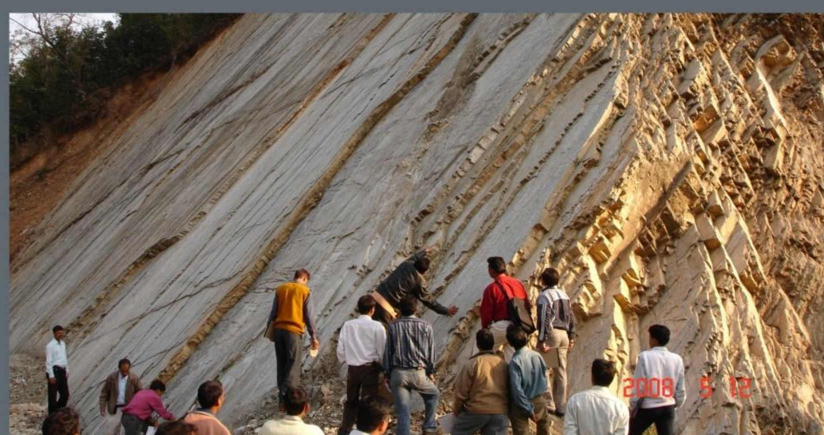
Contours of Spring Water Management in the Himalaya

2011

EXPERIENCES FROM KEY PARTNERSHIPS



ACWADAM

Plot no.3, Lenyadri Co-operative Housing Society,
Sus Road, Pashan, Pune – 411021.
Phone: 020-25871539
Email: acwadam@vsnl.net
Website: acwadam.org

ACWADAM

Contours of Spring Water Management in the Himalaya

Advanced Center for Water Resources Development And Management

Experiences from Key Partnerships

Bibliographic reference: ACWADAM 2011. Contours of Spring Water management in the Himalaya: Experiences gained from key partnerships. ***Ref:*** *ACWA/HYDRO/2011/H12*

Principal contributors:
Himanshu Kulkarni, Devdutt Upasani, Kaustubh Mahamuni, Amit Upmanyu and Raghuram.

ACWADAM

Plot no.4, Lenyadri Co-operative Housing Society, Sus Road, Pashan, Pune – 411021.

Phone: 020-25871539

Email: acwadam@vsnl.net, acwadam@gmail.com

Website: www.acwadam.org

Cover page (Clockwise from top): Groundwater fed lake in Ladakh, field activities in Kumaon, panoramic view of Uttarakhand Himalaya, *Naula* - traditional spring structure.

ACWADAM

Acknowledgement

ACWADAM has been actively pursuing action research activities in the Himalaya for the past four years, with various *partner* organisations. This document is a result of ACWADAM's interventions and experience gained by working in different areas of the Himalaya. The document is an overview of ACWADAM's limited but varied experience in the Himalaya, through hydrogeological facilitation to various programmes on spring water conservation and management. ACWADAM has ventured beyond the precincts of its activities and projects to compile this document. It is an effort to bring forward a practitioner's perspective on the importance of hydrogeology in spring water related work. Many organizations have played a pivotal role in ensuring the initiation of hydrogeological studies in the Himalaya and ACWADAM's involvement in the same. ACWADAM is grateful to all its partner organizations for their support in organizing field visits, collection of data and regular monitoring of springs in their area. Without their articulation of the need to develop hydrogeological perspective in various Natural Resources Management Programmes, this document would not have been possible.

Foremost, we would like to thank CHIRAG for involving ACWADAM in their spring development programmes. CHIRAG introduced us to Himalayan springs and prodded us towards developing a fresh perspective on the Himalayan groundwater resource. Apart from providing logistical support to ACWADAM's research initiatives in Kumaon Himalaya, CHIRAG assisted student interns from ACWADAM in undertaking detailed hydrogeological research leading to the publication of formal M.Sc. theses. ACWADAM is particularly grateful to Himmotthan and its partner organizations (Garhwal Vikas Kendra and Himalayan Educational and Resource Development Society) for initiating spring development projects in the Garhwal Himalaya and supporting ACWADAM's action research activities. Ladakh Ecological Development Group (LEDeG) is credited with providing us an opportunity to diversify its research agenda by exposing ACWADAM to the urban and climatic contexts in the Himalayan region. We extend our gratitude to GTZ for logistical support and field assistance in Himachal Pradesh, through a demand to use hydrogeology as a means of developing a multiple-stakeholder process in ensuring sustainability of water supply. We also thank our partners in the spring recharge (*Dhara Vikas*) programmes of Sikkim – State Institute of Rural Development (Sikkim), Rural Management and Development Department (Sikkim), GTZ and People's Science Institute, all of whom have been greatly helpful in shaping our perspectives on water resources in the Himalayan region.

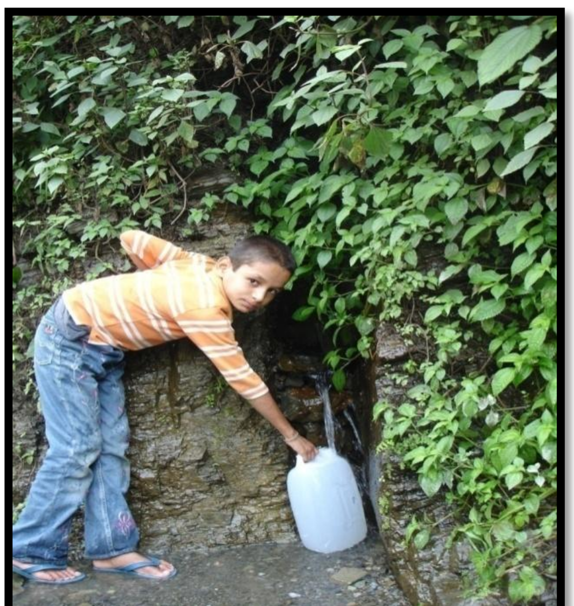
ACWADAM is thankful to Ford Foundation, Himmotthan, Arghyam Trust and GTZ for their financial assistance and technical support in this ongoing process of learning about groundwater resources of the Himalayan region. This document is a small milestone in the longer journey we have undertaken in a highly challenging *hydrogeological setting* of the country. Finally, we would like to state that there were many individuals and organisations that helped shape this endeavour. It is difficult to name each one of them. We remain grateful to all of them and continue to draw from their knowledge and experiences in our quest to learn more about water in this hydrogeological setting.

Contents

Introduction

Himalaya "the water tower of the earth" has always been the greatest challenge for any hydrogeological study. The immense challenge in understanding the groundwater in the Himalaya arises from the highly varied geology and structure of the mountain belt. The colossal mountain ranges are part of the Alpine - Himalayan mountain belt spanning from Spain in the west to Indonesia in the east. The Himalaya stretches for 2500 km all along the northern border of India touching seven international boundaries. Nearly 40 million people reside in the Indian Himalayan Region (IHR)(Census 2001). For the majority of the rural Himalayan population, springs are the fundamental source of drinking water. Most villages are located at high altitudes as scattered hamlets; they are at a great disadvantage as most of the fresh water flowing in the streams originating in the Himalaya is not accessible to them. The beneficiaries of the stream water are those living in the lower reaches of mountains and the foothills of the Himalaya. The upland inhabitants face problems of drinking water and irrigation. Nearly 4/5th of the Himalayan population is directly involved in agriculture. Even though only 12.5% of total land area is cultivated, only 11% of the cultivable land is under irrigation, almost 64% of which is fed by natural springs[1].

About 60% of the population depends on natural spring water for fulfilling their domestic and livelihood needs such as drinking water, sanitation and irrigation[1].The dependency of majority of the population on spring water implies that with changing climatic conditions and rainfall pattern, a large number of villages, hamlets and settlements are facing potential drinking water shortage. In fact, half of the perennial springs have already dried up or have become seasonal and nearly 8000 villages are currently facing acute water shortage for drinking purposes[1]. The topographic as well as geologic constraints ensure that sinking wells to tap groundwater is difficult, if not impossible. Only systematic and detailed hydrogeological investigations can present any possible escape from the existing crisis and the impending peril. The springs have provided water to the mountain communities for centuries and the revival of this traditional source of water is extremely important for the region's sustainable growth.



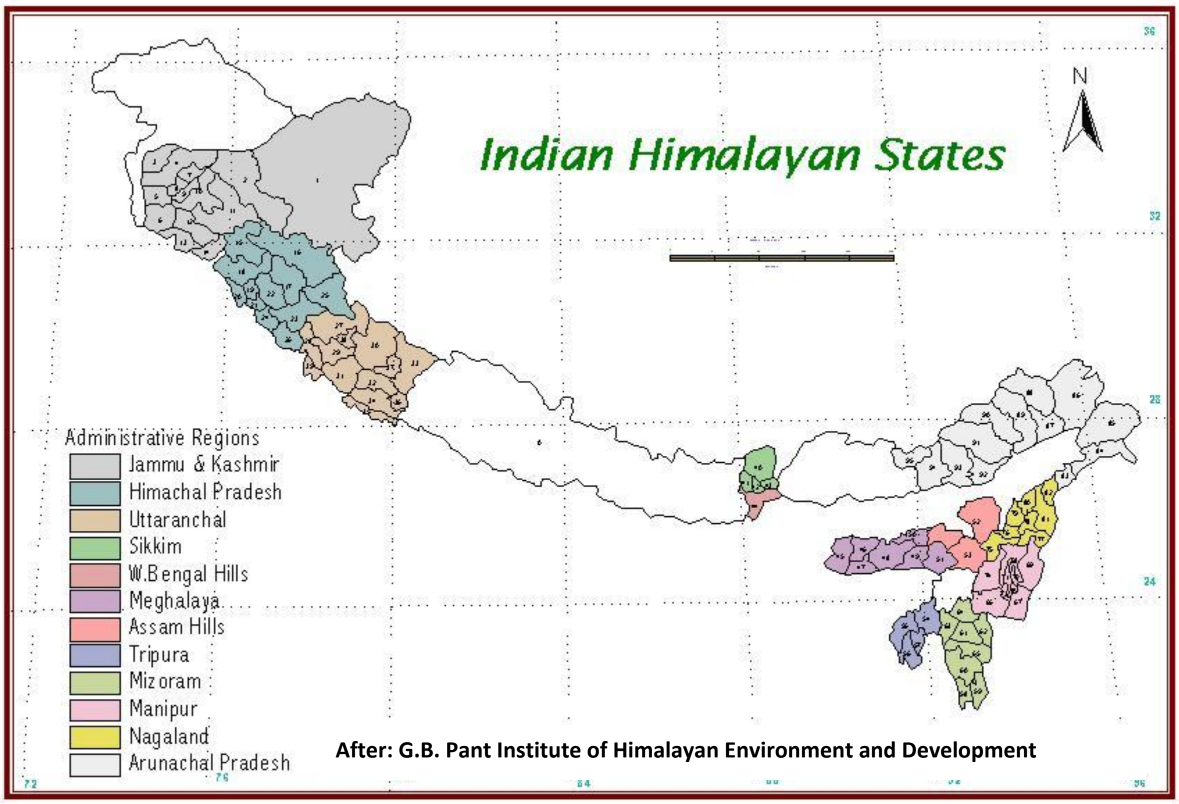
Involvement of the community in development, monitoring and maintenance of springs is

1. *Rana and Gupta, 2009*

essentialand an achievable task, as there are cultural and religious beliefs that motivate people to protect springs. Any programme attempting to develop this natural resource must involve - assessment of the geologic controls on the springs (at micro level), the recharge potential of the spring through spring-shed development measures (at micro level), the maintenance and protection of springs, effective monitoring of the spring discharge and water quality, and active participation of the community. The first step in understanding Himalayan springs is to develop a short background understanding of the Indian Himalaya.

INDIAN HIMALAYA

The Himalaya is spread across 12 Indian states stretching for a length of 2500 km and width of 250 to300 km. It is bounded by 27^{o} 57′ - 37^{o} 5′ N latitudes and 72^{o} 40′ - 97^{o} 27′ E longitudes.



The Himalaya covers the states of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, Meghalaya, Assam, Tripura, Mizoram, Manipur, Nagaland and Arunachal Pradesh. The mountain range is generally divided into -

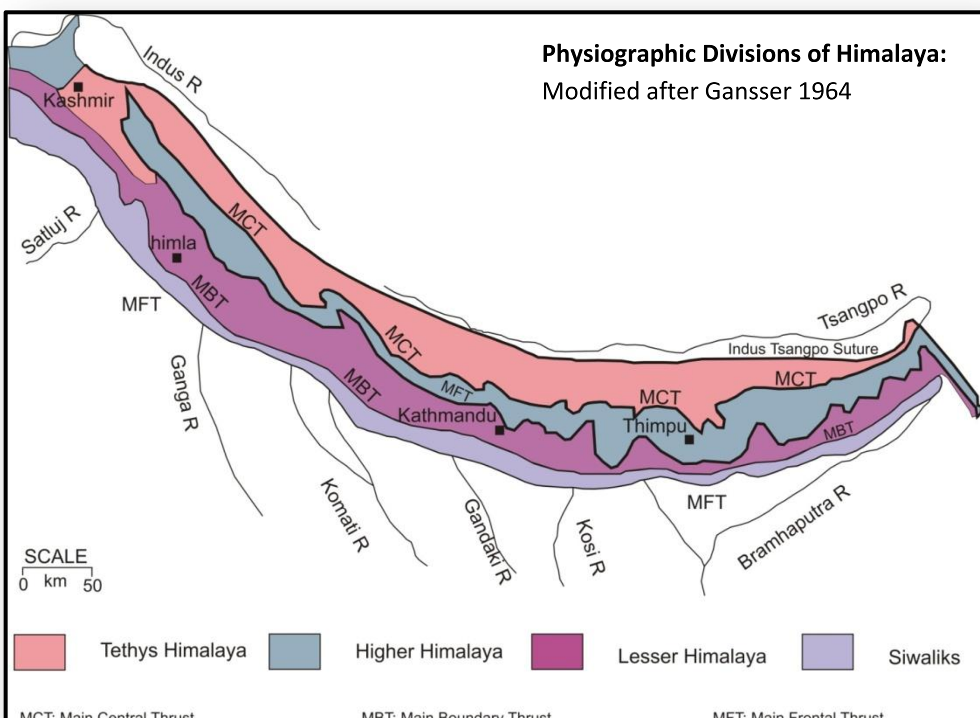
a) Eastern Himalaya- Darjeeling (West Bengal), Sikkim, Assam, and other eastern states.
b) Central Himalaya- largely in the country of *Nepal*.
c) Western Himalaya- Jammu & Kashmir, Himachal Pradesh and Uttarakhand.

Physiography of the Himalaya

The Himalaya is divided into different units based on its changing physiographic or topographic expression controlled by tectonic elements. The Himalaya starts from the foothills or the Siwalik ranges in the south and extends upto the Tibetan Plateau or the Trans Himalaya in the north. The different physiographic elements of the Himalaya include:

1. Sub-Himalaya or *Siwaliks*
2. Lesser Himalaya or *Himanchal*
3. Higher/Greater Himalaya or *Himadri*
4. Tibetan or Tethys Himalaya
5. Trans Himalaya

The Himalayan Frontal Thrust (HFT) separates the foothills of the Himalaya - the Siwaliks or the Sub Himalaya - from the Indo-Gangetic plains. These foothills are relatively low altitude hills almost entirely composed of *Siwalik* sediments. These river borne deposits of sediments represent the last phase of Himalayan orogeny (uplift). In general, the hills have a *hogback* appearance with steeper southern slopes and gentler northern slopes. The *Siwaliks*and the *Himanchal* are separated by narrow longitudinal valleys called as "*Duns*" in the western and central Himalaya and "*Dwars*" in the eastern Himalaya. The altitude varies from 300 to1000 m above MSL and the width from 5 to30 km.



The Lesser Himalaya or *Himanchal* forms the central chain of the mountain belt,bounded by the Main Central Thrust (MCT) in the north and the Main Boundary Thrust (MBT) in the south. The altitude ranges from 1000 to5000 m above MSL and the width varies from 60 to90 km. Himanchalcomprises highly deformed and altered rocks.

The Higher Himalaya or *Himadri* are the northern-most ranges of the Himalaya. The *Main Central Thrust (MCT) separates Himadri from Lesser Himalaya or Himanchal*. Snow-clad peaks, glaciers and deep longitudinal valleys or gorges characterise *Himadri*. The range has a granitic core flanked by metamorphosed sediments. The elevation varies from 5000 to 7000 m above MSL and the width varies from 40 to 60 km.

The *Tethyan* or *Tibetan Himalaya*can be separated from the Higher Himalaya by low angle faults known as the South Tibetan detachment system. Also called Trans-Himadri Thrust, it parallels the MCT and dips to the north. The Tethyan Himalaya consists of unmetamorphosed sedimentary rocks, which are rich in marine fossils. Tethyan Himalaya is bounded by the 50-60 m wide Indus-Tsangpo Suture Zone in the north. This suture is also called the Main Mantle Thrust. Tethyan Himalaya contains high mountains with general elevations varying between 3500 and 4800 m. The Trans – Himalaya extends north of the Indus-Tsangpo Suture, into Tibet.

Groundwater Development: Springs and their Significance

Since there is great diversity in the physiography, the geology and structural setting, the groundwater system in the Himalaya presents a highly complicated picture. The extent of the aquifers, their geometry, their hydrogeological properties, viz. storativity and transmissivity show great variation. High degree of deformation in the Himalaya resulting in intense folding, faulting and development of fracture zones contributes to the loss of aquifer continuity in the mountain belts.

Under the prevailing conditions, a large number *springs* form in the mountain ranges of Himalaya. The abrupt termination of the aquifer along the mountain slopes and exposures in valley portion causes the aquifer to discharge groundwater in the form of springs. Many springs owe their genesis to structural features such as fractures, faults and other weak planes. These fractures and faults serve as channels through which groundwater flows and finally emerges from a suitable orifice in the form of springs. Traditionally, spring water is considered clean due to the natural filtering that occurs during infiltration. Water from springs sufficed the village needs in the past. In recent times, both the quantity (discharge) and quality of water issuing from the springs is reported to be undergoing depletion and deterioration respectively. The study of springs involves a synthesis of two branches of science - hydrology and hydrogeology[2] (Brune, 1975). Hydrology is primarily concerned with the study and understanding of surface water while Hydrogeology is the study of water in the subsurface including its chemical, physical and environmental characteristics. For the sustainable development and management of springs, it is essential to understand the hydrogeology and the surface water features in the area. Kresic, 2010has stated that any workable, realistic plan drawn for the management of springs must fulfil the following prerequisites:

a) Hydrogeologic and hydrologic characterization of the spring type, drainage (discharge) and recharge area, and recharge and discharge parameters, such as water quality and quantity.
b) Reliable predictive modeling of spring discharge and water quality, achieved by collecting discharge and quality data of springs.

Additionally, the importance of demand side management is also emphasized in literature. Demand management refers to initiatives that ensure the satisfaction of the current water requirement in times of limited resource availability, by augmenting the efficiency of water use. At a local scale, this implies the involvement of the community, educating various stakeholders and especially the community about:

1. Resource protection
2. Preventing contamination of the aquifer
3. Land use management and control, especially in the recharge area

ACWADAM in the Himalaya

We have attempted above, to summarise (through a simplified description) of the region, the regional geological setting of the Himalayan region, a setting that plays a crucial role in the formation of mountain aquifers that feed springs and spring systems. Advanced Center for Water Resources Development and Management (ACWADAM) is playing a pivotal role in the initiation of rational, knowledge driven management of the precious spring water resource in the Himalaya. ACWADAM has taken the responsibility of conducting thorough hydrogeological studies pertaining to springs in the Himalaya in collaboration with different organizations. Often, our partners, – Central Himalayan Rural Action Group (CHIRAG), Himmotthan, People's Science Institute (PSI), Deutsche GesellschaftfuerTechnischeZusammenarbeit (GTZ) GmBh and Government of Sikkim through its *DharaVikas* programme – have stimulated and guided our own perspective-building of spring water in the region. ACWADAM's objectives while working on spring water include:

2. Brune, 1975

1. To conduct detailed hydrogeological investigationsfor demarcation of the recharge area, characterizing the nature of the spring (type), collection of spring discharge and quality data.
2. To disseminate information obtained from the hydrogeological investigations to partner organisations and other stakeholders in an attempt to develop improved interventions in the enhancement of spring discharge and improved water quality.
3. To develop recommendations for the protection of the aquifer systems behind springs and prevent source water contamination.
4. To train individuals from partner organisations and the community for collection of spring discharge and water quality data.
5. To prompt communities to establish spring management systems based on sound hydrogeological investigationsthat correctly define the resource and its characteristics.

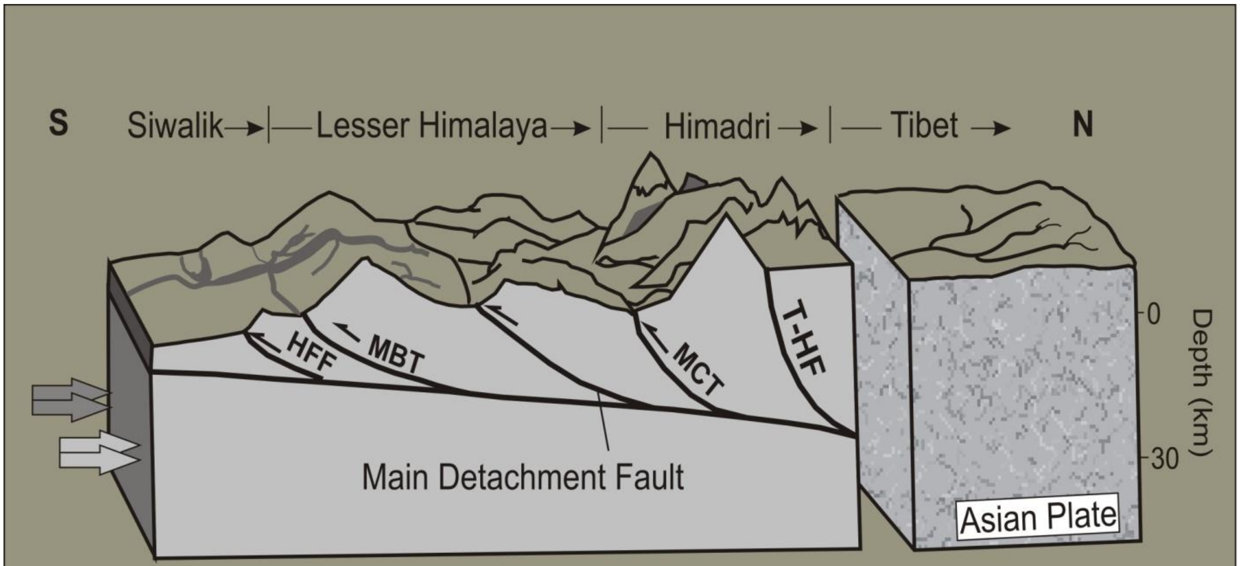
ABOUT ACWADAM

ACWADAM is an organization engaged in research and education on groundwater. It carries an experience in issues relating to the management and sustainability of groundwater. ACWADAM's work spans many parts of India. The ACWADAM team has worked in academics, corporate and voluntary sectors, in the single area of water resources management, particularly groundwater management. ACWADAM has been involved in two international projects related to groundwater, one on community based groundwater management and the other on groundwater recharge.

ACWADAM's steady growth since 1998 has involved working with several leading NGOs as well as the Governments of Maharashtra, Uttarakhand, Madhya Pradesh, and more recently with the Sikkim and Andhra Pradesh Governments. Founded in the late '90s, by like-minded professionals from the University of Pune,ACWADAM possesses experience of some 30 years or more on work related to hydrogeology, the science of groundwater. Its strength stems from the factthat the core team in ACWADAM has worked mainly on the sustainability of groundwater resources in hard rock aquifers in India, including conflicts between irrigation and drinking water supplies. A lot of this work involved collaboration with international organizations, leading to high-quality research outputs. This work also enabled ACWADAM to interface with leading international water experts. ACWADAM, through the course of its partnerships, developed an expertise and wide-ranging experience in the identification and characterization of aquifers, the foundation for understanding groundwater resources.

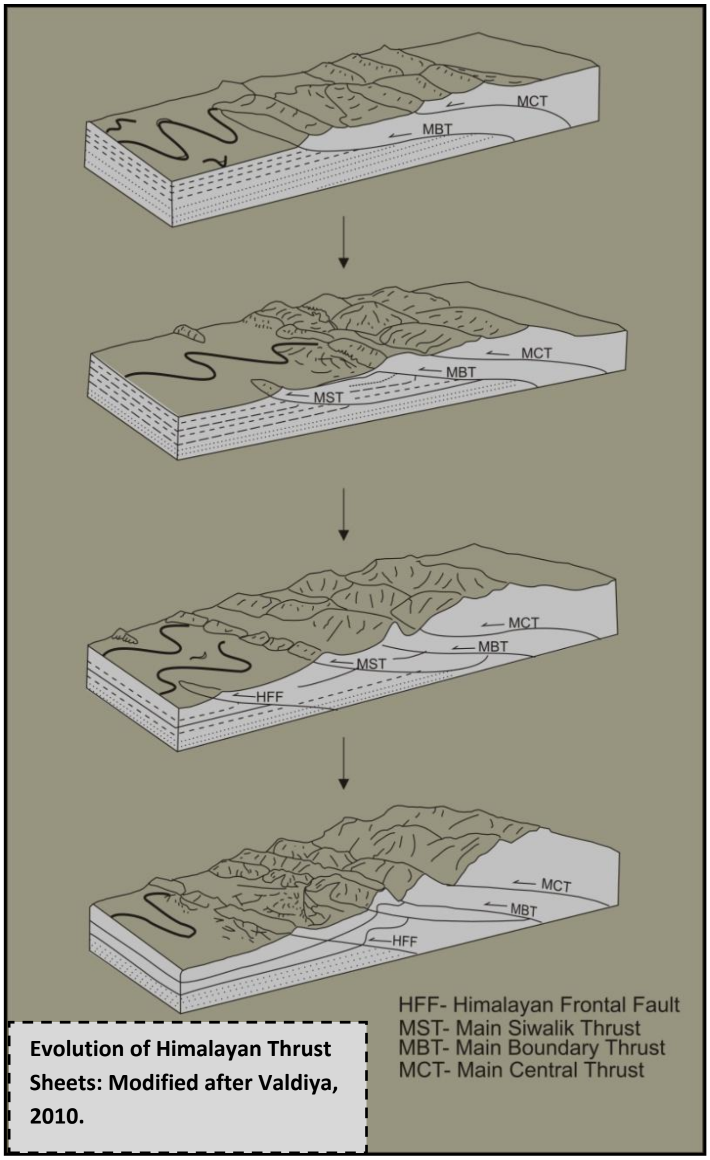
Geology and Himalayan Aquifers

Himalaya has forever intrigued geologists and motivated many workers to study the geological and structural setting of the mountain belts. Sufficient literature exists, describing the geology of the Himalayan mountain belt. Many workers can be credited for their classical work - Middlemiss, Auden, Gansser andValdiya, to mention a few. Detailed geological information about the Himalayan region can be obtained from publications of the Geological Society of India, Bangalore and research papers from reputed journals. However, most geological literature is stratigraphy-oriented. The evolution of the Himalaya and structural setting has also been studied at a regional scale but comprehensive geological study at local scale is missing hitherto. For applied hydrogeological purposes such as the application of this knowledge to an improved management of spring water, more locally focused geological studies leading to somewhat demystifiedrecommendations is necessary.



Major Tectonic elements along the Himalaya: Modified after Valdiya 2009

Himalaya is composed of rocks of varying ages from Precambrian (older than 540 million years) to Quaternary (younger than 2.6 million years). Likewise, there is great diversity in the lithology or the rock type of the mountain belt. It is essential to understand that the structural evolution of the mountain belt and the disposition of the different rock types influence the physiography of the Himalaya.



Evolution of Himalayan Thrust Sheets: Modified after Valdiya, 2010.

The Himalayan mountain ranges evolved nearly 55 million years ago when the Indian plate collided with the Asian plate. This halted the Indian plate's northward journey and the mighty Himalaya was born. Such collisions involve folding of the rock layers and formation of mountain belts, referred to as "Fold Mountains". Such a mountain building event is called "Orogeny". The collision also involved the formation of numerous faults and thrusts. These thrusts are responsible for the longitudinal zonation of the Himalayan mountain belt. Movement of rock layers along these thrusts and several other local thrusts or faults has caused complications by bringing differing lithologies in immediate juxtaposition. In Lesser Himalaya, for example, metamorphic rocks are in tectonic contact with weakly metamorphosed or sedimentary rocks. As there have been many episodes of deformation and metamorphism, the geological setting is rather complicated. Any hydrogeological perspective developed for the region must take this into account.

Siwalik

The Siwalik ranges are composed of the youngest sediments (consolidated and unconsolidated). These sediments were deposited by the rivers draining the rising Himalayan Mountains. The Siwaliks are composed of dark red, brown to grey coloured sandstones and shales. At many places, the sandstones are soft and massive interspersed with conglomerate and silt layers. Pink or brown silt and sand are intercalated with grey sandy to earthy clays. Massive boulder conglomerate are also observed in the Siwalik valley. Lenses of limestone are occasionally found within sand layers.

Lesser Himalaya

The Lesser Himalaya is extensively covered by sedimentary rocks, which have been partly metamorphosed. The dominant lithologies in the Lesser Himalaya include quartzite with siltstone and slate, carbonate rocks (limestone and dolomites), phyllite. The sedimentary formations are occasionally interbedded with metavolcanics. The Lesser Himalaya comprise of rocks as old as 2500 million years old to 500 million years old. The sequence in the Lesser Himalaya generally starts with quartzites at the base, occasionally containing lenses of limestone; overlain by thinly bedded slate, limestone and dolomite. These are overlain by sequences of coarse grained to fine grained quartzites and occasional pebble beds. The younger Precambrian formations (700 – 540 million years old) are composed of carbonates and phyllites (Kumar 2005). Younger granitoids and mafic intrusive rocks have intruded the sedimentary formations. The sedimentary sequences are underlain by basement complexes of granites and gneisses. These intrusions are known by different stratigraphic names in different parts of the Himalaya. The Lesser Himalaya also contains boulder beds composed of fragments of quartzite, shale, limestone, siltstone, chert and vein quartz embedded in clay matrix. The older rocks in the Himalaya are capped by Tertiary (65 million to 2.6 million years old) sedimentary rocks. The rock types include conglomerates, sandstones, shales and limestones. The deposition of the rocks is related to the uplift of the Himalaya.

Greater Himalaya

The Greater or Higher Himalaya consists of a metamorphic core of granitic composition that is flanked by metamorphosed sediments. The core is referred to as Central Crystallines in geological literature. The metamorphosed sediments are an assemblage of mica schists, quartzites, calc-silicate rocks, gneisses and granites. The metamorphic core of the Himalaya also forms the axis of maximum uplift in the mountain belt. The Central Crystallines are prominent in the states of Uttarakhand and Himachal Pradesh; however, best sections for geological investigations are available in Kashmir. The intrusive granites and gneisses are of varied age and known by different stratigraphic names in different states of the Indian Himalaya. The Higher Himalaya also contain metamorphosed sedimentary formations that include slate, phyllite, local conglomerate, graphitic schist, talc schist, limestone and dolomitic limestone.

Tethys Himalaya

The Tethyan Himalaya is composed of highly fossiliferous sedimentary rocks formed by sediment deposition in a marine basin. The rocks of the Tethyan Himalaya are of varied age (600 million years to 65 million years old). The sedimentary rocks of the Tethyan Himalaya include sandstones with intercalation of siltstones, thickly bedded limestone; limestone-shale-siltstone-sandstone intercalations, sandstones with lenticular conglomerate, shale composed of volcanic ash, volcanic rocks including basalt, andesite and few granitic rocks. Occasionally, in younger formations calcareous sandstones (calcium rich cement) are also found with intercalations of limestone.

Trans-Himalaya

In the Trans-Himalaya, batholiths (sizeable bodies of igneous rock) are formed as a large linear complex of gabbro-diorite-granite composition. The Trans-Himalaya extends to the north of the Indus-Tsangpo Suture and Shyok Suture Zones into Tibet and China. The Trans-Himalaya consists of granitic plutons (a distinctive mass of igneous body crystallized under the surface of the Earth) and Ophiolites (slices or sections of Earth's oceanic crust that have been uplifted and exposed within the continental crust).

Himalayan Aquifers

The complex interplay of rock types and rock structure in the Himalayanot only give rise to diverse hydrogeological environments, but such environments lie in close proximity to each other. The hydrogeological setting in mountain areas is a result of variation in the rock type and structure of the aquifers. Overlap and inter-fingering of different lithounits or rock strata lead to the development of composite aquifers (aquifers formed by a grouping of different rock types). Such overlaps are facilitated by structural deformation such as folding, faulting and development of fracture zones. Loss of aquifer continuity at mountain slopes or along faults and fractures, leads to the formation of springs. Spring discharges vary considerably depending on the hydraulic conductivity of the aquifers (rock type and rock openings). Moreover, change in the quantity of precipitation on account of altitudinal differences is responsible for varying degrees of temporal variation in the discharge of springs.

Aquifers in Himalaya, due to the discontinuity of the rock formations by conditions imposed by the terrain and the structural setting, are often only of local extent. Even within a small area, many separate aquifers may be encountered; these aquifers may be composed of a single lithology or may be composite in nature. Despite such an intricate and complex geological setup, majority of the watershed development programmes and spring development strategies implemented in Himalayan villages give no regard to the geology of the *catchment*. Even in geologically less complex areas, the success of watershed development programmes depends highly upon a sound geologic input. In the Himalayan mountain belts, therefore, many projects with watershed or spring development agenda run the risk of limited scope, sometimes leading to the failure of achieving the full objective of the project.

ACWADAM, in partnership with other organizations, is attempting the development and implementation of scientifically motivated, hydrogeologically driven spring development programmes in the Indian Himalayan Region. The hydrogeological input provided by ACWADAM is intended to identify and “treat” the recharge area of the aquifer / spring. This is important because the diverse hydrogeological setting in the Himalaya means the size and location of a recharge area of a spring can be highly variable. ACWADAM is also attempting to help partner organisations monitor spring discharge and spring water quality in a bid to understand spring behaviour and to help capacity building of partner organizations and the community through a knowledge and information driven process.

Springing to action
Challenges and Programmes

Mountain environment systems have come into great focus due to their fragile nature and vulnerability. The development-push in the mountain ranges and a changing climate pose threat to the stability of the mountain systems and damage natural resources. The major concerns are ecological; protection and management of natural resources are strongly related to forestry, agriculture, livestock etc. with the prospect of achieving environmental security for the population that is strongly dependent on these resources for livelihoods. Environmental concerns are clubbed with economic and developmental aspirations of the Himalayan people leading to deterioration of the environment[3]. The high dependency of the inflating population on the natural resources and lack of suitable technologies to enhance production or mitigate mountain specificities leads to the marginality of farmers, ultimately promoting poverty[3].

Studies from the Himalayan region, concentrating on development interventions, reveal the


View near Leh

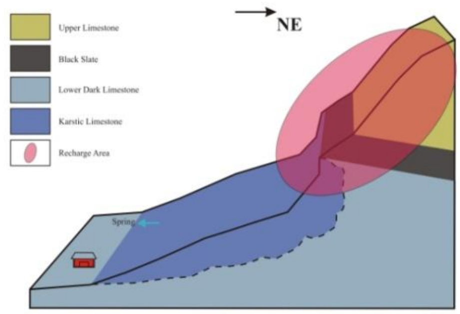
exploitation and degradation of natural resources, more so about the precious groundwater resource. ACWADAM's own experience from working in the Himalaya portrays an acute state of affairs. Pressures from a growing population, changing aspirations of people and an increasingly urban lifestyle has meant that demand on water resources will continue to grow at a rapid pace, making conservation of groundwater resources extremely vital. Springs in the Himalaya and have sustained the mountain populations for thousands of years. Recently, with reduction

3. Singh,2006

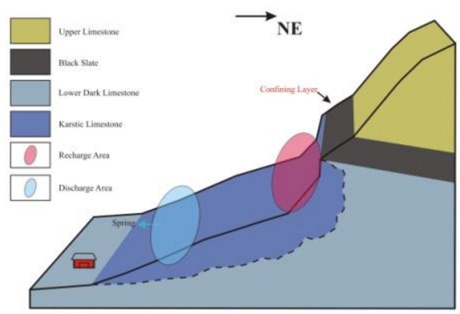
in the intensity of monsoons and changes in climatic conditions, there are instances of drying up of springs in the Himalayan region [4]. Many other springs have shown decline in their discharge over the past decades, clearly indicating depletion in groundwater storages that feed such springs. Depletion of spring discharge and the large difference in river discharges during wet and dry seasons results in too-little and too-much water syndrome, a characteristic of the desert country[5]. Reduction in the discharge of springs is attributed to deforestation, changing land use, intense grazing, and decline in rainfall[6]. Unplanned rapid urbanization and tourism haveaggravated the problem; construction of hotels and resorts on sites of springs has worsened the situation. The number of springs has reduced drastically over the years due to the aforementioned reasons. For example, the number of operating springs in the Almora region has gone down from 360 to 60 over the last 150 years[7].

Hydrological research in the mountain region is largely limited to micro-watershed studies. Study of springs has not drawn sufficient attention to develop comprehensive, scientifically-based crisis-resolving interventions. In general, there is consensus on the lack of knowledge of mountain water resources and many factors are considered responsible for this deficiency – harsh environment and poor accessibility leading to difficulty in conducting proper hydrological studies[8].

ACWADAM with its interventions in the Himalaya is striving to add to existing research and narrow the gap between existing research and the required inputs to spring water management.Most importantly, it is



Recharge Models based on the treatment of specific area above the spring irrespective of geology



Revised Model of recharge post Hydrogeology input from ACWADAM

4. *Valdiya and Bartarya,1991*
5. *Valdiya and Bartarya,1989*
6. *Valdiya and Bartarya,1991; Rawat and Rawat, 1994*
7. *Kumar, 2006*
8. *Tripathy, 2010*

essential to introduce hydrogeological concepts and techniques in the existing watershed development programmes. Intervention at community level is important to shield the interests of watershed as well as spring development programmes. In this regard, ACWADAM is making serious attempts at demystifying the science of hydrogeology and training individuals from partner organizations. Many civil society organizations and government agencies have been involved in the development of watershed programmes and spring recharge programmes. Most interventions were largely based on a *genericprinciple* of catchment area treatment, prior to ACWADAM's involvement. Established programmes worked on a 10-20 ha model i.e. ten to twenty hectares, just upslope of a spring were chosen as the recharge area (watershed area) of the springs, with no regard to the underlying geology and its control on the movement of groundwater to the spring in question. The lack of a strategy involving classification of springs and consideration to the diversity in the location and size of the recharge area of the spring meant that investments in such initiatives would not necessarily result in the positive impacts.

The premier institutes involved in water resources management and spring development in the Himalaya include Central Ground Water Board (CGWB), Himmotthan Society, Central Himalayan Rural Action Group (CHIRAG). The *DharaVikas* project underway in the State of Sikkim is a Government of Sikkim initiative involving the State Institute of Rural Development and other partners. The *DharaVikas*hopes to arrest the disappearance of springs and develop strategies for the conservation of springs. The technical input for these strategies is being provided by ACWADAM afterundertaking detailed hydrogeological investigation of the spring catchments and studying factors like spring discharge and spring water quality.

Capacity building is an important component of ACWADAM's work in the field of groundwater development and management. Educating the stakeholders about the geological controls on the flow and storage of groundwater and the significance of the science in relation to spring water management is actively undertaken by ACWADAM in all its endeavours. ACWADAM has engaged partners from the Civil Society during the last three years, to spread awareness, develop knowledge and begin systematic work that will lead to improved spring water management in different parts of the Indian Himalayan Region. Ultimately, the learning gained by ACWADAM through its interventions in the Himalaya is expected to result in improved understanding of springs and further demystification of the complexities of catchment area treatment of mountain aquifers along with the dynamics of communal specificities. The understanding gained by these long standing initiatives are intended to enable ACWADAM to attempt policy advocacy at state level, concerning spring development andmanagement thereby leading to improved drinking water security in the rural Himalaya.

Many newgroundwater management initiatives have begun in the country, initiated and run by both Government and Non-Governmental Organizations. In an effort to change the current method of resource management, the Ministry of Water Resources constituted a Ground Water Resource Estimation Committee with the aim of revising the current methodology of groundwater estimation established by the previous committee (Ground Water Estimation Committee, 1984). The report of the committee (Ground Water Resource Estimation Methodology, 2009) proposes many changes and improvements in the existing methodology, revised norms of groundwater resource assessments, groundwater assessment in different environments (e.g., saline areas, command and non-command areas etc.), groundwater assessment in different seasons. However, no attempt is made for estimation or assessment of groundwater in mountain systems. The comprehensive report lacks any assessment of aquifer systems that provide water to springs. This fact is stated here to solely establish the lack of a clear research initiative concerning springs and mountain aquifers. Despite a number of reports and statistics proving the importance of springs for the Himalayan people, research initiatives have been insufficient and inadequate to resolve the crisis.

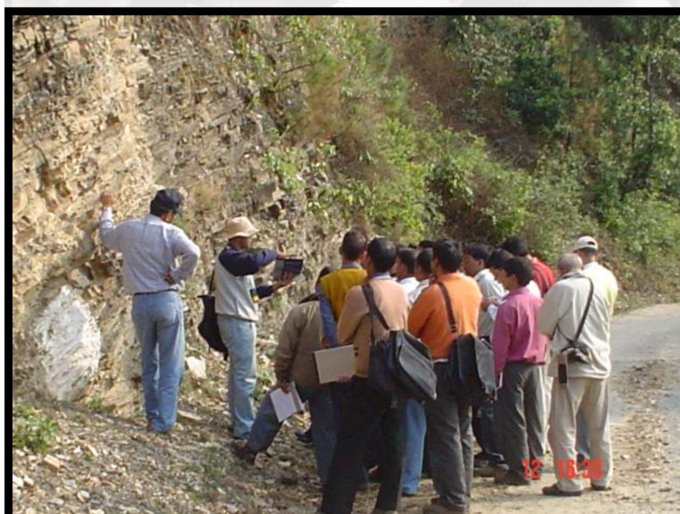
Most natural resource management projects in the Himalayan region focus on livelihood enhancement. Although such programmes were initiated years ago, almost all watershed or spring development schemes were operationalisedwithout a clear understanding of the geological regime of the region and completely oblivious to the science of hydrogeology. Therefore, implementation strategies did not account for variability in hydrogeological factors. Complications arise as aquifer boundaries rarely conform to administration boundaries; or for that matter highly simplified assumptions in terms of the "catchment" of springs. Variation in land use pattern also affects the recharge measures selected for implementation. Undertaking recharge measures is relatively simpler in community owned property holdings, so, the principle of water as a common pool resource, also takes a beating. In case of private land ownership or land under the aegis of the Forest Department implementing effective recharge measures becomes a problematic task. The spring recharge plans, therefore, evolve according to the strategic demands of implementation in an area. It is worth noting that civil societies more effectively rope in the community and attempt to reach private owners, thereby making implementation of recharge measures through active community participation possible. Government agencies on the other hand are able to implement recharge measures in forest lands where non-governmental organizations and the community are not permitted to undertake measures. Our involvement with both government organizations and civil society initiatives has helped improve ACWADAM's understanding of various aspects of development of spring recharge plans and sustainability of rural water supply. In spite of being a research and training institute mainly focussing on the demystification of the science of hydrogeology and providing scientific inputs to spring recharge programmes, ACWADAM's policies have evolved through conceptualization of administrative and socio-economic issues.

Spring development programmes in the Himalaya- ACWADAM's Experience

CHIRAG:

CHIRAG works on water, rural development and livelihoods, and is based in the Kumaon region of Uttarakhand in India. Chirag'sactivities include community, forestry, soil and water conservation, the development of watersheds, increasing the availability of fodder, animal husbandry, agriculture and horticulture, drinking water, primary health care, primary education and the development of knowledge and skills among young people[9].

CHIRAG primarily focuses on community forestry, soil and water conservation, catchment area protection, agriculture, animal husbandry, fodder development and conservation[9]. Watershed development programmes mainly focus on catchment area protection and treatment. Although, watershed development programmes involved treatment of spring catchment as well, there were no dedicated spring recharge programmes in CHIRAG's agenda. Their spring treatment plan followed the 10-20ha models wherein geological conditions and their control on the behaviour of springs was hardly considered. CHIRAG approached ACWADAM in 2006 with the very challenge of moving beyond the *generic* model of spring water catchment treatment. Members of their watershed development team attended the biannual training conducted by ACWADAM at Pune and returned with fundamental hydrogeological perspectives about spring water.



Training at Chirag…

ACWADAM was then invited for further training of CHIRAG staff in Kumaon; 7-8 workshops

9. *www.chirag.org*

were conducted at different centres in CHIRAG's area of work, over a period of 4-5 years. These included educating CHIRAG's staff about the basic concepts of hydrogeology, the controls of geology in the movement of groundwater and storage, the meaning and importance of aquifers, their geometry in relation to prevailing topography, structural control in movement of groundwater and generation of springs. CHIRAG's field staff was introduced to processes governing the formation of springs, identification of spring types based on their genesis, identification of recharge area and other such relevant details. Field facilitation and assessment of the geological setting of some of their spring sites were also undertaken. Recharge areas for some of the springs were identified and treatment measures suggested. Many springs in CHIRAG's area are fracture-controlled with little variation in the dip of the rock formations.Therefore, emphasis was on constructing recharge structures that are conducive to the slope of the ridges – dip and escarpment slopes were identified as a basis to understand spring hydrology better. Through student dissertation programmes, ACWADAM has involved students in understanding the hydrogeological regimes in CHIRAG's area, mainly in Naukuchiatal and Bhimtal areas. These dissertation programmes served the dual purpose of introducing students to the complexities of mountain hydrogeology and providing field facilitation to the partners.

Following ACWADAM's involvement, CHIRAG has developed satisfactory understanding of the geology and basic concepts of spring hydrogeology. Identification of groundwater recharge areas, based on geological mapping and spring water characterisation has been a key input to CHIRAG's spring recharge programme.CHIRAG is working on the development and management of nearly 80 springs in Kumaonover the next few years and subsequently attempt training their partner organizations, once they have acquired sufficient knowledge and experience in development of springs. ACWADAM continues to provide CHIRAG key technical and training support.

V-notch for measuring spring discharge.

Water quality measurement at CHIRAG.

HIMMOTTHAN:

Himmotthan(started as a State-based Cell) was set up to coordinate the *HimmotthanPariyojana* in 2006andwas officially registered as a society in 2007. Apart from monitoring, evaluating and handholding under the *Pariyojana*, *Himmotthan's* mandate includes idea incubation by implementing pilot programmes, up-scaling strategies, village institution development and data base management, liaison and fund raising[10]. Learning from CHIRAG's partnership experience in watershed and spring development,*Himmotthan* approached ACWADAM and a sensitization-cum-awareness building exercise was undertaken for the *HimmothanPariyojana* in Dehradun (Uttarakhand), with special reference to spring water under the Water and Sanitation Programme (WATSAN). The first training workshop was conducted by ACWADAM in September 2008. Subsequently, the scope of the project was widened to develop an improved approach towards catchment area planning and treatment of water sources under the Water and Sanitation (WATSAN) projects in parts of Uttarakhand, under the *Himmotthan Initiative*.

ACWADAM's initial involvement highlighted the importance of sound geological understanding in planning and management of water sources. The role of surrounding geology is also important in the planning of wastewater disposal, especially in context to sanitation practices – upstream versus downstream issues. The initial workshops conducted by ACWADAM brought to light the following shortcomings in the proposed scale of planning: lack of knowledge of science of hydrogeology (with implementing agencies), flawed methods of data acquisition, emphasis on building structures without any attention to the science of hydrogeology, absence of robust management systems that include processes of conservation, protection and recharge. In this light ACWADAM collaborated with Himmotthan in order to develop capacities of the partner organizations who are working on aspects of conservation of catchment to ensure drinking water security. The specific objectives of the programme included:

1. capacity building of partner organizations under the *HimmothanPariyojana*to bring site-specific hydrogeology into planning and management of spring water under the WATSAN programme
2. facilitation of specific activities through case studies at 15-20 spring locations across the state of Uttarakhand, development of a systematic process that includes the study
3. planning and execution of catchment treatment of spring water

10. www.srtt.org

Secondary objectives of the project involved the development of thumb rules based on the experience gained during the project, documentation of the complete process through a formal publication at the conclusion of the project.

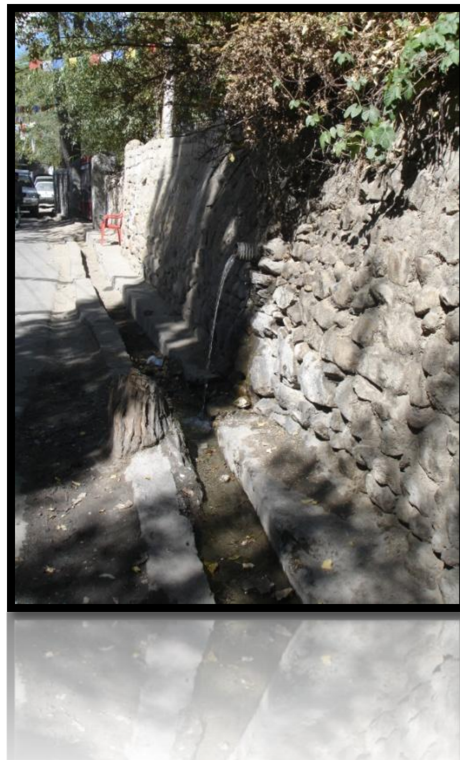
Under the WATSAN programme, pilot projects have been implemented and documentation developed as *case studies*. Three levels of case studies are undertaken – intensive pilots, semi-intensive pilots and the partner cases. Additionally, ACWADAM is also providing technical assistance to many partner organizations for identification and treatment of spring recharge zones. The case studies are intended to develop a comprehensive understanding of spring systems in the Himalaya, which can be shared with policy makers and other stakeholders for modification of the treatment strategies in spring development programmes.

The springs in the Garhwal Himalaya (most partners under the WATSAN are based in Garhwal) are more diverse in nature when compared to Kumaon springs. Unlike Kumaon, springs in Garhwal were found to be controlled by multiple geologic features, for example, lithology, structural features, dip of rock formations etc. Recharge areas of springs vary tremendously, based on the geological controls and location and construction of recharge structures is in accordance with the hydrogeological regime established in the catchment.

As stated previously, many unscientific models existed in the spring development initiatives of partner organizations and ACWADAM's contributions facilitated the impeachment of unscientific elements from existing spring development plans. Conventional treatment plans were based on 10-20ha models; these models have now been discarded by the partner organizations that now rely on site specific hydrogeologically driven treatment plans for the recharge of springs.

Measuring spring discharge and water quality at spring capture sites…

LEDeG (Ladakh Ecological Development Group):



Urban springs…

The Ladakh Ecological Development Group (LEDeG) is a grassroots organization that has been working in the region since 1983 towards a vision of a sustainable future for Ladakh. Ladakhiculture and environment are part of this sustainable future. LEDeGhas been working on various Ecological, Cultural and Developmental issues in Ladakh region for about three decades. LEDeG has been active in carrying out awareness programmes related to the environment, culture and development in the region. Their current thrust areas are Renewable Energy, Livelihoods and Urban Environmental Issues. Their ongoing projects include Installation of community based Micro-Hydro Power Units and Solar Photo-Voltaic Power Plants, Passive Solar Housing, Promotion of Solar Devices and appropriate technologies, Income Generation Projects with women's SHGs on Handicrafts and Food Processing[11]. ACWADAM is currently collaborating with LEDeGon a project promoting sustainable use and management of groundwater in the town of Leh. The main objective of the project is to create a comprehensive, knowledge-based approach to sustainable use and management of groundwater.

LEDeG approached ACWADAM in 2009 with the intent of obtaining technical expertise on water resource management in Leh town. The rapid urbanisation of this hill town has had drastic impact on the water resources, especially on groundwater resources and springs in and around Leh town. Members of LEDeG staff attended the July 2009 training on groundwater management conducted by ACWADAM in Pune. LEDeG's study is important because of its relevance to growing concerns around urban hydrology in and the impacts of tourism on water resources in a tourist hot-spot. LEDeG had no programme established for water resources assessment and impact of modernisation on the availability and quality of groundwater. With this joint initiative, LEDeG and ACWADAM hope to develop a comprehensive understanding of the

11. www.ledeg.org

urbanisation related effects on the hydrogeology of mountain aquifers and the impacts of urbanisation on springs. The project started from January 2010, expected to be at the least a three-year study, attempts to generate scientific knowledge regarding the nature and extent of the groundwater resource.Other objectives include identification of alternative technological solutions of water use practices for sustainable groundwater management, and dissemination of information regarding groundwater and alternative technological solutions among the stakeholders and decision makers in order to promote awareness towards the need for sustainable groundwater management.

There is a compelling need for accurate measurement and analysis of various climatic as well as hydrogeological parameters in a comprehensive study on Himalayan groundwater. In this regard, the study includes monitoring of weather parameters (a permanent weather station has been establishednear Leh town), variation in stream discharge,regular measurement of spring discharge and data collection from hand-pumps, wells, and borewells from different parts of the town along with aquifer mapping.

A growing concern is the increasing stress on water resources from the booming tourism in the area. The proposed project also aspires to understand the scientific as well as social aspects related to groundwater abstraction. Facilitation and dissemination of hydrogeology related information is ACWADAM's primary objective in the project. Such understanding, it is hoped, willcomplimentLEDeG's research on the water demand-supply situation in Leh town.

Measurements at a hand-pump site

Three field visits have been conducted by ACWADAM since the commencement of the project. The initial reconnaissance visit was followed by purposeful visits that included setting up of a data monitoring system and hydrogeological mapping in the area. An initiation workshop was conducted to introduce the concepts of hydrogeology to the stakeholders, during the last visit by ACWADAM TEAM. Several field visits have been planned through the length of the project with specific objectives, which include various levels of capacity building interventions.

DHARA VIKAS:

The *DharaVikas* scheme is a Government of Sikkim initiative with a multitude of partners, including the ArghyamTrust and Peoples Science Institute (PSI), WWF-India, The Mountain Institute-India, other Government bodies(RMDD & SIRD) and ACWADAM. Various local organizations are also involved in the project. Many organisations involved in the project have experience of undertaking watershed development activities in the mountain regions; others like PSI have previously undertaken *spring-shed* development programmes[12]. The conceptualised strategy primarily focuses on construction of recharge structures and slope treatment in the spring catchment to increase the percolation of water in the subsurface by reduction in the surface run-off. However, little consideration was given to the geology of the subsurface in the initial interventions of the project and a 10 Ha area above the spring was chosen for catchment treatment. For this very reason, the spring-shed development ventures were frequently unproductive.

Drying springs and hilltop lakes in Sikkim…

12. www.sikkimsprings.org

Hydrogeology Training at Sikkim: Lecture Session

Hydrogeology Training at Sikkim: Field Session

ACWADAM's involvement in the project at the beginning of 2010 commenced with selection of springs for collection of data and group exercises for improving the understanding of hydrogeological principles among the participants. Field facilitation is coupled with capacity building exercises and providing back-stopping support to organizations involved in the project, a process in keeping with ACWADAM's modus operandi. In order to develop a first-cut understanding of the science of hydrogeology, 15 members from partner organizations were invited to participate in the July, 2010 training session in Pune. The comprehensive training session was followed by field exercises in the spring-shed area (aimed at the identification of spring recharge area and planning of recharge measures for different springs on the basis of hydrogeological investigations conducted). Refresher workshops, to revisit the skills and knowledge acquired during intensive training sessions and for the development of future strategies in the treatment of individual springs, have been planned from time to time.

ACWADAM is currently conducting hydrogeological study of 30 springs and 3 hill top lakes in Sikkim under a project funded by GTZ. The implementation of the new study will also be under the *DharaVikas* scheme with the respective partners.

Recharge Measures: Percolation pit

Saving the lakes of Sikkim…

Deutsche GesellschaftfuerTechnischeZusammenarbeit (GTZ) GmBh:

Deutsche GesellschaftfuerTechnischeZusammenarbeit (GTZ) is a federally owned organization working for the German government. They work in the field of sustainable development by providing solutions for political, economic, ecological and social development with core competency in capacity development[13]. ACWADAM undertook a rapid hydrogeological appraisal for facilitatingwork with regard to the Bohal spring system, Himachal Pradesh for GTZ India Himachal Pradesh.

The Bohal spring system forms part of the water supply to Palampur town. Over the last few years the discharge of this spring was diminishing and concerns about its catchment area were expressed. Following the conventional approach to catchment area treatment implies treating a defined area in close vicinity of the spring. This frequently adopted approach is unproductive and has little regard to sub-surface geology. ACWADAM's intervention in the area was to provide inputs on the hydrogeology of the area to develop a hydrogeology based catchment area treatment plan for the Bohal spring system. The main objectives of the programme were to create a hydrogeological map of the spring catchment, characterization of the spring, identification of spring recharge zones and the development of broad plan of actions around the spring including recommendations for protection, augmentation (recharge) and the overall conservation of the spring system.

The outputs of the assignment included - a technical report on the broad water resources behaviour in the study area including a conceptual model of the groundwater systems based on the hydrogeological mapping, a map suggesting the feasible recharge and discharge areas and development of strategy for conservation of the Bohal spring system. Additionally, hydrological regimes bordering the Bohal spring system were studied for a better understanding of their effects on the spring system. This quick hydrogeological appraisal has led to scientific inputs to an institutional water sharing and protection arrangement between the Bohal Panchayat and the Palampur Municipal Council.

13. www.gtz.de

Case Study examples: A Synopsis

Churinda spring, Uttarakhand

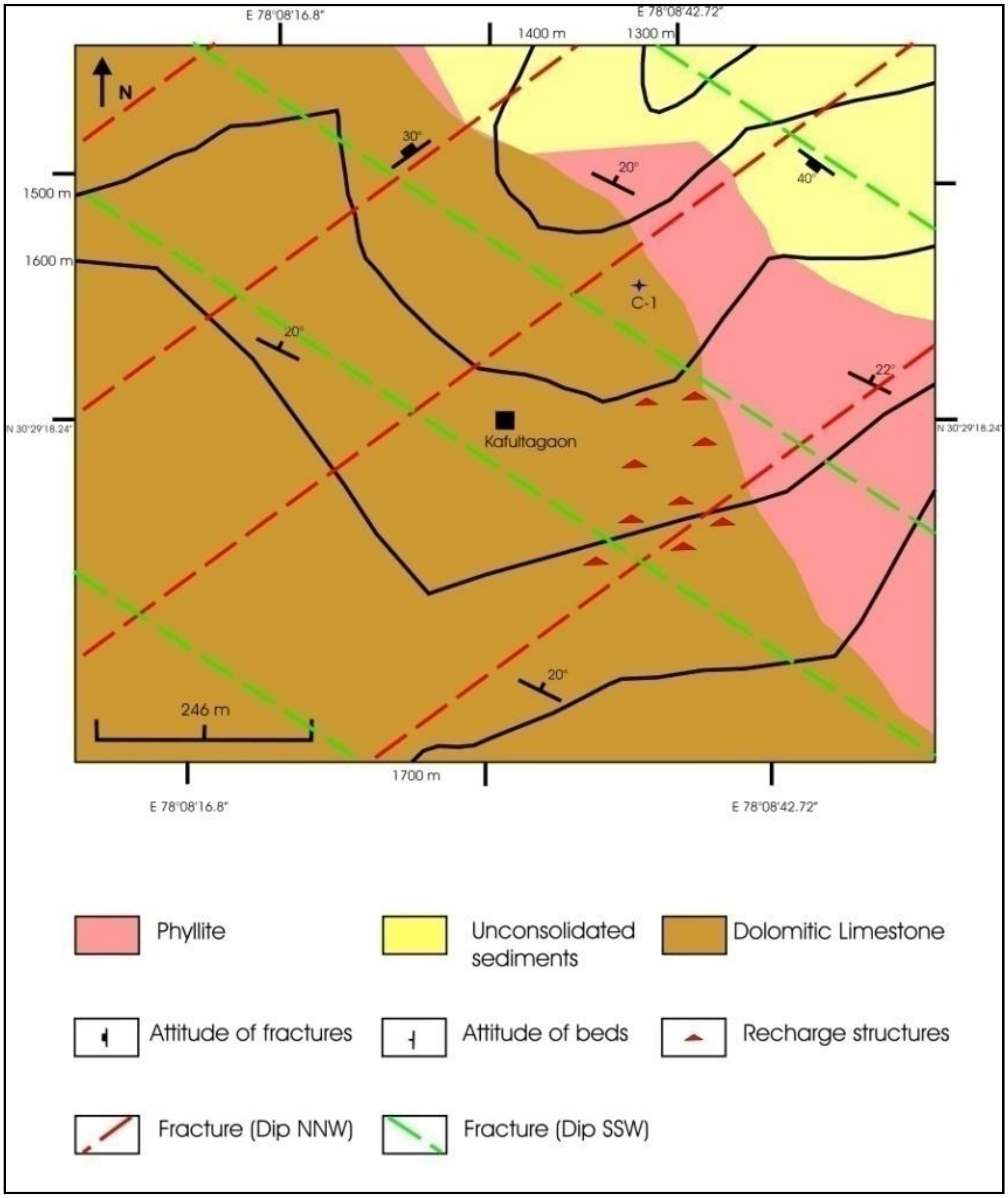
LOCATION

- The Churinda spring (C1) is located near the village of Mathamali (SE of the main Thatyur town).
- The spring is located at N 30° 29' 42.4" E 78° 08'44.9" at an elevation of 1235 m.

GEOLOGICAL SETTING

- The lithology in the area primarily consists of cherty dolomitic limestone and phyllite.
- The limestone and phyllite are overlain by unconsolidated sediments of variable grain size.
- The limestone and phyllite beds dip towards NE by 10º-20º.
- Two prominent sets of fractures are developed in the area –
  - One set of fracture dips NNW by 30º- 40º.
  - The other set of fracture dips SSW by 40º- 48º.
- The spring issues from the limestone bed near the phyllite – limestone contact along the dip slope of the ridge.

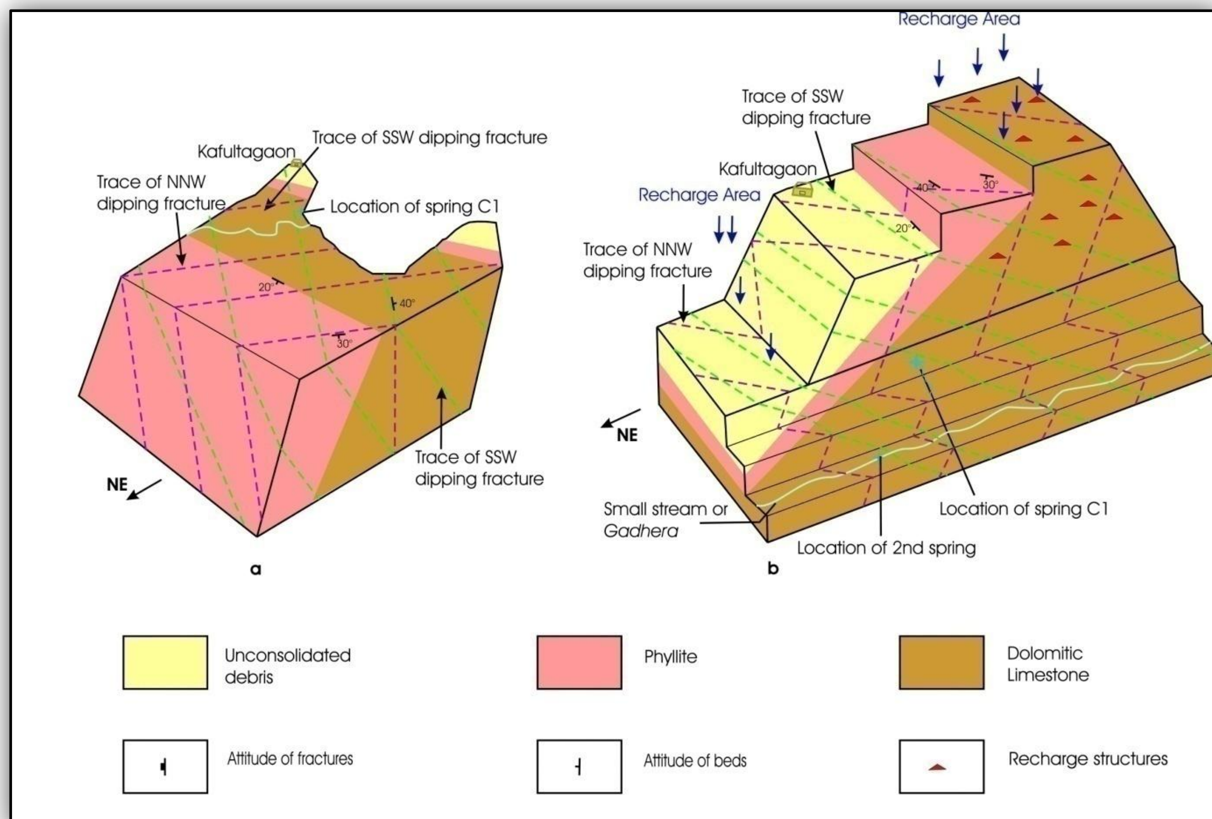
Karstic Limestone



Geological map of Mathamali – Kafultagaon area: Churinda spring (C1).

HYDROGEOLOGY

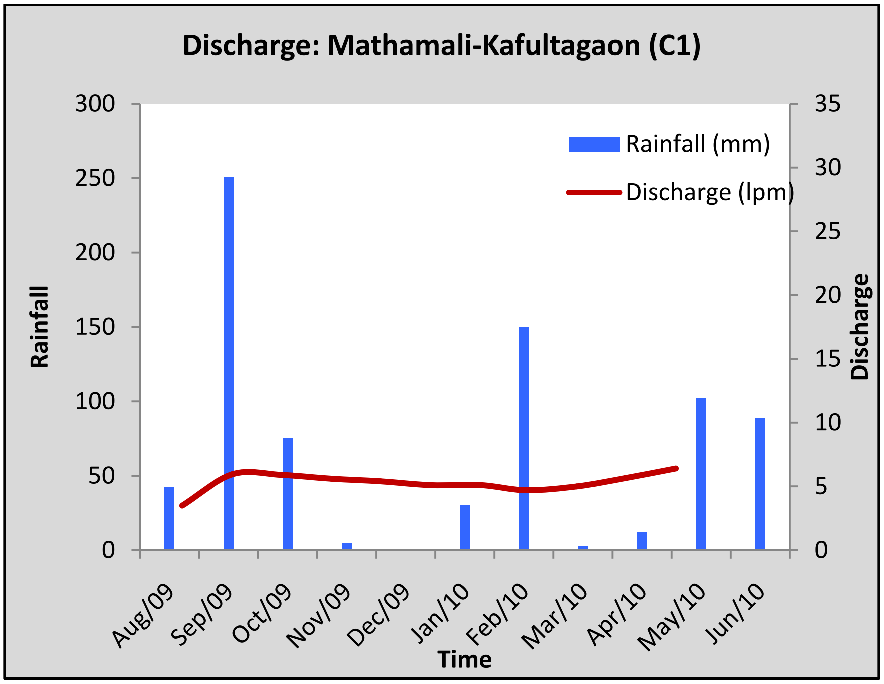
- Primary *porosity* and *permeability* of the limestone is nearly negligible.
- *Secondary porosity* and *permeability* in the limestone is generally developed by fractures, faults and cavities produced by dissolution of rock.
- The NNW dipping fractures in the limestone bed control the recharge to the spring C1.
- Spring C1 can be referred to as a *fracture or tubular spring* issuing through fractures from the limestone bed.
- Recharge area of the catchment is to the south of the spring along the dip slope of the ridge.
- Groundwater movement is from the SW to the NW – controlled by the NNW dipping fracture and the dip of the beds.

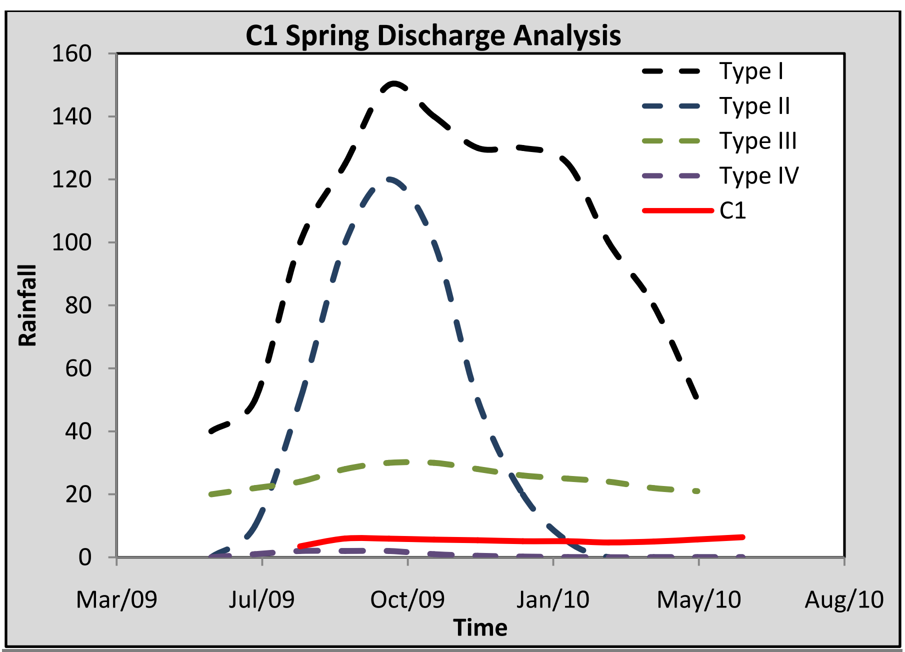


Geological cross-sections / block diagram for Kafultagaon/ Mathamali spring. a) Relationship between the two major set of conjugate fractures. b) Block diagram of the catchment area depicting the relationship of the spring to the dip of the lithological units and the fractures. Location best suited for construction of recharge structures is also depicted.

SPRING DISCHARGE

- The rate of discharge of the spring varies enormously from 3.5 lpm to approximately 6.4 lpm.
- The average discharge (Aug 2009 – June 2010) of the spring is 5.3 lpm.





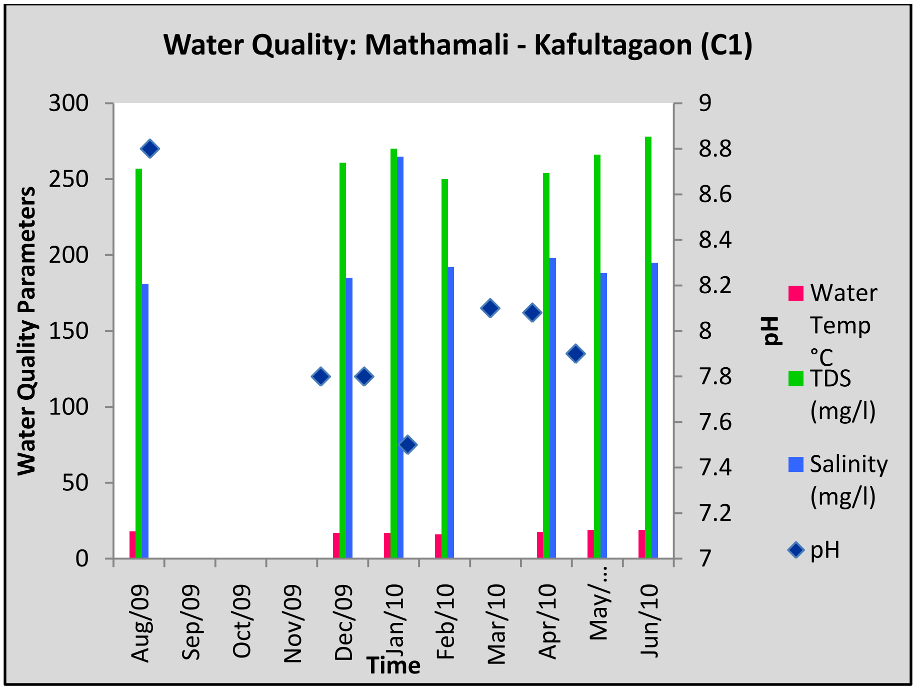
- Change in spring discharge reflects on the hydrogeological parameters of the aquifer viz. Transmissivity and Storativity.
- Based on the pattern of spring discharge one can deduce the nature of the aquifer.
- The spring discharge curves depicted in the figure "***C1Spring Discharge Analysis"*** are model patterns with understood hydrogeological properties.

MODEL	***Aquifer Attributes***	***Transmissivity and Storativity of Aquifer***	***Nature of the Aquifer***	***Classification based on Discharge***
Type I	Large Storage, rapid flow	High T, High S	Unconfined / Confined	High perennial discharge
Type II	Low storage, quick transmission	High T, Low S	Unconfined / Confined	Widely ranging discharge
Type III	Slow flow, moderate to large storage	Low T, High S	Mostly Confined	Sustained perennial discharge
Type IV	Very Limited storage	Low T, Low S	Very local aquifer	Low discharge, highly seasonal

- The discharge pattern of the spring C1 nearly resembles the ***Type III*** in the figure.
- As in the case of J1 the aquifer of spring C1 also has low transmissivity and possibly high storativity.
- The spring C1 yields sustained perennial discharge of low magnitude.
- The field observations are confirmed by the discharge analysis – the aquifer for spring C1 is fractured limestone confined by an overlying phyllite bed.

WATER QUALITY

- As dolomitic limestone is composed of minerals, mainly calcium - magnesium carbonates, readily soluble in water.
- The spring water is expected to have a moderately high TDS content and it is observed that the C1 has a much higher TDS and salinity in comparison to J1 and D1.
- TDS content in the spring water is observed to decline by influx of fresh water during rainfall.



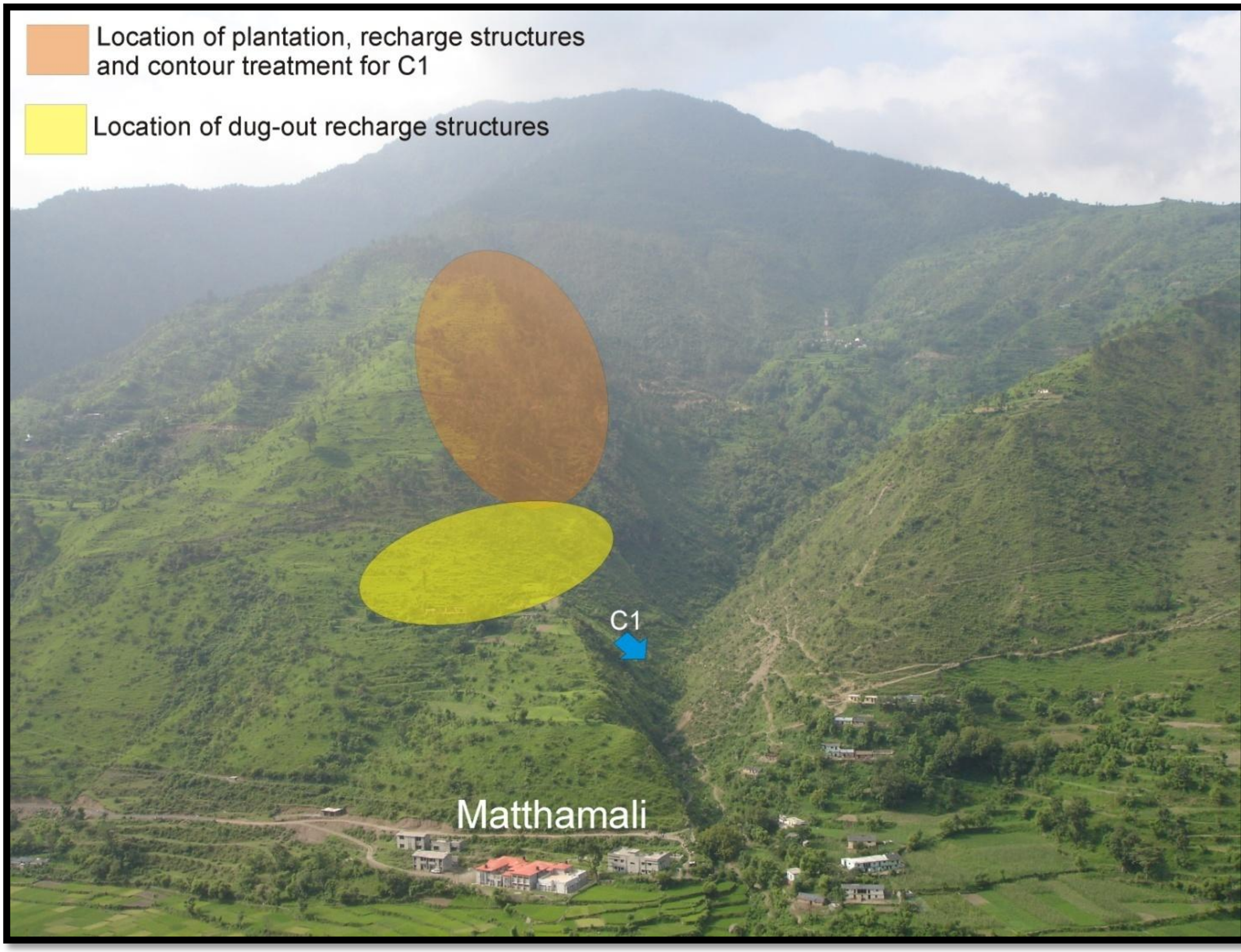
MONITORING THE SPRING

- The spring discharge as well as water quality is monitored regularly by the staff members of GVK.
- Discharge and quality data is collected every month.

RECHARGE MEASURES

- Trenches and infiltration pits - constructed along the *dip slope*.
- Plantation of *Napier* grass, other local grasses and trees to stabilize recharge structures and retain moisture in the soil.
- Construction of check dams along *Gadheras*.
- Recharge measures concentrated on the limestone bed below the contact between limestone and phyllite, as phyllite acts as confining layers.

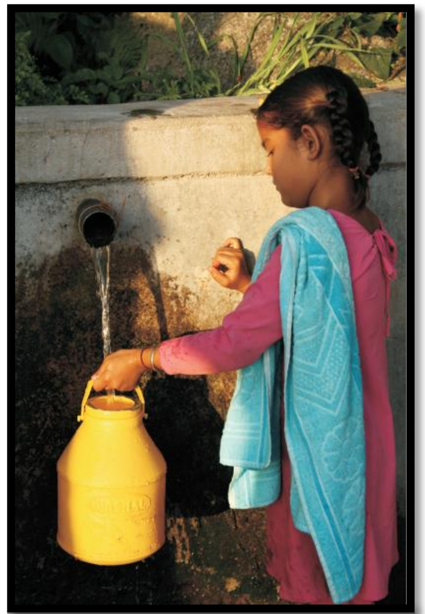
Recharge Structure: Contour Trench with slope adjustment of farm.



Treatment Plan for Mathamali (C1) Spring.

Bohal Spring, Himachal Pradesh

The Bohal spring system forms part of the water supply to Palampur town. However, during the last few years, the discharge of this spring is reported to be dwindling.Any 'treatment' measures planned to revive or rejuvenate the Bohalsprings ought to be based upon an understanding of the hydrogeology of the spring system. The study leading to this report aimed to create such an understanding, as a platform for the planning and execution of catchment area treatment with specific regard to the Bohal spring system. Moreover, the Bohal spring system lies outside the administrative boundaries of Palampurtownship and hence is a classic case of a resource whose boundaries have little overlap with the boundaries of the administrative unit it services.



Low discharge spring in Palampur.

GEOHYDROLOLOGY OF BOHAL SPRING SYSTEM

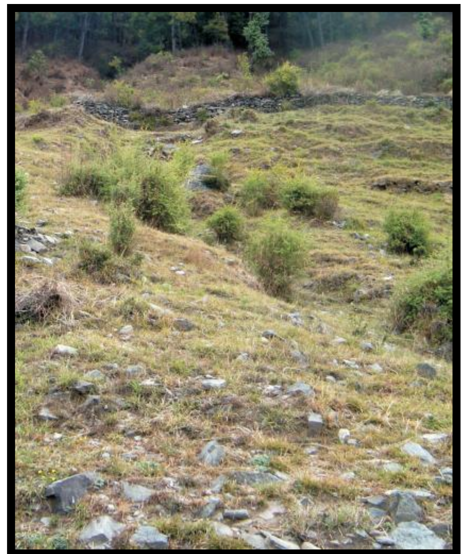
The area around Palampur town is geologically and structurally complex. A variety of folded and fractured rocks can be observed in the area. The town is situated on the eastern bank of Neugalriver. The entire town sits on a ‘terrace’ formed by the fluvio-glacial activity of the Neugal river and the then existing glacier. The terrace is dominantly composed of unconsolidated material, weakly compacted at places. A wide range in size of the material is observed, generally ranging from fine silt tohuge boulders. This terrace is topographically represented by a contiguous flat stretch of an area, with an average elevation of 1280m.

High discharge spring in Palampur.

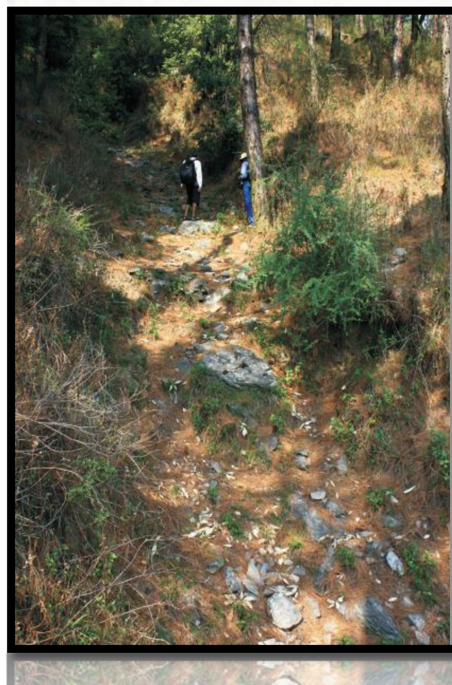
The Bohal spring is located ~5-6 kilometers from Palampur in the NNE direction. The terrain is mountainous, exhibiting different characters in terms of geology, elevation, folding and fracturing.

The dominant rock types in the area include sandstones and shales. An entire sequence of folded sandstones and shales is apparent. The dip of rocks changes from NNE on one flank to SSW on the other flank, indicating an antiform or synform. The amount of dip varies from 35° to 45°.

Three dominant sets of fractures are observed in this folded system. The first set of fractures is along the bedding planes, trending 40°, i.e. to the northeast, and dipping at an amount of 35°. The second set of fractures trend in the opposite direction of the bedding, i.e. towards 220° (towards southwest) with a similar dip amount. The third set of fractures is actually the axial planes or the fold axes of the anticlines and synclines. These are vertical to subvertical in nature and strike in the 110° direction. The anticlinal crests of these ridges have been eroded to form valleys. These ridges reach a maximum elevation of 1550 m. These folded ridges also extend on the western flank of the Neugalriver. Parts of these ridges are overlain by loose, unconsolidated sediments, on the eastern flank of Neugalriver, just south of the Bohal springs.



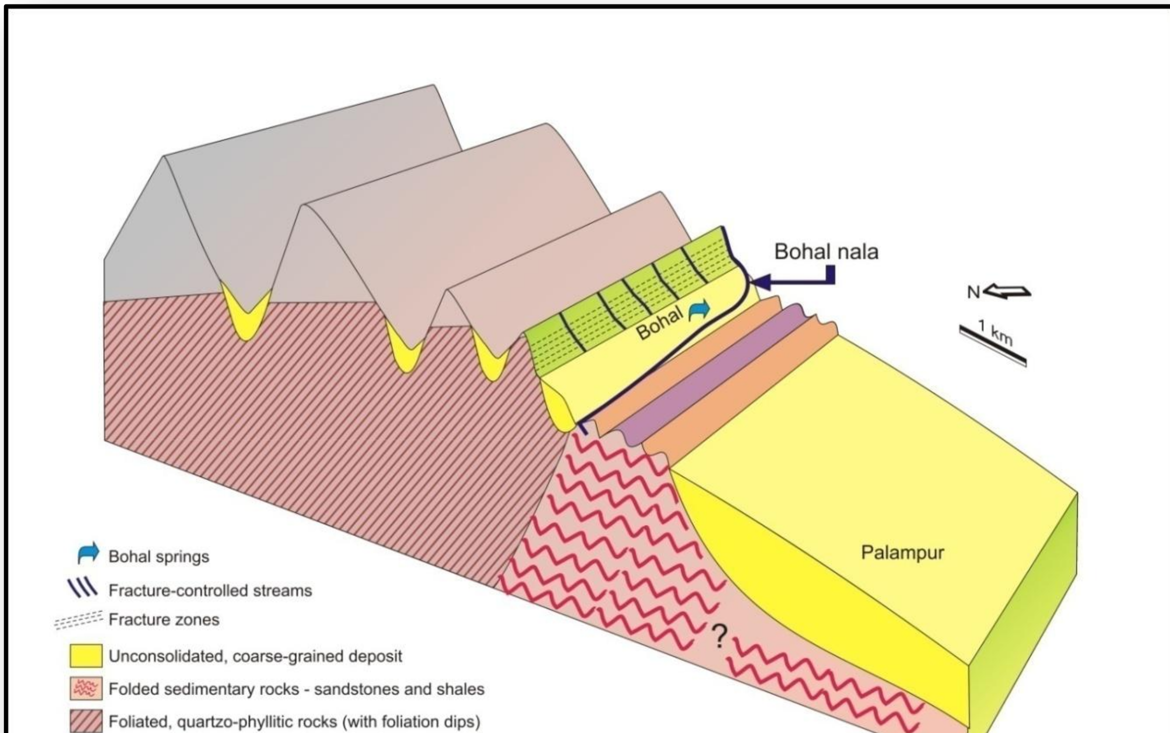
Unconsolidated sediments -'*Debris*' deposited on the Bohal ridge.



Shearing observed along the2nd set of vertical fractures.

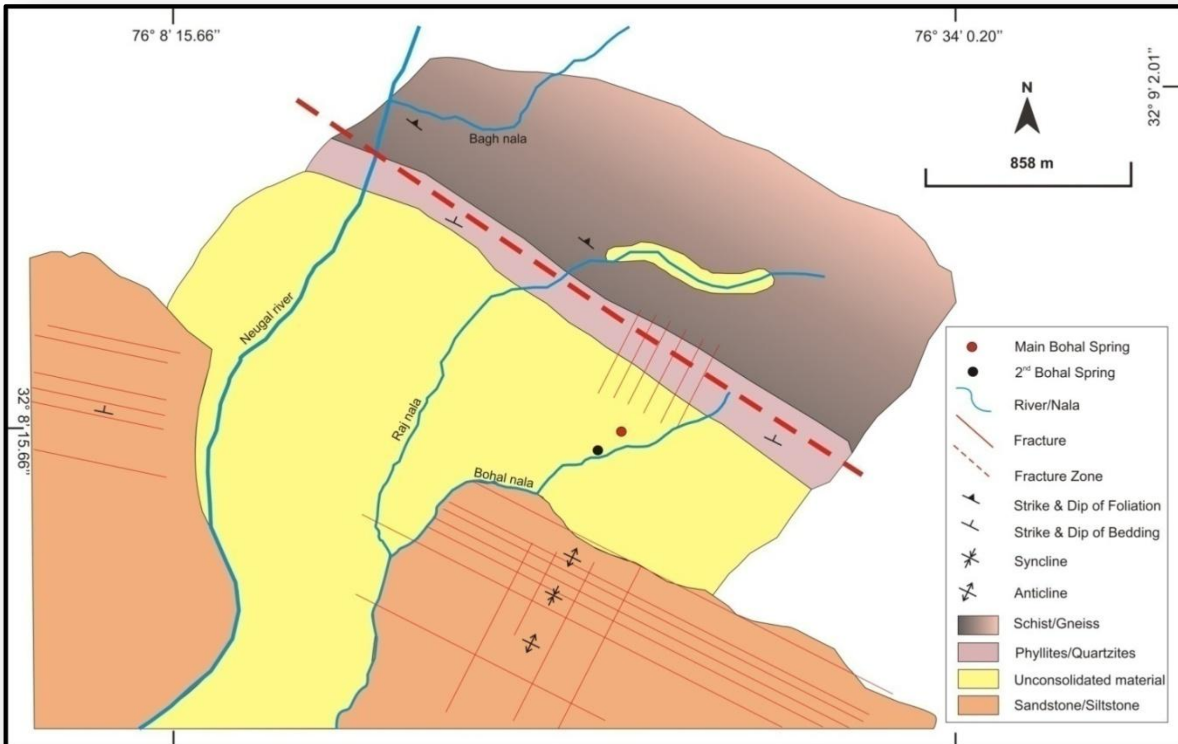
A contact between these sedimentary rocks and the overlying Loose, unconsolidated sediments overlie these sedimentary rocks further northeast of these sandstone-shale ridges. This debris extends uphill to an elevation of ~1890 m representing the southwestern slope of the Bohal ridge. It consists of extremely fine grained material to medium sized rock fragments - *gravel, cobble and some boulders*. A few boulders of granites are apparent from within this sediment. The sediments are dissected by the southwesterly flowing Bohal nala. The Bohal springs emerge from this unconsolidated sediment deposit (also referred to as *debris)*. This sediment is deposited over Quartzites and Phyllites (belonging to the Lesser Himalaya), which continue upwards and are exposed on the upper reaches of the 'Bohal' ridge at an elevation of ~1890 m. This exposure of quartzites andphyllites is a thin band, only a few metres across. These rocks strike along the NW-SE direction and dip with an amount of 50-60° in the northeast direction.

A fracture zone trending 110° (WNW-ESE) is observed cutting through the quartzo-phyllitic rocks. This zone is a set of closely spaced, deeply incised sub-vertical fractures. A second set of widely spaced, deeply incised, linear fractures, trending almost perpendicular to the first set, are observed trending 15-20° (NNW-SSE). These fractures are also vertical and a clear evidence of shearing/fracturing is observed along them. Both these sets are evident in the quartzo-phyllitic rocks and the sandstone-siltstone sequence downslope but show little evidence in the loose unconsolidated sediment exposed between the two, lying concealed in the bedrock underneath.



Block diagram - showing geology along transect from *Bindh nala to Palampur* (section approximately along the Neugal river)

Granites and gneisses overlie the quartzo-phyllitic rocks. These gneisses lie exposed on the ridge top of the Bohal - Raj *nala* divide, at an elevation of 1930 m. All the ridges further northeast are underlain by granites/gneisses. Unconsolidated debris is seen deposited in the valleys of these gneissic ridges, further northeast. The gneisses have undergone various degrees of fracturing. Almost 18-20 different sets of fractures are evident in these gneisses.

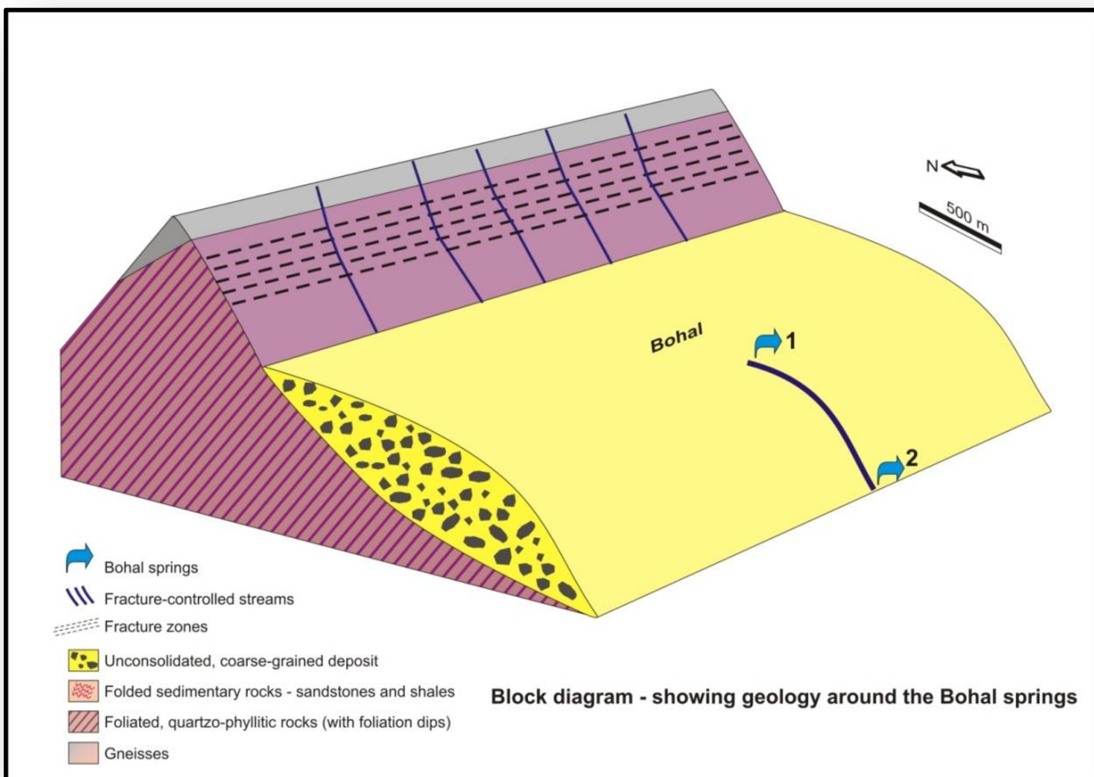


Geological map of the Bohal spring System

Bohal spring system

The Bohal spring system is made up of diverse geology and structure. This diversity finds expression in the topograpphy, the surface water system and the groundwater system. Groundwater systems of a study area can be classified into different classes based on geology, structure, elevation and type of spring/aquifer.

The Bohal*nala*, which originates from the ridge top on the eastern margins of the Bohal ridge, flows down in the SW direction. It flows over the Quartzite-Phyllite rocks in the upstream portion. Further down, it cuts through the unconsolidated sediment and then encounters the sandstone-shale ridges, where it flows along the strike of the sedimentary rocks, before entering the Palampur*fan* of sediments. Many first order streams are formed along the 2nd set of vertical fractures trending NNE-SSWin the upper parts of the ridge, where quartzites and phyllites are exposed.. All these streams are part of the Bohal*nala* system, although they tend to disappear (as subsurface flow) in the unconsolidated sediments between the Bohal ridge (quartzites and phyllites) and the Bohal*nala* channel. The Bohal springs are located in this central portion underlain by the unconsolidated sediments.



Block diagram - showing geology around the Bohal springs

The main Bohal spring emerges from the unconsolidated sediments at an elevation of 1650 m. This sediment deposited over the quartzites and phyllites acts as the *'aquifer'* for the main Bohal spring. The water flowing through the first order, fracture-controlled (*nalas*) streams emerging from the Bohal ridge area, as well as the precipitation directly on the sediment, infiltrates and gets stored in the*unconfined aquifer (unconsolidated sediment)*. As groundwater fills up in the aquifer, the water level rises and eventually cuts the ground surface to emerge as a spring. Asimilar situation is observed further down southwest of the main Bohal spring in the same aquifer. Due to a sudden change in slope, the water table of the aquifer intersects the ground surface, giving rise to the second Bohal spring. This spring emerges and flows into one of the fracture-controlled streams that join the main Bohal*nala* further downstream.

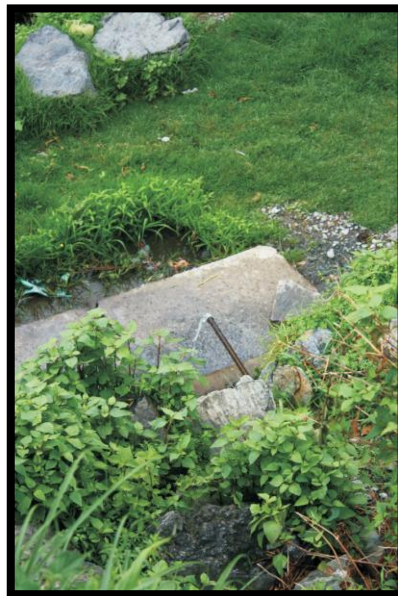
The main Bohal spring and the second Bohal spring, which emerge from the same aquifer (unconsolidated sediment) are thus classified as *depression springs,* although the system also includes fractures (two major sets control the recharge upstream) and a contact (between the quartzo-phyllitic rocks and the unconsolidated sediments).

The western boundary of the Bohalspring *recharge zone* marked by deeplyincised fractures in the forested area.

STRATEGY FOR BOHAL SPRING MANAGEMENT

Summary of findings

- The Bohal spring system is a resultant discharge point for an aquifer system constituted by coarse, loose, unconsolidated sediment resting on top of metasedimentary rocks – mainly phyllites and quartzites. It lies within the boundaries of the Raj *nala* to the north and west and the Bohal*nala* to the east and south.
- The aquifer feeding the Bohal springs is an unconfined aquifer, the base of which lies in the metasediments. It is difficult to predict the thickness of the aquifer through this rapid appraisal, but it is likely to be of the order of 20 to 50 m, even thicker at places.
- The loose, unconsolidated material also forms a thick, extensive aquifer system (a shallow aquifer underlain by a deeper, confined aquifer) underneath Palampur Township.
- The spring system in Bohal is somewhat complex as it is a result of a combination of two geological formations (sediment plus underlying metasedimentary rocks).



One of the discharge points of the Bohalspring system - *for local use*.

- The main recharge area for the Bohal springs lies within a zone characterised by two intersecting fracture zones, exposed on the south facing slopes of the Bohal catchment (north of the Bohal springs). One of these fracture zones trends along the WNW-ESE direction (trend in the range of 120° to 130°) and lies largely covered underneath thick vegetative and soil cover. These fractures are quite deep-seated and are traversed by another set of parallel fractures trending NE-SW (about 35°). This second set of fractures is coherent with a set of parallel streams originating at the Bohal ridge line. The length of the recharge zone is about 850 m, with an average width of about 200 m.
- The discharge of the Bohal springs is derived from an aquifer having high storativity and moderate transmissivity, formed in the loose, unconsolidated sediment. Hence, there are multiple points of discharge from this system; Bohal springs 1 and 2 being two of such points.

Recommendations

Protection-related

1. The recharge zone (as indicated in the map and cross-sectional block diagram) must be protected to retain the vegetative cover and conserve soil.

Protecting the recharge zone (above)and the channel between the twosprings in Bohal (below) is veryimportant.

2. A social regulation protecting the area from deforestation is necessary to protect the spring system. Whetherthis can be achieved through pure social regulation or through a formal system of legislation or even a combination of both, ought to be discussed.

The gently sloping portion of Bohal, justdownslope of the forested rechargezone, where recharge measures(recharge pits) can be

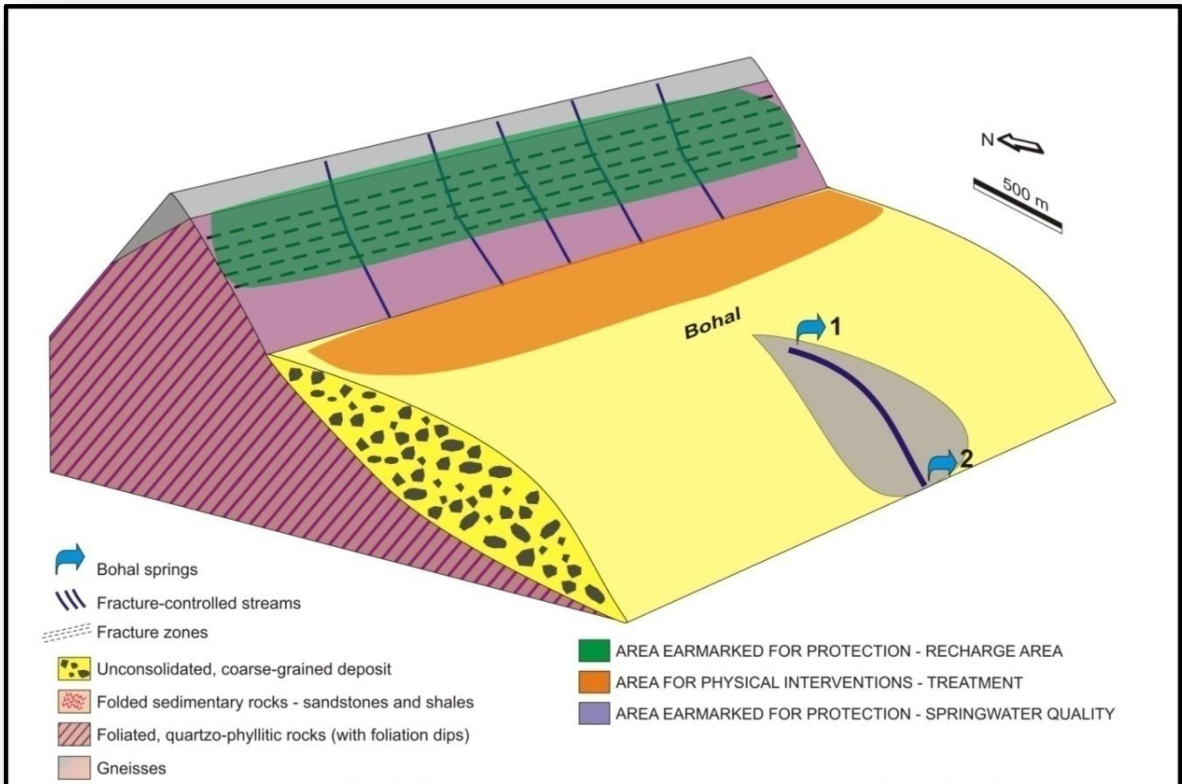
3. Clearly, the issue of protecting Bohal springs involves multiple stakeholders – community, forest department, Palampur Municipal Council including the Water Supply and Public Health Engineering Departments, Irrigation Department and so on.

4. Regulating a zone of at least 300 m, as a radial zone of protection around the two Bohal springs must be ensured too. Currently, this location is used as a local land-fill site, including for the dumping of biomedical waste.

Treatment related

1. The best zone for conducting 'physical' measures of catchment treatment, mainly to augment / maintain spring discharges for the Bohal spring lies at the junction of the steeply sloping forest lands (coherent to the main recharge zone for the Bohal spring) and the gentler private lands in Bohal (upstream and upslope to where the springs are located).

2. The physical measures can include appropriate water harvesting structures (for infiltration) such as recharge pits.



Block diagram - showing management strategy for Bohal springs

The overall strategy for managing Bohal spring system

The Bohal Spring system, near Palampur, is a combination of two springs that supply drinking water to Palampur town since the year 1952. This is the oldest system of water supply for Palampur town, managed by Palampur Municipal Council. The spring has an interesting history. In the 1950s and '60s, this system (reliant on the Bohal spring) was just about sufficient to meet the water demand of Palampur town; however, the population of Palampur grew, the gap between demand and availability (from the spring) widened and theMunicipal Council had to look for other sources of water. Moreover, local residents report that the discharge of the Bohal spring decreased in last 10-15 years, also implying that the gap further widened, as availability decreased. The absence of reliable data regarding spring discharge only makes all these deductions conjectural.

The widening gap between availability and demand prompted the Municipal Council of Palampur to source additional water supplies from the Neugal River through an additional pipe line laid down by the Irrigation and Public Health (IPH) Department. This has closed the gap between demand and availability from the Bohal springs, but at the cost of water quality. Demand – Supply figure for the Bohal Spring (below) attempts to capture, in a timeline, the relationship between availabilityfrom the Bohal springs against the backdrop of demand – separated into a 'total demand' and 'drinking water demand'. The data for this graph was generalized to some degree, but is based on secondary data supplied by GTZ from Palampur.

Palampur Municipal Council is reported to have entered into a formal agreement with the local community in Bohal village and involve them in the protection of recharge areas, augmentation measures (recharge) and an overall protection and conservation strategy around the Bohal springs. Such an agreement, with appropriate protocols, will not only ensure sustainability of supply from the Bohal spring system, but would probably be a first of its kind in terms of multistakeholder, participatory, community managed systems of groundwater protection in India.

Research Prospect and Potential

Our current action research initiatives are opening avenues to a fresh articulation about groundwater resources in the Himalaya mountain range. Community centred action research interventions are not only essential but indispensable for resource conservation in eco-fragile systems like the Himalaya. Conventional approaches involving structured, time-consuming research, although necessary,are unable to contribute significantly to effective policy discourses. For research to transform into a crisis-resolving intervention, community participation is crucial. Capacity building of implementing agencies and other stakeholders is imperative and of great consequence; it must be based on robust knowledge systems, nevertheless.

In mountainous regions community mobilization around water can be challenging, energy intensive and an exhaustive task because of complex hydrology and hydrogeology and due to the scattered nature of habitations. Protection and conservation of springs in the Himalaya through watershed programmes must include due consideration to underlying geology and understanding of the basic hydrogeology in order to impact spring discharge and quality. ACWADAM through the knowledge and skills accrued by working in the field of groundwater for over a decade has contributed to introducing hydrogeologyto such programmes in the Himalayan region. ACWADAM has collaborated with key partner organisations to provide hydrogeological inputs to programmes on conservation and recharge of springs. Alongwith capacity building of partner organizations, ACWADAM has undertaken comprehensive action research for both facilitation of the ongoing projects and the development of a knowledge base that could facilitate and encourage workers in the region to partake groundwater resource augmentation and protection ventures. ACWADAM's interventions and experiments have yielded satisfactory results in the spring-shed or spring development programmes. However, there is a pressing need to expand the scope of research in the Himalaya for upgrading the understanding of groundwater science considering a complex scenario of changing socio-economic conditions under a strong climate change footprint. Comprehensive research activities such as isotope -tracer studiesare needed to compliment ACWADAM's basic hydrogeology input. Due to the difficulty imposed by terrain, borehole data is non-existent. The understanding of confined aquifer systems and related groundwater complexities is only marginal, despite ACWADAM's action research work. Future research initiatives need to target these issues and effectively address the community levelissues that impede the implementation of groundwater development programmes in the Himalaya. Such research initiatives need monetary investments that only large organizations and federal agencies are capable of. The links to advocacy efforts to influence policy will develop only on the back of strong action research programmes that are inclusive of the aforementioned factors.

ACWADAM is committed to improve its research capabilities and simultaneously evolve community based mechanisms for spring management. By doing so, it would strive to get a practical groundwater management agenda with implications for policy development for the Himalayan region. The build up of capital for investment in such research has always been challenging and most funding agencies in the country have been reticent in this regard. However, ACWADAM carries with itself the momentum of action-oriented research and the experience of working in diverse groundwater environments across the country. ACWADAM's work in the Himalaya is pioneering of sorts, in that there is demystification of the science of hydrogeology and groundwater research. With ACWADAM's growing experience and acquisition of more effective capacity for improving spring recharge, conservation of hill top lakes and the management of mountain aquifers, ACWADAM is confident of developing a typology of groundwater resources for these mountain systems.

ACWADAM's endeavours are envisioned to bring about the necessary change in the existing policies related to groundwater management and spring development programmes in the Himalaya. Ultimately, ACWADAM believes that research that does not catalyse improved action is unlikely to result in robust policy formulation. Mitigating potential impacts of social, economic and environmental changes on water resources involves bridging the gap between prevalent customs and ideal practices through education and training of all stakeholders. The winds of change are soaring through the mountains and we intend to drive them in the direction of sustainable development, using the small beginning we have made...

Selected Bibliography

Auden, J. B. (1934) The Geology of Krol belt. Rec. Geol. Surv. India, v 67 (4), pp. 375-454.

Brune, G. 1975. Major and Historical Springs of Texas. Report 189, Texas Water Development Board, Austin.

Bryan , K (1919) classification of springs. Jour. Geo. v. 27, pp. 522-561.

Freeze, R.A. and Cherry, J.A. (1979) Groundwater. Prentice Hall Inc., Engelwood Cliffs, New Jersy, 604 p.

Kresic, N and Bonacci, O. 2010.Groundwater Hydrology of Springs, Chp.4; p129-162.

Kresic, N. 2010. Groundwater Hydrology of Springs, Chp.2; p31-83.

Kresic, N. 2010.Groundwater Hydrology of Springs, Chp.5; p165-226.

Kumar, B., Piped dreams (Almora sees springs vanish, rivers die). *Down to Earth*, June 2006, pp. 36–38.

Kumar, C.P. (Year unknown) Development in ground water hydrology: An overview

Kumar, G. (2005) Geology of Uttar Pradesh and Uttaranchal. Geological Society of India, 384 p.

Negi, G. C. S and Joshi, v. (2002) Drinking Water Issues and Development of Spring Sanctuaries in a Mountain Watershed in the Indian Himalaya. Moun. Res. Dev. v. 22, no. 1, pp. 29-31.

Rana, S. and Gupta, V. 2009.*ASCE Pub*. Watershed Management in the Indian Himalayan Region: Issues and Challenges.

Rawat, J.S. and Rawat, M.S. (1994) Accelerated Erosion and denudation in the Nana Koshi watershed, central Himalaya, India, Part I: Sediment load. *Mountain Research and Development*, 14(1): 25-38.

Singh, J.S. 2006. Sustainable development of the Indian Himalayan Region: Linking ecological and economic concerns. Current Science. Vol. 90, no. 6: 784-788.

Stevanovic, Z. 2010. Groundwater Hydrology of Springs, Chp.9; p339-387.

Tripathi, M. Water Resources, Present Scarcity and Future Prospects: Challenges in Terms of Nothing Rest for Management Micro watershed approach of a Kumaon Lesser Himalayan catchment of Western Ramganga River (Almora) Uttarakhand, India. Water and Geoscience (WSEAS Press).2010.

Valdiya, K.S. &Bartarya, S.K. 1989. Diminishing discharges of Mountain streams in a part of the Kumaon Himalaya. Current Science. 58: 417-426.

Valdiya, K.S. &Bartarya, S.K. 1991. Hydrogeological studies of springs in the catchment of the Gaula River, Kumaon Lesser Himalaya, India. Mountain Research and Development. 11: 239-258.

Valdiya, K.S. (1980) Geology of Kumaon Lesser Himalaya. Himanachal Times Press, Dehra Doon, 292 p.

Vashisht, A.K. and Sharma, H. C. (2007) Study on hydrological behaviour of a natural spring. Curr. Sci. v. 93, no. 6, pp. 837-840.

White, W.B. 2010. Groundwater Hydrology of Springs, Chp.6; p231-266.

List of Papers and Reports from ACWADAM's publication

ACWADAM, 2009. A study of the significant geohydrological factors controlling water resources in Ramgarh Block, Nainital District. Uttarakhand.

ACWADAM, 2009.Understanding the water resources in Naukuchiatal area of Nainital District, Uttarakhand.With special reference to hydrogeological characters.

ACWADAM, 2010. Geohydrology in Spring water management: Case studies from Garhwal Himalaya, Uttarakhand.

ACWADAM, 2010.Hydrogeological factors pertaining to mountain springs of Thatyur, Jaunpur Block, Uttarakhand.

ACWADAM, 2010.Managing the Bohal Spring System: A strategy based on Geohydrological mapping.

Useful Websites

www.chirag.org

www.srtt.org

www.ledeg.org

www.sikkimsprings.org

www.gtz.de

Glossary

Anticlines	A geological term used for a fold in rocks, which is convex upwards or sloping downwards from a common crest.
Aquifer	A saturated geological formation, which will yield sufficient quantity of water to wells and springs.
Calc-silicate rocks	Rocks composed of chemically precipitated carbonate minerals along with silicate minerals.
Carbonate rocks	Rocks dominantly composed of chemically precipitated carbonate minerals, such as limestone and dolomite.
Chert	A very fine grained (microcrystalline) variety of silicacomposition.
Confined aquifer	An aquifer where water is stored under some pressure due to an overlying impermeable layer.
Conglomerate	Large pebbles cemented in finer grained matrix.
Depression springs	Springs formed when the groundwater table intersects the ground surface.
Diorite	Grey to dark grey igneous rock composed of Iron-Magnesium minerals with minor amount of silicate minerals.
Dip of rock	Refers to the inclination of the rock beds with respect to a horizontal surface.
Dip slope	Refers to that component of the topographic or ground slope, which is along the dip of the underlying geological formations.
Dolomite	Mineral or rock composed of Magnesium-rich carbonate mineral.
Fan	Fan-shaped sedimentary deposits formed by rivers while emerging from mountains and canyons into plains.
Faulting	Refers to discontinuity and displacement in rock bodies along a planar fracture.
Fluvio-glacial	Term used to denote combined effects of rivers and glaciers.

Fold	The curving or bending of rock layers due to plastic deformation.
Fold axis	The central axis along which folding has occurred, synonymous with crest line and trough line.
Fold mountains	Mountains formed by compression and folding of rock strata during continental collisions.
Gabbro	Coarse grained dark grey rock composed of Ferrous-Magnesium minerals.
Gadhera	Local term for a valley carrying a small stream.
Gneiss	A metamorphic rock generally made up of bands that differ in color and composition.
Granite	An igneous rock, usually of medium to coarse grained in texture.
Granitoids	Variety of rocks similar in composition to granite.
Himalayan frontal thrust (HFT)	A *thrust plane* separating the Indo-Gangetic plains from the Siwaliks.
Hydraulic conductivity	It is the measure of the rate at which water moves through an aquifer. It is the ease with which water moves through a porous medium such as soil or an aquifer. It is measured in m/day.
Indus-Tsangpo Suture	It is interpreted as the boundary and the zone of collision between the Indian plate and the Eurasian plate.
Isotope	Atoms of same elements with same atomic number but different mass number.
Limestone	Rock dominantly composed of chemically precipitated mineral Calcite (Calcium Carbonate).
Lithologic Contact	Contact between two different rock types.
Mafic	An adjective used to describe rock or mineral rich in iron and magnesium.
Main Boundary Thrust	A *thrust plane* separating the Siwaliks from the Lesser Himalaya.
Main Central Thrust	A *thrust plane* separating the Lesser Himalaya from the Greater

	Himalaya.
Metavolcanics	Refers to metamorphosed volcanic igneous rocks.
Orogeny	Mountain building event following continental collisions.
Permeability	Generally used to refer to the ease with which groundwater moves through a porous medium such as soil or an aquifer.
Phyllite	A foliated metamorphic rock.
Primary porosity	Porosity developed in the rock at the time of its formation.
Quartzite	A hard metamorphic rock formed from sandstone.
Recharge area	Addition of infiltrated water to an aquifer.
Sandstone	A sedimentary rock composed of sand sized mineral grains.
Scarp slope	Refers to that component of the topographic or ground slope which is opposite to the dip of the underlying geological formations.
Schist	A recrystallized and foliated metamorphic rock rich in platy minerals such as Mica and Chlorite.
Secondary porosity	Porosity developed in a rock after its formation due to fracturing and weathering.
Shale	Very fine grained sedimentary rock composed dominantly of clay minerals. Shale exhibits thin laminae or bedding.
Siltstone	A sedimentary rock with grain size smaller than sand but greater than clay.
Slate	Metamorphic rock characterised by the development of parting surfaces and formed from mudstone.
Storativity	Measure of the amount of usable groundwater stored in the aquifer. It is defined as amount of groundwater released from the one square metre of the aquifer for drop in groundwater level by one metre.
Syncline	A downward-curving fold, with layers that slope toward the center of the fold. In other words, the fold is convex downwards.

TDS	Total Dissolved Solids.
Tectonic contact	Contact of two different rock formations along a fault or any other deformational surface.
Terrace	Step like structural features bordering rivers.
Thrust	A thrust is a fault along which there has been dislocation of rock formations.
Transmissivity	It is the ability of an aquifer to transmit groundwater through its entire thickness. It is measured in m^2/day.
Unconfined aquifer	Partially saturated aquifer not confined by an impermeable bed on the top whose water table is free to fluctuate under atmospheric pressure.