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GROUNDWATER MANAGEMENT PROJECT
IN
THE KATHMANDU VALLEY

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JAPAN INTERNATIONAL COOPERATION AGENCY

HIS MAJESTY'S GOVERNMENT OF NEPAL
NEPAL WATER SUPPLY CORPORATION

GROUNDWATER MANAGEMENT PROJECT IN THE KATHMANDU VALLEY

FINAL REPORT

MAIN REPORT

NOVEMBER 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

PREFACE

In response to a request from the Government of Kingdom of Nepal, the Japanese Government decided to conduct a study on the Groundwater Management Project in the Kathmandu valley in the Kingdom of Nepal and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Nepal a study team headed by Mr.Takao Ichimiya (Nippon Koei Co.,LTD), and composed of members from the Nippon Koei Co., LTD. and Japan Engineering Consulting Co.,LTD from January 1989 to February 1990.

The team held discussions with concerned officials of the Government of Nepal, and conducted field surveys. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Kingdom of Nepal for their close cooperation extended to the team.

November 1990

Kensuke Yanagiya

Kensuke Yanagiya
President
Japan International Cooperation Agency

November,1990

Mr. Kensuke Yanagiya
President
Japan International
Cooperation Agency
Tokyo, Japan

LETTER OF TRANSMITTAL

Dear Sir,

We have the pleasure of submitting to you a Final Report of "Groundwater Management Project in the Kathmandu Valley" which is prepared for the consideration by the Government of Nepal in implementing the optimum water resources management in the Kathmandu Valley.

This report consists of four volumes. The Executive Summary contains the summary of the study result. The Main Report comprises the result of the water resources management study. Supporting report contains the analysis and discussion in the sector of socio-economy, hydrology, hydrogeology, groundwater simulation, surface water resources, water supply system, population projection, and water demand to support the main report. Data Book contains basic data of the study.

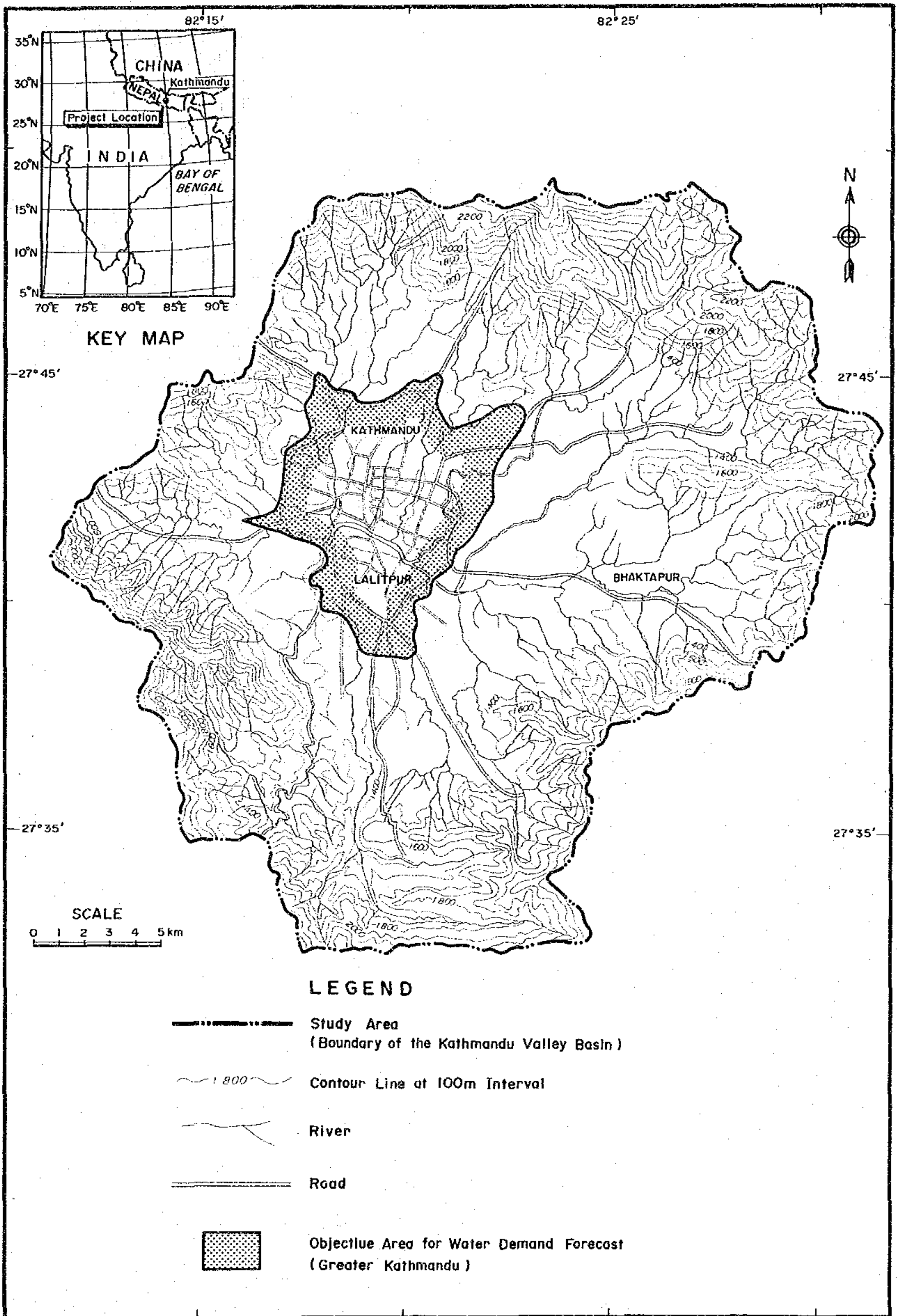
All members of the Study Team wish to express grateful acknowledgement to the personnel of your Agency, Ministry of Foreign Affairs, Embassy of Japan as well as officials and individuals of Nepal for their assistance extended to the Study Team.

In conclusion, the Study Team sincerely hopes that the study results would contribute to the future water resources management in the Kathmandu Valley.

Yours Sincerely,

T. Ichimiya

Takao Ichimiya
Team Leader



HIS MAJESTY'S GOVERNMENT OF NEPAL
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JAPAN INTERNATIONAL COOPERATION AGENCY

LOCATION MAP

SUMMARY

A.BACKGROUND

1. The study area is located in the whole Kathmandu valley. The floor is about 1,300 m above sea level and about 585 km^2 in area. The valley is almost fully utilized as agricultural land, with the paddy fields widely distributed over its floor. There are three cities in the valley, Kathmandu, Lalitpur (Patan) and Bhaktapur (Bhadgaon). The valley is populated by about one million (as of 1990) inhabitants, of whom 0.5 million are concentrated in these three cities. The objective area of projected water demand located in the central part of the Kathmandu valley which is composed of urban area of Kathmandu and Lalitpur. Kathmandu and Lalitpur are located side by side and function as one city which is called Greater Kathmandu. Its population is estimated 0.43 million (as of 1990). Kathmandu is the capital of the Kingdom of Nepal and the seat of government administration and all other activities.

2. The municipal water supply system of Greater Kathmandu has a history of more than 100 years, and many of the facilities are superannuated. The executive agency for water supply and sewerage is The Nepal Water Supply Corporation (NWSC) which belongs to The Ministry of Housing and Physical Planning (MHPP). This body was called The Water Supply and Sewerage Corporation (WSSC) before March 1990. In the early 1970's, deficiencies in the water supply became notable. To cope with the needs, a Master Plan was prepared in 1973 by UNDP. The First Project, Second Project and Third Project were executed successively under a loan from IBRD, and were completed in 1987. Their main achievements were construction of a number of reservoirs and transmission pipe lines, as well as 43 deep wells of which 30 wells are in use.

3. The water source before and for the IBRD's projects had been solely surface water. Groundwater was added in the projects. The quantity of water was thus increased to meet demand for the time being, but the quality of the well water was undesirable for the water supply. Since it contained a high percentage of ammonia, ferrous and manganese matters which caused complaints from consumers. Delivered well water has a reddish color, suspended matter and un unpleasant odor, all of which makes the well water unsuitable for the domestic use including drinking, cooking and washing. After a while such well water was mixed with surface water and sent to consumers. This improved the situation to some extent but there was no way to improve the quality and no countermeasures have been taken on this matter. Moreover water distribution to consumers is made by a "twice a day" system which has been practiced since the beginning and the rate of losses including leakage and those unaccounted for are very high.

4. It was stated in the 1973 Master Plan that the water resources of the valley would be exhausted by the year 2001, and it was necessary to search for water outside the valley. In line with in advice a study to find the best new source of water was made in 1989 by UNDP. As a result of this study, and a Melamchi Khola located to the north of the valley was selected and a feasibility study of the waterway tunnel is under way by UNDP. It is intended that water from that source will become available before 2001.

5. To cope with the increasing demand before 2001, it is also necessary to expand the water sources which are available inside the valley before 2001, as well as to establish a plan for water management before 2001. The government of Nepal accordingly requested the Government of Japan to provide technical cooperation on these matters. In response to this request, the Government of Japan organized, through The Japan International Cooperation Agency (JICA), the study team for The Groundwater Management Project in the Kathmandu valley (the study team). The study was commenced in January 1989 in close collaboration with NWSC. By November 1990, field work in the valley and office work in Tokyo had been completed in three phases each. Five reports, Inception, Progress 1, Progress 2, Interim Report and Draft Final Report were prepared and discussions with NWSC were made at each submission of these reports. This present report is a Final Report incorporating the Government's comments.

B PRESENT CONDITIONS

6. Geography and hydrology: The kingdom of Nepal has a territory of 147,181 km^2 and a population of about 18 million in 1990. The country is rectangular in shape and has four different topographic regions in the East-West direction. These are the Himalayas mountain range, Mahabharat mountain range, the Siwalik mountain range and the Terai plain which is the northern fringe of The Ganges alluvial plain. The Kathmandu valley is located to the south of the Mahabharat mountain range, and about 1/3 of the longitudinal side distant from the eastern side. The floor of the valley is situated at about 1,300 m elevation, whereas the surrounding mountains are about 3,000 m above sea level. There is only one drainage system, the Bagmati River which has many tributaries in the valley that are finally unified as a single river. Hence, there is only one outlet from the valley. The drainage area is 585 km^2 at Cobhar which is located close to the final outlet. The floor occupies 400 km^2. The Study Area of the present study coincides with the drainage basin of the Bagmati River. The annual precipitation is 1,300 mm on the floor and 3,000 mm on the slopes of surrounding mountains. The average precipitation over the drainage area is 1,912 mm. There are distinct rainy and dry seasons. The bulk of the annual precipitation, some 80%, falls in the rainy season which starts in June and lasts till September. Evaporation measured by pan is 3.7 mm/day. The annual total run-off of the Bagmati River at the outlet of the valley is estimated at 500 MCM.

7. <u>Land Use</u>: Of the drainage area, about 420 km^2 or 80% are used as agricultural land. Of this area, 220 km^2 are paddy fields and 90 km^2 are upland. About 7,600 ha in total are irrigated by surface flow. There are numerous irrigation systems which depend on the river water. As these irrigation systems are either old or incomplete, all of them have low irrigation efficiencies. In the dry season, only limited areas are irrigated because of decrease in the river flow. Maximum unit irrigation requirement is estimated at 1.2 l/s/ha which occur during the trans-planting period in June. If a master plan study is made to review and rehabilitate existing irrigation systems, it is evident that not only would the agricultural benefits be increase but also a surplus of river flow would be realized which would increase the water resource for municipal water supply.

8.<u>Geology</u>: The Kathmandu Valley is composed of two series of geological successions; one belonging to the Quaternary deposits which underlie the central part of the valley and overlie the basement rocks the other consisting of Precambrian to Devonian (Paleozoic Era) basement rocks surrounds the Valley. Many mountain ridges extend to the valley bottom from the surrounding mountains, implying that there are many buried ridges. The depth to the Precambrian bedrocks from the ground surface is confirmed to range from several tens of meters to more than 500 m. The thick quaternary deposits of central part of the Valley consists of lacustrine deposits and fluvial deposits. The lacustrine deposits are classified into three types which are arenaceous sediments, argillaceous sediments and intermediate types between these two.

9.<u>Present groundwater use</u>: About 60 tube wells were being operated in the valley at end of 1989, and the estimated annual groundwater abstractions from these wells reached around 14 million cubic meters. Of the 60 operating wells 28 belong to NWSC, however the production of NWSC wells amounts to over 80 % of total estimated abstractions from all the tube wells in the valley. About 30 spouts are used in Kathmandu and Lalitpur area for domestic supply to local people. The estimated yield of the largest scale spout varied between about 3 l/s in the dry season and 15 l/s in the rainy season. However, the quality of the spout water is poor as shown by the coliform count of from 50 to 250 per ml, and also the water has a much higher chloride ion content than water from deep well.

10.<u>Trend of groundwater level</u>: The static groundwater level in the Study Area has declined since commencement of the development of NWSC wells in the Third Project. This groundwater development has resulted in a progressive fall of about 10 meters in the water level during the past 4 years in the Manohara well field. This decline in groundwater level is serious since groundwater abstraction is growing significantly every year.

11.Water quality of groundwater: A high concentration of iron(Fe) in a range of 1 to 3 mg/l, ammonium(NH_4+) in a range of 0.05 to 6.5 mg/l, nitrogen(N) in a range of 0.1 to 4.8 mg/l and potassium permanganate ($KMnO_4$ Cons.)in the range of 3.9 to 16 mg/l are confirmed in most of NWSC tube wells in the valley. However ,such high concentrations of ions are not found in the surface water sources of NWSC.

12.Hydrogeology : Availability of groundwater recharge in the valley is controlled by the widespread distribution of lacustrine deposits interbedding the impermeable black clay which prevents easy access to the aquifers. In northern part of the valley, the upper deposits are composed of unconsolidated highly permeable materials which consist of micaceous quartz sand and gravel. These unconsolidated coarse sediments are as thick as 60 m and forms the main aquifer in the valley. The quality of the groundwater is characterized by low electrical conductivity such as 100 to 200 micro-simens/cm and the transmissivities of the aquifers range from 83 to 1,963 m^2/day.

13. In the central part of the valley,the upper deposits are composed of impermeable very thick (as thick as 200 m)stiff black clay accompanied by some lignite.Unconsolidated low permeable coarse sediments underlie this thick black clay. The quality of the groundwater is characterized by very high electrical conductivity, 1,000 micro-simens/cm in some wells located near Tripueswor. The transmissivities of these aquifers range from 32 to 960 m^2/day. Generally, water head pressure of this area is high, especially all deep gas wells are self-flowing. According to dating analysis, age of gas well water is about 28,000 years. This mean that the confined groundwater of the central area is probably non-rechargeable stagnant or "fossil" groundwater.

14. The southern part of the valley is characterized by a thick impermeable clay formation and basal gravel of low permeability. The aquifer is not well developed and is only recognized along the Bagmati river between Cobhar and Pharphing

15.Recharge : The main aquifer in the valley is a nearly isolated body surrounded and confined by lacustrine deposits. Therefore the flow of water in the aquifer is quite small as confirmed by water chronological analysis by C^{14} and Tritium. Average permeability of the aquitard in the main aquifer is estimated at 0.00033 m/day, or 12 cm/year.

16.Existing Water Works: There are eight (8) water supply systems managed by the NWSC in the valley for Kathmandu-Lalitpur (Greater Kathmandu) and two (2) systems for Bhaktapur. Of the former, the three (3) systems for Chapagaun, Dood Phokari and Lokhat use springs as the water source mainly to supply to villages around the cities.In the other systems, the water sources are surface water and/or groundwater, and the water is collected either at a treatment plant or reservoir, from where it is distributed to the cities. As a result of the investigation, the available water sources for water supply in the valley can now be assumed to amount to 60,540 m^3/day from the surface water and for 55,620 m^3/day from groundwater, amounting to about 116,160 m^3/day. For the groundwater, however, because of the extreme drawdown caused by mutual interference due to the close proximity of many wells, in addition to such factors as facility repairs, electrical faults, etc., the actual abstraction of groundwater may be assumed to be much less than the above the mentioned value.

17. Water Quality: Chemical analyses of existing water resources during dry and rainy seasons have shown that the springs have stable water quality both in the dry and rainy seasons, neither is there any problem with river water as a resource for water supply, if appropriate treatment is applied, although its turbidity may increase immediately after rainfalls in the rainy season. However, groundwater, except for that from the Pharphing well field, contains very high levels of iron, manganese and ammonia, which exceed permissible levels as a water source for water supply. The currently practice of supplying groundwater without treatment results in additional problems.

18. Water Supply: Both surface water and groundwater from all sources, either remain untreated or after treatment through the treatment plants of each system, are stored in the distribution reservoirs, from where they are distributed to the cities through the intermittent supply approximately for three hours each in the morning and evening. The main distribution reservoirs for the Greater Kathmandu are the Balaju, Bansbari, Maharajganj, Mahankal Chaur and Shaibhu reservoirs. According to an analysis of their operation records of August 1989, the daily average supply amount from the above 5 reservoirs amounted to 61,155 m^3/day, of which surface water and groundwater amounted to 39,199 m^3/day and 21,956 m^3/day respectively.

19. Treatment Works: There are now five water treatment plants, at Balaju, Maharajganj, Sundarijal and Sundarighat for the Greater Kathmandu, and at Bansbari for the city of Bhaktapur. One of these, the Sundarighat water treatment plant used to take raw water from the Bagmati, but has recently been shut down because of heavily contaminated raw water due to the increased inflow of an urban sewer. The following describes both the facility and existing status of operating and maintaining each water treatment plant.

20. Balaju Treatment Plant: The Balaju treatment plant was constructed in 1961 to treat the surface water from springs at five locations within the Bisnumati basin. The design capacity is 10,900 m^3/day. When the turbidity of raw water is high, it is designed to add a coagulant to the raw water, but in practice no coagulant is added and the raw water is sent directly to the sedimentation basin. Because of imposing an excessive load on the filter basin and of insufficient coagulation, as well as inadequate washing, the filter media are too contaminated for satisfactory filtration. For disinfection, bleaching

powder is added, but as the quality of filtered water is bad, the residual chlorine is found to be about 0.1 ppm or less in the reservoir.

21.Maharajganj Treatment Plant: This treatment plant was constructed in 1960, and treats the surface water from such springs at Bisnumati and Shivapuri. The design capacity is 2,400 m^3/day.The sedimentation basin was demolished in 1987 due to severe water leakage, and the raw water is now flowing directly into the filter basin. For this reason and because of inadequate washing facilities, as well as the excessive load imposed on the filter basin, the filter media are substantially contaminated.For disinfection, bleaching powder is added, but because of the untreated groundwater flowing into the reservoir from the Bansbari reservoir, as well as the poor quality of the treated water, the residual chlorine is less than 0.1 ppm in the reservoir.

22. Sundarijal Treatment Plant: This treatment plant was constructed in 1966. The water resource for this treatment plant is Bagmati river water from the Sundarijal Dam which was constructed for the Sundarijal hydroelectric power plant. The design capacity is 19,600 m^3/day.When the turbidity of the raw water is high during the rainy season, both a coagulant (alum) and lime are added. But the rate of dosage of both the coagulant and lime is insufficient. The raw water, after the addition of chemicals, is mixed in the channel, then sent to the sedimentation basin. There are three filter basins, each being washed daily. Because the chemical dosage is insufficient and because the capacity of the back washing tank is not enough to continue the washing for a sufficient time, the filter media are contaminated. For disinfection, bleaching powder is added. After chlorination, water is supplied to villages along the transmission line, and then stored in the Mahankal Chaur reservoir.

23. Bansbari Treatment Plant: This treatment plant treats Mahadev Khola river water and supplies it to the city of Bhaktapur. The design capacity is 4,900 m^3/day, but because this plant is not provided with a chemical feeding facility, the raw water flows directly into the sedimentation basin without the addition of coagulant. Especially when the turbidity of the raw water is high during the rainy season, it remains unsettled in the sedimentation basin and flows directly into the filter basins. There are three filter basins. But, for lack of washing equipment, washing of filter materials is manually performed by removing them from the basins.For disinfection, bleaching powder is added to the reservoir. The residual chlorine was found to be about 0.1 ppm in the dry season, but less than 0.1 ppm in the rainy season.

24. Distribution System: Water is now being supplied intermittently to Greater Kathmandu and Bhaktapur from the reservoirs of each system for approximately three hours in the morning and evening. This hourly supply method has been employed ever since water supply commenced in the Kathmandu valley.On the other hand, villages around these cities are mostly situated along the transmission

lines from the water resources up to the reservoirs or treatment plants, through which water is supplied to them directly. The reservoirs were greatly increased in the capacity after the First and Second World Bank projects. The capacities of the reservoirs are now 24,500 m^3 and 5,600 m^3 serving Greater Kathmandu and Bhaktapur respectively.The reservoirs at Balaju, Maharajganj, etc. are now suffering from water leakage as a result of their deterioration. The Bansbari and Shaibhu reservoirs are both insufficient in capacity, causing overflows between the water supply hours.

25. Distribution Networks: Since the distribution networks in cities have been expanded in a disorderly way over a long period to keep pace with increasing demand, both new and old multiple pipelines have been laid under the same roads thus resulting in a very complex distribution system. Incomplete distribution systems also fail to maintain uniform water pressure, often causing water cuts at the ends of the pipelines. For this reason, water is supplied in distribution blocks by carefully operating the valves within the systems during the hours of water supply.The quality of water supplied right after starting the water supply and certain time thereafter was analyzed. Results show that the water quality right after starting the water supply contains very high levels of contaminating substances, which decrease as time goes on. This is attributable to the entry of such substances between supply times and flushing in the pipelines due to the sudden change in the flow velocity caused right after starting the water supply. This is a product of the intermittent water supply method.In this survey, on-site analysis of residual chlorine was made simultaneously upon sampling water. No residual chlorine was found, except from samples in the city of Lalitpur being supplied from the Shaibhu reservoir where the water quality is relatively good.These results indicate that if the water contains very high levels of ammonia, iron and manganese, but lacks residual chlorine, the inside of the distribution system becomes a favorable breeding environment for iron bacteria, nitro bacteria, etc.This results in increased chlorine consumption, as well as in deterioration of the water quality within the distribution pipes. Therefore, the current water quality can not kill pathogenic bacteria and causes the discharge of bacteria and colored water from taps.

26. Required Residual Chlorine and Anti-Corrosion: The level of residual chlorine to be maintained in the tap water must be sufficient to kill such pathogenic bacteria as those causing dysentery, typhoid, etc. Generally, this level has to be 0.1 ppm or upwards as free residual chlorine, while more than 0.2 ppm is necessary during epidemics or right after resuming the service after interruption of supply. Meanwhile for the anti-corrosion program, the past examples have shown that effective results were obtained when the pH was 7.5-8.0 and the Rangelier's index -1.0 or upwards. The Rangelier's index however was -1.50, -2.65 and 0.08 for the Balaju, Mahankal Chaur and Shaibhu systems, respectively. It may be deduced, therefore, that water supplied other than from the Shaibhu system are high corrosive.

C.DEMAND

27. Population Projections: The future populations of urban areas in the Kathmandu and Lalitpur Districts have been projected by many investigators for various projects since 1973. However, the population projections in previous studies vary widely. In the present study, a careful review is made on the two latest studies; by Proctor and Redfern(1984) and by Binnie and Partners(1988), and further a population projection was made by a different method from these studies to examine the large difference between their projections. The result of the present study together with the above-mentioned projections may be summarized as follows:

Studies	Urban Population (,000)			Average Annual Growth Rate (%)*		
	1981	1991	2001	1971-1981	1981-1991	1991-2001
(A)P & R, 1984	316	479	729	4.08	4.16	4.20
(B)B & P, 1988	316	593	958	4.08	6.29	4.80
(C)Present Study	315	486	734	4.08	4.34	4.12

*Exponential model
P & R: Proctor and Redfern
B & P: Binnie and Partners

As is obvious from the above table, that the population forecast in the present study (C) is close to that by Proctor & Redfern (A). The relatively high forecast of population by Binnie and Partners was due mainly to the high growth rate which was estimated from voter's lists for the period 1981-1986. However, since it is difficult to examine the reality of the above growth rate in course of the present study since it may have been influenced by social and political factors outside the scope of the study, the water demand study for urban areas of Kathmandu/Lalitpur, which is discussed in the succeeding paragraph, was carried out on the basis of the population projected in the present study.

28. Present Water Demand:In order to understand how the water supply is actually being used, a consumer survey was conducted during the 1st and 2nd field investigations. The number of samples were 52,246 for the first survey and 24,693 for the second survey respectively. In the first survey, the average consumption per connection, per capita consumption, number of consumers per connection, type of toilets, monthly average consumption, etc., were surveyed. The second survey covered the category of connections (functioning, metered, non-functioning metered and non-metered), category of use (domestic, commercial, industrial and institutional), number of consumers per connection, consumption per connection, etc. Through these surveys useful information was obtained which could not be obtained from the existing data. The original unit of consumption by use can be applied only to data on functioning metered connections, since the original

unit of consumption by use for nonfunctioning metered connections and non-metered connections was found to be respectively 1.10 and 1.77 times of that of functioning metered connections. The monthly consumption pattern was estimated from both the actual monthly consumption of functioning metered connections and the variation in average monthly temperature.

29. Planned water Supply Amount:Water demand projections for establishing the water supply plan up to the year 2001 as the planned water supply should thus be based on the following conditions:

(a) The population to be served is assumed to be that derived in the above mentioned population projection.

(b) Both the non-functioning metered connections and nonmetered connections are assumed to be improved at the rates of 40% in 1991, 20% in 1992 and 1993 and 10% in 1994 and 1995.

(c) For the per capita domestic consumption, an annual increase due to the popularization of cistern flush toilets is assumed to be 0.37 lcd, and the annual increase in the rate due to the livelihood level advancement is assumed to be 2.5%.

(d) The rate of water leakage is assumed to be improved in accordance with the implementation plan for rehabilitating the distribution system under IDA (20% in 1991, 15% in 1992 and 1993, and 10% in 1994 to 1998). The ultimate objective of the improvement is a saving of 25%.

D.OPTIMUM WATER MANAGEMENT PLAN

30.Criteria :Establishment of the plan for water supply facilities up to the year 2001 will be based on the following conditions:

(a) The development plan for the water supply facilities will consist of developing water sources to meet future water demand, constructing new facilities, and rehabilitating existing facilities to supply safe and potable water.
(b) The additional water resource from outside of the Kathmandu valley will become available after the year 2001 following completion of the water conveyance facilities from outside of the valley.
(c) In order to conserve groundwater resources, abstraction of groundwater will be reduced from the current production amount, and the level of the groundwater shall not be allowed to be lower than the yield computed by simulation.

(d) The increasing water demand up to 2001 shall be supplied from water resources within the valley. The groundwater resources are limited, so development of water resource must depend solely on surface water.

(e) In regard to the surface water development plan, all available surface water sources within the valley shall be examined and then determined.

(f) The available capacity of the surface water, which will be the sole source, will have a high level of monthly variation so the water supply facilities to be established shall coordinated with the planned monthly water supply.

(g) The groundwater shall, without exception, be treated with bio-filters to remove ammonia and iron.

(h) Disinfection equipment shall be expanded and established at all water treatment plants.

(i) The water supply area per system shall be established to minimize the effects upon the quality of water supplied at connections due to variation in the flow rate through the distribution system.

(j) The order of precedence of established schemes shall be decided through comparative examination of the many available implementation plans for improving both quality and quantity.

31. <u>Mathematical Model Simulation on the main aquifer</u>: The FEM mathematical model simulation reveals that

(a) The recharge source of the main aquifer is leakage water through aquitard deposit or squeezed from the aquitard deposit;

(b) The present rate of groundwater abstraction is twice as much as the available capacity. The abstraction should not exceed the critical abstraction amount of 15,000 m^3/day which is linked with conditions such as pump capacity, upper rim of the main aquifer, depth of strainers and well loss.

(c) Artificial groundwater abstraction will cause leakage (or squeeze) of water from upper layers, which may result in stable,or steady condition. But if the abstraction volume reaches or exceeds the critical capacity of 15,000 m^3/day, the pump efficiency will fall and several social problems such as subsidence will occur.

32. <u>Optimum Operation</u>: Optimum pump operation have been established by the Modified Simplex Method. The contributions of each well field will be:

(1)	Bansbari Well field	6,936 m^3/day	(44%)
(2)	Balaju Well field	1,000 m^3/day	(6%)
(3)	Gokarna/Manohara Well field	6,093 m^3/day	(39%)
(4)	Pharphing Well field	1,600 m^3/day	(10%)
	total	15,629 m^3/day (15,000 m^3/day)	(100%)

33. Surface water development: A development plan for surface water in the valley has been formulated to meet the future water demand in Greater Kathmandu up to the year 2001 through exploitability study of all conceivable schemes. In the valley, there are some sixty Government-aided and local farmers' irrigation intakes and nine (9) NWSC's municipal water intakes, where river water is mostly used in the dry season. Therefore, the development plan has been made so as not to interfere with the present arrangements for water abstraction.

34. River water development: For effective use of net surplus river water, additional run-of-river type intake schemes are proposed on six rivers. In this study, two types of intake facilities are envisaged in consideration of site conditions and for ease of operation and maintenance: One is a ground-sill type for the three rivers Manohara, Dhobi Khola, and Lambagar Khola, and the other is a concrete weir type for the Balkhu Khola and Bisnumati river. In the Bagmati river, the existing low intake dam of the Sundarijal hydro-power plant could be used also for further water intake. Their planning rate of abstraction will vary seasonally up to 0.15 m^3/s at a maximum according to natural variations in available river water with proper reliability, say more than 80% dependability on average.

35. Storage reservoir schemes: Storage reservoir schemes have also been studied as the valley's own water source development. The Balkhu Khola. reservoir scheme, located to the west of Kirtipur, has the highest reservoir yield potential of 0.8 (m^3/s) and the highest storage efficiency (effective storage volume divided by dam volume) and appears to be economically superior. However, Bishnu Devi Temple which would be submerged after reservoir impounding is religiously important to local people. Unless this social problem can be solved in advance, this scheme's implementation would be impossible.The Nakhu Khola. dam scheme (at Tikabhairau, $Q=0.6m^3/s$) and Kodku Khola. dam scheme (at Baregau, $Q=0.3m^3/s$) with the Nakhu Khola. water transfer are expected to be attractive in view of their economical superiority and the absence of great technical constraints to their implementation, though compensation would have to be paid for agricultural land to be inundated.

36. Water Quality Improvement Plan :The groundwater has very high levels of ammonia, iron and manganese, and is not suitable as a source of water supply, if it remains untreated. Ammonia, iron and manganese are not necessarily directly injurious to the health, but they consume a great deal of the chlorine added for chlorination, and this creates the problem of reducing the residual chlorine enough so that it is sufficient for preventing the growth of water-borne disease organisms in the distribution system.

Although both iron and manganese can be treated by normal methods, such a high level of ammonia has never been treated in the field of waterworks.

There are several methods of treating ammonia, however, most of which are very expensive and some may generate harmful byproducts such as triphenylmethane gas. Among these methods, an unprecedented experimental biological filtration method was tried out during the field investigation and resulted in excellent treatment effects and without the defers mentioned above. It is recommended, therefore, that groundwater in the valley be treated by this method.

A water quality improvement plan was therefore determined on the basis of a comprehensive treatment system for the groundwater consisting of biofiltration, coagula-sedimentation and filtration for iron removal, and of a conventional treatment system for the surface water. The following describes the proposed water treatment plan for each system.

37. Balaju system: The water resource for this system consists of the existing surface water source (8,700 m^3/day) and a groundwater source in the Balaju well (600 m^3/day).

The existing Balaju treatment plant, where almost no output is assumed due to deterioration, is to be reconstructed to have a treatment capacity of 9,300 m^3/day. The existing distribution reservoir which has serious leakage shall also be rehabilitated. Treated water shall be stored in this distribution reservoir and then supplied (9,000 m^3/day) to consumers by gravity flow. The treated water of 4,300 m3/day from the Lambagar treatment plant will also be sent to this distribution reservoir and then into this system.

38. Lambagar system: The water source for this system will be the surface water to be taken in through a new run-of-river intake (14,300 m^3/day) from the Lambagar Khola (W105). A conventional water treatment plant (13,000 m^3/day) will be newly constructed for this system.

The treated water will be sent in part to the Balaju system and the remainder of some 8,300 m3/day shall be sent to a new distribution reservoir (2,400 m^3/day) through a new transmission pipeline. The water shall be supplied to consumers either by booster pumping system or by gravity flow.

39. Bansbari system: The water resource for this system will consist of the existing surface water source (2,100 m^3/day) of the existing Maharajganj treatment plant, surface water to be taken in through a new run-of-river intake (14,300 m^3/day) from the Bisnumati (W106), and the groundwater source of the Bansbari well field. The groundwater will first be pre-treated through biofilters and then be treated through a new conventional water treatment plant (21,500 m3/day) together with the surface water. Of the treated water, 6,900 m^3/day will be supplied to the north area of the city of Kathmandu via the existing Bansbari reservoir (2,000 m^3) by gravity. The remaining water of 13,900 m^3/day will be sent into the Maharajganj system.

40. Maharajganj system: The existing water treatment plant will be demolished and the existing distribution reservoir (3,750 m^3) will be reconstructed to be supplied via a new water transmission pipeline from the new Bansbari treatment plant. 13,900 m^3/day will be supplied from the reservoir by gravity.

41. Mahankal Chaur system: The water source for this system consists of groundwater in the well fields of Gokarna, Manohara and Dhobi Khola, surface water in the Bagmati (W301) from the penstock of the Sundarijal hydroelectric power plant, and the surface water to be taken through a new run-of-river intake from the Dhobi Khola (W202).

The groundwater will first be pre-treated by bio-filters (18,600 m^3/day) to remove the high concentrations of both ammonia and iron and then will be treated in a new conventional water treatment plant (32,900 m^3/day) together with the surface water.

The treated water will be sent by pumps into the existing distribution reservoirs (9,000 m^3) and then be supplied to the central area of the city of Kathmandu.

42. Sundarijal system: The water treated in the existing water treatment plant is currently sent into the Mahankal Chaur reservoir but this will be diverted into the new Sundarijal system.

The existing Sundarijal water treatment plant will be reconstructed with a capacity of 20,600 m^3/day. The treated water will be sent to three water distribution reservoirs (1,850 m^3 x 2 basins and 1,550 m^3 x 1 basin) to be newly constructed in the water supply area to the east of the city of Kathmandu through the existing transmission pipeline into the Mahankal Chaur reservoir and a new transmission pipeline by which the water will then be supplied at a rate of 6,400 m^3/day, 6,400 m^3/day and 5,200 m^3/day.

43. Shaibhu system :The water source for this system consists of existing spring water and groundwater in the Pharphing well field. The water supply area is the city of Lalitpur. To ensure that water of 24,500 m^3/day shall be reliably supplied to consumers for 5 hours each in the morning and evening supply, a 4,500 m^3 distribution reservoir together with a distribution main shall be newly constructed, in addition to the existing distribution reservoir (2,700 m^3) and distribution main. Disinfection equipment shall also be newly constructed.

44. Manohara system: The water supply area is the southeast part of the city of Kathmandu. A conventional water treatment plant shall be newly constructed with the surface water source taken by a new run-of-river intake from the Manohara (W406). The treated water will be sent into two new water distribution reservoirs (1,850 m^3 each) within the water supply area from which 6,300 m^3/day

will be supplied to consumers by a booster pump system.

45. Balkhu system: The water supply area will be the southwest area of the city of Kathmandu. A conventional water treatment plant will be newly constructed for the surface water resource taken in through a new run-of-river intake from the Balkhu Khola (W802). The treated water will be sent into two new water distribution reservoirs (1,850 m^3 each) within the water supply area and 6,300 m^3/day will be supplied to consumers from one reservoir by gravity and the same quantity from the other reservoir by booster pump type.

46. Concept on Implementation Plan: In order to meet the water demand up to the year 2001 on both aspects of quality and quantity, the priority for establishment of each scheme of water supply facilities should be determined by the following conditions.

(a) The water supply to be increased by implementing the schemes shall balance the increase in water demand.

(b) No existing supply capacity will be disturbed.

(c) A scheme with a groundwater source that causes problems in terms of both water quality and quantity, shall in principle take precedence over all other systems, including the expansion of a new surface water source in the systems concerned.

(d) A scheme which will include refurbishment of an existing water treatment plant shall be quickly completed, including expansion with a new resource of surface water in the systems concerned.

(e) A new scheme with a completely new resource of surface water shall be implemented last.

(f) Through consideration shall be given to the workability and economy of the foregoing.

(g) Among the afore-mentioned surface water schemes, the storage dam schemes will not be needed before 2001. Hence these schemes are not taken up in this study, but proposed as an element to be considered when the plan after 2001 is studied.

47. Implementation Plan: As the result of comparative examination for many available implementation plans, the following implementation order is recommended:

Precedence	Scheme	Main objectives
1	Mahankal Chaur	Quality improvement of groundwater New treatment plant Development of surface water
2	Bansbari, Maharajganj	Quality improvement of groundwater New treatment plant Development of surface water Improvement of reservoir (Ban. only)
3	Shainbhu	Expansion of transmission pipeline and reservoir
4	Balaju	Renewal of existing treatment plant and reservoir
5	Lambagar	Development of surface water New reservoir, treatment plant and transmission pipeline
6	Sundarijal	Renewal of existing treatment plant New reservoir and transmission pipeline
7	Manohara	Development of surface water New treatment plant New transmission pipeline
8	Balkhu	Development of surface water New treatment plant New transmission pipeline

E.GROUNDWATER MANAGEMENT PLAN

48. Criteria

a) Groundwater resources in the valley should not be exhausted.

b) The critical groundwater yield shall be obtained by the optimization simulation, and abstraction of groundwater shall not be allowed to exceed the critical level.

c) During the dry season the potential of surface water sources of the valley does not satisfy the demand of water supply. Hence groundwater management will have to be carried out by a combination of well operation by standard production wells with due regard to conjunctive use.

d) Groundwater monitoring and subsidence monitoring is required to manage the groundwater

49. Groundwater Management Plan: The critical groundwater yield potential of existing NWSC wells (excluding Bhaktapur well field) for the groundwater management of the Kathmandu Valley is estimated at about 15,000 m^3/day with selected standard wells based on groundwater simulation methods. It is recommended that pump yields be controlled to avoid excessive drawdown.

50. Well Operation: Because, during the dry season the potential of surface water resources of the Kathmandu Valley does not satisfy the demand of water supply, groundwater management should be carried out by combination of well operation by standard production wells with due regard to conjunctive use. However, if the total amount of groundwater yield of the standard production wells does not meet the peak demand in the dry season (mainly April and May) then, supplementary groundwater pumping will be required not only from the standard wells but also from other production well during the dry season.

51. Conjunctive Use: In order to achieve conjunctive use, the existing NWSC production wells (excluding Bakutapur well field) have been classified into three groups, namely standard production wells, extra production wells and monitoring wells by a groundwater model simulation method. Twelve production wells have been selected as standard production wells for optimum groundwater management. Other production wells have been chosen as stand-by or extra wells to meet the shortage of surface water during the dry season. Therefore, during the rainy season standard operation pumping is to be carried out with standard production wells. In the dry season peak pumping operations after 1994 will be carried out by all production wells except monitoring wells, on condition that the annual discharge amounts of all NWSC production wells (excluding Bhaktapur well field) shall be controlled to be less than 15,000 m^3/day on a yearly average.

Peak operation forms an exception to the general operation rule. Therefore, careful groundwater monitoring is required to conserve the aquifer. In order to observe the groundwater level, three wells have been selected from NWSC wells and four JICA observation wells as a monitoring well for each well field.

52. Groundwater Monitoring: Monitoring methods include not only groundwater level monitoring, but also production monitoring, water quality monitoring, and subsidence monitoring. The information from these monitoring systems will indicate the time for improvement of future predictions before depletion of the aquifer. Also, the subsidence monitoring is important to preserve the Kathmandu Valley from subsidence.

F.PROJECT COST AND EVALUATION

53. Costs of Projects: For the purpose of determining the priority and for the provisional project evaluation, the projects' costs are estimated provisionally. The results are as follows; namely

Precedence	Project	Foreign Currency Portion	Local Currency Portion	Total
1	Mahankal Chaur	14,030	4,300	18,330
2	Bansbari, Maharajganj	11,599	3,816	15,417
3	Shaibhu	3,579	1,346	4,925
4	Balaju	4,271	973	5,244
5	Lanbagar	11,118	4,452	15,570
6	Sundarijal	11,118	4,452	15,570
7	Manohara	12,746	5,988	18,734
8	Balkhu	11,230	5,790	17,020
	Total	76,774	29,717	106,491

(Unit: US$ Thousand or equivalent)

54. Project Evaluation, Economic Analysis: The economic analysis has been made on the assumption that all the above mentioned eight schemes (projects) will be implemented so that the benefits and the costs of the eight projects may be treated together.

Tangible benefits will be: (1) those caused by the quantitative increase in the amount of water to be supplied and (2) those caused by the decrease in illness and epidemics owing to the improvement of water quality. The benefits will commence in the year following completion of the first projects and will grow to full benefits of US$ 4,115 million per year in year following full completion of the eight projects, namely in 2001. These full benefits will occur every year until 2023, and will disappear as the economic lives of the projects expire. The benefits will thus all disappear in 2031. In comparison of these benefits with the costs of the projects (construction cost and the OMR costs), the economic internal rate of return (EIRR) is estimated at 3.4 %.

55. Project Evaluation, Financial Analysis: On the assumption that all of the construction costs of the project will depend upon loans, the following model is assumed. Namely,(1) the rate of interest is 1 %, (2) the grace period is ten years, and (3) the repayment period is 30 years including the grace period. As to the income, two models are assumed, namely (1) 1.5 % of the house hold income and (2) about four times of the current tariff. In either case, the financial rate of internal rate of return (FIRR) is estimated at less than 2%. However, the loan will be fully refunded during the projects lives of 30 years until 2030, and the income will at all times be more than the relevant operation expenses.

56. <u>Judgement</u>: A municipal water supply project is normally accompanied by low value of internal rate of return (IRR). Nevertheless, implementation of this project provide safe and suitable drinking water to the inhabitants as a basic human needs. Moreover, Nepal is one of the countries whose gross domestic product (GDP) per capita is the lowest in the world. For these reasons, it is judged that these projects are viable.

G. CONCLUSION AND RECOMMENDATION

57. <u>Conclusion</u>: At present, groundwater in the valley is being pumped excessively. The amount pumped has to be decreased to the allowable amount by management. New water sources from surface water are available by the run-of-river method of $0.15m^3/s$ (or 12,600 m^3/day). In the initial stages of developing the surface water, an occasional shortage of water will occur.

58. As a new development, it is necessary to implement the eight projects proposed herewith one after the other so that all of them may be completed by 2001. The fundamental purpose of municipal water supply is to supply the quantities needed of safe and hygienic water containing the necessary amount of residual chlorine at the users' taps. So long as the groundwater of the valley is used, the obstacle to quality will be the high content of ammonia. In purifying the ammonia contained water, ammonia consumes about ten times the amount of chlorine as compared with purifying the same amount of ferrous and manganese contents. Moreover, it can originate matters which are harmful to the human body. Therefore, removal of ammonia is indispensable. Groundwater from which ammonia has been removed as well as surface water has then to be treated by the normal procedures of sterilization. To supply the water quantities only is not the way to achieve the fundamental requirements of supplying municipal water.

59. The eight projects proposed in this report are all needed, are technically possible, and are economically and financially viable. Therefore, all eight of the projects are worthy of implementation.

60. <u>Recommendation 1</u>: It is recommended that there be thorough management of groundwater. Without such management, it would be possible to exhaust the precious aquifer, and give rise social hazards associated with ground subsidence.

(1) Of the existing NWSC's wells, twelve wells have been selected as standard production wells and three wells as observation wells. The rest of the wells are to be reserved.

(2) In normal cases, pumping of groundwater will be made from the standard production wells only.

(3) At the end of the dry season, especially in April and May, when surface water runs short, the reserve wells may have to be operated. However, the pumped amount should not exceed 15,000 m^3/day on a yearly average.

(4) When water from outside the valley becomes available, certain water source will have to be found in place of the reserve wells in order to preserve the groundwater.

(5) Monitoring of the groundwater has to be made in order to preserve groundwater and to prevent ground subsidence.

(6) Legal feature of groundwater of the Kathmandu valley should be defined in the near future as public water. Based on this, general legislation management/preservation including regulation of exploitation should be established.

61. Recommendation 2: The eight (8) projects proposed in this report,

1. Mahankal Chaur Project,
2. Bansbari and Maharajganj Project,
3. Shaibhu Project,
4. Balaju
5. Lambagar Project,
6. Sundarijal Project,
7. Manohara Project,
8. Balkhu Project

are to be implemented. It is, therefore, recommended that the necessary steps are taken for their implementations. The priority of implementation will follow the above-given precedence for technical reasons.

62. Recommendation 3: It may happen, even after water from outside the valley becomes available, that the surface water in the valley will run short by the end of the dry season, especially in April and May, and this may cause difficulty in maintaining the peak supplies. Accordingly, plans for storage dams for the valley are worthy of further studies.

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ABBREVIATION

ORGANIZATIONS

NWSC : Nepal Wter Supply Corporation
WSSC : Water Supply and Sewerage Corporation
MHPP : Ministry of Housing and Physical Planning
DHM : Department of Hydrology and Meteorology
DWM : Department of Watershed Management
MWR : Ministry of Water Resources
CIRD : Central Irrigation Regional Directorate
WSSB : Water Supply and Sewerage Board
DMG : Department of Mines and Geology
IBRD : International Bank for Reconstruction and Development
UNDP : United Nations Development Programme
JICA : Japan International Cooperation Agency
GTZ : Deutsche Gesellschaft fu"r Technische Zusammenarbeit
JIS : Japan Industry Standard
CBS : Central Bureau of Statistics
MPLD : Ministry of Panchayat and Local Development
DWSS : Department of Water Supply and Sewerage

UNITS OR OTHERS

GDP : Gross Domestic Product
NRS : Nepali Rupees
MCM : Million Cubic Meter

1. INTRODUCTION

1.1 Project Background

A master plan for water supply and sewerage of Greater Kathmandu (urban area of Kathmandu and Lalitpur) and Bhaktapur was prepared in 1973. Based on the masterplan, the First, the Second and the Third Projects were implemented and completed in 1987. The main achievements of these projects are 43 wells of which 30 wells are useful, some transmission pipelines and reservoirs. The quantity of the well water has been worse than expected being rich in ferrous manganic and ammonia constituents.

NWSC is rehabilitating the existing distribution networks which at present allow heavy losses and deliver a poor quality of water.

The sustainable yields of the completed wells have not been clarified as yet. In addition, methods of utilizing the surface flow which is wasted in the rainy season have not yet fully been studied.

Under these circumstances, the Government of Nepal requested the Government of Japan to provide technical assistance to study the need for groundwater management including full utilization of surface water, purification, and formulation of a total management plan of groundwater and other water resources.

1.2 Objectives of the Study

The basic concept of the Study was as follows;
To assess the potential of the water resources comprising groundwater and surface water inside the Kathmandu valley, and to plan an improvement in water quality and quantity for water supply in Greater Kathmandu (urban area of Kathmandu and Lalitpur).

Accordingly, the objectives of the Study were as follows;

- to evaluate the potential of the groundwater, including spouts ,in the Kathmandu valley,
- to evaluate other water resources in the Kathmandu valley,
- to prepare an improvement plan for the quality of water supplied in Greater Kathmandu,
- to prepare an optimum management plan for the water resources of the Kathmandu valley, to cover the next ten years,
- to transfer technical knowledge to the Nepalese staff concerned.

1.3 General Work Progress

The Study commenced in December 1988 for completion by the end of November 1990, and consisted of three stages of investigation. The work schedule was as shown in Fig.1.3.1. Work flows are shown in Fig.1.3.2., Fig.1.3.3, and Fig.1.3.4.

1.3.1 The 1st Stage (December 1988- March 1989)

The 1st stage work consisted of preparatory works at home and 1st field surveys in the dry season including data collection and review of existing reports. At the beginning of this stage, the outline of the work schedule and plan of operation for the Study were explained and discussed with NWSC. The following works were performed in this stage.

(1) Preparatory works at home
(2) 1st field surveys

- Contract with the local contractor for surveying, the drilling of geological borings, and drilling of observation wells
- Carrying out the supervisory work on the surveying and geological borings
- Preparation of technical specification for the geological borings and observation wells drilling
- Execution of electrical prospecting
- Sampling and water quality analyses of surface water and groundwater
- Field reconnaissance concerning geomorphology, geology, hydrogeology and meteoro-hydrology
- Observation of groundwater level in the dry season and establishment of a groundwater level monitoring system
- Preparation of an inventory of existing wells
- Carrying out of pumping tests on existing NWSC wells
- Flow measurement of rivers, springs and spouts
- Investigation for planning of water supply distribution and treatment systems
- Establishment of the rain gauges and staff gauges
- Execution of water treatment trial on groundwater
- Selection of promising sites for surface water ponding

The results of 1st stage study were compiled in Progress Report(1) which was submitted to NWSC at the end of March 1989.

1.3.2 The 2nd Stage (June 1989 - October 1989)

The 2nd stage work consisted of 1st analysis of home work and 2nd field survey in the rainy season including well drilling for groundwater level observation. However the drilling program and main course study for the second stage was delayed by the fuel crisis all over Nepal for about three months and one month respectively. The following works were performed in this stage.

(1) 1st analysis at home

During the period from June to July 1989, the following work were performed by the JICA's experts in Japan.

- Hydrogeological analysis
- Hydrological analysis
- Analysis of surface water exploitability
- Analysis of the functioning of existing water purification plants
- Planning of new water purification plants and rehabilitation of existing plants
- Water demand analysis
- Chemical analysis of groundwater and surface water in total 30 samples

(2) 2nd field investigation work

The JICA study team carried out the following works during this stage from beginning of August to the middle of October 1990 in cooperation with counterparts.

- Monitoring rain fall and groundwater level in the rainy season
- Installation of automatic groundwater level recorders and automatic rain gauges
- Flow measurement of rivers, springs, and spouts in the rainy season, and re-installation of staff gauge for river water level
- Meteoro-hydrological and hydrogeological survey
- Sampling and analyses of surface water and groundwater in the rainy season
- Investigation for water purification plants in rainy season
- Execution of water treatment trial for existing water sources containing high ammonia and iron
- Investigation for planning of surface water exploitability
- Socio economical investigation

The results of 2nd stage study were compiled in Progress Report(2) which was submitted to NWSC in October 1989.

(3) Drilling of observation wells

The well drilling campaign was commenced on 23rd March, but the drilling work was suspended for about three months by the fuel crisis all over Nepal until end of June 1989. Finally four observation wells were completed at end of November 1989.

1.3.3 The 3rd Stage (October 1989 - November 1990)

The 3rd stage work consists of 2nd and 3rd analysis at home. The following works were performed in this stage.

(1) 2nd analysis at home

During the period from middle of October 1989 to the middle of February 1990, the following work was performed by the JICA's experts in Japan.

- Hydrogeological analysis
- Water balance analysis
- Groundwater simulation
- Planning of surface water ponding and water intake system
- Dating analysis of groundwater
- Analysis of the functioning of existing water purification plants
- Planning and design of new water purification plants and rehabilitation of existing plants
- Socio economic analysis

During the absence of the main JICA study team (from October 1989 to February 1990) the counterpart staffs were monitoring surface water discharge and rainfall observations, and groundwater level observations.

The results of 2nd analysis at home were compiled in the Interim Report which was submitted to NWSC at the end of February 1990.

(2) 3rd analysis at home

During the period from end of April to middle of June 1990, the following work was performed by the JICA's experts in Japan.

- Groundwater simulation
- Evaluation of groundwater development potential
- Evaluation of surface water exploitation plan
- Evaluation of new treatment system
- Planning water resources development master plan
- Evaluation of projects

The results of 3rd analysis at home were compiled in the Draft Final Report and this report was submitted to NWSC in the middle of June 1990. The draft final report was explained and discussed with NWSC in the middle of October 1990. This final report is herewith prepared, incorporating the NWSC's comments.

1.4 Organization of the Report and Personnel

The Final Report is compiled from the study results of field surveys and home analysis carried out by the JICA study team from December 1988 to November 1990. The report consists of four volumes, namely; main report, supporting report, data book, and exective summary report. The principal results of the study are described in the main report, and more detailed description and information are given in appendixes of the supporting report and data book. The outline of the study is explained in the exective summary report.

Field surveys were carried out in cooperation with counterparts who were assigned to the study by NWSC. The list of counterpart personnel is given in Table 1.4.1. The assignment schedule of the JICA study team is given in Figure 1.4.1.

2. STUDY AREA

2.1 Socio-Economy

2.1.1 National Socio-Economy

Nepal is a traditional agricultural country located in a mountainous area bordered by China to the north and by India to the south, east and west. Nepal has an area of 147,181 km and had a population of 15,022,839 in 1981, and about 90 % of the economic active population was engaged in agricultural and agro-industrial sectors.

The main agricultural crops of Nepal are paddy, maize, wheat, potatoes, sugar-cane, oil-seeds and jute, and the greatest production area of these crops is the Terai region (plain area). In addition to these crops, livestock farming also is a significant agricultural industry of Nepal, being widely carried out in the country as a whole.

Gross Domestic Product (GDP) amounted to NRs. 74,575 million in the fiscal year 1988/89 at a real average growth rate of 4.8 % per annum during the period 1983/84-1988/89, to which the agricultural sector contributed more than 50 % every year. On the other hand, the per capita GDP showed NRs. 4,134 in 1988/89 with a real average annual growth rate of 2.1 % for the same period.

External trade amounted to NRs. 4,115 million in exports and NRs. 13,870 million in imports in 1987/88, and 35 % of the total trade amount was trade with India. Major trade commodities were food, manufactured goods and live-animals for the export and machinery, transport equipment and manufactured goods for the import.

In Nepal, imports have exceeded exports every year and such a trade deficit has made a main cause of unfavorable balance of international payments. For example in 1986/87, current account of the international payments showed minus NRs. 2,858 million, and this deficit was supplemented by capital account which included external loans and grants.

2.1.2 Regional Socio-Economy

The Study Area (Kathmandu valley) is located in the hilly area of Central Region and has an area of 585 km^2. Administratively, the valley is composed of three districts; Kathmandu, Lalitpur and Bhaktapur. Each district has some towns (urban areas) and villages (rural areas) which consist of 130 units in the valley as a whole.

According to the 1981 census, the valley had a population of 766,345 of which 363,507 was in urban areas and 402,838 in rural areas. The average annual growth rates were 2.14 % for the entire valley, 3.76 % for the urban areas and 0.87 % for the rural areas, during the period 1971-1981. The fact that the population growth in the entire valley showed a lower rate than that (2.62 %) in the country as a whole might be due to out-migration from the valley to other places and/or a relatively significant effect of family planning (See APPENDIX-H, Population Projection).

Kathmandu, the capital city, is a centre of politics, the economy and commerce of Nepal and has headquarters of all ministries, departments and corporations of the Government. The first historic reference to Kathmandu as a capital was in the 11th century A.D., hence Greater Kathmandu and Bhaktapur have many vestiges of ancient civilization which are playing important roles in fields of tourism sector and scientific research. Industry is also extensively carried on in the valley, and especially in Greater Kathmandu including industrial estates called Balaju and Patan, respectively. Further cottage industry is scattered everywhere in the valley.

Rural areas in the valley had a crop land area of about 38,000 ha in 1987/88 and produced 88,000 tons of paddy, 35,000 tons of wheat, 24,000 tons of maize and 17,000 tons of potatoes, mainly as the staple food of inhabitants in the valley. However, in recent years there has been a tendency for the crop land area to decrease due to the progress of urbanization in the valley.

During the period 1982/83-1987/88, consumer prices in Greater Kathmandu showed a significant rise at the average annual rates of 9.84 % for overall items, 10.30 % for food, 13.61 % for vegetables, 11.50 % for meat, 16.19 % for oil and 11.03 % for housing, while the prices for sugar, clothes, footwear, transport and communications remained relatively stable.

Details of the socio-economy are given in Appendix A.

2.2 Topography and Geology

2.2.1 Topography

The Kathmandu valley has the shape of an indented circular basin occupying about 585 km^2. Kathmandu City is situated in the western central part of the basin. The central part of the Kathmandu valley consists of very gentle and flat lands at elevations of 1300 m to 1400 m, and the flat land is surrounded by high mountain ranges of more than 2000 m in elevation.

The Bagmati river is the only river system in the valley, and drains all the water collected into the valley basin to the south. The Bagmati river dissects the mountains of Mahabarat range to the southwest of the valley. The landform of the Kathmandu valley was classified by interpretation of aerial photographs into three categories: flat lands; high relief areas; and gently inclined slopes. The land form classification map is shown in Fig.2.2.1.

Potential areas for groundwater recharge are limited to the flat plains and low-lying alluvial plains because exploitation of groundwater in the surrounding high mountains would be difficult. No potential damsites are to be found on the flat plains except where the low hills are not composed of bedrocks because dam foundation rocks are not to be expected on the flat plains within a reasonable depth. Hazard prone areas have also to be eliminated from the potential damsites.

2.2.2 Geology

The Kathmandu valley is composed of two series of geological successions; one is Quaternary, which overlies the lower portion of the valley; the other is Precambrian to Devonian (Paleozoic Era), which surrounds the Kathmandu valley. The geological map prepared in this study is mainly based on interpretation of aerial photographs at an approximate scale of 1:60,000 with supplemental field point checking. The geological map is shown in Fig.2.2.2.

Many mountain ridges extend to the valley bottom from the surrounding mountains, implying there are many buried ridges. The depth to Precambrian bedrocks from the ground surface was confirmed by electrical prospecting and existing well logs to range from several tens of meters to more than 500 m. The ground surface of the Kathmandu valley bottom is flat but the buried bedrock surface is estimated to be abound in irregular shapes and high relief.

The thick geological deposits of the flat part of the Kathmandu valley consist of lacustrine deposits and fluvial deposits. The lacustrine deposits are classified into three types: arenaceous sediments, argillaceous sediments and intermediate types of these sediments. This classification is made based on field observation, the results of electrical prospecting and the logs of the existing wells.

Arenaceous deposits, which are composed of coarse to medium grained sand with small rock fragments, are believed to have been supplied from the northern mountainous areas which consists of gneissose rocks.

Argillaceous deposits composed of clay materials are considered to have been supplied from erosion of the limestones, which underlie the southern mountainous areas.

Intermediate types of the above-mentioned two kinds of deposits are distributed in the central part of the valley from the west to the east between the areas composed of arenaceous deposits and argillaceous deposits. Materials of this type are composed of silty clay or clayey silt with intercalations of sandy layers and clayey layers.

In the shallow zones of the materials, a small amounts of water seepage are occasionally observed on the top of clayey layers along the boundaries between the clayey layer and the sandy layers, indicating the impermeability of the clayey layers. Percolation of precipitation accordingly seems to be obstructed by the clayey layers in this area.

High potentiality for groundwater recharge is not to be expected in these areas because of the presence of such impervious materials. The arenaceous sediments are limited to the northern margin areas of the bottom parts of the Kathmandu valley and the materials seem to be supplied alternately from erosion of limestones and phyllites which underlie the western and southern mountainous areas.

2.3 Meteorology and Hydrology

2.3.1 Rainfall

A rainfall observation network in the study area has existed since the early 1970s. At present, 23 meteorological service stations in and around the study area are operated under the management of the Department of Hydrology and Meteorology (DHM), Ministry of Water Resources. All stations are equipped with standard rain gauges or automatic recording rain gauges.

The Kathmandu valley in the semi-tropics is characterized by a warm and temperate climate having a rainy season during the monsoon period from June through September caused by the winds from the Bay of Bengal. Rainfall varies substantially according to altitude i.e. from about 1,300 mm/year in the valley bottom to about 3,000 mm/year in the mountains along the valley rim. Monthly variation indicates that about 80 % of the annual rainfall occurs during the rainy season and that July or August are generally the wettest months.

An isohyetal map was prepared taking into consideration the relationship between annual rainfall and elevation. Based on this map, the annual basin rainfall in the study area was estimated to be 1,912 mm as shown below.

Unit:mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
19	21	32	71	125	309	509	491	252	68	7	8	1,912

2.3.2 Runoff

The surface water resources of the study area are the Bagmati river and its tributaries. The Bagmati river has its origin in Siwapuri Lekh (mountain area) situated to the north of the Kathmandu valley. Its major tributaries, all originating in the hilly region, are Mai Khola, Nakhu Khola, Balkhu Khola, Bisnumati river, Dhobi Khola, Manohara river, Khodu Khola, Hanumante river and Godawari Khola.

Since there are only long-term data for the runoff at Sundarijal station, these have been used for estimation of natural runoff at the ungauged sub-basins. The runoff data at Sundarijal was elaborated on a daily basis for the 46 years from 1941 to 1986 by the tank model method and reduced to a 5-day basis. The natural runoff at ungauged sub-basins required for estimating the available water resources at each potential dam/intake site was estimated from the product of the specific discharge at Sundarijal and the ratio of their basin rainfalls. The results are incorporated in the water balance simulation study in the chapter 3.2. The synthesized runoff and specific discharge at Sundarijal is summarized below.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
** Runoff (m^3/sec)												
0.23	0.20	0.19	0.21	0.31	0.90	2.30	3.09	2.17	0.95	0.44	0.29	0.94
** Specific Discharge (m^3/sec/100km^2)												
1.4	1.3	1.2	1.3	1.9	5.6	14.4	19.3	13.6	5.9	2.8	1.8	5.9

The annual runoff at Cobhar which is situated almost at the outlet of the valley with a catchment area of 585 km^2 is estimated at 500 MCM, and a runoff coefficient estimated at 45 %. The average monthly discharge at Cobhar is estimated as follows.

Unit: m^3/sec

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.48	1.89	1.44	1.73	2.49	15.50	47.30	53.87	35.39	16.73	7.00	3.88	15.81

2.3.3 Evaporation

Evaporation by class-A pan has been observed at Kathmandu airport since 1976. The following table shows the average value of daily pan-evaporation from 1976 to 1972.

Unit:mm/day

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.4	3.0	4.1	5.0	5.1	4.7	4.5	4.6	3.7	3.3	2.6	1.9	3.7

2.3.4 Flood

A flood study was required for deciding the design flood of potential damsites. However, no flood records exist for any of the potential damsites. For the estimation of the probable flood at ungauged damsites, the relationship between the probable flood runoff and drainage area is generally used. In order to evaluate the design flood at the damsites, the recorded maximum floods in Nepal and the probable floods estimated in existing and on-going projects near the study area are plotted against the drainage area. This figure includes Creager's Envelope Curve having the C-value of 42 corresponding to the recorded maximum floods.

The probable flood with recurrence interval of 2 - 1,000 year and probable maximum floods (PMF) at the damsites are estimated using the derived C-value in each case. The results may be summarized as follows:

Unit:mm^3/sec

Return Period	C-value	Balkhu kh. (CA=$37km^2$)	Sundarijal (CA=$30km^2$)	Kotkhu kh. (CA=$16km^2$)	Lele kh. (CA=$15km^2$)	Nakhu kh. (CA=$43km^2$)
2	10	105	90	58	55	116
5	18	188	163	104	99	208
10	24	251	217	138	132	278
20	30	314	271	173	164	347
50	39	408	353	224	214	452
100	46	481	416	265	252	533
200	55	575	498	316	301	637
1000	77	805	697	443	422	891
PMF	107	1,119	968	615	586	1,239

2.3.5 Sediment

Sampling of suspended sediment was done at the Cobhar station between August 1966 and July 1978. Applying the daily discharge of the Bagmati river at Cobhar during from 1965 to 1980, annual total sediment load at Cobhar having the catchment area of 585 km^2 was assessed. The average suspended sediment load for 16 years was 0.69 million tons per year. The design sediment load is estimated to be 1,350 ton/km^2/year, allowing 15 % for unmeasured bed load. From soil bulk density, this is equivalent to an annual depth of 1.2 mm.

2.4 Hydrogeology

2.4.1 Groundwater use

(1) Trend of Abstraction from Tube Wells in the Study Area.

In total 87 wells were confirmed, consisting of 38 NWSC production wells, 4 NWSC observation wells, 37 private wells and 8 gas wells. The location of these wells is shown in Fig.2.4.1.

About 60 tube wells were being operated out of the above mentioned 87 wells in the Kathmandu valley at end of 1989 with estimated annual groundwater abstractions amounting to around 14 million cubic meters. However, in 1972 no confined aquifer had been developed. Figure 2.4.2 shows the trend of abstractions from tube wells in the Kathmandu valley from 1972 until 1989. In 1980, NWSC had just started groundwater development by using old WHO wells.

Total estimated groundwater abstractions grew remarkably in 1988, because almost of NWSC wells are prepared into operation conditions. Of the 60 operating wells 28 belong to NWSC, but the production of NWSC wells amounts to over 80 % of the total estimated abstractions from all the tube wells in the Kathmandu valley.

The estimated groundwater abstraction from NWSC well field may be estimated to have been 0.66 to 1.24 million cubic meters per month in 1989 (See Table 2.4.1). The most developed well field is Bansbari well field which abstracted more than 40 % of the total abstracted by NWSC wells.

However these abstractions may reach the maximum abstraction level. For example in Gokarna well filed, there are five productive wells. Of these, three wells were being operated in March 1989. However three months later when a fourth well (GK1) was pumped, two wells (GK2 and GK4) could not continue pumping because of too much draw down due to interference from GK1.

The total pumpage rate from private wells and gas wells is enormously smaller than the NWSC wells. The trend of groundwater abstraction volume of private wells and gas wells has been almost constant during the last several years, but production from NWSC wells is increasing greatly.

These NWSC wells are mostly located in the northern part of the Kathmandu valley, because this area has the best aquifer conditions for groundwater development compared with other parts of the Kathmandu valley.

On the other hand, the most of the private wells are located in the central part of the valley where Greater Kathmandu is situated. However, groundwater in this area requires several treatment procedures due to its very high ammonia and nitrogen content.

The 8 "gas" wells belong to the Kathmandu gas project of the Department of Mines and Geology (DMG) and are located on the right side of the Bagmati river between Kalimati and Thapathali. All the gas wells are self-flowing with discharge rates ranging from 0.41 to 8.47 l/s.

(2) Spouts

31 typical spouts in Greater Kathmandu were surveyed in the dry and rainy seasons. The location of surveyed spouts is shown in Fig.2.4.3. The results of discharge and quality surveys are shown in Table 2.4.2.

The discharge of spouts in the rainy season in Kathmandu City is almost same as the dry season, however in Lalitpur area is generally very large compared with the dry season. The estimated yield of the largest scale spout in Lalitpur area varied between about 3 l/s in the dry season and 15 l/s in the rainy season.

This shows the difference in hydrogeological conditions between Kathmandu and Lalitpur. Lalitpur is underlain by permeable terrace deposits, whereas no permeable terrace deposits are found in the Kathmandu area.

The EC value of spouts range in MS/cm from 180 to 920 and in the wet season is generally higher than in the dry season. According to chemical analysis by the study team, the spout water has bacteria, and bacteria coli counts of 50 to 250 per ml, and also the water has a much higher chloride ion content than water from deep wells.

Existence of bacteria, bacteria coli and high chlorides are sign of water quality contamination. Spout water is derived from a shallow aquifer which is situated not many meters below the surface of the urban area of Greater Kathmandu. Consequently, the source of pollution of spout water is seepage water from the domestic waste water of Greater Kathmandu. So that, from the viewpoints quantity and quality, spouts are not recommendable as water resources for a main water supply system.

2.4.2 Hydrogeological structure

(1) Groundwater Recharge and Discharge

The area for most favorable recharge of sandy formations is located mainly in the northern part of study area, where the recharge area is enough to receive much of the annual precipitation. But, precipitation is not very effective for groundwater recharge.

Since, the lacustrine aquifers of the recharge area have no great capacity and the mean annual precipitation is about 1,700 mm of which 70% falls during the monsoon seasons (only three months), the water runs off quickly and stream flow is not well sustained during the dry season. Thus streams in the study area receives some groundwater from the shallow aquifer after the monsoon season.

Availability of groundwater recharge in the valley is controlled by at least two main conditions the most serious being the widespread distribution of lacustrine deposits interbeded with impermeable black clay which prevents easy access to the aquifers. In many areas the argillaceous lacustrine deposits begin from shallow depth below the surface and extend to great depths.

Recharge sources may occur above the impermeable argillaceous lacustrine deposits. These also may be absent near the mountains to the north. In the central part of the valley argillaceous lacustrine deposits are virtually continuous from the surface to 200 m or more.

The second problem is the poor quality of groundwater in the central part of valley which is caused by an excessive accumulation of decayed organic matter. The Kathmandu valley has a large scale natural gas well field with potentially good economic prospects. This would appear to be the source of ammonia and nitrogen which is found in groundwater in the valley.

The groundwater quality survey and dating analysis indicates that the confined aquifer in this valley is stagnant. Thus, the possibility of developing the confined aquifer may be limited to pumpage of water from storage with proper grondwater management.

(2). Hydrogeological formation

The hydrogeological formation of the study area has been classified into 6 types of formation according to the hydrogeological condition of study area (See Figure 2.4.4).

Formation A ; This formation consists of river deposits, talus deposits, fan deposits and top soil . This formation sometimes forms a shallow aquifer and is found all over the flat plain of the valley. The deposits to the north are sandy, but those to the south is predominant clay and silty clay.

Formation B ; This formation consists of arenaceous deposits or intermediate types of arenaceous and argillaceous deposits. This formation is mainly distributed in the northern part of the valley and forms the main aquifer of the northern part of the Kathmandu valley.

Formation C ; This formation consists of stiff black clay called Kalimati clay which is categorized as argillaceous lacustrine deposits. These impermeable clay formation deposits in the center and south of the valley are about 200 m in thickness from ground level.

Formation D ; This formation consists of an intermediate type of arenaceous and argillaceous deposits of lacustrine deposits which underlie Formation C and form the deep central aquifer.

Formation E ; This formation consists of weathered basement rock which overlies basement rock. This formation sometimes has a very small capability as an aquifer, but usually forms an aquifuge.

Formation F ; This formation consist of basement rock, and usually forms an aquifuge (hydrogeological basement).

(3) Groundwater district

Based on the physical and chemical properties of ground water and geological structures, the Kathmandu valley is divided into three groundwater districts. (Figure 2.4.1 shows the boundaries and the location of wells.) A schematic geologic cross section and hydrogeological formation are shown on Fig.2.4.4. and Fig.2.4.5.

Northern groundwater district ;

The northern groundwater district, which include the Bansbari, Dhobi Khola, Manohara, Baktapur and Gokarna well field are the principal water sources for water supply to Greater Kathmandu by NWSC.

The upper deposits in the northern part are composed of unconsolidated highly permeable materials consisting of micaceous quartz, sand and gravel. The unconsolidated coarse sediments are as thick as 60 m and form the main aquifer in the valley. However, these coarse sediments interbed several impermeable fine sediments. Groundwater stored in these aquifers has become depleted due to unfavorable recharge conditions especially in Dhobi Khola well field.

The quality of the groundwater is characterized low electrical conductivity such as 100 to 200 micro-simens/cm and with transmissivities of the aquifers in the range of from 83 to 1,963 m^2/day. The southern boundary of this groundwater area bounded with central groundwater district.

Central groundwater district ;

The central groundwater district includes Greater Kathmandu. The upper deposits are composed of impermeable very thick (as much as 200 m)stiff black clay accompanied by some lignite. Unconsolidated coarse sediments of low permeability underlie this thick black clay.

Groundwater stored in these aquifers includes marsh methane gas all over the area. The quality of the groundwater is characterized by very high electrical conductivity, 1,000 micro-simens/cm in some wells located near Tripueswor.

The transmissivities of these aquifers range from 32 to 960 m^2/day. The water head pressure of this district is generally high, the deep gas wells in particular being self flowing. The existence of soluble methane gas may indicate stagnate aquifer conditions.

<u>Southern groundwater district</u> ;

The southern groundwater district is located between the southern mountains and a geological structural line from Kirtipur to Godawari.
This area is characterized by a thick impermeable clay formation and of basal gravel of low permeability. The aquifer is not well developed and is only recognized along the Bagmati river between Cobhar and Pharphing.

2.4.3 Hydraulic condition of aquifer

The transmissivity indicates the potential for groundwater development. The distribution of transmissivity in the Kathmandu valley is shown in the transmissivity map based on pumping tests (See, Figure 2.4.5). The transmissivity of each well is shown in the inventory of wells of Data Book C (C-2 Inventory of wells).

The study area is divided into five groups with value of transmissivity as summarized below,

Grade	1	2	3	4	5
Transmissivity (m^2/day)	> 500	500-300	300-100	100-10	< 10

First grade area, the aquifer of the sandy formation shows highest transmissivity (T > 500 m^2/day),which are expected most high potential development of groundwater in the study area. Second grade area, the aquifer of the sandy formation shows medium to high transmissivity (T=500-300 m^2/day), which are produced medium scale of groundwater by tube well.

Third grade area, the aquifer of sandy with silt formation shows medium transmissivity(T=300-100 m^2/day), which are produced medium scale groundwater with much drawdown. Fourth grade area, the aquifer of the silty sand formation shows low transmissivity (T=100-10 m^2/day) which can not get enough water for water supply by tube well. Fifth grade area, clayey sand formation shows very low transmissivity (T < 10 m^2/day) which can not expect groundwater development by tube well.

According to Figure 2.4.5 middle reach of Manohara river at east side of Kathmandu air port is most highly potential area for groundwater development. On the other hand, southern area is not expected any large scale groundwater development.

2.4.4 Groundwate level trend

The static water level in the study area has declined since commencement of the development of NWSC wells in the third project (See Table.2.4.3). This groundwater development has resulted in a progressive fall of about 10 meters in the water level during the past 4 years at MH6 well in the Manohara well field.

Well hydrograph of existing wells are shown in Figure 2.4.6. The trend of a decline in water level is still serious as shown in these well hydrographs. At Gokarna well field, the water level of GK5 shows about 4 meters of lowering, about one month and a half after GK1 pump started, then GK2 and GK4 wells stopped pumping, due to water level influence from GK1, but, the water level of GK5 is not recovering.

Similar phenomena have been experienced at Manohara well field. MH6 well suffered about 8 meters of lowering of the water level during the period from February to December 1989. The phenomena of both well fields showed the effects of the radius of influence of a well cone of depression.

Two JICA observation wells have also shown the trend of a decline in water level.(See Fig.2.4.6). The water level of JW1 rose about 1 meter during the period from October 1989 to January 1990, but fell again about 2.1 meters from the middle of January to March 1990. On the other hand, the well hydrograph of JW4 shows a decline in water level trend of only about 0.8 meters.

2.4.5 Dating analysis

The transit time or age of groundwater data as obtained by radio active isotope of tritium and carbon-14 helps in determining the recharge and discharge system of aquifer.

The results of tritium measurement may be summarized as follows:

Sample Number	Concentration of Tritium
PH-1	Less than 0.38 T.U.
SP-1	9.7 ± 0.2 T.U.
GK-3	Less than 0.38 T.U.
DK-5	4.3 ± 0.2 T.U.
BB-7	1.7 ± 0.1 T.U.

T.U.(1 T.U.= ^3H / ^1H = 10^{-18})

From the above results it would seem probable that PH-1 and GK-3 do not include recent precipitation. SP-1 (spout water at Kathmandu) is known to include recent water. If recent precipitation contains 20 T.U. of tritium, this would indicate that this spout water may contain about 50% recent precipitation. Aquifer GK-3 may not receive any recharge from recent precipitation. The results of carbon-14 measurement may be summarized as follows:

Code Number	Sample Number	B.P.age	(Before A.D.1950)
Gak-14562	JW-1	9,170 ± 270	(7,220 B.C.)
Gak-14563	DMG-4	28,890 ± 1,370	(26,970 B.C.)

From the above results, these samples may have entered the ground about 9,000 to 28,000 years before A.D.1950. This means that the confined groundwater of the central part of the Kathmandu valley is probably non rechargeable stagnant groundwater.

2.4.6 Chemical properties of water

(1) Electrical conductivity

Iso-electric conductivity contours (Fig.2.4.5) shows conductance of water and the trend of groundwater flow. Generally the EC value of surface water in the surrounding mountain area is quite low (less than 100 MS/cm). EC of the groundwater shows about 200 MS/cm or less in the northern part of the valley, meanwhile EC value of private wells in center and southern part shows high electric conductivity (more than 500 MS/cm).

It may be noted also that the electrical conductivity contours form a circle at the gas well field between Kathmandu and Lalitpur along the Bagmati river. This suggests that the groundwater in the deep aquifer in the center and south is remote from the recharge area and there is no possibility of natural discharge from the valley except for evaporation loss.

(2) Chemical Analysis

Chemical analysis for the hydrogeological study was carried out in Japan on 31 water samples taken during the first field stage from existing NWSC wells, private wells, spouts, springs and the main river courses, and 4 samples taken during the second field stage from JICA observation wells. The location of sampling points is shown in Fig.2.4.7. The results of analysis are shown in Table 2.4.4.

(3) Classification Analysis

Accordingly to the results of classification analysis by trilinear diagram as shown in Fig.2.4.8, most of water samples were categorized as carbonate hardness type ($Ca(HCO_3)2$) or carbonate alkali type (NaHCO3).

Water samples from the southern mountain and sample No.10 are typical of the carbonate hardness type as low salinity and low sodium hazard water which is generally found in shallow and good quality aquifer in a carbonaceous rock area. Water samples from rivers in the northern area are carbonate alkali type being low carbonaceous.

Stiff's hexa-diagram is shown in Fig.2.4.7 to further illustrate the pattern of water quality. The carbonate alkali type with a very small amount of total ion density is located in the northern groundwater district. The carbonated hardness and carbonate alkali types with very large amounts of total ion density are located in the central area deep aquifer. The carbonated hardness type with a medium amount of total ion density is located in the southern area.

(4) Chemical Quality of Groundwater

High concentrations of ammonium(NH_4+) ion, nitrogen(N) and potassium permanganate ($KMnO_4$ Cons.) were recognized in central area of the Kathmandu valley as shown in Stiff's hexa-diagram. There are relatively high concentrations of these ions in sample No.12 at gas well DMG5 and sample No.13 at Himalaya Hotel. In these samples, the NH_4+ content is 78 - 100 mg/l, the Kjeldahl N content 58 - 62 mg/l, and $KMnO_4$ Cons. content 46-51 mg/l.

According to the report of "Natural gas resources in the Kathmandu valley" May 1980 JICA, these ions contents are higher than observed in groundwater from ordinary Quaternary gas reservoirs in Japan. This fact reflects the rapid or strong disintegration of organic matter in the sediments.

2.4.7 Artificial recharge

In the Kathmandu valley, there has been a considerable decline in groundwater level in recent years due to excessive use of groundwater for water supply compared with natural recharge of groundwater. In order to increase the recharge of groundwater, artificial recharge is to be considered. The main purpose of artificial recharge of groundwater will be to reduce declining groundwater levels.

Two methods have been developed for recharging groundwater, namely direct and indirect methods. The most widely practiced methods are direct surface methods for shallow unconfined aquifers such as the basin method, stream channel method, ditch and furrow method, flooding method. Recharge well methods are typical subsurface direct injection methods for deep confined aquifers. Indirect methods are to keep and manage forests in natural recharge areas for good groundwater recharge conditions.

The possibility of artificial recharge will depend on the hydrogeological conditions, land use, and water resources for artificial recharge.

Direct surface methods for artificial recharge require large flat areas with high permeability and a sufficient depth of water table from the surface. The permeable sediment layer in and around the river bed in the northern part of the Kathmandu valley may be a most suitable direct surface recharge area, but the thickness and distribution of the permeable layer is limited, and during the rainy season water table is high beneath the river bed, and also surplus surface water in the rainy season is very turbid and will require sedimentation.

Water reservoir and/or sedimentation ponds will be required for storage of artificial recharge water and sedimentation of turbidity, because the potential water for artificial recharge in the Kathmandu valley is only surplus surface water in the rainy season .

Well recharge is another typical direct recharge method using a tube well for entry into a deep aquifer. Clogging is the most serious problem of the well recharge method. Therefore, the quality of recharge water has to be of a higher standard than drinking water quality.

Consequently, artificial recharge in the Kathmandu valley would be very costly, and efficiency of recovery of artificial recharged water would be uncertain. If sufficient water and of the right quality for artificial recharge is available in the Kathmandu valley, such water should be allotted to the water supply system directly.

2.5 Surface Water Use

2.5.1 Land use and irrigation

Most of the land within the valley is used for agriculture. Hilly land is covered by forest, left as shrub, or partly terraced for cultivation near the villages. The agricultural land is classified as lowland area (Khet) or upland area (Pakho). Lowland areas are further classified as rainfed and irrigated according to water availability for irrigation. Present land use in the study area in each category is summarized below.

Agricultural Land	421.8 km^2	64.3%
Lowland (net)	(222.6 km^2)	(33.9%)
Upland (net)	(92.0 km^2)	(13.9%)
Forest	134.3 km^2	20.5%
Shrub	68.9 km^2	10.5%
Sand, Gravel, Boulders	4.6 km^2	0.7%
Urban	26.4 km^2	4.0%
Total	656.0 km^2	100.0%

In the valley there are a number of irrigation systems abstracting water from the river. Some are government aided irrigation systems and some are locally developed farmers' systems. Their net commanded area is estimated to be about 8,000 ha in total, but the irrigation efficiency is low owing to poor facilities, and the irrigable area in the dry season is limited due to the lack of river water.

2.5.2 Present water use

Present water use is mainly related to the activities of irrigation and municipal water supply. Irrigation systems are studded along the Bagmati main stem and its tributaries around the basin as summarized below:

River basin	No. of systems	Net Commanded Area (ha)
Bisnumati,Dhobi	14	860
Bagmati	4	310
Manohara	12	510
Hanumante	55	1,640
Godawari,Khodu,Nakhu	43	3,780
Balkhu	2	310
Others	4	210

Since there are few operation records in the irrigation systems, irrigation water requirement usage for the water balance simulation study was estimated by adopting the standard procedure recommended by FAO on a monthly basis from 1941 through 1986 with modifications according to the available data and information. The irrigation water requirement at these irrigation systems are summarized below:

Unit:lit/sec/ha

River Basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bisnumati & Dhobi	0.4	0.6	0.9	0.7	0.6	1.1	0.9	0.9	0.8	1.0	0.3	0.3
Bagmati	0.4	0.6	0.9	0.7	0.6	1.1	1.0	0.9	0.9	1.0	0.3	0.3
Manohara	0.4	0.6	1.0	0.7	0.6	1.0	0.8	0.6	0.5	0.9	0.3	0.3
Hanumante	0.4	0.6	0.9	0.7	0.5	1.1	0.9	0.8	0.8	0.9	0.3	0.3
Godawari,Khodu & Nakhu	0.4	0.6	1.0	0.8	0.6	1.2	1.1	1.0	1.0	1.0	0.3	0.3
Balkhu	0.4	0.6	1.0	0.7	0.6	1.2	1.1	1.0	1.0	1.0	0.3	0.3

2.6 Existing Water Supply Systems and Facilities

2.6.1 General

In order that the current water supply facilities in Greater Kathmandu may satisfy the increasing water demand following a recent rapid increase in the population, three water development projects have already been implemented, based on the 1973 master plan. These projects have included both the development of water resources such as springs, deep wells etc., and construction of water supply facilities such as reservoirs, pipelines, etc.

However, the existing water supply facilities cannot perform their functions efficiently, because of deterioration, incomplete construction, and insufficient and improper operation and maintenance. Consequently, they often supply water of inferior quality and in insufficient quantities. Moreover, there is the problem that each project has been expanded without sufficient study of the rationality and balance in the entire system.

With regard to quantity, after completion of the 3rd project which involves the construction of new wells, the available water supply should rapidly increase and meet the water demand by 1994. The water quality analysis conducted during the field surveys has, however, confirmed that the groundwater being produced in these wells contains very high levels of iron, manganese and ammonia.

The quality of water from the existing treatment plants which treat the surface water is already insufficient, but the supply of untreated groundwater containing high levels of iron and manganese is generating colored water and blockade of pipelines as a direct effect. This makes the problem on waterworks in Greater Kathmandu more serious.

Also, although some of the water is chlorinated, the chlorine is mostly consumed by the ammonia. It is, therefore, far from achieving the ultimate object of waterworks which is to supply safe and sanitary water to consumers at adequate pressure and in sufficient quantity. The following describes the current status of the water supply systems and facilities in Greater Kathmandu.

2.6.2 Source of supply

Surface water and groundwater are used in combination as water sources. There exist seven intake facilities for water supply to Greater Kahmandu which are operated by NWSC.

Groundwater is mostly being produced by wells constructed under the 3rd project. The groundwater produced by well fields of Bansbari, Dhobi Khola, Manohara and Gokarna in the northern part of the Kathmandu valley and through southern Pharphing well field, is now being supplied to the cities of Kathmandu and Lalitpur. For the city of Bhaktapur, there is Bhaktapur well field in Bore.

The following describes both the available capacities and water quality for the existing water sources.

(1) Available capacities of present water sources

The water supply systems managed in the Kathmandu valley by the NWSC can broadly be classified into eight systems which supply the cities of Kathmandu and Lalitpur, and two systems for the city of Bhaktapur. Of the former, the three systems for Chapagaun, Dood Phokari and Lokhat use springs as their water source mainly to supply villages around the cities.

For each system, the water is collected either at a treatment plant or reservoir, from where it is distributed to cities. As a result of this investigation, the available capacity of the water source for water supply in the Kathmandu valley can now be assumed to account for 60,540 m^3/day from surface water and for 55,620 m^3/day from groundwater, amounting to 116,160 m^3/day.

For the groundwater, however, because of the extreme drawdown caused by mutual interference due to the closeness between wells, in addition to such factors as facility repairs, electrical faults, etc., the actual available abstraction of the groundwater may be assumed to be much less than the above mentioned value.

Table 2.6.1 gives the available capacity of surface water and groundwater for each system.

(2) Quality of water sources

The 1st and 2nd field investigations have undertaken water quality analyses on existing water sources during the dry and wet seasons, respectively. Results show that the springs had a stable water quality both in the dry and wet seasons, i.e. there is no problem in regard to water quality. The river water also poses no problem in particular as a water resource for water supply, if an appropriate treatment is applied, although its turbidity may increase immediately after rainfall in the wet season.

The groundwater, however, except for that from the Pharphing well field, contains a very high level of iron, manganese and ammonia, at levels not permissible as a water source for water supply. Supplying groundwater without treatment as at present results in additional problems.

Table 2.6.2 gives the results of analyzing the water for iron, manganese and ammonia from each well field.

2.6.3 Water supply

Both the surface water and groundwater supplied from each source, either remains untreated or after treatment through the treatment plants of each system, is stored in the distribution reservoirs, from where it is distributed to the cities through the intermittent supply of approximately three hours each in the morning and evening.

Using operation records over a period from August 3 to August 12, 1989 collected during the field investigations of five major reservoirs (Balaju, Bansbari, Maharajganj, Mahankal Chaur and Shaibhu) supplying water to the cities of Kathmandu and Lalitpur, and the wells supplying water to each of the above reservoirs, the inflow amount and supply amount of these reservoirs were analyzed.

It was found that the average inflow to the five reservoirs accounted for 39,080 m^3/day from surface water and for 21,890 m^3/day from groundwater, amounting to 60,970 m^3/day, and the water supply amount from the reservoirs to the cities of Kathmandu and Lalitpur accounted for 61,155 m^3/day.

The results of these analyses are given in Table 2.6.3.

2.6.4 Treatment works

In Greater Kathmandu, there are now five treatment plants: four at Balaju, Maharajganj, Sundarijal and Sundarighat to supply water to the cities of Kathmandu and Lalitpur; and one at Bansbari for the city of Bhaktapur.

Of these, the Sundarighat treatment plant used to take raw water from the Bagmati, but this has been abandoned, because of heavily contaminated raw water due to an increasing inflow of urban sewerage in recent years. The following describes both a summary of the facilities and the current status of maintaining and operating each treatment plant.

(1) Balaju treatment plant

The Balaju treatment plant was constructed in 1961 to treat the surface water from the Lambagar Kh. and springs at five locations within the Bisnumati basin. The design capacity is 10,900 m^3/day. When the turbidity of raw water is high, there is provision for adding a coagulant to the raw water at the raw water inlet channel, but in practice no coagulant is added and the raw water is sent directly to the sedimentation basin.

Because of imposing an excessive load on the filtration basin and of insufficient coagulation, as well as inadequate washing, the filter media are too contaminated for satisfactory filtration.

Into this treatment plant, the groundwater is sent both from the Balaju well and the BB7 well in the Bansbari well field, but this flows into the reservoir untreated. For chlorination, bleaching powder is added at the filtered water channel, but as the quality of filtered water is bad, the residual chlorine is found to be about 0.1 ppm or less in the reservoir.

(2) Maharajganj treatment plant

This treatment plant was constructed in 1960, and treats the surface water from two springs at Bisnumati and Siwapuri. The design capacity is 2,400 m^3/day.

The sedimentation basin was demolished in 1987 due to a severe water leakage, and the raw water now flows directly into the filter basin. For this reason and because of inadequate washing facilities, as well as an excessive load imposed on the filter basin, the filter media are substantially contaminated. Also, because of having only a filter basin, the raw water flows directly into the reservoir during washing.

For chlorination, bleaching powder is added to the filtered water channel, but because of the untreated groundwater entering from the Bansbari reservoir or other wells, as well as the poor quality of the treated water, the residual chlorine is less than 0.1 ppm in the reservoir.

(3) Sundarijal treatment plant

This treatment plant was constructed in 1966, and is one of the main treatment plants for the city of Kathmandu. It treats water from the Sundarijal dam (Bagmati), with a design capacity of 19,600 m^3/day.

When the turbidity of the raw water is high during the wet season, both a coagulant (alum) and lime are added to the raw water inlet channel to increase alkalinity and to adjust the pH. Although the rate of dosage of both the coagulant and lime is determined by a Jar test, the actual dosage rate differs from the results of this test, and is insufficient. The raw water, after addition of chemicals, is mixed in the channel, and then sent to the sedimentation basin.

There are three filter basins, each being washed daily. Because the chemical dosage is insufficient and because the capacity of the back washing tank is not enough to continue the washing for a sufficient time, the filter media are contaminated.

For chlorination, bleaching powder is added to the filtered water channel. After chlorination, water is supplied to villages along the transmission line, and then stored in the Mahankal Chaur reservoir.

2.6.5 Distribution system

Water is now being supplied intermittently to the cities of Kathmandu, Lalitpur and Bhaktapur from the reservoirs of each system for approximately three hours in the morning and evening. Villages around these cities, however, are mostly situated along the transmission lines from which water is supplied to them directly.

The reservoirs were greatly increased in the capacity during the 1st and 2nd projects. The capacities of the reservoirs are now 24,500 m^3 and 5,600 m^3 to serve Greater Kathmandu and Bhaktapur respectively.

The reservoirs at Balaju, Maharajganj, etc. are now suffering from water leakage due to deterioration. Both the Bansbari and Shaibhu reservoirs are also insufficient in capacity, causing overflows between the water supply hours.

Since the distribution networks in the cities have been expanded in a disorderly way over a long period keeping pace with increasing water demand, both new and old multiple pipelines have been laid under the same roads thus resulting in a very complex distribution system. The incomplete distribution systems also fail to maintain uniform water pressure, often causing cuts in water supply at the ends of the pipelines. For this reason, water is supplied in distribution blocks by carefully operating the valves within the systems during the water supply hours.

In the 1st and 2nd field investigations, sampling points were selected at six or seven points in each distribution system, and water was sampled at these points right after starting the water supply and at certain times thereafter to check the variations in the water quality. Results show that the water quality immediately after starting the water supply contains very high levels of contaminating substances, which decrease as time goes on. This is attributable to the flowing-out of such substances from the pipelines due to the sudden change in the flow velocity and is a product of the intermittent supply method.

In this survey, on-site analysis of residual chlorine was made at the time of sampling. No residual chlorine was found, except from samples collected from water in the city of Lalitpur being supplied from the Shaibhu reservoir where the water quality is relatively good.

These results indicate that if the water contains very high levels of ammonia, iron, manganese and few residual chlorine, and if there is only intermittent flow of water in the pipelines, residual chlorine is completely consumed by ammonia and the inside of the distribution system becomes a favorable breeding environment for iron bacteria, nitro bacteria, etc. This results in deterioration of the water quality within the distribution pipes. Therefore, the current water quality can not kill pathogenic bacteria and causes the discharge of bacteria and colored water from the taps.

The level of residual chlorine to be maintained in the tap water must be sufficient to kill such pathogenic bacteria as those causing dysentery, typhoid, etc. Generally, this level is required to be 0.1 ppm or upwards as free residual chlorine, while more than 0.2 ppm is necessary during epidemics or right after reopening the service after supply halt.

Meanwhile, for the anti-corrosion program, the past experience has shown that effective results were obtainable when the pH was 7.5-8.0 and the Rangelier's index -1.0 or upwards. The Rangelier's index was -1.50, -2.65 and 0.08 for the Balaju, Mahankal Chaur and Shaibhu systems, respectively. It is, therefore, assumed that water supplied from systems other than the Shaibhu system are highly corrosive.

3. WATER RESOURCES

3.1 Groundwater Simulation

3.1.1 General

The groundwater basin in the Kathmandu valley (hereinafter called "the groundwater basin") is isolated and independent of other groundwater systems outside the valley. The main aquifer ranges from EL. 900 m to El. 1350 m and is confined by lacustrine deposits some 50 to 200 m in depth, or alluvial fans less developed in some places along the margin of gentle hills in the northern and south-eastern part of the valley. The total area of the groundwater basin is 326 km^2 and its boundary is shown in Fig.3.1.1.

Groundwater abstraction by NWSC from this main aquifer has recently caused a rapid drawdown of groundwater level, which may have serious consequences on water supply to the valley in the near feature. Notwithstanding this phenomenon, no appropriate assessment on basin-wide exploitability has been conducted up to the present because of lack of information on the geology and hydrogeology of the valley.

This study aims at the following three items by means of mathematical model simulation (FEM) based on the field investigation and hydrogeological analysis ;

1) To simulate the original groundwater level,or condition before abstraction by NWSC (year 1972),
2) To simulate the present groundwater level as the result from abstraction in the last two decades (year 1989),
3) To establish the optimum management plan for groundwater use including the pump operation program for existing tube wells

3.1.2 Groundwater basin of the Kathmandu valley

(1) Permeable area

The deposits within the valley are predominantly lacustrine. Furthermore,the ground surface of the relatively lower and flat area is covered with silty clay. Therefore even infiltration of rainfall into the shallow aquifer is quite limited.

The total infiltration area for the unconfined shallow aquifer in the Kathmandu valley mentioned above is 86 km^2,or 26 percent of the total area of the whole groundwater basin. Fig.3.1.2 shows the geological conditions in the valley and estimated permeable area.

The main aquifer for exploitation is confined and isolated both laterally and vertically. Therefore the recharge sources of the main aquifer are squeezed water from the confining strata or leakage water of unconfined aquifer through confining strata, both of which lie above the main aquifer. This water movement is caused by the difference between the total heads of the concerned strata. The amount of this groundwater flow is quite small if groundwater is not abstracted artificially from the main aquifer, or under natural conditions. But drawdown of the piezometric head of the main aquifer by artificial abstraction as conducted now will cause increased supplementary recharge from above. The hydrogeological structure of the groundwater basin is described in detail in APPENDIX-D.

(2) Seasonal Fluctuation of Piezometric head of the Main Aquifer

Continuous observation on groundwater levels at several tube wells has been carried out by JICA team since March 1989. From October 1989, automatic water level recorders have also been installed at four observation wells which were constructed during the study by JICA team. These data,however, do not cover one hydrological cycle so far. Therefore, previous well hydrograph data are used to assess the seasonal fluctuation of groundwater level and recharge into main aquifer. Those are;

Well	District	Ground Elevation	period
B12	North	1320 m	Dec.1971 - Nov.1972
WHO 7A	North	1359 m	Jun.1972 - Nov.1973

To assess the annual fluctuation of groundwater level in the long term, tank model simulation is carried out which develops the relationship between rainfall and groundwater level. The model is first calibrated with the observed well hydrograph and corresponding rainfall data. Long term data on groundwater levels are then synthesized by the model and observed rainfall data. Annual fluctuation (Maximum groundwater level - Minimum groundwater level) of long term average at these two sites are estimated as follows;

Well	Area	Assessed Period	Estimated Mean Annual Fluctuation
WHO 7A	Sundarijal	Jan.1940- Dec.1986	1500 mm
B12	Maharajganj	Jan.1947- Dec.1975	457 mm

Both wells are located in the Northern part of the basin and strainers are installed in the main aquifer. Therefore fluctuation of the groundwater level represent that of the main aquifer. The groundwater level has an annual cycle. Maximum water level occurs in September, and minimum in the end of June or beginning of July. Average annual fluctuation at B12 and WHO 7a are 457mm and 1,500mm respectively.

(3) Aquiclude leakage

A confined aquifer lying between impermeable layers cannot be recharged, even if the piezometric head of the aquifer is lower than that of adjacent layers. The layer above the main aquifer in the valley is, however, thought to be an aquiclude, though not impermeable. Therefore, the difference in piezometric head between the main aquifer and the upper aquifer may cause basin-wide movement of groundwater called aquiclude leakage as illustrated in Fig.3.1.3. The possible causes of differences of head are thought to be 1) physiographic effectiveness , and 2) artificial abstraction from the main aquifer.

80 percent of the annual rainfall in the valley is concentrated from June to September (the Monsoon season), and the ground surface in the valley is mostly in a saturated condition during this period. On the other hand, ground water level decline gradually after the Monsoon season. This annual fluctuation of water level in the shallow aquifer causes fluctuation in the piezometric head of the main aquifer in deep strata in the valley. The leakage factor, or permeability of the aquitard layer on the main aquifer, is calculated by the following equation based on the abovementioned phenomenon;

$$S \frac{h1}{T} = k' \frac{(h2-h1)}{L} \cong k' \frac{(h - hm)}{L}$$

$$\text{or,} \quad k' \cong \frac{L S}{(h - hm)} \frac{h1}{T}$$

where,
k': permeability of aquitard layer
S : storage coefficient
h1: piezometric head of the main aquifer
hm: annual average of h1
h2: groundwater level of shallow aquifer
h : ground level
L : thickness of aquitard

Based on this equation, the permeabilities of the aquitard in the groundwater basin at well WHO 7A and B12 was estimated to be 0.00032 m/day (3.7×10^{-7}cm/sec) and 0.00034 m/day (3.9×10^{-7}cm/sec) respectively. Fig.3.1.4 indicates the observed well hydrograph and illustrates the basic concept to estimate leakage factor.

3.1.3 Numerical model and calibration

(1) Numerical model

The main aquifer in the valley is considered to be one confined body according to the hydrogeological survey and chronological analysis of groundwater abstracted from the aquifer. Therefore one confined aquifer model with a leakage factor is applied in this study as illustrated in Fig.3.1.3.

The applied numerical equation is a two dimensional equation with the vertical leakage factor as shown below;

$$\frac{\partial}{\partial x}\left(Kx \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(Ky \frac{\partial h}{\partial y} \right) = S \frac{\partial h}{\partial t} + \frac{k'}{b'}(H - h) \qquad (5)$$

h : piezometric head
K_x, K_y : permeability in the x,y direction
S : storage coefficient
h : piezometric head of confined aquifer
H : elevation of unconfined aquifer
k' : permeability of the aquitard
b' : thickness of the aquitard
t : time

For difference approximation, the Finite Element Method (FEM) with Galerkin's method is applied to the equation above.

(2) Meshwork of the groundwater basin and boundary condition

The boundary of the whole groundwater basin is identifiable from the geology. The outer rim of the whole groundwater basin coincides with ground level contour of El. 1,400 m in the Northern and Central districts. In the Southern district, the ground level of the outer rim ranges from El.1,400 to 1,500 m .

The area inside the boundary is divided into 1,212 rectangular or triangular elements,each of which is formed by three or four nodes. These nodes represent the boundary of the whole groundwater basin/sub-basin, existing production well sites and observation well sites. The FEM Meshwork developed is shown in Fig.3.1.5.

Each element has average transmissivity which represents the transmissivity of the area of the element. The average transmissibilities are classified into 7 categories ranging from 10 m^2/day (category 1) to 700 m^2/day (category 7). Classification of transmissivity by the category was conducted based on the spatial distribution of transmissivity in the basin developed through the hydrogeological study. Classified zones in the mesh map is shown in Fig.3.1.6.

The groundwater basin is isolated from other groundwater bodies outside the valley,therefore recharge outside the valley is thought to be negligible. On the other hand, leakage through aquitard may play an important role in the recharge of the main aquifer. Leakage is caused by the difference of head between water table of unconfined aquifer and the main aquifer. The head of the main aquifer is an unknown variable and the elevation of unconfined aquifer should be given as a quasi-three dimensional boundary condition. The unconfined aquifer changes with the annual cycle, but this fluctuation is relatively small for the thickness of the aquitard. In the rainy season the elevation rises nearly to ground surface. Thus the water level of the unconfined aquifer is temporally set to be the ground elevation at the corresponding node. This elevation has to be finally fixed by calibration of the model. The boundary conditions are summarized below;

the basin boundary :
discharge zero at all the nodes on the basin boundary,
elevation of unconfined aquifer :
ground level at all the nodes within the basin as initial values.

(3) Steady state condition

The ground water level may have been in nearly steady condition in the early stages of the 1980's, say 1983 because no pump was operated in the Northern district except for a tube well named BBOLD. Therefore, ground water level data at 19 pump wells mainly in the Northern district which were constructed as production wells before 1984 are selected for calibration of the calculated groundwater level under steady state condition of 1983.

Calibration under steady condition can be carried out by changing a leakage factor of the aquitard layer lying above the main aquifer, and the ground water level above the main aquifer. Changing of transmissivity category is also used for fine adjustment.

In this study, the leakage factor is fixed at 0.00033 m/day, or the average value of leakage factor at well WHO 7a and B12 (see section 3.1.2.(3)). Groundwater level above the main aquifer is assumed to be a function of the ground elevation. This function is selected by trial-and-error method in order to make the calculated groundwater level of the main aquifer coincide with the observed one. Finally the function is selected as follow;

$$H = 1280.0 + (h - 1280.0)*0.7 \quad (h<1300.0)$$
$$H = 1294.0 + (h - 1300.0)*0.2 \quad (1300.0 \le h \le 1330.0)$$
$$H = 1300.0 + (h - 1330.0)*0.6 \quad (1330.0 < h)$$

where H : groundwater level of aquitard layer (m)
h : ground elevation (m)

The calibration result is shown in Table 3.1.1 and Table 3.1.2. Based on the model and selected parameters mentioned above, groundwater level in following three steady state conditions are calculated:

1: Pump operation of tube wells as at the end of 1972
2: Pump operation of tube wells as at the end od 1983
3: Pump operation of tube wells according to optimum operation
(see section 4.1)

The first case represents the original groundwater level of the main aquifer. The second one is the condition before exploitation of the Third Project Wells. The third one is the condition under optimum operation of existing wells which is described in section 4.1

Water level began to decline in 1983 even when abstraction volume was only 13 percent of that in 1989. Centers of drawdown of groundwater are Bansbari, Balaju , Baneswar and Bhaktapur and the drawdown area is quite limited. Maximum drawdowns of the areas are 2 m, 3 m, 1.5 m and 3 m ,respectively. Groundwater contour maps in 1972 and 1983 are shown in Fig.3.1.7.

(4) Recharge Area

The recharge of the main aquifer depends on difference in the piezometric head between the main aquifer and the aquifer above. The area where artificial recharge is feasible is quite limited in the valley. Fig.3.1.8 indicates the possible artificial recharge area which is identified by the area where the difference of piezometric head is more than 10 m.

(5) Non-Steady state condition

Abstraction of groundwater by pumping has increased in recent years, especially since 1984. The non-steady state model is therefore calibrated by the actual drawdown from 1983 to 1989 on the assumption that groundwater level was in a steady condition in 1983.

The parameter for non-steady state simulation is storage coefficient which indicates the sensitivity between piezometric head and abstracted water volume. Table 3.1.3 shows the coefficient deduced from pumping test in a few wells, and comparison of observed and calculated drawdown.

The minimum values among the results of actual pump tests, 2.3×10^{-4}, also match well. Therefore this value was finally selected as typical for the whole valley.

Based on the selected value of storage coefficient, the change in drawdown levels from 1983 to 2001 were calculated. The groundwater levels at production wells from 1985 to 1989 are shown in Table 3.1.4.

Serious drawdown occurs at Bansbari in 1987 and the drawdown area spreads mainly in northern to north-western directions around Bansbari. The area where drawdown is more than 10 m appears only in this area. On the other hand, drawdown of more than 10 m extends to the whole the Northern district in 1989. In 2001, the drawdown area of more than 10 m does not extend so much compared with drawdown in 1989. But the drawdown become worse in the area where huge drawdown occurred in 1989.

Groundwater contour maps for 1985, 1987, 1989 and 2001 are shown in Fig.3.1.9, Fig.3.1.10 and Fig.3.1.13. Drawdown contours in corresponding years are shown in Fig.3.1.11, Fig.3.1.12 and Fig.3.1.14

3.1.4 Optimization of existing pumping operation

Recent drawdown of piezometric head of the main aquifer indicates that the present pump operations exceed the appropriate volume limited by aquifer features, location of strainers of the wells and installed pump capacity. In order to develop maximum pump abstraction that satisfies the abovementioned constraints, optimization by means of Simplex Method based on a linear relation between abstracted volume and the piezometric head with the constraints was conducted. This problem here is expressed by a LP (Linear Programming).

The objective function is total pumping volume, whose value is to be maximized. Variables are abstraction volume from the concerned wells. The first constraint is deduced from the upper elevation of the main aquifer and the location of the strainers at the wells. The second constraint is the pump capacity installed in the wells.

Conditions for optimization are summarized in Table 3.1.5. Well loss factor is varies between wells and will depend on design and construction. The well loss factor of tube wells in the Northern district ranges from 40 percent to 60 percent. Thus optimization by several well loss factors are estimated in order to check sensitivity of the factor. The optimum pumping volume at 40% ,50% and 60% are 18,900 m^3/day, 15,600 m^3/day and 11,900 m^3/day, respectively. Finally the case of 50 % of well loss is applied to develop the optimum pump operation to be relatively on the safety side. Table 3.1.6 shows the contribution of each well under well loss condition of 50 %. Contributions of each well field are ;

- Bansbari well field	6,936 m^3/day	(44.4 %)
- Balaju well field	1,000 m^3/day	(6.4 %)
- Gokarna/Manohara well field	6,093 m^3/day	(39.0 %)
- Pharphing well field	1,600 m^3/day	(10.2 %)
Total	15,629 m^3/day	(100.0 %)

The groundwater levels and drawdown under the optimum condition are shown in Fig. 3.1.13 and Fig.3.1.14.

3.2 Water Balance Study of Surface Water Resources

The aim of the water balance study is to estimate the net surplus river water available for future water sources of Greater Kathmandu water supply. The balance study was carried out on a 5-day discharge basis under hydrological conditions during the 46-year period from 1941 through 1986.

The study was divided into two steps: (i) construction of a water demand and supply balance simulation model within the Kathmandu valley and (ii) estimation of surplus river water which is available for the future water sources on the basis of the simulation model above.

3.2.1 Water balance model

The water balance model, of which the configuration is schematically illustrated in Fig. 3.2.1, consists of (i) the Bagmati mainstream and nine (9) major tributaries; that is, the Bisnumati, Manohara, Hanumante rivers and the Balkhu, Lambagar, Dhobi, Godawari, Kodku and Nakhu Khs., (ii) existing intake sites for irrigation and municipal water supply, (iii) alternative surface water intake sites newly selected in this study for run-of-river type (hereinafter referred to as "ROR" type) and storage reservoir type development schemes and (iv) existing irrigation areas.

(1) Water balance points

Existing irrigation intake sites;

In total, fifty six(56) intake sites which are operated for a total command area of 7,400 ha by the Government and local farmers are incorporated as balance points into the balance modal, as shown in Fig. 3.2.1.

Municipal water intake sites;

In addition to 9 existing NWSC's intakes in the Kathmandu valley, 15 alternative intake sites for ROR type and storage reservoir type schemes are prepared in the model as tabulated below;

Rver Basin	Nos. of Intake Site			Total
	ROR Type		Storage Dam Type	
	Existing	Alt.	(Alt.)	
1. Bisnumati Kh.	5	1	-	6
2. Dhobi Kh.	1	1	-	2
3. Bagmati Kh.	2	2	1	5
4. Manohara Kh.	-	3	-	3
5. Hanumante Kh.	1	-	-	1
6. Godawari Kh.	-	2	-	2
7. Kodku Kh.	-	1	1	2
8. Nakhu Kh.	-	-	2	2
9. Balkhu Kh.	-	-	1	1
	9	10	5	24

The alternative intake sites above were selected on the basis of (i) a map study by use of 1/50,000 and 1/10,000 topographic maps covering the whole Kathmandu valley and (ii) field reconnaissance conducted by the Study Team's Geologist, Hydrologist, Dam Engineer and NWSC's counterpart personnel during the first and second field investigation stages. In the areas of the central flat plains, special attention was paid to topographical and geological conditions in connection with ease of facility construction and operation/maintenance works and certainty in stable abstraction of low flow during a long-term project life, since it was confirmed that river courses of several sections have been shifting due to river bank erosion by flood discharges in the plain areas which are made of the thick quaternary lake sediments composed mostly of sand, silt and clay.

Table 3.2.1 compiles the meteoro-hydrological features at the various water balance points above.

(2) Natural river runoff

The Sundarijal stream station located in the upper reach of the Bagmati mainstream was adopted as the key station. The key station is defined as a station having reliable and long-term data on natural river runoff which are to be used for estimating natural river runoff in an ungauged basin. The natural runoff data at the Sundarijal station are prepared by means of "Tank Model Method" for 46 years (1941-1986), as stated in Section 2.3.

The whole valley basin was divided into 69 sub-basins for estimation of natural river runoffs at all balance points from their own basins. The runoff from each sub-basin was derived by transposing key station's runoff data, using a conversion factor, herein taken to be the ratio of the annual rainfall volume in the sub-basin to that in the key station catchment. Furthermore, an adjustment factor was also introduced into the central flat plain because of the difference in rainwater retention capacity in the underground zone between the flat plain and the high mountainous area of the key station catchment, as shown in the following equation:

$$Qi = Qs \times (Ri \times Ai)/(Rs \times As) \times AF \quad \ldots\ldots\ldots\ldots\ldots (A)$$

where, Qi = natural runoff of ungauged basin (m^3/s)
R = annual basin rainfall (mm/y)
A = drainage area (km^2)
AF = adjustment factor due to rainwater retention capacity
i = for ungauged basin
s = for Sundarijal stream gage basin

(3) Water demand

There are two (2) major types of water consumption in the Kathmandu valley:(i) municipal water consumption for Greater Kathmandu, Bhaktapur and other small towns/villages fringing the cities and (ii) irrigation water consumption for the total command area of 7,400 ha, in the balance model.

For this balance study, the irrigation water demand was thoroughly examined on a monthly basis over the whole Kathmandu valley as stated in detail in Section 2.3, since irrigation is extensively developed along the Bagmati main stream and tributaries and is expected to continue competitive river water consumption to municipal water supply. The irrigation demand is summarized in Table 3.2.2.

Meanwhile, the municipal water demand was assumed as follows in accordance with actual supply water records collected in the course of this study:

River	Intake site	Present Demand*
1. Bisnumati Kh.	Allye	1,252 (m^3/d)
	Mahadew Kh.	2,862
	Boude	1,252
	Bhandare	1,610
	Bisnumati	1,120
2. Dhobi Kh.	Shivapuri	2,000
3. Bagmati Kh.	Sundarijal	20,000
4. Hanumante Kh.	Nagarkot	4,320

Note, * present intake capacity

(4) Procedures of balance calculation

(a) Water demand and supply balance is calculated at every balance point on a 5-day basis.

(b) Surplus Water (S) at any point is given as the difference between river runoff (R) and present water demand (D) at the point. If the river runoff is larger than the water demand, the difference is discharged downstream as net surplus. If the case is adverse, no surplus would exist. The relationship between D,R and S is expressed as follows:

If $R > D$, then $S = R - D$
If $R <= D$, then $S = 0$

(c) If there is no balance point upstream from the objective point, the river runoff is the natural runoff from its own sub-basin. On the other hand, if there is one point or more upstream from the objective one, the river runoff is the sum of (i) the natural runoff from its own sub-basin, (ii) surplus river water to be discharged from the immediately upper point(s) (iii) catchable irrigation return flow(s) coming into its own sub-basin.

(e) In the study, 20 % of abstraction water for irrigation is assumed to return to the downstream river.

(d) Net river water at arbitrary balance point is calculated by repeating the above-mentioned procedures, as illustrated in Fig. 3.2.2.

(5) Verification of balance model

The appropriateness of the water balance model constructed in this study was confirmed by two kinds of verification as follows:

(a) In the first step, the water balance calculation was made for the 46-year period (1941-1986) in accordance with the above procedures under the condition of no river water abstraction for irrigation and municipal water in order to

examine the basic hydrological relationship between rainfall and natural runoff.
The calculation resulted in the preferably acceptable relationship in terms of representative hydrological factors of (i) annual runoff coefficient: f=0.53, annual loss=892 mm/year and correlation coefficient between annual rainfall and runoff=0.88 at Cobhar which is the lowest balance point with 585 km^2 in catchment near the outlet of the valley.

(b) In the second step, the calculation was carried out under the condition of present river water abstraction in order to compare the simulated and observed river runoffs. The comparison was made at Cobhar on the basis of both river runoffs for 8 years (1965-1969 and 1977-1979), when Cobhar has reliable river runoff records on a daily basis. As shown in Fig. 3.2.3, two kinds of flow duration curves coincide well with each other and their mean discharges result in the same value. Moreover, seasonal distribution patterns of both river runoffs have also good coincidence.

3.2.2 Available water for future water supply

For future water supply to Greater Kathmandu, surplus river water was examined as the available water source at 22 sites: 7 existing intake sites and 15 new sites within the valley through the water balance calculation on a 5-day discharge basis during the 46-year period (1941 - 1986) using the simulation model constructed above. The locations of the sites are shown in Figs. 3.2.1 and 3.2.4.

As the river maintenance flow, Q95 (river discharge with 95% dependability in time) is required to be remained at the most downstream balance point on each river, except for the Bagmati river. The Bagmati river is a sacred river for Hindus. The very important temple of the Pasupatinath is situated on both banks of the river upstream of Kathmandu. The river is used there for ritual bathing and cremations. In the dry season, the flow in the river is usually about 0.3 m^3/s at the Pasupatinath, but often drops to less late in the season and the river becomes highly polluted. In the Bagmati river, river maintenance flows are assigned to the Pasupatinath and Gokarna Shore temple sites at 0.3 and 0.2 m^3/s, respectively. The maintenance flows correspond to the 1.1-year drought discharges or Q85s at the respective sites.

The surplus river waters for 22 sites above are compiled in Table 3.2.3.

The simulation results imply that river water could be developed as future water sources at only a few sites in the Kathmandu valley as discussed in Sub-section 5.5.

4. WATER DEMAND

4.1 Population Projections

4.1.1 General

Future population of urban areas in the Kathmandu and Lalitpur Districts have been projected by many investigators throughout various projects since 1973. So the primary objective of the present study is to review the previous studies and to select the most appropriate projection for estimating future water demand.

The population projected in previous studies, however, vary widely. For example, the forecast 2001 population ranges from 384 thousand to 958 thousand (See Table 4.1.1). In the present study, a careful review is made of the latest two studies; Proctor and Redfern, "Water Supply and Sewerage Studies, Nepal 1984", Appendix 'D'- Population Projections; and Binnie and Partners, "Water Supply for Greater Kathmandu, from outside the valley 1988", Appendix 'N'- Population. A further population projection is carried out in a different way from these studies to examine the large difference between these two projections.

Details of the present study are described in Appendix H "Population Projections", and the following gives an outline of the study.

4.1.2 Study approach

The main references used for this study are the "Population Monograph of Nepal, 1987" and "Population Projection of Nepal 1981-2001, 1986" published by the Central Bureau of Statistics. The population projections are made in two stages; (A) initial estimates of population and (B) adjustments to initial estimates.

(A) Initial Estimates of Population

Although this study aims at projecting the urban population of Greater Kathmandu, the populations of other areas in the Kathmandu valley also are estimated for making an adjustment to initial estimates of the urban population. The process of the estimation is as follows:

(1) Objective Areas for Initial Estimates of Population

The initial estimates of population are made for twelve areas: the Kathmandu valley as a whole, three districts of Kathmandu, Lalitpur and Bhaktapur, and urban and rural areas in the entire valley and three districts. These estimates are made for respective projection years of 1986, 1991, 1996 and 2001.

(2) Conditions and Assumptions for the Initial Estimates

The initial estimates of population are obtained under the following assumptions and conditions:

(i) These estimates are made by using both mathematical and component models for each projection year up to 2001.

(ii) Population growth rate (r) is regarded as the sum of the natural growth rate (r_1) and the migration growth rate (r_2); $r = r_1 + r_2$.

(iii) The natural growth rate (r_1) applies the average rate of the country throughout the valley, assuming that there is no difference between the rates of the country and the Kathmandu valley, and its projection is quoted from "Population Projection of Nepal 1981-2001, 1986", which was prepared for four different scenarios; high, plausible, medium and low variants.

(iv) Intercensal growth rates for each area in the valley shown in Table 4.1.2 would be composed of both natural and migration growth rates, according to the assumption in (ii) above. Accordingly, an approximation of historic migration growth rate for each area in the valley would be obtained by subtracting the natural population growth rate of the country from each intercensal growth rate in the valley.

(v) First approximations of the future migration growth rates could be estimated by the method of least squares using the intercensal migration growth rates obtained in (iv) above.

(vi) The approximation of future population is estimated by using the 1981 census population and the growth rates obtained by using the sum of the future natural and migration growth rates. This estimation of population is made for all of the afore-mentioned twelve areas in the valley for the respective projection years, and the results are given as the initial values (input data) of the following adjustment.

(B) Adjustments to Initial Estimates

The final results of the population forecasts for each projection year were found by making the following adjustments for the approximation of future population estimated in (vi) of (A).

(1) First Adjustment

For the whole valley and each of three districts, the sum of the urban and rural population should be equal to the respective population of the valley as a whole and three districts estimated separately. If they are not equal, the difference, as an estimation error, is distributed to respective initial estimates of urban, rural and the population as a whole in proportion to their population sizes. Thus, the revised values of population are given as input data for the following second adjustment.

(2) Second Adjustment

The second adjustment is carried out under the condition that each sum of urban, rural and whole population in three districts should be equal respectively to the urban, rural and whole population of the Kathmandu valley. If there are discrepancies in these values, the results obtained by the 1st adjustment are revised in proportion to the population sizes of three districts and the valley by urban, rural and whole areas, and the population revised in the 2nd adjustment are again given as input data of the above 1st adjustment.

The adjustments of (1) and (2) are continued till the forecasted population attains to a necessary accuracy for each projection year by scenario (high, plausible and low variants). Details of the study approach are given in Appendix H.

4.1.3 Results and considerations

Results

Out of results of the above adjustment, the forecast urban population of the Kathmandu and Lalitpur Districts for each projection year together with the estimated population growth rates among projection years are given in Table 4.1.3, and among them the results for plausible variant in the projection years of 1991 and 2001 are summarized below:

Urban Area	Urban Population('000) 1981	1991	2001	Average Annual Growth Rate(%)* 1981-1991	1991-2001
Kathmandu	235	379	595	4.78	4.51
Lalitpur	80	107	139	2.91	2.62
Kathmandu/Lalitpur	315	486	734	4.34	4.12

*Exponential model

As seen in the above table, Greater Kathmandu in 2001 are estimated to be 2.5 times and 1.7 times of the census population in 1981 respectively.

Considerations

Concerning the total urban population of Kathmandu and Lalitpur, a comparison of the results of the present study with the projections in two recent studies mentioned in Para. 4.1.1 is summarized below:

Studies	Urban Population ('000) 1981	1991	2001	Average Annual Growth Rate (%)* 1971-1981	1981-1991	1991-2001
(A) P & R, 1984	316	479	729	4.08	4.16	4.20
(B) B & P, 1988	316	593	958	4.08	6.29	4.80
(C) Present Study	315	486	734	4.08	4.34	4.12

*Exponential model
P & R: Proctor and Redfern (See Para. 4.1.1)
B & P: Binnie and Partners (See Para. 4.1.1)

As is obvious from the above table, the 2001 population of 734 thousand forecast in the present study (C) is close to that (729 thousand) by Proctor & Redfern (A). On the other hand, the 2001 population forecast by Binnie and Partners (B) is fairly large compared with those of the other two projections (A) and (C).

The relatively large forecast of population by Binnie and Partners is due mainly to the high growth rate which was estimated from the voter's lists for the period 1981-1986. However if this growth rate (6.29 % per annum) is realistic, the population forecast by Binnie and Partners would be preferable to the other forecasts.

However, since it is difficult to examine the reality of the Binnie and Partners growth rate in course of the present study, the water demand study for Greater Kathmandu (urban areas of Kathmandu and Lalitpur), which is discussed in the following paragraph, is carried out on the basis of the population projected in the present study.

4.2 Results of Consumer Survey

In order to understand how the water supply is actually being used and to contribute to future planning, a consumer survey was conducted during the 1st investigations. Because of incompleteness and discrepancies in the result of the survey of the 1st survey, The 2nd consumer survey was intensively executed in the 2nd investigation, whose results are assessed to estimate the present water consumption

In the 1st investigation collected both the meter reading records and the consumer's ledger data over a period of eight months from July 1988 up to February 1989 at Tripureswar (Kathmandu) and Jaulakhel (Lalitpur) offices of the NWSC, from which both the average consumption per connection and the per capita consumption were tentatively assessed.

1st consumer survey

Furthermore, 20 households per ward were surveyed by questionnaire to assess the status of installing water meters, the number of consumers per