REPUBLIC OF LIBERIA

FEASIBILITY STUDY FOR MANUAL DRILLING

MAPPING OF FAVOURABLE ZONES

PRACTICA FOUNDATION

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CONTENTS

1.0 INTRODUCTION

The objective of this study is to organize and revise existing hydrogeological data in Liberia in order to have an initial knowledge of areas where environmental and hydrogeological situation could make hand drilling techniques potentially suitable at low cost and as sustainable solution to increase the availability of potable water for the population.

The institutions concerned with this study are the Liberian Hydrological Service (LHS), Ministry of Lands, Mines and Energy, Ministry of Public Works and Ministry of Health. Other International structures that collaborated are UNDP and Action Against Hunger (ACF).

The present document is structured in three parts:

- Databases concerning information on water points
- General data of Liberia, concerning the aspects that contribute to the objectives of the project.
- Identification and cartography of the regions favorable to hand drilling and the feasibility of the project in the context of the national water supply policies in Liberia.

Baseline documents of the project

N°	Title of publication	Institution	Remarks
1	Preliminary study for the Water Supply of Kolba City Kolahoun, Lofa County (1982)	LHS	Investigated ground water potential
2	Reconnaissance Survey of fourteen towns in Grand Cape Mount County (1980)	LHS	Investigated ground water potential
3	Water supply of Belle Yella Town, Lofa County (1985)	LHS	Survey recommended hand dug wells
4	Preliminary study for the Water Supply of Kahnplay Town, Nimba County (1981)	LHS	Investigated ground water potential in overburden
5	Preliminary study for the Water Supply of Zorzor City, Lofa County (1983)	LHS	Investigated ground water potential in overburden
6	Preliminary study for the Water Supply of Graie Town, Nimba County (1981)	LHS	Investigated ground water potential in overburden
7	Preliminary study for the Water Supply of Tappita Town, Nimba County (1981)	LHS	Investigated ground water potential in overburden
8	Recommendations on the water supply for 18 villages in Gbehlay Srohlay, Nimba County (1981)	LHS	Investigated ground water potential in overburden
9	Preliminary study for the Water Supply of Foya Kamara, Lofa County (1982)	LHS	Investigated ground water potential in overburden
10	Report on the water supply systems for the industrial plantation in Zarway, Grand Cape Mount County (1980)	LHS	Described water well drilling in overburden
11	The water supply for Vahun, Lofa County (1979)	LHS	Described hydrogeological conditions of the town
12	Report for the inspection of 76 wells in Nimba and Maryland Counties (1980)	LHS	Detailed characteristics of hand dug wells

13	Stratigraphy and structure on the Coast of Liberia, USGS (1972)	LHS	Described sedimentary basins of Liberia
14	Hydrogeological characteristics of the unconsolidated sediments in the Monrovia area (1981)	LHS	Described the geology of Monrovia and its environs
15	Geological, geophysical and mineral localities map of Liberia – A digital compilation (2007)	LHS	Contained metadata set of the geology of Liberia

1.1 LIBERIA GENERALITIES

1.2. Physical setting

Liberia is situated on the southwestern corner of the West Coast of Africa. It has a surface area of about 111,400 sq. km. out of which 14% is covered by water. Liberia borders Sierra Leone to the west, Guinea to the north, Côte d'Ivoire to the east and the Atlantic Ocean to the south.

Climate

Liberia has a tropical climate with relatively small variations between day and night and between seasons. Temperatures never exceed 37 degrees C. There are two seasons - the wet season from May to October and the dry season from November to April. The annual rainfall averages 4,320 millimeters inland. The average humidity in the coastal belt is 78% during the wet season, but it is liable to drop to 30% from December to March when the Harmattan winds blow from the Sahara.

The climate, especially on the coast, is warm and humid year-round, dominated by a dry season from November to April and by a rainy season from May to October. The dusty and dry *harmattan* (desert winds) blows from the Sahara to the coast in December, bringing relief from the high relative humidity. Deforestation and drought in the Sahel have affected the climate, lengthening the dry season by almost a month in some areas.

Mean annual temperatures range between 65° F (18° C) in the northern highlands to 80° F (27° C) along the coast. Rainfall is irregular, and the rainy season varies in intensity and begins earlier at the coast than in the interior. The greatest amount of rainfall, 205 inches (5,200 mm), occurs at Cape Mount and diminishes inland to about 70 inches (1,800 mm) on the central plateau. The interior has hot but pleasant days and cool nights during the dry season.

Relief

There are three major physiographic regions of Liberia in parallel with the coast. described below:

The Coastal Plains

The coastal plains are about 350 miles (560 km) long and extend up to 25 miles (40 km) inland. They are low and sandy, with miles of beaches interspersed with bar-enclosed lagoons, mangrove swamps, and a few rocky promontories—the highest being Cape Mount (about 1,000 feet [305 meters] in elevation) in the northwest, Cape Mesurado in Monrovia, and Cape Palmas in the southeast.

The Rolling Hills

Parallel to the coastal plains is a region of rolling hills some 20 miles (32 km) wide with an average maximum elevation of about 300 feet (90 meters); a few hills rise as high as 500 feet (150 meters). It is a region suitable for agriculture and forestry.

The Dissected Plateau

Behind the rolling hills, most of the country's interior is a dissected plateau with scattered low mountains ranging from 600 to 1,000 feet (180 to 305 meters) in elevation; some mountains rise to 2,000 feet (600 meters). A striking feature of the mountainous northern highlands along the Guinea frontier is Mount Nimba.

Soils

Four types of soil are found in Liberia. Latosols of low to medium fertility occur in rolling hill country and cover about three-fourths of the total land surface. Shallow, coarse lithosols, in the hilly and rugged terrain, cover about one-eighth of the land. Infertile regosols, or sandy soils, are found along the coastal plains. Highly fertile alluvial soils represent a small percentage of the land area and are utilized largely for agriculture.

Drainage

There are several important rivers in Liberia. The longest is the Cavalla River shared between Liberia and Cote D'Ivoire while the Mano River is shared between Liberia and Sierra Leone. St. Paul River is the second longest river feeding Mt. Coffee hydro-electric plant and providing the bulk of the raw water for Monrovia.

There are only two major lakes in Liberia – Lake Shepherd in Maryland County and Lake Piso in Grand Cape Mount County, with Piso being the larger of the two. Both of them are situated along the Atlantic Ocean, with Lake Piso characterized by a vast expanse of wetlands and lowland forest vegetation.

The Mano and Morro rivers in the northwest and the Cavalla in the east and southeast are major rivers and form sections of Liberia's boundaries. Other major rivers include the Lofa in the north and St. Paul, St. John, and Cestos rivers southward, all of which flowing perpendicular to the coast. The Farmington River is a source of hydroelectric power. Waterfalls, rapids, rocks, and sandbanks occur frequently in upstream sections of most rivers, inhibiting river traffic, and limiting navigation inland to short distances. During the rainy season there is often severe flooding in the coastal plains.

Liberia forms part of the West African Shield, a rock formation 2.7 to 3.4 billion years old, composed of granite, schist, and gneiss. In Liberia the shield has been intensely folded and faulted and is interspersed with iron-bearing formations known as itabirites. Along the coast lie beds of sandstone, with occasional crystalline-rock outcrops. Monrovia stands on such an outcropping, a ridge of diabase (a dark-colored fine-grained rock).

Water resources. Liberia is endowed with abundant water resources, but the proper management and planning of these remain crucial to meeting the national priorities and goals and reducing conflicts between competitive uses. This problem is further compounded by various administrative, technical and political problems, particularly the poor state of the Liberian economy after 14 years of civil strife.

Generally, groundwater is available and can be exploited in most parts of the country in quantities needed for rural water supply, which relies on dug wells and to some extent on drilled boreholes. Data from the rural water supply program indicate that the depth to the water table in shallow wells can be less than one meter. Drilled boreholes can be as deep as 100 meters. However, reliable data on boreholes and yields and data on water quality both from surface and groundwater are scarce.

Domestic sewage, however, causes many problems as the only conventional sewerage system, which was already poorly functioning before the civil crisis is out of operation. Some sewage water is collected by vacuum trucks and disposed of into lagoons and other water bodies. In some areas there are indications that water quality is deteriorating due to mining, logging, farming and industrial activities.

1.3. History of water and sanitation in Liberia

Urban Water Supply

Prior to 1948, water was available to the residents of Monrovia only from private wells and cisterns most of which were highly contaminated. Thereafter in 1948, three wells were constructed in Point Four, which supplied water to Monrovia. As the population rapidly grew and the economy developed, the demand exceeded the productive capacity of these wells. In 1952, infiltration galleries with a pumping station were developed in New Kru Town (Bushrod Island). Since then, the water supply system had undergone successive expansions to culminate by 1980, in the capacity of the White Plains Water Treatment plant being increased to 60.5 million m^3 per day. A chronological development of Monrovia's water supply between 1948 and 1980 is given in Table 1 below.

The Monrovia Water Supply System was damaged on three occasions between 1990 and 1992. It was put out of operation again in 1996 and in 2003. Recent rehabilitations have restored the system to 25% its pre-war capacity of 16 million gallons per day, pumping and distributing about 4 million gallons of water per day to Monrovia and its environs.

Between the period 1970 and 1985 pipe-borne water supply systems were developed and commissioned in ten (10) urban centres (mainly county capitals) as shown in Table z. All of these systems were severely vandalized during the war and none has been restored to pre war conditions.

Nine of the Outstations were constructed specifically by Liberia Water and Sewer Corporation (LWSC) while the tenth plant was inherited from the Liberia Mining Company in Tubmanburg when the Bomi Iron Mine closed down in 1977. Seven of the Outstations (Tubmanburg, Harper and Greenville excluded), were constructed between 1978 and 1985 at a total cost of $17.34 millions provided as a soft loan by the West German Government (KFW).

The laudable policy of launching regional development by massive investment in basic infrastructure beginning in the late ‘70s has not been fruitful in this particular sector. Indeed, after the investment of nearly $20 M in Outstation Infrastructure, only 35,000 people were benefiting before the war. Four water treatment plants (Buchanan, Greenville, Kakata and Zwedru) rely on Groundwater, which is pumped from deep boreholes while the other six Outstations use surface water. For design purposes, the per capita consumption for the treatment plants was set at 70 liters per person per day (18.5 US gallons/day) and plant capacity was designed in general to meet the needs of populations projected 15 years ahead.

At the outbreak of the war, LWSC reported that the nine functioning water treatment plants produced an overall average of 658,000 GD (29 l/sec) compared with the design capacity of 3.7 MGD (163 l/sec.) This water served 34,000 people or an average of 19 G or 72 liters per person/day. The similarity between declared consumption rate and design capacity suggests that since there was probably only limited bulk metering and most usage was on an un-metered flat rate basis, Outstation water production was estimated by means of billing rather than flow into the transmission mains. The aggregate Production of the Outstations was probably much greater than that declared.

TABLE 1: CHRONOLOGICAL DEVELOPMENT OF MONROVIA’S WATER SUPPLY SYSTEM

YEAR	**DESCRIPTION**
< 1948	No protected water supply to Monrovia.
1948	Three wells were constructed in Point-Four which supplied water to Monrovia.

1952	Infiltration galleries with a pumping station were developed in New Kru Town (Bushrod Island). The average production capacity of the collector wells was 1,500 m^3/day and a maximum capacity of 3,785 m^3/day. The transmission main was a 16" diameter transmission main extending approximately 5,500 meters from Bushrod Island pumping station to the Monrovia distribution system. The system also included a 2,270 m^3 reservoir located at Mamba Point, the highest elevation in the city, and a distribution system extending from Mamba Point reservoir throughout Monrovia proper to the Camp Johnson Road area. The total length of the distribution system installed was approximately 20,700 meters, all of cast iron pipe, of which 50% was 4", 40% was 8" and 10% was 6" diameter.
1954	Ducor Reservoir constructed.
1957	The population of Monrovia had increased to over 50,000 and it became apparent that Bushrod Island filtration galleries were not capable of meeting the increased demands. There was also the problem of sea water intrusion as a result of over-exploitation of the wells. To meet the increasing demand, a slow sand filter plant at White Plains approximately 21 km upstream the Saint Paul River from Monrovia was constructed to augment Bushrod Island galleries.
1960	Slow sand filters at White Plains water treatment plant commissioned. The treatment plant facilities included intake and raw water pumping station at the Saint Paul River, settling basins, slow sand filters and chemical feed equipment. The White Plains plant had a capacity of 5680 m^3/day. Finished water was pumped to Monrovia through a new 16" diameter transmission main along Mount Coffee Road approximately 18.7km in length. The project further included a booster station located on the new 16" transmission main at Bushrod Island and the construction of a 3785 m^3 reservoir at Mamba Point with the same elevation as the Ducor Reservoir constructed in 1954. Only two major extensions to the distribution system were made in this phase. One was the 6" main from the new 16" transmission main to the Monrovia Brewery, and the other was the 6" diameter asbestos feeder main to the Sinkor area.
1961	Early in 1961, the above facilities were inadequate to meet the rapidly increasing water demand of the fast growing population which was now estimated at about 75,000. As a short-term solution, the plant capacity was increased to 7750 m^3/day.
1967	The third phase of the Monrovia's water supply expansion started; involving intake, raw water pumping station, two flocculation basins, two settling basins, and four rapid sand filters. Also included were chemical facilities, clear water pumping station, clear water reservoir of 3,785 m^3 capacity, chlorination and electrical facilities.
Dec. '68	A 36" diameter transmission main was constructed from White Plains to Monrovia via Johnsonville, Paynesville, Congo Town, where the main reduces in diameter to 24" extending to Sinkor, and ending as 16" main at Mamba Point. Substantial reinforcements and extensions of the distribution system were made under this expansion phase. The total length of the distribution system was doubled by adding some 30 km of cast iron pipes ranging in diameter from 4" to 12". These facilities provided a safe and reliable water supply for the greater Monrovia area until about 1973/74.
1980	With consecutive improvements to meet the rising demand, by 1980, the capacity of the White Plains Water Treatment plant was increased to 60.5 million m^3 per day (that corresponds to a continuous

	production of 700 liters per second, 24 hours per day).

TABLE 2: DETAILS OF OTHER URBAN CENTER WATER SUPPLY SYSTEMS

No.	City	Water Source	Year Completed	Design Population
1	Gbarnga	Surface water	1978	7500
2	Sanniquelle	Surface water	1979	9500
3	Voinjama	Surface water	1980	8600
4	Buchanan	Groundwater/ Nine boreholes/ Six operational before 1990 with the capacity of 300,000GD	1981	31000
5	Kakata	Groundwater/ Four boreholes/ Two operational before 1990 with the capacity of 213,000GD	1984	20800
6	Zwedru	Groundwater/ Three boreholes/ Two operational with the capacity of 32 cu m/hr	1980	8000
7	Robertsports	Surface water	1985	3000
8	Harper	Groundwater	1971	10000
9	Greenville	Groundwater/ Infiltration gallery	1970	8000
10	Tubmanburg	Surface water	n.a	10500

Note: The population served is estimated for the year of completion of the water supply system. (source: National Action Plan 1985 -1997).

The minimum price of water from 1985 to the outbreak of the war was $ 2.1 per 1000 gallons. Approved budgets for total operating expenditure of the Outstations were $L 476,5000 1989 and $L 511,443 in 1990. Billed cost recovery in 1989 ($L 230,000 expected but only partially collected) was sufficient to meet only about 48% of annual current expenditure which consisted of $L 179,750 for chemicals, fuel, spares, etc., and $L285,600 for personnel (56 field staff and 11 headquarters staff). Budgeted expenditure did not include any provision for capital investment or repayment of debt.

Rural Water Supply and Sanitation

Records suggest the implementation of a structured rural water supply program from 1974. The NRWP as it was referred to, began in the then Ministry of Local Government, Rural Development and Urban Reconstruction as a US Peace Corps Volunteer program. Major activities included the development of shallow hand-dug wells fitted with Consallen and Aweiller hand pumps, spring catchments systems and mini hydro electric dams, such as one constructed in Yandohun, Lofa County.

In 1975, an Act of the Liberian National Legislature created the Agency for Action Development and Progress (ADP) which managed many programs that had direct impact on the wellbeing of rural people. The National Rural Water Program, the National Feeder and the rural sanitation programs were then transferred with their staff to the Agency for Action, Development and Progress. As a result of increased funding support particularly from donors (UNDP, UNICEF and the EU) a rural sanitation (VIP latrines) component and nine county-based (cable tool, percussion) drilling fleet was added, although the nomenclature remained unchanged. Water and sanitation project activities were also implemented through the EEC in 4 counties (Grand Bassa, River Cess, Sinoe and Grand Kru Counties). The Program also seconded technicians to agricultural projects with rural water supply and sanitation components. These were the German Technical Cooperation (GTZ) rural development project, the World Bank funded Lofa and Bong Counties Agricultural Development projects.

In 1982, an Act of the National Legislature of the People's Redemption Council (PRC), created the Ministry of Rural Development and transferred the activities of the Agency for Action, Development and Progress and made the National Rural Program headed by a Program Coordinator, a full fledged program with an annual development budget to serve as matching fund to donor support.

Rural water supply and sanitation had been a shared responsibility among a considerable number of agents. By 1987, there was a strong collaboration with the Ministry of Health & Social Welfare – Division of Environmental & Occupational Health (DEOH), the Ministry of Lands, Mines & Energy – Liberia Hydrological Services (LHS), Plan International and the Christian Health Association (CHAL), a creation of the Lutheran Church of Liberia. Other areas of work included the formulation of an organized body to harness the cooperation of the fragmented structure of water supply and sanitation activities, what has become known in history as the National Water Supply and Sanitation Board.

The National Rural Water Program received a major boost in 1987, when the British Overseas Development (ODA), under the British Government granted funding to hire the services of M Sir McDonald & Partners.

The work of this consulting firm resulted into the commissioning of documents for the rehabilitation of the Program. These included a thorough assessment of existing capacities – logistical and manpower and the subsequent formulation of guidelines to the policy aims and practical implementation of activities of the Program. Among these are the Policy and Implementation Manual and Social Appraisal documents.

The work of the consultants coincided with the implementation of the Southeastern Village Water Supply Project based in Grand Gedeh, Sinoe, Grand Kru and Grand Bassa Counties. The war pre-maturely disrupted the implementation of the software component of the project.

2.0. METHODOLOGY FOR THE IDENTIFICATION OF THE FAVORABLE ZONES:

For the identification of zones favorable to manual drilling in Liberia, the following conditions have been mainly considered: geological, hydro geological and morphological suitability.

GEOLOGICAL SUITABILITY - Manual drilling can be carried out only in the granular formations which hardness is suitable to be drilled by a manual tool for perforation not motorized.
It is referred to many modestly or not consolidated sedimentary formations and the covering of the base rocks (overburden layer, weathered rocks).
Several geological formations as their overburden layers show characteristics thickness, hardness and permeability, favorable to the realization of manual drilling.
The overburden and weathered layers are not mapped on the available geological maps, but in several parts of the country they constitute rather deep and permeable surface aquifers to allow their exploitation with this type of drilling. To identify these zones the potential overburden layers (thicknesses and characteristics) of each geological formation has been considered.
The presence of hand dug wells with large diameter (1-3 meters) has been also considered an important positive factor. Even if there is a presence of hand dug wells in hard rocks, the existence of a considerable number of hand dug wells potentially indicates conditions of low hardness and sufficient permeability of the surface layers.
The main limitation of the analysis is that the records of water points (well and drillings) do not contains stratigraphic logs nor general data on lithology, which obliged to estimate the potentiality only on general information concerning the geological formations and the aquifers.
The delimitation and the classification of these zones were made on the basis of vectorial Geological Cartography (USGS 2007 and provided by the Liberia Hydrology Service) and the reports agreed by the LHS.

For the delimitation of the zones with exploitable alteration layers, the available data (depth of hand dug wells) have been used to check and modify the interpretation made on the basis of geological map and the general characteristics of the various formations.

HYDROGEOLOGIC SUITABILITY - In the sedimentary basins and alluvial sediments, the piezometric level of the ground water has to be in the first 25 meters. In crystalline rocks, the alteration of the base rock has to be thickest possible, made up of permeable materials, and wet at the base on a height higher than 4 meters. The general analysis of the distribution in the space of the water points with their static levels also allow to consider homogeneous zones where, for sterility of the formation or for topographic motivations, the water level is lower of the depth desired for manual drillings.

MORPHOLOGICAL SUITABILITY – In certain zones, the morphological conditions of the crystalline formations or of the alluvial deposits can be cause of a high thickness of alteration and therefore favorable to manual drilling. A morphological analysis was carried out to identify the zones where the overburden and weathered layers can be probably thicker, for example on the alluvial deposits of limited extension and thus not recorded in the geological map; moreover, the analysis of morphology can be also used to estimate the depth of the static levels. The geographical location and the morphological environment of the formations having a fragmented distribution were also considered. The classification of the topographic characteristics was made starting from the Digital Elevation Model (SRTM) coming from radar surveys and available in Internet.

2.1. Classification according to the geological suitability

2.1.1. Methodology of estimation of the geological suitability

The main information source for the delimitation of the geological suitability in the various zones of the country was the USGS Geological map in vectorial ESRI shape files. It is a geological map including 76 formations or groups of formations with similar characteristics.

No other detailed maps in vectorial format, has been found.

For the estimation of the geological suitability, the 76 formations or groups of formations have been synthesized into 20 and the following parameters were considered:

- the hardness of each formation (in relation of the suitability for manual drilling). For the case of hard rocks, the presence and the characteristics of the layer of alteration has been taken into account
- the thickness of the tender layers.
- the general permeability of the aquifer and/or of the overburden and weathered layers when it is present.

From these parameters it has been possible to evaluate a general aptitude of each geological formation (or its alteration layer) to develop an aquifer usable by manual drillings.

The simplification of the geological map and the hydrogeologic characteristics of the formations or groups of formations obtained has been made in collaboration with the Liberia Hydrological Service.

The GIS database of the water points of Liberia has been made in gathering many other databases and tabular data and totaling about 3500 hand dug wells and 360 boreholes.
It provided valuable information on:

- geographical coordinates of the water points (with good quality of "georeferencing")
- administrative units of the water points (town or village, district, county)
- static water levels,
- depth of the wells/boreholes,

The quality and validation check of this database showed:

- reliable geographical coordinates (No filtering GIS necessary)
- fairly homogeneous information (each level of information is present in different percentage: water level in hand dug wells is present in about 30% of records, total depth in 62-65%)

The limit of manual techniques of drilling is around 30-40 m and the depth of the static level should not exceed the 25m.
In the case of boreholes it must be checked that, if the static level is less than 25 meters, it can refer to the 'aquiclude' pressure level, where the real water table is in a depth not accessible with hand drilling tools.
The hand drilling can be only realized in the tender formations.

Therefore it is estimated that:

- hand dug wells and boreholes having a static level comparable with the one awaited for manual drillings indicate aquifers with accessible water level. As already specified, in the case of boreholes it must be checked if it is an aquiclude (e.g. Co-presence of well and drillings with similar Static Level or comparation between Static Level and Total Depth of the wells: where the difference is limited, the arrival of water coincides with the Static Level, therefore the water table is surely not in pressure).
- the hand dug wells having a depth comparable with the one awaited for manual drillings indicate favorable grounds to the hand drilling techniques;
- the concentration of the hand dug wells compared to boreholes shows the zones more favorable to the manual digging.

The distribution of the wells estimated starting from the database cannot be exhaustive compared to reality on the territory because:

- <u>many counties do not have water points data</u>
- many wells are not recorded in the official information (for example, the presence of traditional wells may be under estimated).

- the distribution of the wells is not only related to technical feasibility, but also to the distribution of the population and the presence or not of alternative sources of water.

Therefore in the analysis it has been regarded that a great presence of traditional wells is a potential indication of the existence of tender and exploitable layers by manual drillings, but the zones where the number of wells is limited have not automatically be considered as “not positive”.

2.1.2. First results of the geological classification of feasibility

The result of the classification of the geological formations and the comparison with the database hand dug wells and boreholes is the geological map of aptitude for manual drillings. These first geological classes of aptitudes were defined in the following method:

- High feasibility: concerns the sedimentary formations that show very favorable characteristics (low hardness, sufficient permeability) in all the zones where they can be dug with manual drillings
- Medium feasibility: concerns the formations which present sediments or alteration layers with hardness, thickness, permeability and static level conditions which are considered partially favorable to manual drillings; this kind of feasibility is also concentrated in the zones with thick overburden layers (often by the presence of a strong rock fracturation) and connected with the hydrological network.
- Low feasibility: the formations present not favorable bed rock conditions and do not present, in general, exploitable alteration layers.

2.2. Classification according to the morphological feasibility

Most of the country is formed by geological units which are not favorable because of the nature of the bed rock, but can be covered by an important alteration layer, exploitable by manual drillings.

The existence of permeable sub-surface layers and low hardness can be related to the thickness of the weathered layers (in relation to the characteristics of the rock), but also with the existence of a surface morphology which can reveal the presence of not mapped deposits of unconsolidated or alluvial sediments. In the available cartographic information there is not a geomorphologic map. For this reason it has been used as cartographic basis a map prepared from the Digital Elevation Model (SRTM). An automatic procedure based on an algorithm (Topographic Position Index) has been applied to this map. At each zone a class of topographic position has been assigned. The identified topographic fields are:

- Depressed zones
- Weak slope zones
- Steep slope zones
- Relief zones

The algorithm makes a comparison between the elevation in each pixel and in the close ones, within a distance which must be defined by the technician according to the drainage density.
In this case the zones more interesting to analyze were the already defined Medium feasibility zones on weathered layer in order to classify them better.
The results of this analysis has been the exclusion of the relief zones and of the ones with a slope higher than 5°, mainly to avoid the presence of emerging rocks in medium feasibility formations.

2.3. Classification according to the hydrogeologic feasibility

The observation of a concentration of hand dug well with static levels higher than 25 meters force to a declassification to weak feasibility of the zones where the formations would have a good geological aptitude. In general the conditions of sterility of the formation or the depth of the water level are an independent parameter to evaluate the feasibility of this tool.

2.4. Integrated Analysis

The territory of Liberia has been thus classified, by taking account of the above mentioned principles, in the following categories of feasibility of Manual drilling.

<u>Category of feasibility:</u>

1. High - This zone was classified with strong potential on the basis of presence of granular layers of sediments with a good permeability, a static level rather close to the ground surface, and a good possibility of being dug with the techniques of hand drilling. Studies should be carried out to check water quality. Classification relates to the majority of the recent alluvial sediments.

2. Medium with thickness constraints - This zone was classified with medium potential, but the thickness of the overburden layers is irregular. It has a medium permeability (locally variable). In general the static level should be rather close to surface, and the sediments concerned present a good potentiality to be dug with the techniques of manual drilling.

3. Medium with permeability constraints - This zone was classified with medium potential, but the permeability of the overburden layers is irregular. In general the static level should be rather close to the surface of the ground, and the grounds concerned present an average potentiality to be dug with the techniques of manual drilling; these conditions must be thus checked at the local level.

4. Medium with thickness and permeability constraints – the thickness and the permeability of the overburden layers is irregular. The granular sedimentation anyway allows the presence of hand dug wells and the suitability is not low; these conditions must be thus checked at the local level.

5. Low (F) – Cause of the conditions of morphological situation, slope, hardness, permeability and static level, these zones do not show the characteristics of feasibility of manual drillings.

Considering the absence of drilling logs, in certain formations, particular constraints can be constituted by deep superficial clay layers which can determine acquicludes. This constraint can cause a bad interpretation of the static level.

In order to improve the drinking water availability for the populations of Liberia, it can be noticed that the best advantages could be obtained by crossing information related to the number of inhabitant and its growth rate, the rate of water accessibility (information not available) and the zones having better feasibility of manual drillings. There will be probably the best results in terms of effectiveness, in the Departments which present high population and rates of increase, located in areas with low level of water availability, and in the more favorable territories in terms of suitability for this type of tool.

3 Conclusions

The feasibility study of manual drillings in Liberia has been carried out on geographical basis (GIS), through the collection of geological data and integrates the data collected on ground water.
The study has helped to have a rather broad vision on the geological and hydrogeologic context of Liberia and allow a general identification of the favorable zones for manual drilling, with all the limitations of a massive data processing.

In the HIGH favorable zones, the limitations and the constraints indicated will be anyway regarded as factors to deepen locally, to improve the possibilities of success in terms of good characteristics of drilling.
In the MEDIUM favorable zones, the conditions of thickness of the overburden and weathered layers, of permeability and the conditions of the underground water resources, could be considered locally by the local geologists according to their experience and through the studies of geo lithologic and geophysics surveys which could be carried out in a second phase.

1 - Hand drilling

2 – Samples

3 – Completed

Feasibility study of manual drilling

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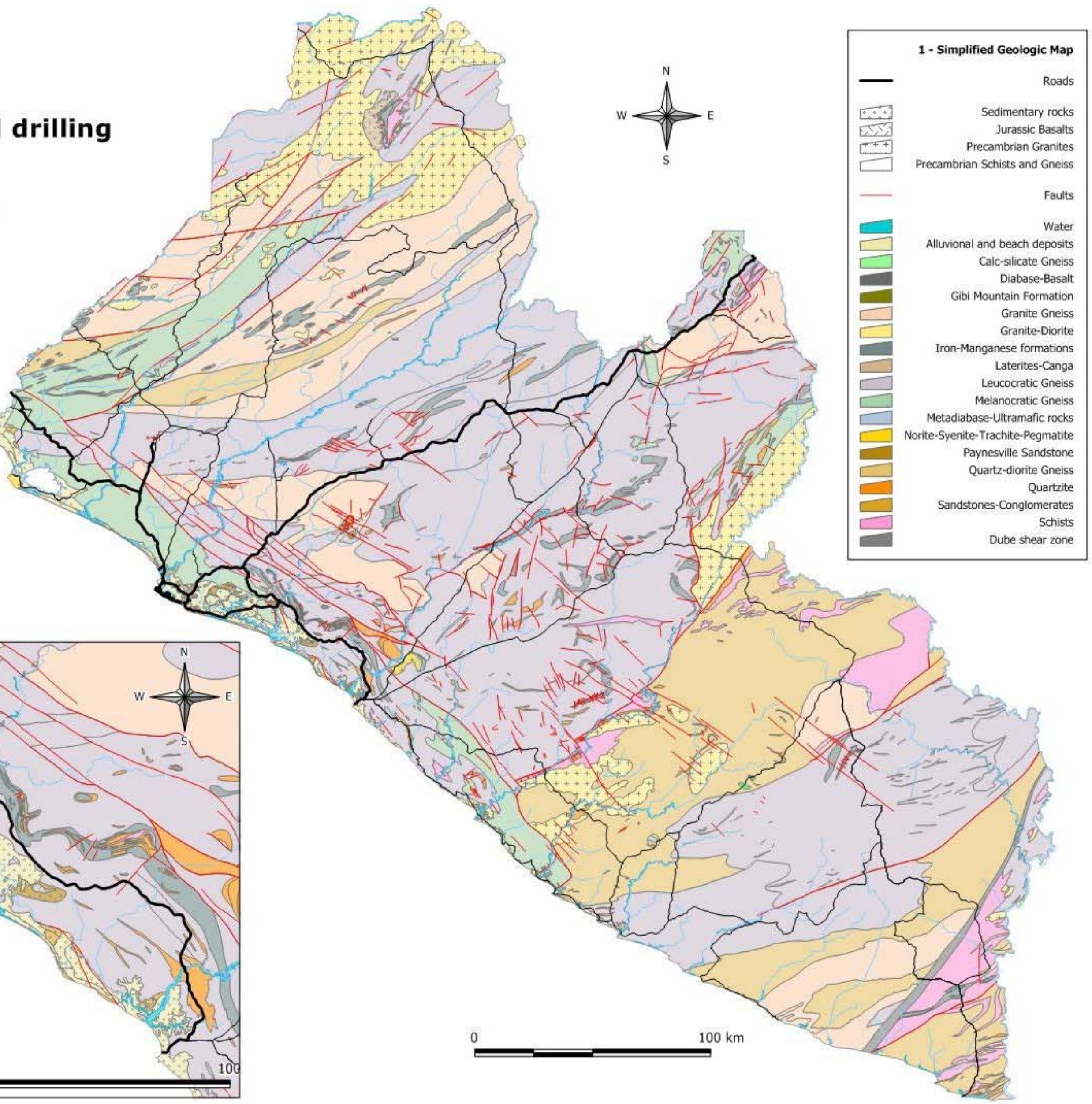
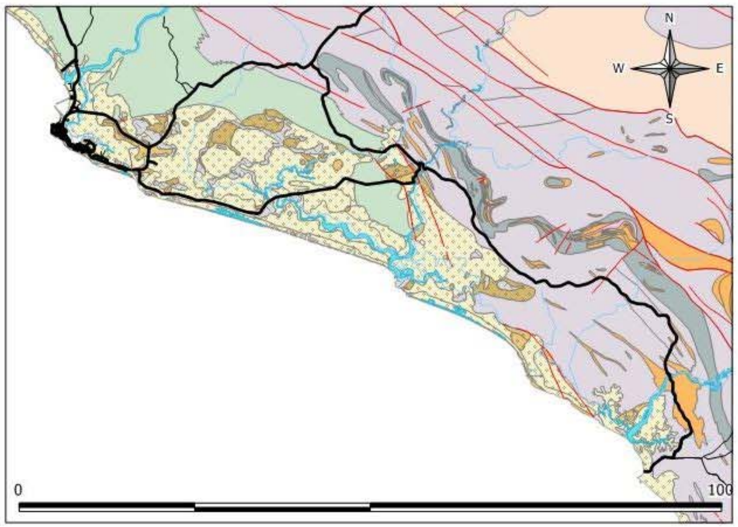
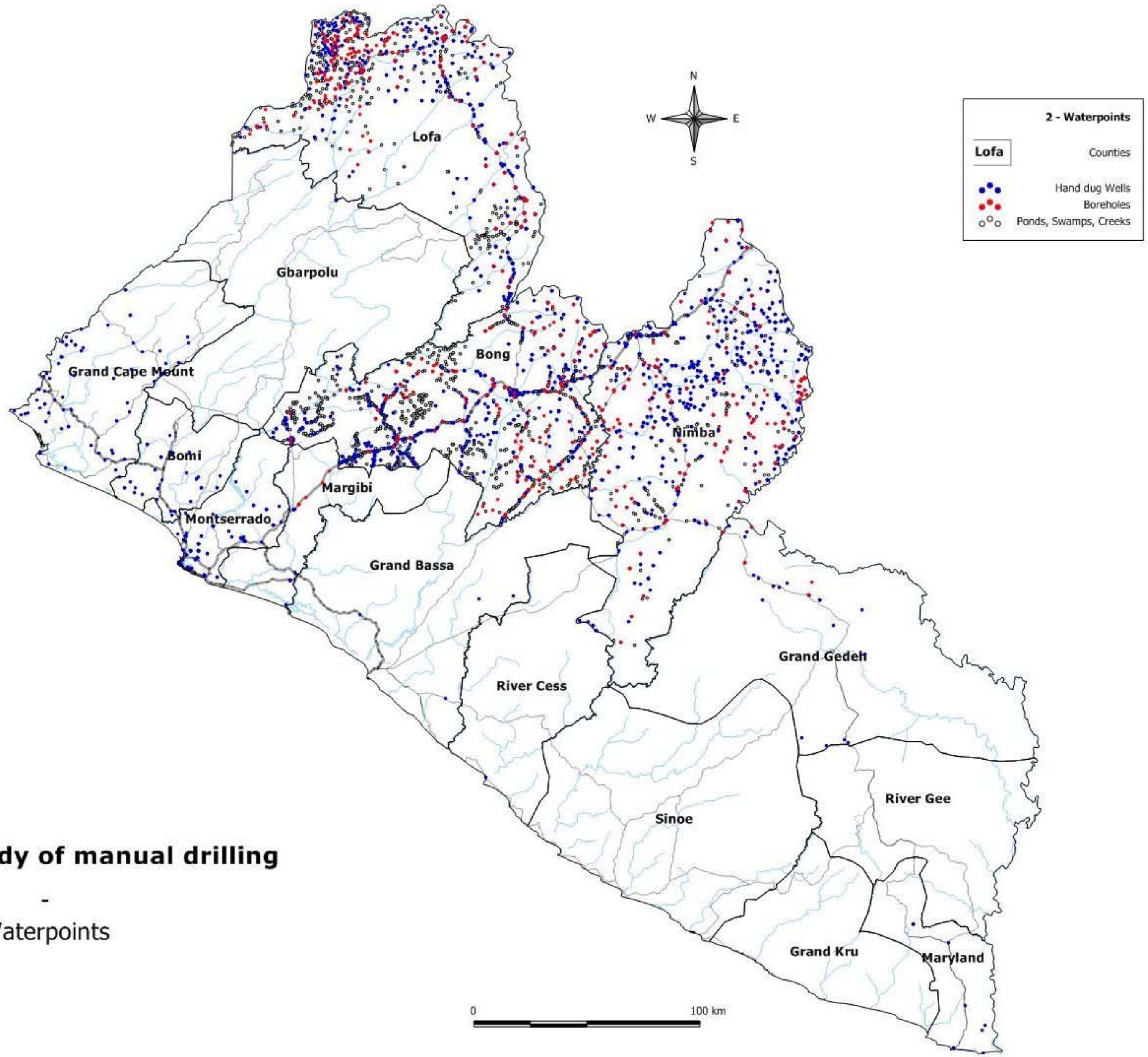
Simplified Geologic Map







Feasibility study of manual drilling

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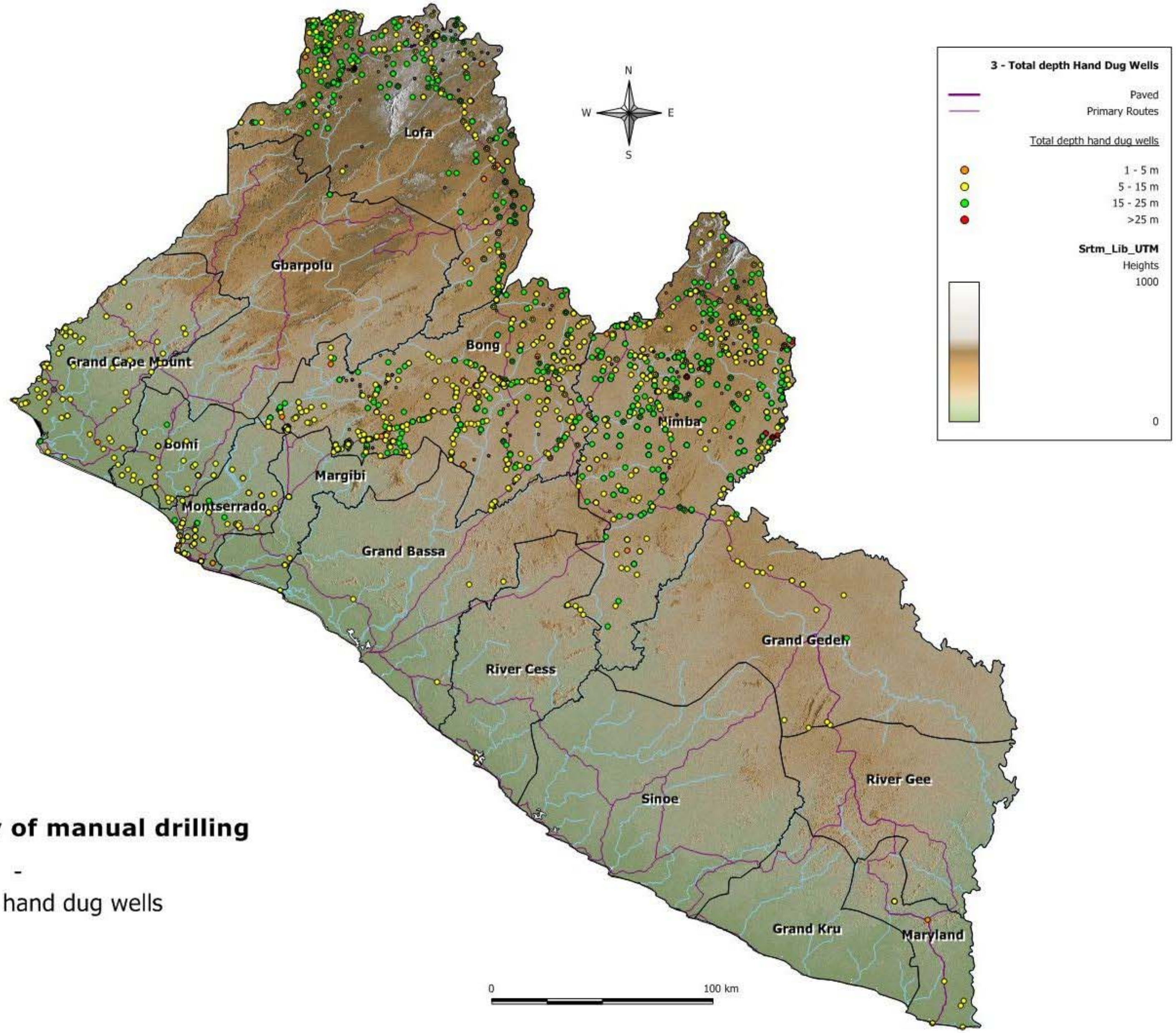
Waterpoints

Feasibility study of manual drilling

-

Total depth hand dug wells



Feasibility study of manual drilling

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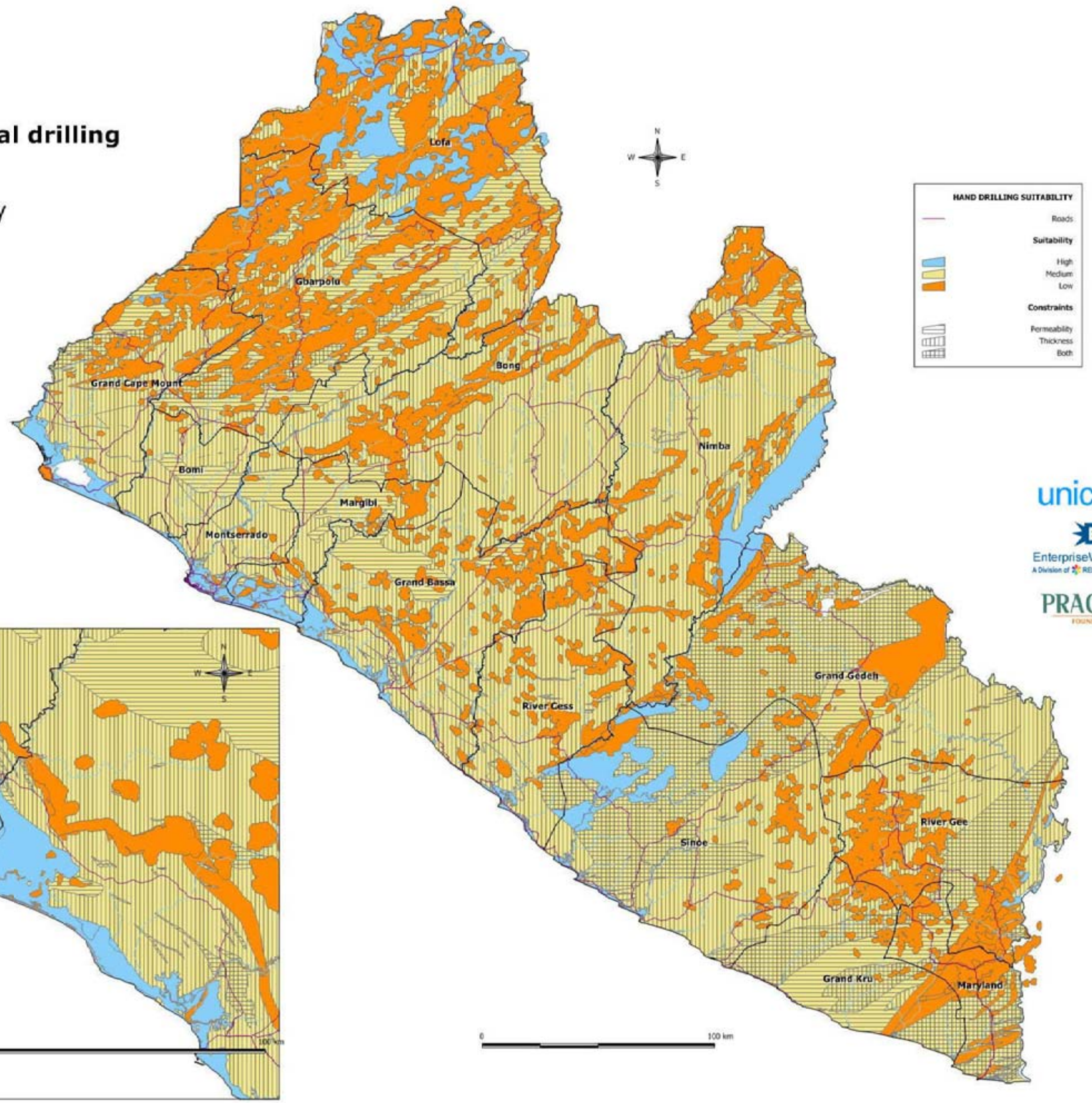
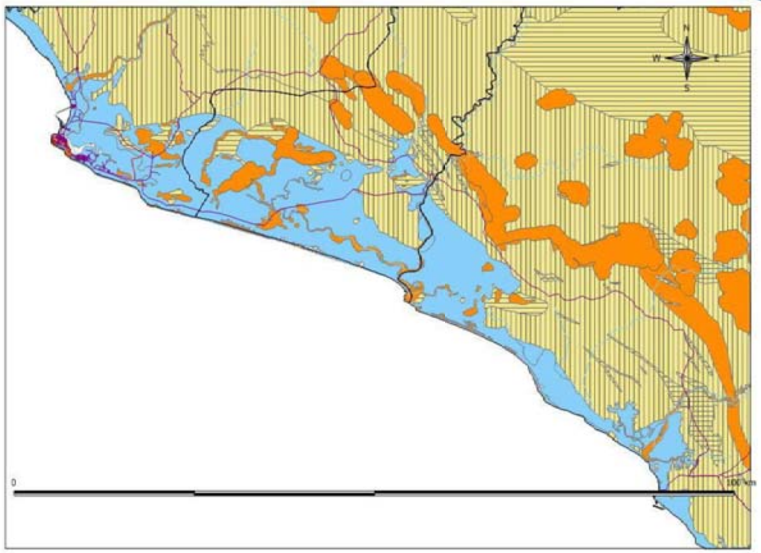
Hand drilling suitability





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