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ANNEXURE

1. BACKGROUND & NEED

1.1 Cold Deserts

Cold deserts are a distinct biome of the world and a very difficult habitat. Lands of high elevation in the rainshadow of some mountain range, they are characterised by extremely cold winters, moderately hot summers, and arid or semi-arid conditions. Located in the interior of continents, away from any source of moisture, cold deserts manifest remarkable ecological variety and biological diversity. Their geographic remoteness and unfriendly climatic conditions greatly constrain economic growth and development. Enviromental degradation, which is on increase, is an additional cause for concern.

Apart from the distinct natural characteristics, they are resource deficient and difficult habitats in terms of natural hazards as well. A rarified atmosphere, fast blowing winds - eroding the immature sandy soils, extreme variations in daily and seasonal temperatures along with scanty or no precipitation during spring and summer, ensure short growing seasons (2-5 months) with exposure to harmful infra-red and ultraviolet radiations. Unharvested glacial melts, frozen soil moisture during early spring and low relative humidity during the growing season are some abiotic features. These regions experience two pronounced seasons - a short, cloudless, arid summer and a long, windy, freezing winter. Blizzards, snowstorms and avalanches are common. Water resources are minimal and the main form of precipitation is snow, but only 10inches or less per year. They are typically covered by sand dunes and pebbles and rocky soil, and often contain large deposits of minerals and gemstones; flora and fauna are typical of each distinct cold desert region and include some rare varieties. In terms of habitation, they are usually sparsely inhabited.

1.1.1 Cold Deserts of the World

Two major mountain systems span the Earth's surface - one separates Eurasia from Africa and India and stretches from the Atlas beyond Kerinci in Indonesia; the other circles the Pacific Ocean and reaches to Antarctica, and includes the Andes, the Rockies and Brooks Range, the Central Range in Siberia, and ranges in Japan, Australia, and New Zealand. Cold deserts of the world exist in both these mountain systems: the Atacama on the coasts of S. America, the Gobi Desert and the Taklamakan in Northern and Western China, the Tibetan Plateau, Turkestan in Southwestern Russia, the Great Basin in Western USA. Although alike in various environmental aspects, they differ in degree in terms of natural resource availability, as well as in socio-cultural aspects of indigenous communities and their environment management practices.

The major cold deserts of the first mentioned mountain system, in which the Indian cold deserts lie, include

a. The Moroccon Highlands - This is a valley in the High Atlas range in the Moroccon highlands.

b. Iranian - This region lies in the Hindu Kush Ranges covering parts of Iran, Afghanistan and Pakistan.
c. Turkestan - This region stretches from the Caucasian Mountains across the Pamirs to the Tien Shan covering parts of the Middle East and Southwestern Russia.
d. The Gobi & the Taklamakan - This region comprises two contiguous cold deserts in northern and western China.
e. Tibetan Plateau - This region lies in the Himalayas & Karakorams, covering parts of India & Nepal and all Tibet.

The Iranian, Turkestan, Taklamakan and Gobi deserts, and the Tibetan Plateau are in reality a continuous belt. In terms of the socio-cultural aspects of these regions, running west to east in the mountain range under focus, the cold desert pockets beginning at Morocco and reaching up to the Turkestan cold deserts are inhabited by communities that are primarily of Persian descent and follow Islamic traditions. The Gobi and Taklamakan have a mix of the Persian-Islamic communities and the Chinese-Buddhist communities, while the Tibetan Plateau is inhabited by communities that are primarily of Mongolian descent and follow Buddhist traditions.

1.1.2 Cold Deserts in India

Cold deserts in India are a part of the Himalayan cold desert stretch and have been formed primarily due to the rainshadow effect of the towering main Himalaya mountain wall and its offshoot ranges which run in an arc from the Indus gap in the north-west to the Brahmaputra gap in the north-east. The average elevation of this imposing barrier is more than 6000 mts, thus creating an effective barrier against the movement of the rain-bearing SW monsoons to the regions lying to the north of it. There are two physiographic classes of cold deserts in India: the trans-Himalaya which lies across the main Himalaya and is part of the vast Tibetan plateau and the inner dry valleys within the main Himalayan range which lie in the rainshadow zone.

The two physiographic classes of cold deserts in India are as follows:
a. Trans-Himalaya: The Trans-Himalaya lies across the main Himalaya and physiographically forms a part of the vast Tibetan plateau which lies further north. The average elevation of this region is more than 3000 mts, eg., Ladakh, Lahaul, Spiti, and Pooh.
b. Inner Dry Valleys: These are smaller valleys within the main Himalayan range which lie in the rainshadow zone, and are arid regions although not a part of the Trans-Himalayas, eg., parts of Uttarkashi, Chamoli and Pithoragarh in Uttaranchal.

The cold deserts in India include:

i. *Western Himalayan India* -

the Ladakh region - This includes the districts of Leh and Kargil in the state of J&K. It comprises the valleys of Indus, Gilgit, Shyok, Zanskar, Markha, Rumbak, Drass, Shigar, Suru, Nubra, Khaplu, Salt Lake, and Puga.

the northern Himachal region - This includes the districts of Lahaul & Spiti, Kinnaur, and the Bharmour region in Chamba district in the northern part of the state of Himachal Pradesh. It comprises the valleys of Chandra, Bhaga, Chandra-Bhaga, Spiti, Pin, Sutlej, Hangrang, Ropa, Sangla, Bhaba, Tirung, Gyanthing, Pejur, Keshang, Mulgoon, Yula, and Bharmour

ii. *Central Himalayan India* -

tracts in northern UP - This includes Nilang, Mana & Niti, and Upper Pithoragarh in the state of UP. It comprises the valleys of Jahnvi, Goriganga, Kuti, Chandans, and Darma

iii. *Eastern Himalayan India* -

North Sikkim - This includes the Lachung and Lachenchu valleys in the northern part of the state of Sikkim.

1.1.3 The Western Himalayan Cold Deserts

Spread over an approximate area of 74,809 sq.km, the cold desert area in Western India covers 12 out of 131 desert blocks in India. Leh and Kargil districts of Ladakh in Jammu & Kashmir and Lahaul & Spiti along with some parts of Chamba and Kinnaur districts of Himachal Pradesh comprise this cold desert area. Similarity in their phsiographic location and the consequent geomorphic processes still unfolding in this region lend to this entire region a largely similar texture. Each of these districts is described in greater detail:

i. *Lahaul & Spiti*

The district of Lahaul & Spiti lies in the state of Himachal Pradesh in northern India. It has an area of 13,835 sq. kms. and a population of 31,294. Keylong is the district HQ. It is one of the frontier districts of India and has a very difficult terrain with ice-fields, snow-covered peaks and a most inhospitable climate. Lahaul comprises the three valleys of Chandra, Bhaga, and Chandra-Bhaga, one great mass of mountains and the Lingti plain of about 260 sq. kms. area. Spiti comprises four distinct regions - Sham is the lower region situated on both sides of the river Spiti between its confluence with Lingti and its junction with Pare, Pin is the valley of the same river located on both sides of the river with about ten inhabited villages, Bhar is the middle region located midway along the river above the town of Kaza, and Tud is the higher region and includes all the areas above the river Spiti and the waste tracts of Tsarab. The main amongst the numerous rivers in Lahaul are the Chandra river and the Bhaga river which amalgamate into Chandra Bhaga or Chenab river. In the Spiti valley, as the name indicates, the main river is the Spiti. The other famous river joining it is the Pin river which has its source near Bhabha Pass and ultimately joins Spiti Lingti, Gumto and Parechu. The total area of Spiti is 710,081 hac, of which 482 hac is forested, 51 hac is under shrubberies, 1214 hac is the total cultivated land, 158,086 hac is desert land & grasslands and 549,807 hac is the total uncultivated land. The total area of Lahaul is 911,162 hac of which 135,369 hac is under forests. The irrigated, cropped area is 3,375 hac, with 139 hac sown more than once, and 319 hac under miscellaneous tree crops and groves. 218,835 hac are permanent pastures and 4,416 hac is barren uncultivable land.

The economy of the region is at a subsistence level and based primarily on agriculture. Agricultural operations begin in April and end in September before the snow sets in. The traditional crops on the uneconomic holdings used to be barley and buckwheat and pulses like peas, oil-seeds, etc. These are the cash crops even today. However, with the opening of the vehicular roads, people have shifted from cereal crops to commercial crops like seed potatoes. Kuth has also been introduced in the region. Apricots, strawberries, cherries and apples grow wild, although horticulture has not been too successful. Although agricultural productivity is low, due to the intensity of the cold crops do not have to suffer the typical diseases. While, Lahaulas primarily lead an agro commercial life, the Spitians are predominantly agro pastoral, with livestock population outnumbering the human population.

ii. *Kinnaur*

The district of Kinnaur lies at the south-eastern tip of Lahaul & Spiti and consists of an area of 6,401 sq. km. The population is 71,270 (1991 census). The district consists of a series of mountains and precipitous ravines descending rapidly to the bed of the Sutlej. It is bounded on its northern frontier by spurs of snowy mountains which separate it from Spiti and on the east by similar spurs by which it is shut off from Tibet. Sutlej, the principal river of the district arises in the Himalayas and has plentiful and perennial sources of water. It enters Kinnaur district from the Tibetan territory. The main feeders of the river in the district are Lee or Spiti, Baspa, Tidong, Wangar and Darbang, apart from various other small streams, some of which are seasonal.

Traditionally, Nichar and Kalpa sub-divisions were known for their stately cedars and kail trees. This apart, beyond Karchham, large wild forests of chilgoza trees abound and its edible nuts fetch a handsome price and are the main source of income for the locals. Of late, there has been an indiscriminate felling of trees by the ever growing local population and the forest lessees, creating massive erosion problems in the district. Out of the gross area under cropping, as much as 9,659 hectares were under cereal crops. In Kinnaur, the local variety of millets are grown as cereals. Kinnaur district has a distinct place in the country in terms of quality of apples and temperate fruits like walnuts, almonds, raisins, chilgoza, apricots, etc. Ever since the creation of a separate district, horticulture has been emphasized and encouraged so as to commercialise the traditional agrarian economy. This is evident from the fact that fruit production grew from 300 tonnes in 1960-61 to 4,500 in 1978-79; during the same period, the area under horticultural production increased from 290 hectares to 2,463 hectares. The state Government is trying to commercialise dry fruits like almonds, chilgoza, raisins, and to popularise it amongst the people. Though the entire Kinnaur district is ornamented by perennial foaming rivers and rivulets, due to the difficult topographical conditions, not much headway has been made in matters of irrigation.

iii. *Kargil*

The district of Kargil has an area of 14,036 sq. kms. and a population of 81,067 (1991 census). This district is distinctly marked as one of the backward areas of the state of Jammu & Kashmir. The altitude of inhabited areas range from 8,500 ft to 13,000 ft. The climatic conditions are severe during winter and snowfall in the Drass region is exceptionally heavy. At times the temperature touches -40°C. This results in the blockade of the roads for more than six months every year from December to June. At other places, rain and snowfall are scanty, on an average not exceeding 15 inches per year. The difficult terrain and topography of the district is a big dampener in the development of the district. There are two tehsils in the district, *viz* Kargil & Zanskar, and seven blocks, namely Kargil, Chiktan, Drass, Sankoo, Zanskar, Shergole and Taisuru. There are a total of 127 villages in the district, out of which 102 are in Kargil and 25 in Zanskar tehsil.

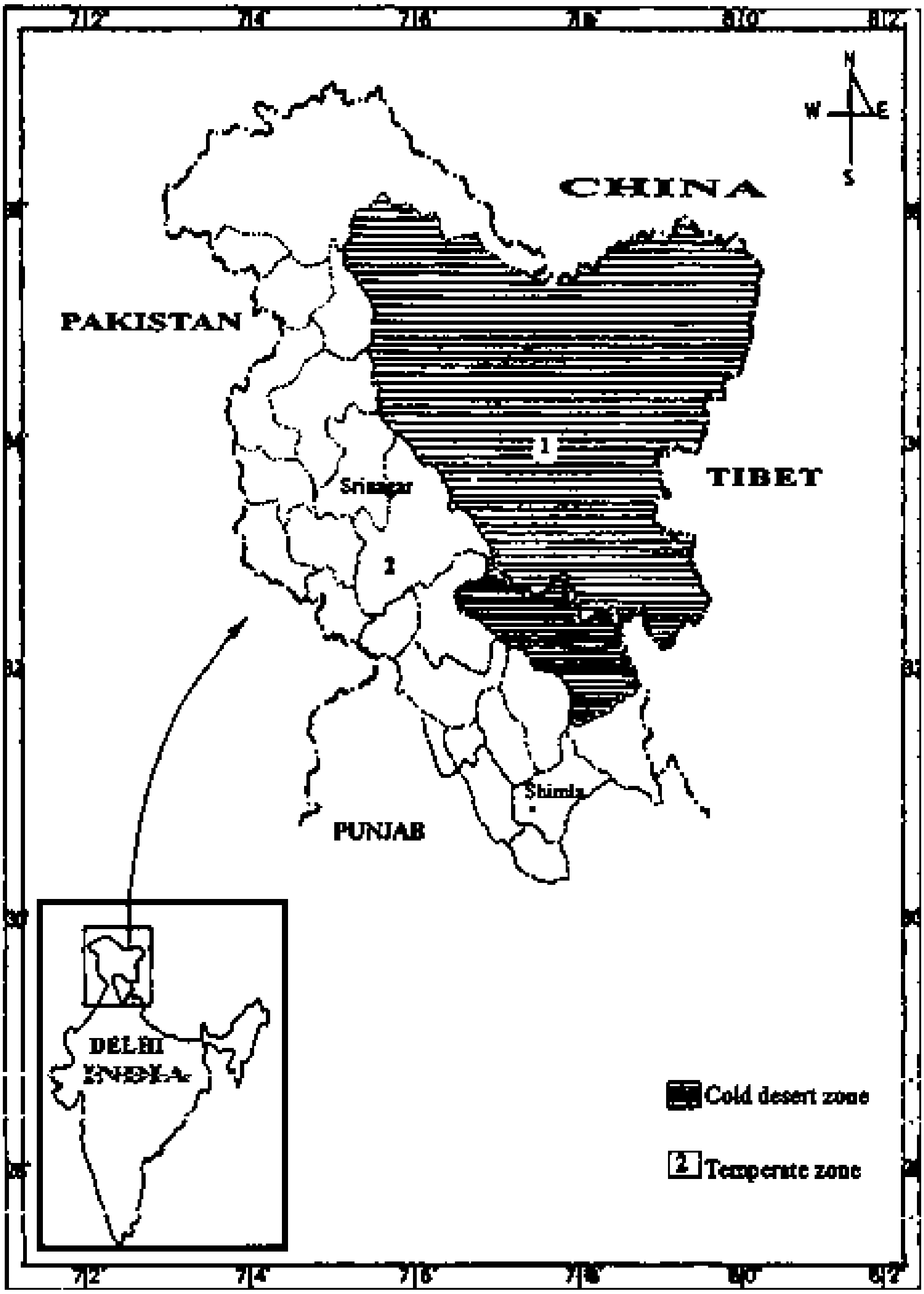
Agriculture is the main occupation in the district and about 91% of the working force is engaged in this pursuit alone. The major crops of the district are wheat and millets. The main source of irrigation is canals and agricultural operations continue to be based on primitive and traditional lines. The introduction of new agricultural methods and distribution of improved varieties of seeds are the main focus of the government for giving the district a boost in agricultural production. Improvements in and extension of minor irrigation facilities are receiving top priority. Considerable attention is also being given to the development of horticulture in the area. The Halman variety of apricots suggests a promising market outside the state. Distribution of budded apricot plants to the fruit growers, fertilisation of fruit trees, sulphur fumigation and hygienic sun-drying demonstration of apricot (Halman variety), and supply of polythene sheets at 50% subsidy for protection of the apricot from rain and dust, are the various measures being taken to improve the export of the fruit to other parts of the country.

iv. *Leh*

The district of Leh in the Ladakh region of Jammu & Kashmir state of India is a culturally and ecologically unique land in the course of transition. 45,110 sq. kms. of land composed of different river valleys amidst high mountain ranges, with the elevation of inhabited areas ranging from 8,500 ft. to 13,000 ft. A cold desert with scarce water and rainfall - among the lowest in the country -, and hot summers at 36°C and freezing winters at -32°C. Hemmed in by the highest of mountain ranges, this region has lived largely undisturbed and self-contained for centuries, much as the neighbouring Tibet. Traditional wisdoms made spirituality and harmony between man and nature a way of life. The two rivers Indus (with a mean discharge of 3850 m^3/sec and 1263,000 km^2 drainage area) and Shyok flowing through the district do not presently contribute much to irrigation; only the snow-fed nallahs in the district provide water for irrigation purposes. There are five administrative blocks in the district *viz* Leh, Khaltsi, Nyoma, Nubra and Durbuk.

The main source of livelihood for the people in the district is agriculture, supplemented to a large extent by animal husbandry. In view of the climatic conditions of the region, agricultural operations are possible only during summer. These are confined mainly to river valleys and nallah plains. The main crops cultivated are wheat, barley, vegetables and fruits like apple, apricots, etc. Smaller millets are also grown to some extent apart from oil crops in some pockets as a double crop. The total area under cultivation in the district is 15,338 hectares. To improve the quantity and quality of fruit, good varieties of fruit plants are being supplied to the farmers at nominal charges. Ladakh has great potential for the development of livestock in several rich rangelands in the high altitude areas of the district. The climatic conditions also necessitate the use of animal protein in the form of milk, meat and eggs. The main feature in the livestock of the district is the unique species of animals which are not found in other parts of the country. These are pashmina-bearing goats, yaks, the dzo and dzomo (cross between yak and cow) and Zanskari horses. The livestock is commonly reared in the belts of Changthang (Nyoma Sub-Division), Khaitsi and Nobra. The Changthang belt is famous for its pashmina goats. The altitude of this area varies from 12000 to 16000 feet. A quickly developing sector in the area is that of tourism. Although currently restricted to Leh and some other habitations like Alchi, Padum, Lamayuru, etc., tourism provides supplementary income to several families through transport services, hotels, guide services, and also associated sectors like handicrafts.

Fig. 1: Map of the Western Indian Himalayas



1.1.4 Characteristics of Cold Deserts in India

Climate

The climatic conditions prevailing in the cold desert regions vary from dry temperate to arctic. These regions experience two pronounced seasons - a short, cloudless, arid summer and a long, windy, freezing winter. The great Himalayan mountain has a profound influence on the climate of the cold deserts. It blocks the SW monsoons, which are gigantic land and sea breezes, thus making the cold deserts devoid of rainfall. The extra-terrestrial weather systems of Central Asia also have a bearing on the prevailing climatic conditions of the cold desert regions. In winters a high pressure system builds over Central Asia and a low pressure over the Indian Ocean, resulting in the flow of winds from north to south. This causes precipitation in the form of snow in the cold deserts. Blizzards, snowstorms and avalanches are common. Snowfall is very heavy in the upper reaches. Winter sets in early and the first snowfall of the season may be received in mid-October. Winter temperatures of inhabited regions touch -40^{o}C. The northern cold dry winds and western disturbances affect the cold deserts during these winter months, bringing on even more cold since there is no barrier between these and Central Asia. The summer season begins in May depending upon altitude, latitude, aspect and topography, and continues till September. The snow cover in the lower tracts melts, but the higher reaches lie above the line of perpetual snow. With summer, conditions become conducive for vegetative growth and this heralds the start of cultivation. Summer temperatures vary widely and have been known to shoot up to 35^{o}C during the day; night temperatures however drop fairly rapidly. Summers are cloudless and arid and the period from May to October experiences low relative humidity and are generally the drought periods. A short autumn season follows summer, beginning in late September and continuing till the onset of winter in early or middle November. This is the harvesting season for the cold desert inhabitants. Winter is the longest and the most severe season in the cold deserts and it continues from middle November to April. There is heavy snowfall and many rivers, lakes and streams freeze during winters. There is a short spring season between winter and summer. Strong winds blow throughout the year and blizzards, snowstorms and avalanches are also common.

Soil & water conditions

There is a vast variation in the geology of the cold desert areas which causes significant changes in the soils of these tracts. The principal soil types of these regions are red & black soils, ferrugenous red soils, brown forest soils, mountain and hill soils, high altitude meadow soils and alpine soils. The nature and composition of soils in the cold deserts depends on- prevailing climatic conditions, nature and type of vegetation, parent rock and dominant geology and topography and terrain. The soil is very fragile and not very productive and the climatic conditions allow a very short growing season. It is shallow, rocky, impervious, has high silt content, and lacks organic matter. The cropped area typically has red and black soils, while pastures and grasslands have brown soils.

Water resources are minimal with the glacier-fed streams the only source of irrigation. Rainfall is very low and in the core zone, it may be restricted to a few showers each year. The total annual rainfall in these regions is usually less than 50 cms, and even lower in some tracts. The bulk of the precipitation received each year is in the form of snow. The glaciers and glaciermelt are the main source of water is the region. The rivers that run through the region are wide and fast-moving, but their high silt content and position vis a vis habitations (typically lower than habitations) disallows their usage for water requirements.

Forests & terrain

The slopes of the cold desert region are totally barren, with the exception of a few species of shrubs, which are the main soil binders of the region. Sparce natural vegetation results from over-exploitation by a variety of agencies - e.g. grazing by both domestic and migratory animals, harvesting (of vegetation) to meet energy needs viz. fuelwood and dry fodder for winter besides demands from pharmaceutical agencies. Additionally, both migratory birds and rodents utilize dispersed seeds as a means of sustenance thereby jeopardizing natural regeneration. Features such as high transpiration due to excessive heat (often causing mortality), inadequate photo-hours especially during winter, injury due to frost causes poor seed germination, poor plant growth, poor root formation, deformed canopy, reduced radial growth etc. and other physical signs/phenotypic manifestations which in turn affect the productive biomass production in the region.

Natural vegetation is overwhelmingly herbaceous - comprising of a few tree species and a few shrub species. The lower altitudes experience higher temperatures and water availability is better. This facilitates the growth of broad-leaved species like alianthus, poplars and nitrogen fixing plants like rubenia. Shrubs like Rosa webbiana and seabuckthorn are also common. At higher altitudes the vegetation is sparse with grasses dominating the floral diversity. Willows and poplars grow in the 9,000-12,000 ft. zone. This zone has a huge diversity of plants like Rheum australe, Arnebia euchroma, Aconites, Asters, which are known for their medicinal properties. *Juniperus wallichiana, J. communis, Caragana* spp., *Artemisea* spp., *Lonicera* spp., *Potentilla* spp., *Myricaria* spp., *Koleresia dutheii, Ephedra, Salix,* spp., *Juniperus* spp., *Rosa* spp., *Caragana* spp. *Rhododendron* spp., *Betula utilis* are found here. Additionally, manmade forests of poplars, willows, *Hippophae* spp. and *Myricaria* spp. can also be seen along river banks, rivulets and *nallahs.* The herbaceous element is comprised of *Thymus, Medicago, Trifolium, Anemone, Potentila, Epilobium, Verbena, Allium, Aconitum, Delphenium, Aquilegia, Primula, Geranium, Polygonum* and *Cannabis.* This abundance of the herbaceous element, both in Laddakh and in the cold desert of Himachal, has been the mainstay of the traditional medicinal system prevalent in this region. The nature of flora along with man made interventions have ensured a land use pattern typical to this region.

The principal forest types found in the cold desert regions are as follows:

- Himalayan Moist Temperate Forests*:* These forests are found mainly in the transition zone between the cold deserts and the main Himalaya. The main species are those occurring in the wetter parts of the Western Himalayas like *Cedrus deodara, Pinus wallichiana, Quercusspps, Abies pindrow, Picea smithiana, Rhododendron arboreum, Berberis spps, Princepia utilis, Deutzia spps, Vitis spps, clematis spps, Geranium spps, Senecio spps, Angelica glauca, Heracleum candicans, etc.*

- Himalayan Dry Temperate Forests*:* These forests are found in the drier areas receiving less rainfall. The bulk of the precipitation in this area is in the form of snow, though the elevation may range from 1800 mts to 3000 mts, depending upon local site conditions. The main species are *Pinus gerardiana, Juniperous* *macropoda, Populus spps, Salix spps, Quercus spps, Alnus spps, Rosa spps, Lonicera spps,Ephedra gerardiana, Artemesia spps, etc.*

- Sub-Alpine Forests*:* These forests are found near the snowline in the cold deserts and the transition zone between the cold deserts and the Himalayas. This zone has the species of *Quercus semecarpifolia, Betula utilis, Pinus Wallichiana, Rhododendron,* etc., and herbs like *Anemone spps, Potentilla spps, Rheum spps, Gentiana spps, etc.* The growth of trees is stunted in this region because of the extreme climatic conditions.
- Moist Alpine Scrub*:* These forests are found in cold and dry conditions. In this zone *Salix spps, Juniper spps* and *Rhododendrons* dominate and species of herbs like *Bergenia, Potentilla, Aconitum, Asters,* are also common.

- Dry Alpine Scrub*:* These are open scrub grasslands occurring near the snowline in the drier parts of the cold deserts. These are the most common type of vegetation in the core areas and extend upto the line of perpetual snow. The vegetation is mainly dominated by the species of *Juniperus, Ephedra, Rosa, Arnebia, Hyoscyamus, Aconitum, etc*.

The entire area is highly mountainous with several peaks, valleys and passes, and a severely undulating terrain. The region begins from an altitude of 9,000 ft. and altitudes of the peaks soar to beyond 20,000 ft. Habitations are found uptil 16,000 ft.

The fauna of this entire region is quite unique. Due to poor/rudimentary communication facilities the yak has been the major animal for burden. Besides yaks, livestock comprise mainly sheep and goats. While the major fauna species of cold desert in Jammu & Kashmir are snow leopard, ibex, snow cock, partridges, magpie etc. A large number of migratory birds visit the lakes and rivers. Pashmina goat, Changthangi sheep, yaks, donkeys and double humped camels are animals of economic importance. The ibex, bharal, brown bear, tibetan wolf, nayan, marmot, snow leopard, lynx, weasel, vole, snow cock, snow partridge, chukor, chough, raven etc. are found in the cold deserts of Himachal Pradesh. This uniqueness is being preserved through the establishment of two sanctuaries namely the Pin valley National Park in Spin and the Sechu Tuan Nala in Chamba. As mentioned, yak and sheep dominate livestock composition. Additionally land extensive management and transhumance along with the barter system of converting livestock into other usable commodities are features that characterise animal husbandry practices. Chief among the many problems faced by the livestock sector are - insufficient supply of fodder, overgrazing right up to alpine meadows and difficulty in stall feeding in snow bound areas etc. The *Gaddis* - a migratory tribe of Bharmour, use goat milk to supplement their diet.

Socio-economic conditions

The cold desert districts have an agro-pastoral economy with potatoes, green peas, hops, millets as the main crops. The cropping season is of 4-5 months and allows a single crop only. The main source of irrigation are the glaciers and water is brought into the fields by the system of kuhls. Kuhls are the traditional system of irrigation, consisting of channels, through which water is drawn from the entry points of the glacier fed streams to the agricultural fields. Horticulture is predominant in parts of the cold desert, for instance Lahaul and Kinnaur with the people growing hops, seed potatoes, peas, apples, apricots, and also kuth in their fields.

The people also rear cows, sheep, goats, yaks and churus for milk, wool and meat, and horses and mules are generally used for transportation purposes. Although there are no natural forests, plantations are raised by the Forest department and progressive farmers of the place, and the timber used for house construction and fuelwood, and the leaves used for fodder. Weaving woolen articles - shawls, carpets, rugs, socks, etc. - is the main craft of this region which keeps the women busy during winters.

People stock all essential items before snowfall. Outdoor activities are not possible during winters and the most common activities include clearing of accumulated snow from the roof tops, looking after cattle and domestic animals, weaving and handicrafts, and social activities like marriages, chankas, etc. The houses are kept warm by burning bukharis using wood, dried plants and kerosene. Majority of the people of the HP cold deserts migrate to warmer places like Kullu and Manali, leaving a few household members to look after the house and the cattle.

Most of the population is into subsistence cultivation. Cash crops, wherever they are grown, provide handsome returns to the farmers. 10% of the population is employed in the government, while another 15% is involved in services and trades, viz, tourist guides, transport and hotel business, masons, etc. Since the arable land is very little, many are involved in petty jobs such as drivers, road labourers, etc., as well. Lack of employment and income opportunities is leading to migration of the better educated from the region.

The society is patriarchal, and a majority of the indigenous population follows Buddhism, although Lahaul has a quaint admixture of Hinduism and Buddhism, and Kargil is predominantly Muslim. All cold desert areas are characterised by strong cultural values. Having been isolated and insulated for very long, the communities are rather closed and the cultures quite unique. The communities tend to be self-reliant. Marriages and most social interactions are restricted to being within the community. The seasons and the climate are very much a part of community life and even determine it. Summers are used for agriculture and income generation, while winters are used for ceremonies and festivals. People are god-fearing and still believe in evil spirits, ghosts, and exorcists. The gompas have a profound influence on daily lives and decisions and the lamas are called in for all celebrations and problems. Although, it is now eroding, in some of the area like in Spiti, the traditional society was polyandrous with all brothers marrying a single woman.

1.2 Cold Desert Issues

Cold deserts face serious disadvantages to their development associated with an interplay of factors such as limited natural resources, remoteness and fragile ecosystems. Environmental issues include extreme atmospheric dryness, inadequacy of freshwater resources, and inadequate irrigation potential, and lead to problems of low soil productivity, inadequate sanitation, etc. Secluded in their high habitats, the indigenous population had managed to eke out their needs and adapt to the harshness of their chosen habitat with traditional NRM techniques.

As development and tourism impacts them, the ecosystem integrity of these cold deserts is under great pressure. Damaging forms of development are also bringing about significant environmental changes. Although the indigenous people of this plateau had developed a code for protecting their wildlife and flora far in advance of the west centuries ago, these traditional wisdoms are gradually being eroded, lost in the highway side villages and receding in the inner villages as well. The indigenous systems of land tenure, water allocation, grazing rights, and hunting limits are little in use today. Desertification is escalating, the utilisation of resources turning unsustainable. Pressure brought about by increasing human and animal population is causing further degradation - the little vegetation is getting depleted. Accelerated erosion, loss of regeneration capability, and a drop in the productivity of vegetative ecosystems are cold desert issues today. Cold deserts have rich deposits of minerals and semi-precious stones. Indiscriminate quarrying from mountainsides for these has had adverse effects as well with the loss of land that could have been put to more productive use and of the productive top soil. The already sparse vegetation cover is also removed for this purpose. In the absence of a network of roots to hold the soil, landslides are a common phenomenon in cold deserts. This is aggravated by inappropriate methods of road construction, like blasting. The unique flora and fauna of this region is also being impacted heavily due to excessive hunting and collection - for instance, the valuable medicinal and aromatic plants of these regions have received excess attention from drug manufacturers and collection is reaching unsustainable levels.

Some examples of cold deserts in India are - Ladakh, Lahaul & Spiti, North Sikkim, etc. Composed of different river valleys amidst high mountain ranges, the elevation of inhabited areas in these regions range from 8,500 ft. to 13,000 ft. It has highly arid conditions with rainfall among the lowest in the country - the annual average rainfall from is 279 mm, hot summers at 36°C and freezing winters at -32°C. Most of the areas of the hot Thar Desert get more rainfall than these regions. The economy of these regions is at a subsistence level and based primarily on agriculture, with some animal husbandry and some trading activities as well. Only a small percentage of the land lying below 4500 metres is fit for human habitation - the land between 4500 m and 5000 m is used for grazing, and that below 4500 m is used for agriculture. Dryland cultivation is not possible and the entire cultivated area depends on assured irrigation.

Given below are some of the key developmental issues of cold desert areas:

Erosion of traditional wisdoms

Despite the severe conditions, in the past the people of these cold desert regions not only managed to survive, but were also able to enjoy a life of greater prosperity than that of many other peoples. This is because a strong fabric of practices of sustainable natural resource management. These traditional wisdoms are gradually eroding however, lost in the highway side villages and receding in the inner villages as well. The power and influence of the local level institutions that managed the application of these traditional practices have also eroded over time. The younger generations do not follow these traditional institutions and their norms as the elders did. Many of these wisdoms are documented in the traditional tests of the region; the younger generation however do not know the language of the texts either.

Another factor that affects the application of these wisdoms is their applicability for modern day problems and environment. The pressures of modern civilisation have led to problems not encountered in the past and thus probably not addressed by the traditional wisdoms. The loss of efficacy of these traditional wisdoms have thus led to the disregarding of these as well.

Climatic conditions

- Harsh, severe climate: The climatic conditions of cold desert regions are very harsh. As mentioned earlier, winters are extremely severe with temperatures touching -40ºC in inhabited areas. Bitter winds blow in from the Central Asian plateau, and the terrain lies completely frozen. There are raging blizzards that block the sun out for days. In summer the mercury rises to touch even +30ºC during the day. These temperature extremes and wide variations distress humans and animals, and also cause enormous damage to all infrastructure. Most infrastructure is unable to withstand the stresses of these variations. The area is characterised by very high wind velocities which also does considerable damage to all infrastructure. The working conditions are extremely tough. Atmospheric oxygen is very low. The area is snowbound for a good five to six months of the year and no work is possible during these months. These reduce the work output.

- Changing microclimate: The climate of the cold desert region is undergoing subtle changes that is disturbing the life patterns of the inhabitants. Snowfall has been reducing and becoming more unpredictable and untimely. At the same time, precipitation in the form of rainfall has been increasing. These changes are leading to the vegetation and crops being damaged. It is also leading to damage of the houses and buildings and architectural monuments.

Ecological fragility & natural resource deficiency

- Land & soil: The region has vast tracts of wastelands but they cannot be cultivated/afforested due to non-availabilty of water and also some inherent qualities of the soil such as its highly acidic nature (pH 4.5 - 6.5), loamy to sandy texture and primitive stage of weathering. Virgin soil, it has very low organic matter content, and similarly low water retention capability. Although 95% of the population is dependent on agriculture, the low soil fertility results in low productivity and yield and hence low returns from agriculture. Due to the rugged, mountainous terrain, arable land is limited, and the lack of water for irrigation and irrigation infrastructure is a hurdle for creating more arable land. The hydraulic gradients and rapid stream responses lead to flash floods, destroying land and agricultural produce. High wind erosion and avalanches also cause damage to the land.

- Vegetation: The cold desert region is ecologically very fragile. Geographically recent, it has a high degree of endemic flora and fauna. The climatic conditions support only shrubs and bushes and a limited variety of trees. The predominant vegetation types are Himalayan Moist Temperate Forests, Himalayan Dry Temperate Forests, Sub-Alpine Forests, Moist Alpine Scrub and Dry Alpine Scrub. There is a very high demand for fuelwood for cooking as well as space heating in the winters. The supply/availability however is highly inadequate in comparison to the demand, and this outstripping demand is fast denuding the hillsides of the little vegetation of shrubs and bushes that they possess. Fodder available for the livestock population is inadequate and steadily depleting as the common property resources and high altitude meadows are degraded due to overgrazing and the depletion of water resources. The physical burden on women is also increasing due to depletion of water and fodder resources. Access to/collection of these resources requires greater effort today, as the sources are becoming more and more distant. The inadequacy of water also prevents undertaking of wasteland development for energy plantations or afforestation. The region is a habitat of a variety of rare, endangered & endemic plant species that have medicinal & aromatic value. Indiscriminate fodder/firewood collection and lack of conservation measures has resulted in the depletion of this natural wealth. With the degradation of this natural heritage, the related Indigenous Traditional Knowledge is also depleting with very few repositories left.

- Water for irrigation & drinking: The main sources of water in cold deserts are glaciers, snowmelt, springs, lakes and streams. Precipitation is very low and evaporation rate very high. Water is an important and scarce resource and thereby affects the status of other resources as well. The region had developed a unique distribution system of construction of kuhls (channels carrying water) and zings (water storage reservoirs) and an effective system of water rights and sharing. They have also developed techniques for creating artificial glaciers and snow harvesting. These traditional techniques however are not as effective given today's escalating water inadequacy. With global warming, glaciers are receding, and streams & springs are drying up. The depleting water resources for irrigation is leading to reducing yield and frequent crop failures, and resulting in impoverishment of the small and marginal farmers. Water has to be drawn over long distances and evaporation losses are very high. The soil has very low water retention capacity, hence percolation ponds have not worked. The water channels - kuhls - are affected by silting and choking in summer and damaged by avalanches in winter. This also results in high seepage and wastage of water. Although sowing has to be done early in summer, given the short cropping season, the glaciermelt is typically not available then, and presowing water is a continual battle for the region's farmers. Although extensive river systems exist, they cannot be harnessed as the terraced fields are located at a higher elevation than the riverbed. The silt content in the water flow is very high as a result of wind and water erosion, and this causes enormous clogging of any lift irrigation mechanism, rendering it a failure.

  Scarcity of water for irrigation and domestic usage is a severe problem in the region. In summers, the glaciermelt which is reducing by the year due to global warming, has to be managed for all water requirements. In the frozen winters, there is an acute shortage of water for drinking; snow has to melted for domestic requirements. Piped distribution of water is also not feasible due to sub-zero temperatures. Women play a key role in managing the water flow/sharing/usage, and have to undergo considerable physical stress due to the scarce water resources. The reducing water resources is leading to crop failures and thus affecting the economy. Decreasing water resources is also depleting the vegetation in the wild. There are serious drinking water problems as well. Water is frequently taken from contaminated sources leading to a high incidence of water-borne diseases.

- Irrigation infrastructure: Kuhls and zings are the traditional irrigation infrastructure. Kuhls are essentially channels of great length that channel water from glaciers/streams/rivers to the agricultural fields and village tanks. Since water has to be brought from great distances, there is considerable effort required and cost invested to construct these long kuhls. Local, traditional kuhls are 'kuccha' where the channels are not plastered with cement. Running water cuts the edges and sides of the kuhls, and winters typically damage them because of rockslides or glaciers. Every summer begins with kuhl maintenance which is typically a community activity. Sand and pebbles that flow with the flowing water in the kuhls, tend to block the kuhls or form a layer at their base which causes the waterflow to diminish or overflow to other unwanted directions. Besides, there is considerable seepage and wastage also from the kuhl floors. 'Zings' are tanks used to store water for irrigating the plantations and fields. These tanks are usually of the size of 10m x 10m and located at hill tops. Water is brought into the tanks through pipes from water sources on ridge tops; the water is gradually released downwards into the plantations/fields as it begins accumulating in the tank. Tapping water sources below the field level frequently becomes a problem however. Although certain technologies like hydraulic rams were implemented in certain sites, they have not been successful in the long term. The high silt content in the river water chokes the pipes and prevents waterflow. Most of these hydraulic rams are lying non-operational today.

Environmental threats

Floods are also a cause of concern in these regions and the region has witnessed devastating floods in the past causing large scale damage to habitations, crops and livestock. For instance, Shansha village in Lahaul has suffered from flood damage to 25-30 bighas almost every year which implied an expenditure of Rs. 45,000-50,000. Moreover the running water also cut into the boundaries of fields causing a shrinkage in the cultivated land. The landmass gets cut from the base and gradually weakens as more water seeps in and cuts off the sides, and ultimately get washed away. The terrain of this region is rugged and the absence of vegetation on the slopes enhances the rate of erosion and also the risks of landslides and avalanches. The high wind velocity also leads to high levels of wind erosion.

Welfare inadequacies

- Basic minimum services & facilities: The region has a paucity of the basic minimum services and facilities - for health care, higher education, communication, power, water. Because of the sparsity of population, the providing of these facilities is far more expensive than in other regions, and their reach and coverage is also very low. The establishment costs of infrastructure is very high, due to the terrain, its remoteness, lack of transportation, greater effort required in construction, etc. The operation of whatever exists is hampered by the difficult physical conditions. Maintenance needs are also high due to this, but maintenance is made difficult because of the physical conditions and high costs. The situation is especially pathetic in the snowbound winters- health care centres lie unmanned and unreachable because of blocked roads; schools close completely; communication and power breakdowns cut off the region for months; water in pipes gets frozen. The harsh climatic conditions dissuade competent staff especially in health & education services, leaving several basic minimum services/facilities unattended. Infrastructure for power is especially weak, and there are long periods without power during winters, when infrastructural breakdowns cannot be mended. Communication and contact between habitations also breaks down completely during the winters.

- Low development index: The low levels of literacy and awareness that help a society evolve and become mainstreamed have been limited in these remote and insulated regions. Most women were not educated, although primary education is today common for the girl child as well. There are few graduates and even fewer people taking to professional education. Several inequities and negative customs have therefore tended to persist.

Subsistence economy

- Incomes & livelihood options: The livelihoods of the people are completely dependent on the natural resource base of the area which is however rather deficient and fragile. The economy of the region is based primarily on agriculture. The climatic conditions allow only one crop, and the shallow, nutrient-deficient soil and inadequate irrigation possibilities restrict the crop yield. Cash crops which fetch higher incomes require more water, and hence can rarely be grown. Landholdings are also small. Hence incomes are limited. There is a considerable amount of dependence on wages from government contracted labour to supplement family incomes. The area is also characterised by a closed economy. Markets for primary produce are far off thus increasing the product price and consequently decreasing the market share & spread. The lack of a market disallows the emergence of any other occupation or livelihood stream, for products would lack viability because of logistical costs. Employment and other livelihood opportunities are very few except in tourism and government contracts; these too are seasonal. The human resource capacity for enterprise development, and professional level of products/services is very low. The sparse population, difficult terrain, fragile ecology and seasonal variations make it difficult to set up large scale industries.

- No industrialisation: There are no industries at all in the cold desert region. The conditions of low availability of raw materials, power, water, etc., as well as inadequate labour due to sparsity of population and low technically skilled human resources, makes industrialisation a difficult proposition for cold deserts. The fragility of the environment on the one hand and the difficult logistics and marketing of products also compound the issue. This however limits employment opportunities which typically industries can provide.

- Short working season: As mentioned, the cold deserts are snowbound for half the year. Since cultivation is the sole occupation, livelihood activities can be carried out only for the six summer and autumn months. The period of photosynthesis and plant growth is very limited. This naturally limits the output and hence the incomes.

- High cost of living: Since it is a closed and subsistence economy, material and products produced outside the area is typically not available in the area, and if available, is extremely costly. Cash revenues are also very low since sale of products produced within the area is very low, most of it being consumed by the producers themselves. Labour is expensive since most local people work on their own farms, and hired labour is only available from among the migrant population. Therefore the cost of living, if one were to live a life like in places outside the area, would be very high.

Technology inadequacy

- Appropriate technology for cold deserts: Cold deserts because of their features face problems of technology transfer. The closed system makes it almost completely dependent on indigenous and traditional technologies. The uniform development framework applied by the government on the other hand, does not recognise the uniqueness of the cold desert region, both in terms of the problems and the potential. Various technologies for natural resource management or livelihood generation that are in use in other parts of the country, fail in this region, and attempts have not been made to appropriately adopt them to the region's requirements. For instance, solar energy has potential to solve the problems of firewood and power, but the existing technology is suitable only for lighting, although space heating is also a major requirement in the region; during winters, sunshine for recharging of the solar cells is also unreliable. Wind velocities are high and can be tapped, but maintenance is a problem during winters. As mentioned earlier, irrigation technologies like hydraulic rams have also not succeeded because of excess silting. Generation of power and maintenance of most systems is difficult in winters. Large scale power projects cannot be set up mainly due to siltation and high seismic activity.

- Low technical infrastructure: The cold desert areas also lack the facilitative infrastructure that encourages technical improvement and enterprise building. Quality and testing services are not available, and credit facilities and marketing services are minimal. As a result, the cold desert areas and their products tend to remain in a technological time warp of the past, and risk-taking is low and development pace very slow.

Socio-cultural issues

- Closed societies: Insulated for years, these cold desert regions have developed highly closed societies. While much that is culturally unique and beautiful has evolved in these insulated conditions, information flow and awareness have been limited. The society has therefore tended to be quite inward-looking and traditional, not evolving at the same pace as other better connected areas.

- Dependency culture: Like other tribal areas, cold desert areas too have been provided substantial subsidies in various forms by the government. While this probably facilitated the area to rise out of the poverty trap, continued availability of these subsidies has created a dependence culture among the people. There is a tendency to expect benefits without making the requisite effort for it.

- High migration: Since cold desert areas have so many inhibitors of development, the more progressive and ambitious among its inhabitants tend to migrate out from the region to seek their fortunes in the hills and plains south of the region. The effect of this for the cold desert regions themselves are that they lose some of their best human resources who could otherwise have probably taken them further up the development ladder.

- Border area syndrome: Since all the cold desert districts lie along the Indian border, they suffer from several associated problems. Several of the areas have restricted entry to outsiders and are somewhat constrained in terms of freedom of action and movement, compared to other non-border areas. This makes trade and free commercial interactions and logistics rather difficult, which in turn limits economic development of the people of the region. Frequent war-like situations and conflicts and border skirmishes cause damage to life, property and business as well. Further, there is typically a large contingent of the army in the area which is also a drag on the already limited resources of the region.

Pressure on the ecosystem

Pressure brought about by increasing human and animal population is causing further degradation. The little vegetation is getting depleted. Desertification is escalating, the utilisation of resources turning unsustainable. Accelerated erosion, loss of regeneration capability, and a drop in the productivity of vegetative ecosystems are cold desert issues today. Cold deserts have rich deposits of minerals and semi-precious stones. Indiscriminate quarrying from mountainsides for these has had adverse effects as well with the loss of land that could have been put to more productive use and of the productive top soil. The already sparse vegetation cover is also removed for this purpose. In the absence of a network of roots to hold the soil, landslides are a common phenomenon in cold deserts. This is aggravated by inappropriate methods of road construction, like blasting. The unique flora and fauna of this region is also being impacted heavily due to excessive hunting and collection - for instance the valuable medicinal and aromatic plants of these regions have received excess attention from drug manufacturers and collection is reaching unsustainable levels.

1.3 Water Status of Cold Deserts

Mountain water resources

There is no detailed scientific evaluation available for Himalayan water resources. This is partly due to insufficient network of observations for both precipitation and stream discharge measurements. However, the available estimates show that the water yield from a high Himalayan catchment is roughly double that from an equivalent one located in peninsular

India and this is mainly due to additional inputs from snow and ice melt contributions from high altitudes.

According to the Irrigation Commission (1972), 200 km^3/yr are added to Himalayan streams from areas lying outside the catchment of national boundaries. Murthy (1978) estimates that the Himalayan water resources are 245 km^3/yr; Gupta (1983) and Kawosa (1988) estimated that 8634 km^3/yr is the total amount of water flowing from the Himalayas to the plains. Bahadur & Dutta (1996) reported that a very conservative estimate gives at least 500 km^3/yr from snow and ice meltwater contributions to Himalayan streams. Alford (1992) reports that the specific runoff in the Himalayas is at a maximum in an altitude belt of considerable human activity - 1500 to 3500m and this is about 515 km^3/yr from the upper mountains. Bahadur (1988) re-evaluated that 400-800 km^3/yr. flows down as meltwater contributions from the snow and glacier fields in the high mountain region as against earlier conservative estimates of 200 km^3/yr to 500 km^3/yr.

One should seriously consider development of water reservoirs at altitudes of 3000 - 4000m to increase the period of water availability to downstream users. This will be helpful in reducing the surface runoff and also the severity of the freeze-thaw cycle. Longer availability of water in the high altitude region will be helpful in generating cheap hydroelectric power and maintaining the greenery thereby reversing the environmental degradation of the mountain system.

- Himalayan snow & ice reservoirs: The Himalaya - the abode of snow and ice contains over 50% of permanent snow and icefields outside the polar regions. This region covers an area of 4.6 million km^2 above 1500m, 0.56 million km^2 above 5400m and 3.2 million km^2 above 3000m (Upadhyay, 1995). The altitude of permanent snow line is highly correlated with the freezing level (zero degree C) altitude of the free atmosphere. The following gives the distribution of permanent snow and ice in these mountains, having a significant cooling effect on their neighbourhood, regional and global environment.

Distribution of Permanent Snow & Ice in the Himalayan Region

SUBREGION	VOLUME	SURFACE AREA
	(Km3)	(Km2)
HINDUKUSH	930	6200
KARAKORAM	2180	15670
HIMALAYAS	5000	43000
TIBET	4820	32150
TOTAL	12930	97020

In these high mountains, it is estimated that 10 to 20% of the total surface area is covered by glaciers while an additional area ranging from 30to 40% has seasonal snow cover. There are of course, variations in the depth of snow and ice from place to place depending on the location. The importance of meltwater contributions from these natural freshwater reservoirs diminishes from west to east, being the greatest in the Indus basin and least in the Brahamputra. In Nepal, Japanese studies have shown that the glaciers on the southern (or the Ganges) slope of the southern Himalayas are "warmer" and more active than those on the northern slopes. Detailed studies of the high snowfields and glaciers could provide much useful information from a hydrological perspective.

- Natural lake systems: Both saline and freshwater natural lakes exist in high altitude regions. Saline lakes abound in arid regions while those lakes which are extremely poor in electrolytes are abundant in humid regions, nurtured by the monsoons. These lakes are situated at altitudes varying from 600m to 5600m and are exposed to climatic conditions that vary from the cold deserts of Ladakh to the wet humid region of Manipur. Very few studies have been undertaken on the Himalayan lake ecosystems and the water management programmes are either completely lacking or grossly inadequate (Zutshi, 1985). The inflow of high silt load from glaciers is rendering the lake waters turbid and unfit for biological activity and are gradually filling these lakes. The other impact is from pollution from agricultural, industrial, human and cattle wastes. Restoration plans for the lake systems should be undertaken on ecological considerations following their geophysical environment and annual rhythm in chemical and biological compositions.

Cold desert resources

Lying in the rain shadow of the Himalayas, the average annual precipitation in the cold deserts, which is only in the form of snow, is extremely low. A few rivers and streams and snow-fields and glaciers are the major sources of water in this region. Most of the small rivulets disappear in the summer, but the main rivers are perennial ones, fed by the glaciers. There is a huge variation in the discharge of rivers and streams over seasons and time of day. The ratio of maximum to minimum discharge lies typically between 1:10 and 1:25. There are some lakes as well, but their water is brackish.

Water is found generally either at the extreme top (in the form of snow and glaciers) or in deep valley bottoms, while most settlements are in between without regular water supply systems for drinking, food production, and other uses.

Most of the villages are dependent on glacier-fed streams. For instance, only 9 out of 112 villages in Leh region can access water from the river Indus. Water for irrigation & domestic purposes comes almost totally from glaciermelt transported over long distances through an intricate system of channels (kuhls). Agriculture is not possible without irrigation. Water is available mainly in the late evening in the streams, and the flow of the streams is adequate for the irrigation needs only for a part of the summer season. Hence water is traditionally stored in small tanks called zings. There is a high level of seepage loss however in the process and irrigation efficiency is only 50-60%. Snowmelt is also the main source of water for drinking purposes as well. Piped water supply, wherever available, can be used during the summer months only, and has to be stopped during the winter due to freezing of water in the pipes. In places, tubewells have also been installed for drinking water.

Like elsewhere in the Himalayas, this region is also facing the problems of depleting water resources - thinning/retreating glaciers. The impact of this is much more severe here however, due to the lack of rainfall. The kuhls are no longer adequate in number and distribution is skewed, their increase not in tandem with the spread of habitation. They also have to be extended considerably because of the retreating glaciers. Unlike in the past, when the glacierfed streams flowed through the cultivation period of the summer months, the decreasing snowfall has led to a few months of water inadequacy. There has been a considerable drop in the water table as well, resulting in the drying up of the underground acquifers and rendering the tubewells ineffective.

There has also been a shift away from a subsistence agriculture to niche agriculture. This has resulted in a change in the land use pattern - local crops are used to the harsh climate of the area but the newly introduced commercial species have a higher water requirement. This has reduced the availability of water for drinking purposes. The traditional institutional framework for water management is eroding, and the indigenous water management techniques are becoming grossly inadequate for present needs - this is bringing about its sociological & hydrological pressures. For instance, the drudgery of women, the traditional water fetchers, has grown considerably. Most of the households today do not have adequate access to safe water.

Traditional institutions are also under threat leading to a disruption in the centuries old management of water supply in the region. The kuhl system of water transportation and storage succeeds due the mutual cooperation of the residents. There is also a social hierarchy established by the system, the greater the share of a family in the water rights, the greater the amount of land it owns. But in recent years, greater social mobility and rising dominance of the market economy has broken down traditional institutions that ensured the repair and maintenance of the kuls. This has resulted in a decrease in water availability of locals. Also greater dominance of the market economy means that access to kuhls will no longer be on availability and need and monetisation of this resource will leave many of the region's families impoverished.

The danger of increasing desertification because of depleting groundwater resources is also feared. Recent studies have shown that pollution of local water is increasing which puts potable water at risk. With the population growing at a fast pace, the problem of water supplies for these high mountain households will be extremely acute in coming years. The crisis of decreasing availability of water is not only going to hamper seriously the economic development of the region, but is also likely to threaten the very survival of the already marginalised cold desert people.

1.4 Need for & Issues in Water Management

Water is an integral aspect of all facets of the mountain environment and enters into virtually every resource development or management project in some way. All disciplines involved in resource planning or management have developed numerous technologies for modifying the natural characteristics of volume, rate, timing, or quality of water at a site. Basically, all technologies are variations of a few basic themes: storage of water during a period of surplus for use in a period of deficit, transfer of water from an area of surplus to one of deficit, or improving water quality. Approaches to water resources engineering or management have however evolved largely in the two-dimensional environment of the lowlands. These operational models are often misleading when applied to the high energy, three-dimensional environments of the mountain ranges. Because of the characteristic irregularities of topography, surface and subsurface texture, high mountain areas present extremely difficult problems of hydrometeorological or energy exchange observation and sampling, and therefore of generalisations, unlike in lowland areas. In mountainous regions, the most critical factors are topography and meteorology. The nature of precipitation also makes a difference to the water management strategies. Once again, there has been a neglect of the cold desert environments.

Improved water management practices are critical for ensuring the availability of drinking water for household usage, production of foodgrains, meeting the need for biomass, and for improved living conditions in the cold desert region. More efficient use & water harvesting methods can also contribute towards improvement in the conditions of other natural resources and thereby contribute to the reliability of water supply systems. To be successful, water management should be based upon an understanding of the water budget in a mountain area - the precipitation, the evapotranspiration, and the storage gain/loss. While hydrology determines the supply against the demand for water, economics and engineering in water use can influence it significantly. Effective long-term techniques for water management need to include a combination of conservation techniques and efficiency techniques, both at pre-consumer stage and post-consumer stage.

One of the main hurdles in the development of India's water management system is that it has tended to be piecemeal due to the compartmentalisation of the administrative structure. Irrigation, drinking water, sanitation are perceived and treated separately. Water management today has moved from the particularistic and infrastructure-based approaches of the past towards an integrated, local institution based approach. This is apart from the erosion of the traditional structures and practices. Traditional water harvesting systems have passed the test of time and are suited to the specific environments in which they have evolved. It is essential to rehabilitate the traditional systems that already exist. They worked efficiently in different social, economic, and political environments but a mere replication of the past may prove to be counterproductive. Water management today should include the revitalisation of effective traditional systems, blending them with appropriate modern technology to enhance their effectiveness. Local management systems must take into account the nature of water harvesting systems, historical traditions of the area, local sociopolitical realities and government policies, and modern technologies that can be effectively allied with these.

Thousands of Indian villages still do not have any local source of drinking water. Given the unreliability and inadequacy of precipitation, the seasonality of surface water sources, and the expenditure involved in the supply of piped water, water harvesting structures can play a useful role in meeting the survival needs of the people. This needs to be integrated with appropriate sanitation and water treatment systems for effective usage, budgeting, recycling, etc.

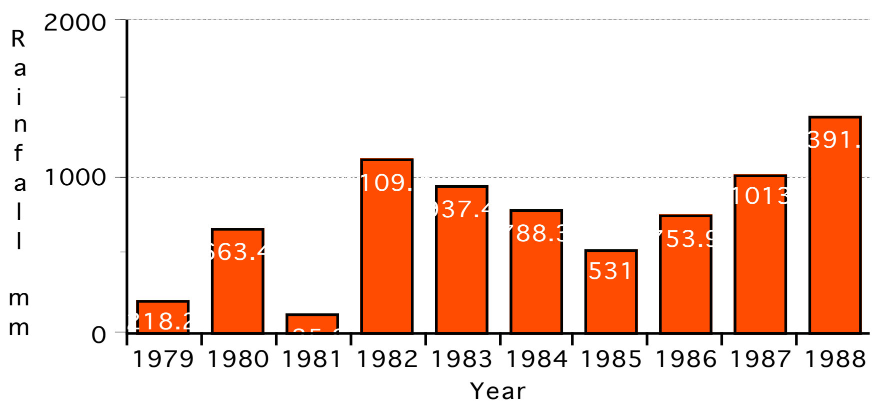
2. AREA DESCRIPTION

Mountains in cold deserts are bare from top to bottom except for a few favoured localities. The general impression is of desolate grandeur, but inspite of the utter want of vegetative cover, there is beauty in the scenery. The scarped sides of the hills expose a great variety of strata, each of a different colour. In the background one can get a glimpse of some snowy peaks standing against a very blue sky. In the front are the bold sweeps of the river and the cliffs, supporting the plateaus, (actually ribbons of level land). The white houses and green fields of the villages are conspicuous when viewed from long distances. All this, seen through an excessively clear, pure and rarified atmosphere, makes as pretty a picture as is possible in the absence of vegetation and large expanses of blue water. The valleys at places, are more than 3 kilometres in width. There is level land on either side of the river, giving the appearance of terraces. This level land on which villages are perched, varies from fifty to a thousand metres in width. Villages are built around occasional springs or streams on these flat pieces of land. These flat pieces of land have been grouped into three different forms based on their elevational profile.

2.1 Types of Settlements

All cold desert settlements are wet point settlements and rely on the minimal water available for meeting the irrigation and drinking needs. Geographically, the settlements are located at the river basins, on steep river banks located about 50-100m above the rivers, and on highlands located high above a river. Settlements of the steep banks and highlands types are the most deprived in terms of water availability as the only source of water for these is the glacial melt. Rainfall in cold deserts is minimal as indicated by the following chart. The enormous Himalayan mountain ranges divert the monsoon waves and as a result the area gets scanty rainfall. The rainfall data also reveals the steady increase in annual rainfall, an indication of the changing climate of the region.

Year-Rainfall for Lahaul Spiti



Based on the location with respect to the river the target region can be categorised under three distinct types of settlements.

a. Basins

These settlements are located at river basins, at a height of about 20-50m above the basin. The basins are either spread on one side of the river or on both the banks. These are essentially flat tracts of lands but at a few places are also in the form of moderately sloped terraces. The banks are not too steep and water for irrigation can therefore be drawn directly from the river with the help of diversion channels, for eg., in Tabo in Spiti or in Jispa in Lahaul. The diversion channels are however quite long, ranging from 2-3 kms, to allow water from upstream to flow to the fields by gravity.

Water management problems of basin settlements:

The river is the primary water source for basin settlements. The diversion channels constructed to channelise river water to the fields need frequent maintainence and repairs however as rivers in cold deserts carry very high silt loads. Channels have to be frequently cleaned of the accumulated silt in order to maintain the desired flow of water. Also the fixing of the channel gradient needs special skills to allow water in required quantity and velocity to flow through the channel. Desilting tanks are now coming up in these regions which help prevent silt from entering the channels.

b. Steep banks

In the middle regions of the valleys, steep cut banks separate the villages from the river. Settlements are located at about 50-100m height above the river level. These villages depend on glacial melt for both drinking and irrigation needs, for eg., Kaza in Spiti, Khoksar in Lahaul. These differ from the basin settlements essentially due to the fact that they are located considerably above the river basin. Hence water needs are supplemented primarily by the natural springs and glacial melt. Water is stored at night time in large circular tanks located high above the fields. This water is then released during the day to the fields. Apart from the gravity flow there is also the option of pumping water from the river directly.

Water management problems of steep bank settlements:

Since these settlements depend on natural streams and springs for their water needs, they have a high level of dependence on the snowfall in a given year. Due to global climatic changes in recent years, snowfall has been affected both in terms of the time and quantity. Apart from this, the water infrastructure also needs annual maintenance and repairs just before the onset of the sowing season. Although lifting water from the river does seem a possibility, the few water pumping schemes tried in these regions have been rendered dysfunctional due to high silt loads of the river which causes frequent damage to the pumping devices. But considering that water needs to be lifted to just about 100m or so, water lifting devices do need to be considered as an option. Suitable desilting mechanisms with appropriate maintenance measures could take care of the silt loads of the river.

c. Highlands

These include the highest settlements of the valley, more than half a kilometer above the river bed. Flat tracts of land on high mountains are the typical features of these kinds of settlements, although at places terraced fields also exist on moderately sloped hill faces. The river is completely inaccessible from these places. These settlements therefore have to depend solely on snowmelt for meeting their water requirements, for eg., Kibber in Spiti, Rashal & Gondla in Lahaul. Pumping water from the river is also a difficult option for these settlements. Hence just like the steep bank settlements, here also water infrastructure in form of zings and kuhls are used to channelise water to the fields.

Water management problems of highland settlements:

Like the steep bank settlements, glacial melt is the primary water source for these form of settlements and hence they too have a high level of dependence on timely and adequate snowfall. The remoteness of these settlements has also prevented modern technological solutions reaching these settlements. Snow harvesting measures are a ray of hope for these form of settlements since, unlike the steep bank settlements which have water lifting as an option for meeting their water needs, water lifting for highlands would be an arduous task. Proper upkeep of the long kuhls and adoption of more scientific methods of irrigation can help in approprately utilising the little water available in the highlands.

2.2 Water Related Problems

Although most of the cold desert area suffers the same water related problems, there are some variations as well that call for concomitant variations in water management measures.

i. Leh and Kargil

Ladakh, located at the edge of the Tibetan Plateau, gets an annual rainfall of only 140 mm. Most areas of the hot Thar Desert in Rajasthan get more rainfall than Ladakh. The central and eastern portions of the Ladakh region receive less than 100 mm of annual precipitation. The villages situated in the southwest are slightly better off. Kargil, which is situated in this region, gets about 239 mm of rain. The major portion of the precipitation occurs in the form of snow in the winter months and hence, cannot be used for agriculture. A large portion of Ladakh is still uninhabited. Only 57,716 ha of land, constituting 0.6% of the total area is inhabited; even within this area, only 28.23% is under cultivation.

The key to civilisation in Ladakh is the intelligent use of water. Ladakh has abundant sunlight and good soils, but without water it is a vast, barren desert. Nearly 68% of the total land of Ladakh lies 5,000 m above sea level, and is virtually unfit for vegetation and human life. Land lying between 4,500 m and 5,000 m, constituting approximately 5.8% of the total land, can be used for grazing. Agriculture is confined to areas below 4,500 m in height. Another major constraint is the climate. Temperatures generally do not exceed 30^{o}C. July and August are the hottest months, with a mean temperature of 19.4^{o}C and

19ºC respectively. January and February are the coldest months, with a mean temperature of -10.9ºC. Hence, the growing season in Ladakh is restricted to less than six months in a year.

Dryland cultivation is not possible and the entire cultivated area of 19,000 ha depends on the assured irrigation from the waters of melting snow through long, winding streams from the upper mountain reaches. Snow and glaciers are the only sources of water. They melt slowly through the day, and water is available mainly in the late evening, too late for cultivation. Also, there are considerable differences in stream flows during the farming season, which creates immense difficulties. At sowing time, when water is needed for irrigation, it is still cold and hence, water from the snowmelt is very limited. On the other hand, as the growing period is short, all farmers need irrigation almost at the same time. Streams are so important to a Ladakhi's livelihood that they are traditionally worshipped. No activity that pollutes the streams, including washing of clothes, is permitted. Unfortunately, this is not practised now in urbanised places like Leh.

The main crops cultivated here are barley, peas and wheat. The area has a short sowing season - May to October. Since most of the glaciers begin melting only around June, i.e., after the sowing period, the region suffers from paucity of water for irrigation for the sowing period. From June to August there is an abundant supply of water, which goes unused into the river.

ii. *Lahaul & Spiti*

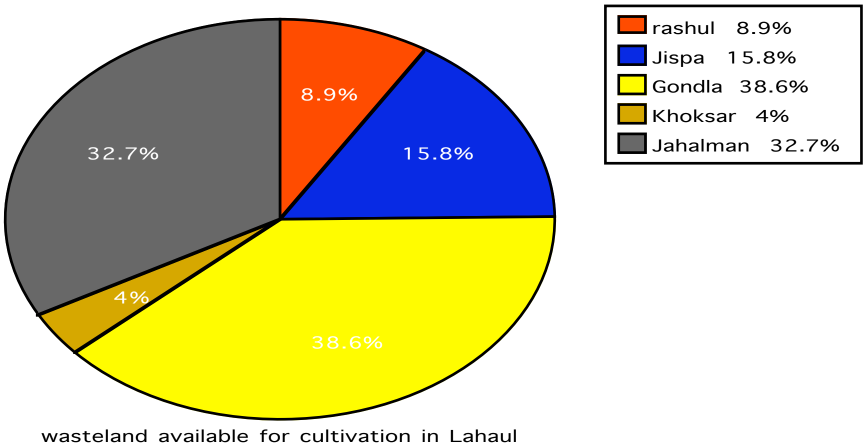
Bounded by Tibet in the east and Ladakh in the north, the Lahaul-Spiti district of Himachal Pradesh is located at a mean elevation of 3,048-4,572 m. The district is spread over an area of 1.22 mha, which makes it one of the largest districts in the country. But it has a population of just 33,000. Thus it is one of the highest (in terms of altitude) inhabited areas in the world with one of the lowest population densities.

In the wild and desolate Lahaul & Spiti valleys, temperatures plummet to -40ºC. Rainfall is scanty and the annual average from 1971 to 1979 was 270 mm, ranging from a low of 27.1 mm in 1976 to a high of 583.8 mm in 1972. The low monsoon clouds get blocked by the high mountains and leave the area dry and devoid of vegetation. Very little published material is available on the irrigation methods of the local cultivators. They depend largely on diversion channels to irrigate their crops, as in Ladakh and Kargil. The area under cultivation in Lahaul-Spiti is just 3,007 ha and of this, only 137 ha is cultivated more than once a year. The entire cropped area in Lahaul-Spiti has to be irrigated, which poses an enormous constraint for agriculture.

Spiti is an important trading post on the route connecting Ladakh and the plains of Himachal Pradesh. Villages in the Spiti sub-division are located between 3,000m and 4,000m, which means that they are snowbound six months in a year. The soil is dry and lacks organic matter. But despite these handicaps, the Spiti valley has been made habitable and productive by human ingenuity. The cropping season in Spiti is between May and October. Wheat and black pea are grown in black soil, green pea in sandy soil, and black pea and barley in yellowish soil. A remarkable feature of farming in Spiti is the meticulous utilisation of all available space, however small. Even the boundaries of fields and edges of pathways are used to grow fodder grasses. Fertilisation in winter is done with human waste collected in a novel way: each of Spiti's double-storeyed houses in equipped with a dry latrine on the top floor, the waste being collected in a room below.

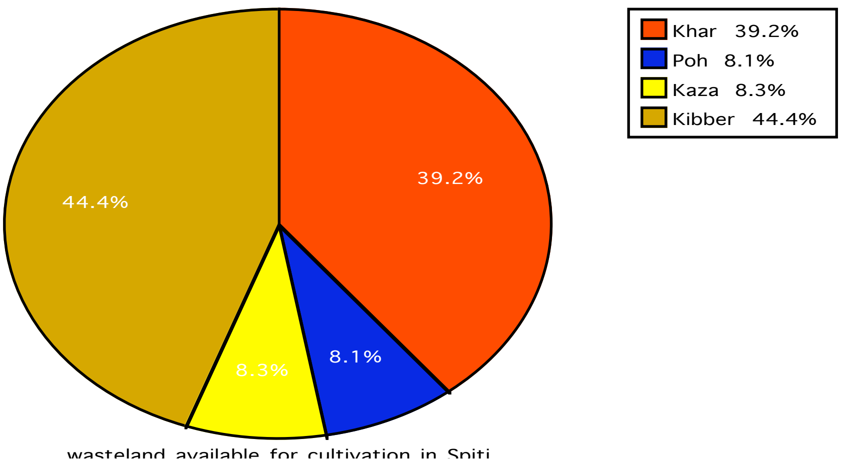
The major crops cultivated in this region are millet, green peas, black peas and wheat. The availability of water in these valleys differs from that in the Leh-Kargil sector. Sowing here begins in late April and there is abundant water available at that time with the glacial streams flowing at peak discharge. The flow however keeps reducing through the cultivation period and most of the streams dry up by the end of August, just before the harvest, when the crop is waiting for the last 2-3 crucial irrigation schedules for harvesting in September.

Both the regions suffer from paucity of water for irrigation, although at different time-zones. The insufficient water resources for irrigation has resulted in low usage of available land for agricultural purposes since all agriculture has to be irrigated. The reducing water resources is on the one hand leading to increasing desertification of the area as a whole and degradation of the natural vegetation, and on the other causing reduced agricultural yields and even enhancing wastelands.



Wasteland availability in Lahaul due to water shortage

Wasteland availability in Spiti due to water shortage



The amount of water received during the whole season has also decreased over the past few years and typically does not last the entire period of cultivation. The issues concerning availability of water are primarily due to the following:

i. *Receding glaciers*

In the rainshadow of the monsoons that serve the rest of the country, the agrarian communities of the cold desert region had established their settlements mostly along glacial streams, which have served them with water consistently for generations. Recent micro and global climatic changes have now begun affecting the Trans-Himalayas however. Global warming has led to a reduction of snowfall during the winters for the last 5-6 years in the region and the glaciers are receding at a very fast pace. Since these communities depend solely on glacial melt for meeting their drinking and irrigation needs, the impact of these climatic changes has emerged as a major problem.

Apart from the reducing flow of the streams and availability of water for farming activities, this implies that the kuhls that are constructed to carry the water from the glacier point to the fields now have to be stretched across longer distances, which in turn enhances the cost of construction and maintenance of these kuhls as well. Further, several smaller glaciers have become pale shadows of their former selves, and melt completely before the cultivation season ends, thus rendering several farmlands dependent on their waters, fallow.

ii. *Problems related to accessing river water*

The potential of power generation from flowing water has been known to people for long. Numerous water mills found in the area clearly indicate this fact. Some of them are still functional and being used for grinding millet (according to locals, millet processed in water mills remains fresh for much longer time as compared to processed millet from flour mills).

But lifting water from the river still remains unsuccessful; even the IPH department has failed in its several attempts to do so. There seem to be two major factors leading to the failure/lack of viability of lift irrigation systems. Installation/operation of pumps is not viable because of non-availability of conventional fuels such as diesel which has to be procured from places outside the target region. This leads to high transportation costs for fuel. Besides, the area remains snowbound throughout the winters and roads into/out from the valley remain blocked for the first month of the cultivation period. Several hydrams which had been installed by the IPH department to tap the potential of flowing water in the river, have also failed because of (as explained by some of the IPH officials themselves):

- high silt load, which leads to wearing off and blockage of the waste valve, and
- high diurnal fluctuations in water level in the river.

Fluctuations in the water level are caused by rapid variations in weather from cloudy to sunny, which in turn impacts the amount of snowmelt. It is difficult to site storage tanks to address these fluctuations.

iii. *Inefficiencies & poor maintenance of traditional infrastructure*

Against the enormity of the problem of depleting water resources, this issue may appear to be insignificant, especially since the present infrastructure is sufficient to tap the bare minimum water available. But a closer look at the traditional system revealed the ineeficiencies and degradation of the brilliantly designed centuries old system for tapping the only source of water. A large portion of the water supplied through the network of *kuhls* and *zings* in cold deserts is lost due to typical cold desert enviroment. The soil being predominantly sandy results in a lot of water getting lost as seepage. The high evaporation rates due to intense sun and strong breeze also cause the water in storage tanks to dry up. Water drawn through long channels suffer damages in winters due to avalanches and have to be repaired each year before the sowing season commences. High silt loads in glacial streams also pose problems of silting up of channels and thus the consequent maintenance. What is more important is that the evolution of this traditional system and its alteration to suit the recent biophysical changes, has ceased owing to lack of attention. Traditionally this infrastructure has been maintained by the village youth, one per family, but the movement of the youth from agriculture to other income generating activities, has affected the labour available for this activity. Well-intentioned government interventions, like constructing cemented kuhls, have also impacted the kuhl maintenance, since these require skilled labour for repair and maintenance as compared to *kaccha kuhls* which were repaired and maintained by the villagers themselves.

2.3 Hydrological Patterns

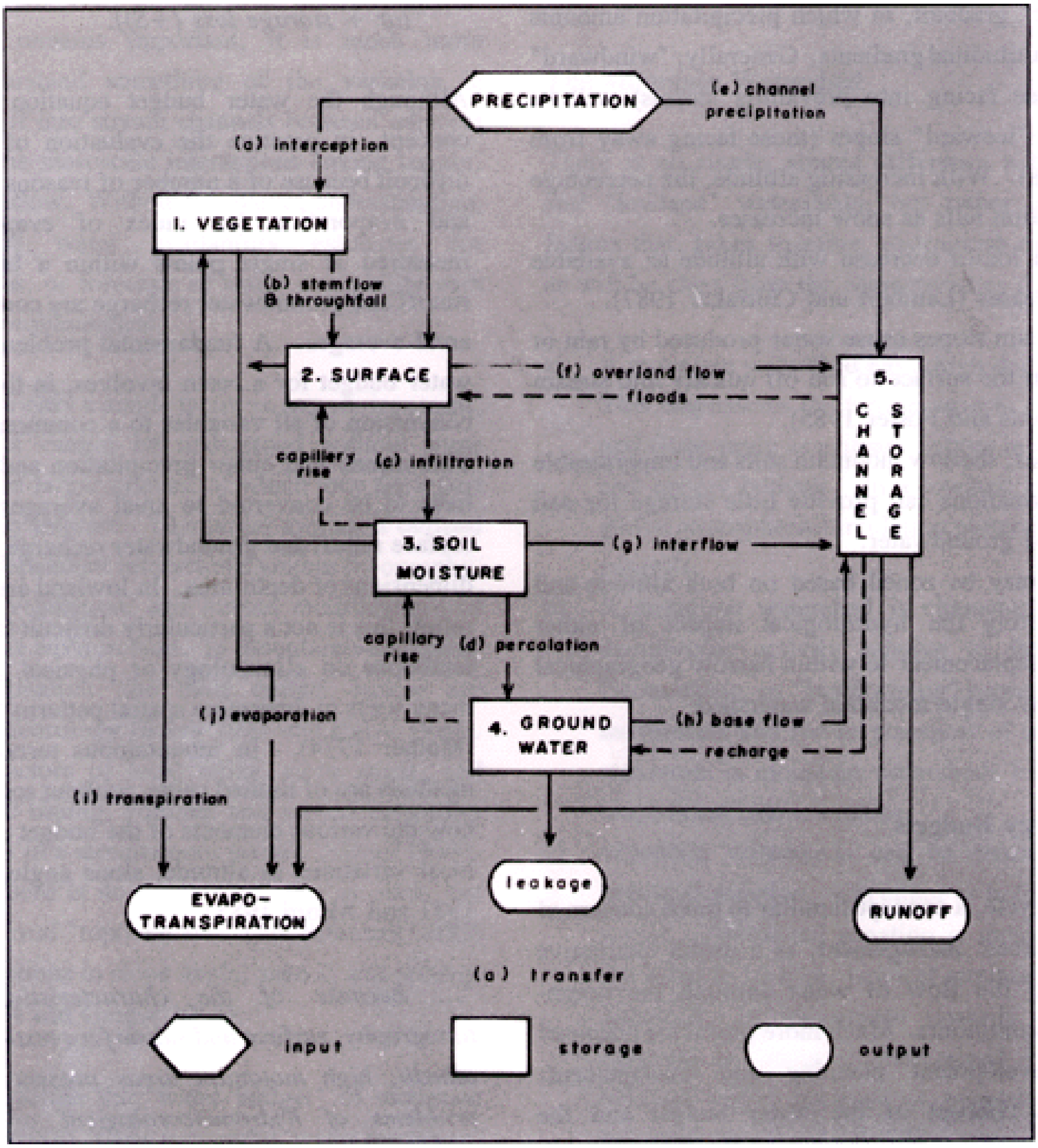
Mountain hydrology is influenced by the interactions among topography, climate, geology, vegetation and human modifications of these elements of the environment; the most critical factors among these are topography and meteorology, viz, local relief, slope angle and aspect and the microclimates determined by these. Thus,

- Precipitation varies complexly with the aspects of altitude and terrain. Generally windward slopes will be wetter than leeward slopes. With increasing altitude, the percentage of precipitation falls as snow increases.
- Evaporation losses decrease with altitude as available energy decreases.
- Steep mountain slopes cause water produced by rain or snowmelt on the surface to run off quickly into stream channels.
- In many cases, shallow mountain soils and impermeable geologic formations can provide little storage for soil moisture and groundwater.

Water moves through the ecosystem as a series of flows and storages. Flows (precipitation, evapotranspiration, surface runoff) are associated with relatively high energies while storages represent a state in which there is temporarily insufficient energy to produce further movement. Storages exist in the form of seasonal snow deposits, glaciers, lakes and groundwater.

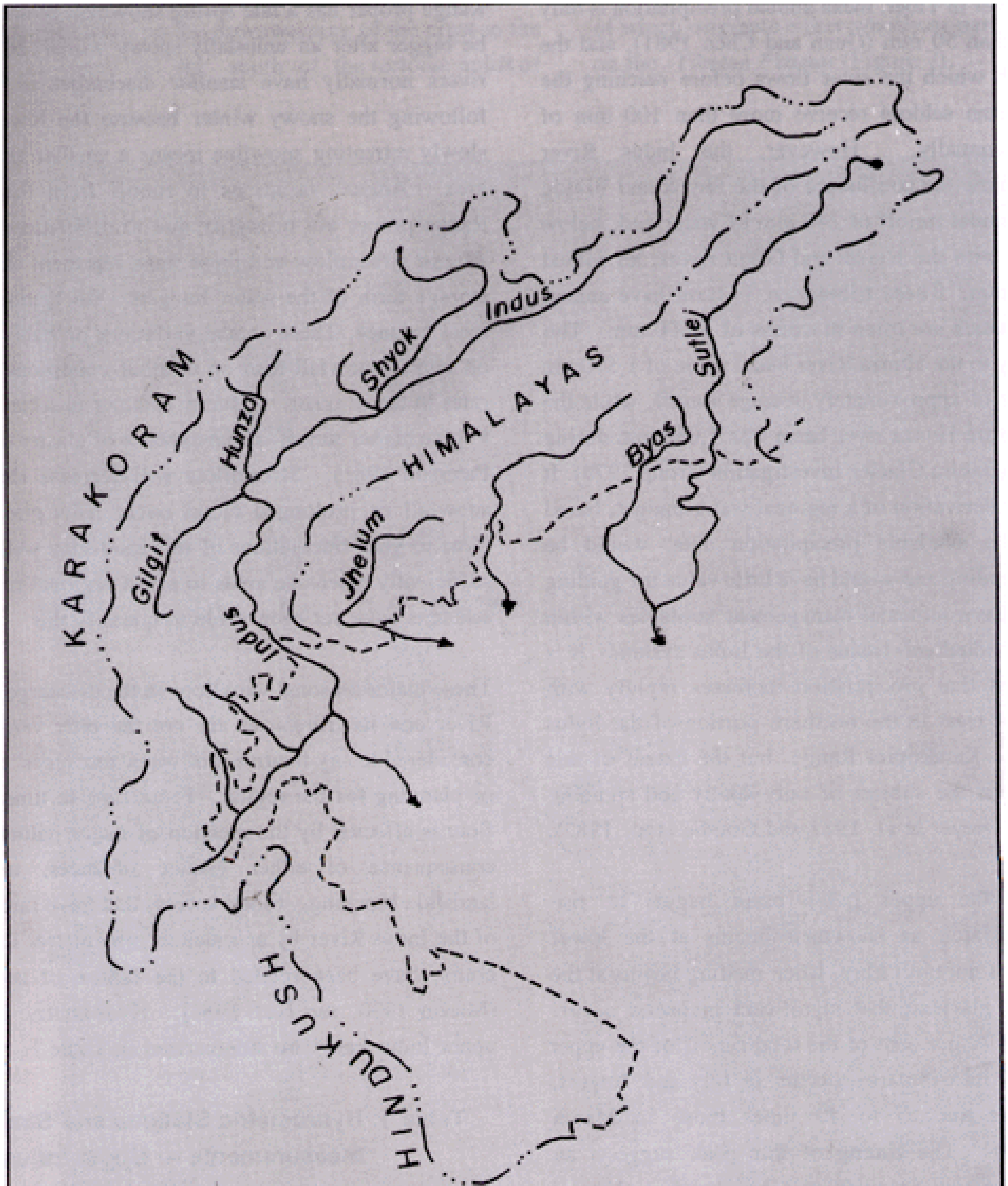
As in any environment, the flows of water and energy in mountain watersheds are defined in terms of standard input-output continuity equations based upon the water budget equation:
Streamflow (Qv) = Precipitation (P) - Evapotranspiration (Et) - Storage (-S) gain (or + storage loss (+S))

Although the water budget equation involves a simple concept, in practice the evaluation of the relationship is difficult in high mountain regions because of the characterisitic irregularities of topography, surface & subsurface texture, etc., and their quantification.



The Indus river system illustrates one of the central problems associated with determining the hydrologic regime of many of the watersheds of the region. At the headwaters of the upper Indus river in Tibet, mean annual precipitation is only slightly more than 50 mm, and the valleys through which the river flows before reaching the plains of Pakistan seldom receive more than 100 mm of precipitation annually. However, the Indus river immediately below its confluence with the Shyok river has an annual runoff of 240 mm of water. Streamflow begins to rise marginally in March as snowmelt begins at the lower altitudes, but it is not until May, when melting begins at the altitudes of the glaciers, that significant increases occur. Between 40 and 70% of the totoal runoff of the uppper Indus basic and its tributaries occurs in July and August, when discharges are 15 to 40 times those in March.

Streamflow varies considerably from year to year. Annual variations in runoff are primarily due to differences in July and August streamflow and these must represent changes in the annual storage term of the water budgets - fluctuations of glacier mass balance. These annual variations probably depend less on winter snowfall than on weather conditions and melting rates in summer. A sunny summer thus can be expected to give higher runoff at the expense of glacier storage. Streamflow will decrease abruptly when snowfall or prolonged cloud cover halts glacier melting.



It is estimated that between 10-20% of the total surface area of the Himalayan region is covered by glaciers. An additional amount - 30-40% - has a seasonal snowcover. This represents a significant form of natural storage, which lasts from a single season, as in the case of the transient snowcover, to decades or centuries in the case of the larger glaciers. The Karakoram ranges contain some of the longest glaciers outside the polar regions, and these are a primary factor in determining both water availability and sedimentation. These glaciers have high snowfall during the winter months as well high ablation (melting) during the summer months. Equillibrium lines, viz the altitudinal zone on the glacier surface where accumulation is just balanced by melt, lie in the range of 4,800-5,400 m. Studies have shown that the annual water exchange at the equillibrium line can exceed 1,000 mm and the mean annual runoff for at least one glacierised basin can exceed 1,500 mm during a summer melt season. This means that the glaciers of this system have very high 'activity indices', an indicator of the total amount of water passing through the glacier system annually.

2.4 Water Use Patterns

A comprehensive study was carried out to ascertain the extent of human water use in these regions. For this a study on the crop calender, water requirement of crops, domestic usage rates, water availability, seepage losses and factors affecting the water availability was made. Villagers were also informed about the maintenance aspects as well as measures for improving the water use efficiency.

2.4.1 Productive Uses

<u>*Irrigation calender*</u>

In cold deserts, crop cultivation without irrigation is not possible because precipitation takes place in the form of snowfall. Agriculture is entirely governed by the season in which water from glaciers (*kangris*) and snowmelts are available for irrigation. This is complemented in some villages by water from springs (*chumik*) and marshes (*nyema*). People take advantage of the available glacial water and perform collective operations for effective distribution and ensured supply of this scarce resource. The first irrigation is typically done 40 days from the sowing of the crop which takes place during April. In the initial stage of watering from the kuhl to the field, the women bring water to the fields by the use of '*urma*'s which are made of animal horns. Watering/irrigation is done in keeping with the prescribed *Bada ghar* based sharing Small beds are constructed in the fields before irrigation water is applied. The method, though time consuming and laborious, checks the loss of nutrients by leaching. Uniform watering of the plants with equal flow, checks the nutrient loss from field to field and from one bed to another.

The pre-sowing irrigation, '*tha chu'*, marks the beginning of the agricultural cycle. The *tol-chu* is the most critical phase of the cycle in Ladakh, as it is during this time when maximum scarcity of water is faced. This is the time when the ambient temperatures are not high enough to induce the melting of glaciers and therefore initial irrigation is dependent solely on snow-melt. It is only after the second watering, *dol-chu*, that glacial water becomes available increasing the quantum of water in the *tokpo*.

The general schedule for irrigation is as follows:

Irrigation no.	Stage of crop growth	
	Local name	English name
I	Tha Chu	Pre-sowing
II	Tol Chu	Germination
III	Sak Chu	Growing
IV	Non Chu	Flowering
V	Gep Chu	Seed setting
VI	Do Chu	Crop ready for harvest

The '*gep chu*' or 4th irrigation depends on the colour status of the crop. If the crop seems yellow in colour, the '*gep chu*' is delayed. However, if the colour position is blackish, '*gep chu*' is hastened. The farmers have developed irrigation schedules to match the stages of crop growth. Thus, irrigation during critical stages results in the maximization of crop yield as well as water use efficiency.

The main cultivated crops in the region are green peas, millets, black peas and *Gandham* (and apples at lower altitudes). The sowing season begins in middle or late April, depending on the altitude of the region, viz, higher the altitude of the place, the later the sowing season begins. Green peas are harvested in late August or early September, while millet crop needs keeping till mid-October. Millets are the staple diet (especially in the form of *sattu*) of the region.

Once water is diverted into particular *kuhls*, fields at the tail-end of the *kuhl* are irrigated first and then the ones above and so forth as water allocation is also determined by the growing period of different crops. Wheat having the longest maturation period is sown first. Its cultivation requires higher temperatures as compared to barley. Thus fields in the lower parts of the villages are usually sown with wheat and the upper reaches with barley. Therefore, water is first diverted to the lower area of the village where wheat is to be grown. This is followed by water to fields planted with peas and then barley and mustard. This system of allocation is clearly based on field situations and effectively eliminates any head-enders versus tail-enders conflict situations.

Water requirement & shortage

Observations made during field visits for measuring discharge in a water supply kuhl indicates an average water requirement of 60 KL per bigha of land for green peas. Differences in quantity of water required by different crops grown here is negligible.

Water for irrigation is available only from the glacier melt. Due to the decreasing amount of snowfall every year, streams, the only source of water for irigation, dry up completly by the end of July or beginning of September. In the absence of any technique available for lifting water from the river, drying up of streams results in obvious damage to crops and vanishing grazing lands for feeding livestock.

Distribution of water is according to village traditions which provides water to farmers as per their landholdings. More land means more water rights. In case of scarcity, *Bara ghars* are given preference over others. These *bara ghars* also bear responsibility for the maintenence of *kuhls* and *zings*, and share it as per water rights given by the community.

2.4.2 Household Uses

In cold deserts, a major chunk of the little water available is used for irrigating the fields. Apart from this, a small quantity of water is spent for household uses, primarily for cooking. Due to the shortage of water, people in cold deserts have learned to use water sparingly. For instance, dry toilets are used. Bathing and washing clothes are also quite uncommon, especially in winters. Some water is now used for growing vegetables in greenhouses which have of late have become a common household feature in cold deserts, especially in Ladakh. On an average, about 40 litres of water per capita per day is the water consumption in cold desert regions, which is way below the standard 135 litres per capita per day for domestic purposes in other areas.

3. TRADITIONAL SYSTEMS STUDY

In mountain watersheds, irrigation has been practiced as an art for about 3000 years now. Historical records bear testimony to the existence of a number of irrigation works in different parts of the country. In the Himalayas, theperennial river Ganges made it relatively easy to divert its flow through inundation channels. In the south, where rainfall is scanty, the practice of trapping rain water in large tanks and ponds for agricultural purposes is widely adopted.

From time immemorial, surface irrigation methods have been followed. The most effective irrigation method for a particular area depends on the slope of the land, the nature of the soil, the type of the crop and availability of funds.

In mountain areas, water continues to be the scarce commodity not only for irrigation but even for drinking and other domestic uses. This difficulty has been experienced very frequently, inspite of the fact that important rivers namely Sutlez, Beas, Ravi and their tributaries originate from these hills. The existing resources are further declining due to heavy biotic pressure and lack of management of existing resources. Most of our Agricultural/Horticultural activities are carried on under rainfed conditions and this require proper management of available water to be conserved for dry periods.

The different research tools employed including the visits to different sites in the target area have been successful in exploring the strengths and weaknesses of the traditional systems of water harvesting. Meetings with community members have also helped in providing different viewpoints on existing problems as well as valuable suggestions and do's & dont's while assessing the options for a solution to the water problems.

3.1 Sources of Water for Irrigation

3.1.1 Glaciermelt

In cold deserts, the source of irrigation as well as drinking water, is snowmelt from the high peaks which runs downward in the shape of small and big *nallahs* (streams) and also spring out at certain points. Some villages get water for irrigating their lands from some perennial torrents. As summers approach, the ice starts to melt and flows down the hill slopes before meeting the rivers. This however depends on the amount of snowfall. Ladakh for instance, experiences rather low snowfall, as compared to Lahaul and Spiti. As a result, people in Ladakh can avail of the glacial melts only till late summers (July-August) when ice from high up in the mountains begins to melt. In the case of Lahaul & Spiti however, adequate snowfall occurs and hence ice starts to melt with the onset of summers, but all of it melts away by August, thus allowing water availability early in the summers. This distribution of snowfall has resulted in predominantly short growing seasons in the cold desert regions.

3.1.2 Dew and Fog

In plains and in valleys, the occurrence of dew and "pale" is very common after the receding of the monsoons. The humidity level is quite high (85%) in the atmosphere at this time. During the night, the temperature falls sharply, resulting in the formation of more water molecules from vapours. As these molecules are heavier, they fall on the soil surface and make the top layer moist and wet.

In the hills, there is a traditional practice of ploughing the fields early in the morning before this dew or fog moisture has evaporated. By ploughing, this moisture is mixed well with the soil particles in the plough layer, i.e. 9"-12" from the top, and this moisture is well retained by the soil. If the soil is clayey in nature, water is retained for a longer time and becomes a source of soil moisture. This is quite useful for land preparation in October-November and for the sowing of rabi crops like wheat, barley and pulses.

3.1.3 Springs

Springs have been an important source of water, especially for fulfilling drinking water needs in mountaineous enviroments. *Chasmas,* as they are called in cold deserts, travel long distances from their origin, making their path through the sandy strata before erupting out from a mountain face. Several of these *chasmas* owe their origin to the natural lakes atop a hill from where they seep in through the loose mountain strata and erupt out at some other point. Discharges of the spring again depend on the snowfall in a given year. More the snowfall, more is the waterflow of the *chasmas*. In recent years however, many springs have dried up due to scanty precipitation in the form of snowfall.

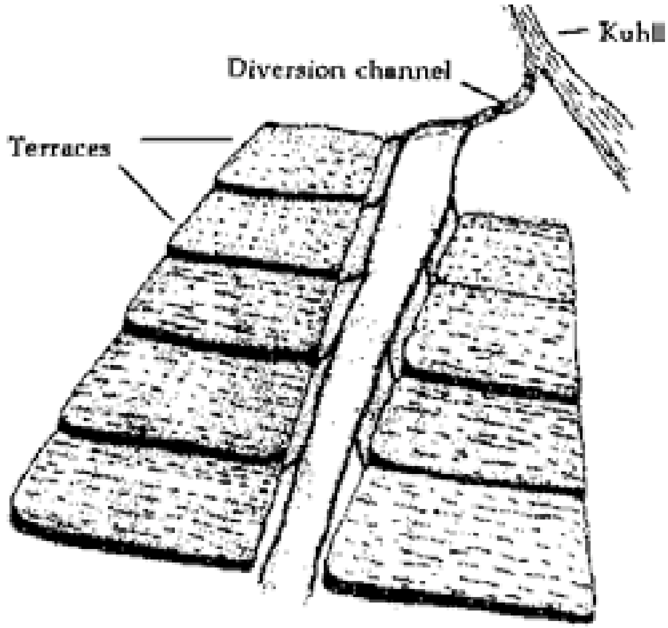
3.1.4 Rivers

Since time immemorial, rivers have been the lifeline of civilisations. All major civilisations existed near the rivers as they not only provide their precious water for mankind, but also bring along with them rich fertile soil. Rivers in cold deserts originate from the glaciers and it is their proximity to the glacier source which makes them highly turbulent and silt-laden. As winters approach the very same rivers show no signs of turbulence with the water turning sky blue. This is due to the low discharge levels as most of the ice has melted away by then. These rivers are a major source of water for irrigation, albeit only for the basin settlements. Long channels are constructed along the river banks to divert water to the fields. The water being silty however, the channels are frequently silted up, and therefore need periodic upkeep. In the process though, rich soil reaches the fields enhancing the productivity.

3.2 Technologies for Water Management

3.2.1 Sourcing & Distribution Technologies

In the hill region, the scope of boring tubewells, canals and even lift irrigation is limited, and such facilities are confined to the low laying areas. The most common source of irrigation in the cold deserts however, remains the small water channels locally called '*kuhls*' or '*yura*' which account for 85.83% of the total area under irrigation in the hills. *Kuhls* are essentially diversion channels to carry water through gravity flow from the glacial water source to the fields. *Kuhls* tap the head of the glacier carrying the glaciermelt water to the village; in most cases however, *kuhls* draw water from glacial stream itself.



Water is diverted to individual fields within a settlement through an intricate network of earthen channels (*kuhls*). Melting waters from glaciers and snow drain into a stream or *tokpo* (Ladakhi), which constitutes the main drainage line for a particular settlement. The water from the *tokpo* is further diverted into the earthen channels and further sub-divided into sub-channels until they reach the fields. In addition earthen ponds called '*zings*' can be found in every village which are used to store water, and are immensely important at times of scarcity. *Zings* have outlets for the release of accumulated water. The *tokpo* and the *zings* are most often used in conjunction to maximize the use of water.

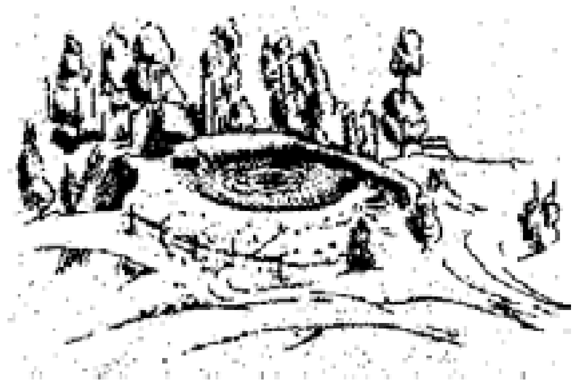
The *kuhls* are built along the hill gradient for maintaining proper gravity for irrigation. If the river has a steep gradient, water is diverted into a canal some distance upstream and led along a contour so that it can flow to fields by gravity. The technique for the preparation of *kuhls* for irrigation purposes seems to have originated since Babylonian times, it is still one of the commonest ways of bringing water to the crops. The *kuhls* often span long distances, running down precipitours mountain slopes and across crags and crevices. Some *kuhls* are 10 kms long and have existed for centuries.

Construction of kuhls (water channels)

In dry temperate zone, *kuhls* are generally made by making notches at the natural watersources and the water is diverted to the fields for irrigation to different terraces, using the natural gravitational flow of water. The irrigation channels are diverted from river tributaries by making use of the natural gradients thus the level of water is higher than that of the cultivated fields. Since the topography of the area consists of very high slopes and rocky terrains, wooden water channels are used at many places as water passes from one place to another. In upper Kinnaur, the channels are simply dug in the ground to regulate the flow of water. However, where the digging of channels is difficult or the channel has to pass through a village path, underground channels covered with slates are constructed. However, in some parts the wooden channels are also used which are put like a bridge over the path. These channels are made by making a deep grove in a tree trunk or a thick branch. Typically the channels are dug in the soil, strengthened wherever required by dry stone walls, and rendered semi-impervious by using fine soil or sods. Each channel where it takes off has a '*raks*' (crude bund or weir of dry boulder) thrown across the *tokpo* and a '*rka*' (sluice, generally a gap) with a '*rka-do*' (a boulder to close or open) to regulate the supply of water at its mouth.

All water movements take place with the help of these *kuhl*s. Water is taken to the field directly from the main stream or from *zings* (storage tanks) through a network of *kuhls*. The head and the tail of a *kuh*l can be blocked or opened according to the direction of the water flow required. The crucial portion of a *kuhl* is its head at the glacier which is to be tapped. The head must be kept free of debris and so the *kuhl* is lined with stones to prevent clogging and seepage.

3.2.2 Storage Technologies



For times of scarcity, water from the *kuhls* is diverted into storage tanks locally called zings. The main sourcing *kuhl* supplies water to a circular storage tank called *zing*. The capacity of a *zing* is measured in terms of the area it can irrigate. Most of the *zings* have irrigation capacity of 20-40 bighas of land. These *zings* are not used till late/mid-July and water from the streams is taken directly to the fields through smaller *kuhls*. At times of scarcity, water from the main stream is used to fill the *zing* at night. Next morning water stored in the *zing* is used for irrigation along with water from the main stream so as to ensure adequate flow of water.

Different available zings in the villages under study and their irrigation capacities were assessed. The discharge in different kuhls in the target project area was measured and irrigation water demand for the target project area was estimated using different methods including theoretical amount of water required for irrigating the entire cultivable land.

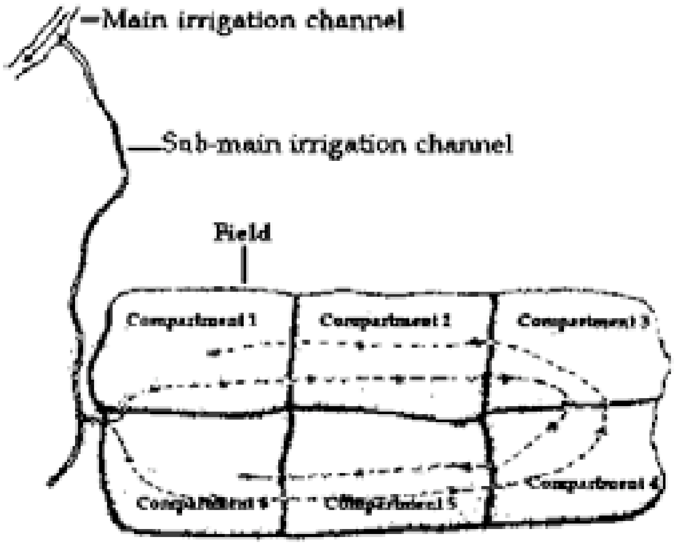
3.3 Utilisation & Conservation Technologies

The success of traditional cold desert life is the result of the most prudent and frugal use of the very limited natural resources. The almost total lack of precipitation means that irrigation is a major problem, and is in fact largely responsible for determining the location of each village. In the absence of pumps, the rivers that run through the cold desert's deep, barren valleys cannot be used for irrigation purposes, and so the farmer has to rely instead on melt-water from the snow-capped mountains far above. This water is led down through a wonderfully ingenious series of channels to small patchworks of fields which have been painstakingly constructed out of the very dust and rocks of the desert. Every last square patch of irrigated land is used, since the severe climate allows cultivation for only five or six months out of twelve. In this time the indigenous communities have not only to meet their day-to-day needs, but also to provide enough food for themselves for the long winter months. Although the land is used to the utmost, no attempt is made to work it beyond its capacity, and the cold desert inhabitants are scrupulously careful to ensure that what is taken from the land is returned. Human nightsoil as well as animal dung is used as fertiliser so that, even without fallowing or crop rotation, good yields are rendered possible year after year. The trees that are grown - the poplar and the willow - are reforested, and not lopped indiscriminately. The glacial streams that provide the water for domestic use are categorised - one may be reserved for drinking, another for washing. The agricultural cycle begins in February and follows the path of the sun. On an eastern exposure high above each village, a large pile of stones in the form of an obelisk (nyitho) acts as an agricultural calender. The point on which its shadow falls below determines when various activities should start. Sowing, irrigating, harvesting are all represented by specific landmarks.

3.3.1 Improved Irrigation Effectiveness

The actual work of irrigation consists in damming and undamming small irrigation channels with a shovel. More than the other agricultural activities, it is sometimes done in the afternoon and evening and in fact well into the night. This results not only from the limited rota access to water but also from the diurnal variation in water flow, at least for those villages without access to a major dam for water storage: flow in the stream is greatest in the afternoon and evening, as a delayed consequence of the sun's melting effect higher upstream. Night water, which is in more abundant supply is diverted to the *zings* and stored there for releasing to the fields along with water from the *tokpo* during the day. In most villages, irrigation is regulated by a *churpon*, who is appointed or elected from within the village. He operates the flow of water, blocking and opening the canals as required. Householders are allotted a certain period of time every week when they can divert the main channels into their own fields.

Progressive compartment irrigation



Water flow to the fields is regulated by apportioning the field into different compartments. The mouth of the first compartment is closed to regulate the flow of water towards the second compartment. The same method is adopted to irrigate the following compartments. The channel is given a downward gradient so that during the second turn of irrigation, water flows directly to the last compartment. This prevents the washing away of the fertile top soil. In upper Kinnaur, this irrigation technique is much more pronounced. The fields are generally divided into small compartments by making earth bunds to allow water to stand in the field for a longer duration for saturating the soil. Hence the need for a second irrigation arises only after 20 to 25 days even in those agricultural crops which otherwise require irrigation after a gap of 10-15 days. At the first turn of irrigation, the first compartment is irrigated, followed by the second and so on. At the second turn of irrigation, however these compartments are irrigated in reverse order, i.e., the sixth compartment is irrigated first, followed by the fifth and so on.

Flooding of glacial water for higher crop productivity

In most Himalayan cold deserts, water is brought in channels from glacial melts for irrigating the fields. Flooding the fields with the glacial water for improving crop productivity is also common. The deposition of fresh silt with unweathered minerals (especially lime) from glaciers improves soil productivity. The glaciermelt is often below 2°C which also protects the crop from different kinds of diseases.

Indigenous drip irrigation

The practice of using pitcher water as a source of irrigation on new fruit plantations in sandy loam/loamy sand soils, in areas of scanty rainfall, is prevalent in the transition zone districts of Himachal Pradesh. The pitcher is placed in soil and the new plant is planted close to it. The pitcher is filled with water during summer months (April-June) and a stone/slate lid is placed on its mouth. The roots draw moisture/water from the pitcher which in turn reduces the mortality of the sapling. The pitcher once filled, supplies sufficient moisture for at least two weeks and is then filled with water again.

Manual irrigation in vegetables

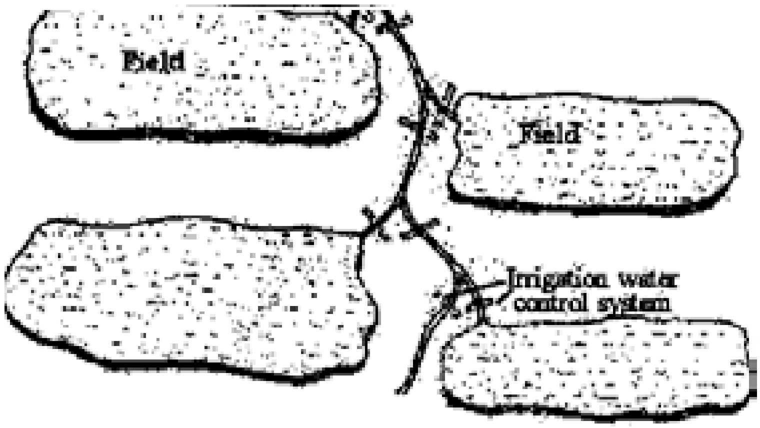
In the initial stage of watering vegetables, people bring water to their fields with the help of buckets. The vegetable crops are watered manually with mugs. In Spiti valley, the women bring water to their fields using '*urma*'s which are made from animal horns. Water is then supplied to each bed separately. This method however, is extremely laborious and time consuming.

3.3.2 Moisture Conservation through Mulching

In Kinnaur, covering the surface of the soil with *chilgoza* tree needles and grass from the *kandas* (hill tops) is a common mulching practice. Mulching conserves soil moisture in the fields. It also helps in the moderation of soil temperature. In this way the hydro-thermal regime of the soil is improved. However, the continuous use of *chilgoza* tree needles increases the acidity of the soil. This is a perfect example of *in situ* moisture conservation with locally available tree leaves and grasses. Thorough ploughing of the soil aids in moisture conservation, and also performs the function of mulching.

3.3.3 Irrigation Control

Supplying water to the fields in optimum quantity is essential for ensuring good crop productivity. Too much or too little watering of the fields can ressult in poor yields. To judge the optimum water required for irrigation, farmers in Ladakh use the technique of inserting a *belcha* (spade) in the soil. If it is completely inserted (front

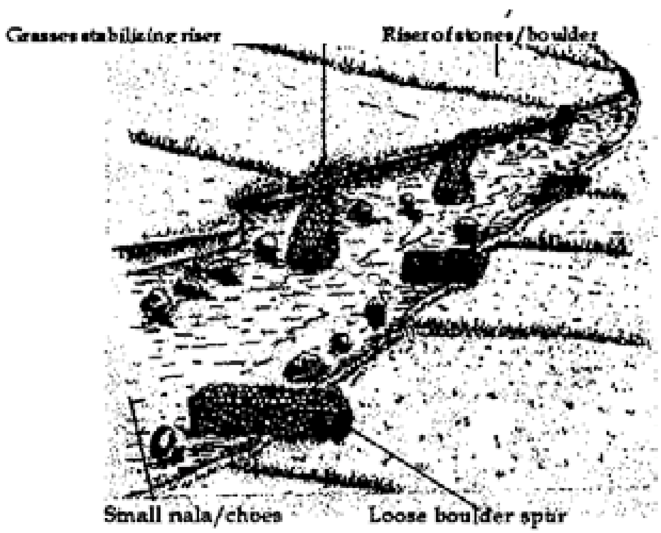


portion), the land is considered to be properly irrigated. In another practice, mud is thrown into the air. If it splits into pieces, the irrigation has been adequate.

In the feeder streams, structures made of loose boulders are created as diversion dams for diverting adequate quantities of streamflow in the direction of the fields. Such structures are also made in the *kuhls* to allow and stop water flow into fields.

3.3.4 Seepage Prevention Mechanisms

In Ladakh *spang* (*ramba* in Spiti) grass is used as the inner lining of *zings* and irrigation *kuhls* for checking percolation losses. This grass, which grows profusely in the region, is found to have properties of non-permeability, similar to that of a polythene sheet or cement lining. Its chemistry needs to be analysed however, as the farmers claim its utility in water retention is far superior to that of a polythene/cement lining.



3.3.5 Use of Kuhls for Water Mills

Kuhls are built along the hill gradient for maintaining proper gravity for irrigation and running water mills. Wooden water channels are also used for running water-flour mills. The water is diverted to the water mill, using the natural gravitational flow of water. Long wooden channels are placed at steep gradients for generating a high speed of water flow. This is necessary for rotating the water mills wheel at the required speed. Granite stones are used for grinding food grains.

3.4 Water Sharing Methods

In cold deserts, participatory management is employed for distribution of water. All disputes regarding the distribution of water through kuhls (water channels) are amicably settled without hampering the water requirement of any period. Unlike most parts of India, there is little social stratification in the cold desert society. This makes for greater homogeneity within the society as a whole, which leads to a sense of equity within the system. The aristocracy and their official exist as a separate class with special privileges at the 'top end', there is a very large middle, and a small low-caste stratum. There are very few landless. The existence of this large 'common layer' of people alleviates the occurrence of internal strife not only within a village but also between villages that have rights over the same resource.

Households and fields are interspersed in most villages. Landholdings are not classified according to the conventional soil quality parameters but according to the value placed by a household to its different fields within its overall landholding. The most prized is *Marzhing*, which is the best quality soil, followed by *Barzhing,* which is middle quality soil and finally *Tharzhing,* which is of poorer quality. In addition in every village one can find some *Olthang*, which is land on which *Ol*, a kind of lucern used for fodder is grown. As a result whatever principle of water allocation is followed, no particular household's fields are favored as they all own some land of differing quality in different parts of the village. Further, this disaggregated pattern of landholding minimizes opportunistic misappropriation of water rights.

Traditional institutional framework for water management in Ladakh

The people of almost every village in Ladakh have formulated detailed rules for the distribution of water through their network of earthen channels to individual fields. In some cases one or more villages are united into a single system by way of having the same *tokpo* running through them, usually lying in the upper and lower reaches of a valley. These rules have been in practice for many years and have been codified into records called the *riwaz-i-abpashi*, almost a hundred years ago, at the time when Land settlement records (*bandobasti*) were being drawn up in 1908, for every village in Ladakh and which are now maintained by the *Patwari*. Prior to the annexation of Ladakh to the kingdom of Jammu in 1840, royal edicts defined the rights of water management systems for certain areas in Ladakh. A study of the *riwaz-i-abpashi* revealed that there are continuities between the two, testifying to the overall resilience of the practices. The *riwaz-i-abpashi* contain details of the canals/*yuras* and the particular fields to which these connect, the principle of water allocation that is followed within the village, sharing arrangements with other villages, the rights of all categories of landholders, as well as any history of dispute.

It is during the critical first two months of the season that the rules for the distribution of water are most in evidence and strictly adhered to. Equity is an overarching feature of the customary practices governing the allocation of water for irrigation in Ladakh. The rules governing the allocation and distribution of water specify the beneficiaries and demarcate the boundaries within which the resource is to be shared. In spite of the fragmentation of households that has occurred over the years, water is still allocated amongst the original number of unfragmented families, which had settled in the particular village. The division of a family's estate due to land fragmentation is not taken into account. Further, preference is accorded to *bandobasti* lands for which the rules for water allocation have been formulated. Any reclaimed land/*notor* is entitled to only surplus water, once the *bandobasti* fields have been irrigated. However, if a household wishes to divert water to its *notor* land it may do so within its own allocated share.

The systems of allocation of water vary between villages but are all based on a principle of impartiality that lends to equity. The rules recognize and fulfill the water requirement of every field. In the more water-stressed villages and in times of water scarcity in all villages, a lottery system, by which each household's turn for receiving water is determined, is operated. Often two families are clubbed together in one or more pairs in each turn to avoid any wastage of water. The impartiality of the system is also demonstrated in cases where a lottery does not exist but distribution takes place by rotation amongst the original unfragmented families. Thus, within each village the system for the rotation of water, that may vary from year to year, and the method for managing and allocating the resource, is defined. All the appropriators know the rules since they have been developed internally and water is passed on from one to the next without the necessity of an enforcing agent. However, within these overarching rules there is an inherent flexibility, which accommodates practical problems that may arise in the actual process of irrigation so that informal agreements are entered into between households for exchanging turns. If a particular household for instance, has cultivated its fields with wheat and therefore needs water, it can exchange its turn with that of a family allotted an earlier turn, which does not need water at that point in time.

Not only do there exist well defined norms for the allocation of water within villages but also between villages that share the same source of water draining into a common *tokpo*. Water becomes a force of cohesion between these villages, which, though demarcated separately in government revenue maps, are geographically contiguous. In the case of inter-village sharing, each village receives water by turn from upstream to downstream. Equity for tail-enders is ensured, in that the downstream village(s) is entitled to an extra day and night of water at every alternate turn, as some water is lost due to seepage by the time it reaches there. In the case of inter-village distribution of water two nested levels of jurisdiction can be determined– within each village and between the villages.

Integral and indispensable to the entire system of water allocation in the villages of Ladakh is the institution of the *chudpon*. Deriving from the word *chu*, meaning water, the *chudpon* is a respected man within the village who is known to have a thorough knowledge of the rules governing the irrigation system, in whom the responsibility for overseeing that the entire system works smoothly and efficiently as laid out in the rules is vested by the people, a decision in which every unfragmented family has a voice. The institution of the *chudpon* moves by rotation, each serving for one agricultural season. In villages where there is a greater scarcity of water, the responsibilities of the *chudpon* include minimizing any wastage of water. Although a *chudpon* is responsible for the repair and maintenance of the irrigation system, he only oversees a task that is undertaken collectively by all the villagers. The irrigation water distribution system is based on the size of landholdings, in which every field is irrigated timely. The *churpun* ensures that each farmer gets adequate water in proportion to the area of land he owns and that no field is left unirrigated. He/she has to inform every household when its turn arrives to receive water; from then on it becomes the duty of the concerned family to ensure that water reaches their fields. Another important duty of the *chudpon* is to mediate and resolve any minor disputes and conflicts over water that may occur in the village. If the disputes are of a more serious nature then the *goba* (headman) of the village is asked to mediate along with the *chudpon*. The *goba* may even request to the *patwari* to consult the *bandobasti* to help resolve the conflict.

It is interesting to note that water availability for the coming agricultural season is predicted depending on the amount of snowfall in early winter, and the structure is modified according to these predictions. For example, in one village, a major water shortage led to the appointment of four *chudpon*s, instead of the usual one *chudpon* in order to manage the scarce water as efficiently as possible. This flexibility within the system indicates that the rules are tailored to the local circumstances and can be modified within an established framework so as to adapt to their needs and specific characteristics of their environment.

<u>*Traditional institutional framework for water management in the Himachal cold deserts*</u>

The water sharing system in Spiti is also instrumental in maintaining the carrying capacity of the surrounding cultivable land. Due to limited water availability, inheritance laws in Spiti traditionally seek to prevent fragmentation of landholdings. The eldest son inherits not only the land, but also the farm implements, the family house and the family's water rights. His siblings either serve in the common household or, more likely, become monks or nuns in Buddhist monasteries. Thus a sort of population control has been evolved which serves to stave off pressure on the landholdings.

Water rights are owned exclusively by members of the *bada ghars* (big houses), who are descendants of the original settlers or founders of the village. This system, besides establishing the pre-eminence of the *bada ghars*, has also installed a local social hierarchy. The greater the share of a family's water rights, the more land it controls. In one large village for instance, water rights over the single *kuhl*, irrigating 32 ha, are shared by 18 *bada ghars*, and payment is generally made in kind or by providing free labour, but often the water is given freely. Water transactions are based on trust and are neither written down nor codified.

When a good snowfall assures abundant water, *kuhl* water is freely dispensed, but when water is scarce, equality gives way to a preferential system. During a water shortage, *bada ghar* members irrigate their fields first; others get water only later in the season. This practise has the advantage of ensuring that the demand for labour is spread over the entire harvest season because the *bada ghar's* crops ripen early, when other families are free to help in harvesting. This spacing of the need for labour does away with demand peaking at the same time throughout the valley, and provides a firm basis for community labour. These cooperative efforts also mean that time and effort do not become areas of conflict between those who require labour and those offering it.

Typically, the *bada ghars* display generosity and big-heartedness in helping the poor in the society with water and even money at times. Nevertheless, water distribution from *kuhls* can create tension, for, when there is water shortage, the *bada ghars* in effect are in a dominant position and suffer the least, unlike those with secondary access who have to await their turn, but are not certain if their share will be adequate. But even among *bada ghars*, the distribution of water shares may be unequal. The factors that determine sharing among them are not clear, and probably were settled when the *kuhl* was constructed with the family that contributed the most in labour and other resources at the time of construction, getting the largest share under the water rights passed on through generations.

The unit of *kuhl* water is one day's supply. Between sowing in April and harvesting in September, water availability is for approximately 70 days. But if a family whose share is 30 days needs *kuhl* water for only 20 days, it can sell its surplus. Water shares are renewed and adjusted every season according to need, but a share cannot be lent, sold or disposed of in perpetuity. This restriction preserves the position of the *bada ghar* families.

In Kinnaur and other regions, *nallas* passing through a village are harvested on turn basis called *pala*. Temporary channels are dug by the farmers towards their fields. The whole community is divided on the basis of number of farm families and one family gets one full water day to irrigate their fields turnwise. For example, if there are 20 farm families in a village, the turn falls after every 20 days. But two adjoining families may share the water for half day each when there is turn of either of the two families. Thus these two families get a chance to irrigate their fields after a gap of 10 days rather than 20 days. This way the distribution of water is so well managed that maximum use of water takes place in a particular village. The turn of a family comes/starts around 2000 to 2200 hrs on a particular day and all the members of the family are engaged in the job on its turn.

3.5 Effectiveness of the Traditional Systems

Traditional systems for water harvesting have proved successful from time immemorial. However in the wake of global warming, all the storage and distribution infrastructure lies deserted once their only source of water turns dry.

3.5.1 Inadequate Water Availability

Global warming has led to lack of snowfall during winters for past 5-6 years in the region. Since these communities depend solely on glacial melt for meeting drinking and irrigation needs, receding glaciers have emerged as a major problem. All villages in the valley are situated along perenial streams which fulfill all their demand for water. Lack of snow during winters has now affected these streams to the extent that most of them dry up by the end of August or latest by September, which happens to be the harvesting season for all major crops grown in the region.

All the irrigation channels (*kuhls*) cannot be run satisfactorily due to the non-availability of sufficient water from *nallas/khads* in recent times, in turn due to the scanty snowfall during the winter months. The majority of the hamlets that lie on the plateaus flanking the main river get water from the streams which trickle down from the cliffs overhanging the plateaus. These hamlets are the worst off for water, for in years of scanty snowfall, the streams dwindle and dry up quickly, by the beginning of August. Excess snowfall in winters would result in reduced water in natural springs as the spring source freezes, whereas less snowfall in winter results in the reduction of level in natural springs during summer and consequently crops suffer.

3.5.2 Seepage Losses

A study to estimate the seepage losses from the existing channels (*kuhls*) in these regions brought out the following facts:

Discharge at two different points at known distances along the *kuhl* was measured. Difference in discharge is used as a rough estimate of seepage losses.

Discharge upstream	=	5.13 ltrs/sec
Discharge downstream	=	3.76 ltrs/sec
Distance between two points	=	250 mtrs
Seepage Loss	=	0.33 ltrs/mtr/minute

Water losses from the *kuhl* depend upon:

- ◇ Seepage losses due to porosity of soil. (Porosity of soil depends in turn upon the type of soil and the moisture contained in the soil. More the moisture contained, the less will be the seepage.)
- ◇ Evaporation losses due to an intense sun. (Rate of evaporation varies as the weather alternates from sunny to cloudy; because of intense sun and cold winds.)
- ◇ Moisture losses due to dry winds. (Moisture losses are maximum between 3.00 pm

and 6.00 pm)
- ◇ Losses due to water required by wild bushes and grass in the *kuhl*.

3.5.3 Maintenance of the Irrigation Infrastructure

The traditional clay structures of *kuhls* and *zings* are extremely vulnerable to environmental damage and require considerable labour for frequent repairs. Improvements have involved creating cemented *kuhls* and *zings* of larger size, which however face the problem of cracking as a result of expansion and contraction due to climatic extremes. The *kuhls* and *zings* in the region get the attention of the villagers only during the irrigation season, and the earlier cooperation is no longer evident.

3.5.4 Scope for Water Reduction Potential

Due to the acute water scarcity and harsh climate conditions of cold deserts, the inhabitants have developed water management methods that ensure minimal use of water to meet their daily needs. Hence very little scope exists for reduction of water usage in cold deserts.

3.5.5 Breakdown of Social Institutions

The water sharing system, carefully nurtured through the centuries, now runs the risk of being upset through government interventions as well as the changing value system and social structure. This ancient system is slowly decaying, giving way to the need for solving water problems through mutual understanding. Social issues and water shairng conflicts regarding the distribution of water, crop up more frequently, especially at times of scarcity.

4. APPROPRIATE TECHNOLOGIES FOR WATER MANAGEMENT

Water resources management or development represents an attempt to meet an existing or potential demand for water or a related resource, such as energy or food. Commonly, attempts to meet these demands are based upon engineering modifications of the existing water supplies. Engineering modifications, in turn, are dependent upon a quantitative understanding of the temporal and spatial variability of those supplies. It is apparent that a major component of attempts to develop or manage water resources in an environment must be scientific stuides of the resource, in advance of need, if project planning is to be realistic. Within any river basin, attempts to meet demands that exceed the natural supply of water will be, at best, only partially successful. Demographics determine the nature of demands upon water resources. Economics and engineering determine the extent of technologies available and the willingness of a society to apply those technologies. Hydrology determines the extent to which the supply will meet that demand.

In the context of factors affecting the flow of water through a watershed, the environment may be defined as: climate, geology, topography (or terrain), and vegetation. Environment management, from a water resources perspective, is a matter of determining the extent to which a change in any one, or some combination, of these factors will produce a corresponding change in the timing, volume or quality of water flowing through a watershed. Alternatively, it is a matter of inducing a change in one or more of the factors so as to produce some desired change or correct a perceived imbalance. Basically all technologies for modifying the natural characterisitics of volume, rate, timing or quality of water at a site, are variations of a few basic themes: storage of water during a period of deficit, transfer of water from an area of surplus to one of deficit, or improving water quality - with an endless number of combinations and permutations of these.

Both Pre and Post consumer conservation technologies needed to be developed for evolving a comprehensive water management plan for cold deserts. For evolving pre-consumer techniques for water conservation, a study was carried out to ascertain the engineering measures that could be adopted. The study started with the identification of potential water sources and the appropriate technologies for tapping these resources. A comparative analysis of the available technologies was carried out to select the best option for the typical needs of cold deserts.

4.1 Pre Consumer Techniques

4.1.1 Potential Water Sources

The following sources of water were studied in depth for their advantages and development needs:

i. Glacial melt streams: Glacial melt is most suited for villages which come under the highlands category. These areas are typically served by a *nallah*, which covers a long distance from the glacier head before joining the river. All irrigation water needs are fulfilled by the *nallah* alone.

ii. Rivers: Basins of the cold deserts are best suited to meet their water needs by diversion channels through rivers. As the basins are situated about 20-50m above the river beds and banks are flatter, water can be diverted through channels to the fields utilising the gradient of the river.

iii. Groundwater: Groundwater can be tapped in the regions classified under steep banks and basins of cold deserts by using handpumps. A water bearing layer or a pervious layer is essential for tapping groundwater as impervious layers do not allow water to percolate in them and therefore do not recharge the underground water channels. Groundwater is free from suspended impurities and their quality is generally reliable. The straining action of the porous strata through which water travels is responsible for improving upon the water quality. The highly sandy strata of cold deserts augers well for tapping groundwater as sandy strata is fairly pervious.

iv. Perennial springs: Another source of water in these regions are the perrenial springs locally called *chasmas*. These are tapped by the villagers for meeting their irrigation and drinking water needs. However the problems arise when these sources are far off from the villages as high costs are then incurred in tapping these sources.

v. Snow: The highlands of cold deserts depend solely on natural streams deriving water from glacial melts. Huge reserves of snow is an gift of abundance that nature has given the otherwise resource deficient cold deserts. Tapping these reserves of snow can provide an effective solution to the water drudgery of the people of cold deserts. This will need construction of dam like structures to store the glacial melts and use them as and when needed. Appropriate siting, huge physical effort and financial requirement, are a few constraints for construction of such reservoirs however.

vi. Marshes, meadows & oozing: Marshlands though not very common in cold deserts do occur at a few places. These areas can be used for tapping underground water

4.1.2 Potential Technologies for Sourcing & Distribution of Water

i. Artificial glaciers

Some attempts have been made to manage the fluctuation in the quantum of water available across the cultivation months towards spreading it in a more uniform manner throughout the cultivation period, through the creation of Artificial Glaciers. This is a technique that has bben developed and implemented in Ladakh for meeting the early cultivation period water requirements of farmers. The scarcity of water in Leh is more pronounced during the sowing season, i.e., in the month of April. In this technique, water from an existing stream is diverted through iron pipes to a shaded area of the valley, where the winter sun is blocked by a ridge or a mountain slope on the south side (in the northern hemisphere). Here, the water is made to flow down onto a sloping hill face. At regular intervals along the mountain slope, small stone embankments are constructed to impede the flow of water and enable the formation of shallow pools. All this is done just before the onset of the winters. As the temperature falls steadily, the shallow pools of water begin freezing in layers. This process continues for months and a thick layer of ice gets deposited upon each embankment. These artificial glaciers, which are formed at comparatively lower altitudes, melt in the early summers and spring, when the traditionally harvested high altitude glaciers do not begin melting, and thus fulfill the early cultivation season requirement.

Tsewang Norphel, the artificial glacier innovator, has created five artificial glaciers in Ladakh, each at the cost of about Rs. 1,00,000. A typical artificial glacier is about 600 feet long and 150 feet wide, and can collect as much as 6 million gallons of water. After losses through seepage and evaporation, as much as half of this water can reach a village about four kilometres away. This can benefit three or four villages, or about 1,500 farmers. All that is required to build an artificial glacier are easily available mountain rocks and the pipes used to channel the water. Norphel's glaciers require no specialized skills, and are usually built by 10-12 local villagers working under Norphel's direction.

A diversion channel is an important component of an artificial glacier scheme. The diversion channel is constructed a little above the foot of the mountain face to divert snowmelt from the mountain face above the channel. Construction of channels ensures the diversion of snowmelt from parts of valley where it would otherwise flow away as runoff to those parts of the valley where it is most required. Apart from this, water enters the channel directly from the glacier mouth as well. The channel thus allows utilisation of huge reserves of snow accumulated on the mountain face which can be aptly termed as a glacier. A typical channel is about 6-7 ft wide with a depth of 3 ft.; there are no limits on the length of the channel. The mountain face on which the glacier is created has to face north to take advantage of the low winter sunshine reaching the north face. This ensures delaying of the melt and hence utilisation of the melt for a longer period.

This technology however is still at the preliminary stage of experimentation (despite good initial results) and needs to be developed to set clear conditions and standards for implementation.

ii. *<u>Snow reservoirs</u>*

The snow reservoir is a technique modelled on the artificial glaciers innovated in Ladakh. In contrast to the early cultivation period water requirement in Ladakh, lack of water is experienced late in the summers in Spiti, in the months of August-September. Snow reservoirs constructed in some shaded region in the highlands of the cold deserts, can prove very useful for meeting this late season water requirement, if the melting of the compacted snow in the reservoir could be delayed uptill September. This would require covering the whole reservoir with charcoal, saw-dust or some insulating material, or by providing artificial shade, from April to end of August.

iii. *<u>Upstream dams</u>*

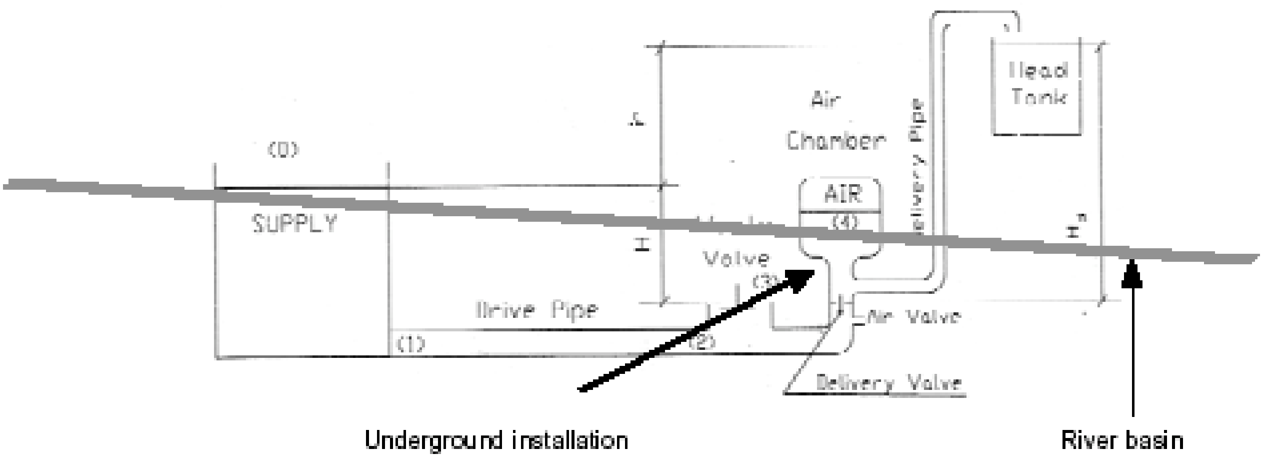
An option similar to the snow reservoir is the construction of a small dam upstream on a stream at an altitude of 14,000 ft. or more and more than 2,500 ft higher than the settlements. The requirement for this would be a large catchment area that could be converted into a reservoir by the construction of a small dam. A thin layer of water would get added daily to this reservoir, and this would freeze during the night - at an altitude of 14,000 ft, the temperature would reach -30^{0}C on winter nights. Long winters will help the deposition of ice formed in layers, which would then need to be covered with saw-dust or coal, in order to preserve it till the end of August.

iv. *Hydram*

For steep banks regions of cold deserts, water lifting devices like hydrams would be very effective. A hydram is a unique device that uses the energy from a stream of water falling from a low head as driving power to lift part of the water to a head much higher than the supply head. The ram operates according to well-known hydraulic principles, with the total force required to elevate a given volume of water being that which is greater than the sum of the forces created by the vertical distance which the water has to be elevated (or the static head) and the resistance offerred to the flow within the suction and delivery pipes (or the friction head). With a continuous flow of water, a hydram operates automatically and continuously with no other external energy source.

A hydram is a structurally simple unit consisting of two moving parts: the waste valve and the delivery (check) valve. The unit also consists of an air chamber and an air (snifter) valve. The operation of a hydram is intermittent due to the cyclic opening and closing of the waste and delivery valves. The closure of the waste valve creates a high pressure rise in the drive pipe. An air chamber is necessary to prevent these high intermittent pumped flows into a continuous stream of flow. The air valve allows air into the hydram to replace the air absorbed by the water due to the high pressures and mixing in the air chamber.

Using a hydram, water can be delivered at a height 10 times the available supply head. Thus, for raising water to 100 m, a minimum of 10 m of supply head is required.



v. *Solar pumps*

Cold deserts are rich in sun and receive more than 5000 W/sq meter for a minimum of 6 hours (cloudy at other times). This enormous amount of solar energy can be tapped to lift water from the river. Technologies available are:

- Photovoltaic array kits
- Small steam driven pumps where the steam generator uses parabolic reflectors.

Solar pumps can be used in basins where water needs to be lifted to a small height.

vi. *Upgradation of kuhls*

Gravity flow is no doubt the easiest and most effective technique, also the traditional method of water harvesting, in the entire cold desert area. Water is diverted from streams to the low lying areas fields or storage tanks (*zings)* through a network of intricate gravity, earthen channels called *kuhls.* Given the rugged terrain of the area and the absence of rain, upgradation of minor irrigation schemes like the traditional diversion channels would have high effectivness. The upgradation can include:

- extension of kuhls
- lining of kuhls with cement/plastic film to reduce seepage
- protection of source points, i.e., kuhls heads
- general maintenance of the kuhls to enhance their efficiency

vii. *Upgradation of zings*

Zings are the age old water management structures adopted across the cold deserts irrespective of the geographic terrain. All existing zings in these regions are made in dry stone masonry leading to frequent damages and hence repairs. The zings also remain unlined leading to high seepage losses. These zings can be also be upgraded in the following ways:

- conversion to permanent structures with cement lining
- increasing the zing sizes for enhancing their capacities
- lining the zings with plastic film to reduce seepage
- general maintenance and desilting to enhance efficiency

viii. *Development & protection of natural springs*

The main objective of spring development is to provide improved water quantity and quality for human consumption. Development of natural springs tends to improve their yield, in contrast to the generally-held belief that discharges decline if the springs are touched. Spring development activities include provision of storage tanks, tapstands, drainage, and catchment area protection. Thus, the design of a standard spring development and protection scheme includes the construction of an intake structure, collection tank, tapstand, and retaining wall, and the provision of drainage, fencing and grassed surround. The intake structure is located at the source of the spring called the 'eye', or the point within the spring where the spring flow is concentrated and follows a stable channel, and collects the water for transfer to the collection tank.

The intake structure also protects the eye of the spring from immediate and future contamination. In concentrated springs, where the water appears in a single channel, water can be tapped easily using a standard catchment structure at the eye. In dispersed springs, where the water flow is diffused and an eye is not discernable, suitable channels may need to be constructed to divert water from diffused sources to the catchment area. A typical intake structure is constructed of a minimum of 2 m backfill above the source of the spring, 1 m of which should be constructed of impervious clayey soil. This construct is protected from erosion by a dry stone retaining wall built to prevent the backfill area from being washed away. Immediately around the spring is constructed a filter bed of dry rubble. In dispersed springs, where the construction of a filter bed may not be possible, a dry-stone channel may be used to the direct water from the spring source to the catchment floor. The stone channel and catchment area are covered with heavy duty plastic sheets to stop the surface water from mixing with the spring water. A concrete pad is required below the filter bed whenever the soil conditions are in doubt. However, it is important to ensure that the concrete pad of the intake structure floor and walls is well drained in order to prevent seepage from undermining the concrete floor. Also, while small plants and grasses should be planted around the spring area to filter surface runoff and prtoect the spring from contamination, deep-rooted trees should be avoided as the root systems can clog the spring and damage the protection works. Finally, the outlet and overflow pipes placed into the intake structure should be sized so as to avoid the possibility of impounding the spring water during peak flow periods.

Spring water should be stored in an appropriate collection device. A small ferrocement tank of 500 or 1 000 l capacity serves to store the water in most cases when the average discharge of the spring under consideration is below 0.1 l/s. If the flow of the spring exceeds 0.1 l/s then a storage tank may not be necessary and direct flow to the point of use could be provided. The size of the tank is determined based upon a minimum supply of 20 ltrs per capita per day. Where a storage tank is provided, the top of the tank should be raised above ground level. The tank should be located as close to the catchment as possible, and the head difference between the intake and the tank should be sufficient to drain off the collected spring flow to the tank without causing a back-up or impounding of the water within the spring. The tank also should be protected by a fence.

An appropriate tapstand, including a washing platform with the provision for drainage, may also be constructed. Regular maintenance of the scheme is required and includes cleaning the storage tank regularly, protecting the storage tank and catchment area with fencing and grass plantings to minimise contamination, keeping the tap area clean and properly drained, and diverting surface water drainage away from the catchment area. Retaining walls should also be constructed on steep hillsides to mitigate landslides.

ix. *Drip irrigation system*

Drip irrigation systems deliver water and agrochemicals (e.g., fertilizers and pesticides) directly to the root zones of the irrigated plants at a rate best suited to meet the needs of the plants being irrigated. Thus, this system makes efficient use of water, especially when compared to conventional methods of irrigation such as furrow, border, basin and sprinkler irrigation systems, which, under arid and drought conditions, suffer from an high rate of water loss and have a low degree of water use efficiency.

Drip irrigation techniques can also be put to effective use for irrigation in cold desert regions. Drip irrigation equipment consists of a grid of pipes which is laid on the fields. The pipes have small holes at regular intervals for water to trickle down to the plants. The network of pipes is fed through a tank sited so as to supply a head of 1-1.5m to the grid for irrigating about 1/2 bigha of land. This helps in generating adequate pressure for water to flow around the grid. Drip irrigation techniques are highly efficient water saving appliances and can cut down water requirements by about 50%.

The capital costs involved in the establishment of a drip irrigation system are high compared to the costs of establishing conventional irrigation systems. However, the labour requirements and operational costs are low. The principle operation and maintenance requirements associated with the implementation of this technology include the need for regular cleaning of the system and careful monitoring of the quality of the source water, as the drip irrigation systems are very sensitive to the clogging of the drippers. The systems also require a relatively high degree of skill to design, install and operate, and are susceptible to theft, damage and disruption by rodents that destroy the drip pipes and drippers.

x. *Dew harvesting*

Dew harvesting helps in maintaining soil moisture by minimizing evaporative losses and increasing soil temperature. It involves preparing soil beds with a 10 to 15 cm thick gravel layer. The pieces of gravel range from 2 cm to 5 cm in diameter. In the evening, the gravel layer cools, and remains cool in the early morning when water vapour condenses onto the gravel creating droplets which pass between the gravel particles and reach the soil surface, moistening the soil. Dew harvesting is a simple, cost effective and easy to implement technique that can be effectively utilised for supplying small volumes of water for specific, supplemental uses.

xi. *Micro-water harvesting/conservancy*

Given the microclimatic changes in the cold desert region, bringing in more rain and less snow, traditional water conservancy/harvesting methods can also be applied during the short rain period. Different types of rainwater catchment systems, viz, rooftop collection, concrete lined tanks or plastic film lined tanks, etc., can be used. These can be used for both irrigation and domestic requirements, although primarily for the latter, given the extremely low levels of precipitation.

xii. *Snow harvesting*

Snow harvesting requires the construction of a pit, generally ranging in size from about 6 to 8 metres in diameter and about 10 metres in depth. The pit is heavily compacted and the collected snow is dumped into the pit to a depth of 2 to 3 metres. The compacted snow is covered with earth, which acts as an insulator, and a bamboo tube is placed about 50 cms above the base of the pit to serve as an outlet. As the snow melts around the bamboo pipe, water trickles along the bamboo and into a pot placed beneath the outlet. The water collected in the pot may be used for household drinking water and can supply water to up to 14 families.

xiii. *Evaporation reduction*

Evaporative losses can be controlled using various technologies. The use of mono molecular organic surface films has been shown to be an efficient technology for reducing such losses. The mono molecular film is applied to an open surface water storage area and allowed to settle over the water surface. Typical mono molecular films are comprised of long-chain fatty alcohols such as cetyl alcohol and stearyl alcohol, chemicals that have the capability of suppressing evaporation. The use of stearyl alcohol in doses of upto 70 g/sq.cm. can reduce evaporative losses by upto 55% of the loss due to evaporation from a free water surface. However the economics and extent of use of this technology are yet to be explored and established. Besides, this technology works best for water storage surfaces that are not open to strong winds; cold deserts however, have very high wind velocities.

xiv. *Tubewells*

Tubewells (with suction pumps) can be used in conjunction with measures for recharging acquifers. This is especially useful for potable water. An estimate of one bucket per person for cooking and drinking needs is satisfied comfortably by these hand pumps. Govt. departments have also installed a few handpumps in these regions.

4.2 Utilisation (Conservation) and Post Consumer Techniques

It must be mentioned here that people of cold deserts have learned this art of using water wisely. Adapting magnificently to the harsh climate of the region water is used very scarcely by the people. Some of the utilisation and post consumer techniques that were identified are described below.

i. *Ridge & furrow method of irrigation*

Where land sloped gently, adequate soil and water conservation mat be achieved through conservation tillage (contour tillage or contour farming. This consists of ploughing and planting crop rows along the contour, rather than up and down slope. This has been found to be highly effective in enhancing soil moisture recharge and soil water conservation. For added security and better infiltration, contour furrows or ridges are tied by hand or with a modified plough. Ties are earth barriers at intervals along a furrow, like rungs on a ladder, their crest lower than the ridges either side. They can, under the right conditions, help hold slight and moderate runoff and control heavier flows. On slightly steeper ground or where there is more aggressive runoff, contour bunds may be efective.

ii. *Moisture conservation through mulching*

As has already been explained under traditional systems study, mulching not only helps in soil moisture conservation but also maintains optimum soil temperature for plant growth. In cold deserts however, use of available mulching material may reduce the availability of fodder. Mulching may rely on non-organic materials as well: a 5 to 15 cm thick layer of sand, pebbles, gravel or dust, spread over the soil is a common strategy. Plating sheeting is also used for mulching by commercial farmers. Too expensive for smallholders, it also presents disposal problems once damaged. Recent developments in mulching are those of hydro-seeding and rolled erosion control systems. Hydro-seeding is the spraying of a mulch, or sewage sludge, or wastewater biosolids, or fibre-mat forming slurry enriched with seeds. Once applied, the excess water evaporates, leaving a moist, soil-anchoring seedbed. Rolled erosion control systems are fibre-mats or sheeting, formed with natural fibres, such as jute, coir, kenaf, bargasse, that biodegrade rapidly.

iii. *Runoff management*

Runoff management techniques need to be adapted to the landscape, the soil and the slope. In the case of a plateau with permeable soil, a very slight incline and therefore relatively little runoff, the tillage should be on the flat area. At the top of a slope of an average gradient, with permeable soil that drains quite easily, there is a high risk of runoff and dessiccation. The land here should be shaped into mounds and depressions in order to confine the water and force it to percolate. Halfway down a hill with a steep, natural gradient and permeable soils, the risk of runoff is high again as is the risk of drought. In this case, crops need to be grown on mounded, tied ridges established along the contour lines, such that all the water is trapped in the partitioned furrows and forced to infiltrate. At the bottom of a slope where the ground is gently sloping and the soil is quite impermeable due to the alluvial content brought down by runoff, there is a danger of waterlogging and temporary flooding. Open ridges should be made running down the slope to let the excess water drain into the stream.

The strategies for runoff conservation include: forcing water to penetrate on steep and uncultivated slopes, slowing down sheet and gully runoff on slopes of average incline, limiting splash and creating infiltration zones in all cropping fields, and slowing down torrential flows in gullies & streams thus forcing the water to deposit its load of silt and clay. Uncultivated slopes of average to high gradient should be afforested. Microcatchments hould be developed on hillsides to help trees grow on them. Suitable farming practices and perennial plantations must ensure good plant cover on the plateax and slopes. Stone and earth bunds should be constructed on valley slopes, and small stone and gabion dams of permeable or impermeable material must be constructed in gullies and streams.

iv. *Recharging acquifers*

The groundwater in the acquifers may be recharged by a variety of measures. These methods may be classified into: direct surface recharge technique, direct subsurface recharge technique, combination of above two, and indirect recharge techniques. Direct surface recharge techniques typically use infiltration basins to enhance the natural percolation of water to subsurface levels. Direct subsurface recharge techniques use injection wells to access deeper acquifers and recharge these. Indirect methods include installation of groundwater pumping facilities near surface water bodies to lower groundwater levels and induce infiltration elsewhere in the basin.

The selection of sites for these recharge structures depends on the configuration of the deep (greater than 100 m depth), confined aquifers, the hydraulic gradient, and the location of the source of excess surface water. The actual designs of the injection wells and connector wells are similar to those of the normal tubewells and depending upon the aquifer characteristics, slot sizes, casing sizes and gravel packing are to be selected. In contrast, groundwater recharge by spreading is best practised in shallow (40 m to 100 m), unconfined or leaky aquifers. Several methods are commonly used. Channel spreading involves changing the pattern of the surface flow in the river channel using "L"-shaped levees (sand bunds), slowing the rate of river flow and increasing the channel length to provide more time for infiltration. The spreading channels have side slopes of 1:1 and very gentle floor gradient slowing the downstream movement of water, allowing time for infiltration, and reducing erosive action of the water. Weirs or small structures may be built across the seasonal and perennial streams to slow the water at an appropriate location. This results in surface water storage, groundwater recharge, reduction of soil erosion and availability of water for other purposes. A variant of this technique is the use of contour trenching, which is better suited for use in hilly areas where surface runoff rates are very high. Planting of trees along contour bunds or trenches further helps to reduce surface runoff rates and soil loss due to erosion. A further variation of the surface spreading technique is the use of recharge ponds, percolation tanks, check dams, and subsurface dikes. In the level dike system, water is made to flow in a zig zag manner across the slopes through the entire system, thus recharging the acquifers. These lentic waterbodies create a "mound" of groundwater within the aquifer immediately below the ponds, which extends up to between 100 m and 1000 m from the recharge structure, depending upon availability of water for recharge. These are the cheapest modes of artificial recharge.

However, the design of the recharge structure requires careful consideration to ensure the correct sizing of the pond both to provide sufficient recharge to meet abstraction demands and to adequately contain stormwater runoff. For an average village with population of up to 500 persons, a 0.5 ha pond, with little water loss due to overflow, is sufficient to provide enough recharge to service the potable water requirements of a tube well-based water supply system. Subsurface dikes are among the most suitable structures for promoting groundwater recharge. Since the entire structure is underground, evaporative losses are insignificant. Two subsurface dikes of 100 m length each, within 300 m upstream and downstream of the water supply well, can capture and infiltrate enough water to service the potable water requirements of a village of up to 500 persons. In general, the sites selected for construction of ponds, tanks, dams and dikes are normally those where manual excavation is possible. Such sites are typically those that have undergone intense weathering, and, as a result, have a high fracture porosity, or are in alluvial areas, which are best suited for infiltration.

Such structures should also be designed in such a manner as to minimize the accumulation of silt and organic matter within the structure. For example, the infiltration capacity of ponds is reduced by up to 25% each year as a result of siltation, and, by the end of fifth year of operation, is reduced to about 10% of the total storage. Thus, 90% of stored water is lost to evaporation. The table below summarises the relative suitability of the various types of artificial recharge structures for a number of typical applications. Periodic maintenance of artificial recharge structures is essential because infiltration capacity is rapidly reduced as a result of silting, chemical precipitation, and accumulation of organic matter. In the case of spreading structures, annual maintenance consists of scraping the infiltration surfaces to remove accumulated silt and organic matter. In the case of injection wells and connector wells, periodic maintenance of the system consists of pumping and/or flushing with a mildly acidic solution to remove encrusting chemical precipitates and bacterial growths on the well tube slots. By converting the injection or connector wells into dual purpose wells, the interval between periodic cleanings can be extended, but, in the case of spreading structures except for subsurface dikes constructed with an overflow or outlet, annual desilting is a must. Unfortunately, because the structures are installed as a drought relief measure, the periodic maintenance is often neglected until a subsequent drought, at which time the structures must be restored (the 5 to 7 year frequency of droughts, however, means that some maintenance does take place). Structural maintenance is normally carried out by several agencies and individuals. Maintenance of minor irrigation tanks is normally carried out by the state irrigation department, maintenance of contour bunds and trenches (along with related afforestation activities) by the state forestry department, and maintenance of farm ponds and related structures by the cultivators.

Suitability of Artificial Recharge Structure for Common Water Resource Development Purposes.

Lithology	Topography	Type of Structure
Alluvial or hard rock	Plain area or gently undulating area	Spreading pond, subsurface to 40 m depth undulating area dike, minor irrigation tank, check dam, percolation tank, or unlined canal system
Hard rock down to 40 m depth	Valley slopes	Contour bunding or trenching
Hard rock	Plateau Regions	Recharge ponds
Alluvial or Hard rock with confined aquifer to 40 m depth	Plain area or gently sloping	Injection well or connection well
Alluvial or Hard rock with confined aquifer to 40 m depth	Floodplain deposits	Injection well or connection well
Hard rock	Foot hill zones	Farm ponds or recharge trenches
Hard rock or alluvium	Forested areas	Subsurface dikes

In cold desert areas an integrated series of techniques need to be employed, for example, damming the gullies of minor streams, constructing subsurface dikes and/or percolation tanks along their tributaries, contour bunding and trenching on slopes, installing check dams-cum-minor irrigation dams on the main stream courses. Terracing and afforestation of hillsides, which help to retain runoff and increase infiltration, may also form part of an integrated basin-scale water resources development plan.

v. *Water resuse*

Water reuse, and the reuse of wastewater in particular, is receiving increasingly wide attention. However, since it is considered to be of marginal quality even post treatment, treated wastewater can provide a secondary source of water for purposes such as toilet flushing and irrigating private gardens. The very low volumes of water used by cold desert inhabitants for domestic purposes make the installation and operation of such dual distribution systems unviable. However, the family water use levels are on the increase and the burgeoning tourism & hospitality industry in the region has led to higher levels of water use in hotels and restaurants. Wastewater treatment and reuse systems might have potential especially in these establishments.

Preliminary treatment of wastewater is basically screening of settleable organic and inorganic solids by sedimentation and removal of materials. Approximately, about 25% to 50% of the incoming BOD5, 50% to 70% of the suspended solids, and 65% of the oil and grease is removed during the preliminary or primary treatment process. This process largely reduces the volume to be treated through secondary and advanced treatment processes, and, for some purposes such as irrigation of orchards and vineyards, may be considered sufficient treatment for reuse, depending upon the local acceptance. A bar screen made of long, narrow, metal bars spaced at 25 mm is used for preliminary treatment. The primary treatment process consists of grit removal. Basically two types - horizontal flow and aerated types - of grit removal techniques are used. Primary settling tanks are then used to remove the readily settleable solids prior to further treatment. The treatment process involves chemical treatment and flocculation, and passage through second and third stage settling tanks. A study by Chen (1993) to evaluate the effectiveness of primary treatment of municipal wastewater before discharge into the ocean indicated that the removal of suspended solids was always less than 50% while COD and BOD5 removals were in the range of 23% to 41% and 15% to 27%, respectively.

The main purpose of secondary treatment is to remove non-settleable solids remaining in the wastewater stream after the preliminary and primary treatment process. Efficiency is estimated at about 85% removal of BOD5. This technique involves biochemical processes for the oxidative or reductive degradation of biodegradable organic pollutants, and includes such technologies as the anaerobic and facultative ponds as well as aerated lagoons.

4.3 Technology Studies

4.3.1 Hydraulic Rams

Although several hydrams have been installed in the cold desert region, most have been total failures. Site visits to hydram sites in Spiti valley and Leh and consultations with concerned officials have revealed the following details:

- Around 40 hydrams that have been installed in Spiti valley by the govt. deptts. like IPH and DDP and agencies like HIMURJA have not been working.
- Hydram installed by the DDP in Khurik, 16 kms ahead of Kaza in Spiti, worked for only 15 days. Three hydrams have been installed here in parallel to lift water to roughly 300ft. Kuhls were constructed to the length of 150 mts to the collection

tank. Very long delivery pipes were being used to lift water, thereby considerably reducing the quantity of water being pumped due to losses. Considerable pipe lengths may also cause clogging if the desilting is not effective.

- Discussions with IPH officials also revealed that hydram was not a viable option for the region given the sandy strata of the region with low water retention capacities and limitations of hydrams in lifting huge quantities of water. To irrigate 1 Ha of land it requires 5 lps of water in Spiti whereas in other districts of Himachal, where hydrams are functional, it requires only 1 lps.
- Long channels on steep river banks have been constructed to ensure adequate supply head to the hydram thereby necessitating periodic maintenance, for these long earthen channels incur periodic clogging and damage. Lack of funds for maintenance has meant that the channels lie deserted preventing functioning of the hydrams. To prevent clogging and damage to the channels from the loose soil of the steep banks, retaining walls need to be constructed along the channel. This in turn enhances the costs of the project. Desilting arrangements for preventing silt entry to the hydrams and storage tanks to accont for the river fluctuations also add up to the costs of civil works.

Three reasons behind the failures of hydrams in the region.

a. Unskilled staff and poor maintenance due to lack of funds and lack of interest among the locals
b. High silt load which is not removed even after constructing baffle walls in the desilting tanks. The silt destroys the plates and washers in the equipment .
c. High fluctuations in the level of water

A thorough study was therefore carried out of not only the installed hydrams but also the technologies used to address the above issues. Desilting basins constructed at different places in Spiti were visited and inputs on the performance of these systems were collected from the concerned implementing/operating agency, viz the IPH (Irrigation and Public Health department).

i. *Lift irrigation scheme at Lingti*

The Lingti river emerges from Gya peak in the north, the highest peak in Spiti valley, and joins the river Spiti at Lingti, 20 kms from Kaza. The IPH has a lift irrigation scheme at Lingti for supplying water to ‘Subling Maidan’, 83 m above Lingti river with an average discharge of 4.375 gps. The scheme uses a desilting basin. Water from the river is brought to a 6 ft wide channel fitted with baffle walls. The tank is 13 ft long and tapered at ends; the delivery and discharge from the tank is connected to *kuhls*.

Water from the main kuhl is brought to low velocities in the desilting basin, which uses baffle walls on either sides to increase its retention time. The tank itself consists of two parallel open channels operating one at a time. Due to the high amount of silt deposited, these channels need frequent cleaning for which one of the channels is kept out of operation at a time.

The basin is constructed midway through a 50-60 m long kuhl to the pump house. The 92 hp pump has been functional for the last five years with minimal maintenance at intervals.

Other specification of the scheme are:

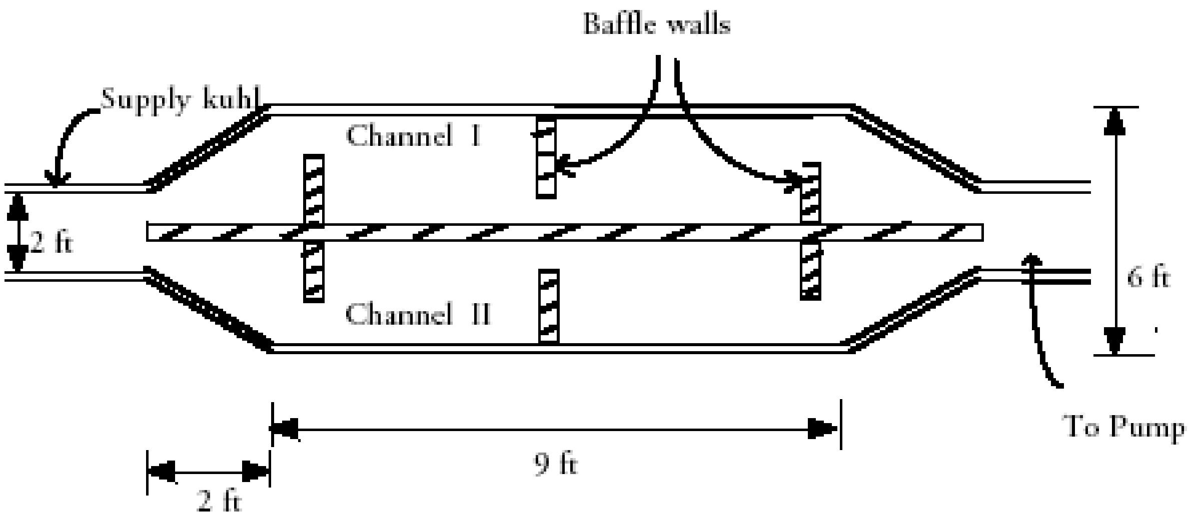
Total culativated area	60 acre
Discharge	4,375 gallon
Source	Lingti *nallah*
Length of rising main	188m
Dia of rising main	200 mm
Dia of section	125mm
Total head	83 m
Pump set	92 Hp

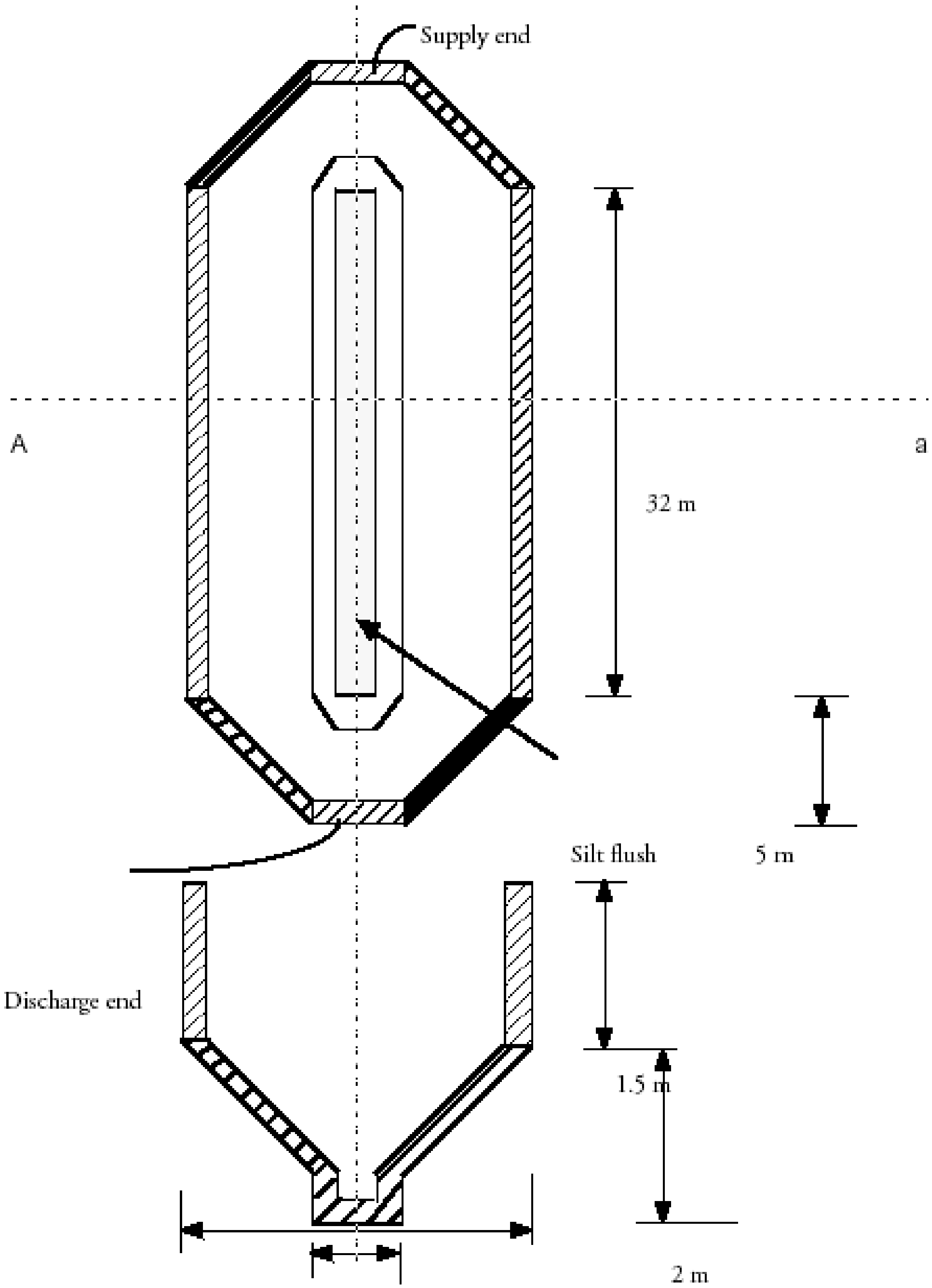
Figure: Desilting basin for Lift irrigation scheme in Lingti (approximate dimensions)

The pump has been operating for more than five years (during summers; irrigation season) without reporting any problems due to the high amount of silt in the water. According to the pump operator, it irrigates around 400 bighas of field and almost 60 bigha per day. Fuel requirement for the operation of the pump for a period of 8 hours is 20 litres of diesel.

ii. *Desilting basin for Lingti micro-hydro power plant*

A 400 KW micro-hydro power plant has been set up at Lingti river, including two units of 200 KW each. The power plant uses an open type desilting basin, some 150 m before the surge tank. It is a 32 m long storage tank with a taper of 5 m length at the ends, 10 m wide and 4 m deep with slopes on all sides. A flushing system is employed for regular disposal of silt. The effectiveness of this silting basin could not be known as it has not been under operation for long. The Lingti power plant was undergoing maintenance (a leakage in the channel) and the water was made to bypass the desilting basin. A desilting basin is a temporary basin with a controlled release structure formed by excavation and/or construction of an embankment to detain sediment-laden runoff and allow sediment to settle before discharge.

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32 m
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5 m
Discharge end
1.5 m
2 m

iii. *Hydram at Bhopal, used for pumping sewage water*

Two types of hydram designs are available with EEDS (the implementing agency for the above), namely the single and double model, based on the number of delivery pipes that are used. Costs for the above models are Rs. 35,000/- and Rs. 70,000/- respectively. These hydrams can lift water to five times the supply head. To lift water further up, the size of the delivery pipes would need to be reduced which would bring down the delivery disharge considerably. Hydrams in parallel to lift water to higher heads could be an alternative but have not been tried by EEDS as yet.

A 3" x 6" hydram (drive pipe dia. = 3" , delivery pipe = 6") has been installed in Bhopal to pump sewage water to a height of 16 ft. The supply head available is 3 ft, with waste valve frequency of 60 cycles per minute. The pump has been operational for the last two years in spite of handling sewage. Water pumped is used to irrigate a garden nearby. The design of this hammer ram is altogether different from all the hydrams installed in Spiti. It has a vertical waste valve and the slope of the drive pipe could be varied according to the available slope at the site, which is not possible in designs that use a waste valve perpendicularly aligned with the drive pipe, viz, of the kind employed in Spiti. But as abrasive value of silt is much higher than that of sewage water these design modifications alone are not sufficient to counter the silt load of rivers in cold deserts. Huge sums of money would be required for periodic maintainence of channels and tanks which would frequently get silted up.

iv. *Hydrams at Leh*

LEDeG - an NGO in Leh has been promoting a wide range of technologies based on solar and hydro resources such as Ram Pumps, Improved Water Mills, Micro-Hydels, Trombe Wall Space Heating System, PVC, Water Heaters, Ovens & Crop-Driers etc., for over 10-12 years.

All the hydrams at Leh have been installed on natural streams carrying clear water thereby avoiding the silt problem. No hydrams have been installed on Indus river although the silt load in it is less than in river Spiti as river Indus has travelled 200-300 kms before arriving at Leh. A few earlier attempts to install hydrams on river Indus have failed. Another feature of hydrams installed at Leh is the magnitude of irrigation demand being served. Most of the hydrams installed in the Ladakh region were however, smaller in size, 15 mm x 1.5" and 2" x 4", 75 cycles and 25 cycles per minute respectively. The hydrams were in working condition using the *nallah* as a source and were catering to the needs of just one or two households. The beneficiaries are thus made to bear the cost of civil works and their maintainence, thereby ensuring proper functioning of the hydrams.

A small hydram at Ganglas, Leh, is worth mention, in which a supply head of 1 m is being used to pump water up to 11 m; another at Palam uses a fall of 2.5m for lifting water to 6m using a 4"x2" hydram. At both sites the length of drive pipes being used is eight times the fall. Silt load was not a problem here as water used to drive the pump was taken from a stream and not from the river.

Solar pumps have also been used to lift small quantities of water but the initial costs for solar pumps are high.

4.3.2 Other Options for Water Lifting

i. *Zero head water turbine/pump - an innovation by Mr. Nirepen Kolita, Assam*

A turbine/pump designed and installed by Mr. Kolita delivers water up to 2". At present it is being used to lift water to 10 ft. However, water can be lifted to higher heads with an increased flow velocity. The setup consists of a water wheel suspended on the river for deriving power to lift water. To lift water to higher heads, the size of the delivery pipe would need to be reduced to 3/4" which will however considerably reduce the discharge. Costs for the system are lower than a hydram. The technology can thus be adopted on an experimental basis, taking into account the low costs for the system.

ii. *Mangal water wheel*

The Mangal Turbine is being used in the Bundelkhand region to lift water to about 11m with a supply head of 1m. Check dams are provided to create the requisite head. A discharge as high as 90 l/s is being delivered with the water wheel thus making it an ideal choice for use in irrigation. The water wheel turbine machine consists of a water wheel which is firmly mounted on a steel shaft and supported on two bearing blocks firmly fixed on foundation supports. The shaft is coupled with a suitable gearbox (gear ratio of 1:120) through universal couplings for stepping up the speed of rotation. The output shaft of the gearbox is coupled with a centrifugal pump for lifting water. For lifting water to higher heads using the Mangal Turbine, a multistage pump will need to be used which can also resist abrasion by silt. Regular maintainence of civil works will also be needed to ensure a regular supply of water to the turbine. A mangal water wheel costs 2,12000/= including the installation and demonstration charges.

Four Mangal water wheels have been installed in series at the site on river Sajnam. A check dam has been constructed across the river Sajnam to create a head of 1 m for the water wheel of 14 feet dia. The construction of the check dam ensures that enough water is available even during the dry periods. Gates have been provided to regulate the flow of water to the wheel. The water wheel is coupled to a centrifugal pump by a step up gear. Water is being pumped to a height of 11 m with a 360 m long underground delivery pipe of 225 mm dia. A km long gravity channel then supplies water from the outlet chamber to the fields irrigating an area of 200 acres. A discharge of 90 litres/second is being supplied. In Kanjighat, a water wheel is sited some 8 km from the village. Six water wheels have been installed in series here. Two wheels of sizes 14 ft and 4 ft dia are being used. A 928 m long delivery pipe with 200 mm dia pumps water to 12 m using 1m head catering to the irrigation needs of an area of 100 hectares.

The Fuel-less Mangal Water Wheel Turbine Pump-cum-P.T.O. Machine utilises the energy of flowing water for lifting water for irrigation purpose and doing many other rural works in remote areas. It requires low water heads upto 1 m which is created by low cost check dams. The water wheel turbine machine consists of a water wheel which is firmly mounted on a steel shaft and supports on two bearing block fixed on foundation supports. The shaft is coupled with a suitable gearbox through universal couplings for stepping up speed of rotation. Output shaft of the gear box is coupled on one end with a centrifugal pump for lifting water and the other end is mounted with a suitable pulley for deriving power for operating any machine. Design of the water wheel turbine is simple. It is available in different sizes to meet the varying requirements.

The machine has the following characteristics:

1. No diesel or electricity is required to operate the pump or any other machine.
2. The design of the machine is simple and it can be operated easily.
3. Water can be lifted to many times more than the available head.
4. It can be used for doing multifarious and agricultural works in addition to water pumping, such as operating atta chakki, sugar cane crushing, threshing oil expelling, etc.
5. It does not create any environmental hazards.
6. It provides a clean alternative source of energy in remote rural areas for increasing agricultural productivity, rural employment and income.
7. A large acreage of land can be irrigated by the fuel-less pump. Energy conversion efficiency is also high whereas operating cost is minimum.

iii. *Micro turbine developed by AHEC, IIT, Roorkee*

The micro turbine is a conventional turbine with an axial flow propeller. The turbine is using a head of 3 m to lift water to 10 m. More power will need to be supplied to the turbine to lift water to higher heads. For a supply head of 3m a supply of 400 l/s would be needed to deliver a discharge of 10 l/s at an elevation of 40 metres.

4.3.3 *Artificial Glacier in Ladakh*

Norphel, the artificial glacier innovator, has helped construct artificial glaciers at Phuktse, Shakti, Sabo, Stakmo, Muth, Nang and Umla, and collectively, they provide water to 4000 people in 15 villages. The first artificial glacier Norphel built is near the village of Phuktsey. About 1,000 ft (300 m) in length and 150 ft (45 m) wide, it has an average depth of 4 ft (1 m) and can supply irrigation water to the entire village of about 700 people. It was built at a cost of about Rs. 100,000. A series of parallel stone embankments were built on mountain slopes and iron pipes drilled into the diversion channel at regular intervals, to help distribute the water over the slope. After the first dyke topped up, the water overflowed into the next one and, when that one filled, it went into the third. In November, when the temperature dropped, the trapped water began to freeze, creating a series of glaciers. The Phuktse experiment was a success - the glacier became 1000 ft long and 150 ft wide, with an average height of six ft - and it inspired Norphel to move to other locations. (The glaciers at Phuktse and Stakmo are the biggest he has developed and hold up to one million cubic feet of water each.)

An artificial glacier has been constructed at Chang-La (altitude 16,400 ft.) and currently serves the villages of Yokmus, Kharu, Chende and Takkar(Sakti). The channel was constructed with the help of earth moving equipments - an indication of the enormity of the work. A channel, 2 ft. in length and 7 ft. width, has been constructed on a north-facing mountain face that diverts water to a point from where the water can flow by gravity to the low lying settlements. To erect the channel on the mountain face, a stone wall has been constructed all along the channel's length. Due to the irregular gradients along the channel's length, at certain points along the length of the channel the height of the stone wall rises to more than 10 ft. Local grass has been used to fill gaps at the sides of the channel. The channel head is at a glacier point thus enabling water from the glacier as well as the huge snow reserve that would accumulate above the channel to be utilised. There is a direct correlation between the length of the channel and the size of the glacier with the greater the length of the channel, the greater the size of the glacier formed. As the ice begins melting in summers, the channel diverts the meltwater towards the desired point of use. This technique has enabled the inhabitants to utilise water which otherwise used to be wasted. The channel, it is planned, will be extended to the adjacent mountain face thus allowing more water to be tapped. This form of glacier is much larger than the ones tried earlier as the length of the channel runs into kilometres thus enabling harnessing of huge volumes of snow. Construction of the channel has also brought down the damage to the road just below the channel which otherwise suffered heavy damages due to avalanches. The channel however tends to suffer considerable damage and has to be repaired each year just before the onset of winter.

Though the technique is a simple one involving local material and labour, the scale of the construction enhances the project cost. In-depth assessment also revealed that the technique would be successful only where flatter slopes as in Ladakh, are available, and would not make for replication in places like Lahaul & Spiti with higher gradients.

4.4 Appropriate Technology Assessment

4.4.1 Lift Irrigation Techniques

Power generated by flowing water has been known to people for decades. Numerous water mills found in the area clearly indicate this fact. Some of them are still functional and are being used for grinding millet. (According to locals, millet processed in water mills remains fresh for much loger time as compared to processed millet from flour mills.) But lifting water from the river is still counted as an unsuccessful attempt even for the IPH department. Availability of conventional fuels such as diesel, is another problem which makes installation of diesel pumps, a rather infeasible idea. Roads get blocked during winters and little migration is possible only after mid-June. High transportation costs again do not allow the use of diesel for pumping water from the river. Several hydrams installed by the IPH deparment have failed to operate because of the high silt load and high diurnal fluctuations in the water level in the river. Fluctuations in the water level are caused due to rapid variations in weather from cloudy to sunny, which in turn control the amount of snow melt. Because of these high diurnal fluctuations, storage tanks cannot be built anywhere near the river basin. Further, frequent landslides and soil erosion over several years have resulted in high, steep river banks, which cannot receive water using gravity flow without 8-10 km of supply line from upstream. These supply lines, if constructed, again face the problem of being blocked or broken due to landslides.

An assessment of the two lift irrigation technologies studied, viz, hydrams and solar pumps, is presented below:

i. *Hydram installation*

Advantages
- Renewable source, kinetic energy of water is used.
- Ratio of cost and amount of water lifted is low.
- Low maintenance required.
- No skill needed for operation.
- Wide impact, as it would be replicable across the Steep Banks settlements.

Problems
- A good site for a hydram demands a wide river with lowest possible slope on the banks. This is desired in order to avoid the effects of fluctuation in the river level on the supply head for the ram pump.
- For raising water to 100 m height, a minimum of 10 m head is required. It means 100m of supply pipe length (for gradient of river equal to 1 in 10) is required, in case underground construction is not possible (see figure).
- In the absence of a good site available, construction costs might increase manifold.
- Maintainence costs for civil works are very high due to high silt loads in rivers of cold deserts.

ii. *Lifting water from the river using solar pumps*

Advantages
- Using renewable source of energy.
- Low running costs.

Problems
- Cost of technology for amount of water lifted per day is very high.
- Flow delivery rates are very low (for 100 m delivery head) and do not fit irrigation requirements of the village.
- Maintenance required is more- PV cells and the pump require high maintenance.

4.4.2 Sourcing & Storage Variations

Glacial melts and perrenial water sources like springs are the predominant water sources of cold deserts. However, the variation in snowfall affects the availability of water through these sources. Less snowfall in a given year would affect the water availability through glacial melts; increased snowfall on the other hand, results in the drying up of the natural springs due to freezing. An appropraiate solution may lie in having adeaquate storage infrastructure in the form of local tanks called *zings* which would also help recharge the streams and springs of the region.

i. *Snow reservoirs and delaying snowmelt*

Advantages
- Wider impact as it can be replicated easily for similar regions.
- Only solution available for *Highlands* of cold deserts.
- Easy to learn technology which is easily adaptable to the region's traditional methods of harvesting water.

Problems
- An ideal site would be where the south sun is blocked till late in March and April, the most critical and limiting factor impacting the success of this technology.
- To avoid overhead sun after end of April, some provisions such as sprinkling saw-dust, charcoal (both unavailable locally) and wild bushes on the frozen reservoir or providing shading all over the place, which again becomes costly, can be adopted. If shading is not provided, the melting of water during April or May will worsen the situation downstream.

ii. *Tapping perennial sources of water*

Advantages
- Tried and tested technique: All that is needed is an appropriate gradient.

Problems
- Narrow impact, as it does not take into account similar situations prevailing at most of the places in the basins and steep banks without availability of any perennial source nearby. Moreover receding glaciers make nallahs vulnerable to drying up in the wake of global warming.

- High costs incurred in tapping water when the perrenial source is far off from the settlements.

5. CONCLUSIONS

Looking at the water management issues of the cold deserts in a broader perspective, the solutions to the problems lies in combining the ancient knowledge with modern systems. Traditional systems of water management including sourcing, storage and distribution need to be upgraded using modern tools. Ancient wisdom is constantly being lost and hence there is an urgent need to revive it through extensive awareness camps. More efficient water use practices like the drip and sprinkler irrigation systems, dew harvesting, etc., would also help in cutting down water consumption.

It is an irony that despite possesing huge reserves of snow which also feed the rivers of plains the cold desert regions have acute water paucity. The solutions to these problems lie in adopting a wide range of measures both at the pre and post consumer stages. Given below is a potential water management strategy for cold deserts:

I. Pre-Consumer Measures

Ia. <u>*Upgradation of traditional infrastructure*</u>:

The existing water management infrastructure needs to be upgraded. For instance kuhls constructed in basins to tap water from the river need to be aligned after carrying out a survey. Appropriate design to allow for non silting and non scouring velocities in kuhls will help in preventing silting of the channels. In highlands proper lining of kuhls and zings will help bring down wastages due to seepage.

Ib. <u>*Snow harvesting & storage*</u>:

Apart from the above measures, tapping the huge reserves of snow by forming artificial glaciers and/or snow reservoirs can help meet the water requirements, the former for meeting early cultivation season water requirement, and the latter for late season requirement. Upstream dams can also be constructed with the same intent of storing the area's reserves of snow for productive purposes, reducing its wastage as runoff.

Snow reservoirs can be built in villages in the highland/steep bank settlement category. The following should be kept in mind to ensure the performance of snow reservoirs however:

- The reservoir should be sited at an altitude of around 14000 ft. to ensure delay of the melt till late August. Geological investigations will also need to be done for assesment of an appropriate site for founding the reservoir. The snow reservoir should also be sited in a shady area bound by a north facing cliff, and have a stream nearby for allowing water into the reservoir.
- Appropriate regulatory mechanisms for control of inflow into and outflow from the reservoir would also need to be incorporated.
- Implementation of the snow reservoir on a large scale will meet the entire water needs of a village. For this an in-depth assesment of the water requirements will need to be made for ensuring appropriate sizing of the reservoir.

Ic. *Development of water lifting methods*:

It is clear that the river is a definite source of water for the region, but the existing methods for lift irrigation are not suitable for the region, because of factors like excess silt load of the rivers, high cost and low lifting capacity, etc. There is therefore, a need to carry out further research and development work to adapt these existing technologies to cold desert conditions.

Id. *Water resource protection*:

Along with the above technologies for maximum utilisation of available water resources, interventions aimed at protecting and even enhancing the existing water resources would also need to be made. For instance, springs should be protected and developed, aquifers should be recharged.

Ie. *Domestic water requirement measures*:

Water required for domestic purposes could be accessed through tubewells and micro water harvesting structures.

II. Post-Consumer & Conservation Measures

IIa. *Water efficient cultivation methods*:

More scientific methods of cultivation neeed to be adopted to minimise water wastages. Irrigation techniques like the drip and sprinkler system, ridge and furrow method would help cut down water consumptions. Traditional methods of mulching and dew harvesting should also be revitalised.

IIb. *Runoff management measures*:

Measures like afforestation, terracing, stone and earth bunding should be adopted, suited to the nature of the land and the slope, to minimise runoff and enhance percolation into the soil.

IIc. *Groundwater conservation*:

Construction of large no. of storage reservoirs will also help recharging groundwater and the natural streams.

IId. *Reuse of wastewater*:

Although, given the low level of domestic usage of water, the scope of wastewater reuse is low, the little domestic wastewater could be reused for purposes like kitchen gardens or even watering of village woodlots.

III. Institutional Measures

IIIa. *Awareness sessions*:

The community in cold desert areas needs to be educated on the impact of their water usage patterns and practices, and the availability and potential of different technologies for improved water management. Awareness programmes should also be carried out on the value of and need for reviving the ancient systems and practices of water management.

IIIb. *Community action for advanced technologies*:

The progressive and development oriented members of the community in cold desert regions need to be mobilised for improved action for water management, in terms of evaluating, developing and incorporating advanced technologies for water management in the region. The trial water management group formed at Poh village for the implementation of the pilot project was a great success. Formation of more such groups will help in improved and updated water management action.

IIIc. *Equitable water management institutions*:

Water management institutions that promote a more equitable sharing of water should be brought about by facilitating the existing institutions to develop greater equity in representation.

ANNEXURE

A TECHNOLOGY ADAPTATION CASE STUDY OF POH VILLAGE IN SPITI

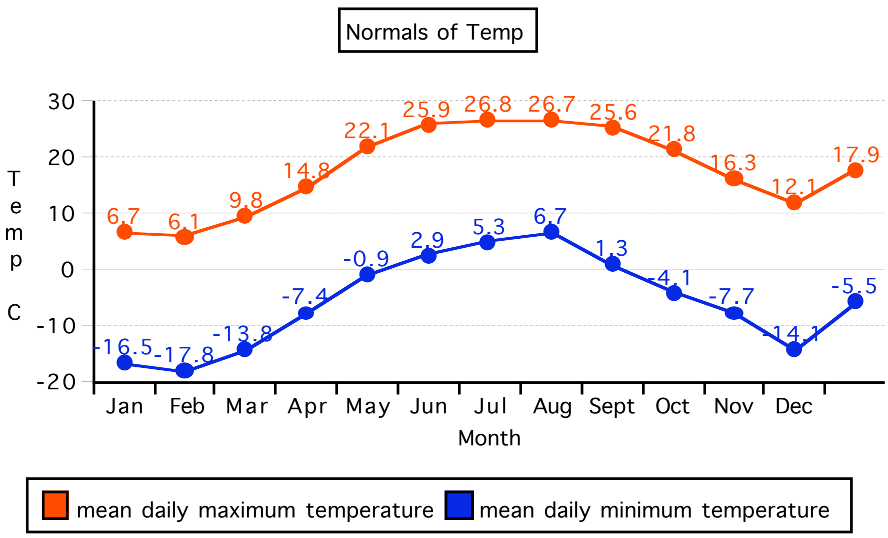
The settlements lying in the steepbanks/highland category face the maximum water inadequacy and hence it was decided to take up a pilot project in a cold desert pocket which falls under the steepbanks/highland category.

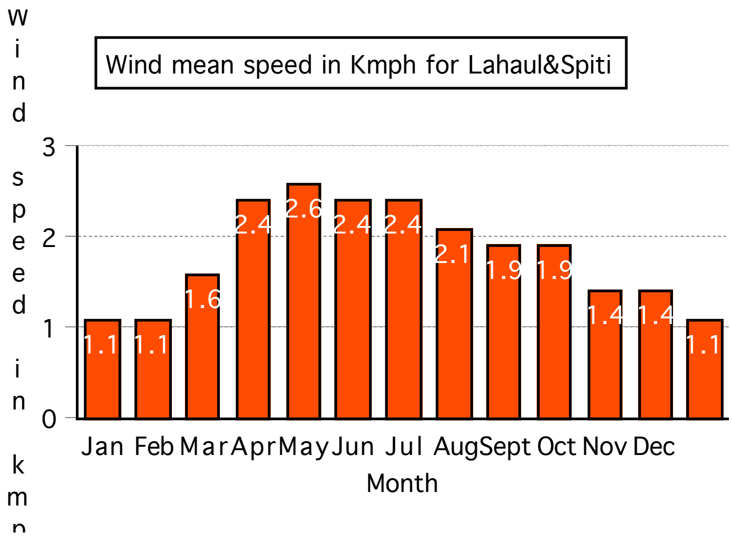
THE CASE STUDY SITE

The project site was planned to be under the highlands/steep banks category of cold desert settlements, as these are the predominant kinds of settlements in cold deserts. The plan and technology, would thereby be replicable for a larger number of cold desert settlements.

Poh village was thus chosen as the site for implementation of the pilot project. Geographically, Poh is situated 32^0 3' N, 78^0 19' E, at an altitude of 11,290 ft, along the Spiti river flowing W-E from Kunjum la, in Lahaul and Spiti, to Khab in Kinnaur. Poh has a population of 184 people with 46 households. The total area of Poh village is 113 ha with only 1ha area covered by forests. 21 hectares of land is irrigated by private canals while 1ha of land lies unirrigated. The culturable waste, including gauchar and groves, covers a large 69ha while land not available for cultivation is 21 hectares.

'Spiti', meaning 'the middle land', lies between the snow covered ranges of the Himadri Himalayas on its south and the comparatively flat Tibetan Plateu at its north. Monsoon winds from the south gets diverted north-west by the high peaks of the Himadri region, leaving the Trans-Himalayas, including Lahaul & Spiti, Ladakh and Zanskar, a desert. All of the precipitation is in the form of snow in the winters, with a maximum of 30 mm rain (300 mm snow). The following charts give an indication of the temperatures prevalent in the region:





The ideal season for Poh village (and Spiti valley in general) begins with a snowfall at the end of April. By the time May enters the valley, only the snow on the peaks and glaciers remain, leaving the river basins and mountain slopes on either side of valley free for cultivation activities. After snow departs, it is time for fierce winds to carry away the dry soil. Dormant wild bushes now come up as there was some moisture left in the soil by the snowmelt. By August-September they will turn half the mountain face green and will probably start bearing brightly coloured flowers.

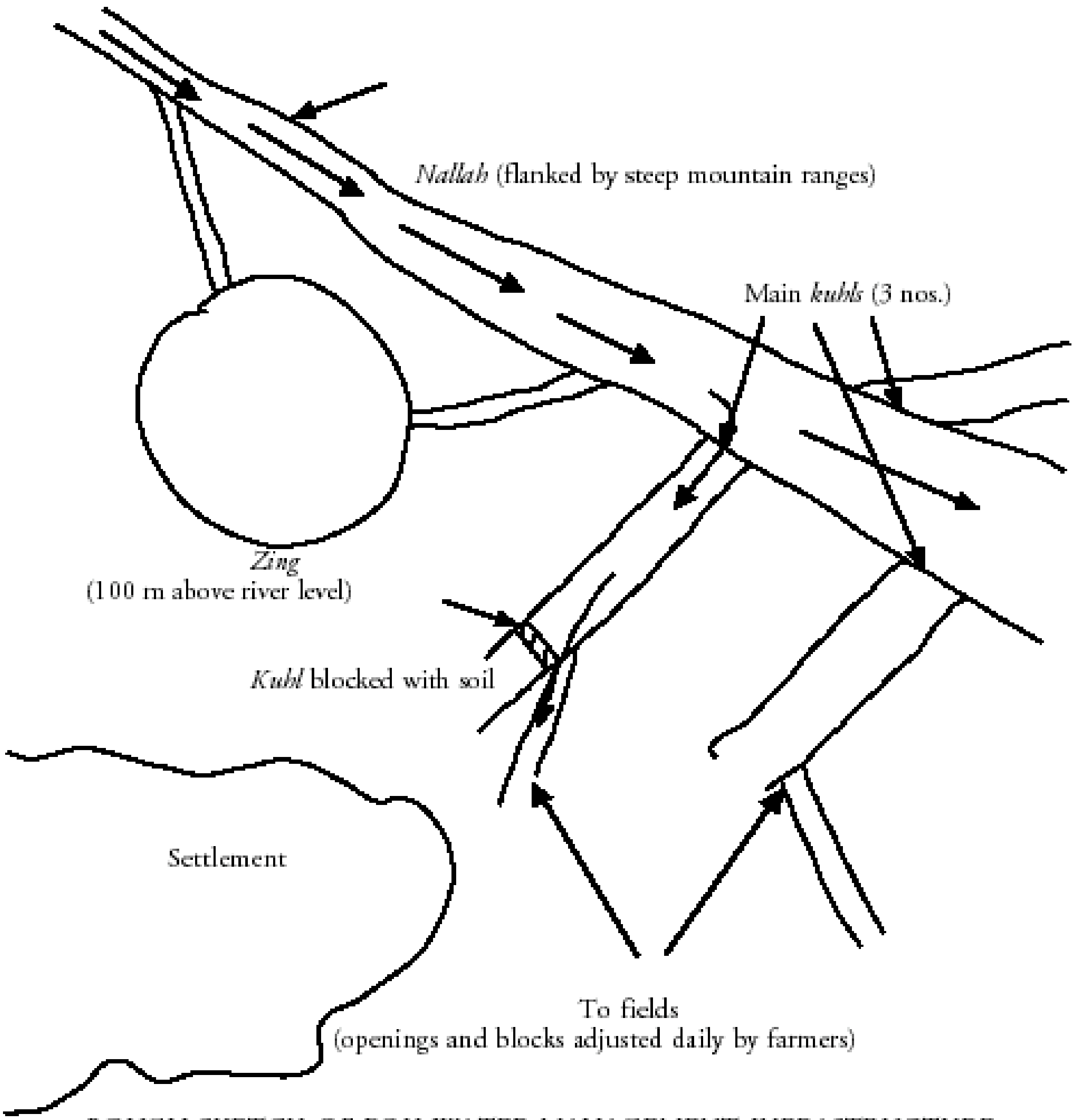
In May the Poh *nalah* flows with clean drinking water in the morning which turns muddy and silty by the end of the day. The amount of water and the flow also gets doubled by the evening. Everything from the sun and wind to clouds causes noticeable change to the water in the *nalah.* The flow in the river, some 250 ft down, multiplies many times its flow since the winters. The silt load increases by 10,000 times from December to May and some 70,000 times by June.

The Poh fields are sown mostly with *Hara Mutter* and millet. Even a 4-5 hours of snow would be enough to wet the fields for one or two days, so that the farmers can begin ploughing and sowing seeds in moist fields. The fields are irrigated for the second time, around the 20th of May. This date changes based upon the altitude of the fields, with a delay of 15-20 days for Lossar (13,545 ft) or Kibber (13,750 ft). And till now water for irrigation and drinking is not a problem except that water needs to be fetched from handpumps or natural *chasmas*. There are 3 handpumps in Poh, 2 of which are working. For drinking and cooking, the water requirement is one bucket (15-20 litres) per person on an average. For Poh, drinking water is also available from the *nalah*, but only early in the morning after which it starts carrying silt, as the flow increases.

The next round of irrigation begins at around 5th of June and then after every 7 days, the fields would need water. Harvesting of *green peas* begins in September. Except for some lucky years, the *nallah* dries up by the end of July or mid August.

THE NEED

Water management infrastructure in Poh village



ROUGH SKETCH OF POH WATER MANAGEMENT INFRASTRUCTURE

Poh *nallah* is the main source of irrigation water for Poh village. Apart from Poh *nallah*, Pomrang *nallah* (which also joins Spiti river from opposite side) is also a perennial source of water. In August-September 2001, during a severe water crisis, Poh farmers would fetch water from Pomrang *nallah* using a 1.5 km PVC pipeline made availble by IPH department. However, between Poh and Pomrang, the Spiti river is 50-100 m wide and 40-50 m deep, which makes the construction of a permanent *kuhl,* difficult. Hence Pomrang *nallah* can at best be a supplementary, and the not the main, source of water.

Land use

Irrigated by source	21 hectares

Unirrigated	1 hectare
Culturable waste including gauchar and groves	69 hectares
Area not available for cultivation	21 hectares

(District census handbook, Census of India, 1991)

In addition to the above, 200 bighas of *Notod* land located on the opposite bank of the river , has been given to the landless younger sons of the village which they use for cultivation. About 1 ha land has also been planted with poplar and willows by the forest department.

Water storage and distribution

There is one *kaccha kuhl*, 15-18 m in dia, 3-4 m deep, with a storage capacity adequate for irrigating 15-20 bighas of land. The main *kuhl* draws water from the main *nallah* or *zing*. The main *kuhl* gets divided into three major *kuhls* which get further divided into minor *kuhls* and carry water directly to the fields. Water from the three major *kuhls* is drawn by blocking and opening suitably with soil and rocks. The sizes of *zings* at Poh are as follows:

Diameter of circular zings in metres = 18 m
Depth of zings in metres = 4 m
Vol. of the zing in KL = 1017.36 KL

Other similar ponds can also be made in the village for storing water.

Water use & adequacy

The total irrigation requirement of Poh village during lean seasons is 80,000 KL. The main cultivated crops in the region are green peas, millets, black peas and *Gandham* (and apples at lower altitudes). The sowing season begins in middle or late April. The water requirement for irrigation is crucial at the following times:

- immediately before sowing seeds
- one month after sowing
- after a 15 days interval
- after every 7 days till the crop is harvested

Green peas are harvested in late August or early September, and millets in mid-October. Millets constitute the staple diet (*sattu*) and production is about 50-60 quintals from 15-20 bighas of land, provided adequate water is available.

Based on field observations, the irrigation requirement for cultivating green peas is as follows:

Volume of water (litres)	Time (seconds)	Discharge(l/s)
10.61	3.66	2.89
11.72	4.60	2.54
11.16	3.34	3.47
12.28	4.13	2.97

Average discharge = 2.97 L/s ~ 3 L/s
Area of the field = (40 * 17) sq meters.
Time taken to irrigate the field = 4.5 hours
water requirement for 680 sq meter of land = 48.6 KL
Water requirement per bigha of land for green peas = 57.2 KL

It must also be noted that the difference in quantity of water required by different crops grown here is negligible.

Water from the *nallah* is drawn into 3 major *kuhls*, at 5-6 l/s of discharge which satisfies the water requirement for the whole village. Unused water is put back into the *nallah*.

- Approximate dimensions of the *zing*: 18 m dia , 4 m deep
- Volume of water contained: 1017 KL
- Land irrigated by stored water in the *zing*
  - Theoretical 17.78 bighas
  - As suggested by community members 15-20 bighas

At the start of the cultivation season, the Poh *nallah* has much more water than that required by the whole village during its peak irrigation season. The water adequacy is however affected in the latter part of the cultivation season.

Some of the available water is wasted because of seepage in the process of distribution. Measurement of the discharge at two different points at known distance along the *kuhl* revealed the following:

discharge upstream	=	5.13 l/s
discharge downstream	=	3.76 l/s
distance between two points	=	250 m
seepage	=	0.33 l/m/min

The difference in discharge is used as a rough estimate of seepage losses.

Factors affecting water availability

- Water for irrigation is available only from the glaciermelt.
- Due to the decreasing amount of snowfall every year, Poh *nallah*, the only source of water for irigation, dries up completly by the end of July or latest by the start of September. In the absence of any technique available for lifting water from the river, the drying up of the *nallah* results in obvious damage to crops as well as the vanishing of grazing lands for feeding livestock.
- Only a thin stream of water is available late into the summers. This is used by farmers directly in the fields during the day; in the night, water is stored in the *zing*, and this water is used for irrigation the next day.
- Distribution of water is according to village traditions which provides water to farmers as per the size of their landholdings, i.e., more land means more water rights. In times of water scarcity however, the *Bara ghars* are given preference over the others. These *bara ghars* also bear responsibility for the maintenance of the *kuhls* and *zings*, and share it as per water rights given by community.

APPROPRIATE TECHNOLOGY OPTIONS

After an extensive study of appropriate technology options available, specific to cold deserts, the following technology options were assessed to have value for the region:

a) construction of artificial glaciers and delaying their melt
b) installation of hydraulic rams with a design that can handle high silt load, and/or installation of solar pumps
c) upgradation of existing traditional infrastructure

The selection of appropriate technologies for the pilot project site was done keeping in mind the following:

◇ The selected designing solutions should be of utility to the pilot project area.
◇ An adequate site for construction/installation of the selected technology should be available.
◇ The pilot project area should have a sound water management body for managing and solving all water issues.

Snow Reservoir Creation

Geographic features and climatic conditions in Spiti valley come closest to Ladakh, where farmers have learnt this basic and simple technique of constructing artificial glaciers to meet their early cultivation season water requirements. The Poh residents however face the problem of late season water inadequacy. The option therefore was the construction of a small reservoir upstream on the nallah at a suitably high altitude in a shady area above Poh village. In winters, a small portion of water from the adjacent *nallah,* when diverted to the reservoirs, will freeze at night. The whole process when cotinued for days will result in the filling of the reservoir with ice. The reservoir would also need to be protected from the summer sun through measures like sprinkling of sawdust, etc., in order to delay the melt of the ice in the reservoir to the time of water shortage in the village.

The main issue with a snow reservoir however, would be the appropriate siting, and the supply of material and availability of labour for construction at the site. The site needs to be selected keeping in mind, the appropriate altitude for delayed meltwater, the amount of solar radiation at different times throughout the year, as well as the vicinity to the village. The transportation of the material would have to be through mules and distance of the site from Poh village would lead to lower actual work hours

Hydrams

This is the most suitable technique for raising water from the river, using the head available from the river itself. Hydrams can lift water to 10 times the head supplied. Hence, for lifting water by 300 ft, a drive head of 30 ft would be required. With the available gradient in river Spiti (1 in 100) long diversion channels would need to be constructed to supply this head. A few considerations which need to be taken care of however. A good site for installing a hydram would include space near the river basin where sufficient supply head is available. River basins however are more prone to damage due to landslides. Also, the diurnal and seasonal fluctuations in the river level need to be considered for an appropriate siting of the hydram. This factor along with the lack of space near the river basin to construct storage tanks, have contributed to the failure of hydrams in the region. The IPH has installed more than 20 hydrams in the past 5 years, all of which have failed, a big issue being the high silt load in the Spiti river.

A modification of existing designs, that could take care of the high silt load in the Spiti river, would need to be developed therefore. A desilting basin would also need to be constructed before the storage tank; a suitable storage would also need to be designed and constructed to tackle the diurnal fluctuations in the river flow/level.

Traditional Technology Upgradation

Given the failure of technologies for lift irrigation in this region, an alternative strategy could be the upgradation of the traditional infrastructure of *kuhls* for gravity flow and *zings* for water storage, to improve their efficiency. For this, it would be necessary to identify a perennial source of water near the target area and construct reinforced, concrete *kuhls* to carry water by gravity flow. The zings could also be given an impermeable lining to reduce seepage as well as losses through evaporation.
The problems with this strategy is that the kuhls frequently need to be across long distances, demanding at some places, rock cutting as well, and the construction cost could well run into crores. *Kuhls* are also vulnerable to breakage/blockage due to frequent landslides. In such cases, these *kuhls* lie unrepaired in the absence of skilled labour or the next IPH intervention. Further, some of the places do not have any perennial water source left in vicinity.

PROJECT DESIGN

Data Collection

- A recce was carried out of the entire pilot project area and the available sources of water identified.
- The monthly variation in the Poh *nallah* was determined by conducting actual experiments at different times of the year, from May through to October 2002.
- The monthly demand for irrigation water is calculated by studying the crop calender and water requirement for each crop for a known area of irrigated land.
- The fit of each identified technology option was checked against the conditions of the pilot project area.
- All the above activities were carried out in collaboration with the local population and the water management functionaries in the local committees.

Project Technologies

After assessing the pros and cons of the various water management solutions available it was decided to take up two of them for a pilot project implementation. The solutions were selected keeping in mind their replicability for cold deserts. Since a vast portion of cold deserts falls under the highlands and steep banks category the solutions taken up for implementation should be able to cater to such regions. Hence the following options were decided to be taken up for implementation:

- Construction of snow reservoir and delaying the melt
- Upgradation of the traditional water management infrastructure

Hydram installation was not carried out, considering the high failure rates of hydrams in cold deserts and the need for designing work prior to implementation.

SNOW RESERVOIR AT POH

Site Selection

Construction of the Snow Reservoir was taken up first. The site for the construction of the snow reservoir was selected keeping in mind the amount of solar radiation at different times throughout the year and vicinity to the village. The site selected for the construction of the snow reservoir is situated 100 ft. above the village which lies at an altitude of 11,300 ft, on the left bank of the Poh *nallah* (viewing upstream). A cliff facing north towering to more than 30ft would shade the reservoir thus delaying the melt. The terrain of the site is extremely rocky with the soil predominantly sandy. The area receives 3-4 hours of sunshine in summers, which is the maximum in June, and a maximum of 1 hour of sun during winters; there is almost no sunshine all through December. This minimal amount of solar radiation makes it an ideal site for the construction of an artificial glacier. Also, the site is free from the risk of landslides. Although, the site is located somewhat lower than the desired altitude, this was demanded by considerations of cost and maintenance. For large reservoirs, both dam construction and delaying the melt, are expensive options, especially if construction needs to be carried out at high altitudes which can only be reached by trekking for 4-5 hours. Also, the proximity to the village, it was felt, would ensure good maintenance by the villagers. Melt delaying would be addressed through additional shade and sprinkling of substances like sawdust.

Construction of the Snow Reservoir

A reservoir 10 meters wide and 27 meters long was constructed along the Poh *nallah.* Looking downstream, the right side of the reservoir is the high vertical face of the mountain itself. The other three sides are made of crate walls- metal wire mesh filled with dressed boulders. The reservoir has a capacity of more than 625 KL.

Construction began on 12th of September and took one month. The work involved the purchase of crate wires, collecting and dressing boulders, filling the crates with these boulders and finishing, including excavation and covering the inside surface with local weeds.

Initial attempts at ice formation inside the glacier failed because of the late arrival of the first snows in the valley. Initially, in the first week of November, some water was released into the construction site and a thin layer of ice was achieved after a few nights, but work could not be continued further. Hot weather, in the absence of a snowfall, could no more support the formation of ice. Work for the creation of glaciers could finally be started only after 30th January, after the first snowfall, and was often interrupted by cloudy days when nights are warmer and water needed to be prevented from entering the glacier and melting the already stored ice.

A *kuhl* was constructed to divert water from the stream to the glacier site. After 30th January, water was released in large quantities and made to spread over the whole reservoir area, at nights, which would then freeze. It was expected that by the first week of March it would be almost impossible to obtain this freezing of water. To make the best use of the limited time, the inner walls of the reservoir were covered with polythene and water was filled upto a certain level inside the reservoir. The idea was to obtain a thick mass of ice directly from the stored water. This was inspired by the fact that the water in the *zing* freezes during winters as suggested by the villagefolk. This strategy failed this year however- only the top layer of the water in the reservoir would freeze, the rest of the water slowly leaking out from underneath the walls. This idea was therefore abandoned and the alternate method of releasing small amounts of water and making it spread over the area and freeze before the next release of water, was adopted. By this method, however, the *kuhl* needed to be dug again and again since the frozen water inside the *kuhl* would block the flow of water to the reservoir. As winter progressed, it became possible to release water even during daytime though.
To avoid any further blockage of the *kuhl*, it was necessary to dig more than 2ft deep inside the hard ice surface. After an initial success, this became a problem since the water entering the glacier was warmer and began cutting the hard ice from beneath the frozen mass of ice formed inside the reservoir. Various other techniques were then tried for bringing the water from the *kuhl* to the surface, such as making a miniature dam in the *kuhl* using an iron sheet and later with the help of silt. All these failed however. Finally, the *kuhl* was blocked at its head and pipes were laid to bring the water to the reservoir. Pipes have the problem of getting choked and suffering breakages due to the formation of ice inside during the nights; hence, every morning, the pipes would need to be cleared by laying them in the sun. A diversion channel from the main *kuhl* was also dug to control the flow rate of the water entering the glacier. Water leaking from the glacier through this diversion channel has also frozen outside the actual glacier such that much more area than the reservoir capacity has been covered by the ice formation; the amount of ice is much more inside the reservoir though. The thickness of the ice formation varies from 1 meter on the downstream side to a little more than 0.5 meter on the upstream side, and a total of

approximately 200 KL of frozen ice has been obtained in the reservoir. For insulation of the reservoir thus formed, saw-dust mixed with a local weed, *Somlata*, was spread over the surface to protect it from melting due to the summer sun.

Assesment of the Reservoir Performance

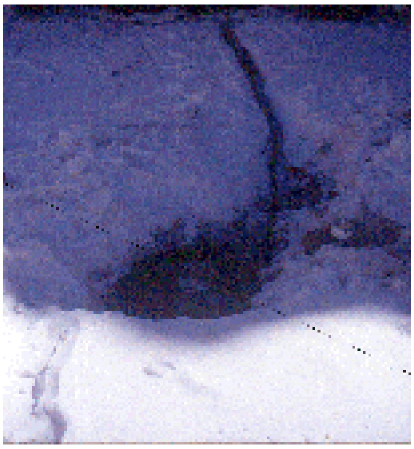
At the start of the summer of 2003, there was a fair amount of ice inside the reservoir. Approximately 300 KL of ice was available against the estimated 625 KL which is 48% of the designed capacity of the reservoir. There were a combination of reasons that led to the reservoir storing less snow than intended. Siting of the reservoir at a low altitude was the most prominent one.

However, the region experienced sudden, unexpected, heavy snowfall in April '03. Summer snowfalls are rare and tend to melt almost immediately due to the higher temperatures at that time. The April '03 snowfall melted immediately and resulted in heavy flows in the Poh *nallah* which caused considerable damage and landslides. The *nallah* damaged one wall of the reservoir as well, and caused the ice at the damaged end to melt away - by the end of April. Hence, although the ice formation was achieved, it could not be retained till the time of water shortage at Poh.

Overall, the results could be said to be encouraging as the pilot project had met with partial sucess. Studies carried out revealed that the siting of the reservoir at a higher elevation would result in considerably more ice formation in the reservoir and in delaying the melt. Mr. Chewang Norphel, the artificial glacier innovator, feels that even with a reservoir constructed on a higher altitude, it is difficult to delay the melt beyond June. A site with 2-3 months of continuous shade facing north might succeed in delaying the melt to Poh's water requirement period. A small glacier could be constructed at a higher altitude for further testing of the potential of this solution.

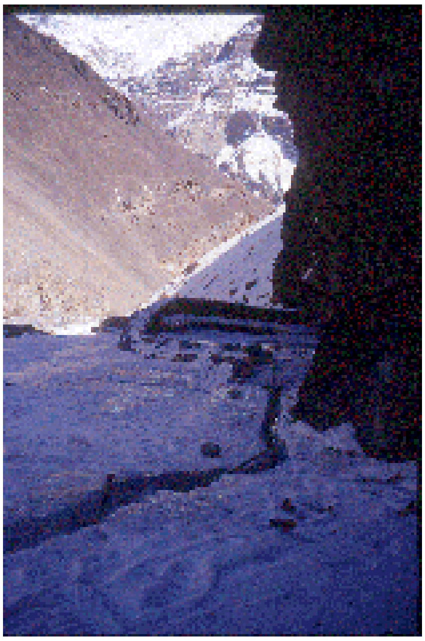
Direction
of
main stream

Artificial glacier - viewed from downstream



Direction c
main strear

Kuhl head



Intake kuhl to the reservoir

Artificial Glacier - Viewed from upstream

Direction of
main stream

Pipes laid along the intake kuhl to avoid
water leaking from beneath the glacial mass

UPGRADATION OF TRADITIONAL WATER MANAGEMENT INFRASTRUCTURE AT POH

Renovation of the Poh Zing

An ancient *zing* in Poh village is utilised by the villagers for storing water during periods of water scarcity. Water is first diverted to the zing through the adjacent Poh *nallah* at night and released during the day to the fields. The *zing* is a circular tank with a diameter of 18 m and a depth of 3 m. The *zing* has been made in dry stone masonry with walls of thickness 0.6 m. It has a storage capacity of 1017 KL approximately and can irrigate about 10 bighas of land at a time. Due to the lack of maintenance by the Poh villagers, this *zing* is however in urgent need of repairs. After assessing the state of the existing *zing* at Poh, it was decided that the following steps would help in upgrading its performance:

- ◇ The size of the *zing* would need to be increased to a dia of 36m from the existing 18m. This would double its existing storage capacity.
- ◇ The *zing* should be converted into a cemented one to prevent frequent damages.
- ◇ Gated structures at the entry and exit points should be created to regulate the inflow and outflow of water.
- ◇ A settling tank should be constructed at the entry point to the diversion channel for allowing silt-free water to enter the *zing*.
- ◇ The *zing* should be lined with local grass or polysheet to reduce seepage losses.

Kuhl Repairs

Every summer in the cold deserts begins with *kuhl* maintenance which is typically a community activity. Sand and pebbles that flow with the flowing water in the *kuhls*, tend to block the *kuhls* or form a layer at their base which causes the waterflow to diminish or overflow to other unwanted directions. Besides, there is considerable seepage and wastage also from the *kuhl* floors. Though lining with local grass is known to people, its use is diminishing slowly as the process is a labourious and time consuming one, another instance of the eroding traditional wisdom.

Apart from the mechanical devices discussed, an effective water management plan can be developed by making improvements to the time tested *kuhl* system of irrigation. The high seepage and evaporation losses from the existing *kuhls* reduces their efficiency. Cost effective mechanisms for reducing the high seepage and evaporation losses occuring in the region due to sandy strata can be made, thereby improving discharge capacities of existing *kuhls*. Lining the *kuhls* with polythene sheets is one way of reducing seepage losses.

The construction of these long *kuhls* also involves significant costs and periodic maintenance. A possible solution for this can be provided by constructing small ponds for harvesting glacial melt. The ponds can be constructed near the fields to avoid long *kuhls* and hence avoiding large costs and maintenance problems. One problem with the technique though can be that of getting the land for constructing the ponds. Such ponds would also not be able to fulfill the entire irrigation needs in the lean seasons as huge quantities will need to be stored, and could only supplement some other source. Water is available in plenty at Poh from April to mid July for meeting the irrigation needs. However from mid July to September the region faces acute water scarcities. A total water requirement of 80,000 KL is needed for this period which is a huge quantity to be stored using small ponds. A significant portion of the above requirement can be supplied through these water harvesting structures while the rest can be made available from the Poh *nallah*.

Discussions with the Poh villagers and the existing watershed committee brought forth the suggestion that the kuhl and zing upgradation should be taken up through the Desert Development Programme funding allocated for the village.

SOCIAL TECHNOLOGIES

Community Awareness

Faced by serious disadvantages, the inhabitants of cold deserts devised their own ways to adapt to these regions. Techniques devised by them have excellent scientific reasoning but the younger generation unfortunately, is losing this traditional wisdom due to the ill effects of commercialisation.

Several community meetings were held and the following aspects covered during these meetings:

- People were informed of the depleting water resources due to global warming and hence the need for proper management. In some areas people acknowledged how in the past few years the snowfall pattern had changed. Areas receving adeaquate glacial melt at one point of time were now facing a drought like situation.
- Awareness was also created on the ancient techniques of water management like dew harvesting, moisture conservation through mulching, lining of water conveyance and storage structures with local grass and much more.

Further, following the technology studies, sessions were also held with groups of villagers for imparting to them the findings of these studies. The different technologies, their pros and cons, and the potential for adapting them to the cold desert conditions, the required technology adaptations and modifications, were also explained to the locals.

Improving Water Use Efficiency

Community meetings were also held to encourage villagers towards more efficient use of their water resources. In cold deserts people have been practising the flooding system of irrigation quite prevalent in the plains of our country where water is available in abundance. This results in huge wastages of water particularly due to low soil retention capacities. Villagers were also informed about alternate methods of irrigation like the ridge and furrow method and the more modern ones like the drip and sprinkler systems of irrigation. Water wastages are minimal in this method as compared to the flooding irrigation method. The farmers were also taught about drip and sprinkler irrigation methods.

Meetings were held with selected locals to discuss issues such as- measures to prevent degradation of traditional systems of water management, methods for effective usage of ground water and techniques to replenish it, etc., as well.

Their existing traditional knowledge for instance, of using the local grass which has excellent seepage resistant qualities, for lining the kuhls, were also discussed and revived. The farmers were taught about traditional practices of dew harvesting for irrigation as well as rainwater harvesting for domestic uses (since rainfall in the region is on the rise), in use in other parts of the country.

Water reuse methods, typically practised by them, were also revitalised. The locals were told about higher level technologies in use, and exhorted to use domestic wastewater for kitchen gardens and the like.

INSTITUTIONAL FRAMEWORK

As has been already been described in the traditional systems study, in cold deserts there exists an age old institutional framework for water management wherein the *Bada ghars* of each village have the right to the first, as well as maximum access to the water available. The *Bara ghars* are families with higher socio-economic status, which are also responsible for the maintenance of the water management infrastructure, with their contribution in proportion to their water rights. Now this ancient system is slowly decaying however, giving way to the need for solving water problems through mutual understanding. Social issues do crop up, although rarely, regarding the distribution of water, especially at times of scarcity. Typically, the *Bara Ghars* display generosity and big-heartedness in helping the poor in the society with water and even money at times.

Change in Existing Water Management Institution

Although there exists a time-tested water sharing mechanism in cold deserts, critical assessment revealed the following:

- The community institution essentially carries out the function of water sharing alone, and does not cover any other aspects of management of water resources and usage in the area.
- Although the institution is responsible for the maintenance of the infrastructure for water distribution & storage, this responsibility is not carried out to the extent required in current times. Several of the old infrastructure lie in a badly damaged condition which has reduced their efficiency and led to increased water woes among the villagers.
- The institution is not developmental in its approach, in that it does not attempt to develop new sources and/or methods for management of water issues. It tends to focus only on the maintenance of existing systems and infrastructure. With the escalating water problems, this role is not sufficient.
- The institution is not completely equitable since it follows the old village structure of *bada ghars*. While in the past, this was adequate, the change in value systems making people more selfish and and economy more monetised, the increasing water shortages, the changing family structure and the break-up of the joint families, is making this traditional system ineffective in current times.
- The traditional institution also does not address the water requirements of the *notod* lands granted by the government to the landless younger sons in the village. Without water for irrigating these lands, they lie fallow, and the younger sons typically out-migrate in search of livelihoods.

There is a strong need therefore for creating a community institution which would go beyond water sharing and be responsible for the management of the water resources, including identification of water sources, study and development of water management technologies, including sourcing, distribution and more efficient use of water, and also perhaps be an instrument of change, inducing a more equitable system in the existing water management institution. The strategy recommended for initiating such an institution would be the constitution of a water technologies group comprising primarily younger people and representing the entire community, with membership from both *bada ghars* and others. This group could begin with steps towards taking forward the learnings and experiences of the pilot project, experimenting with and developing new water management technologies, and slowly move into the social institutional aspects as well through intensive training and advocacy work with the traditional institution.

A Trial Water Management Group

The study created one such group for the purpose of implementing the above project. The group's members were briefed about their roles and responsibilities and collaborated with the Pragya Aptech Team in studying the different water management technologies and developing the project plan. They assisted the organisation in actual on-the-ground implementation of the pilot project plan, organising labour and supervising their work, getting the snow reservoir constructed and facilitating the ice formation with periodic release of water into the reservoir, as well as maintaining the reservoir structure, and insulating the ice formation with the locally available material of hay and charcoal. The group has also taken the responsibility of ensuring periodic maintainence of the created structure. A short training session was held to make the group members understand the functioning and maintenance requirements of the said structures. The effective performance of the above group indicates that the proposed community institution would be successful, albeit with some initial handholding and facilitation.

A Technology Assessment & Development Brief
by the
APPROPRIATE TECHNOLOGY TEAM
PRAGYA

WATER MANAGEMENT IN COLD DESERTS

PRAGYA

PRAGYA

Cent. Coordn. Off.: A-212A, Sushant Lok - I, Gurgaon - 122002, India.
Website: www.pragya.org
Phone/Fax: 91-124-2385932, 2386104.
E-mail: info@pragya.org

Pragya is a not-for-profit, non-governmental organization addressing issues of environment conservation and culture preservation in the high-altitude regions of the Indian Himalayas.