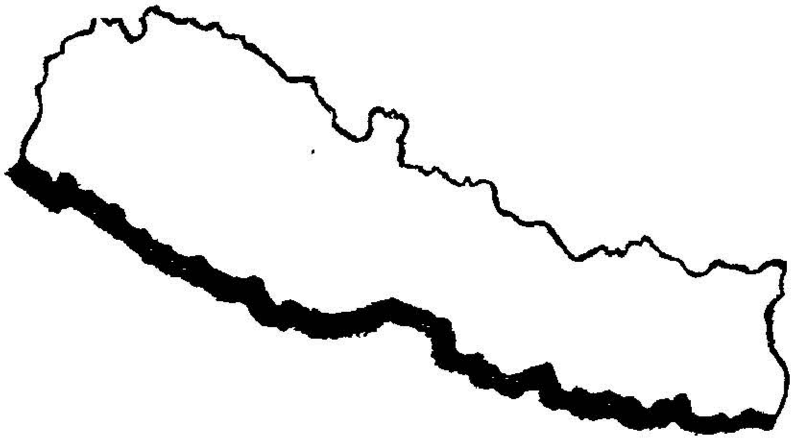

HYDROLOGY AND WATER RESOURCES DEVELOPMENT IN NEPAL

Prepared by the United States Geological Survey
in cooperation with
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Hydrology and Water Resources Development in Nepal

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Abstract

In 1961 a program was initiated to evaluate the water-resources potential of Nepal on a country-wide basis. Beginning as a cooperative agreement between the Government of Nepal and the United States Agency for International Development (US AID), the program was broadened in 1965 when the Government of Nepal accepted assistance from the United Nations in the collection of meteorological data. US AID provided technical assistance for surface water, ground water, quality of water, and sediment investigations under a Participating Agency Service Agreement (PASA) with the U. S. Geological Survey (USGS), and the United Nations (UN) provided technical assistance in meteorological investigations through the World Meteorological Organization (WMO).

By 1969, a nationwide network of hydrological stations had been established for the collection of stream flow, sediment and meteorological data, and ground-water exploration was started in the Terai Belt. The Department of Hydrology and Meteorology, under the Ministry of Power and Irrigation, His Majesty's Government of Nepal, had been established, staffed and equipped to conduct the investigations. Streamflow data resulting from observations in the network of gaging stations were being published annually by the Department of Hydrology and Meteorology.

Average annual runoff in Nepal is more than adequate to meet existing needs for basic water supply and a large potential exists for hydropower and irrigation development from the rivers. There is, however, a wide range in the flow regimens of all rivers and streams.

During the monsoon season, from the middle of June to late September, flooding commonly occurs in low lying areas. In the late dry season, March to the middle of June, runoff is deficient in many areas of the country. For example, flow in the Seti River, although influenced by snowmelt during the slack water season, ranges from 1,180 cubic feet per second to 207,000 cubic feet per second.

Streamflow characteristics for seven river basins are described with special attention to the physical characteristics that govern the runoff in the basins. Maximum and minimum daily discharges, as well as average annual flows during the period 1962-67, are presented for selected gaging stations that make up the nation-wide stream-gaging network. Progress in the full utilization of the water-resources potential of Nepal, except for small-scale irrigation projects, has been relatively slow owing to the pattern of runoff in all sections of the country that makes the development of water resources difficult. Many problems in future water-resources development can be avoided, however, by studying the performance of engineering structures already in operation. During extensive travel in the country by the author many existing projects were inspected and their performance studied as an aid in evaluating hydrological data. This report attempts to point out problems that exist and suggest alternative methods that can be considered in development projects of the future to avoid mistakes of the past.

Future development of water resources is likely to continue at a relatively slow pace, as Nepal has limited foreign exchange and market for power consumption to justify large-scale development of hydroelectric potential. The construction of moderate capacity run-of-the-river type plants is, however, being pursued actively. These plants will benefit many areas of the country but will leave the total potential underdeveloped.

Uneconomic ventures in surface-water irrigation schemes in the past decade indicate that tube wells are probably the more suitable approach to supplying irrigation requirements in the Terai Belt, at least in the near future. The Irrigation Department, His Majesty's Government of Nepal, is actively engaged in a drilling program for areas in the vicinity of Janakpur and Bhairhawa. Also, the US AID sponsored Ground Water Investigations Project, initiated in 1969, will provide essential direction to ground-water development and the installation of tube wells to insure optimum development of the aquifer.

Factors that effect the overall development of the water resources potential of the river basins in Nepal are discussed in some detail, and as in most developing countries the problems are numerous. In general, development will depend on outside assistance from friendly nations. Assistance will be encouraged by the efforts being made by the Government of Nepal to collect and evaluate hydrologic data to document the availability of the water resources. The Department of Hydrology and Meteorology is now (1969) actively engaged in the collection of basic data on all components of the hydrologic system.

Introduction

The present report is based on the observations of the writer, a surface-water hydrologist with the U.S. Geological Survey (USGS), while assigned from December 1964 to September 1968 as a technical advisor to the Nepalese Department of Hydrology and Meteorology under the auspices of the United States Agency for International Development (US AID). The report discusses the history of hydrological investigations in Nepal; the relation of these investigations to the social and economic problems of water-resources development and management; and the general hydrology of the more important river systems of the country.

The 1962 census placed the population of Nepal at 9.55 million. The main populated centers are Kathmandu (fig. 1), Pokhara, Bhairawa, Biratnagar and Nepalganj. Most of the population, however, live in the thousands of small villages that dot the landscape. With the exception of the snow-covered high Himalaya, the country is at least sparsely inhabited (fig. 2).

Figure 1.--Aerial View of Kathmandu Valley. Kathmandu, the nation's capital and rich in Nepalese culture and tradition attracts thousands of tourists each year. Shown in the middleground is the Bishnumati, a tributary of the Bagmati River.

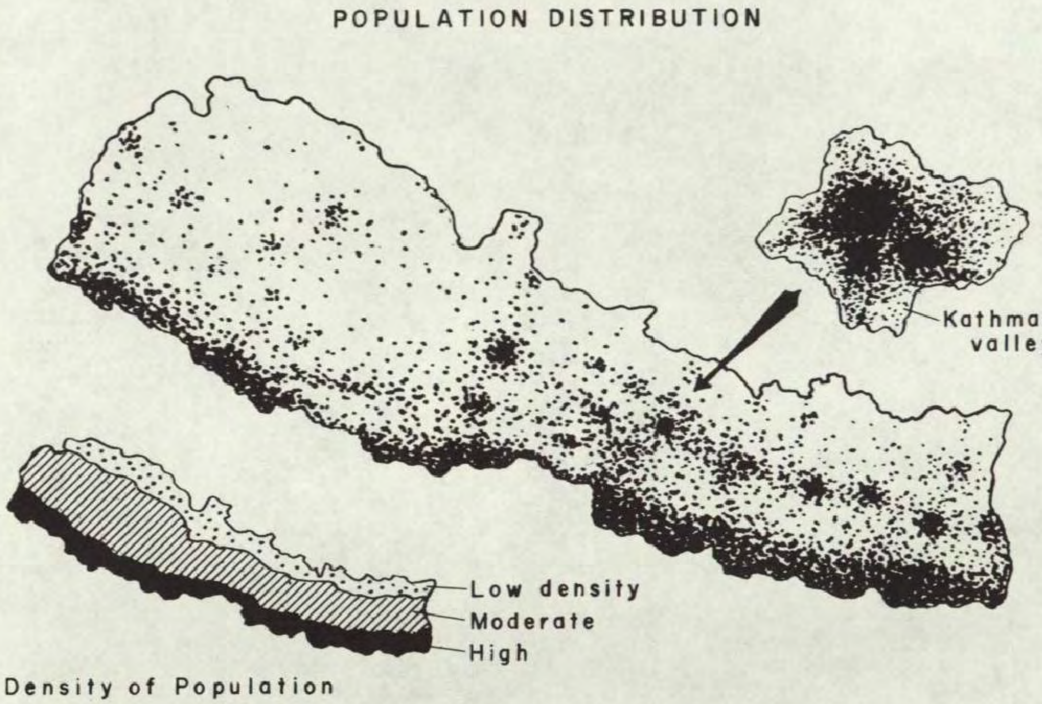

Figure 2.--Population Density of Nepal.

Approximately 8 million of the total population are engaged in agriculture with the main crop rice. Statistics prepared by the Economic Survey of Asia and the Far East in 1963 show that Nepal produced 1,351,000 tons of rice from 3,450,000 acres of paddy fields. Other important products are sugar, jute, timber, milk products and vegetables. Nepal is considered a surplus food country as food grain is exported yearly to India.

The religion of Nepal is predominately Hinduism, followed by Buddhism and Islam in that order. Hinduism and Buddhism have co-existed in the country for the past several centuries and this co-existence has influenced both past and present culture in many ways. The present king of Nepal, His Majesty King Mahendra, has the distinction of being the only Hindu monarch in the world today.

By most world standards. economic activity is relatively low in Nepal. The Council of Economic Planning, His Majesty's Government of Nepal, estimated the gross national product for FY 1967 at 7,650 million Rupees (765 million dollars). Through various aid donors, the Government of Nepal is making an effort to expand the economy and improve the living conditions of the people. Foreign assistance programs are being carried on with the United States, India, United Kingdom, Union of Soviet Socialist Republics, People's Republic of China, France, Israel, Switzerland and United Nations (UN). Many projects are underway to upgrade agriculture and to diversify the economy so as to improve manufacturing, extraction of forest products, transportation facilities and tourism. The success of these projects depends on the extent to which the country can develop and market its natural resources.

The most promising natural resources of the country are water, forests, agricultural land and the scenic grandeur of the world reknowned Himalaya. Known mineral resources do not appear to be sufficiently important at present (1969) to justify mining investment. The water-resources potential is, however, tremendous, but virtually undeveloped. The beneficiation of forest products is increasing and these products could become a valuable export in the next few years. Efforts are being made to increase food production in the Terai Belt which has good soil and a favorable climate. Here, year-round irrigation is planned and improved seed and fertilizer are being introduced to maintain Nepal's self-sufficiency in food for her growing population. The single resource offering the quickest development potential with the least investment is the scenic grandeur of the snowy Himalaya. Mount Everest, Kanchenjunga, Dhulaguri and Annapurna are natural attractions for tourists. The ancient city of Kathmandu attracts thousands of tourists every year (fig. 3). Modern hotels have been built in Kathmandu and the Rapti Valley. Others are planned for Pokhara and Namche Bazar. Tourism is a ready source of hard currency that is sorely needed to develop other natural resources.

Figure 3.--Photograph of Hindu Temple in Downtown Kathmandu. Tourists and religious students from all parts of the world visit the temples and shrines of Kathmandu every year.

Physical Features of Nepal

Topography

The Kingdom of Nepal is roughly rectangular in shape and shares a common boundary with India on the east, south and west. The northern boundary is with the Tibetan Region of China. Nepal, 54,000 square miles in area, lies between latitudes 26°30' and 30°15' north and longitudes 80°00' and 88°15' east. In a linear distance of a little over 100 miles the terrain ranges from the Terai Belt in the south with altitudes as low as 400 feet above mean sea level, to the Himalayan Ranges in the north with altitudes of well over 25,000 feet.

From south to north, there are six well defined topographic regions (Hagen, 1959): (1) the Terai Belt; (2) the Siwalik Hills; (3) the Mahabharat Range; (4) the Midlands; (5) the Himalayan Ranges; and (6) the Tibetan Plateau.

The Terai Belt is the piedmont zone of the Gangetic Plain, virtually all of which lies in India. Nepal includes three discontinuous segments of the Terai Belt along its southern border with widths ranging up to 30 miles. The southern fringe of the Terai Belt is the principal food producing section of Nepal and is densely populated. The northern fringe of the Terai Belt is covered by heavy jungles extending to the base of the Siwalik Hills. The Terai Belt is water

Figure 4.--Aerial view of Typical Khola (Ephemeral Stream) Draining from Siwalik Hills (Background) across Terai Belt. Such streams are dry for as much as 6 months of the year, but during monsoon flash floods they often disrupt the lives of the cultivators. The Terai Belt is the principal food producing section of Nepal.

deficient for 6 months each year except near the major rivers that cross the belt.

The Siwalik Hills form a sharp contrast to the Gangetic Plain and rise steeply to altitudes up to 5,000 feet. The rough slopes, eroded by wind and water, support only sparse forests. The sterile soils formed largely from coarse-grained sandstone are largely unproductive, and the region as a whole is economically unimportant.

The Mahabharat Range which rises to about 10,000 feet, is formed in a major syncline that traverses almost the entire length of the country. The topography is very rugged with steep slopes and a lack of motorable roads that add days of walking to the otherwise short distances between two densely populated areas, the Terai Belt and the Midlands. Runoff from the northern slopes of this natural barrier passes southward through four deep river gorges that cut through the Mahabharat Range. Population density is low and development of this mountainous region presents many difficult problems.

The Midlands, or intermontane areas of Nepal where the bulk of the country's population is concentrated, rank next to the Terai Belt in economic importance. The Midlands, 40 to 60 miles wide, have gentle slopes with altitudes ranging from 2,000 to 6,000 feet. The Himalaya to the north and the Mahabharat Range to the south shield the Midlands from outside influence, and it is here that Nepalese culture has developed and remained essentially unchanged for centuries. Good fertile land and favorable climate offer ideal conditions for a varied agriculture. All kinds of fruits, vegetables and grains are grown in abudance. The rivers, flow east to west or vice-versa as they traverse the Midlands later to pass through the Mahabharat Range on their way to the Ganges. Water thus is plentiful for irrigating the reaches along the streams. Increased agricultural development not only will improve the economy of this area, but would benefit the economy of the entire country.

Nepal's foremost claim to worldwide recognition are the massive Himalayan Ranges that cross the northern part of the kingdom (fig. 5). The Himalaya is not a single continuous mountain range, but a series of several more or less parallel or converging ranges. The main range of the Himalaya east of Mount Everest forms the boundary between Nepal and the Tibetan Region of China. West of Mount Everest the main range lies within Nepal, and is divided into several groups by deep river gorges that traverse the barrier. The main range (Great Himalaya) includes many of the highest peaks in the world with altitudes ranging from 20,000 to somewhat more than 29,000 feet in Mount Everest. The main range is not, however, a major drainage divide. Rather, the divide between the two major river systems, the Ganges and the Brahmaputra, lies to the north of the Great Himalaya along a mountain chain with altitudes of 7,000 to 10,000 feet lower than the main range. The headwaters of the Sapt Kosi, the Narayani and the Karnali Rivers take their origin north of the Great Himalaya and pass through it in deep gorges. This phenomenon suggests these

Figure 5.--Photograph of the Great Himalaya, Nepal's Claim to Worldwide Recognition. These massive snow and glacier-mantled peaks are viewed by all air travellers except during the monsoon when they are obscured by rain clouds.

three river systems are older than the uplift of the Himalaya. During the uplift the rivers progressively deepened their gorges traversing the Himalaya.

The area within Nepal to the north of the Himalayan Ranges is similar in character to the Tibetan region. The area is mostly a cold dry plateau with altitudes ranging from 10,000 to 16,000 feet. The monsoon exerts only minor influence on most of the region. Light precipitation as snow occurs mostly during the winter. In general, runoff from areas north of the Great Himalaya is low. Owing to the inhospitable climate and lack of water, few people inhabit the area. Small scale agriculture is carried on, however, using primitive irrigation methods. Potatoes, barley and other grains are the main crops.

Climate

The lofty and continuous mountain barrier formed by the Himalayan Ranges exerts a dominating influence over meteorological conditions in much of central Asia. The massive Himalaya prevent the dry cold air of the Tibetan region from moving into India, and likewise impede the northward flow of warm moisture-laden air from the southwest monsoon. One can only speculate on what the weather pattern in Nepal would be without the influence of the Himalaya. Most likely the monsoon now concentrated over India and Nepal would cover a larger region, thus reducing precipitation intensity over the region. Temperatures would probably be moderate to cold.

Nepal has two distinct seasons, the summer monsoon wet season from the middle of June to the middle of September and the rather dry winter season. There is a general decrease in rainfall from east to west across the country; however, the main features of the rainfall pattern are governed by topography. Precipitation ranges from about 100 inches in many parts of the country to 15 to 20 inches in the extreme northwest. Maximum rainfall occurs in the Terai Belt and diminishes in the areas to the north.

Figure 6 shows the annual rainfall pattern for Nepal. It should be noted that relatively high precipitation occurs not only in the Terai Belt but also near the river gorges in the Mahabharat Range. Precipitation as hail during February and March is a local phenomenon all over Nepal, often damaging crops and orchards.

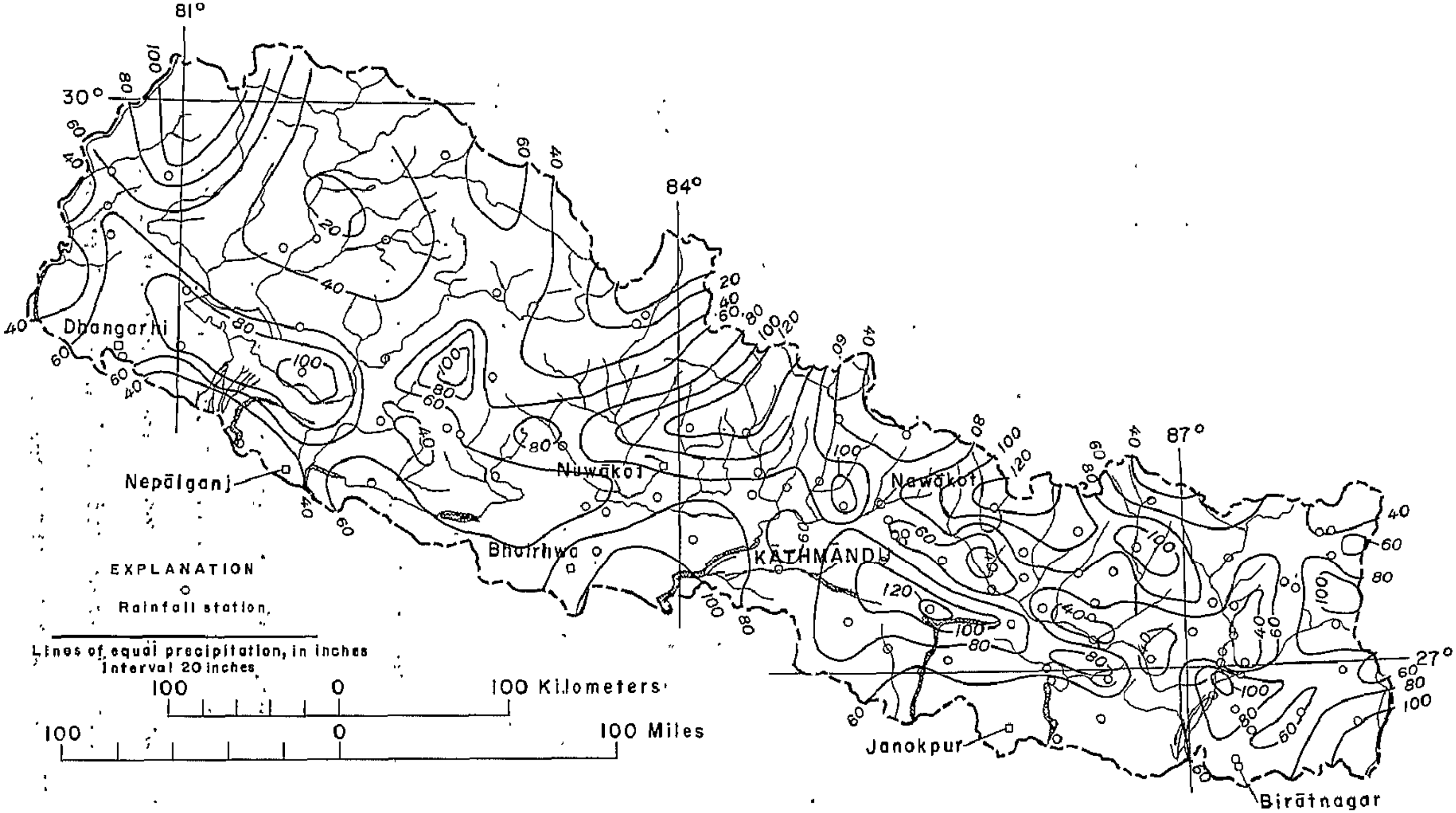

Figure 6.--Map showing Average Annual Precipitation, in inches, in Nepal. Generally precipitation decreases from east to west. Also marked orographic effects in patterns of precipitation intensity and distribution result from great differences in local land-surface relief.

Climates range from tropical in the south to alpine in the north. Temperatures in the Terai Belt sometimes reach 115° to 120°F. The daily mean temperature in the coldest month in the Terai is about 60°F. In the interior temperatures vary with altitude. In the Midlands the climate is mild except in the lower valley areas where hot humid climate is prevalent during the late spring and through the summer. Kathmandu Valley with an altitude of over 4,200 feet shows the effect of altitude on temperature. Here temperatures only occasionally reach 90°F during the high sun period.

For a country with varied topography such as Nepal, wind movement has only a moderate influence except in certain areas. In the Terai Belt southerly winds from the Ganges Plains cause dust storms prior to monsoon. Temperature differences between the hot air of the plains and the colder air of the highlands induce winds of gale force in the main river canyons through the Mahabharat Range and even through the deep gorges that cross the Great Himalaya. Strong winds occur during the day and in some areas reverse during the night to blow at moderate rates.

Water and History of Nepal

The history of human migration and settlement of lands around the world generally indicates that man first favored the major river valleys. Rivers provided game and fish for food, a means of transportation, and a source of water for domestic needs and irrigation of crops. Early Biblical history speaks of the ancient civilizations that evolved in the Nile, Jordan and Euphrates River valleys in the then-known world. The interior of North America was first opened up by the settlers who followed the major river systems.

The early history of Nepal does not appear to follow this typical pattern. Rather, steep stream gradients made the rivers unfit for transportation. Floods during the monsoon season and water-based tropical disease prevalent in the river valley bottoms compelled the inhabitants to establish villages on the hills and ridges. Even today a large percentage of the Nepalese live in localities where water is scarce for 8 months in the year. Even so, this problem does not seem to discourage the hill people. During the late dry season it is not uncommon for villagers living along the ridge crests to carry water daily from the valley areas below. Trips by water-carrier require as much as 3 or 4 hours to satisfy the daily water requirements for the average family.

The early development of the river systems of Nepal would probably have changed the pattern of life, but up until the last 10 years development was limited to small locally-built projects to irrigate winter vegetable crops. Thus, the rivers of Nepal have exerted only nominal influence on the history of the country. They will, however, exert a much greater influence in future years. The following sections examine the potential of the rivers and point out the rôle they can play in the future development of the country.

Importance of Water in Nepal's Development

Nepal's numerous river systems constitute one of the nation's greatest assets and their proper control and utilization is essential to the future development of the country. Water can be made to do many things that will win the race being made in Nepal today to catch up with the 20th century. Evident are the needs for inexpensive hydroelectric power to light homes, to spur industrialization of the economy, and to open up markets for consumer goods that depend on electrical energy. Water for irrigation will play a vital rôle in providing food for a growing population as well as a possible surplus for export.

Water exists in abundance in the snow fields and glaciers of the high Himalaya, in the rivers and streams of the entire country and in the underground reservoir of the Terai Belt. The annual runoff of the streams of Nepal is more than sufficient to meet the requirements of the country in any forseeable development. For example, in an average year the rivers of Nepal discharge 225,000 cfs (cubic feet per second) to the Ganges River in India. This volume is equivalent to the water required to cover all of Nepal to a depth of 56 inches and compares with about 9 inches of runoff for all the rivers that drain co-terminus United States.

Hydrologic Investigations

Water has long been recognized as one of Nepal's most promising resources. Yet, prior to 1960 little had been done to investigate and appraise the resource. The Government of India had collected streamflow data at the proposed power site on the Trisuli River and at the proposed site for the Kosi Irrigation and Power Project on the Sapt Kosi. The Swiss Mission had collected data at Panauti in the Sun Kosi basin. The Government of India had also collected rainfall data at numerous points throughout the country. In general, however, data were left in the raw stage and were available only to the agencies responsible for its collection.

During the mid-1950's foreign assistance programs were introduced to assist Nepal in various development objectives. Many projects were water oriented. Planning for those projects depending on water called attention to the need for basic hydrological data as a prerequisite for the development and utilization of the resource. With the signing of an agreement on November 17, 1960, between the Government of Nepal and the UN, a detailed hydrologic survey and investigation was begun in the Karnali River basin (Sidler, 1965). This survey marked the beginning of a concerted effort to collect streamflow, sediment and meteorological data in Nepal. In 1962 the Hydrological Investigations Project through cooperative agreement between the Government of Nepal and the United States Agency for International Development (US AID) was authorized, and a similar data collection program was undertaken for the entire country. The Hydrological Investigations Project proposed to establish within the Government of Nepal a separate bureau or agency solely responsible for the collection, analysis and publication of hydrological data. The new agency was to be staffed with Nepalese engineers and technicians who were to be trained in all aspects of data collection. Hydrological data collected would be multipurpose in scope and would be made available to other governmental departments for planning and development purposes.

Surface Water.--Prior to the signing of a formal work plan for the Hydrological Investigations Project, US AID entered into an agreement with the U. S. Geological Survey (USGS) for the services of two hydraulic engineers, Fred M. Veatch and Harry Hulsing, for a short-term assignment to Nepal to assess the needs for hydrological data in the development of the water resources of the country together with recommendations for a program to collect the needed data. The assignment covered 5 months, from May 21 to October 18, 1961. At the completion of the assignment, a report, "A Water Resources Investigation for Nepal" (Veatch and Hulsing, 1961) was submitted to US AID and the Government of Nepal.

The formal project agreement between the Government of Nepal and US AID indentified three objectives: (1) to create within the Government of Nepal a Department of Hydrology, (2) to establish a nationwide network of hydrological stations, and (3) to furnish technical assistance from the USGS to assist the Government of Nepal in carrying out the project. The Government of Nepal furnished counterpart personnel for

USGS engineers assigned to the project and local currency in support of budgetary requirements of the new department. US AID furnished technical assistance, dollar currency for equipment and commodities, and local currency as matching funds for the departmental budget.

Implementation of nation-wide hydrologic investigations began in May 1962 with emphasis on the establishment of stream-gaging stations. This phase of the project has expanded until at present (1969) 57 regular gaging stations and 38 partial records stations are in operation (fig. 7). In addition, numerous miscellaneous measurements have been made at other sites to supplement these data.

Table 1 lists the technical consultants and advisors in hydrological investigations who have been assigned to Nepal between May 1961 and the present (1969).

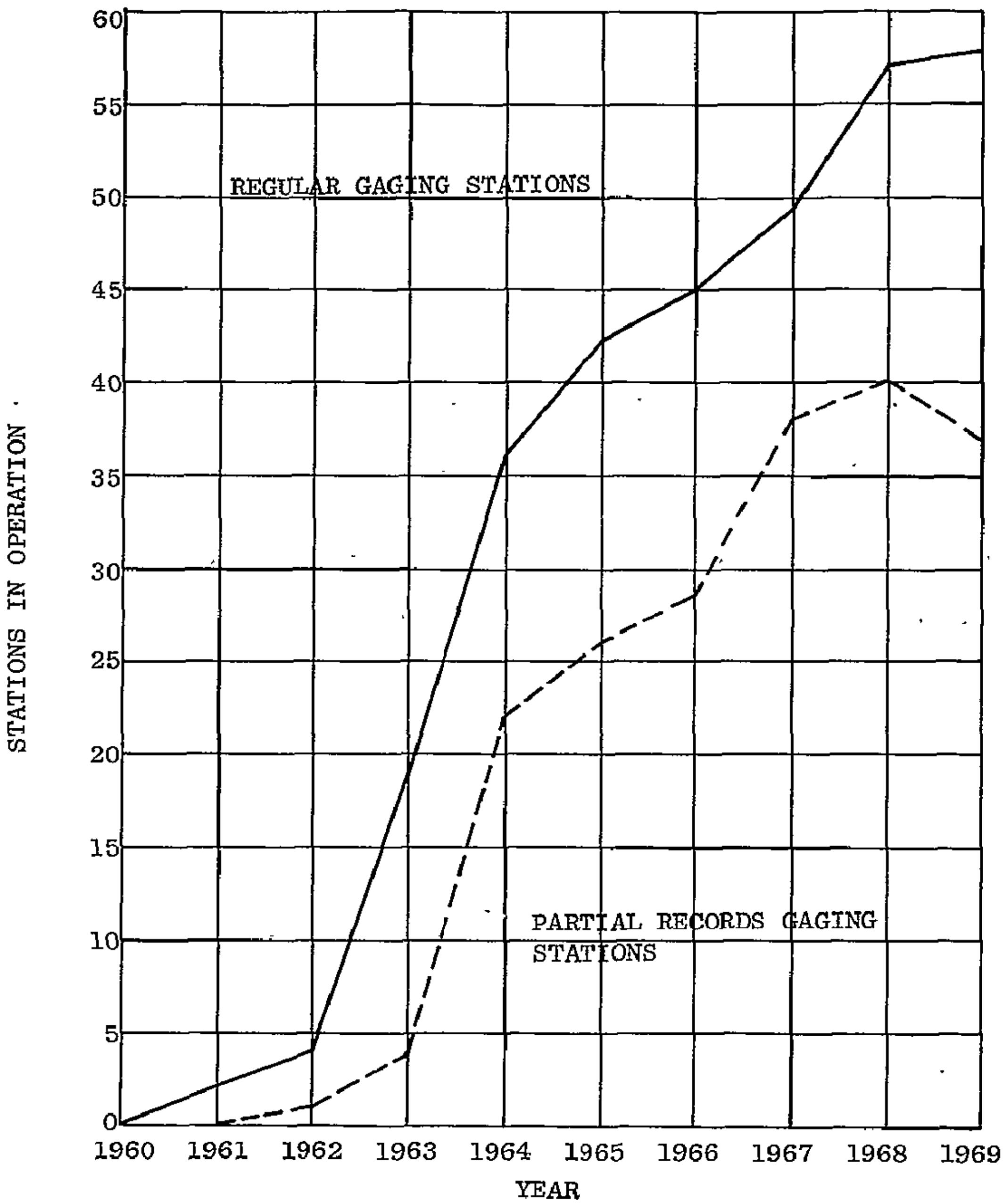

Figure 7.--Graph showing Number of Stream Gaging Stations Operational in Nepal, 1960-69.

Table 1.--Technical Advisors Assigned to Assist Government of Nepal in Hydrological Investigations, 1961-69

Advisor	Title	Sponsor	Tour of Duty	Assignment
Fred M. Veatch	Hydraulic Engineer	US AID	May-August 1961	Consultant on Water Resources
Harry Hulsing	Hydraulic Engineer	US AID	June-October 1961	Consultant on Water Resources
Daniel E. Havelka	Surface Water Hydrologist	US AID	May 1962-May 1964	Advisor on Surface Water Investigations
William F. Curtis	Sediment Specialist	US AID	June-November 1964	Advisor on Sediment Studies
Woodrow W. Evett	Surface Water Hydrologist	US AID	December 1964-September 1968	Advisor on Surface Water Investigations
Mordehai Gilead	Meteorological Advisor	UN WMO	May 1965-March 1967	Advisor on Meteorology
S. N. Venho	Aeronautical Meteorologist	UN WMO	March 1967-December 1968	Advisor on Aeronautical Meteorology
C. Steinitz	Meteorological Advisor	UN WMO	May 1967-May 1969	Advisor on Meteorology
H. M. Babcock	Ground Water Hydrologist	US AID	April-June 1968	Consultant on Ground Water
W. V. Swarzenski	Ground Water Geologist	US AID	April-June 1968	Consultant on Ground Water
G. C. Tibbitts, Jr.	Ground Water Hydrologist	US AID	March 1969-	Advisor on Ground Water Investigations
William Ogilbee	Ground Water Hydrologist	US AID	September 1969-	Advisor on Ground Water Investigations

A summary of records for regular gaging stations published prior to December 31, 1967, is given in table 2 including the following information for each station: (1) station number, (2) location, (3) drainage area, (4) period of record, (5) maximum and minimum daily discharges, and (6) average discharge. The wide range in the flow regime of the rivers of Nepal can be appreciated by comparison of the maximum and minimum daily discharges.

Ground Water.--Data available from the network of stream-gaging stations point out the problem areas in Nepal where surface-water supplies are deficient from January to the middle of June. Because total runoff in all parts of the country is more than adequate for requirements, the need is apparent for storage of the runoff of the rainy season for use during the dry season. As mentioned previously, the snow fields and glaciers of the Himalaya and the ground-water reservoirs of the valleys and plains naturally store water in large but unmeasured quantities for varying lengths of time. Stream-flow records on the major rivers indicate in some measure the water yield attributable to melt water. The ground-water potential, however, needs to be documented by exploring the hydrologic characteristics of underground reservoirs. In development planning, man-made storage facilities in the form of costly dams and surface reservoirs can be avoided, if nature's storage facilities can be used more effectively.

The ground-water reservoir in the Terai Belt of Nepal has an important development potential for irrigation as a means of increasing crop yields and food production. However, knowledge of the availability of ground water in Nepal is now (1969) relatively limited. A study of the ground-water potential in the Kathmandu Valley was completed in 1961 by the Geological Survey of India (Nautiyal and Sharma, 1961). Also during 1967-68, geologists from the Department of Hydrology and Meteorology inventoried about 500 shallow wells in the Terai. Well logs for 18 tube wells in Kathmandu Valley and the Terai are on file in the Ground Water Section of the Department.

In 1967, US AID received a formal request from the Government of Nepal for assistance in making an investigation of the ground-water potential in the Western Terai. It was proposed that the investigation would follow the Hydrological Investigations Project which was scheduled to be phased out in September 1968. Selected for investigation is the area west of the Narayani River and extending southward from the Siwalik Hills to the Indian border. Following the plan of action adopted for the earlier surface-water investigation project, US AID requested assistance from USGS in preparation of a work plan for the new project. By agreement between the two agencies, the USGS assigned two ground-water hydrologists, H. M. Babcock and W. V. Swarzenski, in April-June 1968 to a tour of duty in Nepal. On completion of their assignment, they prepared a report, which (1) points out possibilities for yields from tube wells adequate for irrigation throughout most of the area and (2) recommends a pilot development and study project to evaluate fully the ground-water potential (Swarzenski and Babcock, 1968).

In January 1969, the Government of Nepal and US AID signed a project agreement for a Ground Water Investigations Project based on the Babcock-Swarzenski report. The investigation, scheduled for a 4-year term, will include hydrologic mapping, exploratory drilling, water sampling, and aquifer testing to appraise the development potential of the ground-water resources. Also the project proposal calls for the establishment and training of a Ground Water Section in the Nepalese Department of Hydrology and Meteorology. Participation by the Government of Nepal and US AID will follow a pattern similar to that used for the Hydrological Investigations Project. Technical assistance furnished will include two ground-water hydrologists, a well drilling advisor and a chemist from the USGS.

Meteorology.--The first known hydrologic data to be collected systematically in Nepal are the rainfall records at the Kathmandu weather station which has been operated by the Government of India since about 1900. Beginning in 1948, additional stations were established by the Government of India in connection with proposed hydroelectric and irrigation projects. By 1966, stations in the network numbered about 60 and were located throughout Nepal.

Collection of meteorological data under the Hydrological Investigations Project began in 1963 with the installation of rain gages and maximum-minimum thermometers at stream-gaging stations. The program was expanded in 1965, when the Government of Nepal accepted assistance from the UN aimed at setting up a complete meteorological service to qualify Nepal for membership in the World Meteorological Organization (WMO). The UN has since provided technical assistance through the WMO as well as dollar credits for commodities. The names, positions, and tours of duty of technical advisors provided under UN-WMO auspices are included in table 1.

The network of meteorological stations presently (1969) numbers 102 stations, which record varying types of weather data. Stations formerly operated by the Government of India are now in charge of the Meteorology Section of the Department of Hydrology and Meteorology. Equipment at many of these stations has been replaced with standard equipment adopted for use by the department. Some stations have been relocated to give a better balanced network.

All rainfall data of reliable accuracy collected prior to December 31, 1967, have been compilated and published in a report by the Department of Hydrology and Meteorology (1968).

Quality of Water.--In water-resources development planning the need for quality of water data follows closely in importance the need for data on water availability. Cities or industrial complexes located

Table 2.--Summary of Records for Stream Gaging Stations in Nepal collected by Department of Hydrology and Meteorology prior to December 31, 1967.

Station Number	Stream and Location	Drainage Area (square miles)	Period of Record	Average Discharge (cfs)	Daily Mean Discharge (cfs) Maximum	Daily Mean Discharge (cfs) Minimum
	Sarda River Basin					
170	Surna Gad at Patan near Baitadi	72.6	1966-67	255	4,270	7.06
	Karnali River Basin					
240	Karnali River at Asara-Ghat near Sirkot	7,440	1962-67	16,740	121,000	3,110
250	Karnali River at Beni-Ghat near Belgaon	8,200	1963-67	19,020	148,000	3,350
260	Seti River at Bangga near Belgaon	2,880	1963-67	10,430	141,000	1,180
262	Thuli Gad at Kahnayatal near Belgaon	346	1966-67	728	14,400	44.1
270	Bheri River at Jamu near Choukle	4,750	1963-67	14,350	140,000	2,120
280	Karnali River at Chisapani near Dondajari	16,560	1962-67	45,340	349,000	7,560
290	Babai Nadi at Bargadaha near Kumragaon	1,160	1967	1,810	68,900	166
	West Rapti River Basin					
330	Mari Khola at Nayagaon near Piuthan	764	1964-67	1,980	30,700	187
340	Jhimruk Khola at Kalimati-Ghat near Piuthan	269	1965-67	688	7,520	7.06
360	Rapti River at Jalkundi near Amile	1,990	1964-67	3,160	50,900	42.7
390	Tinau Khola at Butwal	214	1964-67	860	49,800	41.0
395	Banganga River at Bangachia near Taulihava	134	1967	586	27,500	10.6
	Narayani River Basin					
410	Kali Gandaki River at Setibeni near Dumrichaur	2,560	1964-67	8,722	49,100	925
415	Andhi Khola at Dumrichaur near Tansing	184	1964-67	1,120	21,500	35.3
420	Kali Gandaki River at Kota Gaon near Shringa	4,400	1964-67	19,570	280,000	2,390
430	Seti Khola at Bimire Taro near Pokhara	233	1964-67	1,580	12,200	288
440	Chepe Khola at Palungtar near Gorkha	119	1964-67	1,100	16,200	88.3
445	Burhi Gandaki River at Arughat Bazar near Gorkha	1,650	1964-67	5,390	29,100	738
447	Trisuli River at Betravati near Trisuli Bazar	1,590	1967	5,544	23,000	1,030
450	Narayani River near Narayangarh	12,000	1963-67	53,930	273,000	6,710
460	Rapti River at Rajaya near Hitaura	224	1963-67	1,060	22,700	117
465	Manhari Khola at Manhari near Beluwa	165	1963-67	650	16,400	45.9
470	Lothar River at Lothar near Debichaur	65.3	1964-67	358	7,980	19.8
475	Khagari Khola at Tikali	45.6	1965-66	337	10,900	38.8
480	Kair Khola at Jurpani near Jhawani	30.8	1964-67	210	2,990	2.47
485	Burhi Rapti River at Chitra-Sari near Jhawani	71.8	1964-67	752	9,780	47.7
	Bagmati River Basin					
505	Bagmati River near Sundarijal	6.18	1963-67	36.1		1.77
507	Nagmati Khola at Mahankal near Sundarijal	5.29	1963-67	39.1	1,250	1.77
510	Sialmati Khola at Shyamdado near Sundarijal	1.29	1963-67	6.04	239	.35
530	Bagmati River at Gauri Ghat near Kathmandu	26.2	1963-67	98.3	5,300	.35
540	Nakhu Khola at Tikabhairab near Patan	16.4	1963-67	41.1	3,670	.35
550	Bagmati River at Chobhar near Kathmandu	226	1963-67	447	14,700	.71
560	Thade Khola at Darkot near Markhu	5.33	1964-67	27.7	1,940	2 83
570	Kulikhani Khola at Kulikhani	48.6	1963-67	145	4,910	4.94
590	Bagmati River at Karmaiya near Mangalpur	1,050	1965-67	5,340	85,500	194
	Sapt Kosi Basin					
610	Bhote Kosi at Barahbise near Ghumthang	931	1965-67	2,570	12,900	491
620	Balephi Khola at Phalame Sangu near Chautara	243	1964-67	1,400	6,710	216
630	Sun Kosi at Pachuwar Ghat near Chautara	1,900	1964-67	7,110	51,600	1,080
640	Rosi Khola at Panauti near Dhulikhel	33.7	1964-67	79.7	2,150	8.48
650	Khimti Khola at Rasnalu Village near Those	121	1964-67	443	2,880	65.7
660	Likhu Khola at Sangutar near Ramechhap	318	1964-67	2,040	11,700	260
670	Dudh Kosi at Rabuwa Bazar near Okhaldhunga	1,580	1964-67	7,290	43,100	989
680	Sun Kosi at Kampu Ghat near Udaypur	6,800	1966-67	23,670	192,000	4,340
	Kankai Mai Basin					
730	Puwa Khola near Ilam	41.3	1965-67	229	2,140	6.00
770	Kankai Mai at Chepti near Ilam	444	1965-67	1,650	40,600	113

near the oceans have available unlimited quantities of water; yet, the quality of the water often restricts its use. In almost all situations where water is used consumptively, the chemical quality of the water source needs to be known and evaluated. Quality of water deals with the chemical and physical properties of water and usually is studied with respect to the chemical characteristics of constituents in solution as well as with materials in suspension. Early in the Hydrologic Investigations Project it became evident that a chemical quality program would be ineffective until qualified Nepalese chemists and laboratory technicians were available to staff a quality of water laboratory, hence this phase of hydrologic program development was postponed until the inception of the Ground Water Investigations Project. Through 1968 a few samples were collected and analyses were made in laboratories outside Nepal. Table 3 gives the results of chemical analyses of waters from a few selected rivers and streams in Nepal. Chemical analyses of samples from wells of varying depth are given in table 4 and indicate the general chemical character of the ground water in the Terai Belt of Nepal.

Sediment investigations, or the study of materials in suspension, in a quality of water program usually require less sophisticated laboratory facilities than those for chemical analysis. Sediment sampling of selected streams began in June 1964 under the direction of William F. Curtis of the USGS, while on a 6-months assignment to Nepal. Initial field investigations were carried on during the 1964 monsoon,

Table 3.--Analyses of Water Samples from Selected Streams in Nepal

(Analyses by U. S. Geological Survey)

Location	Date of collection	Mean discharge (cfs)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH
			Constituents in milligrams per liter, except as indicated									
Sapt Kosi Basin Sapt Kosi at Chatra	10-28-64	5,000	2.4	2.7	52	11	0.5	0.1	42	4	109	7.2
Narayani River Basin Narayani River at Narayangarh	10-3-64	73,000	2.4	2.0	118	14	1.6	0.0	96	10	212	7.5
Karnali River Basin Karnali River at Chisapani	10-9-64	48,800	1.8	1.6	106	12	.5	0.4	87	7	188	7.3

Table 4.--Analyses of Water Samples from Selected Wells in Nepal

(Analyses by Quality-of-water Laboratory, WAPDA, Lahore, Pakistan. Date of collection under Sample Number)

	Constituents in milligrams per liter except as indicated					
	(1)	(2)	(3)	(4)	(5)	(6)
	May 30, 1968	May 30, 1968	May 30, 1968	June 5, 1968	May 31, 1968	May 31, 1968
Calcium (Ca)	67	67	59	40	55	46
Magnesium (Mg)	31	30	23	18	10	11
Sodium and Potassium (Na + K)	13	13	46	104	21	18
Carbonate (CO_3)	0	0	0	0	0	0
Bicarbonate (HCO_3)	362	354	384	445	242	214
Chloride (Cl)	4	4	4	5	4	4
Sulfate (SO_4)	5	10	10	10	14	5
Nitrate (NO_3)	0	0	0	0	0	0
Total dissolved solids (Residue on evaporation)	330	330	340	400	224	212
Specific conductance (Micromhos at 25°C)	570	570	600	730	400	360
pH	7.85	7.60	7.70	7.45	7.50	7.25
Temperature (°F)	78	78	79	78	79	---
Residual carbonate (Milliequivalents/liter)	0.04	0	1.50	3.79	0.36	0.31

1. Public supply, Bhairahawa, flowing artesian well. Depth 203 ft.
2. Nepal Distilleries, Bhairahawa, flowing artesian well. Depth 175 ft.
3. Bhairahawa airport, 2" driven well and hand pump. Depth 40 ft.
4. Nepal Punarvas Co. (Private) Ltd., Resettlement camp, Nepalganj, irrigation well. Depth 486 ft.
5. Public supply, Birganj. Depth 350 ft.
6. Parvanipur Irrigation Rest House, 2" drilled well. Depth 140 ft.

with emphasis on the training of Nepalese technicians in sediment sampling. At the end of his assignment, Curtis prepared a report (1964) making recommendations for a sediment sampling program to be carried out in conjunction with the nationwide network of stream-gaging stations. Since 1964 sediment sampling has been included for key gaging stations in the Karnali, Narayani, Bagmati and Sapt Kosi basins. The sediment studies program is conducted by the Surface Water Section of the Department of Hydrology and Meteorology. Samples are processed at the Nepalese Bureau of Mines laboratory by technicians from the department.

A Quality of Water Section will be set up under the terms of the Ground Water Investigations Project. Technical assistance planned for the project includes a chemist from the USGS, who will set up a chemical laboratory in the department, and the laboratory will be staffed with qualified Nepalese technicians, who will be given "on job" training. The Nepalese chemist-in-charge of the laboratory is scheduled to receive participant training in the United States with the USGS. Sediment studies will then become a part of the Quality of Water Section utilizing the departmental laboratory to process sediment samples.

Publication of Hydrologic Data.---In 6 years of existence, the Nepalese Department of Hydrology and Meteorology has achieved status as the authoritative source within Nepal for water-resources data. Other departments of the government as well as outside donors depend on the department for basic hydrological data. The department maintains a steady flow of hydrological data to other governmental agencies through the publication of annual basic-data reports. Interpretive studies are made using available data and special reports prepared, which present data in a readily usable form when required by cooperating agencies.

Publication of surface-water records started with a compilation of records available prior to December 31, 1965. Records are kept current by supplemental reports released each calendar year (Nepal Department of Hydrology and Meteorology, 1967, 1968). Information presented includes: (1) streamflow records from the nationwide network of stream gaging stations, (2) discharge measurements made during periods of low flow at partial records stations and (3) discharge measurements made at miscellaneous sites.

Precipitation records prior to December 31, 1967, are presented in a single volume published by the department during 1968 (Nepal Department of Hydrology and Meteorology, 1968). Future reports will be released on a calendar year basis.

Information of a more detailed nature than that published for the hydrological stations is on file in the Department of Hydrology and Meteorology. Data available include average daily discharges, discharge measurements, water temperatures, recorder charts and gage readings for stream gaging stations. For meteorological stations supplemental data available are humidity, evaporation rates, wind velocities, as well as, daily average, maximum and minimum temperatures.

River Basins of Nepal

Major River Basins

The major rivers that transect Nepal (fig. 8) are the Sapt Kosi in the eastern section, the Narayani in the central section, the Karnali in the western section and the Sarda, which forms the western boundary between Nepal and India. These rivers, which originate in the Himalaya or on the Tibetan Plateau, are in part snow or glacier fed and thus have relatively high sustained flow. The combined average yearly flow of the Karnali, Narayani and Sapt Kosi is 159,000 cfs which accounts for 71 percent of the runoff from the entire country.

The importance of the major rivers of Nepal is not the average yearly flow, because it is influenced in large measure by floods during the monsoon season. Indeed, monsoon floods are a menace to adjacent areas in India as the rivers cross the Terai to join the main stem of Ganges. The value of these rivers in the future development of Nepal lies in the high sustained flow from snowmelt during the late dry season. Thus, the long range of snow and ice-covered Himalayan highlands forms a natural reservoir that stores water for release as runoff at the time needed to supplement base flow during the latter part of the dry season.

The pattern of flow of the four large rivers is similar. Extreme high flows occur during the monsoon from the middle of June to the middle of September. Flow then gradually decreases until the end of

February. From March to the middle of June and the end of the dry season there is a gradual increase in flow from melt water.

Sapt Kosi.--The Sapt Kosi is the largest river system in point of drainage area in Nepal. The three main tributaries, the Sun Kosi from the west, the Arun from the north, and the Tamur from the east, come together at Tribeni Ghat to form the Sapt Kosi. The total drainage area at the Nepal-Indian border is 31,700 square miles, 60 percent of which is in Tibet and 40 percent in Nepal. There is a marked difference in runoff from the catchment areas within Nepal that drain the southern slopes of the Himalaya, and those that drain from the Tibetan Plateau. The headwaters of the Arun extend far into the Tibetan Plateau. The total drainage area at the mouth of the Arun is 13,380 square miles--11,160 square miles of which is in Tibet. In the average year the flow of the Arun at the mouth is 1.65 cfsm (cubic feet per second per square mile) of area drained. This compares with 3.43 cfsm for the Sun Kosi which has a drainage area of 7,330 square miles. Seventy-nine percent of the drainage area of the Sun Kosi is in Nepal; 21 percent is in Tibet.

The hydroelectric power potential of the Sapt Kosi Basin is very large indeed. The Arun, for example, falls 7,000 feet in a river distance of 86 miles from the Nepal border. Similar steep stream gradients prevail on the Tamur and on the upper reaches of the Sun Kosi. Large scale irrigation schemes for areas above the Mahabharat Range are not practicable as topographic features limit the acreage of agricultural land that can be irrigated.

The only development of the river basin potential completed to date (1969) is the Panauti hydroelectric station on the Rosi Khola (fig. 9), a tributary of the Sun Kosi. The plant, built by the Soviet Union (USSR) was completed in 1966. It is a run-of-the-river type installation with an installed capacity of 2,400 kw (kilowatts). The Kosi project, located on the Sapt Kosi at the Indo-Nepal border, is nearing completion. The combined power and irrigation project is the largest river development project yet undertaken in the country. It is being constructed jointly by the Government of Nepal and the Government of India and benefits will be shared by both countries.

There are two projects under consideration for further development of the basin: (1) the Sun Kosi Project by the UN and (2) the Sun Kosi Hydel Project by the People's Republic of China. Both projects are foreign assistance projects with participation by the Government of Nepal.

A feasibility study of the Sun Kosi Project was begun by the United Nations Development Program (Special Fund) in 1965. The project proposes diversion of water from the Sun Kosi to the Terai Belt by tunneling through the Mahabharat Range. The diverted water would be utilized for hydroelectric power and irrigation. By various combinations of surface and ground-water development it is proposed to bring most of the Terai between the lower Bagmati River and the Sapt Kosi under irrigation. The

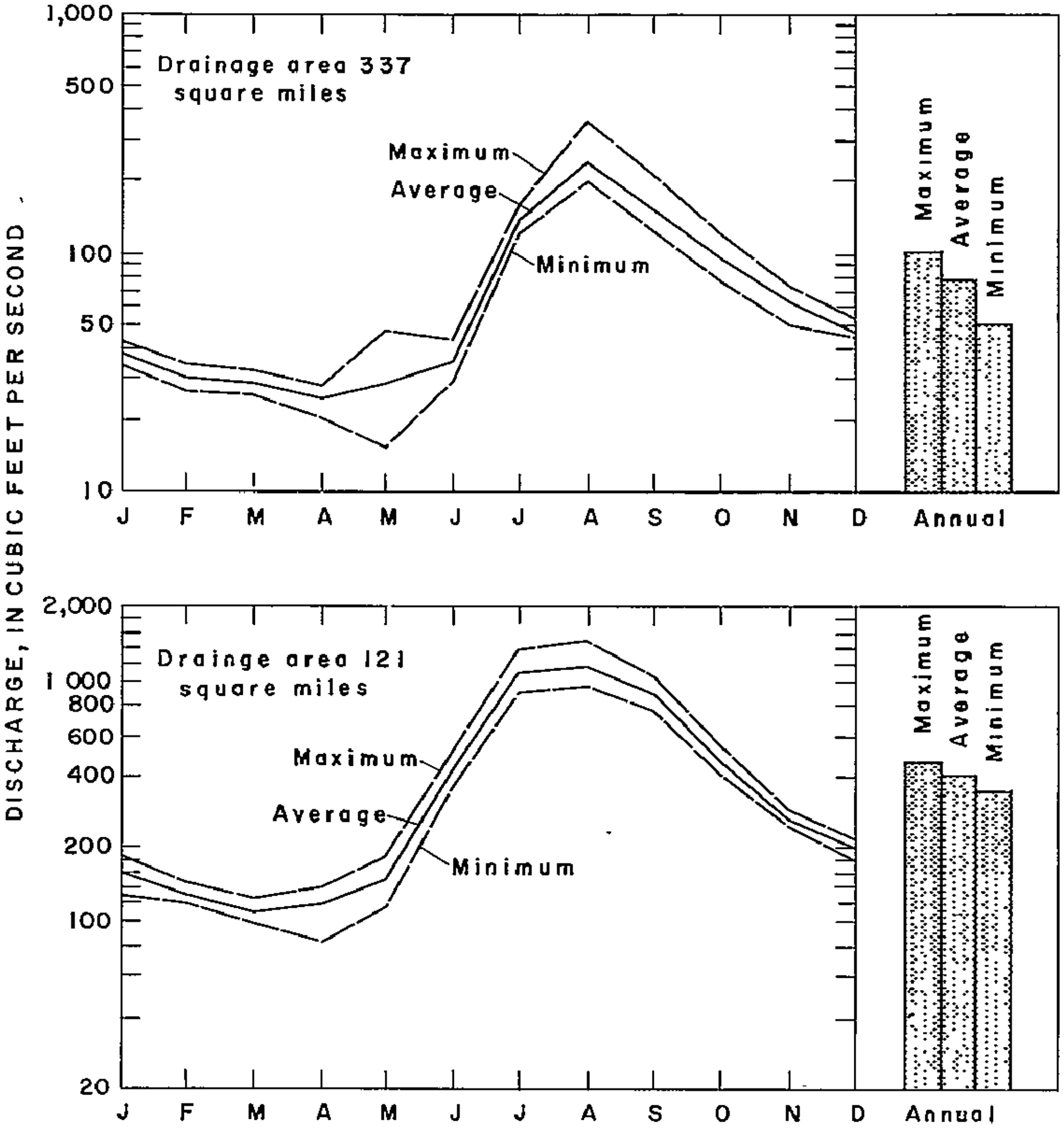

Figure 9.--Maximum, Minimum and Average Monthly and Annual Discharge (1963-67) of Rosi Khola at Panauti and Khimti Khola at Rasnalu Village.

feasibility study is scheduled for completion by 1970.

Construction on the Sun Kosi Hydel Project is scheduled to start in 1969. The project is located 6 miles south of Barahbise and will be a run-of-the-river type installation. The installed capacity will be 10,000 kw. The project is scheduled for completion by 1972.

The Nepalese Electricity Department has programmed a number of small hydroelectric installations on tributary streams in the Sapt Kosi Basin. Construction is scheduled to begin in 1969 on the first of these small plants on a tributary of the Tamur River. The design capacity of the plant is 50 kw and the installation will furnish electrical energy for Dhankuta.

Development in the Sapt Kosi Basin in the next several years will most likely be limited to completion of projects already under construction or in the planning stage. Although technical assistance is provided by sponsors of development projects, the Government of Nepal is required to furnish engineers and technicians as counterpart personnel. Lack of staff in the Electricity and Irrigation Departments tends to limit the number of projects that can be carried simultaneously in Nepal.

Narayani River.--The Narayani River drains the central part of Nepal. The main tributaries are the Kali Gandaki, Seti, Marsyandi, Burhi Gandaki, Trisuli, and the Rapti Rivers. The drainage area at the Indian border is 14,000 square miles.

The central position of the basin and the relatively high flow during the slack water season make the Narayani Basin the most important river system in Nepal in terms of population served. Early concentration of population occurred in the hill areas north of Narayangarh. The eradication of malaria in the Rapti Valley (fig. 10) has resulted in a marked increase in the total population in the basin. It is estimated that one-third of the total population of the country presently reside within the catchment area of the Narayani.

The main tributaries to the Narayani are all economically important to the areas they traverse. The Kali Gandaki and the Trisuli join at Narayangarh to form the Narayani. The Kali Gandaki is considered the main stem of the Narayani and originates in the Mustang area. Mustang is the last of the former small kingdoms that once comprised the region now known as Nepal. Mustang lies in an isolated area to the north of the massive peaks of Dhaulagiri and Annapurna. With the exception of the caravans that have crossed the area for centuries to carry on trade between India and Nepal with Tibet, the borders have been closed to visitors. The area is known as the "Forbidden Kingdom of Mustang." Even today life in Mustang remains uninfluenced by modern civilization. The ancient capital, Lho Mantang, is a quaint city linked with the past. The monsoon is unimportant in the Mustang area and runoff is almost totally limited to snow melt from the north slopes of the Great Himalaya and the Mustangbhot Range which forms the northwestern boundary between

Figure 10.--Aerial View of Hitaura, Important Town in Upper End of Rapti Valley. The road in the background is the Raj Path to Kathmandu, the only highway from the capital to the Indian border. The road in the foreground is the link with Narayangarh near the lower end of the Rapti Valley. The eradication of malaria under a US AID project has opened thousands of acres of fertile land to cultivation in the valley. Prior to 1960 most of the valley was mosquito-infested forest land.

Mustang and the Tibetan Region of China. Precipitation in the Mustang area is in the form of light snow in the winter season. The drainage area of the Kali Gandaki above Jomosom is about 35 percent of the catchment area above Setibeni, the uppermost point presently gaged; yet, the average flow at Jomosom is probably less than 5 to 7 percent of the average flow at Setibeni. This difference emphasizes the influence on climatic conditions exerted by the main range of the Himalaya.

The Kali Gandaki flows south from Mustang through a deep gorge flanked on the west by Dhulaguri (26,810 feet) and Annapurna (26,504 feet) on the east. The altitude of the river bed in the gorge is 8,200 feet, making it the deepest river gorge in the world. The river course south of the gorge is extremely rugged. The stream gradient approaches 500 feet per mile; and the canyon walls extend almost vertically above the stream channel for almost a thousand feet before breaking away on less precipitous slopes.

The average discharge of the Narayani River at Narayangarh for 6 years (1963-67) is 53,930 cfs. The minimum flow recorded during the period is 6,360 cfs, or 0.530 cfsm. The importance of the melt water contribution to the dry season flows at Narayangarh can be appreciated by a comparison of minimum flow from an area that drains the Great Himalaya as against the flow from an area with catchment in the lower ranges (fig. 11). The gaging station on the Seti Khola at Birmire Taro (near Pokhara) measures flow from a catchment on the south slope of the

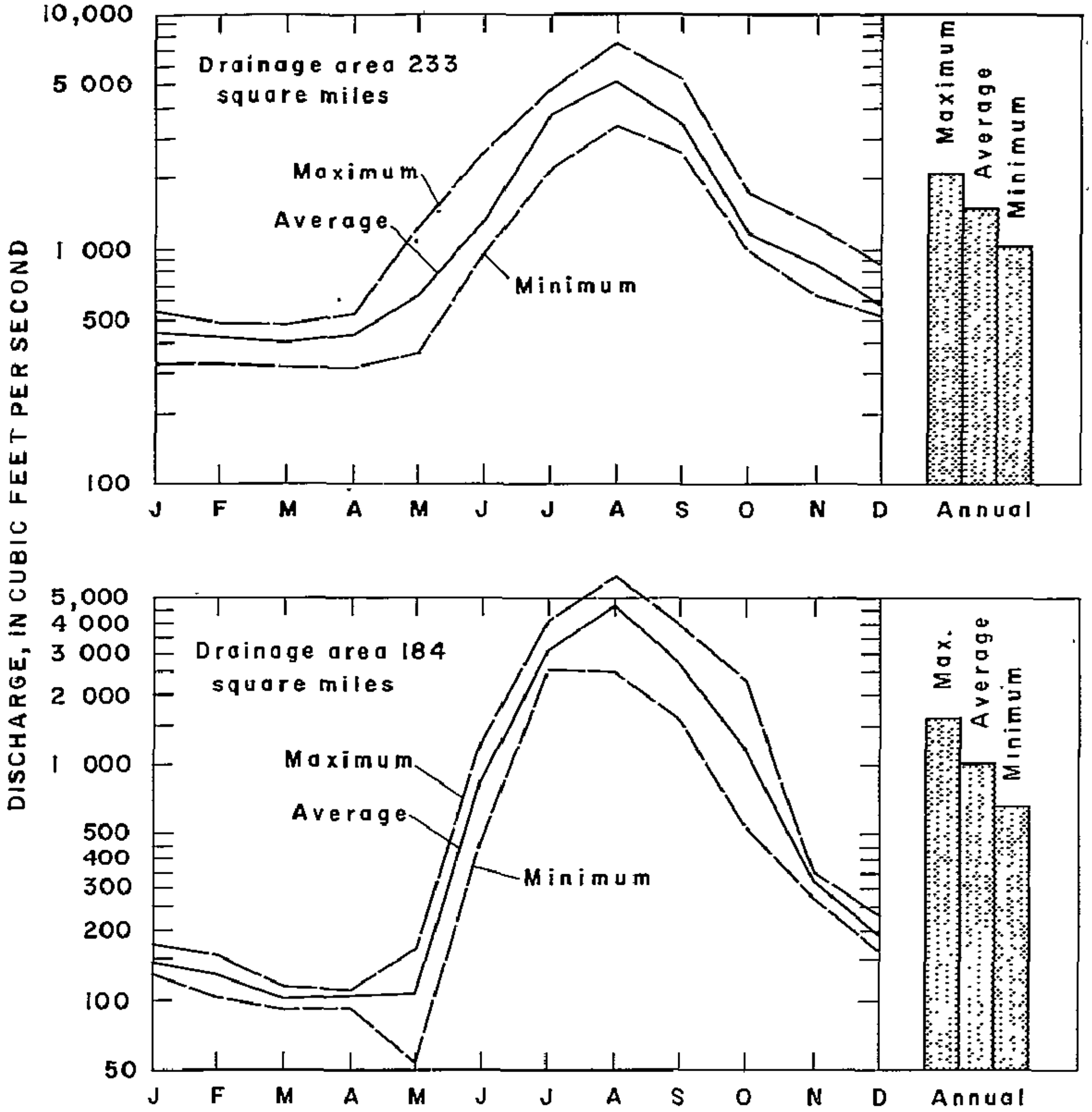

Figure 11.--Maximum, Minimum and Average Monthly and Annual Discharge (1963-67) of Seti Khola at Birmire Taro and Andhi Khola at Dumrichaur.

snow and ice mantled Annapurna Range; whereas, the station on the Andhi Khola at Dumrichaur (near Tansing) measures flow from a rain and spring-fed catchment lying below an altitude of 8,000 feet.

Development of the water-resources potential of the Narayani Basin is currently (1969) small. A combination power and irrigation scheme was completed in 1967 on the Phewa Khola at Phewa Tal in Pokhara Valley where a dam was built at the outlet of a natural lake to increase the usable storage. The released water is used during the dry season for irrigation and power produced by dropping excess water through an inclined flume to the gorge below. The designed capacity of the plant is 250 kw, and 1,200 acres of fertile land in Pokhara Valley are being irrigated.

The Trisuli Hydel Project on the Trisuli River at Trisuli Bazar. when completed, will be the largest hydroelectric power installation in the country. The facility is being built as a joint project between the Governments of Nepal and India. Three units (total capacity 9,000 kw) have been installed and four additional units (total capacity 12,000 kw) are scheduled to be completed by 1971. The plant, in operation since March 1967, furnishes power for Kathmandu Valley.

Construction of the Gandak Power and Irrigation Project on the Narayani River at the Indo-Nepalese border began in 1965. The project is also being built jointly by the Governments of Nepal and India.

The project, scheduled for completion in 1972, will irrigate land both in Nepal and in India. The power facility has a designed capacity of 15,000 kw and power produced will also be shared by both countries.

A minor irrigation project was completed in 1967 at Tikoli on the Khagari Khola, a tributary of the Rapti River. The Tikoli project furnishes water for 14,800 acres east of the Narayani River.

Future development of the rivers of the Narayani basin probably will continue at an accelerated rate owing to the economic importance of the region. Three major highways, the East-West Highway, the Sonauli-Pokhara Road, and the Kathmandu-Pokhara Road are under construction or in the planning stage. The completion of these highways will have considerable impact on the development of the southern and eastern parts of the Narayani basin. Available water resources in the basin will play an important role in this development.

Karnali River.--The catchment of the Karnali River embraces the most remote region of Nepal. North of the Mahabharat Range the Karnali basin is only sparsely populated and the economic level is probably the lowest in Nepal. The Karnali rises in the Tibetan Region of China near Lampiya Dhura Pass between India and Tibet. The river flows southeasterly through the Tibetan Plateau for 61 miles and then enters Nepal in a gorge through the Lipu Lekh (Range). The total length of the river above the India-Nepal border is 330 miles. The river course through Nepal is markedly irregular. In a straight line distance of 110 miles from the gorge through Lipu Lekh to Chisapani, where the river crosses the Mahabharat Range, the river flows 240 miles. In traversing Nepal the river falls from altitudes greater than 12,500 feet to about 700 feet where it enters the Terai.

The main tributaries of the Karnali are the Babai, Bheri, Mugu Karnali, and the Seti Rivers (fig. 12). The drainage area above Chisapani, the farthest downstream point gaged in Nepal is 16,560 square miles. Records available for 6 years (1962-67) at Chisapani indicate a range in flow from 7,560 cfs on March 10-13, 1967, to 402,600 cfs on August 21, 1963. The average flow during the period was 43,300 cfs.

In terms of hydroelectric power potential, the Karnali is considered the most important river of Nepal. The great potential of the Karnali has long been recognized; not until 1966, however, was the extent of the potential and the cost of development fully appraised. The Karnali River feasibility survey, mentioned previously, began in 1961 and field work was completed in 1965. The feasibility report indicates a total design capacity of the combined development in 6,765 mw (megawatts) of electrical energy at a development cost of $1,566,800,000 (Nippon Koei Co., Ltd. 1966). The proposed development of the Karnali River would furnish power sufficient to industrialize western Nepal as well as for much of northwestern India. Since 1966, efforts have been made to obtain financing for all or parts of the project, but as yet funds are not available. In the meantime the collection of hydrologic data is being continued by the Nepalese Department of Hydrology and Meteorology.

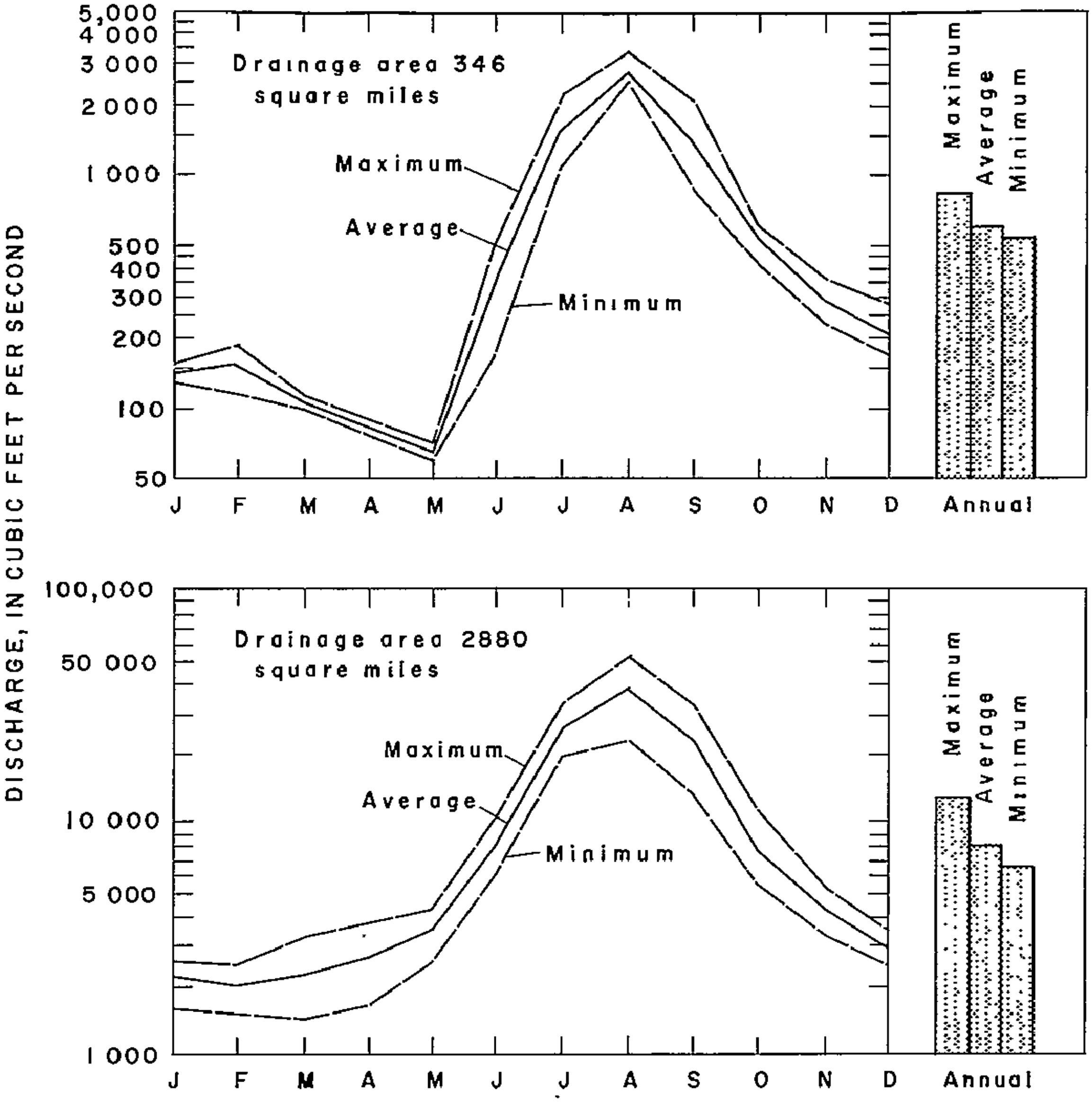

Figure 12.--Maximum, Minimum and Average Monthly and Annual Discharge (1963-67) of Thuli Gad at Khanaytal and Seti River at Bangga.

Except for locally built small irrigation schemes, the Karnali River is undeveloped. Future development will undoubtedly be in accordance with the development plan mentioned above. To Nepal, the economic value of the Karnali River lies in the proximity of this vast source of electrical energy to the densely populated States of Uttar Pradesh and Bihar, and to the metropolitan area of New Delhi in India. Development of the hydropower potential would provide Nepal a valuable export resource. Exports are badly needed to maintain balance with imports, as large quantities of goods are imported each year from India.

Sarda River.--The Sarda River drains the eastern part of Uttar Pradesh in India and the area west of the Karnali River in Nepal. The main tributaries are the Goriganga and Dhaulinganga Rivers in Uttar Pradesh and the Mahakali River that forms the border between India and Nepal. The Government of India has operated a gaging station on the Sarda River at Banbasa since 1930. The drainage area above Banbasa is 5,890 square miles. At Banbasa a minimum daily flow of 1,620 cfs occurred on April 16, 1940, and on September 14, 1962, a peak flow of 398,000 cfs occurred. The average discharge is 23,300 cfs (Nippon Keoi, Ltd., 1966).

Economically, the Sarda River is relatively unimportant to Nepal. Of the 150 river miles that form the boundary between India and Nepal less than 25 miles is adjacent to the Terai. North of the Terai the Sarda River flows through deep river canyons where the land is not suitable for irrigation. Large-scale hydroelectric development in the near future is unlikely as power from the Karnali River development will service the densely populated areas in the Nepalese Terai. Two small tributaries within Nepal, the Chamlia River and the Surna Gad are suitable for small hydroelectric installations and minor irrigation porjects. To date no development of the basin has been attempted and future development is likely to be minor.

Minor River Basins

There are a number of streams that rise in Nepal and flow across the country to join the Ganges River in India. These rivers originate south of the main Himalaya and are not influenced by snowmelt. The streamflow characteristics of these streams from basin to basin are quite similar. Maximum flow occurs during monsoon followed by a marked decrease through October with a further gradual decrease until the beginning of the next monsoon.

Low flow of the minor river systems is effected by diversions for numerous small scale irrigation schemes on tributary streams, high evapotranspiration rates, and loss of water to ground-water storage in the valley areas. During the dry season runoff is deficient in most of these streams and many with headwaters in the Siwalik Hills are dry for several months prior to monsoon. Development of the minor river basins will require storage reservoirs or diversion of flow from the major river systems to supplement flow during the long dry season. Of these minor river basins, three--the Kankai, Bagmati, and West Rapti--are probably most important in terms of the population served. These rivers originate in the hill country of the Midlands where stream gradients are steep and channels are well-defined. In the valley areas of the Midlands and across the Terai these streams flow in braided, anastomosing channels and it is not uncommon for the streams to shift their courses frequently during the flood season.

Kanaki Mai.--Eastern Nepal, north of the Mahabharat Range, is in the catchment of the Sapt Kosi system where the influence of snowmelt assures sufficient runoff even during the extreme dry season. This is a marked contrast with the area to the south of the range where runoff is deficient from January to the middle of June.

The southeastern corner of Nepal is densely populated. Moreover, easy access to population centers in India from both the east and the south makes the area important in the future development of the entire eastern part of Nepal. Important towns such as Biratnagar, Jhapa, Dharan Bazar, and Ilam serve as trade centers between the Nepalese hill country and the plains of India. The area, covering approximately 2,200 square miles, has numerous streams that rise in the Churia Hills and flow south across the Terai to India. The stream channels are wide, shallow and often interbraided, one channel with another. Many of the streams are dry for 2 to 3 months prior to monsoon.

The only stream of particular importance in the area is the Kankai Mai. The Kankai rises on the south slopes of the Mahabharat Range and flows through the Churia Hills to reach the Terai. The minimum discharge during 1965 through 1967 at Chepti was 97.1 cfs. The average discharge for January through May was 314 cfs. The drainage area of the Kankai at Chepti is 444 square miles. The drainage area below Chepti is indefinite as the channel is braided. During monsoon there is often an interchange of flow between the Kankai and adjacent streams.

Development of the Kankai Mai basin at present is limited to small locally built irrigation schemes. The Chatra Canal, being constructed in conjunction with the Kosi Power and Irrigation Project, will divert water from the Sapt Kosi to most of the area between the Kankai and the Sapt Kosi. A coordinated regional plan using water from the Chatra Canal, ground water from tubewells, and proper development of the Kankai Mai would bring most of the fertile land in this important area under irrigation.

Surveys are underway by the Nepalese Electricity Department for small hydroelectric plants on two tributaries of the Kankai Mai, the Tangtin and Bering Kholas.

Bagmati River.--The Bagmati is often referred to as the Holy River of Nepal. The headwaters drain the inner slopes of the mountains that ring the Kathmandu Valley. The Bagmati system is the lone source of surface water for the inhabitants of the valley. In addition to the Bagmati's role as the source of water for irrigation and domestic water supply, the river exerts a major influence on the religious and cultural life. Pilgrimages to observe religious holidays are made many times each year by Hindus from outlying areas of Nepal and India to the many ancient shrines and temples along its banks (fig. 13).

The gaging station at Chobhar near Kathmandu gages the flow of the Bagmati at its exit from the Kathmandu Valley (fig. 14). The minimum flow recorded during 1963 through 1967 was 0.71 cfs. The minimum monthly discharge was 11.9 cfs. During the monsoon, flooding from the Bagmati

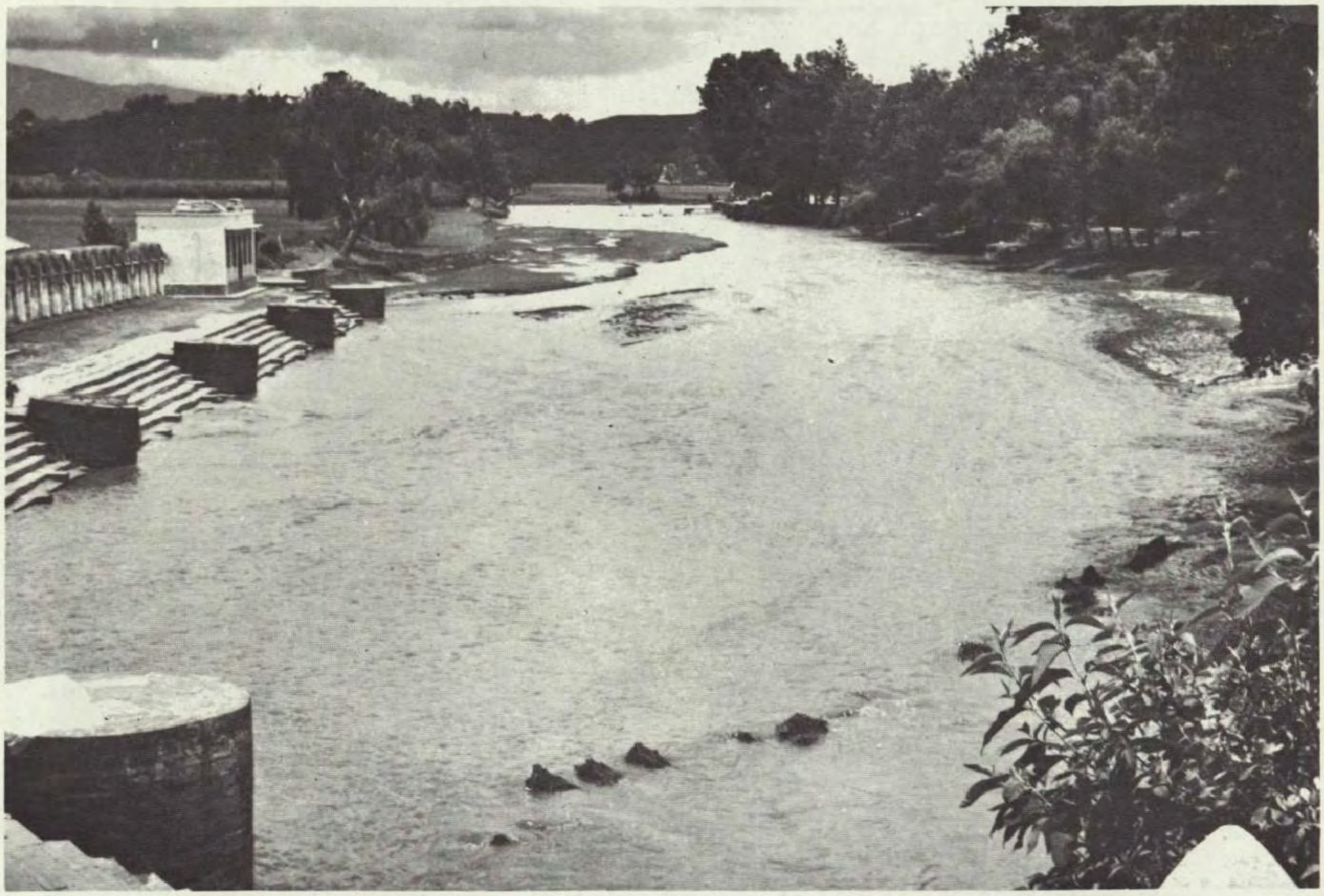

Figure 13.--Photograph of Ancient Shrines and Temples that Prevail along Bagmati, Holy River of Nepal, in Kathmandu Valley.

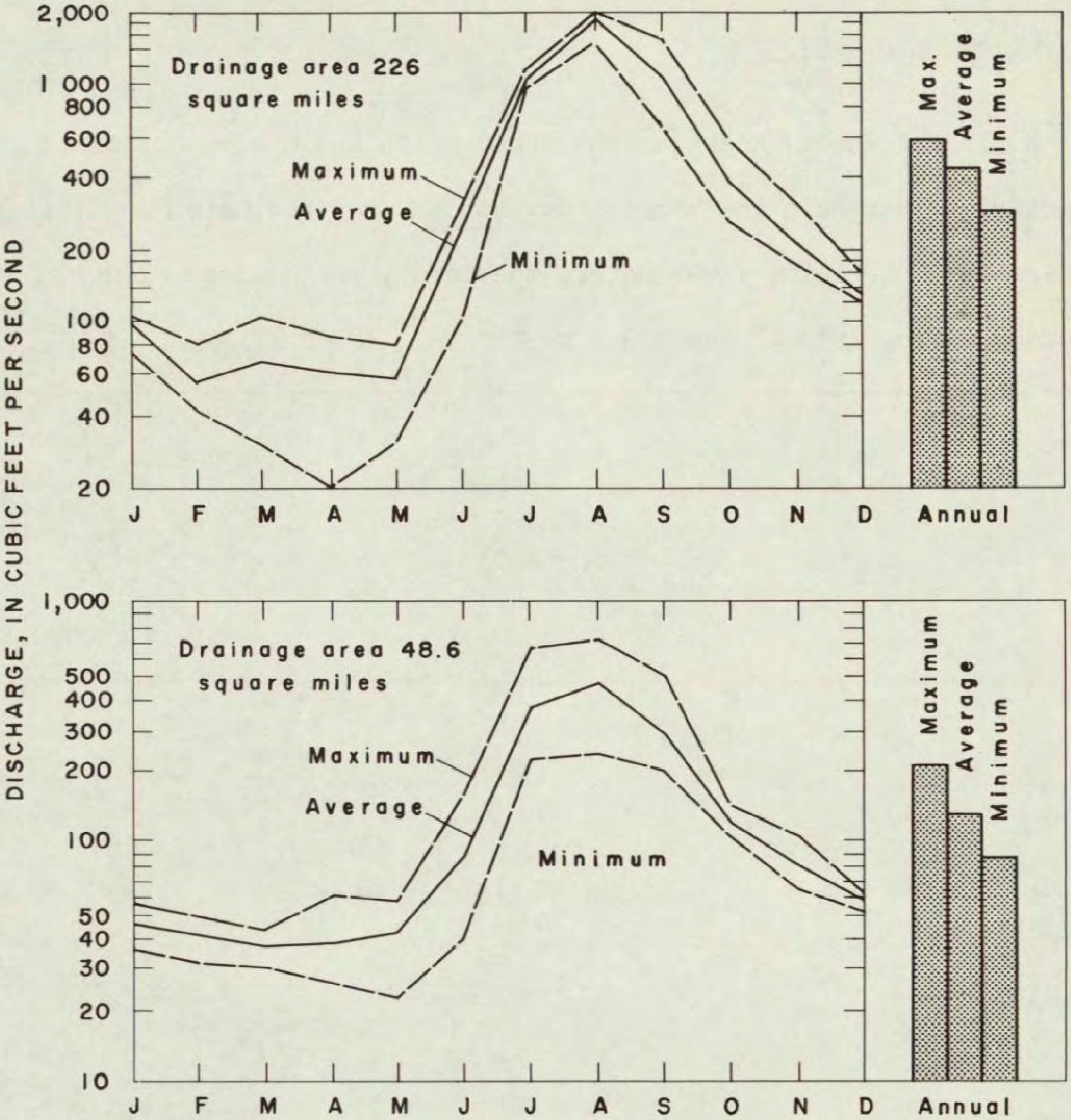

Figure 14.--Maximum, Minimum and Average Monthly and Annual Discharge (1963-67) of Bagmati River at Chobhar and Kulikhani Khola at Kulikhani

often occurs in the low lying areas of Kathmandu and adjacent areas of the valley (fig. 15).

Kulikhani Khola, Kokhajor Khola and Marin Khola are the main tributaries that join the Bagmati downstream from the Kathmandu Valley. At Karmaiya, where the river enters the Terai, the minimum flow recorded during 1965-67 was 173 cfs.

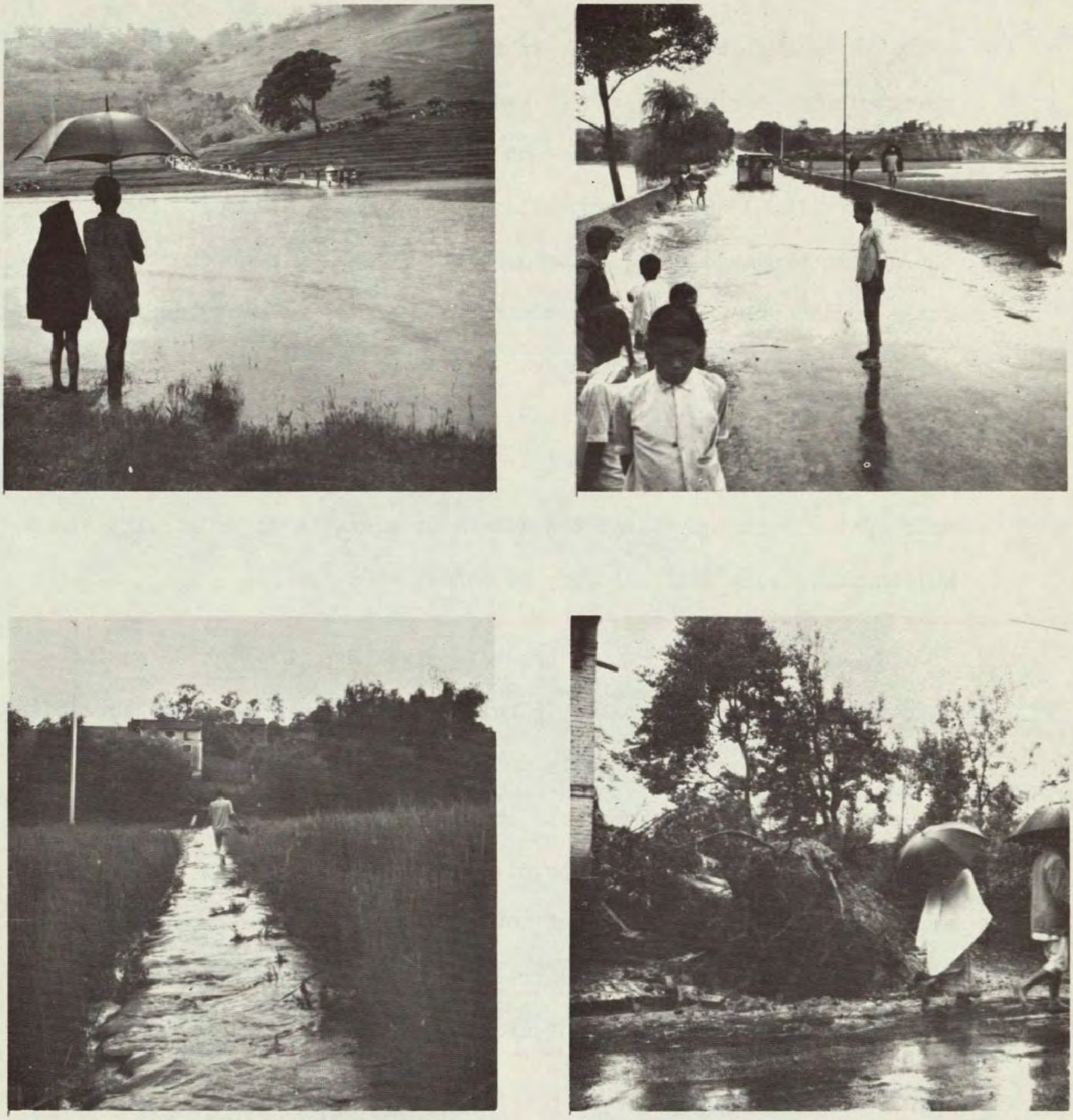

Figure 15.--Photographs showing Flooding along Bagmati River in Kathmandu Valley, August 24, 1966. Scenes show damage to roads, buildings and rice paddies. On this day the Bagmati River at Chobhar crested at 37.88 feet with a peak flow of 22,400 cfs.

Hydroelectric development in the Bagmati basin includes two small power plants, one at Sundraijal and a second at Pharping. A feasibility survey for a power installation on Kulikhani Khola at Kulikhani is presently (1969) nearing completion. The Kulikhani survey, financed by funds allocated under the Colombo Plan, proposes a high dam reservoir to store monsoon flow. Water from storage would be released during the low water season through a tunnel leading to the Rapti Valley to produce a power drop for generation of energy. As completion of the Trisuli Hydel Project now scheduled for 1971 will provide adequate power for the anticipated requirements of the Kathmandu area, it is doubtful that the Kulikhani Project will actually be constructed.

Several minor irrigation projects have been constructed on the Bagmati and tributary streams in Kathmandu Valley. These projects have not generally been effective owing to deficient flow during months when the need for irrigation water is critical. Under consideration in the Sun Kosi Project is a scheme to divert water from the Sun Kosi to the Marin Khola so as to supplement low flow in the lower Bagmati for irrigation. This scheme, if carried to construction, would have considerable impact on adjacent areas in the Nepalese Terai and adjacent Bihar State in India.

West Rapti River.--The West Rapti River basin is the largest of the minor river systems of Nepal. The catchment area lies between the area drained by the Karnali and Narayani Rivers. The divide between the upper reaches of the Karnali and Narayani Rivers and the headwaters of the West Rapti system is a Midlands ridge with altitudes ranging from 8,000 to 10,000 feet. The river flows southeasterly to the Mahabharat Range which it crosses in a narrow gorge then bends to a westerly course through the West Rapti Valley entering the Terai east of Nepalganj. The West Rapti then flows south to the Indo-Nepal border and then southeasterly to join the Ganges River. The total drainage area of the West Rapti basin within Nepal is 4,480 square miles. The main tributaries to the north of the Mahabharat Range are Mari Khola and Jhrimruk Khola. Tinau Khola and Banganga River are the main tributaries in the lower part of the basin. These two streams drain the Churia Hills and flow across the Terai to join the Rapti in Uttar Pradesh, India. The entire West Rapti basin is populated but most densely in the West Rapti Valley and the Terai Belt.

Low flow in the upper reaches of the West Rapti basin is probably adequate for presently anticipated development needs in the area. The minimum monthly discharge of the Rapti River at Jalkundi from 1964 through 1967 was 161 cfs. The drainage area at Jalkindi is 1,990 square miles. With respect to surface water the critical area is in the Terai Belt. Although many small streams that drain the Churia Hills cross the Terai from north to south, runoff is deficient from January through May each year. In the 1,500 square mile area between the Churia Hills and Indian border, the Tinau Khola is the only tributary of importance. The average discharge during January through May for 4 years (1964-67) at the gaging station on Tinau Khola at Butwal was 100 cfs. The minimum flow recorded during this period was 41.0 cfs.

With the exception of small locally built irrigation schemes, the water potential of the basin remains virtually undeveloped. Minor irrigation projects on Dunduwa Nadi and Tinau Khola were completed in 1965, but neither project has been effective owing to deficiency of water and excessive leakage in the canals supplying the areas to be irrigated.

The hydroelectric power potential in the upper reaches of the West Rapti basin is considerable; however, development of the potential will probably be delayed as the area can best be serviced by power from the Karnali River Project. A small run-of-the-river installation in being constructed by the Butwal Technical Institute on the Tinau Khola at Butwal. The Tinau Khola Project will divert water from beneath the stream bed through a tunnel in the rock canyon wall along the stream until sufficient head is available for a power drop. The water will then be discharged through turbines in the underground powerhouse thence back to the stream. The design eliminates the risk of damage to costly headworks from floods and damage to canals by landslides, and is recommended as a model for future run-of-the-river plant installations.

Future Development of Water Resources

Problems of Development.--Water as found in nature is a variable resource both in time and space. The quantity of flow in rivers and streams varies considerably from flood to drought, often making it difficult to judge whether the resource is an asset or a liability. In Nepal, climatic conditions that cause the southwest monsoon followed by the long dry season characterize the water resource as too much or too little for 6-month intervals of the year. Wide ranges in discharge can be expected each year. For example, the maximum discharge of Kulikhani Khola at Kulikhani during 1963 through 1967 was 10,700 cfs. The minimum discharge for the same period was 3.88 cfs.

Water resources play a vital role in the economic development of Nepal. The natural environmental conditions that influence the availability of water also make difficult the development of the potential. Design of water-control structures will require careful study of all available data to assure proper operating performance through wide range in flow regimes. Development schemes that are practicable in one part of the country may be impracticable in another. For example, it may be desirable or even necessary to consider the alternatives between surface-water and ground-water development from one area to another.

Because of its climate and terrain the entire southern half of Nepal is destined to face, annually, the menace of flooding. The mountainous terrain in concert with the southwest monsoon induces both high precipitation and rapid runoff, and disastrous floods are commonplace during the rainy season. The design of river development structures, as well as highway bridges and culverts, to pass maximum floods will require close scrutiny to determine if benefits outweigh protective construction costs. Many small projects suitable for a particular locale will remain undeveloped owing to the high costs of flood protection design.

In addition to the hazards of unusually large floods from direct and torrential precipitation, development schemes for Nepal's rivers are also subject to the hazards of floods resulting from temporary blockage of rivers by landslides. The Himalaya are still tectonically active and resultant earthquakes add to the instability of the region. Landslides may result from earthquakes or from undercutting of oversteepened slopes by the rivers. Such landslides block narrow river gorges storing water temporarily and then releasing it quickly and disastrously on collapse of the blockage by erosion and overflow.

A landslide of this nature occurred on August 1, 1968, at Labubesi on the Burhi Gandaki River (fig. 16). Flow in the river was cut off completely and water was stored for 29 hours. Collapse of the blockage on the following day produced exceptionally severe flooding along the river for 25 miles downstream to the confluence with Trisuli River. At Arughat Bazar, all buildings in the section of the bazar along the left bank of the river, as well as the suspension bridge, were destroyed. The bridge, built in 1889, has been a vital link in the east-west

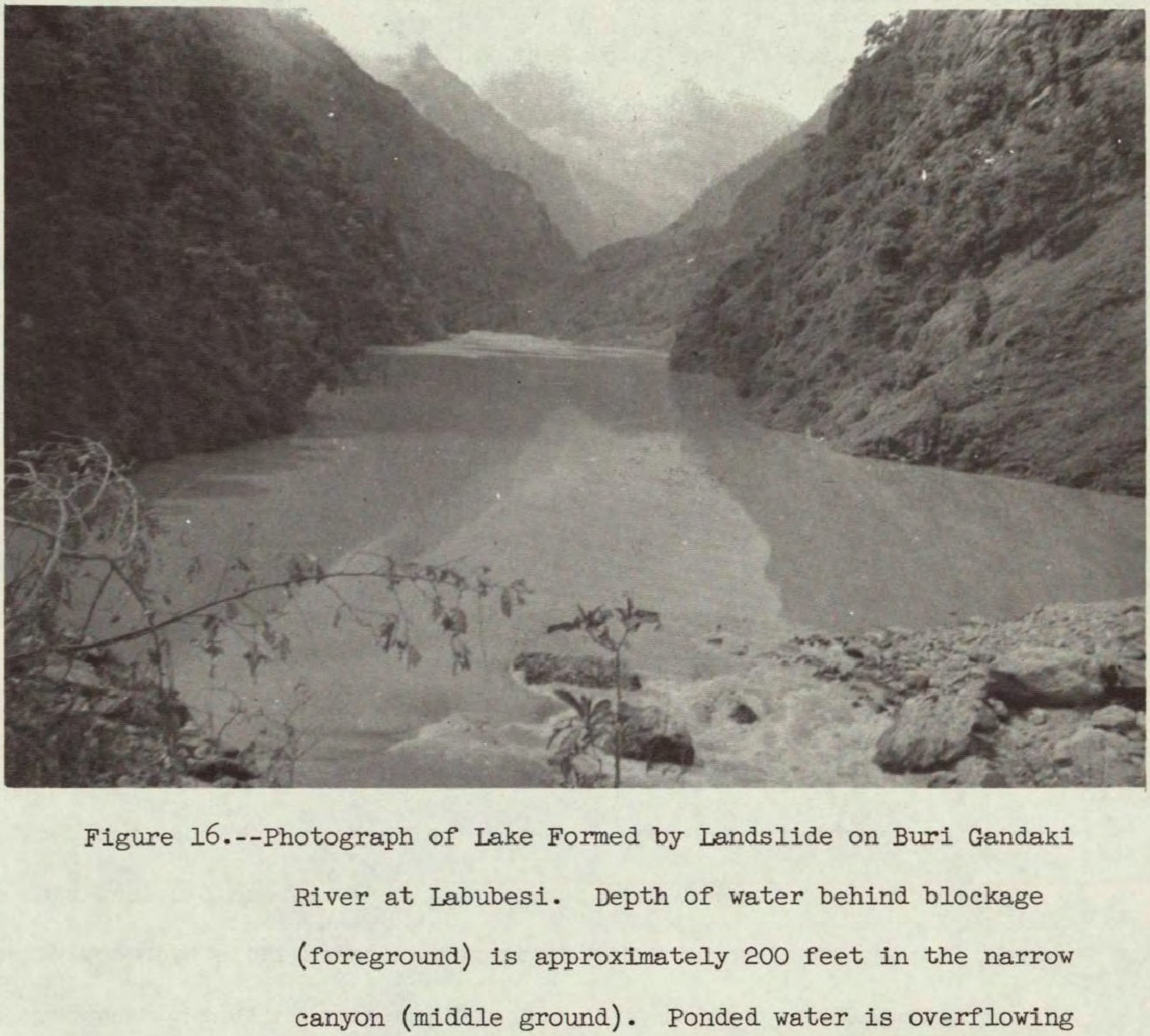

Figure 16.--Photograph of Lake Formed by Landslide on Buri Gandaki River at Labubesi. Depth of water behind blockage (foreground) is approximately 200 feet in the narrow canyon (middle ground). Ponded water is overflowing toe of blockage in foreground. View is upstream.

trail between Kathmandu and Pokhara and to the north-south movement of trade between Tibet and the Indian border. The flood at Arughat Bazar, crested at 47.93 feet, at an estimated discharge of 184,000 cfs. The previous maximum flood recorded at the gaging station at Arughat Bazar for 1964 through 1967 was 20.51 feet with a corresponding discharge of 40,600 cfs. The unpredictable nature of floods of this type pose serious problems in future development of Nepal's water resources.

Suspended material in surface water and sediment loads transported by the rivers of Nepal also has direct effect on the feasibility and cost of water-resources development. The unusually large quantities of bed load materials moved in streams during the monsoon markedly limit the useful life of reservoirs. The deposition of silt in canals and flumes of existing hydroelectric and irrigation systems results in high maintenance costs annually. It is evident then, that special consideration needs to be given to this problem in future project design.

From the foregoing discussion it is evident that there are a number of hydrologic features in Nepal that create difficult problems in development of the water-resources potential. These problems can be dealt with by sound engineering design based on reliable hydrologic basic data. Other related physical problems also exist that require solutions once development proceeds beyond the planning stage. In Nepal, as is the case for most developing nations, there are serious problems in transportation, communications, financing, as well as the availability of construction materials. Concerted solution of these problems is necessary to speed the overall development of the country.

Hydroelectric Power.--High annual runoff together with the unique topographic features of Nepal provide the basic ingredients for hydroelectric power development. The many rivers and streams that drain Nepal's terrain offer a wide selection of potential schemes to the design engineer in development planning. Relatively high heads can be developed by diversion of flow along the same stream or by diversion through tunneling from one stream to another at a lower altitude. Also narrow river gorges may offer natural sites for high dam construction.

Large-scale hydroelectric development not only requires large outlays of capital but also markets for power consumption, neither of which is currently available in Nepal. The delay in implementing construction of the proposed Karnali River Project gives indication that large-scale river development will not take place until construction capital and markets for power are assured. In the meantime, hydroelectric power development will likely be directed to power plants of moderate size linked together in power grids for densely populated areas, or small installations designed to furnish power for one or two villages. The rapid potential loss in reservoir capacity due to the sediment load of streams presently makes run-of-the-river type installations the most economically attractive method of development. Topographic features of the Midlands and adjacent hill areas are ideal for this type development. For example, the Kali Gandaki River, in a reach of 6 miles between Dana and Lete, falls 2,300 feet--an ideal condition for run-of-the-river development. Similar conditions exist on the Babai, Burhi Gandaki, Trisuli, and Tamur Rivers as well as Tinau, Mari, Khimti and Likhu Kholas.

These rivers flow north to south through deep narrow canyons as they pass through the mountain ranges. The rock canyon walls are suitable for diversion tunnels as well as underground construction of powerhouse facilities.

The Nepalese Electricity Department has programmed a number of small hydroelectric installations for construction during the present 5-year development plan. These plants will be located on small tributary streams where high heads are available through inclined or vertical conduits and will furnish electrical energy to villages in remote areas. Transmission costs will be low as power sites are selected near the villages to be serviced. Several projects are in the design stage; but, as yet no actual construction has started.

Irrigation.--The "too much - too little" characteristics of available surface water in Nepal places high priority on development of irrigation systems as a means of increasing food production. In all areas of the country agricultural crops are limited for lack of water, except during monsoon. With the exception of small locally built irrigation schemes, successful surface-water irrigation projects thus far have been limited. Minor irrigation projects have been built in the Terai, Kathmandu Valley and Pokhara by cooperative efforts between the Government of Nepal and India. In 1965, the Bureau of Statistics of the Government of Nepal reported approximately 680,000 acres under irrigation in these systems (Metzer, 1966). In most instances these projects have not come up to expectations. The failure to deliver irrigation water during the dry season is attributed to insufficient stream flow and excessive leakage in the canals supplying the irrigated areas. The irrigation project on the Tinau Khola at Butwal has repeatedly experienced damage to the canal headworks during each monsoon since the completion of the project.

Streamflow data produced by the Hydrological Investigations Project clearly indicates the areas where surface water is a practicable source for irrigation requirements. In the Terai Belt with the exception of the major streams that cross the belt, there are practically no reliable surface-water sources for year round irrigation. Moreover, construction costs inhibit development of the major rivers for irrigation. The areas adjacent to the large rivers can best be brought under irrigation using low-lift pumping stations to divert river water to feeder canals.

It thus becomes necessary to consider the ground-water potential as a principal source for irrigation of most of agricultural land in this food producing area of the country. At present, however, data on the potential of ground water for irrigation in Nepal are quite limited. Hundreds of shallow wells scattered through the Terai Belt furnish water for domestic use, and within the past 2 or 3 years a number of tube wells have been drilled in the Janakpur, Birgunj, Bhairhawa, and Nepalganj areas. The geologic terrain of the Terai alluvium consisting of interbedded gravel, sand, silt and clay, indicates water in sufficient quantity is probably available to permit development for irrigation (Swarzenski and Babcock, 1968). The limits for development, however, are yet to be evaluated by systematic studies.

The Ground Water Investigations Project, which began in March 1969, will appraise and map the gound-water potential for the Western Terai. The UN Sun Kosi Project proposes to make a similar study for most of the Eastern Terai. Hopefully, tube-well irrigation may eliminate future uneconomic ventures in surface-water irrigation schemes in the Terai.

For the Midlands region of Nepal, surface-water irrigation projects appear to be generally feasible. The valley areas along the West Rapti, Babai, Seti (Pokhara Valley) and Rapti Rivers are particularly suitable for this type development. Here again, however, high construction costs will require extensive feasibility surveys to assure that benefits outweigh project costs. Alternatively, the Midlands valleys could be irrigated by diversion of flow from tributary streams, where these emerge from the hill tracts to the valley reaches, into canals serving the terraces and bench lands along the main streams. In the Mustang area this type of development (on a primitive scale) utilizes melt water from the glaciers and snow fields to irrigate barley and vegetable crops.

The individual field or farm irrigation schemes used for centuries in the hill country can hardly be improved upon. Topographic features make it impractical to irrigate sizeable areas of land from a single source even if adequate water were available. In many areas optimum use is already made of the water available, and aid to the farmer can best be provided by the introduction of improved seeds, fertilizer and agricultural practices.

Public Water Supply.--The development of public water supplies in Nepal, except on a small scale, is relatively recent. The vast majority of the country's population depend directly on rivers, springs or shallow dug wells for water for domestic use. Probably the oldest public supply operated as a public utility is the Bhir Dhara system built in 1895 in Kathmandu Valley. The raw water source for the Bhir Dhara system is the Bishnumati River. The distribution is through a 3-inch diameter cast iron pipeline 28,000 feet long. In many villages of rural Nepal, water is supplied through small diameter pipe lines to a community tap by gravity flow.

During the past 5 years considerable emphasis has been placed on installations of drinking water facilities. Modern systems have been installed at Biratnagar, Janakpur, Bhairhawa, and Nepalganj using tube wells as a supply source. Modern treatment plants have also been placed in operation at Sundarijal and Balaju in Kathmandu Valley. The interest of the Government of Nepal in upgrading the living standards of the people is indicated by the number of public utilities in the planning stage or completed during the past 5 years to furnish population centers with drinking water.

In the Terai, the most logical source for domestic or public water supply is from tube wells. Moreover, it is likely that tube wells will be put down for drinking water in connection with the program already underway by the Nepalese Department of Irrigation and Drinking Water, to install tube wells for irrigation.

In the Midlands and valley areas adequate surface-water sources are available to meet future demands for domestic use. However, raw water pumped directly from the streams would require treatment in settling basins and with equipment to add coagulation materials and to remove silt during the monsoon season. More economic would be water sources from one or more small diameter well points put down in alluvium along or near the rivers. The water pumped from ground-water storage would be replenished readily by adjacent streams and pumping heads would remain stable.

In general, springs and small streams offer a ready source of water for domestic use in most of Nepal's hill country. This is not always true, however, where villages are located at or near the tops of the ridges. Tansing, in central Nepal, and Ramechhap, east of Kathmandu, are examples of villages where acute water shortages occur each year. The absence of any catchment area eliminates storage of surface water and available ground-water storage at best can support springs that only flow a few gallons per minute. In many cases the available springs can best be utilized by the construction of tanks to store water during the night to supplement flow during periods of peak consumption during the day. Materials and labor are available in most localities to build masonry storage tanks; only technical assistance and funds are needed. Growth of villages and farming communities along the ridge crests has been retarded in the past by the scarcity of domestic water supplies and this will continue to be the case.

Pollution Control.--Almost all streams in Nepal are subject to varying degrees of pollution. Domestic waste accounts almost totally for such pollution at present. There are no sewage treatment facilities in the country and surface water is not only contaminated by raw sewage but the soil has also become contaminated from centuries of unsanitary practices. Thus, stream pollution is aggravated by soil erosion. Biological contamination is a menace to the population but has little effect on other uses of water. The pollution problem is most acute in densely populated areas such as the Kathmandu Valley where there is high input of pollutants with respect to the quantity of surface runoff.

With the industrialization of the country there will be a tendency to pollute still more the nation's waters with industrial waste. Investigations are now underway for a paper mill in the Hitaura area. Additional industry will undoubtedly follow. Indiscriminate use of the streams for disposal of industrial waste could seriously affect the use of water for irrigation, especially during the low flow season. As far as is practical, industry with waste disposal problems should be located near the major rivers where adequate water for dilution will be available. It is suggested that the Government of Nepal should now consider legislation to protect the nation's waterways from excessive use for waste disposal.

Flood Control.--The annual occurrence of floods in the low-lying areas of Nepal has already been mentioned as a menace to river development and control structures (fig. 14). Surveys of existing structures invariably show flow damage in some degree after each monsoon. The piers and abutments of foot and highway bridges, culverts, low diversion dams, and headworks, are all vulnerable to the raging torrents of the monsoon season. These structures are not intended to retard or control floods. Instead, they are designed to "pass the flood" with minimum resistance. Thus, the design of flood control structures required to harness the wild rivers of Nepal demand maximum engineering expertise. Also construction costs call for tremendous outlays of capital which must be weighed against vulnerability to damage and loss.

Reliable statistics of annual flood damage in Nepal as a whole are not available. Difficulty in travel and communications undoubtedly allow much damage to pass undetected or at leastunreported. In August and September 1954 devastating floods in eastern Nepal claimed an estimated 1,000 lives when more than 100 villages were washed away. Shortly after the flood season the Government of Nepal estimated that at least 25,000 families lost their homes, crops, livestock and other property (Veatch and Hulsing, 1962).

Flood loss in Nepal is diminished somewhat because the Nepalese, inured through long centuries of contact with the problem have learned to live with floods. Most villages and single dwellings, except those of a temporary nature, are built on high ground. Ferries are discontinued during the rainy season and people walk the additional distances required to cross the rivers over suspension bridges. The greatest loss occurs to crops, such as rice paddies, that are grown in the river flood plains. Paddy that is damaged early in the growing season is replanted and the loss is minimized.

Flood control ranks as one of the important needs in this developing country; yet, it is one that will be slow in materializing. To be viable, flood-control measures when applied to any of the major river basins of Nepal will need to be major in scope. Half-way measures will not do the job. The Kathmandu Valley, where the pressure on the land by a rapidly-increasing population is most acute, is in most urgent need of flood-control planning. Some relief from flooding in the areas adjacent to the Bishmumati, Manohara and Bagmati Rivers could be realized by channel improvements. In addition to widening and deepening of channels, planning should consider realignment of the channels to eliminate bends and curves. Probably, the most striking improvement would result in removing the obstruction to flow caused by Chobhar Gorge. Deepening and widening of this constriction would increase the natural stream gradient in the now critical low areas of the Valley.

Flood control is a problem that needs to receive an appropriate measure of attention in the progressive economy of Nepal. It is likely, however, that other development problems will continue to take precedence over flood control and this problem will be pushed further into the future. At present (1969) there is no department in the Government of

Nepal concerned with flood-control planning on a countrywide basis, and it would be well to create such an agency. In this way, planning could begin and the agency would be in a position to prepare and substantiate budget requests that otherwise could not be made.

Conclusions

Nepal has an abundance of water to the extent of an annual surplus, even when future development needs for the resource are considered. However, as most of the surplus runs off during the monsoon season and as most of this surplus cannot be stored in surface reservoirs under prevailing economic conditions, the usable water resources are basically limited to those that can be taken from available stream flow and from ground-water storage.

Generally, north of the Mahabharat Range streamflow is adequate (without surface storage) to satisfy local needs for domestic water supplies and for irrigation of irrigable lands. Hydroelectric potential in the region, if properly exploited, is substantial. The most promising power sites are found in the Midlands and the lower ranges of the Himalaya, where steep river gradients are suitable for run-of-the river development and transmission costs to the valley areas would be economically feasible.

In many areas to the south of the Mahabharat Range, streamflow is inadequate from March to June to meet the requirements for even daily domestic consumption. Many villages depend on shallow wells for local water supplies. Past attempts to develop surface-water irrigation systems on small streams have been unsuccessful because of deficient streamflow during the pre-monsoon season. Preliminary investigations indicate ground-water potential in the area to be adequate for at least limited irrigation. Measures proposed under the government's present

5-year plan call for drilling tube wells to tap the deep aquifers underlying the Terai Belt as a source for water for irrigation. Twelve tube wells, ranging from 200 to 450 feet deep have already been drilled by the Nepalese Department of Irrigation and Drinking Water in the Janakpur, Bhairahawa, and Nepalganj areas. The Ground Water Investigations Project for the Western Terai, undertaken with US AID assistance, will provide information on well spacing, well design and anticipated yields to assure optimum development of the potential. Ground-water exploration in the Eastern Terai by the UN in connection with the feasibility survey of the Sun Kosi Project will guide ground-water development in that area.

Substantial withdrawals from tubewells to meet future requirements for increased irrigation in the Terai Belt will ultimately have appreciable affect on low flow in the streams whose catchment areas lie south of the Siwalik and Churia Hills. With intensive ground-water withdrawals the seasonal decline in flow in these streams would begin earlier in the dry season and many of the streams with low flow sustained by seeps and springs discharging ground water from the alluvial aquifer would cease to flow in the dry season. Under these conditions it is conceivable that areas of as much as 2,000 square miles between the major streams will be without surface runoff for 6 months each year. Thus it would be necessary to provide adequate water for domestic use from public-supply tubewells, as yields from the shallow dug wells may diminish appreciably with development of ground water for irrigation.

A surplus of electrical energy will be available to the area south of the Mahabharat Range, with energy resulting from the combined power facilities of the Kosi and Gandak projects and the Karnali River complex, if constructed. Much of this energy, however, will be needed for pumping ground water in the Terai Belt.

Chemical analyses of the limited number of samples taken from the rivers of Nepal indicate generally good quality surface water in most areas of Nepal. Of the ground-water sources sampled in the Terai, only the area near Nepalganj, where high residual sodium carbonate has been detected, appears to be potentially troublesome with respect to water quality. The movement of sediment and bed load material in the rivers during monsoon presents a serious limiting factor in the use of surface storage facilities in river development planning.

Stream pollution and flood control are problems that the government will be required to deal with in the not too distant future. Immediate steps need to be taken to enact legal controls for pollution abatement and to authorize the establishment of a governmental agency to begin flood-control planning.

It is difficult to schedule a time table for the full development of the vast water-resource potential of Nepal. Development will depend to a large extent on the financial assistance that is available from friendly nations. The most favorable measures to encourage development investment are the efforts being made by the Government of Nepal to collect and evaluate hydrologic data essential to documentation of the water resources.

The Nepalese Department of Hydrology and Meteorology is now established to supply this need on a continuing basis. The department is being developed to assemble data on all components of the hydrological system. Hydrologic data related evaluations readily available will eliminate lengthy delays in feasibility surveys for future projects.

If future development is designed to fill only needs within Nepal, such development will be single purpose in scope. Moreover, there would be a tendency to underdevelop the total water-resources potential. Development along such lines would result in high cost-benefit ratios. On the other hand, if development follows multipurpose river basin development patterns with international connotation, the full water-resources potential can be harnessed and cost-benefit ratios will be lower. Under the latter approach, high dam development of the Sapt Kosi, Narayani and Karnali Rivers at the gorges through the Mahabharat Range would be feasible. Also, schemes to divert flow from the upper reaches of these major streams to the minor river basins can be justified. Rerouting of stream flow from the glaciers and snow fields through basins that drain only the lower slopes can also result in a more favorable distribution of flow during the dry season in the Terai Belt of Nepal and adjacent areas in India.

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Orthographic List of Geographic Names

Names in this report conform to the Board of Geographic Names (BGN), approved standard name where possible to verify.

Where no standard name is listed, this is not verified.

Where part of a name is underlined, the use of the part not underlined is optional.

A BGN or Report name with ending in parenthesis may be a generic ending, describe feature, area, region, author's preferred usage, former name, familar or conventional name of the country. This ending may maintain description of the preceding word.

A BGN or Report name with wording spaced aside will show conventional or familiar spelling usage, and spelling usage in the and spelling usage in the adjacent country.

The BGN and Report name will have description of feature, area, region, other, near right margin. Where none is indicated, this is populated (city, town village, other).

Board of Geographic Names (BGN) approved standard name (for report)	Report name
Town	
Ārughāt Bāzār	Arughat Bazar
Amile	Amile
Bhairhwa	Bhairawa
Birātnagar	Biratnagar
Not verified	Birmire Taro
Banbāsa	Banbasa RR Station
Bīrganj	Bergunj
Bāhrabīse	Barahbise
Butwal	Butwal
Beluwa	Beluwa
Chisāpāni	Chisapani
Chepti	Chepti
Chobhār	Chobhar
Chaukle	Chauklé
Chautara	Chautara
Dhankuta	Dhankuta
Not verified	Dumrichaur
Dharān Bāzār	Dharan Bazar
Dāna	Dana
Debichaur	Debichaur
Dhangarhi	Dhangarhi
Ghumthāng	Ghunthang
Gurkha	Gorkhā
Hitaura	Hitaura

Ilam	Ilam
Jomosom	Jomosom
Jhāpa	Jhapa
Janakpur	anakpur
Jalkundi	alkindi
Jhawani	Jahawani
Kāthmāndu	Kathmandu
Kulīkhāni	Kulikhani
Not Verified	Khauaytal
Karmaiya	Karmaiya
Kumragaon	Kumragaon
Lete	Lete
Not Verified	Labubesi
Mustāng (Lho Mantang)	Mustang
Mārkhu	Markhu
Mangalpur	Mangalpur
Nepālganj	Nepalganj
Nāmche Bāzār	Namche Bazar
Nārāyangarh	Narayangarh
New Delhi	New Delhi India
Okhaldhunga	Okhaldhunga
Pokhara	Pokhara
Panaoti	Panauti
Pharping	Pharpin
Pyuthān	Piuthan
Pātan	Patan

Rasnālu (village)	Rasnalu Village
Rāmechhāp	Ramechap
Setībeni	Setibeni
Sundarijal	Sundraijal
Sunauli	Sonoüli
Not Verified	Shringa
Sirkot	Sirkot
Tribeni (Tribeni Ghat)	Tribeni Ghat
Tānsing	Tansing
Tikoli	Tikoli
Taulihawā	Taulihawa
Those	Those
Trisūli Bāzār	Trisuli Bazar
Udaipur Garhi	Udaypur

Civil Structure

Tribhuwan	Raj Path road
Not Verified	Chatra Canal canal

Area or Region

Tarai	Terai region
Dodājyāri	Dondajari locality

Political Geography

Republic of India	India
Kingdom of Nepal	Nepal
State of Uttah Pradesh	Uttar Pradesh India
State of Bihar	Bihar India

Drainage and Water

Āndhi Khola	Andhi Khola
Arun River (Nepal)	Arun River
P'eng-ch'ü Ho China	
Bāghmati Nadī	Bagmati River
Buri Gandaki	Burhi Gandaki
Babai Khola Nepal	Babai Nadi
Sarju River India	
Bheri River	Bheri River
Biring River	Bering Khola
Bāngangā River	Banganga Khola
Bishnumati Khola	Bishnumati River
Brahmaputra River India convential	Brahmaputra
Tsangpo Tibetan	
Chamlia River	Chamlia
Dhaulīganga River India	Dhlaulinganga
Ganges River India	Ganges River
Gorīganga River India	Goriganga
Nārāyāni (Nepal)	Gandak River India
Gandak River India	
Jhimruk Khola	Jhrimruk Khola
Karnāli River	Karnali River
Kali River Nepal	Gandaki
Sārda River India	Maha Kāli River India
Khimti Khola	Khimti Khola
Kāli	Kali Gandaki River

Kankai Nadī	Kankai India
Kankai Nadī	Kaukai Mai
Kokhājor Khola	Kokhajor Khola
Sapt Kosi River Nepal	Kosi River India
Kulīkhāni Khola	Kulikhani Khola
Likhu Khola	Likhu Khola
Marsyandi River	Marsgandi
Kali River Nepal	Gandaki
Marin Khola	Marin Khola
Māri Khola	Mari Khola
Nārāyāni (Nepal)	Narayani River
Gandak River India	
Not Verified	Phewa Khola
Phewa Tal (lake)	Phewa Tal lake
Rosi Khola	Rosi Khola
Rāpti River Nepal and India	Rapti
Seti River	Seti River
Sapt Kosi River	Sapt Kosi
Sun Kosi River	Sun Kosi
Sārda Khola	Sarda
Surna Gad	Surna Gad
Seti River	Seti Khola
Kali River Nepal	Sārda River
Sārda River India	Maha Kali River India
Trisūli River	Trisuli River
Tamur River	Tamur

Thuli Gadh	Thuli Gad
Tangtin Khola	Tangtin Khola
Tināu Khola	Tinau Khola
Rapti River	West Rapti River

Topography

Kānchenjunga	Kanchenjunga mountain
Dhaulagiri Himāl	Dhulaguri mountain
Siwālik Range	Siwalik Hills
Mahābhārat Lekh	Mahabharat range
Mustāngbhot Himal	Mustangbhot
Lipu Lekh Nepal	Lipu Lekh
Zaskar Range Tibet	
Siwalik Range	Churia Hills
Not Verified	Chobhar Gorge valley
Mount Everest	Mount Everest

Glossary For Table
Station Name
(See Table 2)

BGN approved standard name (for report)	Report name (Populated)	
Belgaon	Belgaon	
Chaukle	Chaukle	
Dodājyāri	Dondajari	locality
Kumrāgaon	Kumragaon	
Pyuthān	Piuthan	
Amile	Amile	
Taulihawā	Taulihawa	
Beluwa	Beluwa	
Pātan	Patan	
Mārkhu	Markhu	
Mangalpur	Mangalpur	
Ghumthāng	Ghunthang	
Not verified	Shringa	
Sirkot	Sirkot	
Tānsing	Tansing	
Pokhara	Pokhara	
Gurkha	Gorkha	
Butwal	Butwal	
Trisūli Bāzār	Trisuli Bazar	
Nārāyangarh	Narayangarh	
Hitaura	Hitaura	
Debichaur	Debichaur	
Jhawāni	Jahawani	

Sundarijal	Sundraijal
Kathmandu	Kathmandu
Kulīkhāni	Kulikhani
Chautara	Chautara
Dhulikhel	Those
Rāmechhāp	Ranechhap
Okhaldhunga	Okhaldhunga
Udaipur Garhi	Udaypur
Ilam	Ilaḿ
Baitadi	Baitadi
Not verified (N v)	Asara Ghat.
Bangāhi	Bangachia
Betrāwati	Betrawati
N v	Chitra-Sari
N v	Gauri Ghat
Jāmū	Jamu
N v	Jurpani
N v	Kalimati-Ghat
N v	Kota Gaon
Kampu Ghāt	Kampu Ghat
N v	Lothar
Manhari	Manhari
Mahānkāl	Mahankai
Nayāgaon	Nayagaon
N v	Palungtar
Phalāmsāngu	Phalame Sangu

N v	Pachuwar Ghat
N v	Rajaya
N v	Rabuwa Bazar
N v	Shyamdado
N v	Sangutar
Tikābhairab	Tikabhairab

Board on Geographic Names (BGN)		Report name (Drainage)
Surna Gād		Surna Gad
Karnāli River		Karnali River
Seti River		Seti River
Thuli Gad		Thuli Gad
Bheri River		Bheri River
Babai Khola	Nepal	Babai Nadi
Sarju River	India	
Māri Khola		Mari Khola
Jhimruk Khola		Jhimruk Khola
Rāpti River	Nepal	Rapti River
Rāpti River	India	
Tināu Khola		Tinau Khola
Bāngangā River		Banganga River
Kāli		Kali Gandaki River
Āndhi Khola		Andhi Khola
Seti River		Seti Khola
Chepe Khola		Chepe Khola
Burhi Gandaki		Burhi Gandaki River
Trisūli River		Trisuli River
Nārāyāni River	Nepal	Narayani River
Gandak River	India	
Manhari Khola		Manhari Khola
Lothar Nadī		Lothar River
Khairanga Khola		Khagari Khola

Kair Khola	Kair Khola
Būrhi Rāpti Nádi	Burhi Rapti
Bāghmati Nadī	Bagmati River
Nāgmati Khola	Nagmati Khola
Siālmati Khola	Sialmati Khola
Nakhu Khola	Nakhu Khola
Not verified (N v)	Thade Khola
Kulīkhāni Khola	Kulikhani Khola
Bhote Kosi	Bhote Kosi
Balephi Khola	Balephi Khola
Sun Kosi River	Sun Kosi
Rosi Khola	Rosi Khola
Khimti Khola	Khimti Khola
Dudh Kosi	Dudh Kosi
N v	Phewa Khola
Kankai Nadī Nepal	Kankai Mai
Kankai Nadī India	

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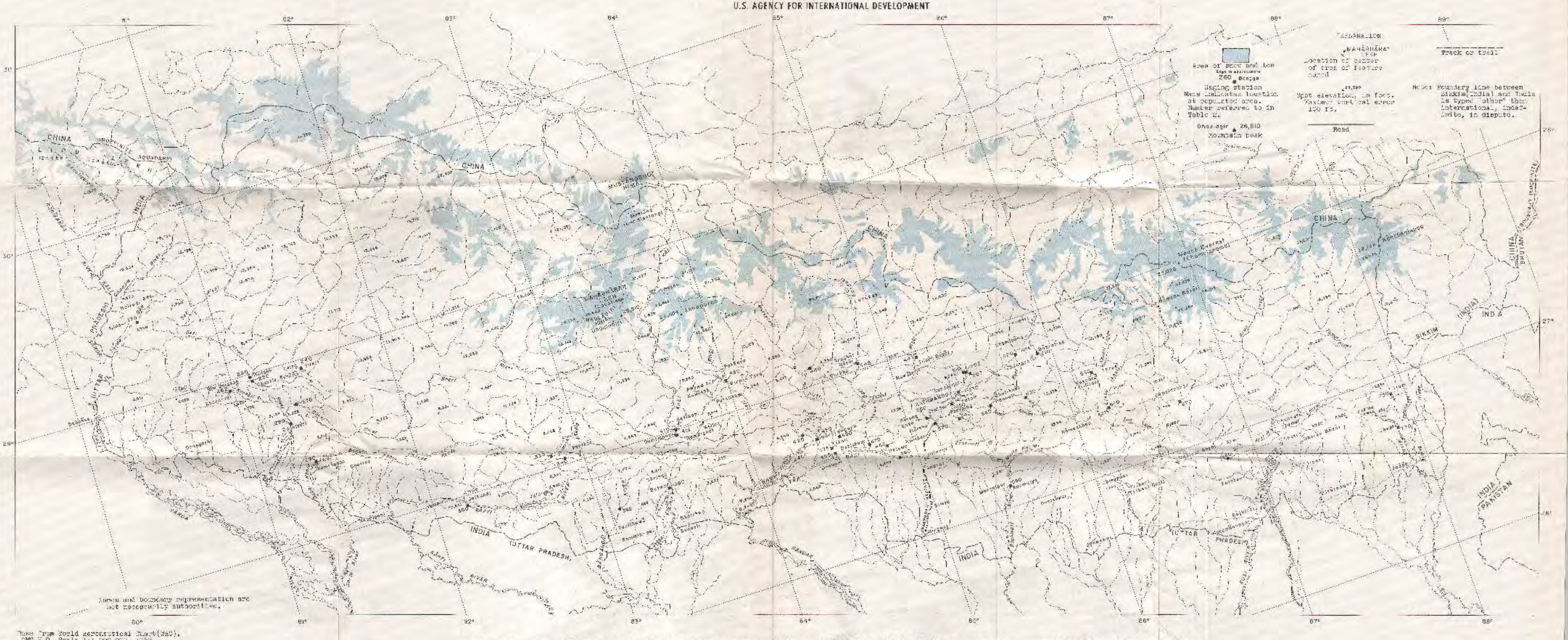
UNDER THE AUSPICES OF THE
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT



Base from World Aeronautical Chart (WAC), ONC H 9, Scale 1:1 000 000, 1966

FIGURE 8.--MAP OF NEPAL SHOWING PRINCIPAL RIVERS AND STREAM-GAGING STATIONS STREAMGAGING STATIONS