3. Survey to select the subsurface dam site

This chapter describes the survey methods of selecting a subsurface dam site and the results.

3-1 Outline of the survey methods

Generally, a subsurface dam site is selected according to the following procedure:

1) Interpretation of satellite images and aero-photographs
2) Geological and topographical survey by preliminary exploration
3) Estimate of the geological structure by geophysical surveys such as electric soundings
4) Verification of the geological structure by test drillings and permeability tests
5) Estimate of the flow mechanism of groundwater by observation of groundwater level

Hydrological and meteorological data, such as rainfall and rate of streamflow, are also collected to determine the need and feasibility of a subsurface dam.

On the other hand, management and maintenance of a subsurface dam requires the active participation of the local community. Therefore, it is necessary to undertake a socio-economic study to understand the potential for the participation of the local people. Once the site has been decided, it is also important to encourage their participation from the planning stage.

3-2 Selection of the project area

(1) Selection of the country for the project
The United Nations Convention to Combat Desertification notes in its preamble that serious drought and desertification has tragic consequences particularly in Africa. Originally, the UN started to deal with the desertification issue, with the serious drought in the Sudan-Sahel region at the end of 1960s to the beginning of 1970s as a trigger. For these reasons, it was decided that this model project be carried out in the Sahel region. Burkina Faso (in particular, the central and the northern part of this country) was finally selected as the site country because it met the following conditions:

1) A country seriously affected by desertification
2) A country with relatively large areas with aquifers of shallow groundwater
3) A country whose political situation is stable

The climate in the northern part of Burkina Faso is characterized by two seasons:

- Dry season (8 months from October to May)
- Rainy season (4 months from June to September)

There are two temperature peaks in a year in this country; the hottest is March to May with a maximum temperature of about 40 degrees centigrade and a minimum temperature of 25 to 28 degrees, and the second hottest is October to November with a maximum temperature of 36 to 39 degrees and a minimum temperature of 22 to 23 degrees. In addition, there are two coolest seasons; December to January with a maximum temperature of 30 to 34 degrees and a minimum temperature of 14 to 16 degrees, and July to September with a maximum temperature of 30 to 34 degrees and a minimum temperature of 21 to 24 degrees.

Going north in this country, rainfall decreases. Ouagadougou, the capital of Burkina Faso located in the central part of the country, has an annual precipitation of 733 mm (annual average between 1990 and 1994), while Dori, a city located in the north-eastern part of the country, has annual precipitation of 474 mm. Most of the rainfall is concentrated in the rainy season.

A total of 80% of the land of the country is on the old rock of the Precambrian.

The main industries of the country are agriculture and livestock farming. A total of 11% of the country is used as farmland, on more than 80% of which millet, sorghum, maize and rice are cultivated. However, the production of these cereals is not stable due to their sensitivity to land conditions and climatic conditions.

(2) Requirements for the selection of the model project site

In particular, the following are taken into account in site selection from the viewpoint of executing the model project:

1) The construction of a subsurface dam of appropriate scale as a model project is feasible at the site.
2) There is a relatively large village near the site to facilitate the participation of local people in the model project.
3) Access to the site from the capital, Ouagadougou, is easy.
4) There are no other projects near the site, to assess the result of the model project properly.

(3) Procedure for the site selection in this project

In this project, the subsurface dam site was selected according to the procedure shown in Fig. 3.1. Equipment and machinery available in Burkina Faso were used as much as possible for the project, avoiding the use of special equipment or machinery.

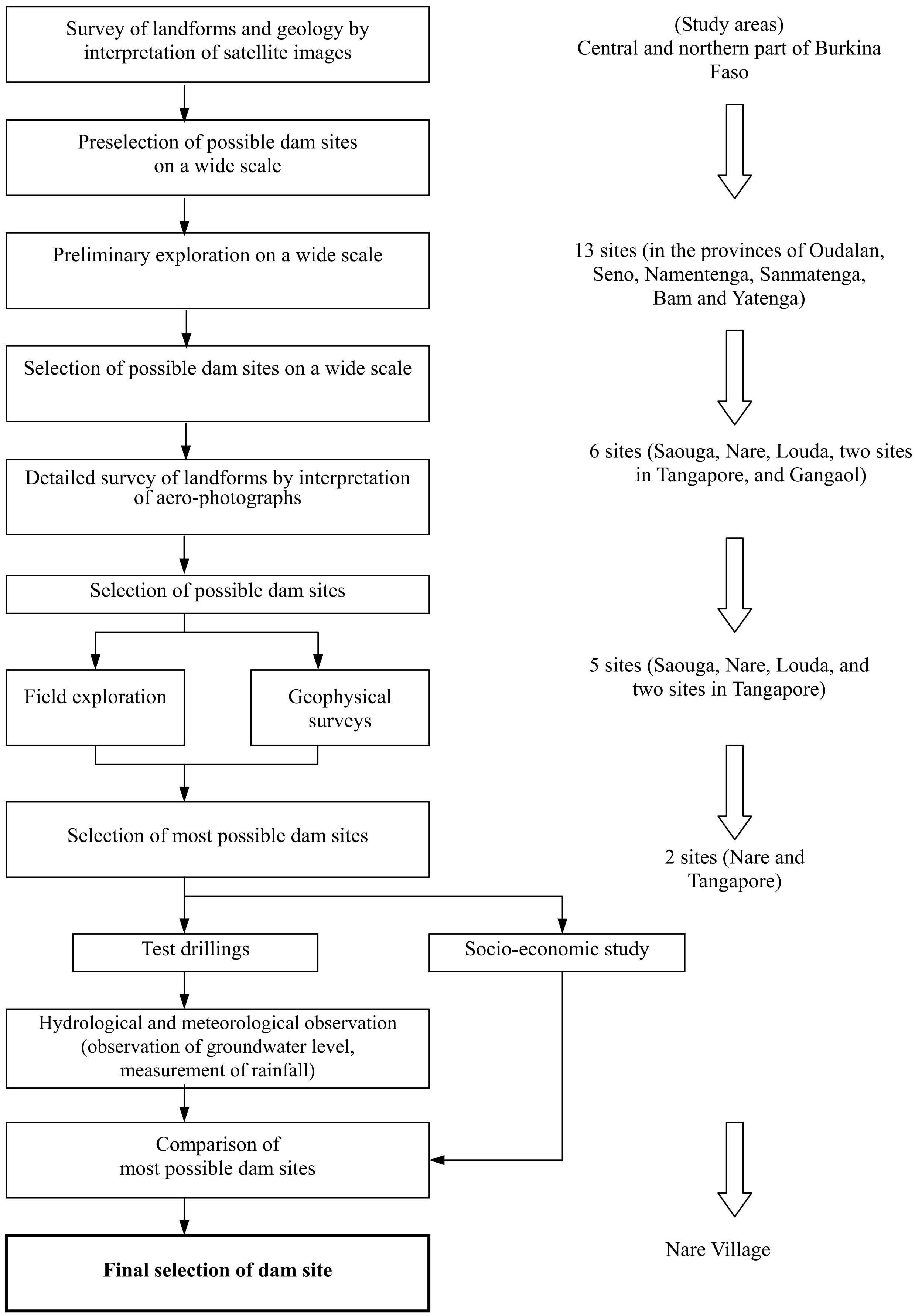


Fig.3.1: Flowchart of the site selection for the subsurface dam

3-3 Distribution of fossil valleys in West Africa

From 1989 to 1999, before launching this project, a feasibility study of the construction of subsurface dams was carried out in Niger and Mali in the Sahel region by a study group (the Sahel Greenbelt Study Group) sent by several Japanese companies. The results showed that the Niger River basin contain a good number of fossil valleys with a hydrogeological structure suitable for subsurface dams. In this study, the presence of fossil valleys was identified along the following tributaries: （Fig. 3.2）

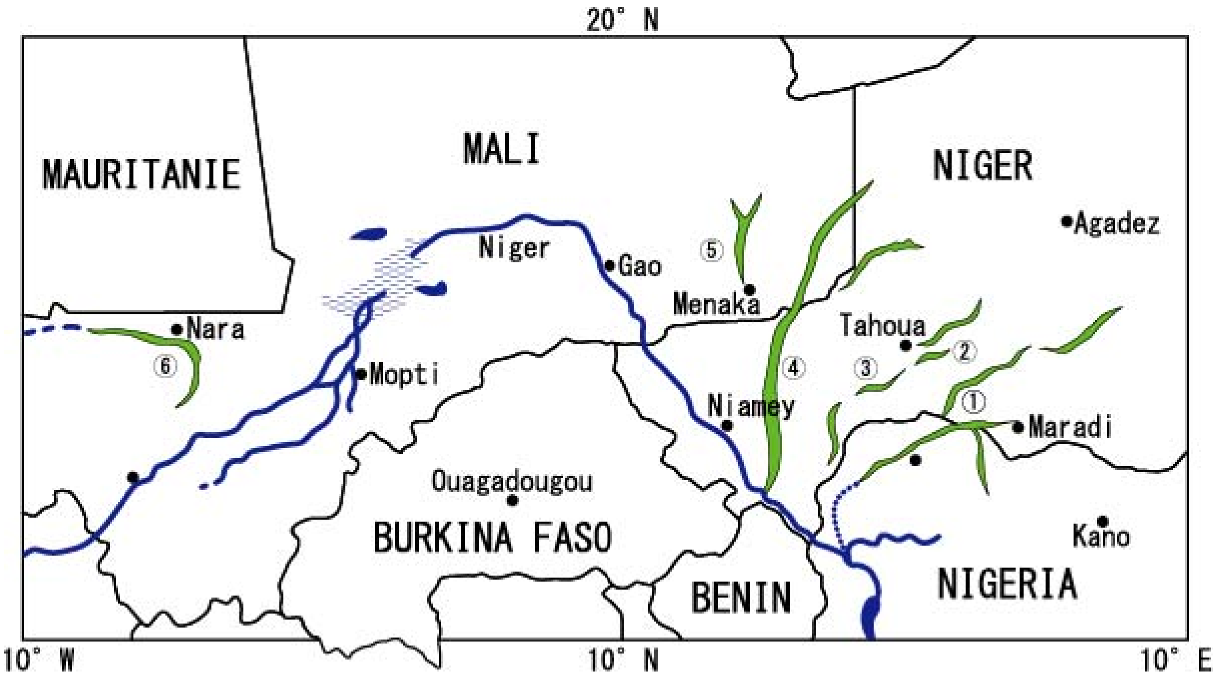
- Goulbin Kaba and Tarka Valley (Maradi, Niger, and Sokoto, Nigeria)
- Souma Valley (the south-eastern part of Tahoua, Niger)
- Dallol Maouri (Dan Doutchi and the western part of Tahoua, Niger)
- Dallol Bosso (the eastern and the north-eastern part of Niamey, Niger)
- Ezgueret River (Menaka, Mali)

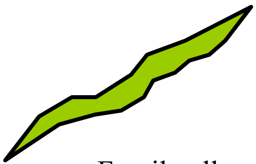
The presence of fossil valleys was also identified in the Senegal River basin along the following tributary:

- Serpent Valley (Nara, Mali)

In general, there are *wadis* (temporary rivers that appear only in the rainy season) on the current ground surface of these fossil valleys. These fossil valleys on the current ground surface are huge compared with the discharge of the current *wadis*. They are several kilometers, or even several tens of kilometers in certain cases. Among fossil valleys that flow into these large fossil valleys, there might be small or medium-size fossil valleys that are suitable for subsurface dams.

This study suggests that there may be fossil valleys of suitable size for subsurface dams buried beneath current rivers in the eastern and the north-eastern part of Burkina Faso, a part of the Niger River basin. In the survey to select the project site, the potential existence of such fossil valleys in the central and the northern part of Burkina Faso was focused on.





Fossil valleys

① Goulbin Kaba, Tarka Valley
② Souma Valley
③ Dallol Maouri
④ Dallol Bousso
⑤ Ezgueret River
⑥ Serpent Valley (tributary of the Senegal River)

Fig. 3.2: Distribution of fossil valleys in Nigeria and Mali

Note: The above "fossil valleys" were identified by the Sahel Greenbelt Study Group of Japan in 1989 and 1990. In fact, there may be more fossil valleys.

3-4 Surveys carried out in this project

3-4-1 Interpretation of satellite images and aero-photographs

Satellite images and aero-photographs are useful means of examining the physical conditions (landform, geology, surface water, vegetation, etc.) of vast areas. They are particularly valuable in surveying flat relief areas without precise topographical maps like Africa.

In this project, satellite images and aero-photographs were interpreted to identify appropriate sites for subsurface dams.

(1) Landforms considered as appropriate sites for the subsurface dam
In the interpretation of satellite images and aero-photographs, the following landforms were considered:

1) Landforms suggesting the potential presence of fossil valleys: These are landforms with excessively wide flood plains, whose line is similar to that of the current rivers (*wadis*, in many cases), compared with the discharge of current rivers (*wadis*).
2) Ring-shaped landforms: These are landforms whose ridges range in a ring shape with a gapped part due to denudation. These landforms are often observed in the area of volcanic rock. Groundwater recharged with rainfall within these landforms converges at the gapped part.
3) Bottleneck-shaped landforms: These are landforms with a bottleneck part of the basement rock, buried by unconsolidated sediment, possibly accompanied by underflow water.

(2) Procedure for interpretation
First, false color photographs on a scale of 1/200,000 or 1/500,000 were made from LANDSAT TM (Thematic Mapper) images covering the central or the northern part of Burkina Faso. On the basis of the interpretation of these satellite images, 13 sites were identified as having potential geomorphological and geological structures appropriate for a subsurface dam.

Next, preliminary exploration in a large area including these 13 sites was carried out. As a result, 6 sites were selected, excluding sites with the following problems:

- Estimation of the underground structure was difficult, or the scale of the underground structure was too large for the model project.
- Access from the capital, Ouagadougou, was too difficult.
- Many other projects already existed.

Detailed landform classification maps were then drawn from black and white aero-photographs on a scale of 1/20,000 or 1/50,000 that covered the selected 6 sites. As the result of this process, 6 sites were narrowed down to 5.

It is recommended that aero-photographs be used for the interpretation of limited areas because the resolution of the LANDSAT images is low and the geomorphological and geological structures interpreted from them tend to be biased toward larger ones.

(3) Results of the selection of possible sites

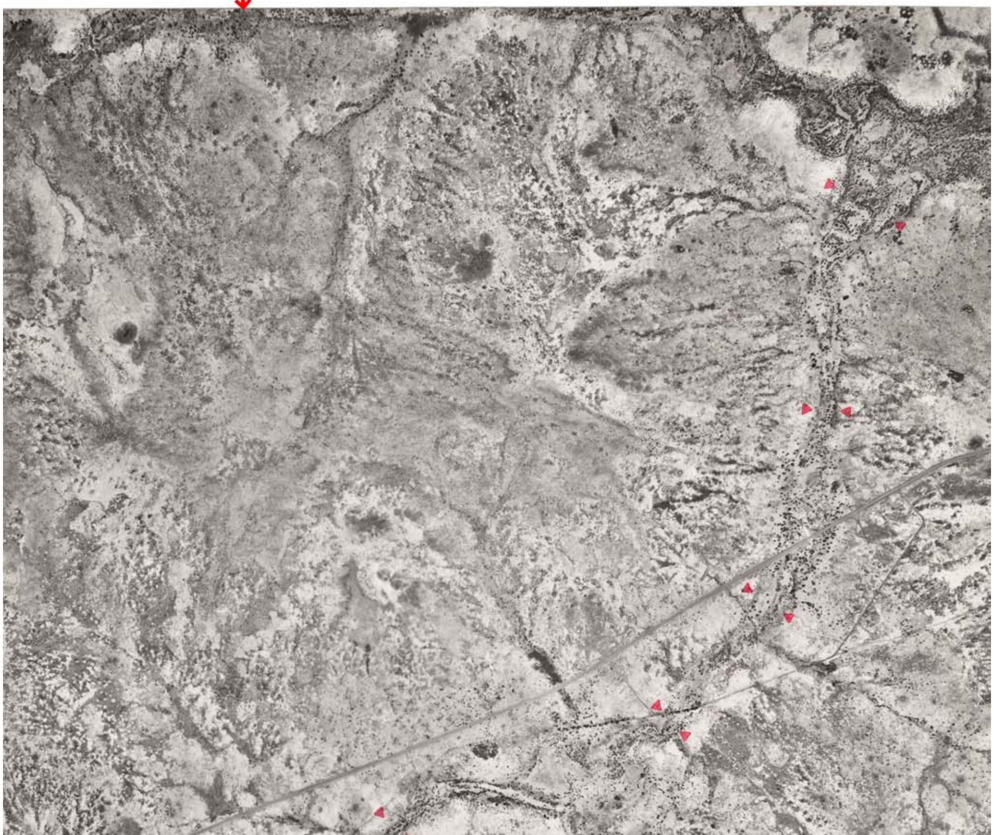
The results of the selection of possible sites for a subsurface dam by the interpretation of the satellite images and aero-photographs and preliminary exploration are summarized in Table 3.1.

Table 3.1: Results of the selection of possible sites for a subsurface dam by the interpretation of satellite images and aero-photograph and preliminary exploration

Regions preselected from LANDSAT images			Results of preliminary exploration (Reason for rejection)	Results of interpretation of aero-photographs (Reason for rejection)
Name of province	Name of village	Checked landform		
Oudalan	Saouga	Fossil valley	Possible	Possible
Seno	North of Dori	Fossil valley	Impossible (The zone could not be identified.)	—
Seno	Yakouta	Fossil valley	Impossible (The structural scale was too large.)	—
Seno	Gangaol	Fossil valley - *wadi*	Possible	Impossible (The catchment area was too small.)
Namentenga	Nare	Fossil valley	Possible	Possible
Sanmatenga	Kouloga	Bottleneck	Impossible (The unconsolidated sediment layer might be too thin.)	—
Sanmatenga	Louda	Ring-shaped	Possible	Possible
Sanmatenga	Bassneile	Ring-shaped	Possible	Possible
Sanmatenga	Tangapore	Bottleneck	Possible	Possible
Sanmatenga	Balou	Bottleneck	Impossible (Poor access)	—
Sanmatenga	Santabe	Bottleneck	Impossible (Poor access)	—
Bam	Around Loga	Ring-shaped	Impossible (Many projects had already existed.)	—
Yatenga	North of Gongoure	Bottleneck	Impossible (Poor access)	—
Yatenga	North of Ban	Special reason *	Impossible (Poor access)	—

Note: It was requested by S.P.CONAGESE that the subsurface dam be constructed here because of the threat of forest extinction.

Satellite image of the area around Nare



Aero-photograph of the area around Nare

Fossil valley

Fig. 3.3: Satellite image and aero-photograph of the "fossil valley"

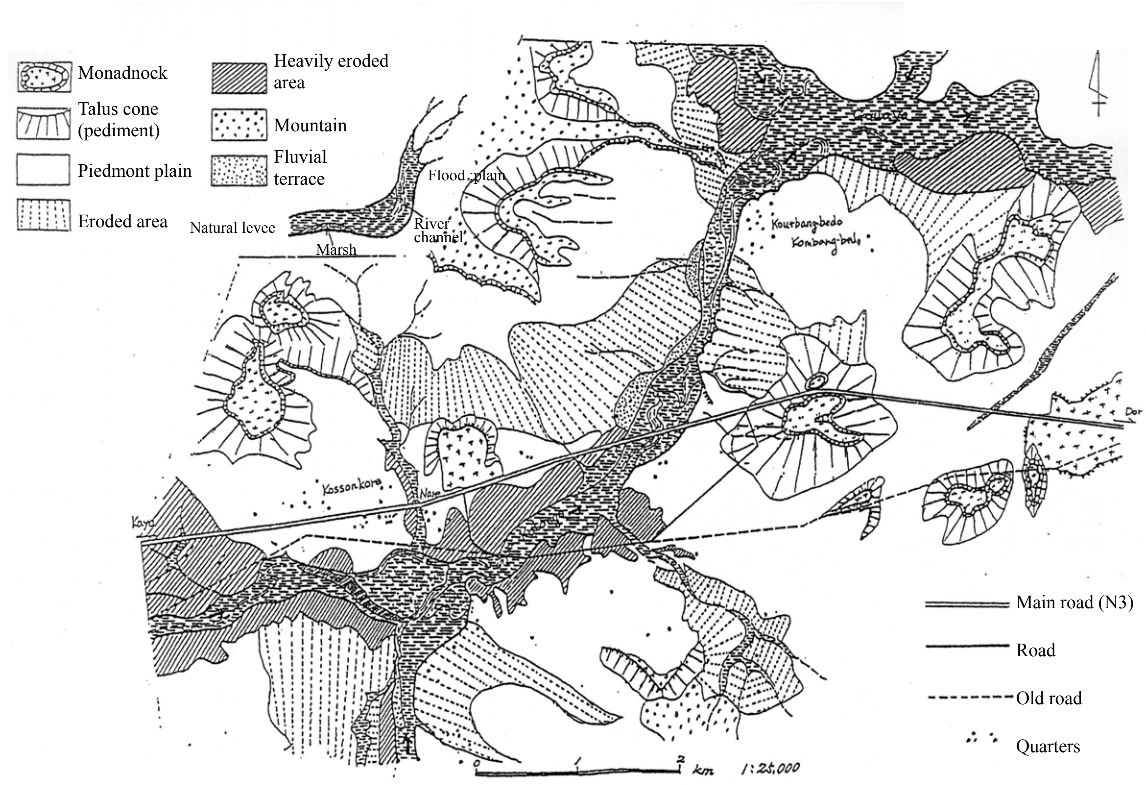


Fig. 3.4: Sample of landform classification maps based on aero-photographs
(area around Nare)

3-4-2 Field exploration

At the 5 sites selected by interpreting the satellite images and aero-photographs and preliminary exploration, a detailed field exploration was carried out to assess the feasibility of constructing a subsurface dam, also taking into account the results of the electric soundings mentioned below (see Section 3-4-3).

During the field exploration, the following surveys were carried out, and the distribution of villages was grasped.

(1) Grasping landform and geology
The landform and geology of the sites were grasped to detect the presence of shallow groundwater and to estimate its structure.

In these surveys, the landform classification maps drawn from aero-photographs were used as topographical maps and preliminary examination charts. Indeed, in surveying an area where flat relief predominates without precise topographical maps, it is sometimes impossible not only to understand the geomorphological significance of the phenomena observed in the field, but also to confirm the present location, without these land classification maps or aero-photographs themselves.

(2) Survey of existing wells
To grasp the presence of groundwater, the following surveys of existing wells were carried out. In these surveys, most of the useful information was obtained from "dug wells" whose side walls were not covered by concrete.

1) Confirmation of the locations of the wells, and landform and geology
2) Measurement of the groundwater level in the wells
3) Confirmation of seasonal fluctuation in the groundwater level by listening to inhabitants
4) Confirmation of geology of the aquifer and its upper strata by observation of the interior of the wells and the surplus soil produced by digging, as well as by listening to inhabitants

(3) Confirmation of the distribution of unconsolidated sediment
Grasping the distribution of unconsolidated sediment that can form aquifers of shallow groundwater was attempted. When it was difficult to directly grasp their distribution, it was estimated from the distribution of the outcrop of the basement rock, which was grasped by careful survey, of the lateritic crust in particular.

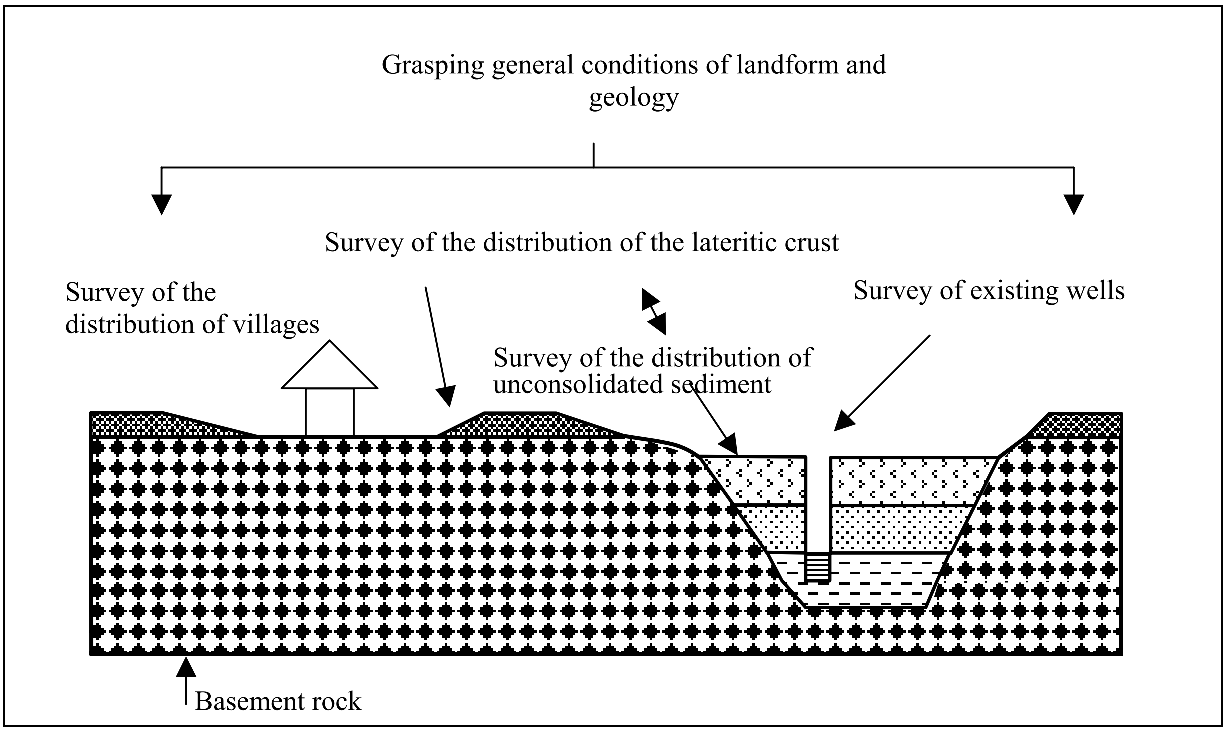


Fig. 3.5: Points of field exploration

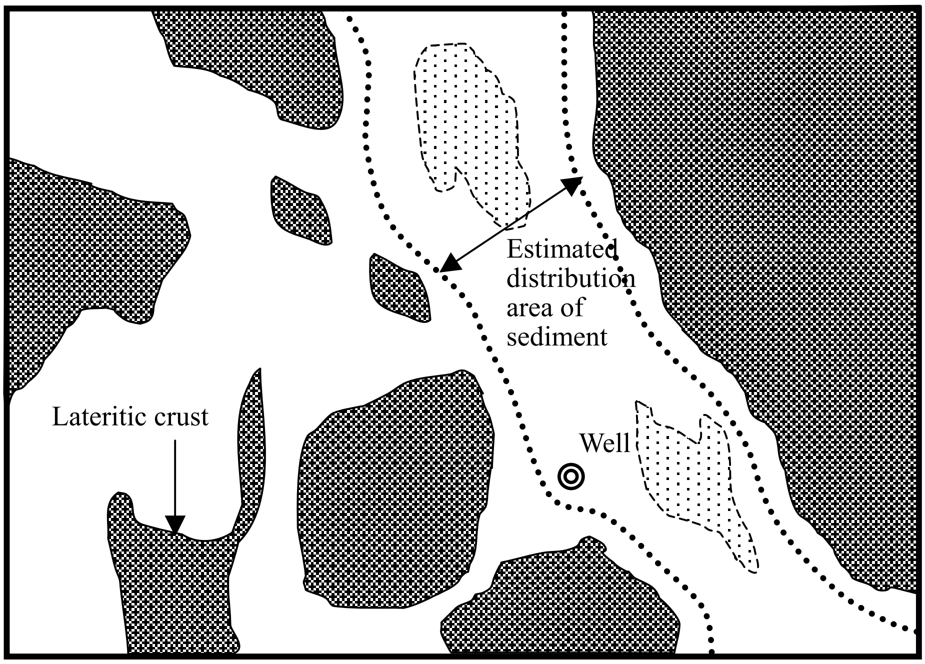


Fig.3.6: Relation between the distribution of the lateritic crust and unconsolidated sediment

3-4-3 Geophysical survey

At the 5 sites selected by the interpretation of satellite images and aero-photographs and preliminary exploration, electric soundings were carried out in addition to field exploration to determine the geological structure.

At some sites in Tangapore Village and Nare Village, magnetic soundings were also carried out, whose results only confirmed those of the electric soundings but with less precision. The electric soundings are thus more useful for detecting underground structure at a shallow depth.

(1) Method of electric soundings

The electric soundings were carried out using the vertical quadripole method (Wenner's method). From their results, resistivity profiles were drawn to analyze the underground structure. One of the resistivity profiles thus obtained is shown in Fig. 3.7.

For the electric soundings and the analysis of their results, the following points were taken into account.

1) Survey lines for the resistivity profiles, whose length was about 150 to 500 m, were set across the assumed underground structure. Along the survey lines, the electric soundings were carried out with an interval of about 50 to 100 m, namely 3 to 10 survey points per line.

2) At each survey point, a sounding line was drawn parallel to the direction of the supposed underground structure.

3) To obtain a three-dimensional view of the geological structure, 2 to 3 survey lines for the resistivity profiles were set as far as possible.

4) The resistivity of the basement rock (lateritic crust, heavily weathered rock, and fresh rock) were determined by lengthening the survey lines to an outcrop of basement rock or to a point where basement rock was definitely present at a very shallow depth. These resistivities determined largely contributed to the geological interpretation of the resistivity profiles.

5) Where there were wells (in particular "dug wells") allowing observation of the groundwater level and geological sections, electric soundings were also carried out near the wells to determine the resistivity of the well site. These resistivities increase the certainty of the geological interpretation of the resistivity profiles.

Resistivity determined by electric soundings reflects not only the electrical properties of the rock and soil, but also those of the groundwater. Even in the strata composed of identical materials, resistivity may vary remarkably if there is a large difference in their water content. Therefore, resistivity is not sufficient for precisely determining the lithological nature of the strata. However, resistivities and resistivity profiles obtained from electric soundings carried out at a large number of points are important clues in estimating the geological structure and the state of groundwater because zones of almost identical resistivity can be considered to correspond to strata with identical lithologies and water content.

(2) Selection of the subsurface dam sites based on the electric soundings

The results of the examination of the geological structure of each of the 5 sites on the basis of the field exploration and the electric soundings were as follows:

a. Saouga (south of Gorom Gorom, Oudalan Province)
This site probably had a fossil valley that was an aquifer of shallow groundwater. However, the construction of the subsurface dam would be too large as a demonstration study.

b. Nare (south of Tougouri, Namentenga Province)
This site probably had a fossil valley that was an aquifer of shallow groundwater. Although constructing a subsurface dam here would be a little too large as a demonstration study, the site was suitable for a subsurface dam.

c. Louda (south of Kaya, Sanmatenga Province)
A ring-shaped landform had been formed at this site, but no favorable aquifer was discovered.

d. Bassneil (north of Korsimoro, Sanmatenga Province)
A ring-shaped landform had been formed at this site, but an unconsolidated sediment layer that could have been an aquifer was likely to be very thin.

e. Tangapore/Kossoden (north of Korsimoro, Sanmatenga Province)
This site was of a bottleneck-shaped landform located downstream of a ring-shaped landform, and the presence of shallow groundwater was suggested by the results of the survey of existing wells. The resistivity profiles by electric soundings also indicated the possible presence of a fossil valley whose size was appropriate for a demonstration study. This site was thus probably suitable for a subsurface dam site.

As a result of the survey described above, 2 sites were selected as candidates for the subsurface dam site: Tangapore Village, Korsimoro District, Sanmatenga Province, and Nare Village, Tougouri District, Namentenga Province.

The number of electric soundings carried out at these 2 sites were as follows:

- at Tangapore: 58 points on 4 survey lines
- at Nare: 95 points on 6 survey lines

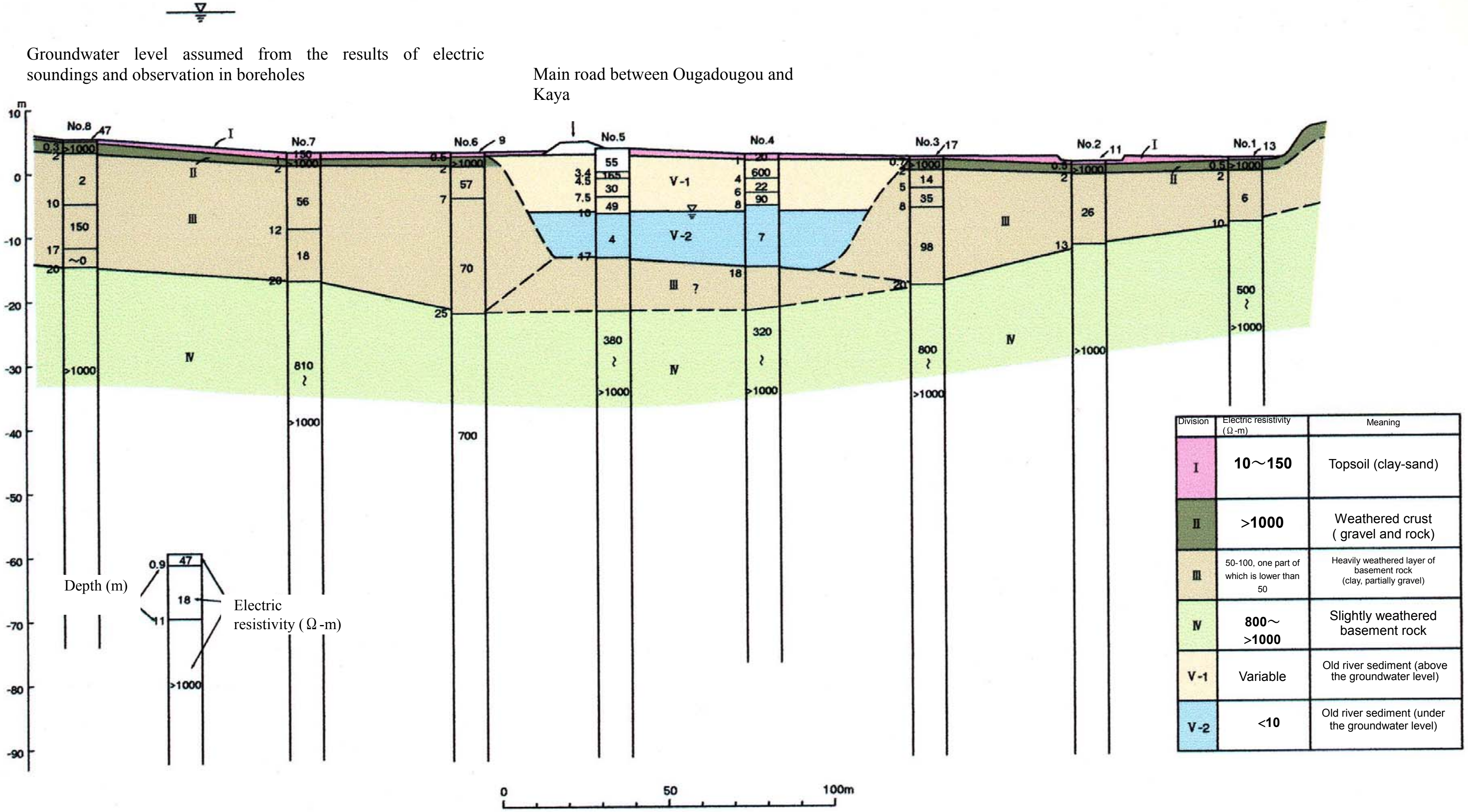
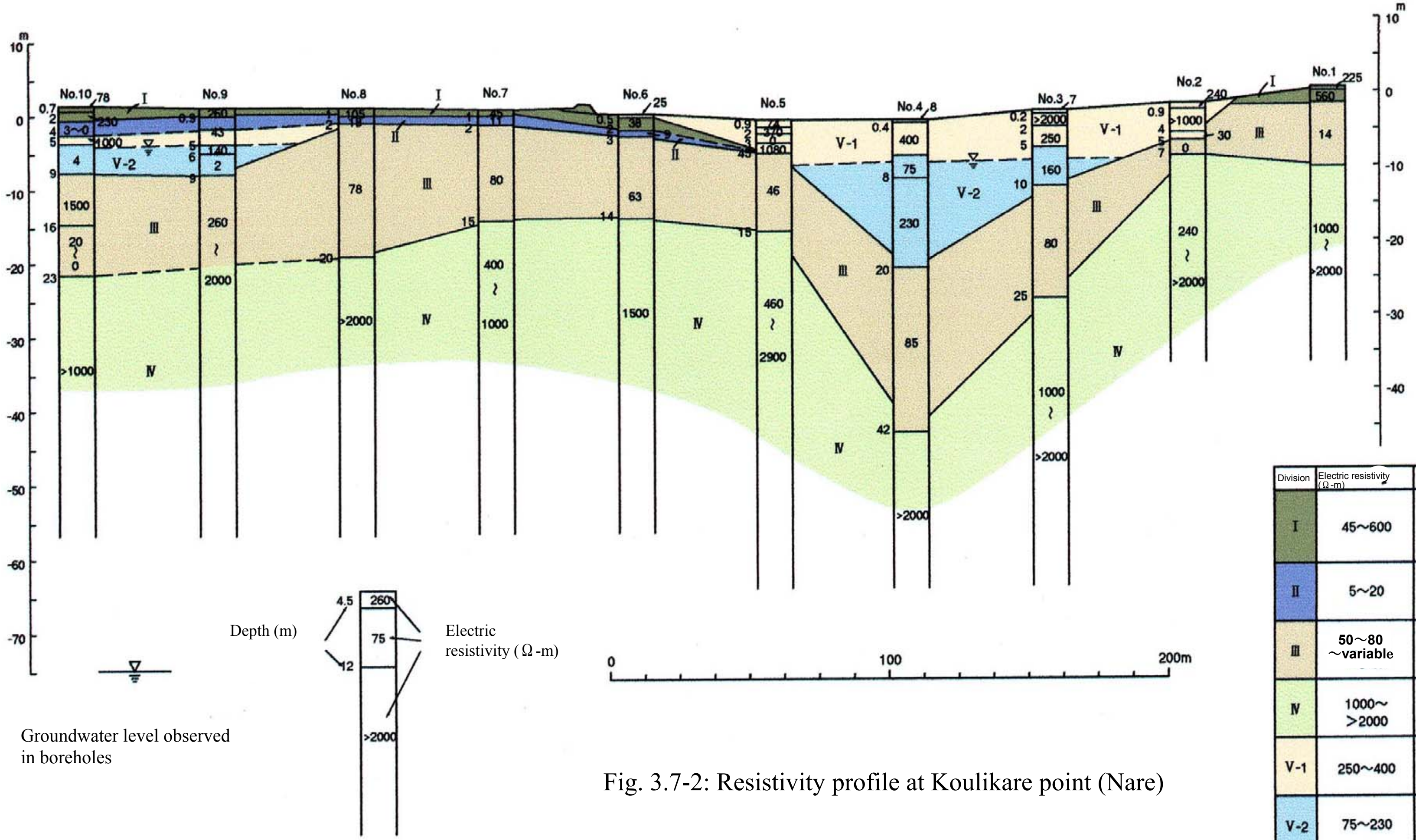


Fig. 3.7-1: Resistivity profile at the north of Korsimoro - point C (Tangapore)

Fig. 3.7: Resistitivity profiles based on the electric soundings



Division	Electric resistivity (Ω-m)	Meaning
I	45～600	Topsoil - weathered crust
II	5～20	Moist layer under the topsoil
III	50～80 ～variable	Heavily weathered layer of basement rock (clay, partially gravel)
IV	1000～ >2000	Slightly weathered basement rock
V-1	250～400	River sediment (above the groundwater level)
V-2	75～230	River sediment (under the groundwater level)

Fig. 3.7-2: Resistivity profile at Koulikare point (Nare)

3-5 Detailed field surveys (test drillings, permeability tests, and observations of groundwater level)

At the two sites (Tangapore and Nare) selected on the basis of the results of the field exploration and the electric soundings, the following detailed field surveys were carried out to confirm the geological structure, to identify hydrogeological characteristics and to estimate rainfall within the drainage basin.

- Test drillings
- Permeability tests in boreholes
- Observations of the groundwater level in boreholes

In parallel with these surveys, meteorological observations (see Section 6-2) and a socio-economic study were carried out (see Section 3-6).

(1) Test drillings
To confirm the geological structure estimated from the results of the electric soundings, test drillings were carried out along the survey lines of the electric soundings.

In this project, boreholes were drilled using a drilling machine for deep wells, and rubble samples (slime) taken during drilling were used to estimate the geological structure. However, it was particularly difficult to distinguish the heavily weathered basement rock (argillized part) from the clayey or silty layers of fluvial deposits. Therefore, it is preferable, for at least half of the boreholes, to use a test drilling machine for geological survey that enables the collection of undisturbed samples.

The number of boreholes was as follows:

- at Tangapore: 3 boreholes of 60-m depth, 3 boreholes of 20-m depth
- at Nare: 2 boreholes of 60-m depth, 19 boreholes of 20-m depth

(2) Permeability tests in boreholes
To determine the permeability of the ground, permeability tests were carried out in the boreholes.

The tests were carried out by observing the lowering speed of the water injected into the boreholes using a tank-lorry or jerry cans to obtain the permeability coefficient of the ground according to the depth. The permeability tests were carried out in:

- 3 boreholes at Tangapore
- 12 boreholes at Nare

(3) Observations of groundwater level in boreholes
To determine seasonal fluctuation in shallow groundwater level, observations of groundwater level were carried out in 3 boreholes at Tangapore and 5 at Nare.

The groundwater level was measured irregularly using a manual water-level sounder at Tangapore, whereas it was measured continuously with automatic water level recorders at Nare.

The observation was carried out for about 6 months before the final selection of the subsurface dam site (from the middle of the rainy season to the first half of the dry season).

However, a longer period of observation is desirable, given the considerable seasonal and annual fluctuation in groundwater level. In addition, as described below in Section 6-4, there is a risk that the level of perched water is mistaken for that of the real groundwater. Therefore, attention should be paid to the observation method of groundwater level.

From the results of the test drillings, permeability tests and observations of the groundwater level, the hydrogeological characteristics of the 2 candidate sites, Tangapore and Nare, were estimated as follows (see also Fig. 3.8 and Fig. 3.9):

Tangapore
The results of the electric soundings suggested the presence of a fossil valley. However, the test drillings did not reveal fossil valley sediment (fluvial deposits). No geological difference was observed between the inside and outside of the supposed fossil valley. The groundwater levels of the inside and outside were almost the same, and seasonal fluctuation in the groundwater level of the inside and outside corresponded with each other. Namely, between the inside and outside of the fossil valley assumed from the results of the electric soundings, there was no obvious geological difference, and hydraulic continuity was practically ensured. This shows that there is no fossil valley at Tangapore.

The reason the electric soundings suggested the presence of a fossil valley was probably the presence of a large fracture zone in the basement rock.

Nare
All the results of the examination of the surplus soil produced by digging of the existing wells, of the electric soundings and of the test drillings showed the presence of a fossil valley beneath the Kolongo River at Nare. The permeability coefficient determined by the permeability tests were 10^{-3} to 10^{-4}cm/sec inside the fossil valley and 10^{-5} to 10^{-6}cm/sec at the valley sides. This shows a geological structure in which the permeable fossil valley sediment is surrounded by impermeable basement rock. In addition, the presence of groundwater was confirmed inside the fossil valley, with no groundwater outside the fossil valley. It was thus deduced that the fossil valley constitutes a groundwater channel.

The observation of groundwater level inside the fossil valley showed seasonal fluctuation in the groundwater level between the rainy season and the dry season, indicating the large fluidity of groundwater.

Figure 3.8 and Fig. 3.9 are schematic figures showing the results of the detailed field surveys.

The site assumed suitable for the subsurface dam, a narrow part of a fossil valley, was immediately upstream of the point where the Kolongo River flowed into its trunk, the Gouaya River. There was thus little risk that the construction of the subsurface dam would "exhaust the groundwater in the downstream area".

All these results showed that Nare Village is hydrogeologically best as a subsurface dam site.

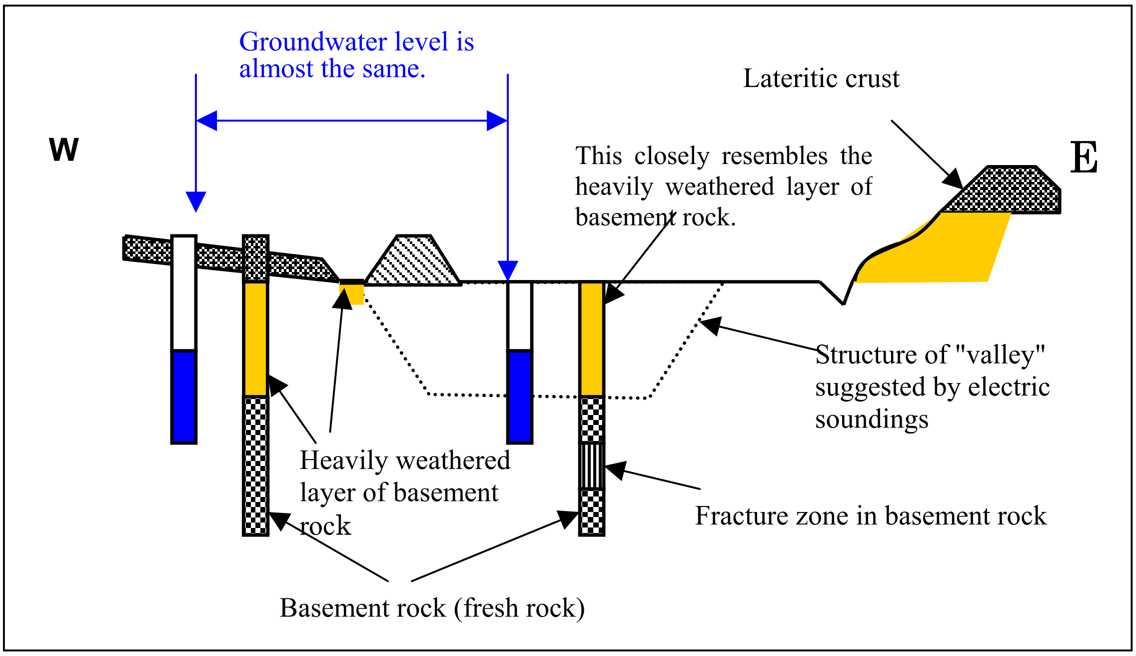


Fig. 3.8: Schematic diagram of the results of the detailed field survey at Tangapore

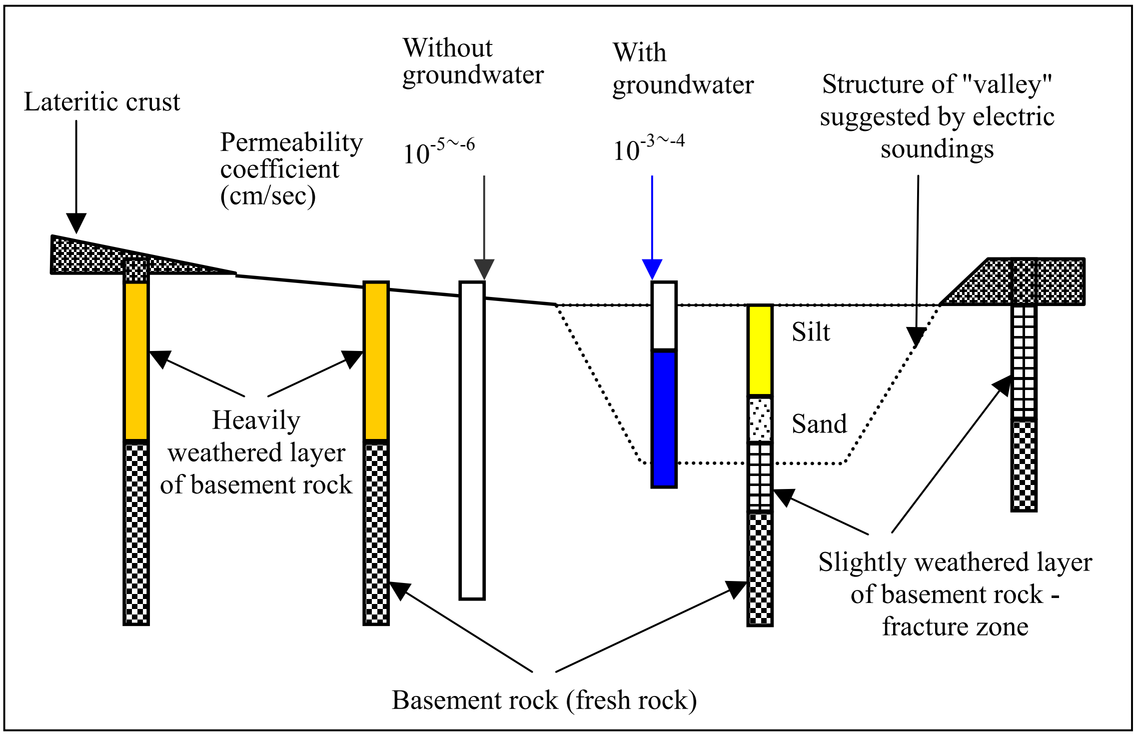


Fig. 3.9: Schematic diagram of the results of the detailed field survey at Nare

3-6 Socio-economic study

As a part of the field survey, a socio-economic study was also carried out at Tangapore and Nare.

A summary of the results of the study is as follows:

Tangapore

- Population: 2,079, all Mossi people
- Public services: One primary school (built in 1995), no dispensary
- Main activities for living: Agriculture, with livestock farming as secondary. Commerce is also active in the market (Korsimoro).
- Common diseases: Meningitis, eye diseases, headaches, tumors, diarrhea, etc.
- Annual average rainfall: About 660 mm until 1995

The village is located in the transition zone between low mountains and peneplain. Not only the peneplain but also the gentle mountain slope are cultivated, and the arable land is exploited almost to the limit. Due to the use of fertilizers in some parts, the food self-sufficiency rate is estimated to be more than 90%. However, considering the situation that no more arable land remains and the land has continued to degrade, the village is likely to suffer serious food shortage with the increase in population in the near future. It is thus primarily important to increase the productivity of the land, and to exploit new water resources for it.

Livestock farming is the secondary activity for living in this village, and has a role of "savings" to prepare for emergency situations such as drought. However, a shortage of pasture and a lack of water for animals in the dry season are problems for this activity.

There were 3 hand pumps, 6 dug wells, 1 small-scale surface dam and 6 reservoirs in the village, but it was estimated that only about 70% of the water demand (about 20 liters per person) for domestic use was supplied. The water in the small-scale surface dam and reservoirs used by livestock animals was also used by the villagers for domestic use, and this situation led to diseases caused by polluted water. Therefore, to improve water quality for domestic use, the exploitation of new water resources was necessary.

Some young villagers in Tangapore had formed a group to undertake the modernization of agriculture, and they were trying to produce compost and to grow some vegetables. Tree-planting education was also promoted in the primary school. Although the lack of water constrained these activities, the will, experience and recognition of the villagers will facilitate their participation in this project that will aim mainly at the effective use of groundwater resources.

Nare

- Population: 2,896, mostly Mossi people with some Fulani people
- Public services: One primary school (built in 1996), no dispensary
- Main activities for living: Agriculture, with livestock farming as secondary (It is the principal activity for Fulani people.)
- Common diseases: Guinea worm infections, eye diseases, dysentery, meningitis, etc.
- Annual average rainfall: About 590 mm until 1995

The village is on a peneplain with some small monadnocks, and the Kolongo River, a tributary of the Gouaya River that is a part of the Niger River basin, runs through the village. The Kolongo River is a *wadi*, a seasonal river that has running water only in the rainy season.

The peneplain and the lowland along the Kolongo River (part of which is flood plain) are exploited as farmland. However, the farmland is only 12% of the territory, and arable land remains. Forest covers only 2% of the territory. Most of the bare land, which occupies about 20% of the territory, was cultivated before. It probably means land degradation has continued due to the cutting and the cultivation of forest and bush.

The farmland is in general barren. Not using either fertilizer or compost, the food self-sufficiency rate in Nare Village is only about (or less than) 60%, which makes the village one of the poorest in Burkina Faso. Many livestock animals, especially cattle, can be seen, but most of them belong to the Fulani people. Few Mossi people keep livestock animals in sufficient number as "savings" for emergencies like drought.

Nare Village, including Kombangbedo Village, did not have sufficient modern water-supply facilities. It had only 1 hand pump and 5 dug wells with concrete rims. Water supply by these facilities was estimated to be less than 60% of the demand. Most of the villagers obtained water for domestic use in the rainy season from the river, and in the dry season, from the dug wells excavated in the flood plain. This led to a high incidence of disease such as Guinea worm infestation caused by polluted water. Many villagers wanted to grow some vegetables to prepare for food shortages and also to obtain a cash income. However, under conditions that did not even allow sufficient water for domestic use, there was only one family who were actually growing vegetables.

Under these circumstances, the villagers of Nare had a strong desire to exploit new water resources. However, they did not have the information required to improve their living conditions or for rural development, and their participation in the model project was expected to be difficult.

The results of the above-mentioned socio-economic study suggest that Tangapore Village was more ready for the project.

However, as described in Section 3-4, it is Nare that has the hydrogeological structure appropriate for a subsurface dam. Finally, it was decided that the model project would carried out at Nare because the feasibility of construction of the subsurface dam was the first priority.