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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLANNING REPORT FOR AN INVESTIGATION OF GROUND-WATER POTENTIAL IN THE MAHAWELI BASIN, SRI LANKA

By Richard H. Johnson

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PLANNING REPORT FOR AN INVESTIGATION OF GROUND-WATER POTENTIAL IN THE MAHAWELI BASIN, SRI LANKA

By Richard H. Johnson

ABSTRACT

The area of eastern Sri Lanka designated by the Sri Lankan Ministry of Mahaweli Development as Mahaweli Systems A, B, C, and D has limited ground-water potential as no really productive aquifers are known to exist. Most wells tapping the shallow bedrock of gneiss and granite yield less than 5 gal/min; a few yield 25 to 50 gal/min. The lower yielding wells can be provided with a hand pump and are adequate to service a few families. On the other hand, the 25 to 50 gal/min wells equipped with power-driven pumps can provide water supplies for villages of 500 to 1000 people or can be useful for irrigation of vegetable gardens. Through the use of geologic field reconnaisance, airphoto analysis and surface geophysical surveys, successful techniques for locating sites for high-yielding wells probably can be developed. The Water Resources Board (Ministry of Lands and Land Development) has utilized such methods for selecting drilling sites in the current UNICEF well program in an area east of the Mahaweli Ganga designated as System B. However their site selections have been constrained by the very limited areas within which a well must be drilled and also by the lack of incentive to provide wells yielding more than a few gallons per minute.

This report describes a program for assessing the ground water potential of Mahaweli Systems A, B, C, and D utilizing geology, surface geophysics, ground-water hydraulics, and an exploratory drilling program. The proposed study will be especially concerned with site selection techniques for high-yielding wells. The work will be a cooperative effort between the U.S. Agency for International Development and the Sri Lanka Water Resources Board.

This project has been designed as a modest effort initially that will concentrate on System B with reconnaisance level studies and limited exploratory drilling in Systems A, C, and D. It has been purposely kept small because it is not certain that a successful technique for optimizing site selections of high yield wells can be developed. If a successful technique is developed and if there is a real demand for high-yielding wells for village water supplies and small plot irrigation, this project can easily be expanded. Such expansion would primarily involve a larger drilling program and more training for the Sri Lankan project staff.

INTRODUCTION

Background

The area of interest is in north-eastern Sri Lanka and encompasses that part of the Mahaweli Development Program known as "Systems A, B, C, and D" (figure 1). The proposed investigation will emphasize System B with less intesive work in Systems A, C, and D. An important phase of the Mahaweli Program is the settling of new farm families within this area when irrigation canals are completed. The settlement program has begun in System B and ultimately will involve 110,000 people. The new villages require the development of on-site water supplies, logically wells. Traditionally villagers have obtained water from tanks (small impoundments), canals, or shallow dug wells, all of which have contributed to the high incidence of water-borne diseases. Deep drilled wells that can be provided with sanitary seals are the logical alternative.

In general, this area can be considered as "ground-water poor." No extensive or highly productive aquifers are known to exist. However, water supplies adequate for the domestic needs of a few families can generally be obtained from shallow dug wells in the overburden or from shallow bore holes tapping the underlying crystalline rock (most gneiss). A few of these boreholes provide yields in the range of 25 to 50 U.S. gal/min (100 to 200 L/min). Such yields would be adequate to provide public water supplies for villages of 500 to 1000 people. Wells providing these higher yields comprise perhaps 10 percent of the drilled wells to date and tap fractured zones in the crystalline rocks. The Sri Lanka Water Resources Board (WRB) reports that they have been successful in locating fractured rock with hydrogeological reconnaissance techniques and surface geophysics techniques and thus have improved upon random well site selection. The Water Supply and Drainage Board (WSDB) has used similar hydrogeological techniques to select well sites.

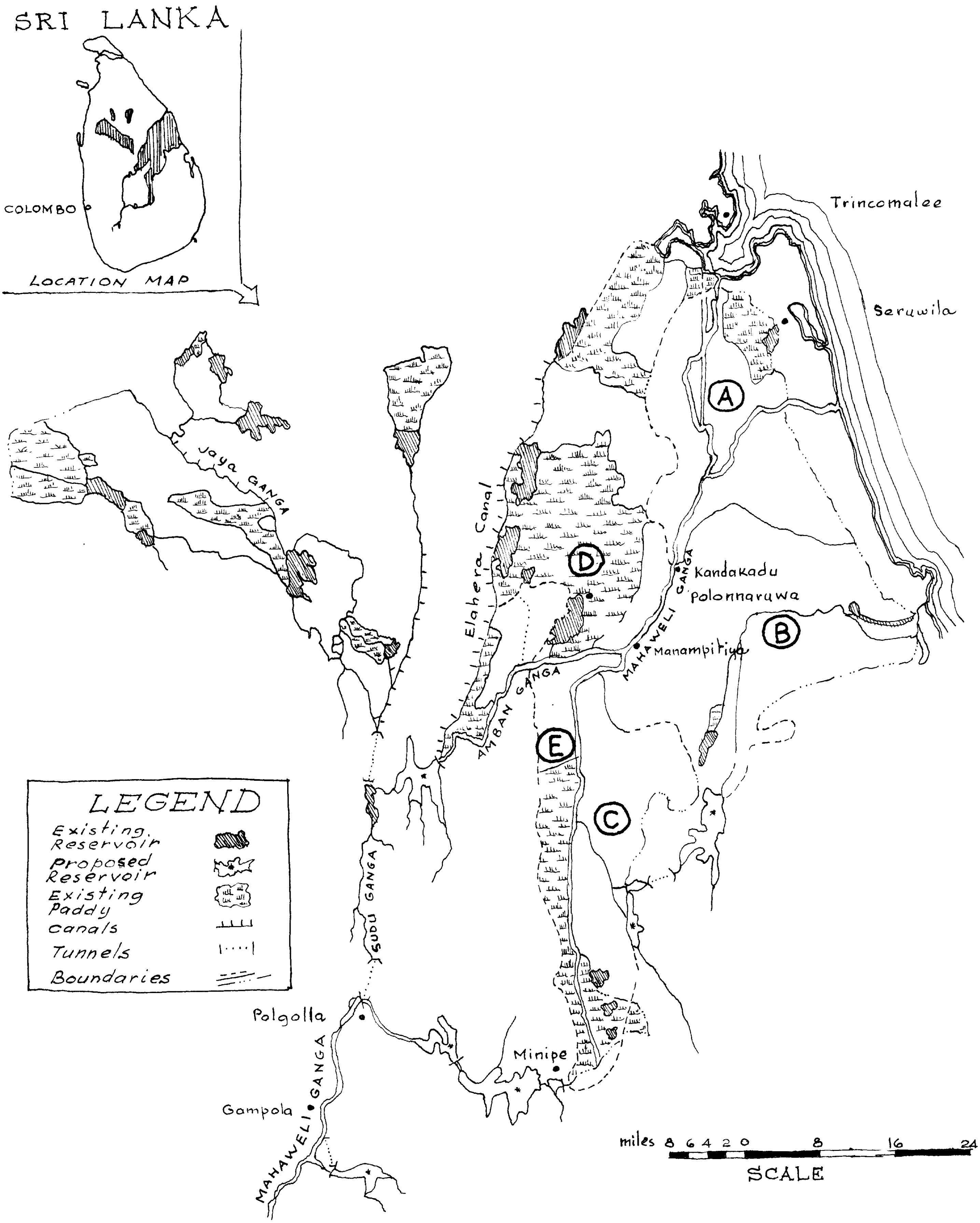


Fig. 1 Location of Mahaweli development program, Sri Lanka (adapted from map by Ministry of Mahaweli development, 1978).

This report outlines a program for assessing the ground-water potential of the area. The program would involve a hydrogeologic analysis of the area utilizing geology, geophysical surveys, exploratory drilling, and the quantitative methods of ground-water hydrology (aquifer test analysis, base streamflow studies, and the like). The study would be especially concerned with the problem of locating and developing moderate-size ground-water supplies in the area, or alternately to determine that such supplies are not available. An important aspect would be application of various hydrogeological and geophysical techniques for optimizing well site selection. An exploratory drilling program would be used to evaluate the success of various approaches. High-yielding wells would, of course, be available for local use following testing. The study would be done cooperatively by the U.S. Agency for International Development (USAID) and the Water Resources Board (WRB) of the Sri Lankan Ministry of Lands and Land Development.

This report was prepared during a 1-month assignment by the writer in Sri Lanka in August-September 1984. The purpose of the assignment was to prepare a scope of work for a ground-water feasibility study in Systems A, B, C, and D of the accelerated Mahaweli Development Program. The work was supported by an interagency agreement between USAID and the USGS. During the writer's visit, he worked directly with the Water Resources Board of the Government of Sri Lanka. This report, which presents the scope of work of a proposed ground-water study, is based largely on discussions and field trips with WRB staff and USAID staff, plus a review of existing hydrogeologic data and reports.

Hydrogeologic Setting

As in most areas of extensive crystalline rock, there are no really productive aquifers in the area of Systems A, B, C, and D. The alluvium bordering the Mahaweli Ganga is generally less than 30 ft (10 m) thick but has promise of providing moderate well yields. The crystalline rocks are predominantly gneisses and the key to obtaining higher than average well yields is to identify areas where the density of joints and fractures is highest. Zones with a higher density of fractures reportedly are most likely to occur in the granitic gneiss and at the contact between different rock types (such as gneiss adjacent to pegmatite). In System 'B', the crystalline rock reportedly has a weathered zone about 10 to 20 feet (3 to 6 m) thick and overlying that, a sandy-clay overburden about 10 to 13 feet (3 to 4 m) thick. However, the writer observed many areas where slightly weathered rock is much nearer land surface. Reportedly most fractures occur in the upper 66 feet (20m) of rock; since wells are rarely drilled below 130 feet (40m) this conclusion is uncertain.

Yields from shallow bedrock wells (average depth: 100 to 130 ft (30 to 40m)) are generally in the range of 1 to 5 gal/min (0.06 to .3 L/s) with perhaps 10 percent of the wells yielding more than 25 gal/min (1.5 L/s). Transmissivities are low; average estimated values are about 40 to 50 ft^2/d (4 to 5 m^2/d) for the gneiss with highest values about 200 ft^2/d (19 m^2/d).

Ground-Water Agencies in Sri Lanka

Capabilities and Role of the Water Resources Board

The logical agency of the Sri Lanka government to work cooperatively on the project is the Water Resources Board (WRB) of the Lands and Land Development Ministry. In addition to having produced the only comprehensive hydrogeologic reports to date, they have a large drilling section.

A. G. N. Wijesekere, Deputy General Manager (Ground Water), directs all of the WRB's ground-water activities. He and S. Basanayake are fully qualified hydrogeologists both having received graduate degrees in England. WRB's scientific staff includes 3 hydrogeologists, 9 geologists, 6 geophysicists, 2 chemists, and 6 civil engineers. The geophysics section is headed by K. Wijesinghe, an experienced geophysicist. At present most of their field work involves resitivity surveys and very low frequency (VLF) profiling. Their equipment was purchased on the advice of Adel Zohdy of the U.S. Geological Survey who visited them in 1980. They also have electromagnetic geophysical and seismic refraction equipment.

The drilling section includes 15 drilling rigs, 13 Japanese and 2 Swedish. Most of the drilling is for production wells and they average about 600-700 wells per year. Site selection for the wells is made (within restrictions) by the geophysicists and geologists.

WRB has a laboratory for chemical analyses of water samples; K. Dharma-wardhana, is chemist-in-charge. They regularly analyze for the principal ions (Na, K, Ca, Mg, Fe, Cl, HCO_3, SO_4 and F) plus total dissolved solids and alkalinity. Field measurements are made of conductivity but not PH or alka-linity. The lab can also analyze for trace metals but not organics and they do not do bacterial counts.

As mentioned earlier, the author observed a 6-hour pumping test on a high-yielding well at 46+ U.S. gal/min (2.9 L/s) located in System B. He was accom-panied by M. Millerithranachi, an experienced engineer who is well versed in pumping-test techniques. The need for maintaining a constant pump discharge and for making logarithmically spaced water-level measurements was understood by him and the well-site geologist. Both were familiar with the standard Theis and Jacob methods of test analysis. However, some equipment problems were evident. Although both a flow meter and orifice set up were on site, neither could be used for flow measurement because of missing parts. An electric water-level indicator malfunctioned during the test and there was no backup indicator or steel tape (except my own) on site for making drawdown measurements.

The WRB's hydrogeological reports are comprehensive and generally include geologic logs, well construction details, hydrogeologic maps, aquifer test analyses, chemical analyses, and the like. However, full analysis and interpretation of the information presented is sometimes lacking (example: failure to relate mapped fracture traces to well yields or transmissivity in the Kurunegala report).

Activities of the Water Supply and Drainage Board

The Water Supply and Drainage Board (Ministry of Local Government, Housing and Construction) is the largest well drilling agency in Sri Lanka, having completed nearly 1,000 wells last year. Some of their wells are drilled by private contractors. At present the Board has 7 drilling rigs (down-hole hammer type) and is to receive an additional 16 rigs (Japanese and Swedish) later this year. The Board is oriented towards well production rather than hydrogeologic investigations.

The hydrogeological activities center around Dr. K.V.R. Rao, a hydrogeologist with the World Health Organization assigned to the Board for the past 5 years. Dr. Rao's primary task has been the training of the Board's geologists in ground-water techniques. At present, the Board has 6 geologists; none of whom have university training in hydrogeology or geophysics. Dr. Rao advises these geologists and gives them on-the-job training. Selection of drilling sites is reportedly made from inspection of air photos, local geology, and land forms. Resistivity surveys are rarely used.

The Board has well organized files of well data and logs and currently is beginning to enter these data into computer storage, having recently acquired an HP-85 computer. They have a chemical laboratory that analyzes for major ions and bacteria but not trace metals nor organics. Although the Board has not yet prepared any reports on the hydrogeology of crystalline rock areas, they are currently compiling a series of 10 case histories of water supplies in such areas.

PREVIOUS STUDIES AND AVAILABILITY OF DATA

Crystalline Rock Investigations Throughout Sri Lanka

An overall summary of the ground-water resources of Sri Lanka is presented in a 1973 report by Fernando. Brief descriptions of the various hydrogeologic terrains in the country are given and ground-water recharge rates are calculated for the various climatic and geologic terrains. These rates are based on a certain percent of the mean annual rainfall infiltrating to the water table. However, the percentages are derived from rock terrains in India and are open to question. Even so, this report provides a general introduction to the ground-water situation in Sri Lanka.

The most comprehensive hydrogeologic investigation of crystalline rocks undertaken to date is probably an appraisal of the Kurunegala District, west central Sri Lanka, by Singh and Jayasena of the Water Resources Board, 1984. This investigation was supported by the World Bank and the report is currently available in final draft form. Detailed description of the crystalline rocks and the exploratory drilling program are presented. Hydrogeologic data including well-yields, specific capacities, and aquifer transmissivities are presented in tables. Aquifer test analyses utilize the standard Theis and Jacob methods. Of the 97 exploratory wells drilled, 22 percent obtained yields exceeding 25 U.S. gal/min (1.6 L/s). Well site selection was based on geomorphology, geologic structure and surface geophysics (very low frequency and resistivity profiling). Landsat imagery was used to map lineaments (surface fracture traces). Plate 9 of this report contains a very informative hydrogeologic map of the Dandagamua area showing the alignment of high-yielding wells and high transmisivities along the fracture traces. Unfortunately this relationship is not discussed in the text.

The first full scale hydrogeological investigation in a hard rock area conducted by the WRB was in the Hambantota District located on Sri Lanka's south coast (Silva, 1984). The study was funded by NORAD (Norwegian AID). This is an area predominantly underlain by gneiss and well yields are similar to those in System B and C areas; namely 1 to 10 gal/min (0.06 to .6 L/s) with a few wells in the 20 to 40 gal/min (1.3 to 2.6 L/s) range (Silva, 1984, and Nash and Basanayake, 1979). The report includes geologic data, water-level hydrographs, aquifer test analyses, and various hydrogeologic maps. The area has very low potential for potable ground-water development because 60 percent of it has saline water. Selection of drilling sites was based on landforms, geology, local dug-well information, and surface geophysics.

An interim report (unreferenced here) on the Puttaklam district on Sri Lanka's west coast was prepared by WRB with funding from the World Bank. The report presents a brief description of the hydrogeology in the area which includes sand and limestone as well as crystalline rock aquifers. A later report is to cover pumping tests.

In addition to the reports mentioned above, geologic logs, well data, and other basic data are available for many areas in the files of the WRB. Streamflow records, possibly useful for the base flow studies to determine ground-water recharge rates and to estimate gross aquifer properties, are collected and compiled by the Irrigation Department (Hydrology Division). Their interest is in high flows and they plot hydrographs only for flood peaks. However the daily discharge values are in files and yearly hydrographs could be plotted manually. No data is in computer storage. An 18 volume report on surface water hydrology of the Mahaweli has been prepared by NEDECO (Netherlands International Technical Assistance Department). This report also places emphasis on medium to high flows.

Mahaweli Basin - System B and C Area Studies

The only hydrogeologic report on System B has been prepared by Louis Berger, IECO and RDC (1982). This report states that hornblende biotite gneiss is the most common rock type and also the least permeable. The report concludes that development will require many wells, each with relatively small capacities. The report discusses siting criteria for wells (rock type, topography, thickness of overburden, etc.) but does not recommend areas where favorable criteria exist. Overall, this is a generalized report and lacks well logs or pumping test data. The principal contribution of the report is a geologic map of the area.

A report by Acres Limited (1979) describes the surface water hydrology of System B, however, only flood flows are discussed.

A fairly comprehensive report of the hydrogeology of System C has been prepared by the WRB (Nash and Basanayake, 1979). The report contains a geologic map for those parts of the area where villages and townships are to be established. A detailed discussion of jointing intensity in the crystalline rocks is presented. The report concludes that jointing is 6 times as great in the granite gneiss as in the hornblende-biotite gneiss. This is further borne out by the aquifer transmissivity data presented (based on slug tests). Frequency distributions of transmissivity suggest average "T" values of 22 and 65 ft^2/d (2 to 6 m^2/d) for biotite gneiss and granite gneiss respectively. The top 10 percentile had "T" values of 54 and 173 ft^2/d (5 to 16 m^2/d). Wells tapping rock with these higher values would provide yields in the 20 to 40 gal/min (1.3 to 2.6 L/s) range (depending on available drawdown).

The System C report also notes that alluvial deposits extending about one-half mi(0.8 km) on either side of the Mahaweli Ganga are "important aquifers", however, no specifics are given. Resistivity profiles suggest thicknesses of alluvium ranging up to 66 ft (20 m). The report also presents a tabulation of chemical analyses indicating that the chemical quality of the ground-water is good.

No hydrogeologic reports have been prepared to date on Systems A and D.

UNICEF Drilling Program in System B

The UNICEF supported drilling program involves construction of 200 village wells equipped with hand pumps in System B. Of these, 100 wells are to be constructed by WRB and 100 by the Water Supply and Drainage Board (in part by private contractors). Because the aim is to obtain yields sufficient for hand pumps (slightly more than 1 gallon or 5 liters per minute) there is no incentive to attempt to obtain higher yields. Even so, the WRB has been utilizing geologic and geophysical techniques to optimize well-size selection. To date (August 27, 1984) the WRB has completed 24 of its 100 wells. The Water Supply and Drainage Board was to have begun drilling in September 1984 and a private contractor (Kampsax-Kruiger) had completed 4 wells on behalf of the board.

Of the 24 wells drilled by the WRB, 3 have yielded 20 to 30 gal/min (1.3 to 1.9 L/s); the remainder have generally yielded less than 5 gal/min (0.3 L/s). The following criteria have been used for well site selection:

(1) geomorphology and topography; valley areas are preferred

(2) information on dug wells in the area from villagers

(3) consideration of rock types; granite gneiss and quartzite are preferred over biotite gneiss. Also preferred are fracture zones at contracts between rock types (example: gneiss and pegmatite)

(4) Surface geophysics; very low frequency and resitivity profiling to identify preferred areas (resistivity lows).

In selecting well sites, the given area in which a well is to be drilled is small (2 or 3 acres), thus optimum use of geology and geophysics cannot be made. Air photos and Landsat imagery have not been used by the WRB because of the limited area available for site selection.

The author observed pumping from a high-yielding well where the drilling site had been selected on the basis of geophysics (low resitivity) and geology (granite-biotite gneiss contact). This well was pumped at a rate of 46 U.S. gal/min (2.9 L/s) for 6 hours (drawdown at least 27 ft or 8 m). Such a well could provide the water supply for a village of 500 people with installation of a deep-well pump.

In summary, the drilling program in System B does not provide a true evaluation of the ground-water potential because the UNICEF program requires only low-yielding wells and because of the restricted area available for well site selection.

PROPOSED GROUND-WATER INVESTIGATION

Objectives

The basic purpose of the prospective investigation is to evaluate the ground-water potential of Mahaweli Systems A, B, C, and D. Emphasis is to be placed on System B with work in Systems A, C, and D to proceed at a reconnaisance level. The study will require innovation due to the widely varying water-bearing characteristics of the crystalline rocks in the area. The approach will involve geologic field studies, surface geophysics, photo interpretation (fracture trace analysis), hydrologic studies including aquifer test analyses and base flow studies, plus an extensive exploratory drilling program. The project will be especially concerned with assessing the feasibility of obtaining moderate size ground-water supplies of 25 to 100 gal/min (1.6 to 6.3 L/s) in an area of generally low well yields. To achieve this, the USAID contractor staff will work with the WRB in developing the methodology for optimizing the selection of well sites.

The USAID contractor will provide consulting to the WRB throughout the project in the areas of surface geophysics and test drilling techniques as well as all facets of hydrogeology. Training for staff of the WRB in specialized areas will be arranged in the United States as needed (examples: short courses in surface geophysics techniques and aquifer test analysis).

Finally, a comprehensive report on the hydrogeology of System B with reconnaissance-level descriptions of Systems A, C, and D is to be prepared that will emphasize the potential for developing moderate-size ground-water supplies.

Approach -- Major Work Items

This project must be considered experimental because the permeability of the crystalline rocks may simply be too low to provide moderate well yields (25 to 100 gal/min) except in scattered localities. The intent is to try a variety of geological/geophysical techniques so that if the permeability is sufficiently high, a successful method of selecting sites for high-yielding wells will be found. Because the success of the project is uncertain, staffing and estimated costs are relatively small. If the project is succesful in developing the desired methodology, the project could easily be expanded. The expansion would be largely in the exploratory drilling activities and to a lesser extent in the hydrogeological and geophysical aspects. An expanded project might include the entire Mahaweli Development areas of Systems A through H. Actually, if successful, the methodology developed could be applied throughout the crystalline rock areas which characterize most of Sri Lanka.

Hydrogeologic Studies

The hydrogeologic studies should include the approaches described here but not necessarily be limited to them. As the project progresses, undoubtedly some techniques will be discarded and ideas for other techniques will develop.

However, the objectives should be: (1) improving upon well-site selection in the crystalline rock areas, (2) determining the hydraulic properties of the crystalline rock and alluvial aquifers, and (3) assembling and analyzing all the existing and newly collected data into an evaluation of the ground-water potential in System B and to a lesser extent in Systems A, C, and D.

In the United States as well as Sri Lanka, it has long been known that there are several indirect indicators of high fracture permeability (and thus above-average well yields) in crystalline rocks. These indicators are as follows:

(1) topography and drainage: valleys are preferred over uplands, especially the linear valleys associated with rectangular and trellis drainage styles (Cressler and others, 1983)

(2) lithology: granite gneiss and quartzite, for example, tend to be more jointed than biotite gneiss (Louis Berger and others 1982; Nash and Basanayake, 1979).

(3) contact zones between rock of contrasting character such as gneiss adjacent to pegmatite (Cressler and others, 1983).

(4) geologic structures that have localized increases in fracture or jointing density such as cores of antiforms.

(5) faults or shear zones

(6) thickness of overburden: generally areas where overburden, especially valley fill, is thick are characterized by high well yields. (Note: this may be due to drainage from the overburden as much as an increase in fracture density).

The standard approach is to use air photos and/or Landsat imagery together with a geologic map to identify the above indicators. Air photos (used with a stereoscopic viewer) are preferred for analyzing land forms and drainage patterns whereas Landsat imagery may be more useful for identifying "fracture traces" that may indicate faults or shear zones. With the freedom to select well sites in the proposed project area it should be possible to test and fully evaluate the techniques listed above. A statistical study that relates high-yield well sites to occurrence with the above indicators should be helpful. To date, no one in the WRB has done this.

Knowledge of the hydraulic properties of the crystalline rocks (especially aquifer transmissivity) is needed to make a quantitative assessment of the areas' ground-water potential. Estimating long-term well yields, drawdowns, interference between wells, and problems of this type, requires knowledge of transmissivity and storage coefficient. Unfortunately determining these parameters in crystalline rock areas is difficult because the standard methods used for obtaining the parameters from pumping test data are derived from equations of flow in porous media such as sand and gravel, and the assumptions of the equations are rarely met in crystalline rock terrains. Even so, these assumptions are often approached in hard rock terrains where the rock is densely jointed and fractured. It is recommended that pumping tests (both single well and multi-well) be conducted where wells are constructed in densely fractured rock.

Wherever thick sections of alluvium are tapped by wells, pumping tests are recommended. The problems associated with analyzing pumping-test data in crystalline rocks do not occur in the alluvium composed of sand and clay.

Areal values of transmissivity can sometimes be estimated from the recession of ground-water levels or base stream flow during dry periods. Methods for calculating transmissitivity from water-level recesssions have been described by Stallman and Papadopulos (in Lohman, 1972) and from base-flow recessions by Rorabaugh (also in Lohman, 1972).

Finally, a description of the hydrogeology and an evaluation of the potential for ground-water development will be made using the data collected from the approaches just described as well as from the results of geophysical surveys and exploratory drilling. The evaluation should be detailed for System B but must necessarily be at a reconnaisance level for Systems A, C, and D.

Surface Geophysics

The WRB currently uses resistivity and VLF profiling to identify potential drilling sites. Low resistivity values are assumed to indicate more fractured rock and often used to finalize a site for drilling. The WRB has recently received EM equipment and it also has seismic refraction equipment. Unfortunately, seismic surveys are rarely carried out because of current restrictions on the use and storage of explosives.

It is recommended that a geophysicist be assigned to the project for several months at the start in order to evaluate the WRB's geophysical techniques and to provide training for their geologists as needed. The geophysicist should be provided with new resistivity and seismic refraction equipment and other equipment at his discretion.

The principal duty of the geophysicst is to evaluate the effectiveness of the various geophysical techniques used to identify fracture permeability. For this purpose, he should make a second visit of a few months about midway through the project.

The geophysicist should also direct work aimed at mapping the thickness of the alluvium along the Mahaweli Ganga and its tributary streams, probably using seismic refraction. Since the thickness of the alluvium is reportedly less than 66 ft (20 m), it should be possible to use a sledge hammer rather than explosives for the seismic surveys.

Exploratory Drilling Program

The principal aim of the exploratory drilling program is to test and evaluate different techniques for selecting sites for high-yielding wells.

A secondary aim is to construct wells for pumping tests to determine hydraulic properties of the rock and alluvial aquifers. Additionally, the program would provide on-the-job training for Sri Lankan drillers in hard rock drilling techniques.

A multi-purpose drilling rig is specified for the project that would be capable of hard rock drilling (with down-hole-hammer) to a depth of 600 ft (183 m) for a 6-in (15 cm) hole. The rig should also have the capability of drilling in alluvial sand and clay (up to 12-in (30 cm) diameter holes) using the conventional mud-rotary method.

It is recommended that an experienced hard-rock driller be assigned to the project for about 3 months to oversee the start of the drilling program. If drilling problems develop later or if the project is expanded, it may be desirable to bring back the driller for a second visit.

It is the feeling of some hydrogeologists in Sri Lanka that water-bearing fractures in the gneiss do not extend below about 130 ft (40 m). However, many wells in south-eastern United States that yield 50 to 100 gal/min (3 to 6 L/s) penetrate water-bearing fractures in similar rocks at depths of 200 to 500 ft (60 to 150 m); (Cressler and others, 1983). Hard-rock wells in Sri Lanka are rarely drilled to such depths. Thus, an important facet of the project will be to drill and test at greater depths in favorable hard rock areas.

Another aspect of the drilling program will involve testing the thicker (20 to 60 ft--10 to 20 m) sections of alluvium along the Mahaweli Ganga and its tributaries. The alluvial wells will require screens and be more expensive and only 10 such wells are planned.

Reports

The findings of this investigation should be presented in a report prepared by the hydrogeologist at the conclusion of the study. However, throughout the study preliminary hydrogeologic maps, pumping-test data, geophysical surveys, and the like should be made available as soon as possible to USAID, to WRB, and to other interested Sri Lankan government agencies.

The final report should evaluate the ground-water potential in Systems A, B, C, and D with special emphasis on System B. It should describe the success or failure of the attempts to develop a methodology for selecting high-yielding well sites. It should delineate those areas where fracture permeability is high and where developing wells yielding 25 to 50 gal/min (1.5 to 3 L/s) are feasible. The report should also present a detailed description of the exploratory drilling program including all well construction details and pumping tests. Summaries of the geophysical surveys and various hydrogeologic studies used to identify high fracture permeability should also be presented. Finally, if successful in finding a methodology of site selection for wells capable of yielding 25 to 50 gal/min (1.5 to 3 L/s) throughout the area, the report should outline an expanded program for evaluating the groundwater resources.

Project Staffing

The key to the project's success is the recruitment of an experienced hard-rock hydrogeologist by USAID (or it's contractor) and assignment of a counterpart hydrogeologist by the WRB for the duration of the project (2 1/2 years). Drillers and laborers should be available from the WRB to operate the USAID supplied drill rig. However, it is recommended that an experienced hard-rock driller oversee the initial phase of drilling (first 3 to 4 months). The WRB has a lot of experience in surface geophysical methods especially resistivity and VLF methods (see earlier section). However it is recommended that a geophysicist visit the project for about 3 months at the inception of geophysical work and again for 3 months or so midway in the project. All supporting technicians, laborers, etc., should be made available by the WRB.

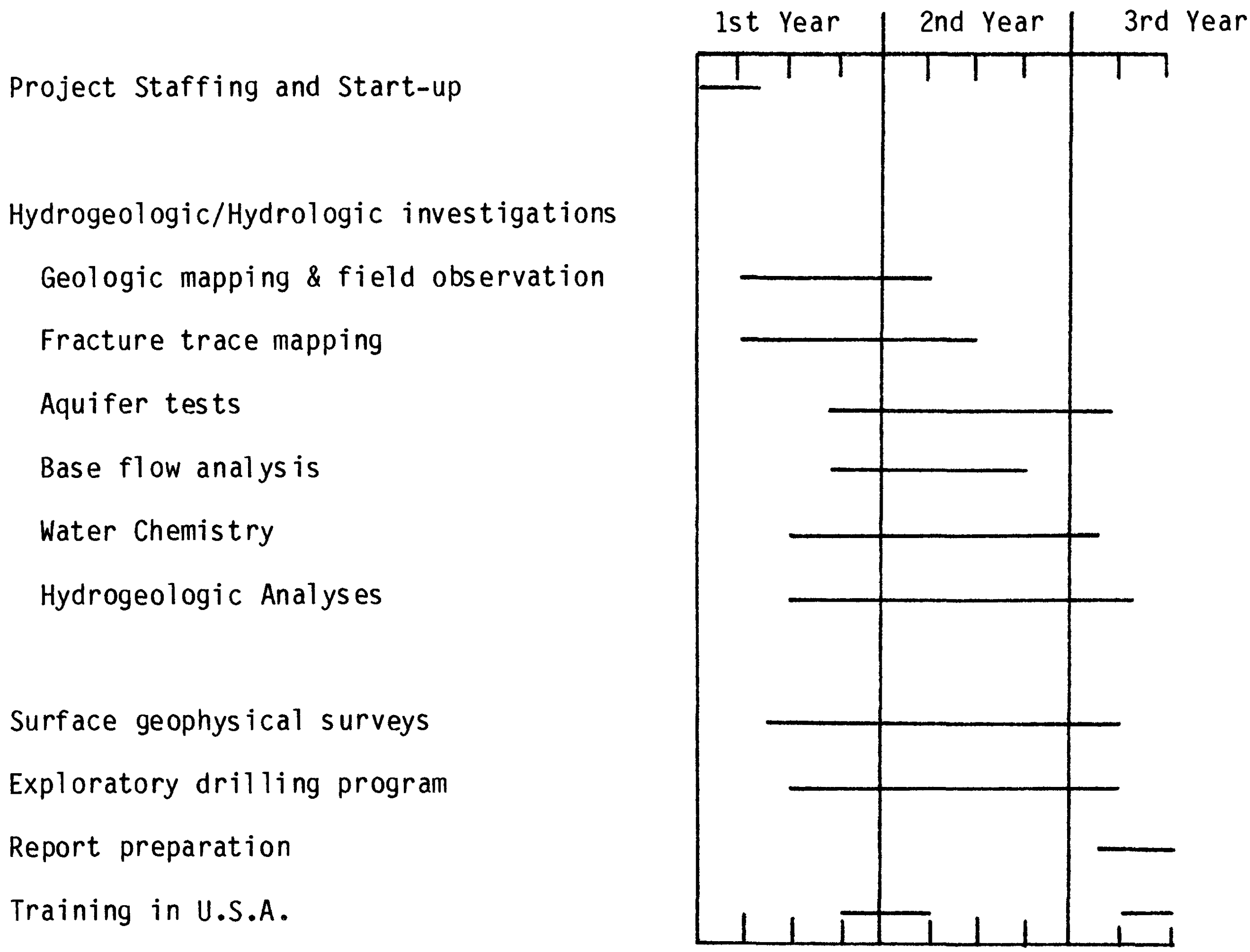
Training of Sri Lankan Hydrogeologists

At present the WRB has two experienced hydrogeologists; A.G. Wijesekere (Deputy General Manager, Ground-water) and S. Basanayake. Both completed graduate programs in hydrogeology at universities in Great Britian. Kingsley Wijesinghe, Chief of Geophysics, is also very experienced. There are several younger geologists and geophysicists who would benefit from specialized training abroad.

Unfortunately, the experience of the WRB has been that hydrogeologists receiving graduate degrees abroad leave that agency for private employment. Formerly, the WRB had 4 hydrogeologists with overseas degrees: two resigned recently. From the standpoint of timely upgrading of WRB's scientific skills and retention of employees with such skills, it is recommended that training abroad emphasize short courses in needed specialties. In the United States, the U.S. Geological Survey, the National Water Well Association, and a number of universities offer such courses. The Geological Survey's training center in Denver periodically offers one to two week intensive courses in surface geophysics, borehole geophysics, aquifer test analysis, groundwater chemistry, computer modeling of groundwater flow and other topics. The National Water Well Association presents a variety of courses at locations throughout the country ranging from drilling techniques to ground-water flow modeling. It is recommended that 3 or 4 of WRB's geologists/geophysicists be sent to the United States for this type of training. In addition it is recommended that senior level managers of the WRB be sent to the United States for graduate-level training in water resources management.

Tentative Project Timetable

The previously described elements of project scope may be implemented on a schedule illustrated below:



Project Cost Estimate

The following cost estimate includes salaries, travel, and housing for a hydrogeologist, consulting geophyscicist and a driller plus all foreseeable equipment and material costs needed to do the project. Also included are costs for training 4 Sri Lankan hydrogeologist/geophysicists in the United States. The cost estimate does not include a contractor's overhead expenses and profit, nor does it include the agency overhead if done under an inter-agency agreement.

Itemized costs are as follows (US 1984 $):

1.	Hydrogeological activities:	
A.	Hydrogeologist - 2 1/2 years (Assumes $100k per year for salary, housing, etc)	$ 250,000
B.	Field equipment (Includes electric water level indicators, steel tapes, conductivity meters (2 at $500), ph meters (2 at $250), float-type water level recorders (5 at $1000), compasses, etc.)	10,000
C.	Air photos, landsat imagery, drafting materials	5,000
D.	4-wheel drive vehicle	20,000
E.	Miscellaneous expenses	10,000
	Subtotal	295,000
2.	Exploratory drilling:	
A.	Hard rock driller-3 months salary, travel, etc.	30,000
B.	Multipurpose drilling rig mounted on 4-wheel drive truck (rotary plus down-hole hammer). Capable of drilling in hard rock to 600 ft. with 6-inch bit. Complete unit with bits, rods, and spare parts).	250,000
C.	Air compressor for drilling rig	35,000
D.	5-ton truck for hauling pipe and cement and for water supply (removable water tank and pump)	35,000
E.	Pumping test unit-4 wheel drive pickup truck ($20k) with 4 portable generators and 4 sumbersible pumps ($2000 per set)	28,000
F.	Well construction materials-includes PVC casing, cement, diesel fuel, bentonite, and well screens (alluvial wells): for 50 rock wells ($1000 each = $50k); 10 alluvial wells ($3000 each = $30k)	80,000
G.	Operating supplies for rig	20,000
H.	Miscellaneous expenses	20,000
	Subtotal	$ 498,000

3. Geophysical Surveys:

A.	Geophysicist-consulting 6 months; 2 3-month visits: travel ($10k per visit) and $50k salary	$ 70,000
B.	Surface resitivity equipment	25,000
C.	Refraction seismic equipment	35,000
D.	Other geophysical equipment (such as VLF and EM)-optional	20,000
E.	Spare parts, chart paper, explosives, drafting materials, etc.	25,000
F.	4-wheel drive vehicle	20,000
	Subtotal	$ 195,000

4.	Training for Sri Lankans: Attendance at hydrogeological or geophysical short courses and water management graduate-level courses 6 trainees-6 weeks each in U.S.A. Travel per diem, tuition, and books: cost per student - $7000.	42,000
5.	Office support for 2 1/2 years Secretary, office space and equipment	60,000
	TOTAL	$1,090,000

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