INITIATIVES FOR AUGMENTING GROUNDWATER RESOURCES BY ARTIFICIAL RECHARGE (AGRAR)

Augmenting Groundwater in Kathmandu Valley: Challenges and possibilities

Ajaya Dixit and Madhukar Upadhya

With support from Suresh Marahatta, Binod Pokharel, Kanchan Mani Dixit and Nirman Shrestha

Nepal Water Conservation Foundation

Kathmandu, Nepal

January 2005

Contents

Goals & Objectives

The goal of this paper is to summarize existing knowledge on groundwater conditions in the Kathmandu Valley with the objective of identifying potential avenues for enhancing groundwater availability to meet municipal water supply needs. The paper is based on an extensive survey of previous published and unpublished reports and accessible data combined with field visits and limited interpretive analysis. Despite extensive efforts, it proved impossible to obtain access to a few key reports. As a result, their findings could not be incorporated into the analysis presented below.

Our analysis of existing information suggests that substantial opportunity may exist for increasing municipal water supplies in the Kathmandu Valley by conjunctive management of surface and groundwater sources including direct and indirect recharge and rainwater harvesting. Particular opportunities for this may exist along the northern portion of the valley in the Gokarna and Manohara areas. Confirming the ability to substantially increase available supplies from in-valley sources would require a systematic technical evaluation of aquifer characteristics in these areas. It would also require effective control over urban development in key recharge areas. While development has yet to occur, the Kathmandu Urban Area is expanding rapidly and active protection is likely to be required for this option to remain valid.

Acknowledgements

This report has been prepared as a contribution to a project entitled 'Augmenting Groundwater Resources through Artificial Recharge' (AGRAR). The British Department for International Development (DFID) commissioned the British Geological Survey (BGS) to undertake this project, which runs from July 2002 to July 2005, through a program of collaborative studies with the Institute for Social and Environmental Transition-Nepal (ISET-Nepal) and other NGOs and universities in India. The aim of the project is to assess the effectiveness of managed aquifer recharge in a variety of environments, both physical as well as socio-economic, and to produce guidelines for effective implementation. Thanks are due to Marcus Moench of ISET and Ian Gale of the BGS for comments on the document. Sonam Bennett-Vasseux of ISET provided extensive editorial support.

Maps 2 – 6 in this paper have all been reproduced from current engineering and environmental maps of the Kathmandu Valley of the Department of Mines and Geology, His Majesty's Government of Nepal.

Acronyms

AGRAR	Augmenting Groundwater Resources through Artificial Recharge
ARPP	Artificial Recharge Pilot Project
BGS	British Geological Survey
CGD	Central Groundwater District
DFID	Department for International Development (UK)
DHM	Department of Hydrology and Meteorology (HMGN)
DMG	Department of Mines & Geology (HMGN)
DWSS	Department of Water Supply and Sewage (HMGN)
GDB	Groundwater Development Board (HMGN)
HMGN	His Majesty's Government of Nepal
ISET	Institute for Social and Environmental Transition
JICA	Japan International Cooperation Agency
JTU	Jackson Turbidity Unit
KVTDP	Kathmandu Valley Town Development Project
LRMP	Land Resource Mapping Project
MLD	Million Liters per Day
NGD	Northern Groundwater District
NEWAH	Nepal Water for Health
NWCF	Nepal Water Conservation Foundation
NWSC	Nepal Water Supply Corporation
RSDC	Rural Self Reliance Development Centre
SGD	Southern Groundwater District
SMEC	Snowy Mountains Engineering Corporation
WSSC	Water Supply and Sewerage Corporation
WECS	Water and Energy Commission Secretariat (HMGN)

Introduction

Kathmandu, Nepal's capital city, sits in a circular valley. Within the valley, municipal and other water supplies depend on monsoon rains and the stream and groundwater systems fed by this precipitation. Following the democratic revolution of 1951, opening of the country and political changes have spurred development in Kathmandu and stimulated population growth. In recent years, migration from rural to urban areas has significantly increased due to economic opportunities in the city and to the deteriorating political conditions and ongoing violence in rural areas. The capital's population, currently estimated at over one million, will undoubtedly increase rapidly in the coming years**.** The expected growth rate of urban population is about five percent (Table 1). In the face of rapid growth, it has become increasingly difficult to meet the water needs of the population.

Table 1: Population growth of Kathmandu Valley

Area	1991	% Growth Rate	2001
Kathmandu, Lalitpur & Bhaktapur Municipalities	598,528	5.16	907,380
Rural areas	466,371	4.9	694,885
Total Kathmandu Valley	1,064,899	5.0	1,602,265

Source: Central Bureau of Statistics, 2001

NB: The two new municipalities of Kirtipur and Madhyapur were Village Development Committees in the 1991 census. Therefore, only census figures for 1991 and 2001 for Kathmandu, Lalitpur and Bhaktapur have been taken to calculate the growth rate of the urban population in the Kathmandu Valley.

Until 1891, the water supply needs of the city's residents were met using springs, rivers and shallow dug wells. In addition, the city and its surrounding areas were served by a network of stone waterspouts called *dhunge dhara* in Nepali (*hiti* in Newari) built around the middle of the sixth century. Located in rectilinear pits, these stone waterspouts were, and in many cases still are, part of a supply system. One such *dhunge dhara* still supplying water is in Handigaun, built in 564 AD. *Rajkulos*, or irrigation channels, through which recharge is incidental, either fed the *dhunge dhara* directly or contributed to high groundwater levels in locations they could access. These *Rajkulos* originally formed a network of channels across at least part of the Kathmandu valley floor. Many are similar to traditional rural irrigation systems – that is, they involve small diversions along existing streams that feed shallow canals running roughly parallel to the stream and feeding adjacent areas. This is, for example, the case of the *Rajkulo* between Bagesvari and Bhaktapur (Becker-Ritterspach 1994 p.26, figure 25). Other *Rajkulos* derive much of their supply by tapping into springs and groundwater sources or, in the case of buried channels, through surface runoff that is channelled into revision holes equipped with gravel filters. They are generally not lined or roughly lined with terracotta pipes, bricks and rough-cut stones. Particularly in urban areas, they have often been capped with flagstones and buried. The description by Becker-Ritterspach of a '*Rajkulo*' in Patan (officially called Lalitpur) is probably illustrative of many in urban areas. According to the author:

> "In Patan a subterranean canal leads from Marccha to Tangal hiti which is interrupted at intervals by revision holes. The distance between the holes – probably containing filters – reaches about 100 m. The depth is surprisingly great: up to about 5 m. The canal is constructed from prefabricated gutter sections made of burnt clay, called *hitidu* by the Newars. The canal sections are covered by ordinary bricks. Finally, the water arrives in the inner entrance of the spout stone (*hitimanga).* (Becker-Ritterspach 1994 p.25)

Whether fed from groundwater or directly from a *Rajkulo*, in many cases the specific source of water for individual *dhunge dhara* is no longer known. The *Rajkulos* feeding them may still exist but their course is now unknown. Regardless of the specific source, the increasing pace of change in Kathmandu has led to the failure of many *dhunge dhara*. In many places, construction of buildings, roads and other structures has cut off water supplies. Furthermore, with urban and industrial growth and inadequate attention to sewerage and drainage systems, both the ground and surface water sources supplying *dhunge dhara* have become increasingly polluted. Although increasingly overwhelmed and polluted, this traditional system still meets a significant portion of the domestic water needs of Kathmandu's population. Since people regard most *dhunge dhara* water as religiously pure, some people also consider it clean enough to drink straight from the stone. Some boil or filter it before drinking it if they have the capacity. Many users also rely on local wells that are dug or drilled into the upper aquifer that underlies the city. In addition, numerous electricity and diesel-operated tubewells along with hand operated rower pumps have been installed in recent years.

Kathmandu Valley is located on the sediments of a lake that once filled the valley. These sediments serve as relatively productive aquifers. The upper, unconfined section of the aquifer, although it has become increasingly polluted in some locations, serves as a primary source of water for many local shallow wells. This water is used mostly for non-consumptive uses such as bathing, washing and gardening. The water in nearly all wells shows high counts of faecal coliform bacteria, especially during the monsoon season. The city's leaky sewer system combined with the presence of numerous areas that are not served by any sewer system and the absence of effective treatment plants contributes to the pollution.

Because of the rise in population, increased economic activity and more modern lifestyle in Kathmandu, the pressure on surface water has increased significantly. The municipal water supply infrastructure systems that use stream flows as their primary source are, however, very poorly managed and the level of service provided inadequate. As a result, large quantities of groundwater are pumped by both municipal authorities and private individuals to meet domestic and other water needs.

The use of pumps to tap shallow groundwater began as early as 1940, when one of the authors remembers a tubewell in his childhood home. The government installed deep tubewells in the mid 1960s, but widespread use of pumped groundwater only began in the 1970s with a World Bank-funded water supply improvement project. At present, shallow groundwater meets the bulk of the domestic water needs of Kathmandu city in both old and new settlement areas where municipal systems cannot supply water. In addition, most industries, hotels and corporate houses pump water from deeper aquifers. Since the rate of pumping from these deeper aquifers is higher than the rate of natural replenishment, groundwater levels in these aquifers are reported to be dropping rapidly.

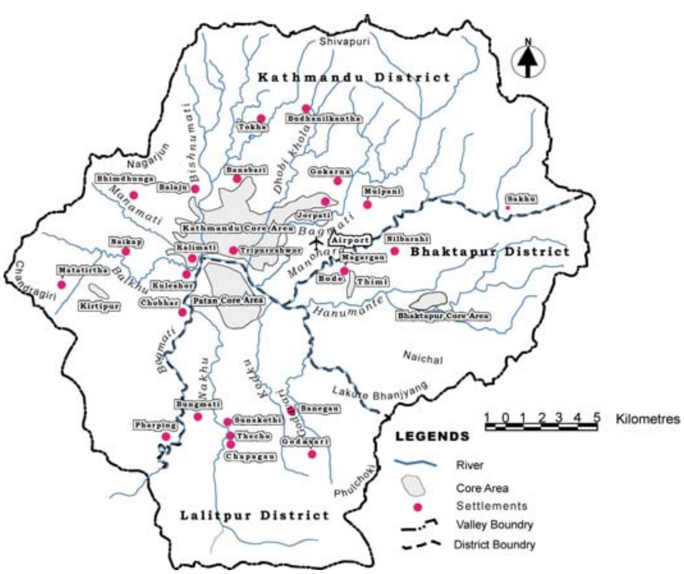
Given reported water level declines and the clear and growing need for dependable sources for municipal water supplies, this report explores the possibilities of groundwater recharge in Kathmandu and aims to develop a conceptual model for achieving such augmentation. It describes the condition of the study sites, compares operational and institutional issues, and assesses the likely impact of artificial recharge interventions on the supply situation.

The Valley

Kathmandu Valley covers 656 km^2 and is surrounded by the Mahabharat Hills. The central part of the valley consists of gentle hills and flat lands at elevations of 1,300-1,400 m. The surrounding hills rise to more than 2,000 m in elevation. Phulchoki to the south of the Valley has the highest elevation at 2,762 m. The valley includes three major cities: Kathmandu, Bhaktapur and Lalitpur (also known as Patan).

Streams and Rivers

Map 1: Tributaries in Kathmandu Valley



The valley is drained by the Bagmati River which originates in the Shivapuri hills to the north. The river flows southwest, cutting through the valley at Chobhar and dissecting the Mahabharat range at Katuwaldaha. The catchment of the Bagmati lies almost completely within the Shivapuri National Park. The settlements of Okhhreny and Mulkhharka and the land their residents cultivate also lie within the catchment area. The Bagmati River has nine major tributaries: Nakhu, Kodku, Godavari, Balkhu, Bisnumati, Dhobi, Manohara, Hanumante and Manamati. The Bisnumati, Bagmati and the Manohara originate in the northern and northeastern watersheds and flow southwest, meeting at the valley floor. The Hanumante River flows west joining the Manahara while the Balkhu flows to the east, joining the Bagmati in the central part of the valley. The tributaries of these three rivers, originating in the south of the watershed, are the Godavari, the Kodku and the Nakhu. They flow from the south to the north to join the Bagmati in the central part of the valley (Map 1).

Population

Kathmandu Valley has both urban and rural residents. Most of the rural population is engaged in agriculture as its primary source of livelihood. This is also the case with some families living in urban areas. Both push and pull factors have led to an increase in the population of the valley. It is difficult to estimate the actual rate of population growth though it has increased in each inter-census period since 1951. The core area of the valley is densely populated but has been growing more slowly than the suburbs since the 1980s. The expansion of suburban areas into adjacent rural areas is likely to continue without regulation.

Past studies have provided different estimates of the valley's population and the rate of population growth has varied in different decades. After the Maoist insurgency began in 1996, security in most of rural Nepal deteriorated and those that could afford to migrated to Kathmandu. The resultant change in the rate of growth in Kathmandu has, therefore, made estimating the actual rate difficult. The predicted population and growth rates based on a study carried out by the Bagmati Basin Water Management Strategy and Investment Program in 1994 are shown in Table 2. The census of 2001 however (Table 3), showed higher figures than those predicted.

Table 2: Population growth rate predictions, 1994

Area	1991	% growth rate	2001	% growth rate	2011	% growth rate	2021
Municipal	598,528	5.0	975,000	4.0	1,446,000	2.0	1,759,000
Rural	466,371	2.0	571,000	-1.2	506,000	-2.0	414,000
Total Valley	1,064,899	3.8	1,546,000	2.3	1,949,000	1.1	2,173,000

Source: HMG 1994

According to the census of 2001, the population of the districts of Kathmandu, Lalitpur and Bhaktapur was 1,645,091 (including 42,826 people of the hilly area of Lalitpur that lies outside the valley) and that of the five municipalities within the valley was 995,966. The total valley population was 1,602,265 (Table 3).

Table 3: Population and density of the three districts of Kathmandu Valley and their urban areas, 2001

District	Total population	Municipality population	Density (per km^2)
Kathmandu	1,081,845	Kathmandu: 671,846	13,586.37
		Kirtipur:40,835	2,766.6
Lalitpur	337,785	Lalitpur:162,991	10,758.48
Bhaktapur	225,461	Bhaktapur:72,543	11,058.38
		Madhyapur:47,751	4,298.02
Total	1,645,091	995,966	
Total Kathmandu Valley population: 1,602,265			

Source: HMG, Central Bureau of Statistics 2002

NB: The towns of Kirtipur and Madhyapur were not yet municipalities in 1991 and hence, using census figures, it is difficult to see the growth rate of urban population in the valley.

According to the Forum for Urban Water Supply, a non-governmental organization, the urban population of the Kathmandu Valley in 2003 reached 1.16 million. This figure does not include the population in the rural areas of the valley. The rates of rural population growth are difficult to estimate because district boundaries have changed between censuses. Compared to Kathmandu district, there have been few changes in the size of the rural populations of Bhaktapur and Lalitpur districts as these comprise large rural areas. Table 3 does not include the floating population that comes to Kathmandu: short-term migrants from the hills, the Tarai and even from north India who come to work as daily wage labourers. Many others come to Kathmandu to conduct business and carry out administrative tasks and remain in the valley for a short period.

Land Use

The Kathmandu Valley floor is extensively farmed and land use has not changed much except in areas adjacent to the three cities. A nationwide land use study carried out by Land Resource Mapping Project (LRMP) in 1976 to establish the intensity of cultivation considered only areas larger than 25 hectares. This survey, appropriate as it was for national planning, is not helpful in promoting understanding of the valley’s land use. Other than for component agriculture, land in the valley is devoted to paved roads, trails, grassland and playgrounds.

The land on the valley rim is also used for agriculture. The hills of the Valley rim are either covered in forests, partly terraced for cultivation or left with most of the trees removed as degraded brush. Cultivated lowland is called *khet* and is furthered classified as rain-fed or irrigated land, while upland cultivated areas are called *pakho*.

The three cities in the valley were originally located away from rivers. According to Tiwari (1988), early settlers were mostly limited to the lower slopes of the hills surrounding the valley. They used water from the hill springs and rivers. But when they moved to ridges and higher land, they moved away from these water sources to places where subsurface water existed at shallow depths. Supply of water was difficult in these new areas. As a result, local inhabitants created *dhunge dhara,* which were fed with water from unconfined aquifers delivered through subsurface channels. Water in the channel was filtered using gravel filters. This system of water supply they called *pranali,* and was a pious social activity to provide tasteful, clean and cold water to the people. At that time, a buffer strip of agricultural land existed between the settlement and the valley's rivers. The advantage of this strip was that the wastewater of the city was used for agricultural purposes. The rivers remained clean and irrigation helped maintain groundwater levels.

The area that is currently being absorbed into urban Kathmandu is undergoing changes in land use practices in this buffer strip. The city has grown in all directions, but it is denser to the north. Kathmandu has also encroached on the adjacent districts of Bhaktapur and Lalitpur. The conversion of rural land into urban has a disproportionate impact on the groundwater situation. It has led to increased pumping in many areas and, probably more importantly, extensive pollution of both surface streams and the upper aquifer. Most development activities are located along rivers, which probably serve as recharge zones where pumping has lowered groundwater levels in the upper phreatic aquifer. This is probably drawing highly polluted river water into adjacent aquifers. In addition, vertical infiltration of polluted water from unlined drains and poorly constructed sewers adds to the pollution.

Since 1990, the road network has expanded rapidly in the valley. The price of land adjacent to roads has skyrocketed. As residential areas have expanded, trails and footpaths have been converted into poor quality roads. Riverbanks, once used as footpaths to access farmland along rivers, have also been converted into roads. The trend of converting agricultural areas into residential properties has escalated the building of riparian roads. All major rivers in the valley have roads and housing complexes on either side of them. Table 4 shows that over 66 percent of the area within metropolitan Kathmandu is residential.

Table 4: Land use in Kathmandu Metropolitan City

Land use	**Area (Km^2)**
Urban (residential, commercial, institutional and industrial) area	3.362
Forest and shrubs	0.247
Parks and exhibition grounds	0.065
Water bodies	0.0532
Agricultural land	0.913
Religious areas	0.015
Road and bus parks	0.1232
Sandy area	0.0693
Airport	0.1486
Vacant lots and others	0.103
Total	5.0993

Source: Kathmandu Metropolitan City, undated

With urbanisation, the pattern of land use is constantly and rapidly changing. As previously mentioned, rural land once used for agriculture is being converted into residential area. The expected annual rate of conversion of rural land to urban area, measured by the Bagmati Basin Water Management Strategy of 1994, is shown in Table 5:

Table 5: Conversion of rural land into urban uses

District	1991-2001	2001-2011	2011-2021
Kathmandu	2%	3%	1%
Lalitpur	0.5%	2%	1%
Bhaktapur	0.5%	2%	1%

Source: HMG 1994

Changes in land use affect the regional hydrological regime, which in turn causes a social response. With increasing urbanisation, more area comes under construction, which may be reducing the permeable area. As a result, less rainwater probably infiltrates into the ground, thereby reducing groundwater recharge. In addition, with an increase in impervious areas, more runoff is generated when it rains. Such runoff scours channels and increases the rate at which water flows out of the valley, probably further reducing groundwater recharge. Building foundations and sewer drainage block subsurface flow. Although no detailed studies have been done, anecdotal evidence from the valley suggests that less infiltration, blockage of subsurface flow and increased runoff reduces soil moisture and affects the groundwater situation.

These developments have had other negative impacts. Mining sand from rivers has become easier and is turning the rivers into sewers. Extensive sand mining is deepening the riverbeds, thereby lowering the water table of adjoining fields (Dixit 1997). Deep river channels cannot provide water to the existing irrigation channels, and paddy cultivation becomes difficult. Higher land prices, particularly when access roads are built, increase the temptation to sell land. This land remains fallow until construction takes place. As a result, the opportunity to recharge groundwater through standing water in paddy fields is lost. Sand mining has also changed the landscape. Agricultural land and hillocks in the vicinity of river catchments have also been used for sand extraction, all of which have direct consequences on the local hydrology.

Pollution from urbanisation is another obvious impact. Major rivers such as Bagmati, Dhobi Khola and Bishnumati have literally become open sewers after their floodplains were converted into residential areas in the early 1980s. Even today, the water quality in the Bagmati River is much better above Gokarna, where urbanization is not as great, but begins to deteriorate downstream due to untreated drainage from new settlement areas. After the river flows through the city, the river water becomes unsuitable even for irrigation.

Geological Setting

Several low hills are aligned in the southwestern valley bottom. They connect the towns of Naikap, Kirtipur, Chovar, Thanagau, and Magargau from the northwest to the southeast. In a southeasterly extention of this line, there are low hills near Banegau. Lacustrine deposits bury the lower slopes of these hills, which are composed of calcareous sandstones. The surface of the Kathmandu Valley is almost flat but it has buried bedrock surface with irregular shapes and high relief. The depth of the Precambrian bedrock from the ground surface ranges from tens of metres to more than 500 m. The thick quaternary deposits consist of lacustrine and fluvial deposits, which have been eroded, but the original thickness of the deposits is unknown.

In the southern parts of the valley bottom gravel deposits are interlayered with clay rich deposits. These deposits are classified into two types. The upper zone is composed mainly of sub-rounded to rounded boulders ranging in diameter from 10 to 20 cm. These layers are semi-consolidated and poorly sorted. The lower zone is an intercalation of gravel and silty clay layers and directly overlies the lacustrine deposits. The layers are mainly composed of calcareous schistose sandstone, and in general dip gently to the north though lacustrine deposits are horizontal or dip gently to the south. The composition of the two geological layers are classified below:

Quaternary

1. River deposits: Sand and clayey materials of lacustrine deposits with small gravel supplied from surrounding tributaries.
2. Talus and alluvial fan: Angular to sub-angular gravel with clayey soil are removed from steep slopes by gravity and washed out from valleys.
3. Terrace deposits: Flat plain facets underlain by rounded gravel with sand, these are higher than the flat plains, which are composed of river deposits.
4. Predominant gravel deposits: Poorly sorted thick layers of sub-rounded to rounded gravel deposits in the southwestern part of the valley bottom. This gravel layer is semi-consolidated and has a maximum thickness of approximately 50 to 70 m.
5. Gravel and clay deposits: Thick layers composed of sub-rounded to rounded gravel and clayey layers overlain by the predominant gravel deposits. In the southwestern part of the valley bottom this layer directly overlies the lacustrine deposits and has a maximum thickness of approximately 50 to 70 m. Both these deposits and predominantly gravel deposits are horizontal or dip about five degree to the north.
6. Lacustrine: Lacustrine deposits are classified into three types:

   a. Arenaceous deposits: Composed of coarse to medium grain sand with small rock fragments, these deposits are believed to have been transported from northern mountainous areas underlain by gneissose rocks. They include whitish sandy materials probably supplied in large part from the erosion of gneiss rocks (augen and banded) that occupy the northern mountain (Shivapuri) range. Arenaceous materials are loose, and since they form steep cliffs beside river channels, are easily eroded by river flows. Gullies composed of arenaceous materials developed on flat plains, especially in the northern part of the valley bottom.

b. Argillaceous deposits: The clayey materials of argillaceous deposits are obtained from the erosion of the limestone underlying the mountains in the south. The dark grey thick clay layer in the western and central-southern parts of the valley bottom is probably supplied from the erosion of the Chandragiri limestone, which underlies the mountain ranges in the southern parts of the valley. The areas along river flanks underlain by argillaceous materials are more gently sloped than areas underlain by arenaceous deposits. Since the percolation of surface water is lesser over argillaceous deposits than over arenaceous deposits, the former is more conducive to cultivation. Landslides are common in areas underlain by argillaceous materials, especially in the middle reaches of the Nakhu Khola River.
c. Intermediate type of arenaceous and argillaceous deposits: Alternating clayey and sandy layers occupy the central part of the valley bottom from the northwest to the southeast. These deposits also include silty clay and silty sand layers. Material eroded from Chandragiri limestone and phyllite, and sandstone of tistung formation (quartzite) fill them. In shallow zones a small amount of water seepage is occasionally observed on the top of clayey layers at the boundary between a clayey and a sandy layer. Because clayey layers are impermeable, they obstruct the percolation of rainfall.

Precambrian and Devonian

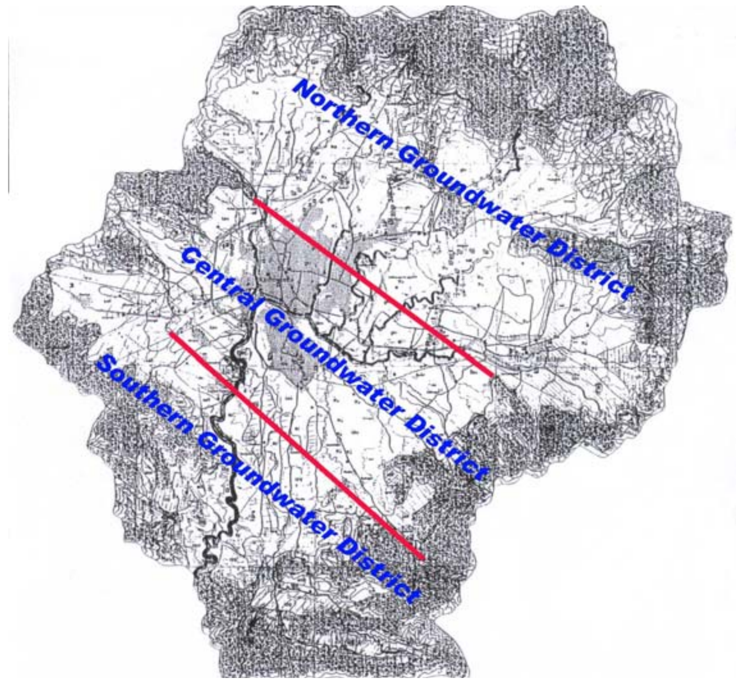
1. Chandragiri formation: Very hard crystalline limestone and quartzites are the main components of this formation. The crystalline limestone in general has a sandstone-like texture.
2. Tistung formation: This formation is mainly composed of phyllite, sandstone and sandy limestone. Weathering is generally intense. This formation seems to be the source of the silty materials in lacustrine deposits.
3. Gneiss: Augen and banded gneiss rocks dominate the northern and northeastern mountain ranges of the valley. The arenaceous deposits of lacustrine deposits are supplied from these rocks.

The Groundwater Aquifers of the Kathmandu Valley

Based on their physical and geological structures, the groundwater aquifers of Kathmandu Valley have been divided into three districts: Northern, Central and Southern. They are shown in Map 2.

Northern Groundwater District (NGD)

Map 2: Groundwater Districts of Kathmandu Valley



The NGD includes the Bansbari, Dhobi Khola, Manohara, Bhaktapur and Gokarna well fields that are the principle sources of groundwater. The total area of the NGD is 157 km^2, of which 59 km^2 is the recharge area. The upper part of deposits in northern Bansbari, Dhobi Khola and Manohara are composed of unconsolidated, highly permeable materials consisting of micaceous quartz, sand and gravel. In general, most rechargeable areas are high plains and low alluvial regions. Extraction of groundwater is difficult in mountainous areas and the mountain ranges surrounding the valley also provide very little possibility for groundwater recharge because of their high relief. The slope is steep and much of the rainwater quickly turns into surface runoff and joins the nearest tributaries. Aquifer transmissivity ranges from 83 to 1,963 m^2/day.

Overall, the NGD can best be described as an inter-bedded aquifer or a series of sub-aquifers with a complex structure. The character of the Dhobi Khola through the Jorpati fields is different from that of the Manohara and Bansbari fields. In most areas, the unconfined upper aquifer has a saturated thickness of only 15 to 30 m. Underneath, layers of clay and bedrock are found at comparatively shallow depths of between 94 and 157 m. Since pumping quickly exhausts perched groundwater, the effective aquifer thickness is much less than the depth of the unconsolidated sedimentary material. In Bansbari, the upper aquifer is unconfined but becomes confined at a depth of 80 to 90 m due to the presence of extensive clay layers. The same is true for Gokarna and Manohara, where the upper aquifer is unconfined while deeper ones are. The static water levels in these three areas are consistent and tubewells drilled here do not seem to have tapped perched groundwater layers. The water quality in these areas is characterised by low electrical conductivity (100-200 micro-siemens/cm).

Central Groundwater District (CGD)

The upper parts of the CGD are composed of thick, stiff black clay with some lignite to depths of 200 m. Unconsolidated, low permeability, coarse sediments underlie the thick black clay. The old urban core of Kathmandu sits over this region. Groundwater stored in the aquifers of this district contains soluble methane gas, which is probably an indication of anaerobic conditions in underlying aquifers. The water has high electrical conductivity, as much as 1,000 micro-siemens/cm in some wells located near Tripureswor. The average aquifer transmissivity ranges from 32-960 m^2/day. The total area of this district is 114.0 km^2. About 6 km^2 in the southeastern part of the CGD near Godavari is covered with sand and gravel deposits and is the only area where recharge takes place. The CDG is densely populated and therefore most of the private wells of Kathmandu are located here.

Southern Groundwater District (SGD)

The SGD is characterised by a thick clay formation and low permeable basal gravel. Though recognised to exist along the Bagmati River between Chobhar and Pharping, the aquifer is not well developed. The eastern area of the SGD is covered with sand and gravel deposits. The areas that help recharge are Thecho, Chapagaun, Chunikhel, Bungamati and Sunakothi. Of the total area of 55 km^2, recharge takes place in 21 km^2. The SGD clay layer is about 200 m thick beneath the city. Six holes drilled by the Department of Mines and Geology indicate that the confined thickness is uniform and that nominal inter-bedded sand layers exist, except near the bottom. Bedrock is found at a depth of 106 m. The 206 m interval between the clay and the bedrock comprises inter-bedded sand and clay. Before large-scale groundwater development took place, there used to be water flow within the aquifer from the north through the deep, confined aquifer section. The flow emerged in the south near Pharping. The development of well fields in northern districts has reduced the flow of groundwater to southern districts. In addition, there are major springs in the Phulchoki-Chandragiri and Nagarjun-Naichal mountain ranges surrounding the valley. In the Phulchoki-Chandragiri range, spring water gushes out from faulted limestone layers. In the Nagarjun-Naichal range major springs emerge from layers of conglomerates. Some of these springs are Satmul, Sesh Narayan, Kutulimul, Muledole, Godavari Kunda, Matatirtha, Baikhumul and Ek Hazar Mul. All are situated at the base of mountains and are a traditional source of irrigation and domestic water supply. Ever since water demand in the valley increased, all these sources have been tapped for the municipal water supply.

Transmissivity

Transmissivity indicates the potential for groundwater development. Transmissivity is measured in m^2/day and can be assessed by conducting pumping tests in the field. The valley is divided into five groups of areas with differing values of transmissivity. The first-grade area, with an aquifer of sandy formation has the highest transmissivity (T>500 m^2/day). This area has a lot of potential for the development of groundwater. Second-grade areas, also with aquifers of sandy formation but with moderate to high transmissivity (T = 300-500 m^2/day), produce a moderate quantity of groundwater if tubewells are used. Third-grade areas consist of aquifers of sand and silt formation and show low to moderate transmissivity (T = 100-300 m^2/day). This type of aquifer produces a moderate quantity of groundwater but has a high draw down. Fourth-grade areas, aquifers consisting of silty sand formation, have low transmissivity (T = 10-100 m^2/day), and cannot produce tubewell water. Fifth-grade areas consist of clayey sand formation that has very low transmissivity (T<10 m^2/day) and are not suitable for developing groundwater.

According to Gupta *et al* (1990), the middle reach of the Manohara River east of Kathmandu airport has high potential for developing groundwater. The region south of the airport of the same river is not, however, suitable for developing groundwater on a large-scale. Gupta *et al.* (1990) showed that the transmissivities of the formations of Balaju, Dhobi Khola and Manohara areas are higher than 300 m^2/day, indicating that they are rechargeable areas.

Groundwater Use

The increase in use of groundwater in Kathmandu has to be analysed in relation to the development of the water supply system. A modern piped water supply system was introduced in Kathmandu in 1891 to serve the nobility and the elite. The common people were served with public stand-posts. In the 1950s, the pace of building new systems increased, and in 1960 water from the Bagmati River (the tailrace of the Sundarijal hydropower plant) was used to meet the growing needs of the valley population. This nucleus has expanded over the decades into a large municipal supply system, currently operated and managed by the Nepal Water Supply Corporation (NWSC). The system exploits water from rivers as well as from a network of wells tapping the lower, confined or semi-confined, aquifers of the valley.

Municipal water production from surface sources has always remained in short supply in the valley. To meet domestic water needs, tubewells were installed at Balaju and Bode in 1961. These extracted 1.7 million and 1.96 million litres of water per day (MLD) respectively[1] Since then, the rate of groundwater extraction has gradually increased to meet domestic as well as commercial needs. Increasing extraction has, however, proved insufficient to meet the demand. As early as 1973, the United Nations Development Programme prepared a master plan to address the water shortage in the valley. Under the plan, the World Bank provided loans for three projects. When the third project was completed in 1987, the Water Supply and Sewerage Corporation, WSSC (previous representation of NWSC), had already drilled 43 wells to extract groundwater. By 1989, the number of tubewells operated by the WSSC rose to sixty.

[1] *Gorkhapatra,* 6 June 1961.

The estimated groundwater abstraction by the WSSC and other private tubewells between 1975 and 1989 is shown in Table 6:

Table 6: Estimated groundwater abstraction from tubewells

Year	Estimated abstraction in MLD			
	NWSC tubewell	Private tubewell	DMG* tubewell	Total
1975	0	1.0	0	1.0
1976	0	1.2	0	1.2
1977	0	1.4	0	1.4
1978	0	3.2	0	3.2
1979	2.4	3.0	0	5.4
1980	3.6	3.24	0	6.84
1981	5.8	3.4	0.4	9.6
1982	6.8	3.4	0.6	10.8
1983	5.8	3.5	1.0	10.3
1984	4.4	3.6	1.2	9.2
1985	5.3	4.5	1.4	11.2
1986	17.6	6.6	1.4	25.6
1987	26.2	6.4	1.6	34.2
1988	28.7	6.3	1.6	36.6
1989	36.4	7.3	1.8	54.5

Source: Japan International Cooperation Agency, JICA (1989)
** DMG: Department of Mines and Geology*

The annual groundwater extraction from these and private wells was estimated to be about 20 million cubic metres. A study conducted by the Japan International Cooperation Agency, JICA, in 1990 estimated that the static groundwater level fell 10 m annually after the WSSC wells were developed.

According to the Snowy Mountains Engineering Corporation (SMEC, 1992), the upper limit of groundwater extraction should be about 40.1 MLD. Estimated extraction levels in 1989 were, however, already much higher than that. In 2002, the NWSC's Optimizing Water Use in Kathmandu Valley Project found that the amount of groundwater extracted by NWSC and private wells for domestic use was about 47 MLD (Table 7). In addition, it is estimated that bulk extraction for other domestic and private use is 13.2 MLD, yielding a total extraction of about 60 MLD, a figure much higher than the upper limit of extraction calculated by SMEC in 1992.

Table 7: Groundwater extraction in Kathmandu Valley

Systems	Groundwater extraction (MLD)			
	Deep tubewells	Shallow tubewells	Dug wells	Total
NWSC	23.79	2.06	3.31	29.17
Hotels	5.5	0.9	0.12	6.53
Private	2.47	1.3	0.71	4.48
Domestic	0.07	0.32	0.19	0.58
Govt./Inst.	5.22	0.41	0.03	5.67
Embassy	0.43	0	0	0.43
Total	37.49	5	4.37	46.86

Source: Optimizing Water Use in Kathmandu Valley Project, 2004

Since mechanised extraction began in the 1960s, groundwater has become one of the most significant sources of water for domestic as well as industrial and corporate uses. Hotels have also dug private wells. Likewise, hospitals, embassies and academic institutions have installed their own wells. In 2000, 206 private wells were known to be operational. Since then, 39 have been rendered useless due to decreased yield (Metcaff and Eddy, 2000). Table 8 summarises the number of wells used by NWSC and other users in different groundwater districts. JICA (1989) estimated discharge for all wells. However, it must be noted that, except for the NWSC wells, the discharge figures for wells installed after 1990 are difficult to obtain.

Table 8: Tubewells used by the Nepal Water Supply Corporation and other* users in Kathmandu Valley

Groundwater District	Total # wells		# wells in use		# wells out of use	
	NWSC	Others	NWSC	Others	NWSC	Others
Northern	57**	46	43	43	14	3
Central	12[†]	150	4	114	8	36
Southern	4[††]	10	4	10	0	0
Total	73	206	51	167	22	39

Source: Metcaff and Eddy, 2000

NB: *These include wells used by industries, embassies, academic institutions, hospitals, the airport and government agencies.
** The Northern District has five well fields: Dhobikhola, Bansbari, Gokarna, Bhaktapur and Manohara
[†] The Central District has four well fields: Bansbari, Bhaktapur, Manohara and Pharing
[††] The Southern District has one well field: Pharping

The ability of the groundwater system to meet demand is limited largely because of its inefficient management and unplanned urban expansion over the last four decades. Overall, water supply from the municipal system is characterised by growing uncertainty and variation in quantities delivered; during the dry season, some households receive water for 0.5-2 hours a day while others get water only once a week or not at all. Estimates by NWSC suggest that demand for water in the Kathmandu valley exceeds 200 MLD, but the capacity of existing supply sources in 2003 was 130 MLD in the wet months and just 85 MLD in the dry season (NWSC

2003). The rate of loss in the municipal system is very high (estimated to be around 60%[2]). Much of this water flows back into the upper unconfined aquifer where, due to pollution, it is rendered unsuitable for urban supply. Daily water production potential from surface and groundwater sources in Kathmandu Valley for 2000 is given in Table 9.

Table 9: Nepal Water Supply Corporation water production potential in Kathmandu Valley

Water source	Production potential (in MLD)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Surface	74	60	53	54	69	104	107	108	108	98	92	88
Ground	35	48	53	52	42	7	7	5	4	11	17	22
Total	109	108	106	106	111	111	114	113	112	109	109	110

Source: NWSC 2000

Since the water production potential in the valley is far short of the growing demand, the government is investing in the Melamchi Project to compensate for shortages and losses. This is a US$ 484 million three-stage scheme to divert water from a stream outside the valley and deliver it to Kathmandu through a 26 km-long tunnel. In the first phase, now expected to be completed by 2009, 170 MLD of water will be transported to Kathmandu. In the second phase, another 170 MLD of water from the Yangri and Larke Rivers of Melamchi will be transferred. A final 170 MLD is to be transferred in the third stage, making a total of 510 MLD water brought into Kathmandu to meet future demand. Although the need to establish effective sewer and water treatment systems in Kathmandu is widely recognized, viable plans to do so prior to the introduction of new water supplies have not been developed.

In addition to the new supplies planned through the Melamchi project, there have also been a variety of initiatives to reduce losses in the municipal supply system. To date, none have had much effect. Regardless of long-term plans, most residents of urban Kathmandu experience significant shortages and disruptions in the supply of water they receive from the municipal system. As a result, poor families continue to depend on stone spouts and wells that tap into the increasingly polluted upper aquifer. Those who can afford to purchase what is believed to be higher quality water from drinking water industries.

Since the Melamchi Project will take a long time to materialize and water demands are not being met, the NWSC in 2003 developed the Manohara well field as part of the 'Bode Scheme.' This scheme is expected to produce 20 MLD to augment municipal water supply in Kathmandu, but production in December 2004 was only 6 MLD. This is addition to the production listed in Table 9.

[2] The estimate of loss is uncertain. According to the NWSC general manager, loss is just 34 percent. See *Kantipur* February 28, 2003.

Interviews and discussions with private well drillers reveal interesting facts about groundwater development in Kathmandu. In some locations, tubewells have to be 25 m or more in depth to collect sufficient discharge, while dug wells in the same vicinity collect enough water even at a depth of about 10-15 m. Private well drillers say that tubewells are less efficient at drawing water even though they are deeper than dug wells. This is true in Kalimati and Kuleshwar of the CGD, indicating lower transmissivity at a lower depth.

Groundwater extraction for commercial use is a recent phenomenon, where wells have been dug in private houses in Gokarna and the water sold to tankers. One household is estimated to be selling an average of 500 m^3 of water a day. Currently, there are three houses involved in this business, but this trend is on the rise. This emerging activity in the use of groundwater will put pressure on an already stressed resource. There is no legal mechanism to regulate this use, although a new groundwater act is planned. The proposal to promulgate this act, which will regulate groundwater extraction, has yet to be finalised by the government[3].

With all these pressures, groundwater levels have been declining at an ever-increasing rate. High levels of extraction have already affected shallow pumps in many localities in the valley. The fall in the static groundwater level indicates that the extraction rate has surpassed the natural recharge rate. This depletion of the natural groundwater supply may be overcome by augmenting groundwater artificially using methods such as inducing recharge. This will help farmers who have relied solely on groundwater for irrigation, those who have lost water from their shallow tubewells and will augment the supply to expanding settlements.

Traditional Waterspouts

Figure 1: *dhunge dhara*

A significant feature of Kathmandu Valley is its stone waterspouts (*dhunge dhara* or *hiti,* Fig. 1), fed by groundwater from shallow aquifers. These fluctuate significantly with the season: in the rainy season discharge increase quickly while it drops in the dry season. The construction of such spouts in Lalitpur demonstrates an understanding of the regional hydrogeology. Lalitpur's core area slopes northeast; the water tables of dug wells follow the same pattern. A thick layer of black cotton soil at the southern outskirts of Lalitpur prevents the flow from seeping into the Bagmati River while creating potential aquifers to the north of the city. This explains why the northernmost stone spouts of Lalitpur yield more water than spouts in other areas. Lalitpur's shallow aquifer catchment area includes the city's core as well as a

3 The same trend of extracting sand from valley rivers existed until the collapse of several bridges, which induced the government to regulate the practice. There has not yet been a similar effort in regulating groundwater extraction for commercial purposes.

narrow area of about 8.5 km^2 extending south about 12 km towards the high ground of Chapagaun (see Map 1). A 1993 survey of dug wells carried out between Lalitpur and several villages along the *rajkulo* towards Chapagaun confirmed that groundwater flows north. The same survey concluded that within Lalitpur's core area, water flows north and northeast (Joshi, 1993).

According to Metcaff and Eddy (2000), the discharge of spouts in Kathmandu Valley during the rainy season is almost equal to that during the dry season, while in Lalitpur discharge is generally higher during the rainy season. In fact, some spouts in Lalitpur yield from 5-15 l/s in the rainy season, a three- to five-time increase over dry season flow. The difference in seasonal discharges between the two locations is due to differences in hydro-geological conditions: permeable terrace deposits underlie Lalitpur but not Kathmandu.

The groundwater level in central Lalitpur is between 4-6.5 m (Joshi 1993). Only in the north and southeast does the groundwater come very close to the surface. In general, areas with high groundwater levels coincide with areas of low soil permeability. Because of changes in soil permeability, groundwater levels fluctuate a few metres over the year, with the greatest fluctuations occurring in the least permeable areas. The lowering of groundwater levels decreases the discharge of *dhunge dhara,* as it has at Subaha, Kanibaha, Mega and Bile. Joshi (1993) states that groundwater levels around the drying up *dhunge dhara* were 3-4 m below surface, the level below which *dhunge dhara* cease to function.

Water Quality

Binnie, Partner and Associates (1973) classified the tubewell water of the NGD into three groups: Group 1- groundwater from the deep, confined aquifer in the southern zone of the NGD; Group 2- tubewell water from the medium-depth, inter-bedded aquifer around Sundarijal; Group 3- represented by only two wells at Dhobi Khola with screens 2.5-18 m belowground.

Chemical analyses showed that the softness, acidity and very low salinity of Group 3 water indicated that recharge into the surface as well as deeper layers along the northern margin was recent. The progressive increase in hardness and salinity through the Group 1 wells is a result of the increased time to recharge the aquifer as groundwater flows south. Table 10 shows the quality of groundwater at the different locations of the NGD.

Table 10: Quality of groundwater in the NGD of Kathmandu Valley

Parameters	Values				
	Group 1	Group 2	Group 3	Desirable limits	Permissible limits
Turbidity (JTU)	75-97	3-15	8-9	5	25
Total Hardness	90-250	25-60	12-18	100	500
Manganese Hardness	29-70	6-24	0-4	30	150
Total Alkalinity	360-640	37-116	21-32	-	-
Free Carbon Dioxide	152-220	8-41	5-12	-	-
Total Dissolved Solids	384-600	80-180	62-86	500	1000

Source: Gupta et al. 1990

NB: All units in mg/l except turbidity, which is in Jackson Turbidity Units (JTU).
Group 1: Groundwater from deep, confined aquifer in southern zone of NGD
Group 2: Tubewell water from medium-depth, inter-bedded aquifer around Sundarijal
Group 3: Two wells at Dhobi Khola with screens at depths of between 2.5-18 m

Agencies Involved in Groundwater Development

Groundwater in the valley has provided an alternative source of water for irrigation and domestic use for a long time. Households have been using groundwater even before municipal water supply systems were developed. As mentioned earlier, government agencies began extracting groundwater by using pumps in 1965. When the municipal supply failed to meet the water requirements of hotels, businesses, educational institutions and factories, these began installing private pumps to extract groundwater. The groundwater depletion of the valley has posed serious questions of sustainability and stability of ground. Three major government agencies are involved in groundwater development in the country, but the scope of their work is limited to the use of groundwater and does not address depletion.

Groundwater Development Board (GDB)

The GDB was formed to encourage the use of groundwater for irrigation. The GDB's activities consist primarily of studying the groundwater potential and constructing wells. However, because most irrigation development using groundwater is in the Tarai, activities within Kathmandu Valley are limited to studying the groundwater potential only.

Nepal Water Supply Corporation (NWSC)

The NWSC primarily focuses on urban water supply using surface sources. Its activities include managing surface water for municipal supply, constructing and maintaining supply lines and managing sewage. The corporation currently operates in 28 municipalities throughout the country, including the Kathmandu Valley. When surface water sources became insufficient, NWSC began tapping groundwater as well.

However, the agency's mandate is to extract water and distribute it, and does not concern itself with augmentation, quantifying and managing the resource.

Department of Water Supply and Sewage (DWSS)

The DWSS is involved in extracting, treating and supplying both ground and surface water to people in rural areas. Although groundwater depletion is recognized as a problem, little attention has been drawn to it. Concern focuses on the availability of water for extraction and distribution rather than exploring ways to augment supply. Attempts to inject water into the deeper aquifer were not successful. Despite the rate of depleting water levels, 10 m/yr (JICA 1990), its extraction has continued unabated.

Artificial Recharge Prospects

With heavy groundwater exploitation in the valley, the water table has been declining at a faster rate than recharge. Extraction of water from the deeper aquifer has posed an even more serious problem since recharge rates are slower than in the shallow, unconfined aquifer.

Rainfall is a principal source of groundwater recharge - shallow, unconfined aquifers are recharged every monsoon, although deeper aquifers are not. However, some are recharged very slowly - in the NGD, a larger area is available for recharge and soils are relatively permeable, but the SGD has a very small area capable of recharging the aquifer. To develop groundwater resources for the long term, this needs to be understood. Because solid scientific information on aquifer characteristics is not available, the complexity of groundwater systems in the valley is poorly understood. A significant amount of rainwater that could be used to meet local demand flows out of the valley without being directed to recharge groundwater.

Rough calculations suggest that substantial amounts of water could be made available if aquifers were used more efficiently or if other storage mechanisms were created. With a catchment area of 656 km^2, Kathmandu Valley receives an annual average of 1,500 mm of rainfall annually. Even if half that rain either evaporates or percolates into the ground, about 500 million m^3 could still be captured. Assuming an average per capita usage of 100 l/day (double of the amount assumed for rural areas), if just six percent of the available 500 million m^3 were harvested, much of Kathmandu's water demand could be met by allocating less than 1.5% of its area to 3 m-deep water tanks (Gyawali 2001) [4].

The real question, though, is how to achieve this. First, let us discuss the possible methods of recharging the groundwater of the Kathmandu valley. Artificial recharge depends on there being available storage capacities and may be accomplished in the following five ways:

---

[4] Available information shows that current groundwater extraction is only about 22 million m^3/yr.

- Rooftop water harvesting and injection
- Ponds
- *Rajkulos*
- Using agricultural fields to promote recharge
- Injecting surface water into deep wells

Rooftop Water Harvesting and Injection

Rainwater collected from rooftops can be stored in tanks and used directly for domestic purposes or to recharge groundwater. Table 11 gives estimates of water quantities that could be collected from rooftops:

Table 11: Annual volumes (m^3) of rain collected for specific rooftop sizes and quantities of rainfall

Rooftop area(ft^2)	Rainfall (mm)								
	400	600	800	1,000	1,200	1,400	1,600	1,800	2,000
400	15	23	30	38	46	53	61	68	76
8,00	30	46	61	76	91	106	121	137	152
1,200	46	68	91	114	137	159	182	205	228
1,600	61	91	121	152	182	212	243	273	304
2,000	76	114	152	190	228	266	304	342	379
2,500	95	142	190	237	285	332	379	427	474
3,000	114	171	228	285	342	398	455	512	569

Source: Dixit 2002

A house with a roof area of 800 ft^2 and an effective annual rainfall of 600 mm (roughly half the average annual rainfall for Kathmandu) could collect about 46 m^3 of water a year. Assuming a per capita consumption of 100 l/day and an average household size of 5.44 people (2001 census), this is roughly equivalent to 85 days of supply or over 23 percent of annual need. The volume collected depends upon effective rainfall (total rainfall minus evaporation, foul flow, interception and withdrawal) and the area of collection. Water thus collected could also be used for groundwater recharge. Some residents in Kathmandu have started channelling rooftop rainwater, which would otherwise flow directly into streams, through pipes into pits 20–25 ft deep. Although the volume of water used to recharge groundwater in these few cases has not been quantified, water thus injected rarely spills over the pit even during heavy rainfall events. This suggests that even during the monsoon there is enough space to absorb the incoming water. Even if only half the water could be recovered the contribution of rooftop rainwater harvesting to water availability could be significant.

It is important to recognize that, although the volume of water recharged would be significant, its usability depends significantly on groundwater quality. Much of the rooftop area available in the Kathmandu valley is in densely populated urban areas. As previously mentioned, groundwater quality in these areas is often low due to pollution from sewage and other sources. As a result, groundwater quality may represent a significant limiting factor. However, if collected carefully, including the disposal of the "first flush" water, the quality of polluted groundwater could be improved through dilution. In addition, it is important to note that much of the groundwater overdraft is related to pumping in the deeper aquifers while recharge using rooftop sources would contribute new supplies to shallow aquifers. Thus, while the potential rooftop quantity that could be captured appears significant, evaluating its effective contribution to water availability would require detailed studies of water quality and the recharge limitations of specific locations.

This approach is potentially applicable in suburban areas such as Tokha, Budanilkantha and Gokarna in the NGD and Godavari in the SGD (see Map 1). Improving estimates of the potential for recharge using rooftop rainwater harvesting would require the following activities:

a. Household surveys to determine roof area, per capita water use, etc.
b. Monitoring runoff from sample rooftops to measure the effective supply available for recharge;
c. Monitoring recharge to determine limitations imposed by infiltration rates, clogging, etc. in different hydrological settings of the valley,
d. Delineation of areas where recharge would not be usable due to low groundwater quality or high surface pollution loads;
e. Creating a model to calculate quantities likely to be recharged over long periods.

Rooftop water harvesting is widely recognized as an acceptable method of collecting water for use during dry periods. However, augmenting groundwater with rooftop water must be done with care because if the water collected is contaminated it could deteriorate the quality of the groundwater. It would be costly to treat contaminated groundwater to make it suitable for human consumption. In peri-urban areas such as Tokha and Budhanilkantha, rooftop water may be safe but in urban locations, contamination must be considered. Care must, for example, be taken to ensure that the collecting surface is clean.

Rainwater harvesting is an effective method to supply water to individual households, but its effectiveness at boosting groundwater levels is not known. Collecting rooftop water is still in preliminary stages and only a few households have started doing it. No data exists on how many houses are currently involved, but the number is expected to rise.

Ponds

Another potential means of groundwater recharge is by using ponds, both traditional and newly built ones. It is estimated that there are over 100 ponds in and around Kathmandu, Lalitpur, Bhaktapur, Sanhku and other villages in Kathmandu Valley (Pradhan 2003). There are 16 traditional ponds in Kathmandu, (Kathmandu Valley Town Development Project, KVTDP 1982) five in Sankhu (Rai 2002) and 42 major ponds in Bhaktapur (Pradhan 2003). In addition, there are many other ponds of various sizes not mentioned in these reports. Many old ponds have been damaged, buried or encroached upon by water hyacinth. A pond was dug in 2000 in the catchment area of the Bagmati within the Shivapuri National Park. The idea is for these ponds to hold water in order to augment flow in the dry months. Ponds help catch water which would otherwise drain away as surface run-off down the steep hill slopes. Some ponds dry up by January, but older ponds retain water for longer periods. One advantage of ponds is that they keep feeding groundwater supplies even after the monsoon is over. However, the effectiveness of these ponds as recharge structures would need to be evaluated, especially where these were not designed as recharge structures.

Opportunities for ponds to contribute substantially to groundwater recharge may exist primarily on the valley margins, particularly in the northern region, where the groundwater quality is high, soils are permeable and sediments are not inter-layered with clay-rich zones. As with rooftop rainwater harvesting, the viability of ponds as a recharge source depends heavily on location-specific characteristics. Detailed information on aquifer conditions is essential for this.

Before more ponds are dug in hills of varying geological conditions, the amount of water that these ponds could add to groundwater needs to be quantified. One way to do this is to monitor springs located below existing ponds to find out how the ponds affect flow in the springs. The use of ponds like those in the Shivapuri area needs to be substantiated by scientific study to ascertain how and when they help augment flow and thus groundwater levels. Building more ponds in the northern districts would be more effective once these parameters are known. It is also important to explore the impact of existing ponds on the recharge process.

Another possibility is to explore the feasibility of impounding small gullies outside the Shivapuri area to allow more water to seep into the ground. Since there are old settlements outside the park, the participation of the local communities can be sought. There are two advantages to impounding: villagers can use impounded water for agriculture, and it would build up the water table in the area. In 2004, the Nepal Water Conservation Foundation (NWCF), along with Nepal Water for Health (NEWAH), Rural Self Reliance Development Centre (RSDC) and the Nepal Federation of Irrigation Water Users, initiated a pilot project to harvest water locally and to enhance livelihoods by building dugout ponds in northern Kathmandu.

Recharge through *Rajkulo*

When *dhunge dhara* and wells were built in the past, it was found that the recharge of groundwater by rainfall alone was insufficient to ensure their supply. Because the *dhunge dharas* in the core city areas of Kathmandu and Patan are located at a depth of 2-3 m belowground, the groundwater that supplies the *dhunge dharas* is shallow and requires constant recharging by *rajkulos*, mostly unlined channels originally built for irrigation purposes. Historically, networks of *rajkulos* supplied water to most of the valley. In recent years, many *rajkulos* have been covered over. Furthermore, traditional *rajkulos* either have been damaged or were not properly maintained, and, as a result, in many places the *rajkulos* no longer convey water to recharge groundwater levels. Because of insufficient recharge, the groundwater level fluctuates 1.5 m during the dry season, a value obtained by measuring water levels at *dhunge dhara* intake sites.

Cleaning and rehabilitating *rajkulos* could substantially contribute to groundwater recharge. Again, as with rooftop harvesting and ponds, local factors including groundwater quality and the nature of underlying sediments would affect contribution levels. A survey of existing *rajkulos* and the surrounding groundwater conditions would be an important first step in order to identify strategic locations where this could make a substantial difference. It is important to recognize, however, that renovation would only contribute to groundwater recharge in certain areas. Kathmandu's drainage system cannot recharge Lalitpur's groundwater, for example, because its hydraulic gradient is from the aquifers towards rivers flowing through the middle of the valley. The fluctuation of groundwater tables in wells in Chapagaun, where *rajkulos* are still used for irrigation, however, is different. The water table was lower in Chapagaun than in Sunakothi, where there are no nearby *rajkulos.* Ponds in Lagankhel and Pulchowk play vital roles in recharging groundwater provided that *rajkulo* feed them constantly and balance losses from percolation and evaporation. A permeability test in March 1992 on the gravel surface near one of the Lagankhel ponds of the Naricha and Nayekhyo aquifers, located 200 m northeast of the pond, measured a permeability of $2.11x10^{-2}$ m/s (0.211 cm/s). Pits dug along the expected flow path in June 1993 showed layers of gravel. Based on these facts, one can conclude that ponds fed by *rajkulo* are a critical medium for recharging shallow aquifers in this location.

Using Agricultural Fields as Natural Recharge Zones

Existing surface irrigation systems could be utilised as major sources for recharge, particularly if fields are redesigned to stimulate and capture flow during both cropping and fallow seasons. A balance would have to be struck between the differing objectives of farmers who want water delivered to their crops and recharge, which prioritises getting water to the ground. Creating recharge areas are, as with ponds, particularly promising in the northern aquifer areas where groundwater quality is high, soils and sediments permeable, and where land use remains dominantly agricultural. Opportunities for this are, however, under threat due to the rapid pace of urban expansion.

Injecting Surface Water into Deep Wells

Some attempts have been made to recharge groundwater into confined aquifers through deep wells. The Artificial Recharge Pilot Project (ARPP), for example, used a deep injection method to recharge groundwater using surface water. The project was piloted in the Manohara River Basin. The site was suitable because the deposits of the Manohara well field are composed of unconsolidated permeable materials consisting of micacious quartz, sand and gravel as well as clay, silt and silty-clay of low permeability. Layers of permeable and impermeable deposits alternate. The Manohara well field possesses both shallow and deep aquifers; the major confined aquifer is over 150 m deep. This well field supplies groundwater to Kathmandu's water supply system. Before injection, transmissivity and specific capacity pumping tests were conducted to determine the permeability of the Manohara field. Permeability ranged from 1.08×10^{-3} to 7.04×10^{-3} cm/s with an average permeability of 3.9×10^{-3} cm/s, a low to medium figure. Transmissivity ranged from 400 to 800 m^2/day and specific capacity ranged from 3.50 to 7.00 l/s/m. The static water level in the Manohara well field is 30 m below ground level.

The water source for the recharge test was a shallow well dug in the river's floodplain, about 450 m from the deep well through which it would be fed to recharge the aquifer. It supplied a constant quantity of water such that tests could be conducted in all seasons. A dewatering submersible pump of sufficient head and discharge using a 3-phase electric transmission line pumped water from the well. The water was conveyed through a 100 mm diameter pipeline from the source well to a water treatment plant of 10 l/s capacity installed in the same compound as the recharge well. The treated water was then injected into the recharge well and monitored.

The recharge well was drilled to a depth of about 200 m in an upland area and the recharge water injected below the static water level. Recharge capacity was limited to a maximum of 10 l/s. Three observation wells were installed within a 150 m-periphery of the recharge well to obtain baseline data on the hydro-geological parameters of the recharge well and the adjacent aquifers and observe the rise of the water level in the aquifer and the response of the aquifer once injection began. Water samples obtained before recharge were used to determine the physical, chemical and bacteriological character of the native groundwater.

The results of this pilot scheme were not encouraging. During the pre-recharge pumping test, an average of 6.25 l/s was pumped for 72 hours. The static water level in the recharge well was 35.53 m below ground level. The resulting drawdown in the well was 20.77 m. The specific capacity measured during injection was 26 m^2/day (0.31 l/s/m, or roughly $1/10^{th}$ of the specific capacity prior to the start of the experiment). The report does not discuss the reasons for this in any detail but it could reflect clogging or other factors that slowed infiltration as injection proceeded. It was assumed that the specific capacity would remain approximately the same during injection and pumping. If the water level were built up one metre at the injection well, water would move into the aquifer at the rate of 1.08 m^3/hr (0.3 l/s). The available water level build-up was a maximum of 35 m; therefore a calculated maximum injection rate of 36 m^3/hr (10 l/s) could be accommodated if clogging did not occur.

The following conclusions were drawn from the pilot study:

- A total of 19,747.87 m^3 of water from the source well was injected into the recharge well over a period of 42 days at an average rate of 470 m^3 /day (5.4 l/s).

- The artificial recharge tests caused a decrease in the specific capacity of the recharge well. The principle cause for this was partial clogging of aquifer materials in the vicinity of the well due to: (a) sediments carried in the recharge water, (b) air bubbles, and (c) the reaction between the oxygen-rich recharge water and the oxygen-poor, iron-rich native groundwater. Intermittent pumping and redevelopment removed the injected sediment by airlifting, even though the specific capacity was lower than pre-recharge specific capacity.
- The specific capacity of the recharge well was considered a useful tool for detecting and evaluating clogging and for determining the effectiveness of well redevelopment.

The recharge operations caused an apparent decrease in the water yield of the recharge well. This was due to the clogging of the screen in the vicinity of the aquifer. The injection head increased with time and sooner or later diminished the rate of flow, meaning that the recharge well would require regular cleaning to sustain the yield.

Assessment and potential of recharge

The above are examples of recharge accomplished isolated cases. Their effectiveness and potential have not yet been studied. As a result, the amount of water artificial recharge contributes to groundwater storage has not been assessed. To that end, a more organized effort at monitoring is needed.

In Kathmandu Valley groundwater recharge is constrained by the widespread distribution of lacustrine deposits and inter-bedding of black thick clay, which limits easy access to aquifers. Due to over extraction, the decline in groundwater levels is continuous and serious. The discharge rates of production wells at Manohara well field, for example, have dropped considerably. The average discharge rate was 40 l/s at the beginning of pump operation in 1985 but only 20 l/s in 2000. This is attributed to changes in groundwater availability, but could as well be due to deterioration and ageing of the wells themselves.

A comparison of estimates of recharge calculated using various methods is shown in Table 12..Their average is close to the amount obtained from water balance computation which suggests an average annual recharge for the Kathmandu Valley basin of 51 mm/year or 45,690 m^3/day. The recharge calculated by the specific yield method is smaller than others. This method may not give an accurate estimate because parameters like annual water table fluctuation and specific yield are taken as constant for the whole basin. This method is used only for unconfined aquifers but Kathmandu Valley also has multi-layered and confined aquifers. The estimate of recharge by this method is less useful than those given by other methods.

Table 12: Comparison of recharge estimates

Calculation method	Estimated recharge (mm/year)	Recharge volume (m^3/day)
Water balance	51	45,690
Base flow separation	55	49,140
Specific yield	38	33,542
Chloride balance	59	53,606
Groundwater flow	41	36,394

Source: Gupta, A.G., G.N. Poudyal and M.N. Shrestha (1990). Assessing Safe Yield for Groundwater Basin in Kathmandu Valley. AIT Research Report, November.

Because of sediment and topographic conditions, suitable potential rechargeable geological units are limited to lacustrine deposits underlain by arenaceous deposits. The mountain ranges surrounding the valley have little possibility for groundwater recharge because of their high relief, though several water springs do originate in mountain ranges composed of sandy schistose limestone.

Argillaceous materials and the intercalation of arenaceous sediments into them underlie the central and southern parts of the valley. In this region, the potential for groundwater recharge is low because of the presence of impervious clay-rich layers. Arenaceous sediments are limited to the northern margin areas of the Kathmandu Valley bottom. According to one field survey, (JICA 1990) grayish clayey sediment 0.5-1.5 m thick is intercalated with medium-to-coarse sandy materials in river flanks even in the northern parts of the valley bottom. As a result, locations where recharge is likely to be viable even in the northern area may be very dependent on site-specific conditions.

Low resistivities of several tens of ohm-m are predominant in the valley bottom, whereas high resistivities in excess of 100 ohm-m[5] are measured in the northern marginal area. Areas of high resistivity coincide fairly well with areas underlain by arenaceous deposits. Some areas with high potential for recharge include:

- Manohara
- Sankhu
- Dhobi Khola (basin)
- Tokha
- Gokarna
- Bhimdhunga

Regardless of soil texture and permeability, studies have found that a large volume of water seeps into the ground. While the catchment area from Mulpani to the Manohara Bridge increases, flow decreases (see Table 14). This can be attributed to the following two factors:

5 See JICA (1990). Groundwater Management Project in the Kathmandu Valley, November.

a) Excessive pumping of water from various shallow and deep wells around Mulpani has lowered the groundwater table which in turn has caused water to flow from the river to the water table and has thus reduced river discharge in the downtown section.
b) The prevalence of agricultural plains close to the Nilbarahi and Manohara bridges have led to river water being diverted for irrigation, thereby reducing their discharge.

An attempt to measure the discharge of various rivers and streams in the valley showed that discharge during the monsoon is high compared to the low flow of the winter. Normally flow increases as the catchment increases. However, at some points along the Bagmati, Manohara and Hanumante rivers, the flow decreases at downstream points. This is not the case in other rivers. Arrows in Table 13 point out declines in discharge.

Table 13: Initial attempt at quantifying discharge

River	Station location	Catchment area (km^2)	Dry season discharge (l/s)	Rainy season discharge (l/s)
Dhobi Khola	26 Bhangal	10.2	18.5	1944
	27 Bhangaltar	11.4	23.3	2084
	28 Dhumbaharai	60.9	4.1	4258
	14 Dhobi Khola ring road bridge	61.2	8.4	5039
Bagmati	19 Gokarna	56.9	233	7467
	5 Gokarna Sankhu road bridge	57.8	246	7783
	18 Gaurighat	66.6	259	5885 ↓
	38 Chobhar	585	1850	32737
Manohara	21 Mulpani	58.2	99.9	3284
	22 Nilbarahi	62.5	74.2 ↓	3100 ↓
	6 Manohara bridge	73.8	24	7489
	7 Manohara ring road bridge	255	177	18737
Hanumante	41 Nagarkot Int.	6.8	NA	682
Tabyakhusi	42 Bramhayani bridge	21.5	NA	506 ↓
Suidi	29 Taikabun	2.5	2.4	37
	30 Taikabun	2.9	6.5	28
Hanumante	16 Hanumante bridge	78.2	15.5	1374
Godavari	13 Saga Confluence	17.2	74.8	659

Source: JICA (1989)

Ways Forward

The annual rainfall in Kathmandu is sufficient to meet immediate drinking water needs. The challenge is to devise technical and institutional mechanisms that can make this happen. Recharge is an option, but the ability to recharge and store rainfall in the aquifers underlying Kathmandu has yet to be explored at the level of technical detail required for an accurate evaluation. Many users depend on groundwater resources for their basic water needs, including irrigation. Increasing use and extraction of groundwater has lowered water levels in some well fields. If continued unchecked, declining water levels could undermine existing wells and possibly springs and other groundwater-dependent sources. Declining water levels present a potential opportunity because they create space in aquifers that can be used to store monsoon runoff. The experiments described above to replenish groundwater through injection wells were, as anticipated, unsuccessful because of the high cost and complicated technical requirements. Other less technically complicated options are worth investigating in greater detail. These include:

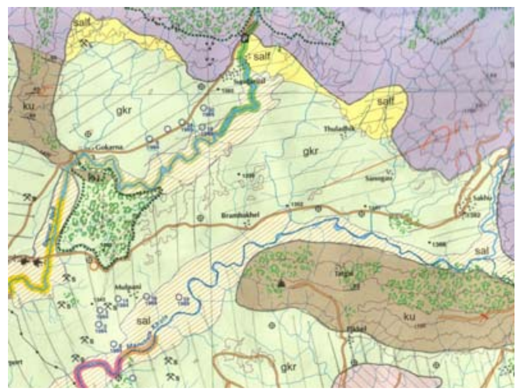
1. *Assessing the full potential of the rivers in the northern parts of the Kathmandu Valley for induced recharge*. A large quantity of water is available during peak flows (when turbidity is a problem for direct river abstraction), but what quantities are available during low flows and what is an acceptable minimum environmental flow need to be ascertained. This type of scheme would probably need to be operated in conjunction with other sources when abstraction is restricted; an ASR that could be recharged during peak flows is an ideal complementary scheme.
2. *Operating the relatively permeable aquifers in the northern parts of the Kathmandu Valley (such as in Gokarna or Manohara) as underground reservoirs.* This would require a combination of careful well field design (locating wells at sufficient distances from rivers so that they tap recharged groundwater rather than current stream flow) and creative approaches to recharge involving, for example, seepage through existing irrigation channels or the construction of infiltration galleries.
3. *The development and implementation of rooftop water harvesting systems in new and existing buildings throughout the valley*. Model rooftop water harvesting systems have already been developed and implemented. By testing these on a larger scale, an estimate of how much water could actually be collected can be calculated.
4. *Establishment of a network of ponds in the foothills surrounding Kathmandu*. Such ponds already exist in some areas, but the degree to which they actually contribute to recharge has not been assessed.
5. *Construction of water harvesting structures in the small valleys and gullies along the margins of the Kathmandu Valley floor* - locations such as the foothills of Shivapuri (in the northern section of the valley) could be optimal.
6. *Encouraging recharge through existing irrigation and agricultural systems*. Agriculture is still a major occupation in many sections of the Kathmandu Valley. A survey of existing irrigation systems could help identify locations where recharge is already occurring or where it could be enhanced. Careful design of well fields with the objective of inducing additional recharge and capturing groundwater could substantially increase supply.
7. *Land regulation, which forbids urban development in the possible recharge zones in the three districts.* Particular care needs to be taken in dealing with the areas in the three groundwater districts which are conducive to recharge. In the

NGD, the recharge areas are located around Tokha, Buddhanilkantha, Sundarijal, Gokarna, Bansbari, Dhobi Khola and Sankhu, in the catchment of the Manohara River.

Proposal for Future Work

Operation of Northern Aquifers as Reservoirs

Map 3



With financial support from the Japanese government, the NWSC has recently developed a major well field in the Manohara area of the Kathmandu Valley. This and the adjacent Gokarna area are underlain by the relatively permeable silty-sand deposits of Gokarna formation (denoted by gkr on Map 3). The gkr formation appears to be in direct hydraulic contact with the highly permeable alluvial streambed sediments along the upper Bagmati and Manohara rivers. A relatively shallow, buried ridge of impermeable shists and quartzites of Kulekhani formation (ku on the map) may, in addition, keep groundwater in these areas at least somewhat hydraulically separate from groundwater in the rest of the valley. The Kulekhani formation could, in effect, serve as an underground dam for the areas upstream of Gokarna in the Gokarna formation and in the Bagmati and Bramhakhel along the Manohara River. Evaluation of the extent to which this formation does serve as a dam would require much more detailed analysis of groundwater conditions than has currently been undertaken. Groundwater contours on the map indicate that flow directions are toward the river, suggesting that the formation may not have much effect on flow patterns. This said, little information is available regarding flow directions during different seasons (contours on the map may represent post-monsoon peak water levels) or how they would change with additional groundwater development in the region.

The above hydrological situation, if confirmed, could provide an opportunity for aquifer storage and recovery. The basic approach would be to design well fields above Gokarna and Bramhakhel so that they tap water stored in the Gokarna formation. Pumping in this area should draw water levels down, particularly during the dry season, and thereby induce additional recharge through the permeable alluvial streambed sediments. In addition, it may be possible to induce recharge in this area by increasing irrigation using traditional systems when surplus water flows are available or by constructing ponds and recharge galleries. Evaluating the possibility of operating the northern aquifers as reservoirs would require the following steps:

1. *Work to confirm subsurface hydrological conditions*. Important questions need to be answered: Does the Kulekhani formation create an underground dam? How do groundwater conditions change with season (does available aquifer space fill up during the monsoon and would additional recharge simply flow into the river)? How deep is the permeable section of the Gokarna formation? What is the degree of hydraulic connection between alluvial stream sediments and the Gokarna formation?
2. *Evaluation of surface recharge options*. How many surface irrigation systems exist in the area? Where do they run? When are they operated? What other considerations may influence their operation for recharge as well as irrigation purposes? Similar questions concerning recharge galleries or ponds have to be answered.
3. *Quantification of excess water available for recharge in the area*. How much excess stream or overland flow is available above the Khulekani formation area? Gauges may not exist so they either need to be established or the information needs to be estimated in other ways.
4. *Modelling to estimate overall storage and recovery*: Development of a realistic groundwater model for the pilot area is needed to make estimates.

Based on NWCF's review of available data, three possibilities for future work on groundwater recharge and water harvesting in Kathmandu Valley appear particularly promising to pursue. The first of these would involve a detailed investigation of opportunities for storage and recovery in the upper Bagmati (Gokarna)-Manohara area. The second is an expanded version of the first that would include construction of an underground dam to enhance storage and recovery options. The third focuses on a widespread program of water harvesting using ponds and rooftops and by rehabilitating *rajkulos*.

Storage and Recovery: Bagmati (Gokarna) –Manohara Area

As discussed above, the NGD has its recharge area in the north, in the foothills of the Shivapuri mountain range. As shown in the Engineering and Geological Map of Kathmandu Valley, the impervious Kulekhani formation runs parallel to and slightly south of the Shivapuri range. As a result, there are small depressions to the north of the formation that probably have a strong potential for holding unconfined groundwater. Most water vendors supply the city with groundwater extracted from this area. There is no information about how deep the Kulekhani formation is. The ridge near Gokarna and to the east of the Manohara River suggests that in the valley where the Manohara and Bagmati rivers flow, the ridge is not very deep. If that is the case, making an underground dam over the ridge could raise its level and thereby increase the depth of the aquifer in the north. As previously noted, much would depend on the nature of groundwater conditions above the ridge. If groundwater flow directions are primarily toward the river and remain that way following construction of a well field, additional recharge in this area could simply increase river flows rather than create stored supplies that could be used between seasons under a managed aquifer storage and recovery program. If, however, groundwater flow directions move down through the gap between Gokarna and Manohara, then an underground dam could assist in creating substantial storage. Underground dams of this type have been used with high levels of success in arid areas (such as in Kutch, Gujarat).

In the Kathmandu case, any dam would need to be evaluated as part of a larger system for operating the aquifer within the Gokarna-Manohara zone. This evaluation would need to analyse specific recharge options, such as induced infiltration through pumping, increased infiltration through agricultural fields, the construction of infiltration galleries and injection. Since previous injection experiments have not proved promising, other options are particularly important to investigate. The aquifer's response to pumping would also need to be evaluated - In theory, pumping groundwater during the summer to meet domestic as well as agricultural needs could help to draw groundwater levels down above the dammed area and create the space in which additional monsoon water could recharge the aquifer. The viability of this would, however, depend on the presence/absence of permeable sediments, confining layers and other location-specific hydrological factors, including patterns of groundwater discharge to the upper Bagmati River. Assuming hydrologic conditions are favorable, simple calculations suggest that approximately 1 million m^3 of water could be extracted per year (see box below).

It is important to recognize that, if hydrologic conditions are suitable, construction of an underground dam and operation of the Gokarna-Manohara aquifer as a reservoir could be a good option for recharge because it would not require the acquisition of substantial land, making the approach far more cost-effective. In addition, the approach is unlikely to have major problems in terms of rehabilitation, resettlement and pollution, nor would it disturb land use patterns. Environmental impacts are also likely to be minor. The only obvious concern would relate to reductions in dry season flow in the upper Bagmati as a result of pumping in the Manohara-Gokarna area. However, because flows in the Bagmati River decrease below Gokarna and then increase further down in the basin (probably due to groundwater contributions downstream), impacts on low-season flows immediately below Gokarna could be substantial while changes in flow further down in the basin may be minor. Evaluation of this would require substantial data and careful modelling of surface-groundwater interactions in the area.

Calculation showing possible water extraction under different conditions

Area under consideration: 28 Km^2
Net area under consideration: 40% of 28 Km^2 = 11.2 Km^2

According to Linsley *et al.* (1975) the approximate average porosity and specific yields of various materials are as follows:

Material	Porosity (%)	Specific Yield (%)
Clay	45	3
Sand	35	25
Gravel	25	22
Sand & Gravel	20	16
Sandstone	15	8
Dense Limestone and Shale	5	2
Quartzite, Granite	1	0.5

The volume of water collected by raising the height of a proposed subsurface dam by two meters under different saturation conditions can be calculated as follows; average porosity is assumed to be 20%:

A) Assuming the area reaches 100% saturation: 1.0 x 0.2 x 2 m x 11.2^6 m^2 = 4,480,000 m^3
B) Assuming the area reaches 75% saturation: 0.75 x 0.2 x 2 m x 11.2^6 m^2 = 3,360,000m^3
C) Assuming the area reaches 50% saturation: 0.5 x 0.2 x 2 m x 11.2^6 m^2 = 2,240,000 m^3

Now, if Specific Yield is assumed to be 10%, only 50% of the water stored could be pumped. Amounts of water that could be pumped under different saturation levels are shown below:

Saturation (%)	100	75	50
Water volume collected (m^3)	4,480,000	3,360,000	2,240,000
Extractable water volume (m^3)	2,240,000	1,680,000	1,120,000

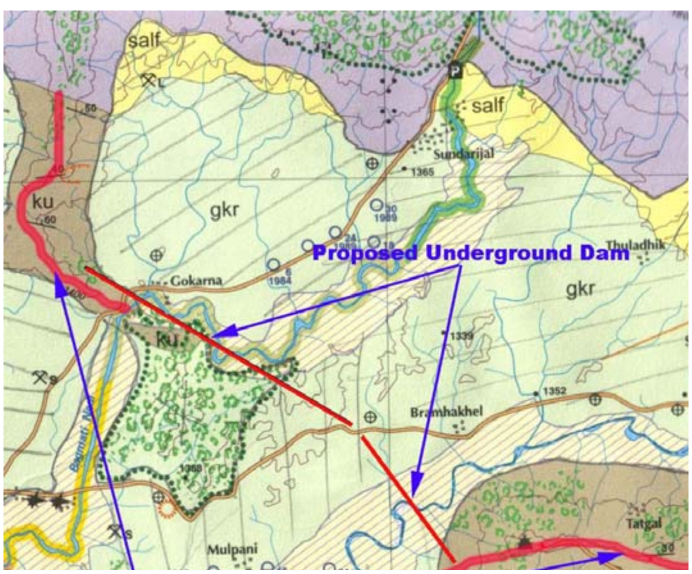
The porosity of the area may vary and high porosity does not necessarily indicate a productive aquifer, since much water can be still retained under capillary tension in small pore spaces even as the lavers are dewatered.

Now to a few details on the potential recharge area. The area under consideration to the north of the schist ridge is about 28 km^2. The amount of water that can be stored in this area cannot be estimated accurately as no work has yet been done to determine the porosity of the subsoil in that area. Detailed fieldwork needs to be undertaken.

The average dry and wet season discharges are about 0.024 m^3/s and 7.8 m^3/s for the Bagmati River and 0.1 m^3/s and 3.3 m^3/s for the Manohara, respectively. Even though the Manohara drains a larger catchment area, its wet season flow is relatively low, indicating that a large part of the runoff from the basin is taken for irrigation or percolates into the groundwater. The wet season discharge in the Bagmati River decreases between Gokarna (at the Sankhu Road Bridge) and Gaurighat (Table 13). The same situation exists in the Manohara River. The discharge should, however, increase as the catchment area increases. The fact that the situation is the opposite of the theoretical projection suggests that both rivers help recharge groundwater in the upper aquifer region even during the wet season. This data must be verified, however, because it could be argued that the irrigation canals between these points divert the water. Most irrigation diversions in the region are, however, relatively localized and excess water should return relatively early to the stream rather than lower down in the basin. If this is the case, the difference in discharge suggests that surface water may be lost to groundwater, an idea that would require further investigation to verify or disprove.

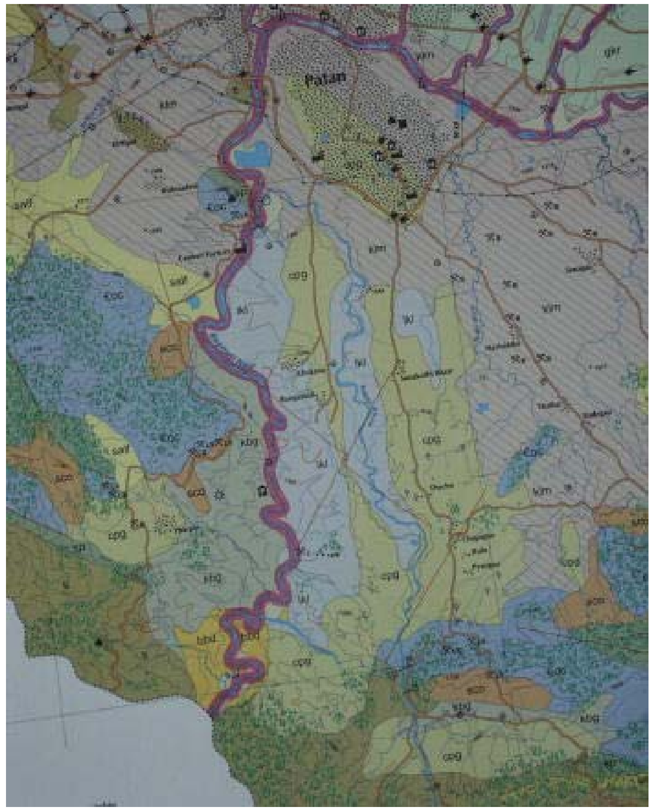
Whether or not the rivers currently lose or gain flow from groundwater under current conditions, intensive pumping of the aquifer in the upper regions to draw groundwater levels down and operate the aquifer as a reservoir would increase infiltration from the river into the aquifer. Under these conditions, increasing the storage capacity of the aquifer could enhance the volume of water stored and later recovered. By using the Water & Energy Commission Secretariat/Department of Hydrology & Meteorology (WECS/DHM 1990) method, the one-day, 20-year return period low flow of the Manohara River at the Ring Road Bridge has been calculated at 1.02 m^3/s. With this discharge and the area to be developed (about 40% of the 28 km^2 recharge area) as a below surface groundwater reservoir, sufficient water could be collected for the valley's needs without disturbing the natural recharging process of the adjoining area.

Map 4: Underground dam, conceptual location



In order to evaluate the potential for groundwater storage in the area above Gokarna, we need to know more about the actual nature of groundwater flow patterns in the region and the underlying hydrology, particularly the height of the impervious ku layer. Whether or not an underground dam might contribute to additional storage in the region would depend on both these factors. In addition, the cost of any underground dam and the viability of constructing one would depend on the depth and length of the underground impervious layer. A detailed survey needs to be done to determine the measurements and structure of the ridges. Detailed surveys of groundwater conditions are also required. These would need to combine both monitoring of water levels in order to determine flow patterns throughout the year and pumping tests to determine how flow and storage patterns could be changed as part of an active system for operating the aquifer. A rough outline of where an underground dam could be constructed to enhance groundwater storage and recovery potential in the area above Gorkarna and Manohara is shown on Map 4.

Water Harvesting in Other Areas

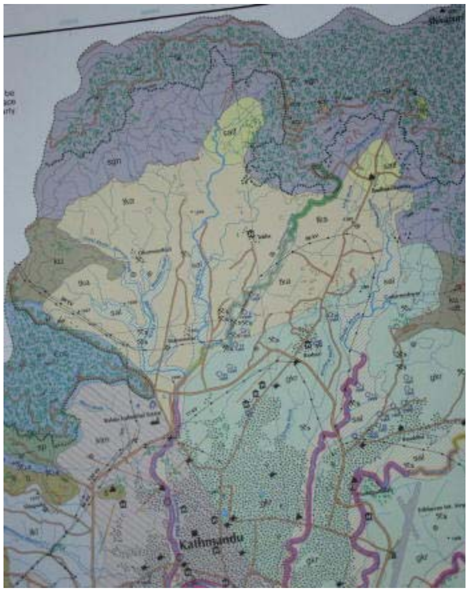


Map 5

The Nepal Water Conservation Foundation has, over the years, been involved in analyses of the emerging problems and current practices of water management, and adopts an interdisciplinary approach to research on water development. This approach is essential in order to systematically evaluate the contribution to groundwater recharge that could be made through rooftop water harvesting, ponds and rehabilitation of *rajkulos*. Specific activities to evaluate the viability of these approaches and the contributions they could make to water supply in the valley include:

1. A survey of groundwater conditions (including infiltration rates, aquifer structure and groundwater quality) along with possible locations for rooftop harvesting, ponds and *rajkulo* rehabilitation. This would largely be a technical review to indicate where each approach could actually contribute to groundwater recharge in areas where the water quality permits subsequent utilization of additional recharge water.
2. A review of the institutional and other incentives facing the households, communities and government organizations that would need to be involved in any program for recharge.
3. Analysis of the ways in which water collected through new systems could be made available to users (i.e. through private wells, through the existing municipal supply system, through water markets, etc…).
4. Analysis of critical challenges (such as the expanding urban area) that would need to be addressed in order for specific approaches to remain viable.

The findings of the proposed study will help us to identify cost-efficient and sustainable solutions and to highlight the need for a democratically contested policy terrain where space for dialogue between state, market and social auditors is encouraged.



Map 6

Water harvesting strategies of the type indicated are likely to be most applicable in the rural areas along the valley edges where agriculture remains the dominant land use. The obvious areas are in the northern portions of the valley underlain by the permeable Gokarna formation, such as Tokha, Sankhu and Gokarna [see maps 5 & 6]. Other possibilities may exist in the southern parts of the valley where alluvial streambed sediments (sal) are present or in formations that, based on the lithology, should have locally high permeabilities: the Chapagaon (cbg), Kobgaon (kbg), Tokha (tka) and possibly even Lukundol (lkl) formations, for example. Evaluation of this option would require:

1. Developing a comprehensive map of surface irrigation systems in the valley or, at minimum, in regions where hydrological conditions (soil types) would appear particularly conducive to this approach.
2. A more detailed hydrological evaluation of regions where formations, based on their lithological descriptions, appear potentially promising.
3. Measuring infiltration rates in existing irrigation channels and fields.
4. Monitoring surface water supplies to determine where and when excess water may be available.
5. Identifying potential locations for wells to induce recharge and aquifer return flows from agriculture.
6. Modelling specific areas to estimate actual amounts of recharge that could be induced and captured as examples of the potential.

CONCLUSION

Substantial opportunities may exist for groundwater recharge and water harvesting to supplement water supplies in the Kathmandu Valley. These opportunities have been sketched out in a systematic but speculative manner in this paper.

Opportunities may exist in the northern portion of the Kathmandu Valley where the permeable nature of the valley fill and upper aquifers could allow both storage and recovery. The upper Bagmati area near Manohara and Gokarna appears particularly promising. Through a carefully designed well field potentially enhanced by specific recharge facilities, it might be possible to ‘operate’ this portion of the aquifer as a reservoir. Additional opportunities may exist through rooftop rainwater harvesting or pond systems.

Investigation of potential opportunities for aquifer recharge in the Kathmandu Valley will require improvements in the availability of and access to basic data. Because data are highly fragmented and often located in project files held by different agencies, it is difficult to evaluate whether or not even basic and widely quoted details of the hydrologic context are accurate. As a result, synthesis of available data and additional data collection in areas that appear to have a high potential for aquifer storage and recovery is an important first step.

In addition to being dispersed, data are also sparse, particularly longer-term monitoring data. A review of existing hydrological monitoring should be undertaken and a strategy for monitoring should be prepared. This should include surface water flow and quality as well as groundwater level fluctuations and quality changes. The strategy should build on the existing network to initially address some of the issues identified in this paper, but should also consider longer-term issues such as climate change, change of land-use and impacts of water imported to the valley.

It is important to emphasize that all opportunities for using Kathmandu's aquifer depend heavily on the ability to control land use and prevent pollution in key recharge areas. At present, the northern portions of the Kathmandu aquifers appear to be relatively unpolluted. Urbanization is, however, occurring rapidly in many parts of the valley. If this occurs across the prime zones suitable for recharge it is likely to reduce possibilities for any project relying on groundwater in the valley. In addition, under current conditions, urbanization will lead to the introduction of heavy pollution loads. The development of effective sewer systems and leakage control are both essential to protect water quality in such areas. Furthermore, reductions in leakage in drinking water supply systems are essential in order to ensure that new supplies developed through artificial recharge are not lost.

Actual evaluation would require much more detailed analysis based on new field data on groundwater conditions in order to substantiate the conceptual possibilities identified here.

References

1. Becker-Ritterspach, Raimund, O. A., 1995: Water Conduits in the Kathmandu Valley, Munshilal Manoharlal Publisher, India.
2. Binie and partners ,1998: Water Supply for Kathmandu-Lalitpur from Outside the Valley, Kathmandu.
3. BPC, technical Assistance to Melamchi Diversion Scheme, 1996. Final Report, Volume 1, February.
4. CBS, 2001: Statistical Pocket Book-Nepal, His Majesty's Government, National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu.
5. CBS, 2002: Statistical Pocket Book-Nepal, His Majesty's Government, National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu.
6. DHM, 1998: Hydrological Records of Nepal, Stream flow Summary, April.
7. Dixit, A., 1997: Inter-Sectoral Water Allocation: A Case Study in Upper Bagmati Basin, in Rajendra Pradhan, Franz von Benda-Beckmann, Keebet von Benda-Beckmann, H.L.J Spietz, Shantam S. Khadka, and K. Azharul Haq (eds). *Water Rights, Conflict and Policy*, Proceedings of a Workshop Held in Kathmandu, Nepal, January 22-24, 1996, International Irrigation Management Institute.
8. Dixit, A., 2002: Basic Water Science, Nepal Water Conservation Foundation, Kathmandu.
9. Gupta, A. S., Poudel, G. N. and Shrestha M. N., 1990: Assessing Safe yield For Groundwater Basin in Kathmandu Valley.
10. Gyawali, D.: 2001: *Water in Nepal*, Nepal Water Conservation and Himal Books, Kathmandu, Nepal.
11. HMG, 1994: Bagmati Basin Water Management Strategy and Investment Program, His Majesty Government of Nepal, Ministry of Housing and physical planning, Kathmandu.
12. HMG, 1998: Engineering and Environmental Geological Map of Kathmandu Valley, Department of Mines and Geology, Kathmandu.
13. HMG, 2004: *Optimizing Water Use in Kathmandu Valley (ADB-TA) Project*, Final Report, Ministry of Physical Planning and Works, HMG/N, Kathmandu.
14. JICA, 1989: Groundwater Management Project in Kathmandu Valley, Final Report (Progress Report 1 & 2).
15. JICA, 1990: Groundwater Management Project in Kathmandu Valley, Final Report (Supporting & Main Report).
16. Joshi P. L., 1993: Feasibility Study of *Rajkulo*; Rehabilitation of Patan's Traditional Water Supply Network, Main Report, Volume 1.
17. Kansakar D. R., 2001: Groundwater Resources in the Hills and Mountain Regions of Nepal.
18. Kathmandu Valley Town Development Project, 1982, *Kathmandu Nagar Chetrako Inventory* 2039.
19. Kharel B. D., 2002: Artificial Recharge Pilot Project Report on Artificial Recharge Test, June.
20. Linsley R.K.(Jr.), Kohler, M., Paulhus, A., Joseph, L.H., 1975: Hydrology for Engineeres (2nd edn.), McGraw-Hill, New York.

21. Metcaff & Eddy, Inc. in association with CEMAT Consultants (P) Ltd., 2000: Urban Water Supply Reforms in the Kathmandu Valley Groundwater Monitoring Program, February.
22. NWSC, 2000: Annual Report, Nepal Water Supply Corporation, Kathmandu.
23. NWSC, 2000, Management Information Report, Nepal Water Supply Corporation (unpublished).
24. NWSC, 2003: Nepal Khanepani Sasthan eak Parichaya, Nepal Water Supply Corporation, Kathmandu.
25. Pradhan Rajendra (ed.), 2003, Law, History and Culture of Water in Nepal
26. Rai N., 2002: Impact of Piped Water Supply in Sustaining Traditional Water Management System and the Existing Water Quality, A case study of Sankhu VDC. SchEMS, Kathmandu
27. SMEC, 1992: Greater Kathmandu Water Supply Project, Final Report, Volume 3, Hydrology, November.
28. Tiwari, S. R., 1988: Tiered Temples of Nepal, Sunita Tiwari, Kathmandu.
29. WECS/DHM, 1990: Methodologies for estimating Hydrological characteristics for ungauged location in Nepal, Department of Hydrology and Meteorology and Water and Energy Commission Secretariat.