Proposed Water-Supply Investigations in Sidamo Province, Ethiopia

by

David A. Phoenix

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Preface

For centuries, the rich grazing lands of southern Sidamo Province, Ethiopia have been explored for water by nomadic herdsmen following a powerful incentive--thirst. Their results - small ephemeral catchments for surface runoff and dug wells tapping shallow ground water - have not always been adequate to stabilize their precarious and migratory existence. Their contribution to the development of Ethiopia is correspondingly hampered. This challenge to the steady economic development of Ethiopia is not new to today's frontiersmen - scientists, engineers, agriculturalists and businessmen - but their teamwork is required. Specialists in range management and veterinary controls working with geologists and hydrologists in their search for permanent water supplies must attempt to improve herds of livestock so that businessmen can systematically market the product. There are reasons to believe that these attempts will be successful, will parallel other developments in Ethiopia and will provide greater stability to the people of this remote region.

Abstract

The present report describes the results of an air and ground hydrologic reconnaissance of some 32,000 square kilometers in Sidamo Province of southern Ethiopia. Existing (1966) water resources developments, chiefly for livestock and village supplies, include surface reservoirs, a few drilled wells, several clusters of dug wells in the Mega area, several scattered springs, and the perennial Dawa Parma River. Surface-water reservoirs range from hand-dug ponds of a few hundred cubic meters capacity to large machine-constructed excavations built to hold 62,000 cubic meters of water. All the existing drilled wells tap saturated alluvium at depths of less than 120 meters. The dug wells tap water-bearing zones in tuffaceous lacustrine deposits or stream-channel alluvium generally at depths of less than 30 meters. The springs mostly rise from fractured Precambrian quartzite and individual discharges are all less than 75 liters per minute. The report also outlines the terms of reference for a longer term water-resources investigation of the region including staffing, housing and equipment requirements and other logistic support.

Introduction

The following report by the writer, a hydrologist of the U.S. Geological Survey, is based upon field reconnaissance of some 32,000 square kilometers (km^2) of Sidamo Province, southern Ethiopia during February 1966 made possible by use of light aircraft and 4-wheel drive vehicles. The report evaluates the requirements and objectives of a water-resources appraisal and development program in Sidamo Province as a part of a long-range livestock marketing scheme proposed for support to the Imperial Ethiopian Government under the auspices of the U.S. Agency for International Development. Attention was mainly directed to ways and means for improving water supplies along about 450 km of the major marketing and livestock migratory route connecting the towns of Moyale in the extreme south consecutively northward with Mega, Iavello, Alghe, and Dilla. Water-supply conditions along cattle routes and grazing areas subsidiary to the main route were also examined from the air. Data held by the Imperial Ministry of Public Works, by the Geophysical Observatory, and the Imperial Ministry of Agriculture, Livestock Division, and discussions with officials of these and other development and research institutions of the Imperial Ethiopian Government provided valuable guidance to this evaluation. Particularly helpful was the experience in air reconnaissance methods provided by air pilot, Mr. Charles A. Temple, and the intimate and first-hand knowledge of the country and its livestock problems provided by Ato Gebrehiwet Zere, Deputy Director, Livestock Division, Imperial Ministry of Agriculture, and Mr. Samuel T. Logan, Acting Chief, Agriculture Division, USAID/Ethiopia. These men accompanied the writer during the 11-day reconnaissance investigation.

The development of water supplies for livestock in southern Ethiopia has until very recently been left to practical and ingenious methods employed through centuries of practice by nomadic herdsmen. Within the limitations of their resources, every conceivable natural situation favorable to the accumulation of water has been employed. Old corral sites, pot holes in granitic rocks, shallow excavations below rocky hill sides, all are used to collect and temporarily store the infrequent rainfall and runoff. Certain types of phreatophytic plants which are sustained by shallow ground water are also known to the nomads and places in which these plants grow are invariably the sites of dug wells. In fact, many of these dug wells have been used so long and persistently that they are now nearing the limits of the nomads' ingenuity as useful watering points.

Succinctly, the herdsman is probably as knowledgeable and resourceful concerning his strategic sources of water, whether it be from ephemeral streams or shallow ground water, as the most sophisticated hydrologist, geologist, or modern day livestock expert. Unfortunately, he is nearing the limits of even his most ingenious and persistent efforts for discovery and maintenance of water supply due partly to increase in livestock population and partly to the increasing demands upon existing water supplies. Estimates, for Sidamo Province, place the livestock population at about 1-1/2 million animals and reportedly it is not uncommon for several thousand to be watered at an individual site in a day. Two solutions to the water shortage problem appear evident and practical. The first would require a decrease in the numbers of dependent animals and here the efficient reduction in numbers, and this by steady and reliable marketing, would strengthen the pastoral economy of these people. The second would require new and increased water supplies from hitherto inaccessible or untapped sources and for which several are believed available.

It is concluded that the exploration for and development of water supplied in this remote and underdeveloped part of southern Ethiopia are both desirable and justified, but that it is attendant to difficult living and working conditions and to a high risk of failure if not supported by well-directed engineering assistance and by special preliminary geologic and hydrologic guidance. Partly, the risks can be reduced by careful studies leading to the selection of appropriate new watering points, from both surface and underground sources and the improvement of existing water points. These studies may also provide guidance to other exploitable resources and hence increased economic interest in the region. Accurate base maps and improved roads and communication, essential to the infrastructure of the region, will facilitate the compilation of the required hydrologic and geologic data and, thus reduce other risks. A large measure of engineering talent will be required in these phases of work. Above all, successful utilization of both the ground and surface-water resources, and ultimately livestock management,will require a careful blending of traditional practices with improved but uncomplicated methods of water utilization and management.

If taken alone, the problems to be encountered by even the best of intentions in range management and livestock improvements in this remote and relatively inaccessible region are many. Certainly without access roads and engineering guidance, even of the most expedient type, drilling operations and the continuing logistic requirements of supply in servicing wells and in constructing and maintaining stock ponds will become difficult if not well-nigh impossible. Also, without geologic guidance necessary to the siting of wells, to the accurate description and correlation of sub-surface strata, and hence to proper well-drilling design and development, it is quite likely that an entire well-drilling program could become a repetitive succession of failures. As for stock pond construction, differences in the vegetative cover, in the thickness and physical properties of the surficial alluvium and in the composition, permeability, and porosity of the underlying consolidated rocks control not only the sediment transported by streams but also to a large degree the incidence of runoff. Throughout very large parts of Sidamo Province stream runoff is a rare event and is probably a direct function of a balance between factors of climate, topography, geology, and vegetation. In Sidamo Province these factors are unevaluated, but it is quite conceivable that the mere construction of reservoirs will be discouragingly inadequate to satisfy requirements for permanent water throughout the long dry season. If the shrubs and trees with which the area is abundantly supplied were wholly or even partly eliminated, will this upset the delicate balance of nature in the region and create even greater problems? One might also ask such pertinent questions as "Where are the rocks favorable to the occurrence of ground water?" "Will the pumping imposed on the ground water supply exceed its safe yield?" "Are there areas where the temporary impoundment of water will effectively recharge the ground water?" "Will the yield from windmill wells be great enough to meet the minimum needs for domestic and stock use?" "Where are the springs?" "Can they be improved?" These and similar and now unanswerable questions can only be satisfactorily solved by systematic areal studies of the relations between runoff, geology, vegetation, and climate.

At present, outstanding deterrents to all but the most basic and exploratory type of water development include a serious lack of roads, communication, housing, schooling, medical, and supply facilities throughout the area. It is not within the scope of this report to propose specific support to strengthen these desirable and necessary aspects of the long-range improvement of the infrastructure. However, the writer is familiar with practical methods employed in opening new and remote country, and it is to these and to the special preliminary studies that attention is directed.

The bare manpower necessities for the successful completion of even the most exploratory of projects in this remote and largely roadless region will require a well-organized and well-coordinated input from engineers, geologists, and bulldozer mechanics and operators and well drillers who are willing and capable of "roughing it" and "coping" under frontier working conditions. However, without the requisite technical equipment and without conditions suitable for effective work, the best qualified and experienced personnel can accomplish little. Therefore, it is recommended that the provision of adequate equipment and housing be recognized as prerequisite for effective operations of personnel assigned to the project, and that personnel not arrive until these essentials are available.

The following sections describe past investigations and water-resources development, the physical features of the region, and project of proposed investigations.

Previous Investigations and Available Basic Data

At present large parts of Ethiopia are remote from routes of travel and therefore little is known concerning natural resources of these areas, and this is particularly true for large parts of southern Ethiopia. Published maps, the basic prerequisites to the assessment of these resources, are adequate only for the most general of reconnaissance purposes. In Sidamo Province these include maps at a scale of 1:500,000 and 1:1,000,000. Rudimentary topography, altitudes of some major landmarks, and the location of strategic towns, roads, trails and water holes are illustrated on the generally available 2-degree quadrangles, scale 1:500,000 compiled by the Geographical Section, British General Staff and published by the War Office, 1946. The adjoining 2-degree quadrangles Stephanie (N.B. 374), Neghelli (N.B. 375), Rudolf (N.A. 371) and Moyale (N.A. 372) covering, in all, 4-degrees of latitude and 4-degrees of longitude were used in the present field reconnaissance to plot geological and hydrologic data and the air routes travelled. The broad physiographic features of southern Ethiopia also are shown on the U.S. Air Force 1:1,000,000 World Aeronautical charts and their equivalent but later compilations by the British War Office, the Lake Margherita and Marsabit quadrangles. The base map for figure 1 showing the availability of water supplies in a part of Sidamo Province, Ethiopia has been prepared from adjoining parts of these two quadrangles.

To assist in all phases of resource investigations in Ethiopia, the U.S. Mapping Mission has since October 1963 been systematically obtaining air photo coverage of the country at scales of 1:50,000 and 1:25,000. Overlapping air photos, scale 1:50,000, along east-west flight lines are now available for most of southern Ethiopia and of the proposed project area.

The results of reconnaissance geologic studies of southern Ethiopia are summarized by Mohr (1961) and are illustrated on the geologic map of Ethiopia, scale 1:2,000,000; the general rainfall and air movement patterns over Ethiopia are illustrated and described by Kebede Tato (1964); and the classification of soils and native vegetation sufficient to provide initial guidance to the recovery and management of water supplies in southern Ethiopia are described by Murphy (1959) and von Breitenbach (1961). Other general information, in part applicable to water-supply problems in Sadamo Province, include a discussion of water laws in Moslem countries by Caponera (1954), and reports on general geology and hydrology of the Upper Nile Basin in Ethiopia (1964a,b) and of mineral resources in Ethiopia (1960), prepared by the U.S. Bureau of Reclamation.

Physical Features

Location and Extent of Area

Sidamo Province embraces about 48,300 km^2 in southern Ethiopia extending from mountains bordering the east shores of Lake Stephanie (a broad playa) and Lake Ruspoli in the Great Rift Valley, eastward to the Dawa Parma River and from the high plateaux of south-central Ethiopia southward to the plains along the international boundary separating Kenya and Ethiopia. It is a broadly triangular area with its northern apex in the highlands and adjacent foothills, and its broad base some 320 km to the south covering the lower lands along the frontier. The region covered by this report lies in southern Ethiopia between 3°30' and 6°30' north latitude and with a broad base extending from 37°00 to 40°00 east longitude.

From Addis Ababa the area is accessible by air transport and by road. A well-graded dirt airstrip is located about 13 km northeast of Mega, and is suitable for landings by light aircraft. It is reached in about 3 hours flying time from Addis Ababa. The airstrip is about 1-1/2 hours drive by automobile from Mega and a good 3 to 4 hours drive from Iavello, a town of about 2,000 inhabitants and administrative center of Sidamo Province (fig. 2). To reach Mega by road from Addis Ababa is a tiresome journey requiring the better part of 3 days travel. The first 170 km of this road is paved as far south as Shashemenne. From here south to Dilla the road can be negotiated throughout the year by 4-wheel drive vehicles but in many places it is steep, winding, and

Figure 2.--Iavello (Yavello), Principal Administrative Center of Sidamo Province. View toward North

rough and requires considerable caution to negotiate safely. From Dilla south to Mega and beyond, the road is one long series of washouts ruts and detours, and travel is reduced to the almost full-time second or low gear speeds of a well-equipped Jeep or Landrover.

Climate and Vegetation

The mean annual rainfall ranges from about 400 (mm) millimeters in the southern plains of Sidamo Province to 1,200 mm in the highlands to the north. It is probably less than 600 mm throughout most of the southern plains. At Moiale on the Ethiopian border and at an altitude of about 1,200 (m) meters the mean annual rainfall for 5 years of record is 819.5 mm. but at Dilla in the highlands some 320 km to the north and at an altitude of about 1,600 m the mean annual rainfall for 6 years of record is 1,407.2 mm. In the highlands the rainfall is monsoonal with a distinct dry season extending from late October to mid-March. In the highlands also, a period of intermittent rains, "the small rains," introduces the heavy rainy season, which usually begins in May or June and ends in mid-October. In the southern plains, at lower altitudes, the period of small rains in March, April, and May is followed by a distinct dry season until the rains again occur during October and November. In the southern plains there are between 80 and 100 days during the year during which rains occur, and most of these are of short duration. Clear sunny days prevail throughout most of the year and day-time temperatures frequently exceed 35°C. The nights, however, are invariably clear, crisp and cool. Generally speaking in the highlands of southern Ethiopia working conditions are ideal throughout the dry season. In the plains at lower altitude ideal working weather prevails through the period from March to October and is uncomfortably hot only during the middle of the day for the rest of the year.

Wind movement in southern Ethiopia during the period from June to early September is predominated by warm moist southeasterlies from the Indian Ocean. After a short period of fluctuation wind direction changes abruptly and during the dry season from early October through the following May the prevailing direction is toward the southwest (Kebede Tato, 1964). The duration and rates of wind movement are not known for Sidamo Province, but in general, air movement ceases throughout most of the night hours and is again resumed during the mid-morning hours. The province is subject to occasional violent winds that accompany thunderstorms but these are of short duration. Wind velocities are believed to be adequate to operate windmills during at least 8 hours almost every day.

The various plant assemblages found in southern Ethiopia are mapped and described by von Brietenbach (1961) sufficiently to provide the student with guidance as to their identity and hence their relationships to water supply and range management. In Sidamo Province as well as elsewhere in Ethiopia the distribution and types of native vegetation are believed to be largely as a result of differences in soils and climate. These are in turn related to differences in physical and chemical properties of the underlying rocks and upon altitude. In the basalt plateau near Alghe and Dilla where the native vegetation has not been removed for farm lands and coffee plantations, and locally in the highland areas surrounding Iavello and Mega, there are various forest species of trees and tall plants intermingled with dense thickets of high shrubs (fig. 3). Outstanding among these forests are species of _Acacia_, _Juniperus_, _Podocarpus_, _Porteria_, _Euphorbia_ and _Ficus_. At lower altitudes and throughout the foothills and plains country of southern Ethiopia where soils cover metamorphic and intrusive rocks, the forests give way to an arid to semi-arid type of woody vegetation consisting of short-stemmed shrubs, 2 to 4 m high, overtopped from place to place by umbrella-shaped trees up to 7 m high - the savannah woodlands of Acacia and thorn bush (fig. 4). Almost everywhere these trees and shrubs are underlain by a carpet of short-stemmed perennial grasses intermingled with annual grasses and herbs. In the most arid areas, notably in the lava plains west and northwest of Mega, grasses form the entire vegetative cover over many tens of square km (fig. 5).

The writer's observations with respect to plant, soil and water relationships were necessarily limited to impressions gained during flight and traverses. In the foothills east of Iavello and northward to Alghe where rainfall may exceed 760 mm per year, plant growth is so dense that ground visibility is reduced to 15 m or less. At lower

Figure 3.--Mixed Cedar, Thorn Bush, and Euphorbia Forest in hills, 8 km West of Iavello.

Figure 4.--Air View of Thorn Bush and Acacia with Undercover of Grasses, 50 km West of Mega. Air Photograph from 150 m Altitude.

Figure 5.--Grassy Plains in Wildlife Area, 48 km Southwest of Iavello.

altitudes ground visibility is much greater, with extensive vistas of tree-studded parks and grasslands. Throughout these areas the valleys are lined with trees and shrubs and with interconnected meadows, but evidence for stream runoff through them is in most places limited to dry ill-connected depressions and to narrow and shallow grass-covered channels. Furthermore, there is little evidence to indicate that cattle find the trees and shrubs a palatable forage. In other places some trees and shrubs also seem to prefer areas of shallow ground water where there are springs and seep areas. These include Ficus, Euphorbia, Acacia, Salix, Lobelia and Tamarindus. Most of these plants are phreatophytes, that is, plants which send their roots to the permanent water table and depend upon ground water for their nourishment. These plants should be studied more carefully as they may indicate the presence of hitherto untapped ground-water resources.

Topography and Drainage

Sidamo Province occupies parts of two physiographic provinces in Ethiopia. These include the Southern Highlands, a high plateau on which altitudes lie between 2,500 to 3,000 m above mean sea level and to the south of this, separated by a broad belt of foothills, the Lowlands, a broad planar belt broken here and there by inselbergs and clusters of volcanic cones. Altitudes in the Lowlands lie between 1,000 and 1,500 m above mean sea level.

The tectonic trench of the Great Rift Valley with eight associated interior lake basins lies along the west side of the report area and on the east Sidamo Province is bordered by the Dawa Parma River which flows southeastward into the Ganale Doria (Juba, Giuba) River. On the south a steep escarpment, along which altitudes drop abruptly over 600 m, limits most of the report area. This escarpment faces southward over vast lava plains of northern Kenya, and parallels the international boundary from the vicinity of Moyale westward for almost 130 km before it arcs northward and dies out midway between and somewhat west of the longitude of Mega. The escarpment is marked by numerous faults and clusters of deep explosion craters.

Southerly trending discontinuous linear ridges extend southward from the Southern Highlands near Alghe and merge with the northwestern end of the escarpment. These ridges form a somewhat sinuous and ill-defined drainage divide that separates the lowland area into nearly equal eastern and western segments. East of the divide, drainage is toward the Ganale Doria and Dawa Parma Rivers or, farther south, and east of Mega, onto a broad sloping surface covering almost 12,000 km^2 of the Southern Lowlands. West of the divide, from the vicinity of Alghe southward to the western slopes of mountains surrounding Iavello, drainage is westerly toward the interior lake basins of the Rift Valley. Further south and from the slopes of the frontier escarpment, drainage is southerly toward the lava plains of Kenya. It is along and adjacent to this drainage divide extending from the highlands near Alghe to the Ethiopian-Kenyan boundary at Moyale that water supplies are most needed to support the marketing routes for livestock from southern Sidamo Province.

Geology

The geologic map of Ethiopia, scale 1:2,000,000, indicates that basaltic rocks of Tertiary age underlie the highlands in the northern part of Sidamo Province and that a basement complex of intrusive and metamorphic rocks of Precambrian age underlie most of the southern part. The metamorphic rocks include all types from those clearly of sedimentary origin gradational to schists and gneisses so thoroughly altered that their origin is obscure. In most places the metamorphic rocks are highly distorted by isoclinal folding. Massive granite and granodiorite commonly intrude the metamorphic rocks. Pegmatites are common among the basement complex rocks west of Iavello and probably elsewhere as well. In the southwestern part of the province the Precambrian rocks are overlain extensively by crystalline basalts comprising the Trap Series of Tertiary age; in the south-central part they are overlain by lacustrine deposits of Quaternary age. In most places the consolidated rocks are mantled by unconsolidated deposits including Holocene alluvial sand and gravel in stream channels and valleys, eluvial clay and clay-rich soils on the hill slopes, and poorly-sorted colluvial coarse sand and gravel along the base of steep escarpments.

The consolidated rocks are also exposed in the walls of explosion craters about 13 km northeast of Mega and at other localities west and northwest of Mega. El Sod, an explosion crater about 16 km northeast of Mega, is about 1.6 km in diameter and 300 m deep (fig. 6).

The near-vertical walls of this crater are formed of metamorphic rocks of the Precambrian basement complex but its rim rocks are composed of near horizontal flows of basalt some 60 to 90 m thick. Magado, an explosion crater about 35 km soutwest of Mega at the base of the escarpment, appears from the air to be somewhat larger and deeper than El Sod. Its inner walls appear to be composed of rocks of the Precambrian complex overlain by several hundred feet of basalt. G. Gori, a crater about 83 km west of Mega and well within the lava fields, has walls about 180 m high that are believed to be composed entirely of basalt. Bedded tuffaceous deposits and other fragmental detritus ejected from these explosive craters may well comprise most of the rocks shown as lacustrine deposits of Quaternary age on the geologic map of Ethiopia.

The most striking structural feature in the region is the escarpment adjacent to the Ethiopian-Kenyan frontier. The southern face of this escarpment is a complex of southward dipping normal faults along which total vertical displacement is probably 600 m or more. In other parts of the lowlands area in southern Sidamo Province faulting is not apparent and may be of little importance in controlling the movement of either ground or surface water.

Figure 6.--Salt Lake in Floor of El Sod, an Explosion Crater about 16 km North of Mega. Capping on Crater Rim are Basalt Flows; the Inner Walls are Metamorphic Rocks of the Precambrian Basement Complex. View Northward.

Existing Water Resources Development

Ground Water

In general, ground water occurs under conditions where recharge is available from precipitation or stream flow and where the soils and rocks are sufficiently permeable to absorb infiltrating recharge and to permit it to percolate into the saturated zone. However, much of the water which falls as precipitation is intercepted and returned to the atmosphere by evaporation and plant transpiration before it reaches permanent bodies of ground water. In southern Sidamo Province ground water occurs in the tuffaceous lacustrine deposits widely distributed east and southeast of Mega; in zones of fractured rock associated with faults along the frontier escarpment near the Ethiopian-Kenyan boundary; in stream valley alluvium overlying the basaltic rocks of the lava plains west of Mega; in beds of fractured Precambrian quartzite; and locally in alluvium along the valley floors of stream courses which descend from the highland areas surrounding Mega, Iavello and Alghe. The rocks, which probably contain little ground water or in which it may be too deep or difficult to reach and hence of limited importance, include the massive metamorphic and igneous rocks or Precambrian age and the basaltic rocks of the Trap Series of Tertiary age that underlie extensive areas of southern Sidamo Province in the lowlands. With few exceptions the location of water-bearing zones and the quantities of ground water available to wells, even in the most favorable situations, cannot be predicted with any degree of certainty from transient observations made during this reconnaissance study.

Existing developments of ground water in southern Sidamo Province are limited to two boreholes (drilled wells) at Iavello, one borehole at Mega and to indigenous dug wells found in a number of places throughout the region. The boreholes at Mega and Iavello were completed in 1964 by the Imperial Ministry of Water Resources. They are all less than 120 m deep, cased with 152 mm A.P.I. casing, and fitted with small motor driven pumps. Each borehole and its installations are protected by locked shelters from which discharge pipes extend to nearby elevated storage tanks and from thence to spring-faucets where water is drawn for livestock or domestic use. At the time of our visit the borehole at Mega was in operation but the boreholes at Iavello were not being used due to mechanical troubles with the pumps. All these boreholes apparently draw water from zones of saturated alluvium and through slot-perforated casings. The development tests performed shortly after they were drilled indicate they have specific capacities (yield in liters per second per meter of drawdown) of about 0.48.

Dug wells, the most common sources of water in Sidamo Province, are constructed according to the practices of centuries of development use and by nomadic tribesmen (fig. 7). Most of these wells are located in the broad plain east of Mega where ground water occurs in tuffaceous lacustrine deposits. One well, however, against the side of a small ravine and about 48 km west of Iavello is excavated some 18 m deep along a shear zone in metamorphic rock. Others were found in alluvium along a dry sandy stream bed in the lava plain about 120 km northwest of Mega. All these wells are at great distance from the most reliable source of permanent water in the region, in the Dawa Parma River (fig. 8).

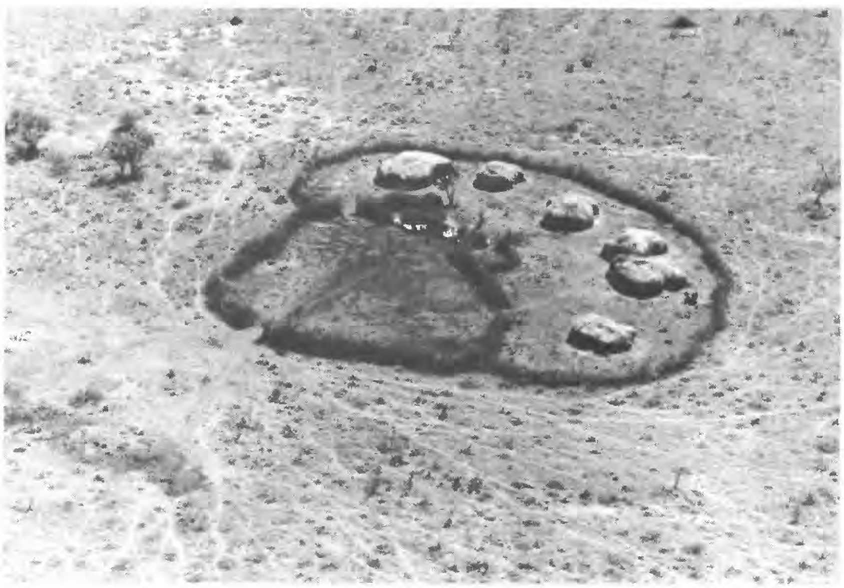

Figure 7.--Borana Family Village near Iavello Surrounded by Thorn Bush Enclosure.

Figure 8.--Herdsmen Watering Livestock along the Dawa Parma River.

The wells east of Mega commonly occur in clusters covering several acres. However, not all wells in a cluster can be used. Some are in good repair and show evidence of recent use, others are rubble-filled depressions, long since abandoned. The wells in use are generally surrounded by thorn brush enclosures and entered through a small holding corral. From the corral, cattle are led down a narrow inclined trench to a watering stage some 7 to 8 m below the general land surface. The well shaft, usually 2 to 3 m in diameter and nearly vertical is separated from the watering stage by mud-walled troughs and a low barrier of cribbed rock. Depth to water in many of these wells is 18 to 25 m below the subsurface entrance and 25 to 30 m below the surrounding general land surface. To provide access to the water each well shaft is equipped with a number of crude log platforms of "stages," depending upon its depth, that are connected by ladders of precariously wedged tree limbs. While watering their cattle, the herdsmen descend into the shaft in sufficient numbers so that water in leather buckets can be conveniently passed from hand to hand upwards to the watering stage, and as a full bucket goes up an empty one comes down. The process is as efficient and productive as the agility and energy of the individuals can make it. Undoubtedly, an occasional bucket of water or even footing is lost in this rather dangerous operation. The results, however, are satisfactory. It is reported that some 75 to 115 liters per minute are hoisted upwards in this fashion and that the work goes on sufficiently to water at least a thousand cattle per day at each well (figs. 9 to 15, inclusive).

It seems inconceivable that these dug wells are the result of a single bold enterprise to obtain water. All those wells examined by the writer occur in settings where, under normal conditions, one might expect the water table to have been at some time in the past, either at or very near the land surface. Those wells east of Mega are located along the axes of very broad, gently sloping valleys leading from the highland areas surrounding Mega. In many places these valleys seem to have been open grassland glades underlain by shallow ground water. It is interesting also that amongst the various abandoned wells in each cluster there are those that seem once to have been simply open shallow depressions whereas others lack the entrance way so typical of the present-day deeper structures. The evidence is inconclusive but it would appear as though the nomadic herdsmen are now and over a long period of time have been mining water and gradually deepening well-shafts in pursuit of the declining water table.

Direct sources of ground water are springs which rise in the highland areas and small seepage lakes in the floors of extinct explosion craters. Among the springs visited during the reconnaissance, were one about 1.5 km south of Mega, two near Iavello, and another near Iarbu Hobok about 125 km west-northwest of Mega.

The spring near Mega rises from a thick, fractured bed of quartzite into a boulder strewn and tree-lined ravine. The bed of quartzite

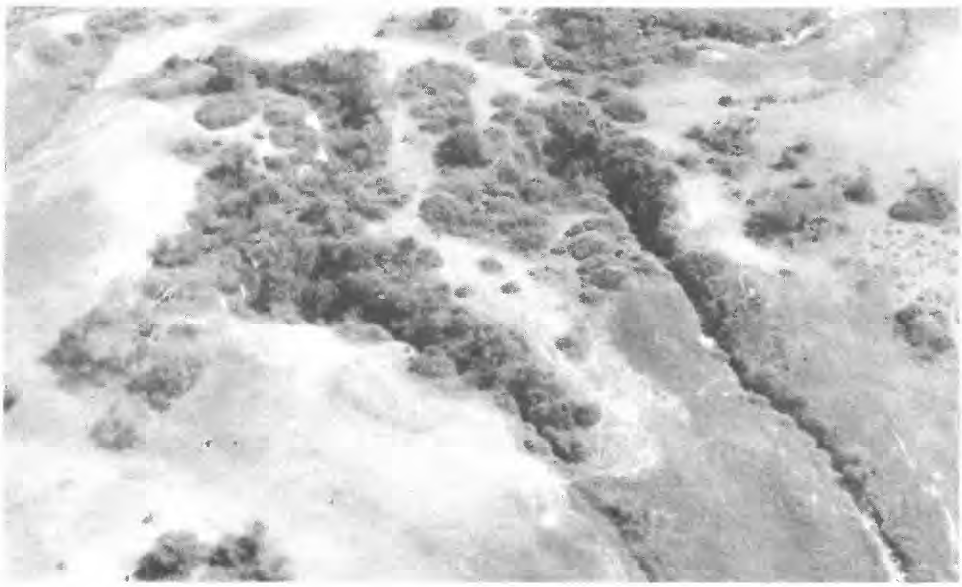

Figure 9--Air View of Soghidda Wells, 43 km Northeast of Mega. Air Photograph from 300 m Altitude.

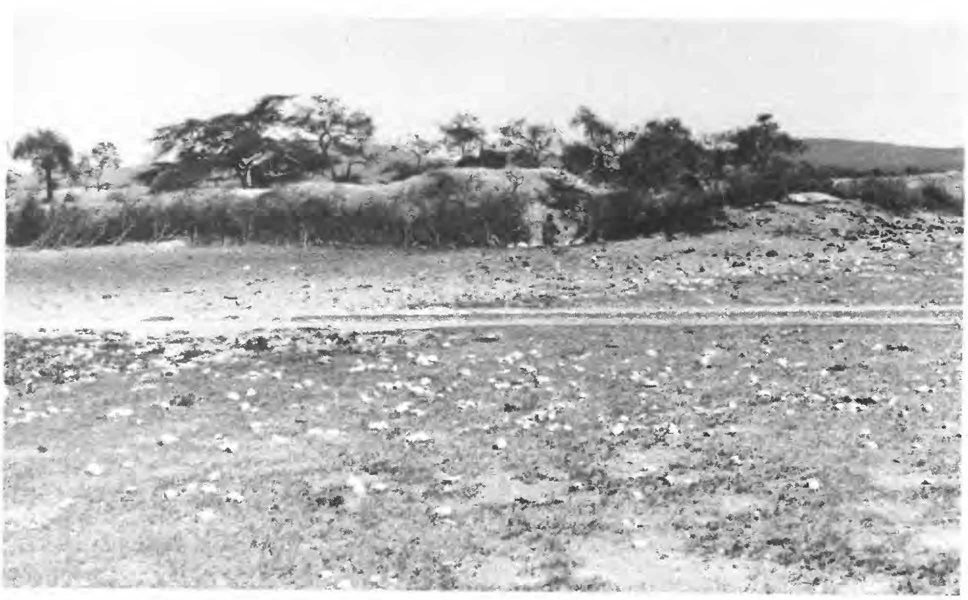

Figure 10.--Thorn Bush Enclosure and Entranceway to El Melbana (well), 35 km Southeast of Mega.

Figure 11.--Incline Leading down to Cattle Watering Stage in Foreground. Well near Mega.

Figure 12.--Cattle Watering Stage, 7 m below General Land Surface at El Melbana.

Figure 13.--Uppermost Lifting Stage, 18 m above water level at El Melbana.

Figure 14.--Watering Cattle from Well near Spring, 1.6 km South of Mega.

Figure 15.--Watering Cattle from Well near Spring, 1.6 km South of Mega.

dips gently southward from the hills surrounding Mega and probably receives recharge from precipitation which falls in these hills. At the uppermost spring head, water discharges directly from the quartzite with a flow of less than 4 liters per minute. Downstream, however, cattle are watered from open pools in alluvium, which are probably sustained by discharge from the quartzite, and also, in one locality, from a 7 to 9 m deep well (figs. 14 and 15). Reportedly, a thousand or more cattle are watered here each day and if so, the total discharge from the quartzite must be at least 75 liters per minute.

At Iavello, one of the springs discharges into a small open reservoir is 3 to 4 m above the roadway in a nearby canyon and it seems likely that the water could be fed by gravity pipelines or siphons from the reservoir to nearby watering points. There is, however, no observable overflow from the reservoir. The second spring near Iavello is on a south facing hillside at the head of a large canyon about 2.4 km northeast of the town. This spring rises from a nearly horizontal bed of fractured quartzite and is developed by a well-constructed spring box. This spring was improved at considerable expense and effort by Italian forces, who once occupied Iavello, but the entire installation including the spring box, discharge pipe, a 2 x 3 x 1 m concrete cistern and two 12 m long concrete watering troughs has been neglected since their departure and are no longer serviceable. The spring yields a small water supply used for domestic supply by nearby villagers and is also used for water livestock. A chemical analysis, given in table 1, indicates a calcium-sodium bicarbonate water of moderate hardness and a relatively low content (184 milligrams per liter) of total dissolved solids. Based on this analysis the water would be suitable for domestic, livestock, irrigation and most other uses.

The spring near Iarbu-Hobok issues from an alluvium composed of volcanic debris in an area underlain by Trap basalt. A chemical analysis given in table 1 indicates a very hard, brackish water (1,110 mg/l dissolved solids) of sodium-magnesium bicarbonate type. The water also contains a high nitrate content (37 mg/l) which may indicate pollution. The water is usable for livestock but poor for human consumption.

Water in the explosion craters occurs in shallow lakes, small peripheral springs and seeps adjacent to the lakes in the floors and in deeper ground water beneath crater floors. In most places the lakes are saline and are used locally as sources of salt. The small seeps and springs around the lake peripheries may be less saline than the water in the lakes but they are at best meager sources of water. In most places the lake water in the explosion crater is believed to be unfit for livestock or human consumption. These crater lakes suggest that the regional water table in their vicinities is at great depth below the general land surface.

At El Sod crater (fig. 6) about 16 km north of Mega, the writer visited a well dug to a depth of about 24 m in the bottom of and adjacent to the south wall of the crater. The water level was about 23 m

Table 1.--Analyses of Waters from Wells and Springs in Southern Sidamo Province, Ethiopia

Analyses by R. T. Kiser, U.S. Geological Survey

	Constituents, in milligrams per liter, except as indicated		
	Iavello Spring 1/	Hobok Spring 2/	El Sod well 3/
Date of Collection of Sample	Feb. 22, 1966	Feb. 16, 1966	Feb. 18, 1966
Calcium (Ca)	19	84	124
Magnesium (Mg)	6	71	156
Sodium (Na)	19	200	1,430
Potassium (K)	6.7	18	96
Bicarbonate (HCO_3)	118	820	388
Sulfate (SO_4)	2.7	57	1,290
Chloride (Cl)	16	136	1,790
Fluoide (F)	0.3	0.6	0.6
Nitrate (NO_3)	3.7	37	3.0
Boron (B)	0.1	0.2	1.7
Silica (SiO_2)	52	107	78
Total Hardness as $CaCO_3$	72	500	950
Total Dissolved Solids (calculated)	184	1,110	5,160
Specific Conductance (Micromhos at 25°C)	260	1,680	7,530
pH	7.2	7.8	8.0
Percent Sodium	34	45	74
Sodium Absorption Ratio (SAR)	1.0	3.9	20

1/ Spring about 2.4 km northeast of Iavello.

2/ Spring near Iarbu-Hobok about 123 km west-northwest of Mega.

3/ At El Sod crater about 16 km north of Mega.

below the general level of the crater floor. A chemical analysis given in table 1 indicates a sodium chloride water with considerable sulfate, a high dissolved solids concentration (5,160 mg/l), and also a relatively high concentration of boron (1.7 mg/l) that may reflect the volcanic environment.

Surface Water

The behavior and quantities of surface water runoff from any area depend in large measure upon the frequency and duration of precipitation, the absorptive characteristics of soils and rocks, the soil moisture and plant requirements, and the slopes and drainage areas involved. The retention and storage of runoff in reservoirs and hence their usefulness as watering points depends upon proper reservoir site selection so as to minimize the loss or retardation of runoff. Ideally, each site should be selected by an individual intimately familiar with the runoff characteristics of the drainage basin above the site and with the water retention properties of the soils and rocks at the site selected for a reservoir.

The only perennial streams in the area are the Dawa Parma River and a few small unnamed streams along the frontier escarpment. Supplies of surface water for livestock in most of southern Sidamo Province must therefore come from runoff that originates chiefly during the rainy season and that probably continues for only short periods of time.

Surface-water reservoirs have been constructed throughout southern Sidamo Province as watering sites for livestock. In most places they have been built and are maintained through hand labor by the nomadic tribesmen (fig. 16) but a few (figs. 17 and 18) of more recent origin have been constructed with earth-moving equipment provided by the Imperial Department of Water Resources. The capacity of the hand-constructed

Figure 16.--Herdsmen Watering Cattle and Removing Silt from Small Stock Pond, 37 km northeast of Mega.

Figure 17.--Three-year Old Stock Pond at Base of Hills, 7.5 km Northeast of Mega. View Eastward.

Figure 18.--Three-year Old Stock Pond at Base of Hills, 7.5 km Northeast of Mega. View Southeastward.

reservoirs is in most places considerably less than 1,200 m^3 of water; the larger machine-constructed reservoirs are built to hold approximately 62,000 m^3. In general the small reservoirs are located on or below rocky hillsides where rates of runoff are high and where the surficial materials insure against water losses by seepage, through underlying rocks such as the granites of the basement complex (figs. 19 and 20). In some places old corrals have been selected for reservoir sites, probably because at these places the movement of livestock has created a more or less impermeable floor to prevent losses by seepage. In other places natural basins in crystalline rocks are used as watering sites. Most of these small reservoirs probably contain sufficient water to provide for only a few weeks use during the dry season. At least 30 of them were seen during the writer's reconnaissance of the region and the greater number are located in foothills surrounding Mega and Iavello. At the time of the writer's visit the "small rains" had just commenced and many of these small reservoirs contained water and were being used for livestock watering.

Four large machine-constructed surface-water reservoirs were examined during the air reconnaissance of southern Sidamo Province. One is on the eastern foothills of the mountain surrounding Mega, another is in the extreme southeast part of the region and about 51 km northeast of Moyale, a third is on foothillls about 61 km southeast of Iavello and a fourth is about 1.6 km downstream from the mountainous entrance leading to the valley occupied by Iavello. Each of these reservoirs is of the same design and of approximately the same size.

They are all rectilinear excavations measuring approximately 135 x 135 m by 3 m deep, and each is bordered on the downstream and lateral sides by an earth embankment about 4 m high. Reportedly, these reservoirs had been completed some 2 or 3 years prior to the writer's inspection. Among these four installations only one contained water (figs. 17 and 18) and the amount in storage was but a small fraction of the available capacity. The absence of water-marks in the reservoir slopes and along the base of the small ditch leading to the reservoir suggested that only small quantities of surface runoff had reached it since its construction. Livestock in the immediate vicinity numbered no more than a few dozen animals and the general lack of footprints in the reservoir area indicated that it was not being heavily used by livestock.

Figure 19.--Digalu Stock Pond, 35 km Southeast of Iavello.

Figure 20.--Eroded Surface of Precambrian Basement Complex Rocks at Digalu Stock Pond, 35 km southeast of Iavello.

Results of Present Reconnaissance

The results of the present (1966) reconnaissance are summarized in figure 1, which illustrates areas favorable, semi-favorable, and unfavorable to the development of water supplies in southern Sidamo Province. Two classifications are indicated, one of which identifies areas for the development of ground water and the other which identifies areas for the development of surface water. The map provides a general assessment of large areas and with exception of a few sites for exploratory boreholes does not provide specific locations for new or improved installations. More detailed geologic and hydrologic guidance in the selection of specific sites is recommended.

The large areas classified as unfavorable to the development of water are those where (1) it will be difficult and costly to drill boreholes, (2) there is probably insufficient rainfall to meet requirements for all but the most ephemeral of stock ponds, and (3) there are rocks in which the possible occurrence of ground water is difficult to assess. Rocks underlying these areas are basaltic lavas of the Trap Series of Tertiary age and metamorphic and igneous rocks of Precambrian age. No known springs or seeps discharge from these rocks except in the bottoms of the deep explosion craters and the discharge from these places is meager and in most places chemically unsuitable for livestock. In most places alluvium covering these rocks is thin and is not water-bearing.

The areas classified as semi-favorable to boreholes and stock ponds are those in which ground water occurs in deposits of sand and gravel underlying the beds and flood plains of ephemeral streams. In these places reservoirs will receive surface water largely as the result of occasional flash floods. In many places measures to recover water will compete with the water requirements of native vegetation including thorn bush and acacia, with fluctuating water tables, and with limited ground-water supplies. The construction of boreholes and reservoirs in these areas should not be difficult but sites should be selected to obtain the maximum thickness of saturated alluvium and to avoid the destructive effects of floods.

Areas classified as favorable to boreholes only are underlain by stratified deposits of volcanic ash and by deposits of permeable sand and gravel. Recharge to ground water in these deposits originates from water falling as precipitation in the mountainous areas that reaches the ground water in stratified deposits by the infiltration of stream runoff. Discharge of this water is by evaporation and plant transpiration and by manual draft from dug wells to satisfy the requirements of livestock. In areas west of Iavello and northwest of Mega ground water moves laterally towards large pans or sumps where it is lost by evaporation or by transpiration of non-beneficial vegetation. The interception of this water by boreholes is probably feasible in many places. In areas east of Mega ground water either circulates laterally and very slowly or not at all. Also it is contained in broad shallow basins formed by the filling of pre-existing topographic depressions in a surface of the Precambrian rocks with deposits of air-or water-borne volcanic ash. The thickness of these ash deposits is not known but their physical character and related water-bearing properties may be associated with the areal distribution of the explosion craters. Ground water in the ash deposits occurs in joints and fractures and in places may also occur in the coarser-textured stratified materials. Withdrawals of water from these deposits locally and from depths exceeding 24 m, are from hand dug wells clustered in at least six widely separated localities. Yield of the well clusters by hand methods is sufficient at times to provide the water required by several thousand cattle per day. The active producing wells are surrounded by abandoned wells in various stages of development. It is possible that the current (1966) withdrawal from these wells may be exceeding the natural replenishment, and if this be the case then increased production from boreholes may jeopardize the life of the existing water supply. It is recommended that two test boreholes in the vicinity of a cluster of dug wells be constructed for observations of the shallow ground water and the water table. No more than three or four boreholes, however, should be constructed in these aquifers until fuller information is obtained concerning their potential long-term yield.

The areas classified as semi-favorable to stock ponds only are those in which the evidence for runoff, i.e., dry stream beds, is negligible. These areas include foothills where upland surfaces support extensive grassland parks and valley floors are lined with thickets of shrubs and trees. The underlying rocks are dense unfractured intrusives and metamorphics, and the alluvium mantling them, largely clay and silty clay, is probably nowhere sufficiently thick or permeable to provide reliable year-around supplies of ground water. Any replenishment to ground water will probably be in competition with the water required by evaporation and vegetation (transpiration).

Areas classed as favorable to stock ponds only lie in the foothills surrounding the mountainous areas, where rainfall and runoff are believed sufficient to support both perennial and intermittent surface-water reservoirs and where igneous and metamorphic rocks prevail and hence are generally unfavorable to the construction of productive boreholes. In some places these rocks crop out over large areas but generally they are covered by alluvial deposits of silty clay, silt, and fine-grained sand. The thickness of the alluvium ranges from a featheredge on hillsides to probably several tens of feet in the valley floors. Locally, these deposits of alluvium may be relatively thick and permeable and if saturated may yield water to dug wells and boreholes. Sandy stream beds traverse the valley floors in many places. Both the hillsides and valleys are covered by moderately dense to dense woodlands. Therefore with the exception of those areas in which the rocks are exposed, the runoff required to sustain surface-water reservoirs would probably be competitive with the water requirements of evaporation and vegetation (transpiration). The elimination of certain types of non-beneficial vegetation from drainage basins would probably be needed before water sufficient to sustain surface-water reservoirs and to support the year-around requirements of livestock could be obtained from surface runoff.

In some places the vegetation is particularly vigorous and these places may reflect areas favorable to the development of small perennial springs.

Areas classified as favorable to stock ponds and springs are mountainous regions where the rocks crop out over large areas and where rainfall and runoff are believed sufficient to support both perennial and intermittent surface-water reservoirs. In these areas the rocks are also sufficiently fractured so that in many places they store ground water; and also where their structure is favorable, they give rise to springs. The probability of high incidence of rainfall and reoccurrence of thunderstorms in these areas may also give rise to occasional heavy runoff or flash floods. Surface-water reservoirs should be constructed with the probability of short-term, high-intensity events in mind. The springs in these mountainous areas nearly everywhere occur in the headwaters of canyons floored by permeable deposits of sand and gravel and overgrown with water-loving vegetation. In these places the water now available to livestock is probably only a part of the total amount of water discharged from the rocks, and methods need to be employed to increase and to localize this water supply. This work should not be undertaken without geologic and engineering guidance sufficient to obtain data on the physical properties of the water-bearing rocks and their geologic structure and the design and cost of appropriate containing and distributing spring-development structures.

Areas of existing water supplies are in the highlands north of Alghe and in areas peripheral to the Dawa Parma River and its major tributaries.

The occurrence and distribution of water in these areas appears to be adequate, both in quality and quantity, to meet needs for livestock without special installations or attention. These areas, however, should be carefully studied to determine (1) the location and distribution of springs, their mode of occurrence, and rates of flow and (2) the location, distribution, and quantities of available surface-water supplies.

Proposed Program of Investigation

Based on the present (1966) reconnaissance the writer recommends a 4-year program of water-supply investigations and pilot development in Sidamo Province that would include the following elements, special equipment and objectives.

Element	Special Equipment	Objective
Drilling of exploratory and test boreholes.	Rotary rig (available in Ethiopia)	Search geologically favorable areas for ground water.
Determine water-bearing properties of sediments penetrated by boreholes	Electric logger. (available in Ethiopia)	Accurate delineation of aquifers and confining layers and improved correlation of strata, plus selection of zones most suitable for development
Continuing record of water-level fluctuations (to start as soon as possible)	Automatic water-level recorder (Stevens A-35)	Identification of factors affecting water-levels, such as use of water from nearby wells, and periodicity and amount of recharge.
Measurement of depth to water in wells.	Steel Tapes (30 and 100 meters)	Same as above.
Determination of conductivity of water and other chemical propertoes such as pH, total iron, nitrate, fluoride and alkalimity.	Conductivity meter and Hach field kit	Determine variation in geochemistry of water geologically and in depth

Measurement of water discharge	50 mm (2-inch) flowmeters	Determine amount of water required by livestock and hence efficiency of windmills as a source of supply
Measurement of water temperatures	Thermometers 20° to 212° F (0° to 100° C)	Determine source of water
Measurement of stream flow	Price pygmy current meter and wading rod	Determine stage and/or discharge of surface water
Geologic and hydrologic mapping	Air photographs scale 1:50,000 overlapping plus controlled mosaics	Determine geologic and hydrologic boundary properties of rocks and overburden, calculate drainage areas and run-off
Geological mapping	Brunton compass	Determine inclination of strata; their structure and position in the subsurface
Geological mapping	Hand lens	Determine mineralogic and physical properties of rocks and their differences
Compilation of data working office	"Stripped" 9 m (30-foot) trailer with chairs and drafting stool and tables	Keep field observation and other records up-to-date, prepare maps and reports
Communication	2-way short-wave radio	Requests for assistance, spare parts, etc., advise on progress
Records	Filing cabinet with lock (in trailer)	Categorize data, preserve records and other valuables

Compilation	Drafting table and accesories (in trailer)	Determine spatial relations, water-bearing zones
do	Office desk (in trailer)	Describe geology, hydrology; recommend drill sites, stock-pond sites, plan spring improvements; etc.
Interpretive report		Explain the basic geology and hydrology of the region; provide guidelines for development of stock ponds and springs and additional wells as an aid in planning long range optimum use of all water resources

Working and Living Conditions

During the field season the geologic and hydrologic investigations team will logically be based at Iavello. The nearest US AID office is at Addis Ababa, capital of Ethiopia and 480 km north of Iavello. Iavello has an Ethiopian population of about 2,000 people and small group of "expatriate" missionaries probably numbering no more than 2 or 3 families. The town is the center for the administrative affairs of southern Sidamo Province and hence the governor and the heads of military and police affairs also reside here. Amharic is the official language. English and Italian are spoken but not by sufficient numbers of people to avoid the necessity for an interpreter or better yet, learning to speak Amharic. Foreigners are treated with utmost kindness and courtesy and this makes up in large measure for the lack of modern facilities and conveniences. Water must be hauled from the nearby spring and boiled and filtered, laundry is done by hand, and cooking and lights are obtained via Coleman or butane lanterns and stoves. All provisions must be well stocked before leaving Addis Ababa and in a manner befitting one who is going into the field. During the writer's brief stay in Iavello and elsewhere he lived in tents, and employed the assistance of a cook and driver-mechanic, both of whom could speak some English. During the dry season of the year a bus reaches Iavello about once a week from towns to the north and trucks loaded with supplies arrive almost daily. During the wet season transport of any kind is quite unpredictable. Expatriate families with children do not live at

Iavello, but the adventuresome wife will find it a hospitable and interesting setting for an occasional visit.

Working in the field will require a good deal of camping out, probably for periods of up to a week or 10 days at a time, and for reasons of both safety and companionship field work would be carried out by teams of American scientists and experienced Ethiopian geologists or hydrologists. This relation also provides opportunity for the exchange of ideas and field methods between American scientists and Ethiopian scientists and engineers. Geologic mapping and reconnaissance hydrological investigations will necessarily resort to photointerpretation and considerable footwork accompanied and assisted at times by packboard, pack mules, donkeys, or camels. All-weather roads are non-existent and bush roads are few and far between. With care, however, much of the country can be traversed by a stout vehicle of the power wagon variety. Field men should bring a light over-under .22-shotgun, .30 caliber rifle and an effective side arm for procuring camp meat and for defense purposes. Thorn bush fences surround all native villages and compounds as protection against night marauders and either this or all-night fires will be required at most camp sites. The area abounds in many species of antelope, giraffe, ostrich, and zebra as well as jackels, hyena, and several species of felines, including lions and leopards. As discussed earlier these "opening" investigations will require a good measure of frontier living under rugged conditions.

Notwithstanding this, the technical aspects of the work appear to be extraordinarily interesting and challenging--as do the non-tecnical aspects.

Ethiopia is a post for which there is considerable interest among American personnel assigned overseas. All US AID families attached to the above development phases of the marketing program will maintain permanent headquarters in the capital city of Addis Ababa; they will join a close-knit American community that throughout the years has maintained a good deal of esprit de corps among its members.

Project Requirements

Personnel

The overall requirements in personnel for the opening of remote country both at home and abroad have been reiterated so frequently that they have become almost a part of the educational curricula for U. S. geologists, engineers, and hydrologists alike. Above all individuals selected for this assignment must exercise good judgement, have a healthy constitution, the desire to work hard,and the ability to "cope" in a part of Ethiopia for which local communications and supplies are practically non-existent.

The reconnaissance investigation carried out in the area indicates that the chief handicaps to effective work will be great distances, a dearth of roads and an all too prevalent lack of communication, supply and repair facilities. The young Ethiopian who accompanied us on our trip is a good example of the type who should be recruited for this job. Although not a geologist he has the right attributes for being a good one. He is young (28) and eager to learn. He has entered the area with confidence, travelled alone by all means of conveyance, purchased cattle from nomadic tribesmen and in general most resourcefully set the stage for the livestock marketing program from this remote area. Recommendations as to technical personnel are as follows:

Chief of Party:--Mature hydrologist with sufficient training in qualitative and quantitative methods so that he can act independently, preferably over 40, and probably in a present grade of GS-13.

He should have considerable experience in dealing with related geologic and hydrologic (including ground water) projects.

Field Hydrologist and Geologist:--These two men should be of equal grade, probably GS-11 or 12, preferably unmarried, or if married, accustomed to periods of separation from home and family, and with experience in quantitative and qualitative field methods employed in geology and hydrology. It is expected that the Imperial Government of Ethiopia will assign at least one well-qualified field geologist to work with the technical staff and be based in the same field station. This would provide excellent opportunities for cultural exchange, one side contributing U.S. techniques and methods, the other a knowledge of the local conditions and problems. There is also a prospect that the project staff will include an Ethiopian hydrologist. Such addition to the staff would be welcomed, in order to develop competent technicians for carrying on when the project is completed.

Other major questions outside the field of hydrology but related to it are the social and economic effects of water-supply developments; a subject of particular interest to the Imperial Ministry of Agriculture. It is realized that such studies will require visits to all sources of water supply and must depend in part upon data that are the concern of the geologist and hydrologist. No specific proposal has been made, but someone specializing in this field may be assigned to work closely with the project staff.

Housing in Field Area

At present there is no suitable space in Iavello, either for office or domicile. Realizing that the project cannot commence effectively until such space become available it is recommended that US AID make all efforts to provide such space before initiation of field work. Requirements in the field would include three 9 m (30-foot) house trailers, one of which can be fitted out with drafting facilities under local supervision, to serve as an office. Ancillary equipment should also include a small 10 HP motor-driven skid-mounted generator (2,000 watt capacity), washing machine, hot-water heater, an outdoor prefab type shower, and 2-wheel trailer mounted with a water tank of about 755 liters (200 gallons) capacity. Camp construction crews should bear in mind that trailers should be grouped at a site that will provide drainage, sufficient head for gravity feet to the plumbing system and a minimum of radio interference. Provisions should also be made for servants' quarters. All vehicles assigned to the project should be equipped with sturdy ball and socket trailer hitch.

Communication with Addis Ababa must be efficient. It is recommended that short-wave radio receiver and transmitter in addition to and compatible with equipment already ordered for use by the livestock marketing program be obtained for the work. A mobile unit is not required.

Two power systems will be required; one electric for lights, radio, and all electric-driven motors, and a second propane for running a hot water heater, stoves, and a compact deep freeze.

Equipment

Following is a tentative list of equipment that will be needed. The "approximate costs" include many estimates, without benefit of catalogs, and may be highly approximate.

Items from U.S. Manufacturer

		Estimated Cost
2	Water-level rec orders, continuous, type A-35 Stevens	$1,000.00
2	Water-meters, Sparling type 2-inch	400.00
1	Conductivity meter battery operated	300.00
2	Hack chemical kits for nitrate, iron, pH. Alkalinity, etc.	100.00
1	Leroy drafting set	50.00
1	Proportional divider, 12-inch	25.00
1 set	Ships curves, triangles, drafting pens and pencils	20.00
1	Planimeter, K and E type	70.00
1	Drafting or drawing set	50.00
1 set	Air photos, contact prints *	2,000.00
1 set	Print laydowns, 1:125,000 *	-
1	Generator (2,000-watt capacity)	400.00
1	10 HP motor unit in combination with above	200.00
1	Wagoneer Jeep Station Wagon	2,500.00
2	Dodge Power Wagons, open bed, canvas cover, or equivalent	6,000.00
1	Two-wheel trailer with springs and 200-gallon capacity tank	800.00

3	House trailers, 2-wheel, 32-foot, gas range, gas hot water heater and small refrigerator in two; one bare of installations to be equipped with office furniture	$6,000.00
1	Small centrifugal pump and gasoline drive unit	250.00
1	Drafting table - 4 legs, upright, tilt top plus drawer	80.00
1	Desk or metal table, plastic top	40.00
1	Drafting stool	15.00
2	Office chairs	40.00
1	4-drawer locking, metal filing cabinet	-
2	Dazor lamps flexible, with desk attachment	30.00
2	Steel tapes, 300-foot, gun-metal blue graduated feet, tenths and hundredths	120.00
2	Steel tapes, 100-meter, gun-metal blue	120.00
2	Steel tapes, 100-foot, gun-metal blue, graduated feet, tenths and hundredths	40.00
2	Steel tapes, 30-meter blue	40.00
2	Geologist's picks	5.00
2	Hand lenses (12 x and 14 x)	30.00
1	Brunton compass	40.00
1	Price current meter, calibrated with wading rods and phones	150.00
2	Stop watches	40.00
	Camping equipment including 2 light weight Safari-type tents with mosquito net lining, 2 light-weight "woods" sleeping bags; 2 light weight canvas flies with grommetts	300.00

2	Trapper Nelson type pack boards with canvas bags	$ 35.00
2	Cots, folding - 36-inch width	30.00
2	Air mattresses	30.00
2	Stoves, Coleman 3-burner	30.00
4	Lamps, Coleman, single mantle	24.00
2	Cooking kits, nest, 4-man	8.00
		$21,412.00

* For beginning phases of the overall project and for use in this proposed project 1,000 individual photographs, scale 1:50,000 should be provided to cover the 1-degree quadrangles in Ethiopia.

(1) 3°00' N to 4°00' N Latitude; 38°00' E to 39°00' E Longitude

(2) 4°00' N to 5°00' N " ; " "

(3) 5°00' N to 6°00' N " ; " "

Each 1-degree quadrangle should be illustrated by print-laydowns, scale 1:125,000.

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Orthography

The spelling of names for physical and cultural features in Ethiopia presents numerous problems in consistency, chiefly because of difficulties of transliterating Amharic, Galla, Arabic, Italian and other locally used languages into exact English equivalents. The following list correlates geographic names used in this report with standard names approved by the Board of Geographic Names (BGN), where possible to verify. Where no standard name is given in the following list, the name is not verified. Where part of the name is underlined, the use of the part not underlined is optional.

Report Name		Board on Geographic Names(BGN)
Addis Ababa		Addis Ababa
Alghe		Algā
Asmara	Eritrea	Asmara
Aselle		Asalā
Adamitullo		Adamitullo
Agaro		Agaro
Amar Cocche		Amar Cocche
Arero		Arero
Auata	stm	Not verified(nv)
Bonga		Bongā
Bole		Bole
Bulchi		Bulchi
Baco		Bāko
Burgi		Burji
Borroda		Borodda
Billate	stm	Billate
Cara		Cara
Cencia		Cencia
Cossa		Kosā
Dawa Parma River		Dawā (Ethi) Dāwa Parma (Ital and Br)
Dilla		Dilla
Dime		Dime
Dalle		Dalle
Digalu	stock pond	
El Melbana	well	Melbana
El Sod	crater	El Sod

Great Rift Valley		Great Rift Valley
Ganale-Doria	(Ethi) stm	Ganālē-Dorya
Gimma		Jimā
Giarso		Giarso
Gogeb stm		Gojab
Gardulla		Gardulā
G. Gorai		
Hora Abgiata	lake	Hora Abgiata
Hosanna		Hosāenā
Hula		Hula
Hobok Spring		
Iavello Spring(Yavello)		Yabēlo
Iarbu-Hobok		nv
Kenya		Republic of Kenya
Lake Stephanie	playa(Kenya)	Ist' Ifānos (Ethi)
Lake Ruspolt		Lake Ruspoli
Lake Zuai		Zeway
L. Langanno		Lāngānā
L. Scialla		Sholā
L. Uombo		nv
Lake Rudolf		Lake Rudolf
Lake Auasa		Awusā
Lake Myluis		Lake Mylius
Lake Marguerita		Lake Marguerita

Mega		Mēgā
Magado	crater	
Massuaua	Eritrea	Massaua
Moyale	(Kenya)	Moyale
Moiale	(Ethi)	Moyālē
Maraua		Maraua
Magado	area	Magado
Neghelle		Nagēlē
North Horr	(Kenya)	North Horr
Omo Bottego	stm	Omo Bottego
Ririba	stm	Ririba
Sidamo Province		Sidāmo
Shashenenne		Shāshamani
Soddu		Sodo
Sagan		Sagan
Soghidda wells		
Uondo		
Uabi	stm	Wēbe
Yirga Alem(Yrgalem)		Yirga Alem

Appendix

A long-range Regional Livestock Development program for southern Ethiopia including development of the water supply is a basic enterprise of the Ethiopian government. A part of this program calls for contract documents covering the drilling of exploratory and test boreholes in the development region, and initiation of this work as soon as possible. Figure 1 indicates 6 sites chosen for exploratory boreholes in areas where they should have a reasonable chance of encountering sufficient water for livestock. Three of these sites are south of Mega, in the central part of a broad valley leading southward from the hills surrounding Mega; two are northwest of Mega along the axis of a similar valley and one is in a low-lying area about 1 mile northeast of the air strip at Mega. The sites can be reached by road with short intervals of cross-country driving.

The three borehole sites south of Mega are believed to be underlain by tuffaceous deposits covered with a thin veneer of alluvial sand and clay. These deposits probably rest uncomformably igneous and metamorphic rocks of the same type that crop out in the hills of Mega. A borehole at the site nearest the hills of Mega may encounter only a thin section of tuffaceous deposits or it may penetrate from alluvium directly into metamorphic rocks. This borehole would be the least likely to encounter water-bearing rocks among the three sites south of Mega. Boreholes at the two southermost sites should encounter water in tuffaceous deposits between 25 and 35 m below land-surface datum.

The two borehole sites northwest of Mega are believed to be underlain by poorly stratified alluvial deposits of sandy silt. These deposits may in turn rest upon volcanic or metamorphic rocks. Very little can be predicted concerning the depth to water, the nature of the water-bearing sediments, or the yield of boreholes at these two sites, but the prevalence of green vegetation along the axis of the valley suggests that ground water may be present at shallow depth in alluvium.

The borehole site about 1.6 km northeast of the Mega air strip is believed to be underlain by volcanic rocks that have originated from nearby explosion craters. The thickness and physical properties of these deposits are not known. They are believed to rest unconformably upon metamorphic rocks. Ground water may be encountered in the lower part of the volcanic sequence directly above the metamorphic basement rocks.

At none of the proposed borehole sites should drilling be attempted beyond depths at which metamorphic or igneous rocks of the basement complex are first encountered.

Provision in a contract covering drilling activities at these sites should include the following requirements:

1. Representative samples of all strata penetrated at each borehole shall be collected at 3 m vertical intervals and at any interval in depth at which water-bearing rocks are first encountered or where drilling rates or other conditions indicate a change in the physical properties of the strata.

These samples should be logged by a qualified geologist and the cuttings, in appropriate wooden containers, and the logs, turned over to representatives of US AID.

2. Electric logs including a resistivity and self-potential log shall be provided by the contractor and become a part of the documentation of each borehole.

3. Boreholes shall be of sufficient diameter to accommodate 152 mm (6-inch I.D. A.P.I.) casing. Casing shall be installed throughout the depth of the borehole and slotted sufficiently to allow optimum conditions for entry of water and elimination of detritus from walls of the borehole.

4. Each borehole shall be developed over a sufficient period of time to insure the removal of drilling mud from water-bearing strata and other fine-grained sediment that might during its subsequent use, impair its efficiency or cause damage to installations.

5. Casing shall be recovered at abandoned boreholes and the cost of the casing less the cost of its installation and recovery shall be reimbursable to the contracting agency at prices and rates stipulated by the contract.

6. Each borehole initiated by the contractor must be originated by a work order from the contracting agency representative in-charge documenting the design and objectives of the borehole and its estimated cost.

7. Each borehole completed by the contractor must be terminated by a certificate of Work Satisfactorily Completed documenting the various rates, costs and items performed by the contractor, this document being the statement upon which payment to the contractor shall be based.

Items for which rates and prices shall be provided by the contractor include the following:

1. Moving equipment to site area for work there and removal from that site area upon completion

EACH SITE AREA THE SUM OF

2. Erection of equipment at a drilling site, dismantling upon completion

EACH SITE THE SUM OF

3.(a) Drilling from surface to full depth drilled, at such diameter as is necessary for completion of a well 152 mm (6 inches) I.D.

AT PER METER

(b) Drilling at such diameter as is necessary for the lining of a well 152 mm (6 inches) I.D.

AT PER METER

4. Supplying and installing (6 inches) API line pipe as well lining

AT PER METER

5.(a) Cleaning out and developing of 152 mm (6 inches) I.D. well

THE SUM OF

5.(b) Provide and install airlift equipment in 152 mm (6 inches) I.D. well and compressor also, remove upon completion of testing

THE SUM OF

(c) Operate compressor for airlift pumping

AT PER HOUR