	8.5 to 35.24%	0.46
5.	Central Public Health Engineering Institute, Nagpur	Walwhan Tank	Mid-sixties	Cetyl alcohol in emulsion form	0.02 to 0.05 kg/ha/day	3.7 to 17.8%	__
		Vihar Lake	— do-	—do—	— do—	6.25 to 20%	__
		Gorawara Lake	— do-	Cetyl alcohol in power form	0.05 kg/ha/day	8 to 16%	
6.	Central Salt and Marine Chemicals Research Institute, Gujarat.	Khodiyar Lake, Bhavnagar	Dec. '62 to June '63 and Dec'63 to June '64	Cetyl Stearyl alcohol in emulsion form	__	10.6 to 24.2%	__
				—do- Powder form	__	10 to 35%	__
7.	National Environmental Engineering Research Institute, Nagpur.	Sagar Lake, Jaipur	April-June 1968	Cetyl alcohol	0.24 kg/ha	48.2 to 57.9%	—
		Jawai Lake, Pali	June & July months of 1966 & 1977	— do—	— do—	23 to 29%	—
		Vihar Lake, Thane	Jan to June 1965	—do—	0.12 kg/ha	6.25 to 20%	__

TABLE 7.13(CONTD.)

1	2	3	4	5	6	7	8
8.	A.P. Engineering Research Laboratories, Hyderabad	Himayatsagar	April '83 to June '83	Cetyl alcohol in emulsion	0.125 kg/ ha/ day	38%	0.22
9.	Directorate of Irrigation Research and Development, Pune	Kondhapuri Tank, Pune	1976-77 to 1979-80	Linoxyd CS-40	0.625 kg/ ha/ day	19.5%	0.39
		Aundhengwath tank, Parbhani	— do—	— do—	— do—	37%	0.18
		Baradhari Tank Ahmednagar	—do—	— do-	— do—	11.17-15.20%	0.92
		Kedarpur Tank Nagpur	-do-	— do—	— do—	34.78%	0.34
		Indira Percolation Tank. Pune	—do-	— do—	— do—	35.00 to 39. 19 %	0.27 to 0.36
10	M/s AEGIS Chemical Industries Ltd., Mumbai.	Ramgarh Lake Jaipur	April '85 July '85	Cetyl-Stearyl emulsion	500 gm/ha/ day for initial 30 days and 250 gm/ ha/day thereafter	23.4 to 29%	Cost per unit area Rs. 15/- per day for initial 30 days & Rs. 8 per ha per day thereafter
		Foysagar, Ajmer	Jan '86 June '86	— do—	— do—	35%	— do—
		Meja dam, Bhilwara	Jan '86 July '86	— do—	— do—	30%	— do—
		Nyari dam, Rajkot	Jan '86 June '86	— do—	— do—	30%	— do—
		Sasoi dam, Jamnagar	Jan '86 to June '86	— do—	-do—	32%	— do—
		Osman Sagar, Hyderabad	April '86 to June '86	— do—	— do—	33%	—do—
11	G.B. Pant University of Agriculture & Technology, Pantnagar.	Study in wind tunnel	___	Hexadecanol Octadecanol chemicals	_____	50%	_____

TABLE 7.14 Details of Evaporation Control Measures Adopted by Various Agencies in India

S. No	Location	Organisation/ Department	Period	Chemical used	% achieved saving in evaporation control	Cost of spreading (Rs. per m3)
1	2	3	4	5	6	7
1	a) Aji-1Rajkot	E.E., Rajkot Irri. Division (Under Guidance of C.S. & M.C.R.I., Bhavnagar	April 1968 to June 1968 (3 months)	Cetyl Stearyl Alcohol (Powder form supplied by C.S. & M. C.R.I., Bhavnagar)	16	—
	b) –Do—	E.E., Rajkot Irri. Division	10.12.85 to 15.5.86 (6 months)	Cetyl Stearyl Alcohol (Powder form)	42	0.81
	c) –Do—	–Do—	26.9.87 to 31.1.88	–Do—	21	1.08
2	Rah Talao, Dholera, Ahmedabad)	M/s Hico Ltd., Mumbai and 'Mahiti Azad Society,	18-24 Feb'86 (7 days)	Linoxyd CS-40 (emulsion form)	26	--
3	a) Nyari (Rajkot) Water Supply	E.E., P.H. Dn., Panchnath Plot, Rajkot.	23.12.85 to 7.2.86	Cetyl Stearyl Alcohol (emulsion form)	23	1.63
	b) –Do—	–Do—	8.2.86 to 15.5.86	–Do— (powder form)	21	0.80
	c) –Do—	–Do—	9.5.87 to 15.6.87	Cetyl Stearyl alcohol (Powder form)	24	0.64
4	Ranghola (Bhavnagar)	EE Bhavnagar Irrigation Division, Bhavnagar	15.2.86 to 2.3.86	--Do--	21	1.13

TABLE 7.14 (CONTD.)

1	2	3	4	5	6	7
5.	a) Sasoi Jamnagar	E.E- Jamnagar Irri. Div. Jamnagar	13.12.85 to 6.5.86 (6 months)	Cetyl Stearyl Alcohol	4.54	0.96
	b) —do—	— do—	From 9.5.87 (43 days)	-do— (Powder form)	10.00	—
	c) —do—	— do—	9.5. 88 to 21.6.88	-do—	10.00	0.51
6.	Aji-3	E.E., Project Dn., Rajkot	1.3. 86 to 31.5.86	-do—	11.54	0.39
7.	Chaprawadi-2 (Rajkot)	—do—	1.3.86 to 25.6.86	-do—	11.80	0.44
8.	a) Bhadar {Rajkot}	S.E., Irri. Circle, Rajkot	28.1. 86 to 15.5.86	-do—	9.	0.44
	b) — do-	—do—	26.2.86 to 31.5.88	-do—	16	0.51
9.	a) Fulzer II (Jamnagar)	S.E., Irri. Circle, Rajkot	27. 1.86 to 29.5.86	Cetyl Stearyl Alcohol	11	0.24
	b) —do—	— do—	110 days (from 13.10.87)	-do—	10.37	0.36
10.	a) Machhu-l (Rajkot)	—do—	18.2. 86 to 28.5.86	-do—	35	0.34
	b) — do-	—do—	110 days (from 13.10.87)	-do- (Powder form)	13.58	0.62
11.	Dhatarwadi (Amreli)	—do—	18.2.86 to 26.5.86 (3 months)	-do—	8	0.74
12	Wadhwan Bhogova (before Temp, bund	— do—	52 days (from 27.9.87)	-do—	12.76	0.69
	(After Temp, bund)	— do—	30 days (from 2.1.88)	--do—	19.04	0.87

TABLE7.14(CONTD.;

1	2	3	4	5	6	7
13.	W.B.-II	— do—	64 days (from 20.10.87)	-do—	12.50	0.83
	a) MOS	— do—	112 days (from 12.10.87)	— do—	16.82	0.68
14.	Malan	—do—	80 days (from 16.10.87)	— do-	22.50	0.65
15.	Rojki	S.E., Irri. Circle, Rajkot	83 days (from 10.2.88)	Cetyl Stearyl Alcohol (Powder form)	20.42	0.33
16.	Varu	— do—	116 days (from 8.10.87)	— do—	21.28	0.62
17.	Phophal	—do—	1 09 days (from 14.10.87)	— do—	13.85	0.57
18.	Ramgarh	S.E. PHED City Circle, Jaipur	April '85	Acilol TA-1618 (emulsion)	20.00	0.45
19.	-do—	— do—	May '85	— do-	24	0.45
20.	—do—	— do—	June '85	— do-	30	0.45
21-	— do—	-do-	July '85	— do—	17	0.45
22.	Udaisagar Lake	Hindustan Zinc. Ltd Udaipur	21. 1.87 to 15.6.87	— do—	25.30	1.00

7.2 Other Evaporation Retardation Measures

By the end of 1983, the efficacy of the chemical WERs had been accepted and confirmed through studies by various research institutes and this method was extensively adopted in Gujarat, Maharashtra, Rajasthan etc. In addition, various agencies had also adopted other methods for evaporation control measures, such as compartmentalization, integrated reservoir management, storing water in under ground cavities etc. These control measures adopted in the country are enumerated in the following paragraphs.

7.2.1 Chennai Metropolitan Water Supply and Sewerage Board

A combination of various methods of evaporation control measures, such as integrated operation of reservoirs, application of chemical and compartmentalization have been adopted by Chennai Metropolitan Water Supply and Sewerage Board in the lakes of Poondi, Cholavaram and Red Hills lakes which supply water to Chennai City. The salient features of these three lakes are given in the Table 7.15

Table 7.15 : Salient Features of Poondi, Cholavaram and Red Hills Lakes, Tamilnadu

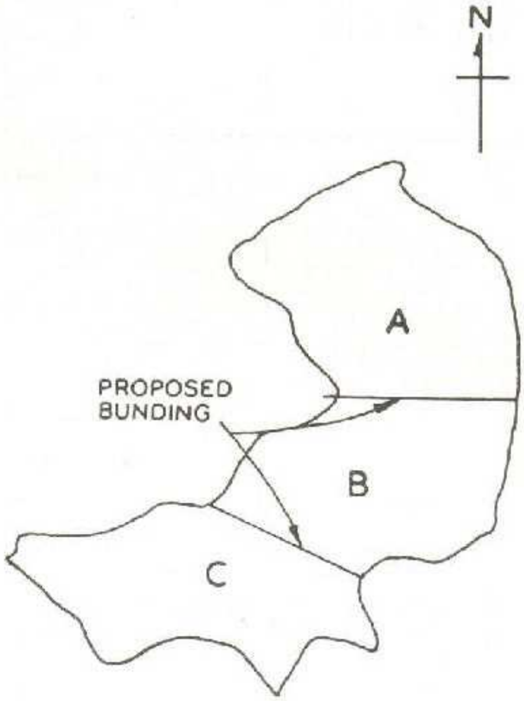
Name of lake	Full tank level (m)	Capacity at FTL (MCM)	Water Spread Area (Sq.Km.)
Poondi	42.06	74.90	33.78
Cholavaram	19.66	24.90	6.26
Red Hills	14.69	75.41	19.73

The water spread area of Poondi Reservoir is nearly 50% more than Red Hill lakes for approximately the same storage volume. Added to this increased water spread area, the Poondi reservoir is estimated to have high seepage loss due to the sandy soil bed. Thus immediately after monsoon the water collected in Poondi reservoir is transferred to Red Hills lake through Cholavaram lake and supplied to Chennai city. The details of the quantity of water saved by adopting this method of integrated operation of reservoir are however, not available.

Evaporation measures with chemical WER were also adopted in Cholavaram and Red Hills lakes from April to June 1988 and in Red Hills lake from June-August 1989. The Cetyl alcohol emulsion manufactured by M/s AEGIS Chemical industries Ltd. Mumbai was diluted and used at the rate of 500 gm emulsion per ha. The chemical was spread by dripping from drums fixed over floating rafts. During the year 1988, a quantity of 2.10 MCM of water (nearly 10 days supply to Chennai city) and during 1989 a quantity of 1.50 MCM was saved , incurring an expenditure of Rs. 13,16,175/- and Rs. 15,78,654 respectively. Thus the cost per 1000 litres of water saved during 1988 works out to 63 paisa and during 1989 works out to Rs. 1.06/- The higher expenditure during 1989 is attributable to the increased use of chemical and labour for more intensive monitoring of spread of chemicals.

Considering the recurring nature of the expenditure every year in application of WER and due to financial strain, the CMWSSB had formulated a proposal for compartmentalization of Red Hill lake for reducing its surface area.

The water spread area of Red Hill lake at full tank level is shown in Figure 7.1 The length of the lake is four times its breadth. CMWSSB proposes to compartmentalize the lake into three parts by construction of two earthen bunds as shown in figure 7.1.



TOTAL CAPACITY AT FULL TANK LEVEL
75.4 Mcum.

The volume and area at Full Tank Level (FTL) for various combination of compartments and percentage reduction in area that could be achieved are given in Table 7.16 It can be seen from this table that upto 46.66 MCM, water can be stored in A and B compartments alone and upto 21.35 MCM in A alone, by storing water at full tank level instead of spreading the water over a greater area, but at reduced elevations. Consequently, there is reduction in water spread area ranging from 15 to 49%. It is pertinent to note that for lower water contents, which is the situation during summer months when the water requirement is also high, the reduction in area of water spread is substantial.

TABLE 7.16 Details of Percentage Reduction in Area due to Compartmentalisation of Red Hill Lake

Percentage reduction in area without desilting but by bifurcation only

Quantity to be stored in MCM	Area in Sq.Km. (A + B + C)	If in 'A' alone	If in A+B alone	If in A + B + C	Percentage reduction in Area
		(Area in Sq.Km.)			
1.02	2.52	1.80	—	_	28
2.53	3.50	2.18	—	—	38
6.67	4.80	2.46	—	—	49
12.74	7.35	4.13	—	—	44
21.35	9.86	5.34	—	—	46
32.76	12.96	—	9.70	—	25
46.66	14.84	—	12.68	—	15
62.66	17.17	_	—	15.59	9
75.41	19.73	—	—	19.73	0

The actual loss through evaporation for one whole year, with and without compartmentalization as worked out by CMWSSB is given in Table 7.17. From this Table, it can be seen that after compartmentalization a quantity of 6.68 MCM of water (about 27 days supply to Chennai city) could be saved annually. As compared to this, the amount of water saved by chemical treatment during the year 1989 (June to August) in Red Hill lake was 2.1 MCM (Nearly 10 days supply to Chennai city), if the chemical treatment is done through out the year the possible saving in water will be of the order of 8 MCM, involving an annual recurring expenditure of Rs. 6.5 million. On the other hand the cost of construction of two bunds is estimated to be around Rs. 2.00 million and this is only one-time expenditure. Thus the compartmentalization is likely to prove more economical. In addition the following constraints experienced in the Red Hill lake during chemical method of evaporation retardation could also be overcomed:

i) Presence of weeds in the lakes often hindered with spray of chemicals evenly, at times making some areas inaccessible.

ii) High occasional wind speeds during the period of operation resulted in dislocation of the diffusers afloat at various locations for dripping the chemical. Change in wind direction sometimes aggravated the problem.

7.2.2 Measures adopted in Gujarat and Other States

Compartmentalisation by construction of dykes to isolate the shallow area of water was adopted in Wadhwan Bhogavo-I (Naika dam) in Gujarat during the beginning of

1988. This dam maintains supply of water to the twin cities of Surendranagar and Wadhwan. The evaporation loss in and around Surendranagar is reported to be between 2.5 to 3.0 / annum. To reduce this huge loss of water due to evaporation, a bund was constructed to isolate the shallow portion of the reservoir, which resulted in reduction of 20% of the surface area of reservoir. Water from this shallow portion was pumped into deeper pocket. By adopting this measure it is reported that a quantity of 0.23 MCM of water could be saved between January and July 1988. The expenditure involved in the evaporation control measures was Rs. 27 lakh, comprising Rs. 12 lakh on construction of bund and Rs. 15.00 lakh on pumping water. By adopting this measure, it is reported that an amount of Rs. 110 lakh on transportation of water in tankers from a distance of about 25 km could be saved.

TABLE 7.17 Details Of Evaporation Losses In Red Hill Lake Before And After Compartmentalisation

5 year average values												Chemical required (as of today in Tonnes)	Chemical required after bifurcation Tonnes
Before compartmentalisation							After Compartmentalisation						
Month	Stage in m.	Area Sq.Km.	Volume MCM	Average area for the month Sq.Km.	Mean monthly average mm	Evaporation loss MCM	Area after bifurcation Sq.Km.	Average area Sq.Km.	Evapo-ration loss MCM	Monthwise reduction in evaporation			
										%	MCM		
Jan	12.99	14.82	14.52	14.66	5.00	2.05	12.38	12.27	1.90	0.15	7	20.50	17.30
Feb	12.82	14.50	44.22	14.39	6.00	2.68	12.16	11.95	2.00	0.68	25	22.30	18.80
Mar	12.70	14.28	42.33	13.87	6.80	2.83	11.75	10.90	2.29	0.54	19	20.80	17.60
Apr	12.20	13.47	34.37	12.42	8.00	3.08	10.05	8.76	2.10	0.98	32	19.30	15.60
May	11.49	11.38	26.91	10.7	7.80	2.52	7.47	6.61	1.60	0.92	36	16.20	11.20
June	11.10	10.17	22.43	9.64	6.40	1.91	5.75	5.35	1.03	0.88	46	14.90	8.90
July	10.70	9.11	18.61	8.67	5.70	1.53	4.96	4.75	0.84	0.69	45	13.40	7.70
Aug	10.35	8.23	15.71	7.47	5.40	1.21	4.55	4.13	0.69	0.52	43	11.20	6.20
Sep	9.75	6.71	11.22	7.27	4.20	0.95	3.71	4.03	0.51	0.44	46	11.30	6.20
Oct	10.19	7.83	14.36	10.43	3.50	1.12	4.36	7.08	0.77	0.35	31	15.60	10.60

Nov	12.04	13.04	33.25	13.25	3.40	1.27	9.81	10.14	1.07	0.20	15	20.50	15.70
Dec	12.26	13.45	36.39	14.13	4.10	1.78	10.48	11.43	1.45	0.33	18	21.90	17.70
Jan	12.99	14.82	46.52				12.38						
						22.93			16.25			207.90	153.50

TABLE 7.17 (Contd.)

		For present configuration of the lake	After compartmentalisation
Annual evaporation loss	MCM	22.93	16.25
Chemical requirement (a) For whole year	Qty. Cost	207. 90 Tonnes Rs. 6.5 Million	0.50 Tonnes Rs. 4.8 Million
(b) For selected period (March-June)	Qty. Cost	78. 60 Tonnes Rs. 2.5 Million	63.20 Tonnes Rs. 2.0 Million
Savings in evaporation loss due to application of chemical:			
(a) For whole year (b) For selected period (March-June)	MCM MCM	8 2.5	5.90 1.85
Savings 6.68 MCM i.e. 29% without chemical i.e. 6380 Million gallons or say 100 day supply.			

Also an amount of Rs. 40 lakh were earned by raising fodder crop in the emptied reservoir bed by using available soil moisture.

Providing underground storages for prevention of evaporation was also reportedly done in Talaji rivulet near town of Talaja in Bhavanagar district in the Saurashtra region. Significant increase in ground water level was registered by recharging the aquifers in the locality. Minimising exposed water surface through storage management or integrated reservoir operation was also used successfully in the lakes of Vaitarana, Tansa, Vihar and Tulsi supplying water to Mumbai city. This method was also used successfully for the two Hiran Reservoirs in Junagarh district of Saurashtra area in Gujarat State.

8.0 CASE STUDIES OF EVAPORATION CONTROL IN OTHER COUNTRIES

8.1 Using Water Evaporation Retarders

8.1.1 Stephen Creek Reservoir, Broken Hill, Australia

The studies on evaporation control were carried out on **Stephen Creek reservoir at Broken Hill, Australia**. During a period of 14 weeks with the application of 10% Cetyl alcohol solution with the average daily dosage of 0.2 oz of solid alcohol / acre. This reduced evaporation by 37%. Due to high velocity of wind, the results were less encouraging.

8.1.2 Lake Hefner, USA

The U.S. Bureau of Reclamation, along with a group of collaborating organisations, investigated the application of the monolayer technique to **Lake Hefner, USA**. The use of Cetyl Alcohol reduced the evaporation by 9% with an accompanied rise in water temperature by 1^{o} C. The practical observation from this investigation is that of all the factors influencing the survival and effectiveness of the monolayer film, the wind speed could probably be considered to be most important. When the wind speed exceeds 8 m/s coverage becomes impossible **(Crow *et al.*, 1969)**.

8.1.3 Malya Reservoir and Other Lakes, Africa

A 3 % solution of Cetyl+Stearyl alcohol blended in Kerosene was used in the experiments conducted on **Malya Reservoir and other lakes in Africa** and it resulted in 11% saving of water under adverse conditions.

8.1.4 Adelaide Hills Reservoir, Australia

Water evaporation control products shield reservoirs to reduce evaporation. The composition of one such water product is hydrated lime, and Stearyl and Cetyl alcohol. This provides an invisible surface film that biodegrades in 2-4 days and is reported to cause no known ecological impact to the aquatic environment. The product would be applied regularly to the reservoirs over the summer period.

The product is currently being trialed in Australia for smaller scale applications and is not considered a proven technology for use on the Adelaide Hills reservoirs. Before implementing this option laboratory and field trails would be required to determine its effectiveness given local conditions and implications for local ecosystems. For example, it is likely that high wind speeds experienced over the reservoirs will reduce the effectiveness of the film by causing it to break up and disperse rapidly.
(Source: www.waterproofingadelaide.sa.gov.au)

8.1.5 Yanling, Shanxi, China-2001

About 42% Reduction in evaporation vs. untreated water was achieved in Yanling, Shanxi, China using Water$avr a patented product of Flexible Solutions International, Inc. a Nevada USA corporation (Source: www.flexiblesolutions.com). Water$avr is a mixture of Calcium Hydroxide powder with a stearyl/cetyl OH flow aid, in a powder form. The same website also mentions about the researches done at the following places. The website of American Water Works Association also lists the following case studies done using Water$avr.

- October 2001, Bakersfield, CA: 27% Reduction in evaporation vs. untreated water.
- March 2002, Chennai India, Anna University 20 to 30% Reduction in evaporation vs. untreated water.
- June 2002, Arizona USA, Private Mining Company 20% Reduction in commercial evaporation use.

8.1.6 Monolayer's Role in Hurricane Mitigation through Evaporation Reduction

Mr. Yu-Lun Lawrence Hsin in his B.Sc. thesis submitted to Massachusetts Institute of Technology in June 2002 has stated that the potential for monolayers to be used in hurricane mitigation comes in their ability to retard the rate of evaporation, which is a key factor in the maintenance of a hurricane's strength. Long chain alcohols have proven particularly promising in field studies to offer a resistance to evaporation.

Mr Lawrence Hsin focused on one particular monolayer—Hexadecanol—to determine its fitness for use in reduction of hurricane strength. To test the properties of the monolayer that were most pertinent, experimentation and apparatus set-up covered four areas: duration of Hexadecanol presence, effects of Hexadecanol submersion, effects of disruption in Hexadecanol film, and the evaporation retardation rates. The first three properties were tested in experiments where surface tension readings indicated the presence of the monolayer. For evaporation retardation experiments, a new laboratory was conceptualized and constructed. From the results of the experiments, it was concluded that Hexadecanol as a *film* is too easily disrupted to be useful in hurricane mitigation. Even though it had the desirable properties of rapid spreading, sufficient duration (also not too long to become an environmental hazard), and ability to rise to the water surface upon the *first* application, this monolayer's inability to reform by itself after being torn apart is far too significant. It is infeasible to use Hexadecanol for the substantial reduction in hurricane strength."

8.2 Other Evaporation Retardation Measures

8.2.1 Compartmentalisation of Reservoirs

Water harvesting agri-systems or the coupling of artificially collected rain water with agriculture and surface storage system, offer a promising way of increasing both the quantity and the dependability of water in arid and semi arid lands. The use of compartmented reservoir in conjunction with appropriate agri-systems provides a relatively low cost and efficient method of storage as compared with conventional storage methods. Based on the principle that the division of a conventional reservoir into compartments with systematic pumping of water to the deeper compartments can achieve evaporation control through reduction of surface area. Few reservoirs were analysed by a computer model and it was found that savings of 50-60% can easily be obtained **(Cluff, 1978)**.

8.2.2 Floating Granular Material

Investigations were conducted to determine the feasibility of reducing evaporation from open water surfaces with white, floating granular material. These studies were conducted on buried 7.2m dia. tanks where almost all energy exchange occur through the water surface. Materials evaluated were Calcium Carbonate dust, silica sand, polystyrene beads, chopped Styrofoam, and Perlite. Evaporation reduction for one week ranged from 21% for silica sand to 64% for chopped Styrofoam **(Myers & Frasier, 1970)**.

8.2.3 Floating Rubber Sheets

Evaporation control for stock tanks in Utah was investigated using floating sheets of foam rubber which is highly resistant to weathering and can be formed into a continuous cover by lap jointing using contact cement. Evaporation reduction of about 75% was achieved by covering 95% of water surface **(Dedrick *et al.*, 1973)**

8.2.4 Foamed Wax Blocks

A review of evaporation reduction studies indicated that shades suspended above a water surface and floating covers on a water surface gave best results. Of the two, floating cover was most practical. Field tests using floating covers of foamed wax blocks, continuous wax and foamed rubber reduce evaporation losses 36% to 84% over 8 years period. Evaporation reduction efficiency of the continuous wax covers began to decrease after a few years of exposure, while the foamed rubber and the foamed wax blocks showed no signs of deterioration **(Cooley, 1983)**

8.2.5 GHD Pty Ltd Australia

GHD Pty Ltd, Australia in its report on “Methods for Reducing Evaporation from storages used for Urban Water Supplies” March-2003 mentions about the effectiveness of various Water Evaporation Retarders.

a) **E-Vap-Cap** is a product produced in Australia by a joint venture of Sealed Air Australia Pty Ltd, Evaporation Control Systems (ECS) Pty Ltd and Darling Downs Tarpaulins Pty Ltd. The product is a multi-layered polyethylene (PE) membrane approximately 0.5mm thick containing buoyancy cells trapped within the layers. E-VapCap reduces evaporation by covering the surface area available for evaporation. The top layer of PE is coloured white and UV stabilised to reflect sunlight away from the water surface and reduce UV degradation, enhancing product life. The bottom layer is coloured black to reduce the sunlight penetration to reduce biological activity below the cover (ECS Pty. Ltd. Website). E-VapCap has been installed on approximately 20–30 water storages ranging from small tanks to storages of 4 hectares around southwest Queensland and northern New SouthWales. E-VapCap is made from polyethylene (PE) in two qualities, normal or food grade, available on request. The cost of the food grade PE is 10% greater than the normal grade. It is unlikely that there would be any contamination of the water supplies from the materials.

   The efficiency of evaporation reduction is dependent on the proportion of the storage that is covered. In areas that are covered, evaporation is reduced by close to 100%. The edge of E-VapCap is embedded into the wall of the storage to prevent movement in the wind, ensuring that the water surface remains protected.

b) **Floating Object- Aquacap**: A research program is developing Aquacap as a method to reduce evaporation from open water storages by covering the water surface with small modular domes. There are a number of other benefits including reduced algal growth and reduced erosion as the domes minimise wave action. Each dome is independent of the other domes and they are reported to be stable in winds of approximately 70 km/h as the dome extends below the water level. This product is still in the research phase and is not ready for commercial use.

   It would be expected that there are similar issues as for E-VapCap as the modules prevent oxygen transfer and light penetration to the water surface and reduce wave action (and hence oxygen transfer). Due to the spaces between the modules the impacts of the Aquacap would not be as great as that for continuous covers, including that of reduced algal growth.

c) **Water Bladders**: Water storage bladders use a similar concept to wine cask bladders. The bladder material, generally polyethylene, provides a complete lining, above and below the water storage. The cover and walls raise and lower with the water level in the storage, reducing both the evaporation and leakage losses from the storage. Wide BayWater has installed a number of these bladders in place of potable water storage reservoirs. The bladders were installed in large earth craters, shaped and packed with material to support the geo-synthetic liner. The bladders installed by Wide Bay Water are relatively small in comparison to most water supply storages, the bladders range in size between 2.5-30 ML In the evaporation control sense this product is simply a floating cover that is joined to a liner, and would have similar advantages and disadvantages to floating covers. The small size of the water bladders may serve to reduce potential problems, as there is a relatively short detention time in storage. If the detention time is increased then more problems may be encountered. The effects of anaerobic conditions may be reduced because of lower organic levels as a result of the floor of the storage being lined; this would be dependent on the organic levels in the influent water.

d) **Hydrotect** is a water evaporation retardant that is an emulsion of 60% water and 40% aliphatic alcohols. The product is claimed to be non-toxic, biodegradable and is suitable for application to drinking water reservoirs. It uses the same method of action that Water$avr uses and achieves similar levels of evaporation reduction. The application of the product involves the creation of a solution and then the application of that solution to the water surface. Methods proposed for application in Africa included using local fire trucks, spray equipped trucks and manual labour. The method selected was the manual application, in this case from boats on the water. The direction of the wind needs to be taken into account to ensure the best spreading of the product across the water.

e) Some **biological covers** may have the potential to provide a small decrease in the volume of evaporation. This is dependent on the species of plant involved and care is required as many species increase the level of evaporation. Studies in Thailand have shown that **Duckweed** can reduce evaporation by up to 10%. It is unlikely that duckweed or other plant would be acceptable for use on water supply storages as it would prevent the use of the water body for secondary uses, such as recreational activities, would potentially create issues for water quality and would impact the existing environment (for in-stream storages). There is also a risk of introducing foreign species that may spread beyond the intended areas.

9.0 PROPERTIES OF CHEMICAL WATER EVAPO-RETARDANTS MONOLAYER

For evaporation control, WER used shall have the following basic properties:

a) It should spread easily and form a compact, cohesive and even mono-molecular film on water surface.
b) The thin film formed by spreading WER should be pervious to oxygen and carbon dioxide, but tight enough to prevent escape of water molecules.
c) It should be sufficiently durable and should reseal itself, in case it is broken due to external disturbances as wind, waves, etc. The pressure of film so formed is also found to give a definite relation to the efficiency of the monolayer.
d) The chemical WER should be tasteless, odourless, non-toxic and non-inflammable. It should have no effect on quality of water and aquatic life.
e) It should not be affected by water borne bacteria, proteins and other impurities in the water.

9.1 Higher Fatty Alcohols

Compounds having the above desired properties which are mainly used for evaporation retardation are Cetyl alcohol or Hexadecanol ($C_{16}H_{33}OH$), Stearyl alcohol or Octadecanol ($C_{18}H_{37}OH$) and Docosanol or Behenyl alcohol ($C_{22}H_{45}OH$) or a mixture of these compounds. All these alcohols should be 99% pure for getting the desired properties of monolayer. Studies on Cetyl alcohol, have shown that it satisfies the following two conditions:

1) It gives a compact monolayer with strong cohesive forces between the residual chains; and
2) Spreading rate and resealing ability are fairly good.

While the first property results in greater reduction in evaporation losses, the latter leads to better resilience to wind and wave action. The film undulates, contracts and expands with the wave action of surface water, instead of breaking beyond certain wind speed.

Another important property of the monolayer formed from the compound Hexadecanol is that the molecules stand on ends like bristles of a brush with one end attracted to water and the other repelled by it. With sufficient Hexadecanol available, the molecules join each other tightly, preventing the escape of water vapour. The film however, is porous to the passage of oxygen and carbon dioxide, a quality which renders its use environmentally safe.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia had recommended Hexadecanol “SI-RO Seal”, a pure form of that chemical containing alcohols in the following proportions, for effective evaporation control by forming monolayer.

Hexadecanol	:	Not less than 80%
Octadecanol	:	Not more than 10%
Tetradecanol & Dodecanol	:	Not more than 5%
Alcohols of chain length less than 10	:	Not more than 0.5%
Unsaturated alcohols	:	Not more than 4%

Some other properties of Hexadecanol are:

Iodine value	:	less than 3
Acid value	:	less than 0.3
Saponification value	:	less than 0.5
Hydroxyl value	:	225-230
Melting Point	:	45-50 ^{o} C

The compound Octadecanol is known to be more powerful evaporation retardant than Hexadecanol but its spreading ability is comparatively less.

Water Management Forum, Gujarat had also suggested certain desired properties of chemical WERs for effective use as a evaporation retardant. These are furnished in Table 9.1.

TABLE 9.1 : Desired Properties of a Chemical Evaporetardant Suggested by Water Management Forum, Gandhinagar, Gujarat.

SI. No.	Description	Desired Property	Remarks
1.	Specific gravity	0.93 — 0.98	—
2.	Acid value	1.0 maximum	Acid value more than 1 .0 indicates higher proportion of acid. This will lead to deterioration with age
3.	Melting point	49°C minimum	Contamination reduces the melting point
4.	Solid content	40% minimum	—
5.	Hydroxyl value of either extracted fatty alcohol	205 — 220	—
6.	Toxicity	Non-toxic	Certificate may be obtained from supplier with each consignment for non-hazardous character of the chemical.
7.	Film thickness	Mono-molecular of about 0.01 micron.	—

Regarding alkoxy ethanols, National Chemical Laboratory (NCL), Pune had developed a series of these compounds on laboratory scale, having C_n-OC_2H_4OH, where n= 16,18,20,22. These chemicals are characterised for their purity and several monolayer properties as rate of spreading, film pressure, represented by Area Isotherm (πA), collapse pressure etc. A comparison of these monolayer properties of alcohols and alkoxy ethanols are given below:

a) Rate of Spreading and equilibrium spreading pressure

These properties are important to understand whether the compounds spread reasonably fast or not. Also, the equilibrium pressure obtained should be high. A comparison of these characteristics of alkoxy ethanols with n-long chains alcohols C_n-OH where n=16,18,20,22 based on the studies by NCL, Pune are given in Table 10.2. From this table it can be observed that alkoxy ethanols exhibit high rate of spreading (dN/dt) as well as equilibrium spreading pressure (πe) as compared to alcohols.

b) Film pressure (Area Isotherm ,πA)

All the alcohols and alkoxy ethanols which have been obtained in pure form (99%) have been tested for πA isotherms by NCL, Pune. This property gives an idea whether particular film forms condensed film or not and also gives various two dimensional phase changes especially liquid condensed to solid state. The results obtained by NCL are given in Tables 9.2 and 9.3.

c) Collapse pressure

It is observed that higher the collapse pressure, better will be the stability of the film. From the study conducted by NCL, Pune it has been observed that collapse pressure of alkoxy ethanols are higher than alcohols. Details of this study are given in Table 9.3.

TABLE 9.2: Rate of Spreading and Equilibrium Spreading Pressure of N-Long Chain Alcohols and Alkoxy Ethanols at 25°C.

Compound Chain length	n-Alcohols		
	M.P.(^oC)	πe dyne/cm	dN/dt
C_{16}	49.5	39.6	2.8×10^{13}
C_{18}	59.4 .	35.2	1.1×10^{12}
C_{20}	64.5	32.6	7.6×10^{11}
C_{22}	71.0	27.6	6.0×10^{11}
	n-Alkoxy ethanols		
C_{16}	43.5	50.4	2.3×10^{15}
C_{18}	51.7	48.9	1.8×10^{14}
C_{20}	60.5	49.0	1.2×10^{13}
C_{22}	65.6	47.2	1.5×10^{12}

TABLE 9.3 Data on Collapse Pressure and Area per Molecule from π-A Isotherms of Alcohols, Alkoxy Ethanols and their Mixtures

Compound	Collapse pressure π_o dyne/cm	Area ^{o}A/molecule
C_{16}-OH	43.0	19.3
C_{18}-OH	39.0	19.4
C_{22}-OH	37.0	19.2
C_{18}-OC_2H_4OH	42.0	18.6
C_{22}-OC_2H_4OH	45.0	19.2
C_{16}-OH+C_{18}-OH (1 : 3)	47.0	18.9
C_{18}-OC_2H_4OH+ C_{22}-OC_2H_4OH (1:1)	47.0	19.3
C_{18}-OC_2H_4OH+ C_{22}-OC_2H_4OH (1 : 9)	49.0	19.5

All the above characteristic properties can be measured with the help of Langmuir film pressure balance which is necessary for testing the quality and to standardise the compounds for water evaporation control both in the Laboratory and field experiments.

9.2 Indicator Oils

For effective retardation of evaporation, the molecular film formed should develop adequate pressure. In most cases the initial film pressure is in the range of 20-30 dyne/cm and equilibrium pressure of 40 dyne/cm can be achieved with appropriate dosage. For testing the pressure of WER film, oils of known spreading pressure (indicator oils) are used. The surface pressure developed by certain indicator oils are given in Table 9.4.

TABLE 9.4 Surface Pressure of Indicator Oils at 21 °C

S. No	Indicator Oils	Surface pressure developed at 21 °C (dyne/cm)
1.	Shell Ensis fluid 256	40
2.	Undocylic acid	34.5
3.	Hexadecyl acetate	34.4
4.	Oloic acid	30.0
5.	Octadecyl acetate	24.0
6.	Shell Vitrea Oil 21	24.0
7.	Triolein	22.0
8.	Lauric acid	21.0
9.	Castor oil	17.0
10.	Ethyl Pholometite	16.5
11.	Shell Vitrea oil 13	16.0
12.	Shell H.S.D.	13.0
13.	Triorozyl phosphate	10.0
14.	Myrystic acid	11.0
15.	Palmitic acid	8.5
16.	Carbon disulphide	2.3
17.	Steanic acid	1.5

10.0 MERITS AND DEMERITS OF SOLID AND EMULSION FORM OF WERs

The Acilol TA-1618 is available in solid lump form as well as in emulsion form. In Saurashtra region of Gujarat State, evaporation control works have been carried out extensively with Acilol-1618 in powder form and emulsion form during 1985-88. The WER "Linoxyd CS-40" is available in emulsion form only. This WER was used for evaporation control in Maharashtra during 1977-80 and 1983-85. The merits and demerits of using powder and emulsion form for evaporation control on the basis of their use in Gujarat and Maharashtra have been reported by the Directorate of Irrigation Research and Development, Pune and are given below.

10.1 Dosage

The daily dosages of WER generally adopted in case of powder form is 75 g/ Ha of area to be treated. In case of emulsion form, the general dosage is 500 g/Ha/Day, which can be reduced to 250 g/Ha/Day after first 15 days. Thus the consumption of the material in emulsion form is about 3 times of that in powder form.

10.2 Procedure of Spreading

In the powder form, the procedure of chemical spreading is found to be simple, while in the emulsion form the procedure for diluting, mixing, and spreading is reported to be cumbersome.

10.3 Effect of Wind

The uniformly dusted WER in powder form develops thin film over water surface, which is reported to be disturbed during high wind velocities. In case of emulsion form, the experiments conducted with Linoxyd CS-40 by Directorate of Irrigation Research and Development, Pune have indicated that monomolecular film gets broken and accumulates to one side when wind velocity is greater than 10 km/ hour.

11.0 GUIDELINES FOR USE OF CHEMICAL WERs

The following guidelines are suggested for using WERs in arid, drought prone or water deficit areas. These are broad guidelines only and may be varied depending on the site conditions or according to the manufacturer's specification for WER and equipment used.

11.1 Application in Emulsion Form

The doze of emulsion per day may be 500g/hectare of open water surface for initial 15 days. It can then be reduced to 250g/hectare/day in the subsequent periods of application. The required quantity of emulsion may be diluted with water 20 to 25 times by volume for ease of application. Mixing of emulsion with water may be done either manually or mechanically. The later, however, gives more homogeneous mix. The diluted mix is then filtered to separate out lumps or impurities which could block the dripping line. Application of the solution is done by dripping from storage drums fitted on floating rafts or on shore dispensers.

The floating rafts may be positioned on water surface in grids of size depending on the capacity of the drums so that the entire area of the water surface is covered. The rafts should be anchored to avoid drift. In case the site conditions do not permit anchoring of floating rafts and the reservoirs to be treated is comparatively small, the drums may be mounted on shore dispensers positioned along the periphery of the reservoir. Prevailing wind direction helps in spreading and building of a film.

Heavy wind velocity and changes in wind direction may break the monolayer and thus special efforts are required for the maintenance of the film after such events. Present and continuity of the film can be ascertained by putting a drop of an indicator oil like castor oil on the treated water surface. If the drop of the indicator oil maintains its shape, it shows the presence of the film.

11.2 Application in Powder Form

The suggested dose for application of WER in powder form is approximately 75g/hectare of water surface per day. As the powder is supplied in lump form, it is required to be pulverized into a fine powder form by using a manual or mechanical pulveriser. The powder can be dispersed on water surface from boat by means of manually operated dusters.

For quickness and economy in application, two dusters may be fixed on either side of the boat. Speed of the boat should be regulated in such a way that minimum disturbances occur on the water surface, while completing the dusting as quickly as possible. Depending on the area of water spread, passes of the boat are suitably arranged while taking advantage of the wind direction.

Presence of the film on water surface may be ascertained as in the case of solution form. About 10 to 15 percent of the daily dose of WER may be kept reserved for use whenever the film is broken.

Depending upon local conditions, a method of combining the use of emulsion and powder forms is generally found optimal. During the night, WER solution may be applied using drips on floating rafts located suitable in the reservoir. During the day, WER powder can be sprayed for maintenance of continuous film, taking into account the wind direction.

11.3 Quality of Water

During the course of application of WER for evaporation control, the quality of water may be monitored and effects on the same shall be carefully studied.

11.4 Equipment Required

The equipment required for spreading WER and for assessing the savings in evaporation losses are detailed in Table 7.11.

11.5 Guidelines for Testing Film Pressure

The pressure that a monolayer builds on the treated surface of water can be indicated approximately by use of oils of known spreading pressures. The spreading pressure of various oils are given in Table 9.4. A small drop of any of these oils is applied over the monolayer, whose pressure is to be assessed, if the indicator oil drop spreads, it is evident that water surface carries a film at a pressure lower than spreading pressure of indicator oil. If the drop does not spread, it indicates that the film pressure is greater than the spreading pressure of the indictor oil. Oils of different spreading pressures in the working range may be kept ready at the site before field application of WER.

12.0 ECONOMICS IN USE OF VARIOUS METHODS

12.1 Chemical WERs

The economic viability of evaporation control by chemical WER in drought/ scarcity conditions have been conclusively proved by the results of the works undertaken in Gujarat, Maharashtra and Rajasthan. However, the success of evaporation control work depends mainly on the site conditions. In unfavourable site conditions, the work may turn out costly, as reported in case of evaporation control measures in Dheku and Ambadi Reservoirs in Aurangabad District of Maharashtra State. The cost of evaporation control work done during 1984-85 in these reservoirs is reported to be around Rs. 10.00 to Rs. 13.43 per m^3 of water saved. One of the reasons for this exorbitant cost is attributed to the high wind speed prevailing at the site.

12.2 Compartmentalisation of Reservoirs

The compartmentalization work done in Bhogavo-1 reservoir during the year 1988 involved a cost of Rs. 12.00 lakh for construction of bunds. Another amount of Rs. 15.00 lakh was spent for pumping water from one compartment to another. This measure had resulted in saving of one month's supply of water. This quantity of water , if provided through water tankers would have cost Rs. 32.00 lakh. The main advantage of compartmentalisation is that expenditure incurred on construction of bunds is a one time measure only. Another benefit from compartmentalization is that the emptied bed of the reservoirs could be used for raising various dry crops using the available soil moisture. In Bhogavo-1 reservoir two crops of green fodder of value Rs. 40.00 lakh were reportedly raised on the emptied bed of reservoir.

This is not to suggest that the chemical evapo-retardants are not to be used. However, other means of controlling evaporation could also be explored in areas with recurring droughts and scarcities and if found more economical and practical, the same could be beneficially resorted to.

13.0 SUGGESTED AREAS OF FURTHER RESEARCH AND DEVELOPMENT

Research and development efforts are needed in the following areas to improve the evaporation control in water bodies.

i) R&D efforts are needed to develop a chemical WER, which should give a more compact monolayer with strong cohesive forces, properties of self spreading and reuniting to maintain the monolayer in resilient state on the water surface for wind velocities higher that 15-20 km per hour. However, the use of chemical WER is presently limited to small and medium tanks, because in large reservoirs wind has a detrimental effect on WER film.

ii) The monolayer formed should be durable, so that the frequency of application can be reduced from 24 hours to 3-7 days to make it more acceptable and cost effective.

iii) There is a need to bring down the cost of chemical WERs presently available. This can be achieved by developing new process technology for mass production of chemical WER.

iv) Little research has been done in India in the field of evaporation control by methods other than chemical retardation. Research efforts are needed to develop effective and economically viable materials for evaporation control, such as floating covers etc. Also there is need to develop/ identify plants for use as wind breakers, which are effective and at the same time have lower rate of evapotranspiration.

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List of Abbreviations

mm	Milimetre
cm	Centimeter
m	Metre
km	Kilometer
Sq.Km.	Square Kilometer
m^2	Square metre
ha	Hectare
m^3	Cubic metre
MCM	Million cubic metre
kg	Kilogram
gm	Gram
kg/ha	Kilogram per hectare
gm/ha	Gram per hectare
mm/hr	Millimeter per hour
kmph	Kilometer per hour
^0C	Degree Celsius
^0F	Degree Fahrenheit
min.	Minimum
max.	Maximum
hrs	Hours
mb	mili bar
M.P	Melting point
CWC	Central Water Commission
NCL	National Chemical Laboratory
ICAR	Indian Council for Agricultural Research
WER	Water Evapo Retardant