A REVIEW OF PROPOSED GROUND-WATER ASSESSMENT STUDIES IN STATES OF GUJARAT, MADHYA PRADESH, MAHARASHTRA, AND MYSORE, INDIA

by C. L. R. Holt, Jr.
United States Geological Survey

Open-file report
1973

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Prepared by the United States Geological Survey
in cooperation with the Government of India
and the States of Gujarat, Madhya Pradesh,
Maharasthra and Mysore under the auspices
of the United States Agency for
International Development

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As described in the August 3, 1970, description of Sub-project 368.6 of the Soil and Water Management Project, which was prepared in co-operation with the Central Ground Water Board, Ministry of Food and Agriculture, Government of India.

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~~Administrative report~~
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U. S. GOVERNMENT PRINTING OFFICE : 1959 O - 511171
867-100

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CONCLUSIONS

The proposed study, Soil and Water Management Sub-project 368.6 (see TOAID A-653, July 31, 1970), states adequately and briefly the goals, objectives, and general approach. This study to assess ground-water supplies that may be developed on a sustained basis comes at an opportune time. Early development of ground-water resources for irrigating crops is vital to India's need for expanding its food production. The drilling of irrigation wells may be restricted in local areas to reduce well interference and to prevent contamination from saline water. The Central Ground-Water Board (CGWB) and the state agencies are prepared to commence the study and put the results into wide use.

Four problem areas are proposed for study--a crystalline rock area in Mysore, a basalt area in Maharashtra, an alluvial valley area (upper Narmada River) in Madhya Pradesh, and a coastal sediment area (lower Narmada River) in Gujarat. These study areas are representative and applicable to larger areas in India having similar hydrology.

The study areas should conform generally to surface drainage basins and their sizes should be small to permit full effort for developing technical experience.

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Both CGWB and the States have many personnel who are well trained in the fundamentals of ground-water hydrology. Special experience is needed in quantitative ground-water assessment and in the systems approach to assessing ground-water availability. Considerable information has been collected by these agencies on geology, ground-water development, and water use.

In the upper Narmada River basin, ground-water development is extensive and about 7,000 additional tube wells have been approved for construction. Unless these wells are properly spaced, sustained heavy pumping may excessively lower water levels in nearby tube wells or dry up dug wells. In the lower Narmada River basin, ground-water development for irrigation also is large and the demand for additional water is increasing. In the coastal plain, saline water is reported to be a problem in areas of concentrated pumping. In the basalt and the crystalline rock study areas, numerous dug wells and a few shallow tube wells yield small amounts of ground water for irrigation. Low storage capacity and irregular joint distribution in the rocks limit the probability for developing large yields of ground water. Information is needed about the occurrence of ground water at depth; the occurrence and movement of shallow ground water in fractures, joints, and weathered rock; and the potential for inducing recharge to the aquifers.

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Ground-water quality is generally good in the four study areas. However, clay soils may become waterlogged and saline if not properly drained and irrigated. Salt water underlying fresh water and potential salt-water encroachment are special quality problems in the Gujarat area.

The project should include the following objectives:

1. Increase experience with the CGWB and the State organizations to conduct system studies in assessing ground-water supplies. Techniques developed in these studies should have application to other areas of India.

2. Estimate the quantity and quality of ground water that may be developed on a sustained basis. This study should include determining aquifer characteristics and appropriate well spacing and suggest techniques for developing wells and methods for restricting saline-water encroachment.

3. Determine ground-water systems and their relationship with surface water. This study should include relationships between alluvial and bedrock aquifers as well as potential for recharging aquifers from surface-water sources.

4. Integrate ground- and surface-water data needed to plan optimum use of water and administration of water programs. This includes developing a network of hydrologic monitoring gages to forecast effects of sustained pumping and the migration of saline water.

5. Provide training opportunities for qualified hydrologists to gain special experience or competence in assessing and managing ground-water supplies.

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USA hydrologists of specialized experience in the geologic terranes and hydrologic problems of the study areas will be required. A project manager, geophysicist, chemist, and surface-water engineer (direct hire or Participating Agency Service Agreement [PASA]) and team leader (contract) will work in all areas from New Delhi as will their CGWB counterparts. Four hydrologist (c) will work and reside in the four states and work with counterparts from CGWB and the states. Specialized training not scheduled for the project will be given in USA or by on-the-job training from special consultants.

Detailed planning and management will be required to meet project objectives in scheduled time. Steps for systematically assessing ground water should aid managers in integrating data, coordinating personnel, maximizing training, and maintaining cooperation between agencies. A work plan illustrates these steps and the coordination of studies necessary to meet the subgoals.

INTRODUCTION

This report documents the findings and recommendations of the author, who was detailed for 30 days to USAID Mission to India to assist in preparing the scope of work for a USAID contract for consultant services for ground-water evaluation. The proposed study, Soil and Water Management Sub-project 368.6, covered three specific areas in four states in central and southern India (See TOAID A-653 of July 31, 1970, revised description of the sub-project). The study areas and principal cities are shown in figure 1.

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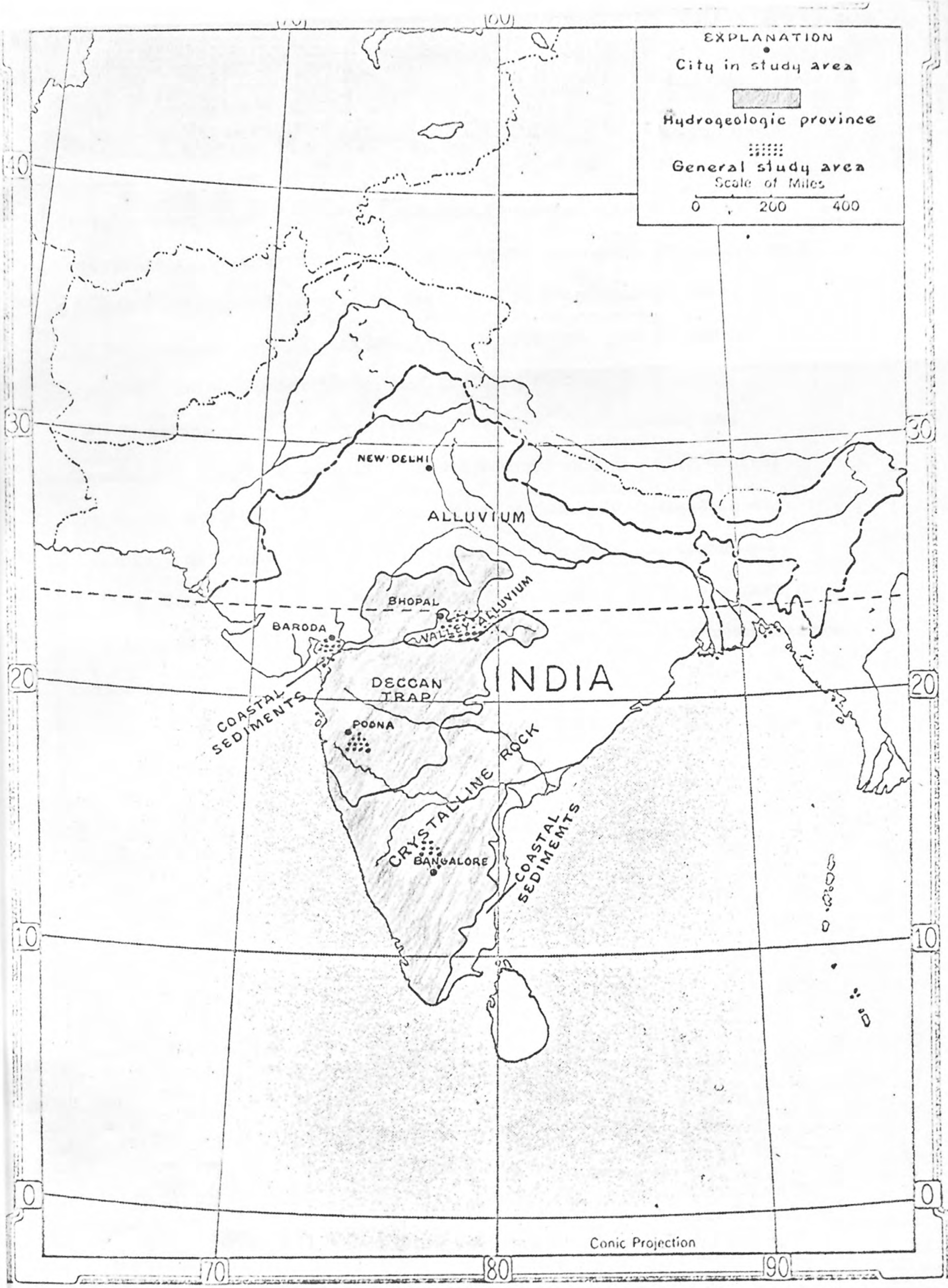

Figure I.—Proposed study areas representative of hydrogeologic provinces in India.

Purpose and Scope

This report is intended to supplement the July 31, 1970, sub-project description by adding recommendations for specific plans and experience requirements for U.S. contractual personnel. The following procedures were used to develop the specific recommendations:

1. Reviewed project objectives, general approach, plan of action, personnel and equipment needs, and training plans.

In making this review; numerous meetings, conferences, and discussions were held with USAID Mission personnel and with Central Government and State Government representatives. Appendix A is a chronology of conferences and field inspections by W. D. Romig and C. L. R. Holt, Jr., from October 28 to November 25, 1970. Appendix B is a list of the Central Government and State Government representatives contacted while reviewing the proposed project.

2. Visited the proposed study areas and assessed the geologic setting, hydrology, water-resource development, and availability of hydrologic and geologic data.

Rapid reconnaissance field trips (Appendix A), conducted by State personnel, gave a general understanding of the character of the areas, the irrigation potential, development problems, and special needs for on-the-job training.

3. Proposed scope of technical studies for each area study.

Specific study objectives were prepared for each area study, based upon the hydrogeologic setting and related problems. Proposed work plans were developed to present work units, completion targets, and sequences of related studies.

4. Proposed technical experience requirements for U.S. contractual personnel needed to undertake project.

A high degree of technical skill and competence will be necessary to conduct on-the-job training of Indian personnel. Both the CGWB and the States have many personnel who are well trained in the fundamentals of ground-water hydrology. Special training is needed in quantitative ground-water assessment and in the systems approach to studying ground-water basins.

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Need for Project

The July 31, 1970, revised description of the project, prepared in collaboration with the Exploratory Tubewell Organization [1] and

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[1] Now the Central Ground-Water Board (CGWB).

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orally endorsed at the Joint Secretary level, states adequately and briefly the goals, objectives, and environments of study areas and the general approach and plan of action.

Visits to the project areas and discussions with officials concerned with ground-water development strongly indicated that the proposed studies and training opportunities are urgently needed. In each area visited the demands for ground water for irrigation and other uses are growing at a rapidly increasing rate. The detrimental effects of well interference and excessive pumping, such as water-level declines, reduced well yields, and saline water intrusion, are of increasing concern to officials. Well drilling is restricted in many areas to reduce the possibility of well interference, pending completion of studies such as those proposed in this project.

The proposed studies to develop the organization and technical experience to assess the ground-water supplies that may be developed on a sustained basis come at an opportune time. The study results will be used immediately in large areas by the CGWB and the State agencies.

Acknowledgments

The many public officials of the Central Government and of the States of Mysore, Maharashtra, Madhya Pradesh, and Gujarat who generously shared their experience, knowledge, and time with Romig and Holt are recorded in Appendix B. Thanks are expressed to those officials who arranged scheduled conferences, travel, and housing.

Special credit must be given to the technical competence and leadership in ground-water development evident in the Central Government and in each of the States. The intense interest of officials in knowledgeably expanding the irrigation development of the country and in the States gave the author full confidence in the success of the proposed project.

The assistance of USAID personnel in expediting this brief study is fully appreciated. Special thanks are given to W. D. Romig, who accompanied me on much of the trip, and shared freely with me his knowledge and experience of ground-water needs in India. Stan Remington's guidance and experience were deeply appreciated. Personnel of the USAID Mission to India gave invaluable assistance in arranging conferences and preparing this report.

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ANALYSIS OF PROJECT

Type Areas

The areas proposed for study should be representative and typical of larger areas having similar hydrogeology within the four States and in other basins in India (fig. 1). The decomposed and fractured granite area near Tumkur is representative of many other crystalline rock areas in India. The Deccan Trap area near Satara appears to be similar to much of the trap terrain that covers a large segment of the country. The alluvium in the upper Narmada basin and the saline water encroachment in the lower Narmada basin may not be fully representative of other areas; however, the techniques used to systematically assess these areas can be applied in alluvial basins and in coastal areas of India.

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Four Proposed Areas

Because the saline encroachment problems in the lower Narmada River basin require several study techniques different from those in the upper basin, it is recommended that this basin be considered a separate study area. The Joint Secretary of Agriculture gave oral agreement to the study of four areas.

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Size of Study Areas

Each area of study should be restricted to a size that can be studied effectively by the assigned personnel and their equipment. The goal of developing the organizational and technical competence to fully assess and wisely develop ground water could not be met if excessive effort was expended on collecting data for too large an area. A thorough and comprehensive study of a small but representative area will permit full effort for developing technical competence.

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Drainage Basin Approach

The author recommends that the study areas conform generally to surface drainage basin. Because ground-water movement is not always restricted to a topographic basin, the study areas should extend to the ground-water divides if at all feasible.

The collection and analysis of surface-water data in the drainage basin will be essential to a full understanding of the ground-water system. A quantitative knowledge of ground water and surface-water relations in the basin is necessary for developing a wise management program.

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ANALYSIS OF STUDY AREAS

Field visits to the proposed study areas, discussions with State and Central Government officials, and review of available published information have supplied background on the hydrogeologic settings, water development, availability of data, and the water problems of each area. This information was useful in proposing the scope and study objectives for each area and in recommending technical experience of contract employees.

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Upper Narmada River Basin

Area of Study

The general area of the proposed study is the part of the Narmada River basin (fig. 1) between Hoshangabad and Jabalpur (26,000 square kilometers).

The proposed area for conducting detailed system studies (13,000 square kilometers) includes the Tendoni and Hiran River basins (both north of the Narmada River) and smaller basins south of the Narmada River. These subbasins have hydrologic conditions representative of those in the entire Narmada River basin and include areas of present and potential tube-well development.

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Geologic Setting

Thick alluvium, consisting of clay, silt, and sand and gravel, fills a structural trough or rift valley. The Vindhyan range of hills on the north side of the valley consists of dense ~~and indurated~~ shale, sandstone, and limestone. The Satpura Range, south of the valley, consists of friable sandstone, conglomerate, and clay. Deccan Trap rocks are largely confined to hills in the valley south of the river. Roy (1953) and Raghava Rao, Roy, and Sikka (1968) describe the hydrogeology in detail.

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Hydrology of Area

The average annual rainfall of about 140 cm (centimeters) ranges between 115 and 200 cm. More than 85 percent of the rain falls during the monsoon period. Surface runoff is large and rapid, and floods and erosion are recurring problems. The Narmada River channel is broad and sand-filled as it meanders through the Narsinghpur and Hoshangabad plains.

The principal aquifers are permeable sand and gravel beds and lenses in the valley alluvium. These beds and lenses differ greatly in thickness, number, and position.

Ground water generally moves toward the Narmada River and its principal tributaries from recharge areas within the valley and the flanks of the Satpura and Vindhyan Ranges. Ground water is under artesian conditions in the beds of sand and gravel intercalated in silt and clay. It is under water-table conditions in shallow sand and gravel and in much of the bedrock.

Small supplies of irrigation water may be developed by tube wells in the sandstone in the Gondwana System and by dug or tube wells in the Vindhyan and Deccan Trap rocks.

The chemical quality of ground water is generally good. State records indicate that total dissolved solids are less than 500 mg/1 (milligrams per liter) and that chlorides are less than 90 mg/1. Boron should be determined in future analyses. Water in the confined parts of the sand and gravel aquifer should be relatively safe from contamination.

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Water-Resource Development

The surface waters of the Narmada River basin are relatively less developed than those in other basins in India. Surface-reservoir development is small; however, the Tawa Rėservoir is under construction, and plans have been prepared for additional development works.

Ground-water development is intensive between Hoshangabad and Jabalpur. Dug wells are common, and many tube wells have been constructed by the CGWB, the State Tubewell Directorate, and by individual farmers. The Directorate has constructed more than 200 tube wells.

Most of the ground-water development has been for irrigation. Irrigation has increased crop yields and the number of crops, which consequently has created an intense demand for more wells.

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Availability of Hydrologic Data

The State Directorate and the CGWB have collected considerable hydrologic data, and the Geological Survey of India/(GSI) has done several studies within the basin. In addition, an inventory of dug and tube wells has been started, and all new tube wells are registered with the Director of Tubewells. About 7,000 tube wells have been approved for construction. Well logs are being systematically compiled. Development tests are being made of all new wells, and 76-hour pumping tests have been conducted for some wells. Chemical quality of water data are available for about 60 wells.

The 10 stream gages are not adequate in number or location for a systems study of subbasins. About 20 precipitation gages are in the area.

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Factors Which May Limit Development

Local water-level declines, caused by improperly spaced wells and sustained heavy pumping, may lower water levels excessively in nearby tube wells or may dry up nearby dug wells.

Regional water-level declines, caused by pumping from confined aquifers, lowers the potentiometric surface and may reduce the yields of tube wells.

Transmissivity and storage capacities are low in some confined aquifers, and sources of recharge may be distant. Increasing recharge to confined aquifers may not be feasible in developed areas. Percolation ponds and spreading areas on permeable outcrops near areas of ground-water pumping should increase recharge, but overdrafts of ground water may occur in major development areas.

Clay soil may become waterlogged and saline if not properly drained and irrigated. However, water quality is generally good and should not be a limiting factor.

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Study Objectives

1. Increase experience of CGWB and the State organization to undertake system studies in assessing water supplies in alluvial valleys.

2. Develop techniques in making system studies of alluvial basins that are typical of other parts of the Narmada basin and of other basins in India.

3. Estimate the quantity and quality of the ground water that may be developed on a sustained basis. This study includes well spacing.

4. Determine the ground-water system and relationships with surface water. This will include relationships between deep alluvial aquifers, shallow alluvial aquifers, and bedrock aquifers, as well as the
/potential for recharging aquifers from surface-water sources.

5. Improve techniques for developing wells in alluvium and for testing aquifer characteristics.

6. Integrate ground-water and surface-water data needed to plan optimum use of water and administration of water programs. This includes developing a network of hydrologic monitoring gages to forecast changes in the hydrologic system.

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Lower Narmada River Basin

Area of Study

The general area of the Narmada basin to be studied in Gujarat is about 4,000 square kilometers. It is located in the Gujarat Plain between the mouth of the Narmada River at Broach (Gulf of Cambay) and Gardėshway near the Narmada Gorge (fig. 1).

The principal subbasins proposed for detailed study are for the Bhada, Orsangir, Ashwin, Man, Karjan, and Amaravati Rivers. Most of these streams drain west from the Satpura and Vindhyan Ranges.

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Geologic Setting

Thick alluvial deposits of clay and silty clay with thin beds (3-13 meters) of sand and gravel extend to the west coast from Deccan Trap rocks to the east and Vindhyan rocks to the northeast. The alluvium is more sandy and probably more permeable in the Gujarat area than in the upper part of the Narmada basin. Sand occurs in the beds of some rivers. Underlying the alluvium are consolidated sediments such as the Gondwanas. The Geological Survey of India has made several detailed studies in this area.

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Hydrology of Area

The average annual rainfall on the proposed project area is about 114 cm. More than 85 percent of the rain falls during the monsoon period, which is June to September. The winter is practically dry.

Surface runoff is large and rapid in the eastern part of the area, where the gradient is steep, and is less rapid in the Gujarat Plain.

Most readily available ground water occurs under water-table and confined conditions in beds and lenses of sand and gravel in the alluvial plain. Movement of ground water is generally toward the rivers and contributes perennial flow to reaches of the larger streams. Fractured and decomposed parts of the trap rock yield small quantities of water.

The ground-water quality is generally good. However, tidal brackish water is in the lower 50 kilometers of the Narmada River, and saline water is in sand and gravel aquifers in this area.

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Water-Resource Development

Surface reservoir development is relatively small in this area. However, tanks are common where the surface is undulating, and several large reservoirs and diversion works are being constructed.

Considerable ground water has been developed by the State Tubewell Dictorate, CGWB, and others from the generally permeable alluvium. The largest yielding tube wells have been from an area paralleling the Narmada River and extending 25 kilometers north of the river and 8 kilometers south. Saline water underlies the area, and it is reported that concentrated development has brought encroaching saline water into the area. Most irrigation in the area is from dug wells and tube wells.

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Availability of Hydrologic Data

The State Tubewell Directorate, the Public Works Department, the CGWB, and the GSI have collected considerable data on the hydrology of the area. Streamflow is measured in the Narmada River and several tributaries. All surface-water records should be analysed. Additional stream gages are needed in the detailed study areas proposed by the Gujarat Design Organization. Accuracy standards need to be emphasized. Precipitation gages are well spaced throughout the area; however, additional gages are needed.

The Directorate of Agriculture maintains an inventory of several thousand dug-cum-bore wells, shallow dug wells, and tube wells. Several hundred tube wells have been developed by the State Tubewell Directorate and the CGWB.

Chemical quality of water data are available for many wells. However, additional data should be collected from aquifers to determine saline water areas and the possible migration of these areas toward areas of ground-water development.

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Factors Which May Limit Development

Local water-level declines, caused by improperly spaced wells and sustained heavy pumping, may dry up nearby dug wells or lower water levels excessively in tube wells.

Regional water-level declines, caused by pumping from confined aquifers, will lower the potentiometric surface and may induce the migration of saline water into previously fresh-water zones.

Clay soil may become waterlogged and saline if not properly drained and irrigated.

Increasing recharge to confined aquifers may not be feasible in all development areas.

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Study Objectives

1. Develop experience within the State organization and the CGWB to undertake system studies in assessing water supplies.

2. Develop techniques in making system studies of alluvial basins that have salt-water encroachment problems. Such techniques should be applicable to other coastal areas in India.

3. Estimate the quantity and quality of ground water that may be developed on a sustained basis. This study includes well spacing.

4. Determine ground- and surface-water relationships, emphasizing the recharge potential from surface-water sources.

5. Estimate potential for recharging confined aquifers with water from unconfined aquifers.

6. Investigate methods for restricting salt-water encroachment.

7. Improve techniques for developing wells in alluvium and testing aquifer characteristics.

8. Integrate ground-water and surface-water data needed to plan optimum use of water and the administration of water programs.

9. Develop a network of hydrologic monitoring gages to forecast effects of sustained pumping and the migration of saline water.

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Deccan Trap Area

Area of Study

The general area of Deccan Trap rocks to be studied in Maharashtra includes 13,000 square kilometers in parts of Satara, Sholapur, and Osmanabad Districts (fig. 1). This area is about 160 kilometers southeast of Poona.

Basins proposed for detailed study (about 8,000 square kilometers) are drained by the Sina, Man, and North Krishna Rivers. These south-flowing rivers are bounded by terraced and scarped mesas, or plateaus, that have flat tops.

Geologic Setting

Differential erosion of nearly horizontal lava flows, which dip gently eastward, have created the scarp topography. Compact basalt overlies softer varieties of Deccan Trap rock. Several large fault scarps dominate the topography.

The lava flows, which cover all of the study area, are described as 1) fine-grained massive basalt, 2) zeolitic basalt, and 3) red "bole"--an alteration clay. Individual flow sheets range from 3 to 32 meters in thickness. Clay and possible pyroclastic deposits of generally less than a meter in thickness separate some sheets.

The extent of weathering and the number and interconnection of joints increase locally the permeability and porosity of the poorly permeable basalt. The thickest weathering zone is in the zeolitic basalt in valleys. Massive and fine-grained basalt lacking joints and the red clay "bole" act as barriers to downward movement of water.

Joints and fractures are conspicuous and trend for long distances. Many tributary valleys appear to be oriented along major directions of jointing.

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Hydrology of Area

The average annual rainfall ranges from 50 to 80 cm, and most of the rain occurs in the monsoon season.

Storm runoff is generally rapid, and most stream reaches have only intermittent flows.

Ground water occurs under both water-table and confined conditions. The largest yields of ground water are developed from the upper weather part of the basalt. Permeabilities generally are low. Small yields of ground water for irrigation may be developed where joints are concentrated, especially in the zeolitic basalt. The massive fine-grained basalt may restrict deep percolation of ground water.

Ground water probably moves generally toward streams, following topography, and probably flows down the valley under the streambeds. Recharge is from precipitation, seepage from bunds, tanks and canals, and from the streams during periods of high flow. Contour bunds appear to effectively retain precipitation and increase recharge to ground water. Bunds adjacent to dug wells were reported to have increased water yields from wells.

The chemical quality of water is generally good. Water in confined aquifers should be relatively safe from contamination.

Water-Resource Development

Dug wells are the major source of irrigation water in the area. About 10,000 dug wells are used to irrigate an average of two crops per year. About 1,000 igph (imperial gallons per hour) of water are withdrawn from the average well, using bullocks to lift mhots containing 30 gallons. The Ground Water Survey, Agriculture Department, has been stressing renovation and improvements to existing wells.

Although few tube wells are used at present, the Agriculture Department has proposed developing 100 medium-duty tube wells. No tube wells have been drilled for assessing ground water in deeply-buried trap rock.

Canals supply water for irrigating about 20 percent of the agricultural area, and tanks supply water for about 2 percent of the area.

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Availability of Hydrologic Data

The GSI and the CGWB have carried out surveys and exploratory drilling of tube wells in many areas. The Agriculture Department has selected sites to construct medium-duty tube wells. It is also inventorying wells and estimating well yields.

Almost nothing is known about the occurrence of ground water at depth. Fractures and joints in the basalt may conduct water to deeper zones.

Rain gages are well spaced areally, but additional gages are needed for quantitative studies.

Monitoring of changes in ground-water levels and streamflows has been done in four areas, but considerable work remains to be done in the proposed study area. Surface-water records should be analysed before establishing new gages.

The number of aquifer and pumping tests is insufficient.

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Factors Which May Limit Development

Excessive pumping from improperly spaced wells in the trap rock and in the alluvium may dry up nearby dug wells or excessively lower water levels.

The probability of developing large sustained yields from deep wells in the Deccan Trap rock is small; however, exploration should fully test the possibilities. The probability of developing large yields of ground water is least in the fine-grained massive basalt and in the unweathered zeolitic basalt. The low storage capacity and irregular joint distribution limits chances of large water supplies. Well development methods may improve the yield of ground water. There is little chance for filtering of contaminants in fractured trap rock.

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Study Objectives

1. Develop experience within the State organization and the CGWB to undertake comprehensive studies in assessing water supplies in the Deccan Trap rock.

2. Develop techniques in making system studies of trap-rock basins, which will be applicable to the large areas of India that are covered with this rock.

3. Exploratory drilling should be used to determine ground-water availability at deep zones.

4. Estimate the quantity and quality of ground water that may be developed on a sustained basis.

5. Determine ground- and surface-water relationships, emphasizing the potential for inducing recharge.

6. Improve techniques for developing dug and drilled wells in trap rock and in testing aquifer characteristics.

7. Integrate ground- and surface-water data needed to plan the optimum use of water and the administration of water programs. This includes developing a network of monitoring gages to forecast changes in the hydrologic system.

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Crystalline Rock Area

Area of Study

The general area of crystalline rocks to be studied in Mysore includes about 10,400 square kilometers. This area is north of the city of Bangalore and is in the Tumkur, Koler, and Chitradurga Districts (fig. 1).

Two areas have been proposed for conducting detailed system studies--the North Pinakini River basin and the Vedavati River basin. Both basins are on the Kapuataka Plateau, which has large granite hills such as the Nandi Range. These two areas include about 8,000 square kilometers.

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Geologic Setting

Both the North Pinakini River basin, which drains mainly crystalline rock terrane, and the Vedavati River basin, which drains thin alluvium over crystalline rock, are representative of the hydrogeologic conditions over a large area. Much of the area consists of coarse to fine-grained gneissic and granitic types of rock, which are locally fractured and penetrated by dikes. Joints are conspicuous and trend for long distances.

Decomposed crystalline rock occurs over much of the area and is thickest in the valleys. In some places the decomposed rock exceeds 15 meters in depth. The permeability of this unconsolidated material may be small because of large clay content.

The North Pinakini River basin consists primarily of fractured and jointed granite with a relatively thick layer of decomposed granite in the valley.

The Vedavati River basin consists of 3 to 12 meters of coarse alluvial material overlying crystalline rock.

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Hydrology of Area

Rainfall averages about 65 cm per year, and most rain occurs during the southwest (June to September) and the northeast (October to December) monsoon seasons.

Storm runoff is generally rapid, and most stream reaches have only intermittent flows.

Ground water occurs throughout the area in joints and fractures in the granitic rock, in the decomposed granite, and in the thin alluvium in the valleys. Recharge is from direct precipitation, seepage from tanks and bunds, and from streams during period of flow.

Ground water moves toward the streams, following the general topography, and probably flows down the valley and under the streambeds in dry periods. Depth to water ranges from 1 to 20 meters, depending on topography and geology.

The potential for ground-water development is best in the alluvial material and decomposed granite in the valleys. Alluvium, however, may be thin in the valleys. Small yields of ground water may be found on slopes where joints are concentrated. There is little or no facility for deep percolation of ground water.

The chemical quality of ground water generally is good.

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Water-Resource Development

Surface waters are retained in tanks and bunds, but no large reservoirs have been constructed in the study area.

Most development of ground water is by several thousand dug wells that have large storage volumes. Drilling of several hundred small diameter wells to depths averaging 45 meters has resulted in yields ranging from 100 to 1,500 igph per well.

More than 70 percent of the wells used for irrigation have supplied water for more than one crop annually, and 27 percent of the wells have ~~yielded~~ supplied water for three crops.

Traditional types of water-lifting devices, such as the kapile, are used for the majority of irrigated land. However, the use of electric and oil engine pumps (air lift and turbine) is increasing.

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Availability of Hydrologic Data

The Ground Water Survey Unit of the Mysore Department of Mines and Geology has made many ground-water resource, geophysical, and irrigation evaluation reports of local areas. This unit has also inventoried wells in the area. The Bureau of Economics and Statistics recently completed a census of irrigation wells constructed in 1968-69. In addition, the CGWB and the GSI have considerable information on the area.

Rain gages are well spaced in the area, although additional gages are needed in the proposed study area.

Stream gages and seepage flow measurements are rare, and their number must be expanded.

Observation of changes in water levels have been made in a few wells, but this program must be accelerated.

The number of aquifer tests and pumping tests are insufficient.

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Factors Which May Limit Development

Excessive pumping from improperly spaced wells in the alluvium and decomposed granite may dry up nearby dug wells or excessively lower water levels in nearby tube wells.

The probability of developing large sustained yields from fractured and jointed granite having low storage capacity is small. Percolation ponds, contour bunds, and spreading areas may contribute recharge to local ground water, especially in areas of development. There is little chance for filtering of contaminants in the fractured rock.

Study Objectives

1. Develop experience within the State organization and the CGWB to undertake comprehensive system studies in assessing water supplies in granitic terrain.

2. Develop techniques in making system studies of granitic and alluvial basins that will be applicable to other granitic areas in India.

3. Estimate the quantity and quality of ground water that may be developed on a sustained basis. This study includes well spacing.

4. Determine ground- and surface-water relationships, emphasizing the potential for inducing recharge from surface sources.

5. Improve techniques for developing dug and drilled wells in granite and in testing aquifer characteristics.

6. Integrate ground- and surface-water data needed to plan the optimum use of water and the administration of water programs. This includes developing a network of monitoring gages to forecast changes in the hydrologic system.

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ASSESSING GROUND-WATER POTENTIAL

The proposed project will require detailed planning and continued management to meet all of the stated objectives. Recommended steps and subgoals for systematically assessing the quantity and quality of ground water that may be developed are given in table 1. Alternative methods also may be used to achieve the objectives of this project. Successfully completing the subgoals within the scheduled time will require the close coordination and cooperation of the Central Government and State agencies, USAID, countractual specialists in varied hydrologic fields, and their counterparts. Also required will be full integration and prompt release of ground- and surface-water information.

A work plan, table 2, which has been prepared for the proposed project, illustrates how these steps and the personnel's time and research can be coordinated and integrated to complete the study steps and meet the subgoals. This plan considers the full use of the geophysicist, quality of water hydrologist, and surface water engineer on each of four studies as well as their support activities with CGWB in New Delhi. Work units, such as the measurement of low flows of streams, have been adjusted to avoid the monsoon seasons.

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Table 1 - Steps for systematically assessing ground water

Phases of Study	Personnel[1/]
1. Field reconnaissance	All
2. Appraise, integrate, and interpret available GW, SW, QW data	L, H, S, Q
3. Hydrogeologic interpretation of aerial photos, soil maps, geology, etc.	H
4. Conduct geophysical surveys to detect bedrock configurations	G
5. Drill test holes - map hydrogeology	D, H
6. Install piezometers - determine recharge and discharge areas	D, H
7. Develop network of hydrologic monitoring gages	H, S, Q
8. Monitor changes in hydrologic system	H, S, Q
9. Determine chemical quality of water in various aquifers	Q
10. Perform field aquifer tests	H
11. Determine boundary conditions	G, H, L
12. Determine quantity and reach of stream loss and gain	S, H, L, Q, D
13. Determine extent of salt water encroachment	Q, H, L
14. Redefine ground-water basin	H, L
15. Determine hydrologic system from previous information	H, L
16. Estimate ~~safe~~ sustained yield and well spacing; model simulation may be used where feasible	H, L
17. Propose methods for increasing recharge	H, L
18. Propose methods for restricting salt water advance	H, L
19. Propose development alternatives based on systems analysis and on relative benefits	M, L, H
20. Final report	M, L, H

1/ Explanation of personnel

M - Project Manager and, if necessary, Assistant Project Manager

L - Team Leader

H - Hydrologist (for each study area)

D - Driller (for each study area)

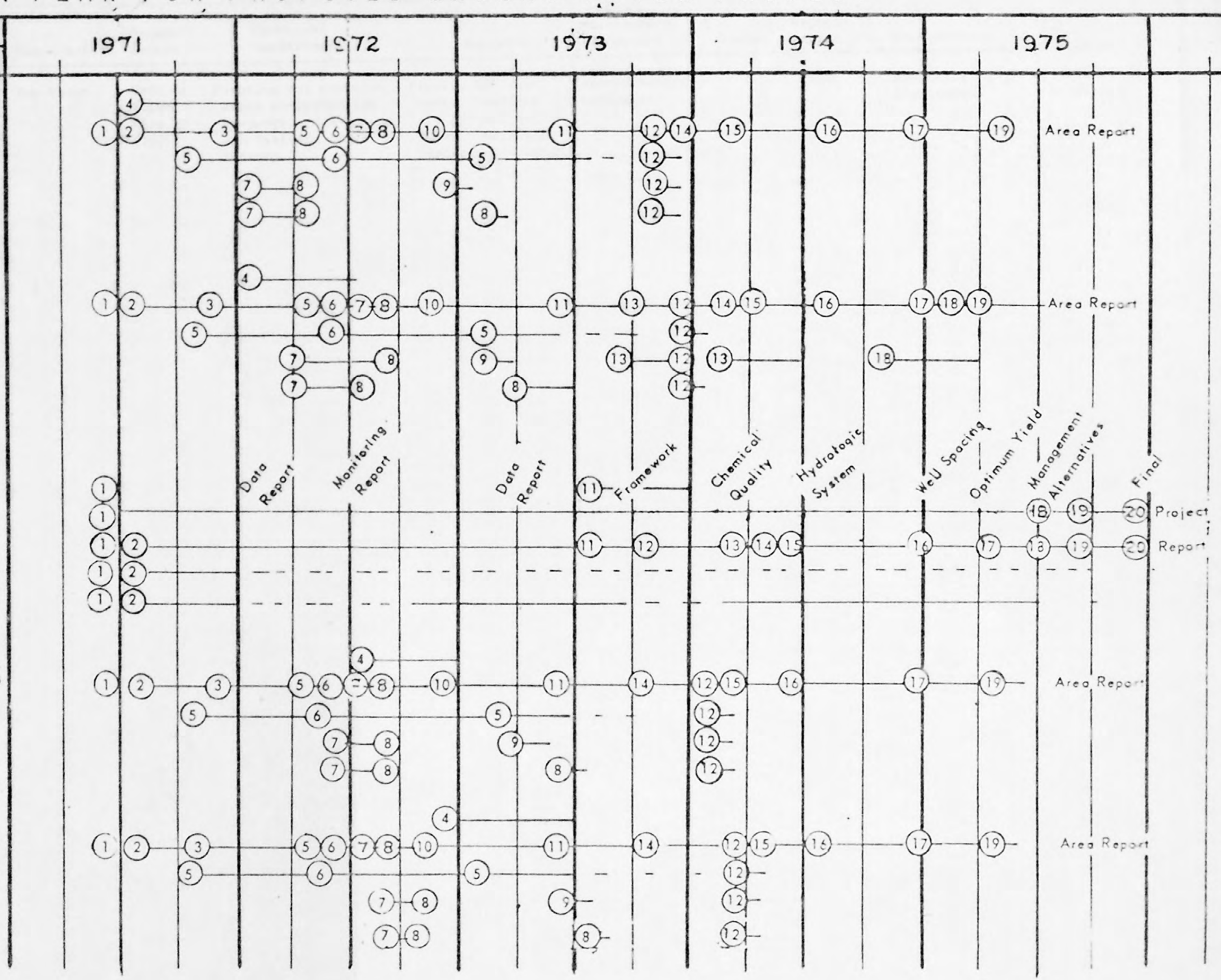
G - Geophysicist

Q - Quality-of-Water Hydrologist

S - Surface-Water Engineer

Table 2 - WORK PLAN FOR PROPOSED GROUND-WATER PROJECT

STUDY AREA	STATE	AREA SQ.M. SQ.KM.	PERSONNEL See table 1		USA	INDIA
Upper Narmada	Madhya Pradesh	5000 13000		(G)		
			GW Hydrol.	(H)	1	1-4
			Driller	(D)		1-3
				(Q)		
				(S)		
Lower Narmada	Gujarat	1500 4000		(G)		
			GW Hydrol.	(H)	1	1-2
			Driller	(D)		1-3
				(Q)		
				(S)		
Entire Project	Madhya Pradesh	12500 33000	Geophysicist	(G)	1	2-4
	Gujarat		Project Manager	(M)	1	1
	Maharashtra		Team Leader	(L)	1	1
	Mysore		GW Hydrol.	(Q)	1	2-4
			SW Eng.	(S)	1	2-5
Deccan Trap	Maharashtra	3000 8000		(G)		
			GW Hydrol.	(H)	1	1-4
			Driller	(D)		1-3
				(Q)		
				(S)		
Crystalline Rock	Mysore	3000 8000		(G)		
			GW Hydrol.	(H)	1	1-3
			Driller	(D)		1-3
				(Q)		
				(S)		



(1) - STEPS GIVEN IN TABLE 1

(G) - ABBREVIATION FOR SPECIALIST

FINAL - WORK UNIT COMPLETION - REPORT DEADLINE

PERSONNEL REQUIREMENTS

USA hydrologists (PASA or direct hire with USGS, or contract) of specialized backgrounds in comprehensive basin studies, ground-water assessment, geophysics, water quality, and surface-water studies, along with counterpart Indian hydrologists, should form an interdisciplinary team supporting the overall project. Their central headquarters could be in New Delhi to assist the CGWB in expanding technical skills and management experience as well as providing advisory services on an all-India basis.

Experienced USA hydrologists with expertise in the hydrology of alluvial basins, coastal alluvium and saline water encroachment, volcanic terranes, and crystalline rock terranes, would expedite ground-water quantitative assessment studies in the respective areas of Bhopal, Baroda, Poona, and Bangalore. Each USA hydrologist and his counterpart Indian hydrologist from the respective State, as well as a counterpart hydrologist from the CGWB, would compose a team responsible for ground-water assessment in the study areas. The team headquarters might be in a community in or near each study area that has a State ground-water organization.

The hydrologist-project manager and the three hydrologists specializing in geophysics, water quality, and surface-water studies should be appointed either through a PASA or direct hire with the U. S. Geological Survey. Short-term (TDY) consultants to provide supplemental training and evaluate project progress also should be provided by the USGS.

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The project leader and the four hydrologists proposed for assignment to the study areas would be supplied by USAID through an appropriate contractor or contractors. The contractor(s) should have extensive experience in ground-water development and management, as well as expertise in the special concerns of each study area.

Personnel requirements proposed for the project are summarized in table 3. Suggested organization of the personnel proposed for the project is given in figure 2.

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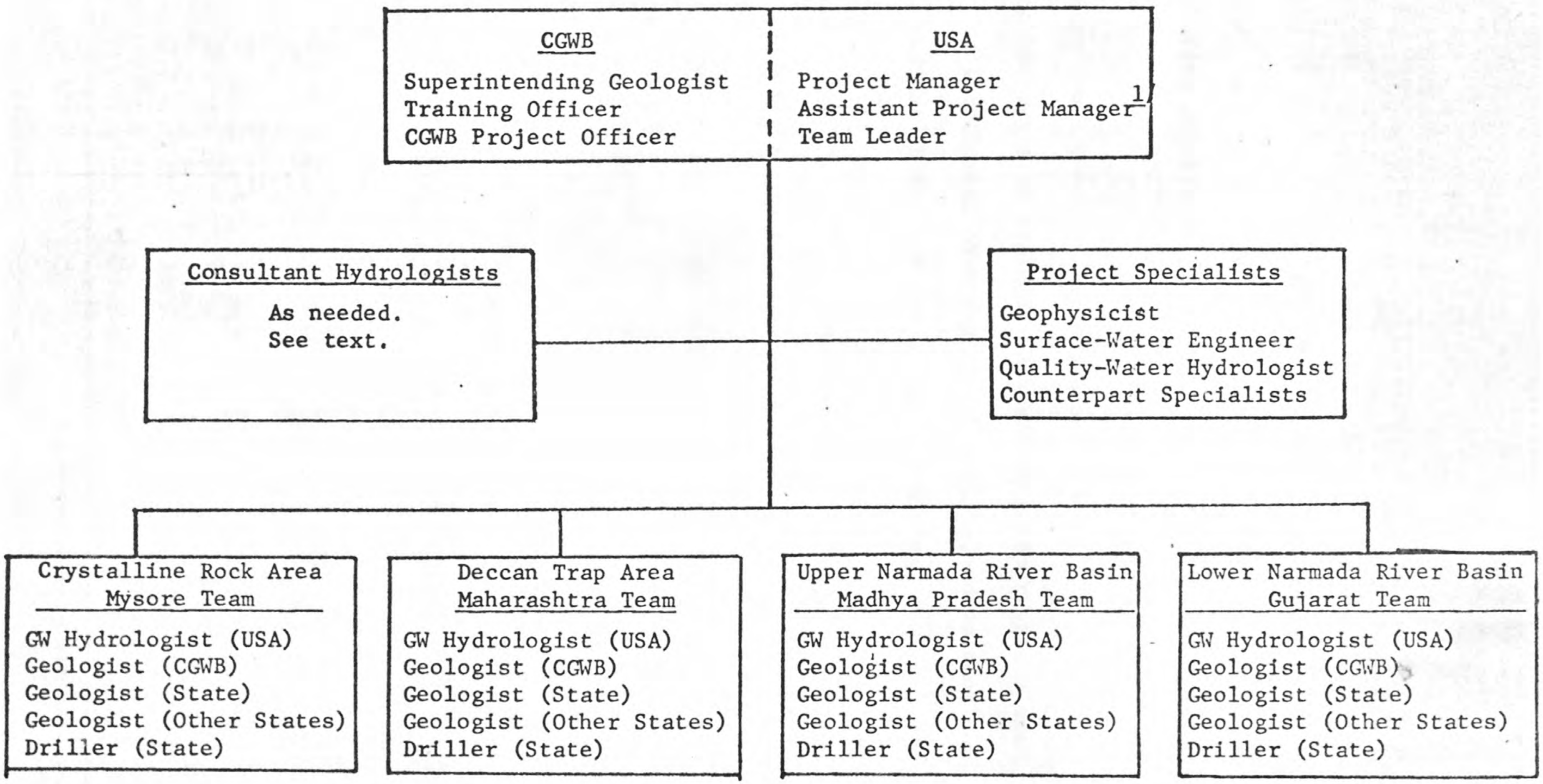
Table 3. Personnel Requirements Proposed for Project

U.S. personnel	Number	Years of duty 1/	Headquarters	Organization	Technical background	Duties	India counterpart personnel	Number	Organization	Headquarters	Years of duty
Project manager (M)- (hydrologist) 2/	1	4/71-12/75 4-3/4 yrs.	New Delhi	PASA or direct hire (USGS)	Planning and coordinating comprehensive projects. Management and training background.	Provide CGI support. Coordinate project activities. Maintain liaison with other organizations and agencies.	Superintending Geologist	1	CGWB	New Delhi (Faridabad)	4/71-12/75 4-3/4 yrs.
Team leader (L)- - - (hydrologist)	1	6/71-12/75 4½ yrs.	New Delhi	Contract	Conducting comprehensive systems studies emphasizing ground-water development.	Direct U.S. contract participants, coordinate project training, meet project goals, and prepare reports.	Assigned Officer for Project	1	CGWB	New Delhi (Faridabad)	6/71-12/75 4½ yrs.
Geophysicist (G) - -	1	6/71-12/73 2½ yrs.	New Delhi	PASA or direct hire (USGS)	Ground-water aquifer studies using seismic, electrical resistivity, and well-logging equipment.	Conduct geophysical studies and train personnel in all subareas.	Geophysicist	1 1-4	CGWB State	New Delhi (Faridabad) Study areas	6/71-12/73 2½ yrs.
Surface-water engineer (S)	1	6/71-6/75 4 yrs.	New Delhi	PASA or direct hire (USGS)	Quantitative surface-water measurements and statistical analysis of streamflow.	Establishing surface water and meteorologic stations, analyze data, measure seepage of streamflow. Train area personnel in surface-water techniques.	Hydrometeorologist (surface water)	1-2 4	CGWB State	New Delhi (Faridabad) Study areas	6/71-6/75 4 yrs.
Quality-water hydrologist (Q)	1	6/71-6/74 3 yrs.	New Delhi	PASA or direct hire (USGS)	Collection and interpretation of water-quality data for irrigation use. Experience in saline-water encroachment problems.	Water-quality monitoring in all areas, training in quality-water analysis and interpretation techniques.	Hydrologist (QW)	1-3 4	CGWB State	New Delhi (Faridabad) Study areas	6/71-6/74 3 yrs.
Ground-water hydrologist (H)	1	6/71-6/75 4 yrs.	Bangalore, Mysore	Contract	Hydrology of crystalline rock terrane. Ground-water system studies. Irrigation development.	Estimate quantity and quality of ground water available on a sustained basis. Develop experience of counterparts in system studies.	Geologist Driller	1 1 1-3 1	State CGWB Other States State	Bangalore Bangalore Bangalore Bangalore	6/71-6/75 6/71-6/75 As appropriate. As needed.
Ground-water hydrologist (H)	1	6/71-6/75 4 yrs.	Satara or Poona, Maharashtra	Contract	Hydrology of volcanic rock terrane. G-W system studies. Irrigation development.	Same as above.	Geologist Driller	1 1 1-4 1	State CGWB Other States State	Poona Poona Poona Poona	6/71-6/75 6/71-6/75 As appropriate. As needed.
Ground-water hydrologist (H)	1	6/71-6/75 4 yrs.	Bhopal, Madhya Pradesh	Contract	Hydrology of alluvial valley. Ground-water system studies. Aquifer tests. Irrigation development.	Same as above	Geologist or engineer Driller	1 1 1-4 1	State CGWB Other States State	Bhopal Bhopal Bhopal Bhopal	6/71-6/75 6/71-6/75 As appropriate. As needed.
Ground-water hydrologist (H)	1	6/71-6/75	Baroda, Gujarat	Contract	Hydrology of coastal alluvium. Ground-water system studies. Saline encroachment problems. Irrigation development.	Same as above.	Geologist or engineer Driller	1 1 1-2 1	State CGWB Other States State	Baroda Baroda Baroda Baroda	6/71-6/75 6/71-6/75 As appropriate. As needed.
Total- - - - -	9	34-3/4 yrs.						30-45			
Additional U.S. Personnel Suggested for Project							Additional India Counterpart Personnel Suggested				
Consultant hydrologist	1	1972-75, 1 mo. each yr=4 mo.	New Delhi	PASA (USGS)	Ground-water systems studies, management.	To review progress of work and make recommendations.	Geologist or hydrologist	2-4	CGWB		
Consultant hydrologists	3-6	1-3 mo. during special phases of project.	New Delhi	PASA (USGS)	Artificial recharge, model simulation, remote sensing, and other specialities as needed.	To give on-the-job training and to advise CGWB on special concerns.					

1/ The starting date depends upon project approvals, contractual negotiations, availability of personnel, and other factors.

2/ Assistant project manager (hydrologist) is recommended to coordinate training of personnel and institutions as well as assist project manager.

Figure 2.--PERSONNEL ORGANIZATION PROPOSED FOR PROJECT



1/ This position not necessary if project specialists are USGS.

TRAINING

The training of institutions and personnel in technical skills and management experience necessary for full development of India's ground water, is a major objective of the proposed project. Techniques and experiences acquired during the studies of the representative areas may be used to assess systematically the potential for ground-water development of large areas of India.

Among the types of training believed to be appropriate are organizational training, on-the-project training, consultant services, and USA short-term and academic training.

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Organizational Training

USA hydrologists having experience in planning, managing, and coordinating comprehensive ground-water studies can assist Indian organizations in developing management capability necessary to assure full application of technical input. This training assistance will strengthen Indian organizations to provide technical backup services to Indian states in effectively managing ground-water resources. Hydrologists serving as project manager, assistant project manager, and team leader will provide organizational training, as well as direct USA participation, in the project. Specialists in surface water, quality of water, and geophysics disciplines will provide training in the special skills and methods.

All of the above USA hydrologists may provide advisory services to the CGWB on an all-India basis during the period of the project.

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On-The-Project Training

Training opportunities will be provided for qualified hydrologists engaged in the project to gain special experience and competence. On-the-project training, by working as a team with USA hydrologists and skilled specialists, should develop, in the shortest possible time, the special experience needed to assess and manage ground water in representative areas of India.

Ground-water hydrologists having technical backgrounds in the geologic terranes and ground-water problems of the study areas will provide specialized training to Indian participants. This training will encompass many phases of hydrology related to comprehensive studies of ground-water resources. USA specialists in surface water, quality of water, and geophysics disciplines will expand the knowledge of Indian participants in special skills and methods.

Consultant Services

USA hydrologists having special skills in subjects such as system studies, artificial recharge, model simulation, remote sensing, and ground-water managemnt could spend 1 to 3 months in India consulting with the project teams. These consulting hydrologists would give supplemental training and provide on-the-project experiences directly pertaining to the geologic and hydrologic characteristics of the study areas. Such training would rapidly increase the skills of participant personnel and immediately benefit the project.

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USA Training

Participants requiring specialized training not available through the above proposed training program might spend 3-6 months in the USA, depending upon their hydrologic specialties and the experience required. Training assignments in subjects such as geochemistry, ground-water pollution, saline soils, well-logging techniques, model simulation, remote sensing, and well-field management should be related closely by an agency supervisor to specific work applications. The use of consultants for on-the-project training may satisfy the need for specialized training in the USA.

Participants requiring basic training in the fundamentals of ground-water hydrology should be proposed for academic training in a USA university recognized for its excellence in this field. The period of education should be for 1 to 2 years depending upon the academic background of the participant.

EQUIPMENT (COMMODITIES)

The CGWB and the States have acquired and are using a basic complement of well-drilling, well-development, and hydrologic-reconnaissance and testing equipment. However, additional specialized equipment will have to be obtained for the subject project (see commodities listed on p. 10-12 of Sub-project description 368.6). It is recommended that this equipment be obtained as soon as possible because much of the equipment requested will be required in the early phases of the study. However, the project manager and his counterpart should review and revise equipment needs at the earliest possible date.

TECHNICAL COORDINATION

A comprehensive systems assessment of ground water in four separate areas having diverse geologic terranes will require management skills, detailed plans, and coordinated studies. Close scientific communication should be established and maintained between agencies. Collaboration and frequent exchange of data and review of findings can be developed through a technical coordination committee.

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APPENDIX A

Chronology of Conferences and Field Inspections

by W. D. Romig and C. L. R. Holt

With Principal Conferees and Field Advisors

From October 28 to November 25, 1970

October 28 (Wednesday)

Arrival in New Delhi. Met by John T. Phelan, Chief of Soil and Water Management Division, USAID. Briefings by R. O. Olson, Agricultural Development; G. W. Evans, DP/P; and D. J. Burdon, FAO.

October 29 (Thursday) - Diwali - Holiday

October 30 (Friday)

Discussion of background information on sub-project with R. O. Olson and O. A. Bauman, Ag. Division.

B. B. Vohra, Joint Secretary, described the interests of the Ministry of Food and Agriculture, Community Development and Cooperation, in the sub-project and discussed the plans for a field inspection. J. K. Jain and K. V. Raghava Rao of Vohra's staff and J. T. Phelan were present.

Visited ETO office at Faridabad for background in related work.

October 31 (Saturday)

Discussions with Dr. Bert Krantz, Dr. Doneen, and Mr. D. A. Williams about Ford Foundation activities in ground-water development and relationships to the proposed project.

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November 1 (Sunday)

Conference with AID staff members on Capital Development Irrigation Sector loan.

November 2 (Monday)

New Delhi to Bangalore by air. Met by J. S. Kanwar and Donald W. Haslem.

Reviewed ground-water development and irrigation in Tumkur area with B. P. Radhakrishna, Director of Department of Mines and Geology, and his staff. G. V. K. Rao, Secretary of Agriculture and Economic Development, and D. W. Haslem, PASA, Bellary, were present.

November 3 (Tuesday)

Visited dug and tube wells in north Pinakini River basin. Inspected exposures of weathered and fractured granite.

November 4 (Wednesday)

Visited dug wells and granite exposures in and around Bangalore and conferred with B. P. Radhakrishna and staff on ground-water problems and needs for increased development and management of ground water.

W. Romig travelled by car to Bellary to review pilot project and see ground-water development in Vedavati River valley.

C. L. R. Holt travelled by air to Poona. Met by Glenn Ellithorpe and N. R. Tankhiwale.

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November 5 (Thursday)

R. Venkataraman, Chief Geologist, Agriculture Department, described hydrologic and geologic studies in Satara-Pandharpur area. T. S. Raju, Senior Hydrologist, Central Ground-Water Board, was present.

Visited GSI office and discussed geology and ground-water development with Kedar Narain, Director, and his staff.

Departed by car for Satara with visits enroute to wells and inspection of exposures of Deccan Trap rock in Katraj and Khandala Ghats.

Discussions in Satara with S. R. Patil and D. D. Jadhab, divisional Soil Conservation officers.

November 6 (Friday)

Departed Satara by car for Pandharpur with visits to wells and examinations of geology along Satara-Padharpur Road.

Returned to Poona along Pandharpur-Poona Road with further visits to wells. Glenn Ellithorpe left by plane for New Delhi.

Conference with R. Venkataraman and his staff on data collection, water problems, and needs for ground-water development in the proposed project area.

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November 7 (Saturday)

To Bombay by air with R. Venkataraman. Rejoined W. Romig in Bombay.

N. G. Abhyankar, Development Commissioner and Secretary of General Administration Department, discussed the needs to increase the development of ground water in the State and expressed support of proposed project and strong interest in state participation in training activities.

November 8 (Sunday)

Left Bombay by air for Bhopal. Met at airport by G. G. Puri, Director of Tubewells, and M. M. Mahodaya, Executive Engineer.

November 9 (Monday)

M. S. Choudhary, Production Commissioner; S. B. Lal, Secretary of Irrigation Department; R. V. Ramakrishna, Joint Director of Irrigation Department; G. G. Puri, Director of Tubewells; and K. V. Raghava Rao, Superintending Geologist, Central Ground-Water Board, described studies and data collection in the Narmada basin. Development of tubewells has been limited (460 meter spacing of wells) because of concern of declining levels. Mr. Choudhary expressed interest in having project director located in Bhopal and state participation in project.

Detailed discussions were later held with G. G. Puri and staff on tubewells program, methods of well development, and ground-water conditions in area.

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November 10 (Tuesday)

The field party travelled by car from Bhopal to Bari to Bareli inspecting shallow (30-60 meters) tube wells in the villages of Ahmedpur, Kutuasir, and Bareli. Yields from these wells ranged from 3,000 to 1,500 igph. Each farmer reported irrigation increased yields from 200 to 250 percent over unirrigated yields.

Via Bareli to Hoshangabad via Obedulaganj, the team visited shallow and P. H. E. wells in the Hoshangabad District.

Inspected department rig at Dolaria and low flow of Hator River.

November 11 (Wednesday)

Hoshangabad to Piparia. Inspected several tube wells and observed test of Suwakhedi Exploratory Tubewell (Central Ground-Water Board). The well completed to depth of 85 meters yielded 45,000 igph. Also visited shallow wells in Bankhedi Block where rice is a new crop.

Observed Tawa Dam site and discussed possibilities of reservoir water recharging ground water in Narmada basin.

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November 12 (Thursday)

Inspected Tubewell Subdivision Workshop at Piparia.

Demonstrations were made of converting reverse rotary to rotary in a drilling rig and experiments were viewed of different types of well screen.

Piparia to Jabalpur by railroad. Inspected Khirkhakheda deep (45 meters) tubewell which had reported discharge of 52,000 gph. Visited Bhedeghat area to see fractured and metmorphosed marble rock.

November 13 (Friday)

Returned to Bhopal from Jabalpur by railroad.

Met with Madhya Pradesh state officials to discuss field observations of ground-water development and management possibilities of proposed project.

J. F. Mistry, Superintending Engineer of Central Designs Organization, and S. C. Sharma, Geohydrologist of Ground-Water Division, described the ground-water studies being made by the State of Gujerat. Separate and detailed discussions of saline water encroachment and well interference problems were held during the Bhopal to Jabalpur field trip.

Returned to New Delhi by air.

November 14-15 (Saturday and Sunday)

Prepared brief trip report and reviewed information collected in the field and reports prepared by the States of Mysore, Maharashtra, Madhya Pradesh, and Gujarat.

November 16 (Monday)

Briefing of Jack Phelan on results of field trips.

Discussion with B. B. Vohra, Joint Secretary; K. V. Raghava Rao; and others of Mr. Vohra's staff on field trip observations and comments on water problems, water development, and possible water management schemes in proposed project areas. Agreement was obtained to consider Gujarat, part of Narmada basin, as special study area. Comments were made regarding the state and Central Ground-Water Board roles in the proposed study as well as on the need to provide training of state personnel in special studies conducted in other states.

November 17 (Tuesday)

Romig and Holt were interviewed by a reporter (The Statesman) for a New Delhi newspaper and for the Voice of America.

A conference was held with L. J. Saccio, Mission Director for AID, and staff members to acquaint them with the team's observations on the proposed project.

W. Romig left New Delhi enroute to Dacca.

November 18 (Wednesday)

J. K. Jain, Joint Commissioner of Minor Irrigation, and C. G. Desai, Deputy Commissioner, discussed with U. S. Madan, AID, and C. L. R. Holt the role of the Central Ground-Water Board and the development of ground water in the proposed project areas. Comments were made regarding water problems, training of state and CGWB personnel, and the need for the proposed quantitative studies.

November 19-24

Preparation of draft of technical report.

November 25 (Wednesday)

C. L. R. Holt left New Delhi enroute to USA.

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APPENDIX B

Agency Representatives and Others

Contacted While Reviewing the

Proposed Project

Central Government

Minstry of Food, Agriculture, Community Development and Cooperation

B. B. Vohra, Joint Secretary

J. K. Jain, Joint Commissioner, Minor Irrigation, Central Ground-Water Board

M. P. Pandey, Superintending Engineer, CGWB

K. V. Raghava Rao, Superintending Geologist, CGWB

L. N. Laddha, Under Secretary, MFA

Government of Mysore

G. V. K. Rao, Secretary of Agriculture and Economic Development, Bangalore

B. P. Radhakrishna, Director, Department of Mines and Geology, Bangalore

S. Jithendra Kumar, Drilling Engineer, Department of Mines and Geology, Bangalore

G. H. Nagaraja, Geologist, Department of Mines and Geology, Bangalore

R. Sampathkumaran, Director, Bureau of Economics and Statistics, Bangalore

M. S. Bhat, Geophysicist, Department of Mines and Geology, Bangalore

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