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ASPECTS OF DEVELOPMENT

HELMUT BUSKE VERLAG HAMBURG

R. Pozzi / G. Benvenuti / G. Gatti / Ibrahim Mahamed Farah

WATER SUPPLY AND AGRICULTURAL USE : A PROPOSAL FOR THE ADOPTION OF SUBSURFACE DAMS IN SOMALIA

Introduction

Subsurface or underground dams have proved to be useful as barrages of the underground water flow in the subsurface of temporaneously present water courses in order to set up, or increase, permanent water reserves during floods.
In other words, it is a matter of creating impermeable diaphragms within loose porous materials with sufficient permeability down to a bed-rock of lesser permeability, or even an impervious one.
The seepage or infiltration waters saturate the porous material until an underground water reserve is built up which will not, therefore, be subject to evaporation. A similar method and the relevant techniques were first used on a relatively large scale, in recent years, in arid and semi-arid countries; however, owing to the general increase of water consumption in all industrialized and densely populated countries, the necessity has arisen to store water, for instance during the spring season when water is usually available in excess of consumption, in order to satisfy the various consumption peaks (projects to this target in the executive stage are at hand from Japan, the USA, and elsewhere).
Other obvious developments have been registered as regards as the convenience of these works: in fact, the issue is no longer confined to preserving water against evaporation, but also, and far more, of not encumbering with an open air water tanks inhabited or not inhabited areas.

Geo-Engineering and Hydrogeologic Prerequisities for the Design of Subsurface Dams

The experience gained in Algeria suggested to A. Robaux (I954) the following classification of works relevant to subsurface dams:

- underground barrages deviating the flow of seepage waters below ground level, channeling them toward consumer areas;
- underground water storage barrages raising the level of the aquifer, thus creating a zone of humid ground for the direct development of suitable kinds of crops;
- underground water storage barrages with captation works of the water reserve thus accumulated - the true subsurface dams.

Obviously underground barrages of this nature will in any case permit to use the water downstream, provided the barrage is complete with captation works, as well as upstream if pumping stations can be installed, or even locally, if the saturated ground is sufficiently close to the surface.

The engineering and hydrogeologic prerequisites warranting the feasibility of subsurface dams are essentially based on the availibility of:

- an impervious bed-rock at reasonable depth, if possible with a lie shaped like a buried basin (syncline);
- a porous reservoir (sands, gravel and intermediate lithotypes) of adequate volume for building up a permanent water reserve, capable of lasting two years without the need for natural recharge (so as to take into account cases of exceptional drought);
- a very ample intake basin to compensate scarcity of annual rainfalls;
- a water course - even of the seasonal kind - collecting any and all precipitations, both intensive and of short duration, in certain regions; seepage may be accentuated by means of bridles and/or cross beams slowing down the outflow.

The first methodological exposé of the more widely used procedures in constructing underground diaphragms is due to R. Tornaghi (I969), and contemplates:

- injection screens;
- tangent or secant poles sunk or cast in situ;
- panels cast in situ following ground removal;
- secant panels or panels placed into 'stabilized soil';
- thin diaphragms cast in situ with the aid of metal angles.

To be added to these are the 'coil-element' diaphragms (ICOS S.p.A., Milan I967) and the 'plastic' diaphragms (Rodio S.p.A., I977).

The former is particularly suited in the presence of relatively strong subsurface aquifer currents for instance at contact between flooding waters and bed-rock, or when one can safely assume the presence of large erratics, difficult to be crossed by standard means. The use of this type of pole also provides an excellent seal between the alluvial porous lithozone and the impervious bed-rock, particularly if the latter consists of crystalline schist which is difficult to be injected. From a technical viewpoint, the contact between the porous reservoir and bed-rock is certainly the most arduous task of diaphragm performance.

In one of the examples mentioned above (ICOS) the rock was located at a depth of about 30 m, with a downstream inclination of about 20°; at the maximum excavation depths, therefore, water pressure against the diaphragms reached 2-3 atm. The use of a 'coil-element' diaphragm permitted the setting up of a pumping station within the range of one ENEL's hydroelectric power plants in Italy. Even using some of the more conventional diaphragms, ICOS has been in a position to construct subsurface barrages specifically designed to raise the level of the aquifer so as to facilitate the exploitation of the available groundwaters. As far as depth is concerned, there appears to be considerable scope

for the use of ICOS diaphragms, since there are examples of blocked river beds in the presence of bed-rock at a depth of IOO m; on the other hand, Bentonite, used in making the diaphragm, produces a lasting effect even after it is removed from the borehole, thus increasing wall impermeability.
While the traditional technology still retains its validity, the past ten years have witnessed the development of plastic diaphragms, using 'self-hardening' muds. These muds (the so-called 'plastic mixtures') are introduced directly on excavation and initially act as drilling fluids, to assume later the required characteristics of strength and deformability.
This has permitted the construction of continuous jointless structures combining excavation and casting into a sole operation, in theory with saving of time and costs.
The mud components most commonly used are cement and Bentonite, which may, in certain cases, be replaced by sufficiently plastic types of clay.
The binder may consist in a cement/pozzolana mixture, provided the lesser cost of the latter component makes for overall savings without prejudice to the desired short or long term results; it may also be necessary to use chemical additives.
For waterproof diaphragms the composition of the self-hardening is generally kept within the following limits:

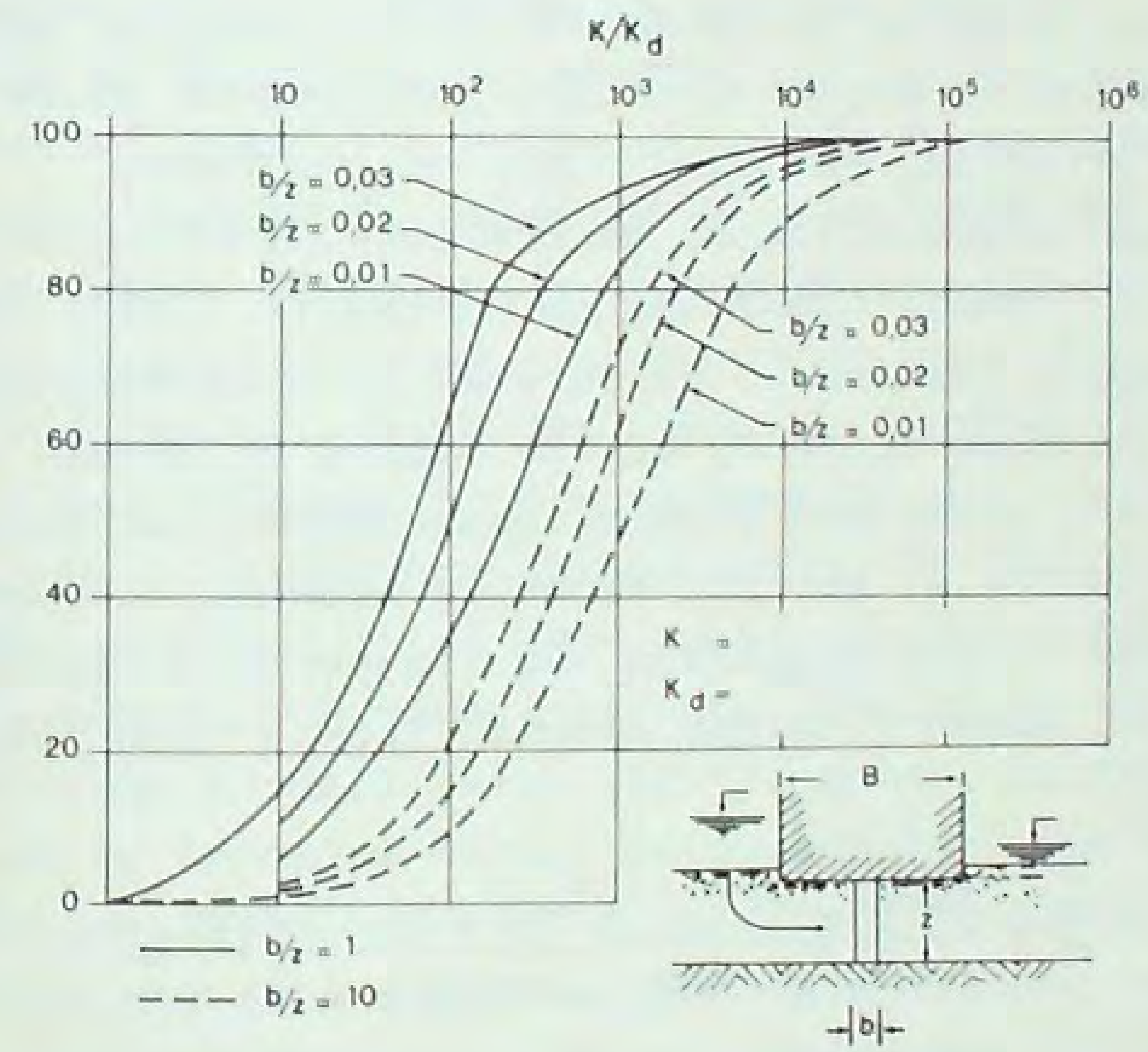
Bentonite/water: 0.04 - 0.07
Cement / water : 0.I5 - 0.30

For applications requiring greater final resistance the cement/water ratio may be increased considerably. The typical permeability of a plastic diaphragm is in the order of $K = I \times IO^{-6}$ cm/sec, at the stage when the mud retains its plasticity; this value decreases to values of the order of $K = I \times IO^{-9}$ cm/sec as soon as the mixture hardens. According to measurements taken, this permeability value will last

even for years after construction.
According to Ambrasey (I963) the efficiency of a continuous diaphragm set into a waterproof substratum is expressed as a percentage ratio between the residual capacity $(Q_o - Q)$ and the filtering discharge Q_o in case of free flow (see figure I):

$$E = IOO\ (Q_o - Q)\ /\ Q \text{ in } \%$$

Figure I. Efficiency of a continuous diaphragm, expressed as residue discharge in relation to the filtering capacity without diaphragm (Ambrassey I963).



K = permeability coefficient of the ground in relation to the diaphragm set into an impervious substratum
b = diaphragm thickness
z = diaphragm depth
B = width of work protected by diaphragm (horizontal extension corresponding to piezometrical difference in height upstream and downstream)

On the basis of laboratory tests and checks in situ the stability of self-hardening muds can be considered as complete even in the presence of waters that are sulphurous, acid or even rich in selenite. Lastly, as concerns their long-term behaviour, there may be a risk of erosion and/or corrosion by underground waters in case of elevated seepage velocity. This risk tends to increase where the bed-rock does not possess a high degree of impermeability; in such an event, it should be considered that a greater injectability of the substratum will bring about an improvement in general sealing conditions. In certain regions, however, the presence of aggressive waters in areas of contact between diaphragm and bed-rock may cause corrosion problems, which, however, seem to decrease due to the lack of sensitivity peculiar to Bentonite-stabilized cement in respect of any agent attacking standard types of concrete.

A diaphragm can obviously also be realized by means of clay block within a trench: according to Ambraseys (I963), diaphragm efficiency (E) can be calculated in this case by assuming an infinite tendency of the number of cracks and by replacing the ratio W/D ("open space ratio") or degrees of imperfection - i.e. the relationship between the overall cracked surface of the diaphragm and its total surface - by the ratio K_I/K, where K is the permeability of the clay blocks. Then:

$$E = \frac{IOO/I\ (K/K_I - I)/D}{B/D + I\ (K/K_I - I)/d + 0.83} \quad \text{in } \%$$

B/D being the ratio between the width of barrage above the diaphragm (B) and the stratum to be diaphragmed, which is supposed to equal the diaphragm length.

Sealing diaphragms may also be manufactured according to a methodology recently developed in Japan and presented by G. Miki in I973 at the 8th ICSMFD in Moscow. The process,

called "Chemical Churning Pile or Pattern (CCP)", consists in introducing into the ground mixtures of cement, or cement plus silicate, by means of an injector placed at the lower end of a boring rod 40 - 60 mm in diameter. The injection fluid is pumped in at overpressure - the 200 - 250 kg/cm^2 standard operating pressure may even rise to 600 kg/cm^2 in certain instances - causing the ground to split at the sides and to mix with the injected product. Thus there will be formed consolidated columns 40 - 50 cm in diameter, which, partially superposed, will result in continuous impervious walls.

The importance of a complete diaphragm system with a particularly tight fit in the contact zone between the man-made structure and the bed-rock is clearly evident. A previous paper by R. Pozzi and G. Benvenuti ("Applied geological and geophysical study for subsurface dams in the Nugal Valley (Northern Somalia)", Padua I979) underlined the theoretical considerations determining this problem: the zones investigated were located in a hardship area from a logistic and environmental viewpoint, therefore quite different considerations relevant to the economical use of one or the other type of diaphragm should apply. It appears obvious that the manufacture of more sophisticated diaphragms should require better and more efficient job-sites: this may involve considerable difficulties. Lack of water, or the widespread presence of brackish water, represent only one of such possible negative aspects, not to mention the difficulty of procuring the necessary raw materials (cement, Bentonite and/or clay) and purely logistic problems. It may well be that earthworks followed by tamping of a clay block prove reasonably convenient after all.

Ground investigations involve the identification of a buried synclinal rock structure with a permeability coefficient between IO^{-5}/IO^{-7} cm/sec, not affected by important dislocations. This identification will obviously start from considerations concerning the regional geologic characteristics and take shape by means of detailed geological surveys, first and foremost by establishing a plan of field surveys of a geophysical mechanical and engineering nature, aimed at defining:

- the lie and form of the impervious substratum;
- the composition and thickness of the porous reservoir, so as to determine the physical and hydraulic characteristics of the future aquifer;
- the presence of clay deposits used for making diaphragms and the possible digging of tube or dug wells.

An additional purpose of geognostic drilling is to equip small diameter pilot wells not only for direct permeability measurements, but also to measure any aquifer currents within the contact zone. A useful tool could be the micrometer currently adopted by Rodio S.p.A. and described by them as suitable to assess natural flow speeds of under I cm/sec, and conveniently lowered into 50 mm boreholes. In fact, as underlined earlier in this paper, when making a technical choice as to the type of diaphragm to be adopted, it is important to assess the hydrogeological and hydraulic conditions prevailing at the bottom of the reservoir. As to the latter, one should evaluate not only its geometrical dimensions, but also its effective porosity, in order to calculate at once the feasible volume of water storage and the necessary saturation time; the time factor will obviously depend on the amount and distribution of rainfall. As concerns effective porosity, it should further be noted that on the whole a value varying between I0% and 20% of overall porosity is more or less acceptable; permeability tests in situ accompanied by drillings, all carried out according to the appropriate procedures and methods, have

long become a standard practice.
It has been said that the use of a good type of colloidal clay instead of Bentonite is feasible for self-hardening muds.
This circumstance could be of considerable economic importance, since Bentonite is generally very expensive, its price being four times the price of cement in certain countries. On the other hand, there are practically, very reduced possibilities to discover clay deposits having crystalline particles with a diameter below 0.002 mm and consisting mostly of Montmorillonite, not to speak of the unlikelihood that such deposits are sufficiently close to the place of application.
As can be seen, economic consideration are closely linked to the strictly technical aspects, particularly so in arid or semi-arid countries where there is a particular need to adopt this type of solution to create permanent water reserves, the benefits of which are self-evident.

Geophysical surveys for choice of site and subsurface dam projects

Knowledge of the structural, lithological and geotechnical features of the underground is of basic importance in determining the feasibility of major civil engineering works, as well as in determining the most suitable technical solutions and evaluating their ultimate cost.
A considerable part of such studies is taken up by geognostic perforations and laboratory tests on rock samples collected during such operations. Perforations or soil drillings are useful in that they permit direct explorations of the subsoil; however, the disadvantage lies in their high cost and in the spot collection of data. To overcome these difficulties, geophysical investigation is being in-

creasingly used, as it permits indirect subsoil exploration at a far lower cost over a far more extended area; in fact, the data so collected in a certain sense provide an average picture of the subsoil around the point of measurements.

More specifically, when designing subsurface dams a geophysical survey will prove very useful in solving two kinds of problems of equal importance in ensuring a good product quality:

- evaluation of the hydrogeological proprieties (physical and hydraulic) of the subsoil with special regard to their horizontal and vertical variations;
- determination of morphology of impermeable bed-rock. So it is possible to point out the more favourable thickness of rock reservoirs and the site where placing the subsurface dam.

Generally speaking, a geophysicist can tackle problems of this nature by resorting to two methods of investigation, namely geo-electrical sounding and seismic refraction surveying, each within its own optimal range of application; their joint use, which is not always possible for technical and financial reasons, ensures a high degree of precision and reliability at the stage of geophysical interpretation.

The first method relies on measuring electrical ground resistivity at increasing depths; it will be the more efficient, the greater the contrast of the resistivity characteristics for each type of ground. The method has quite a good resolutive capacity, permitting the detection of strata with thickness equalling at least the relevant tectonic depth with an appreciable degree of precision. It is particularly suitable when evaluating the water-bearing characteristics of the alluvial deposits.

For these deposits the value of electrical resistivity is, in fact, inversely proportional to their content of super-

fine elements, this practically to their permeability.

A resistivity scale " " is tentatively set forth below:

$\varrho < 10$ ohm.m: prevalence of clays
$10 < \varrho < 20$ ohm.m: prevalence of silt clays
$30 < \varrho < 40$ ohm.m: prevalence of silt
$60 < \varrho < 80$ ohm.m: prevalence of sands
$\varrho < 80$ ohm.m: prevalence of gravel

The seismic method for studies related to problems of civil engineering is the method of refraction based on the varying propagation speeds of the elastic waves in the rocks, such speed depending essentially on the elastic features of the material. The method features a considerably higher resolutive capacity than the electrical one compared with which it is however less incisive when detecting the hydrogeological aspects of loose alluvional soil. Vice versa, the method is particularly suited for determining both the depth and conditions of the rock forming the aquifer bed on which the barrage works are to be anchored. There is, in fact, a neat contrast of the propagation speed not only between alluvial deposits and compact deposits (bed-rock in sensu lato), but between rocks with different degrees of alteration or jointing as well. This method of investigation will therefore be particularly useful where alterating and/or tectonizing processes have involved the bottom rocks, causing a radical change of their physical and at times, even petrographical features.

A typical example is given by the sub-surface barrages which are to be built in those zones in which the bed-rock is made of magmatic or metamorphic rock in general and of granite in particular; a sequence of alterated rock belt, a belt of jointed rock and lastly, compact rock can usually be found justly beneath the alluvials, the bed of the more

important aquifer. Wanting to realize a truly efficient type of work in similar circumstances, cognizance of the importance of both belts as to thickness, extension and degree of compactness should obviously be of considerable interest.
Similar data can be given by seismic studies considering that the typical speed of propagation in sound rock is reduced to I/5, to I/4 in the belt of alteration and to I/3, I/2 in the fractured belt according to the importance of alteration and fracturation.

Geotechnical problem during the design of sub-surface dams

The geotechnical problems arising in the design stage of sub-surface dams with the aid of impervious diaphragms are mainly concerned with the hydraulic and static checks.
The hydraulic check comtemplated an evaluation of the syphoning safety coefficient and a calculation forecast on the delivery of water which may seep in beneath the diaphragm. In many cases the application of approximate methods such as tracing the grid of seepage, can lead to sufficiently accurate evaluations once the type of deposit permeability in question and the aquifer geometry have been defined.
Analytical and final solutions are possible solely in those cases in which the geometry and contour conditions are sufficiently simple and flow-governing equations are linear.
Whenever particularly complex conditions are met, the use of numerical methods becomes absolutely necessary; the construction of models to which one resorts at times, becomes quite a burden, quite besides the hardly acceptable time requirements.
The used numerical methods are mainly those based on finite

differences and finite elements even though other methods are employed at times like those of the characteristics and integral equations (C.S. Desai "Flow through porous media", in: Numerical methods in geotechnical engineering, I977).
The static control which is not indispensable in cases without strongly unbalanced loads at the two diaphragm faces, accentuated stratigraphical heterogeneity will be required in particular circumstances such as levelling and embanking operations near diaphragms, elevated hydraulic loads, presence of soft strata and unfavourable morphologies. Such checks should concern both the overall stability of ground and diaphragm as a whole and the definition of deformation and action taking place inside the diaphragm.
Whilst a control of the overall stability may be carried out by traditional methods of calculation, research of the state of tension and deformation within the diaphragm becomes difficult and little accurate.
In many cases the problem will be faced considering the diaphragm like a beam rammed into the ground and subject to external stress and action by the ground.
As no closed-form solution is possible, recourse is made to discerning solutions applying the method of the finite differences or the method of Zemochkin and using for the ground the Winkler model with springs of rigidity variable according to depth and stratigraphy (elastic or elasto-plastic type).
The major difficulties are, however, not of a mathematical nature, but consist far more in evaluating the action brought to bear on the diaphragm and the definition of a link in harmony with ground reaction-diaphragm displacement; especially the latter aspect of the problem has apparently not been solved yet.
The analysis of the behaviour of sealing diaphragms cannot

be conducted satisfactorily except for the use of the finite elements, particularly when diaphragms are involved in excavations or embankments (G. Gatti / A. Cividini "Stato di tensione e di deformazione in un diaframma plastico e nel terreno interessato da uno scavo profondo in presenza d'acqua", in press).

For a description of the non-linear behaviour of the ground the hyperbolic link type, proposed by Duncan and Chan (see the ISBILD Programme) is frequently adopted. However, in presence of a condition near to failure similar schematics lose efficiency (see Ozawa and Duncan "Elasto-plastic finite element analysis of sand deformation", 1976); it will then be preferable to resort to an elasto-plastic model (see Gioda / de Donato "Elastic-plastic analysis of geotechnical problems by mathematical programming", in: Int. Journal for numerical and analytical methods in Geomechanics, 1979) defined by the elasticity module E and the coefficient of Poisson μ for states of stress contained inside or pertaining to the failure envelope of Mohr-Coulomb.

Referring to a plane in deformations ($\varepsilon_\gamma = 0$), the failure envelope of Mohr-Coulomb in function of σ_x, σ_z, and σ_{xz} (supposing tension $\sigma_y = \sigma_2$ being intermediate in respect of the main tensions σ_I, and σ_3 on plane X, Z) will have the form:

(I) $$(\sigma_x - \sigma_z)^2 + \tau_{xz}^{\;2} = (2c \cos\emptyset + (\sigma + \sigma)\,\mathrm{sen}\emptyset)^2$$

Within the range of tensions σ_x, σ_z, and τ_{xz} the equation (I) represents an elliptical section cone the axis of which coinciding with the straight line

$$\tau_{xz} = 0,\ \sigma_x = \sigma_z$$

For stress conditions appurtenant to the yield surface the plastic and increasing deformations may be expressed, according to the Law of Normality, by the following:

$$\varepsilon p_{ij} = \lambda \frac{\delta f}{\delta ij}$$

in which λ is a plastic multiplier and f the yield function of equation (I).

Calculating by finite elements also creates considerable difficulties which will become the more relevant the greater the complexity of the supposed ground model and the higher the number of elements in play. It will therefore become necessary to provide for an appropriate limitation of the area of discernment both upstream and downstream of the diaphragm, as well as in depth.

Certain indications regarding the dimensions to be adopted are given by F.H. Kulhawy ("Embankments and excavations", in: Numerical Methods in Geotechnical Engineering, 1977).

The module evaluation requires particular attention as its value changes in function of the state of tension. Depending on the required degree of accuracy one may refer to modules corresponding to the initial and final situation or with better results even, associate the module variation with the state of stress.

Nugal Valley: Hypothesis on interventions in favour of zootechnics

We regarded useful putting before some constructive and methodological considerations about construction of subsurface dams; very little notes were published on this subject, although many specialized in subsoil works enterprises boast a long professional experience, obviously

inedited.
In Somalia studies for groundwater reservoirs were made (even by preliminary investigation-drillings) in ex-Somaliland by J. A. Hunt ("Sub-surface Dams in Hargeisa", October I954/May I955) who did work excellently.
Hypothesis on interventions in Somalia were pointed out also by C. Faillace in the I960s. C. Faillace must be considered the most expert in Somali problems. Between I982 and I983 he proposed many projects to the Somali government.
We want to take again the notices published in I978/I979 about sub-surface dams in Nugal Valley (between Garoowe and Sinujiif), adding some unpublished data collected in Togga Nugal in Eyl area, thanks to the field investigations made by R. Pozzi, E. Sommavilla, Saadia Arif Osaim, Ibrahim Mohamed Farah in I979 and I980, later by R. Pozzi and G. Benvenuti, and again by R. Pozzi and Ibrahim Mohamed Farah.
Here it is the reason: about discharges of Togga Nugal to the north of Eyl we have only approximate informations. Perhaps there are some, but dispersed in quite private reports, being always difficult to consult and to be found.
Our own goal concerns the remarkable possibilities that Nugal Valley gives for cattle-breeding, also considering the abundance of fresh-water localized in some sectors not interested by evaporites (gypsum and anhydrites).

Researches in Sinujiif territory

Sinujiif village is situated about 60 km far from Garoowe in the wide talweg of Nogal. The river-bed of Togga is lowered of about 2 m as regards the site on which the built-up areas lies, and is about 200 m large. The sandy-gravel alluvium has 5,3 · IO^{-2}cm/sec permeability and constitutes a site for a remarkable sub-surface unconfined aquifer.

This aquifer is occasionally overworked; mostly people dig by hand little wells in the sub-surface, which are utilized temporarily either for man or for cattle (all the valley is rich in it). We must observe that the geophysical researches, even if limited, have pointed out that reservoir rock has a remarkable thickness and in this way we have a real possibility of tube wells which permit a continuous irrigation.
In April I979 the static level was considerably lowered; dug wells were few and about I,30 m deep; the water temperature was of 28^{o} C, being the air $23,5^{o}$ (at 6 a.m.).
From Garoowe to Shimbiraale up to Sinujiif we have seen a lot of wells in evaporites; Shimbiraale well, 4 m deep, has a strongly sulphureous water.
A few kilometers ESE of Sinujiif, the Togga Nugal Valley becomes less and less marked and the river-bed is no more recognizable. In Kaalis region the Taleh Evaporites outcrop widely, whereas the Togga Nugal shifts northwards, so that it shows again its own river-bed IO km downstream of Kaalis.
In this area we note the transition from the Taleh Evaporites to the Karkar Formation and the Togga bed appears well defined down in the valley, which trends to narrow, with relatively steeper lopes. The morphology appears different from the one represented by our topographics maps. Remarkable facts happened too. The great dry season of I970, in fact, cancelled every sign of life, concentrating at Sinujiif the remained people. However, it is always remarkable the number of camels and wild animals, that find pasture and represent the reason for local life.
We think that the water problem of the Nugal Valley is really to be seen as function of pasture improvement, which would determine an increase of the number of head of cattle,

and, hence, of stable population.
Sinujiif built-up area can improve its water disponibilities either by drilling deeper wells or by creating a sub-surface dam (that is a diaphragm-wall) which should be used for collecting, east of the built-up area, a section of groundwater flow, while obstructing the loss and the pollution from Taleh Evaporites. A sub-surface dam would be very useful also just downstream of Kaalis, near Garas, where the Togga Nugal goes in the Karkar Formation, to give a new impulse to this territory.
The chemical analysis of a sample of water of a sub-surface well in the Togga of Sinujiif (April I6, I979) gave the following results:

Ph: 6,8

Conductivity (28° C): S	: I4IO	
Organic substances ($KMnO_4$)	: mg/l	: 9,48
Ammonia (NH_3)	: "	: 0,500
Nitrites (NO_2)	: "	: 0,075
Total hardness ($CaCO_3$)	: "	: 958,98
Temp. hardness ($CaCO_3$)	: "	: I40
Perman. hardness ($CaCO_3$)	: "	: 8I8,98
Alkalinity P	: "	: 0
Alkalinity M	: "	: I40
Calcium	: "	: 889,0
Magnesium	: "	: 69,98
Sodium and Potassium	: "	: 29,76
Iron	: "	: 0,057
Copper	: "	: 0,00I
Bicarbonates	: "	: I40
Carbonates	: "	: 0
Hydrates	: "	: 0
Sulphates (SO_4)	: "	: 700
Chlorides (Cl)	: "	: 84
Nitrates (NO_3)	: "	: 2,0

Phospates (PO_4)	: mg/l	: ---
Silica (SiO_2)	: "	: I6,80

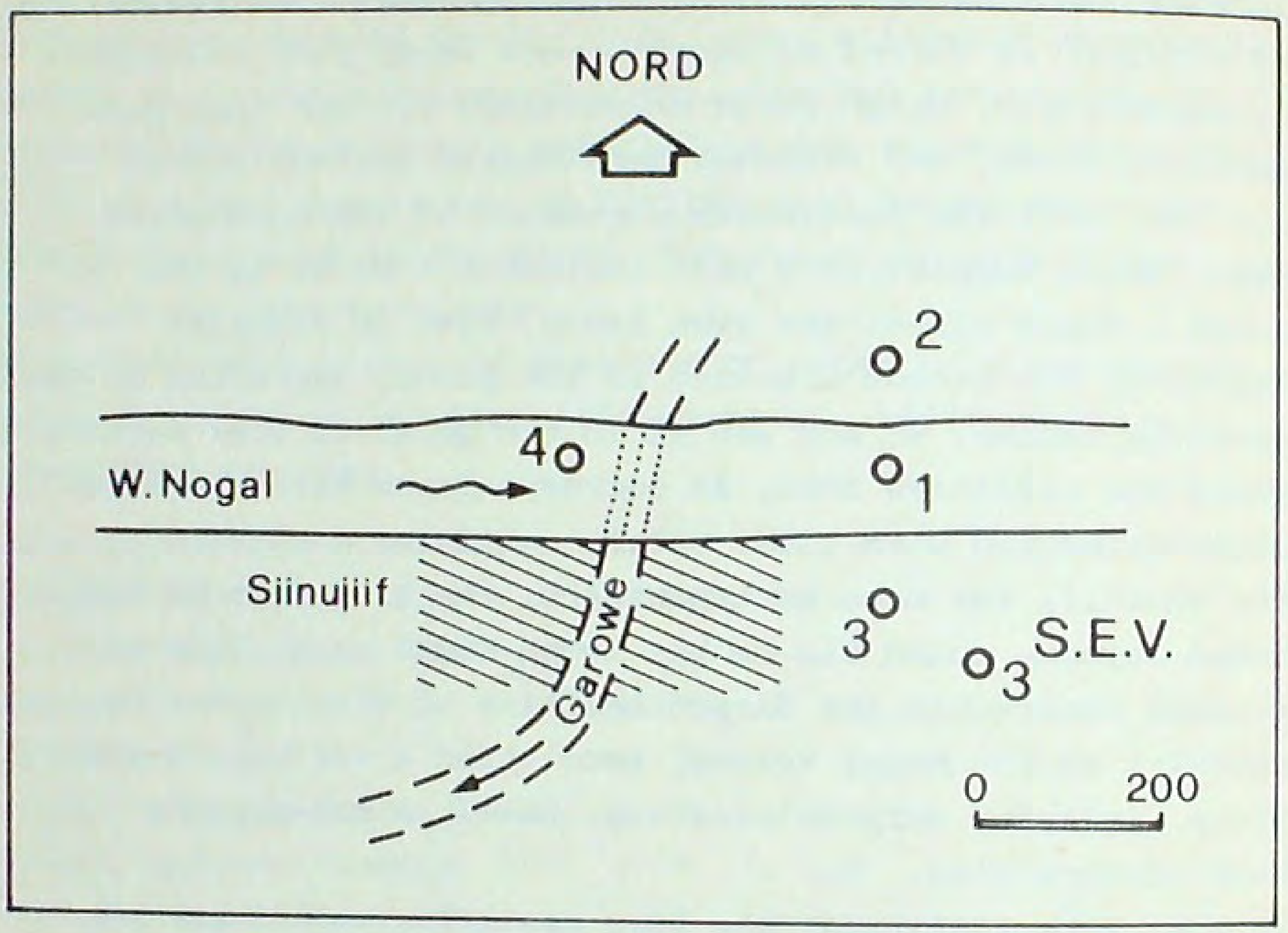
We have also collected samples to see if there exist argillaceous deposits to build the diaphragm-wall. The subsoil of Sinujiif is formed by agrillaceous sand, mud, practically impermeable, which could undoubtedly fit for that purpose. Moreover, the executed geoelectric section points out very well the continuity northward of the conductive zone, where samples have been collected - so as in the south - where values are even lower. Also in Sinujiif territory the stream migrated in the plane, depending on the meteoric regime; we may see it in the geoelectrical section, where the resistive zone, in correspondence with the alluviums saturated with river water, continues southward in the subsoil; far more northeastward, the alluviums of the Togga Garoowe could lie on the Togga Nugal ones. This increases remarkably the disponibilities of groundwater reservoirs of the Nugal Valley, permitting a variety of solutions, everyone very interesting, based on sub-surface dams construction.
We must note that undér the very resistive alluviums, there is a zone still with fair resistivity (I60 ohm.m) which might result productive in the lower part (it is always the same resistivity of reservoir rocks of Garoowe). There could exist, hence, a second aquifer.

Geoelectrical prospection

see Figure 2 and 3

From the interpretation of four S.E.V. diagrams, achieved in this area, the electrostratigraphic landscape would be the following:
- covering. It is very heterogeneous in the upper part,

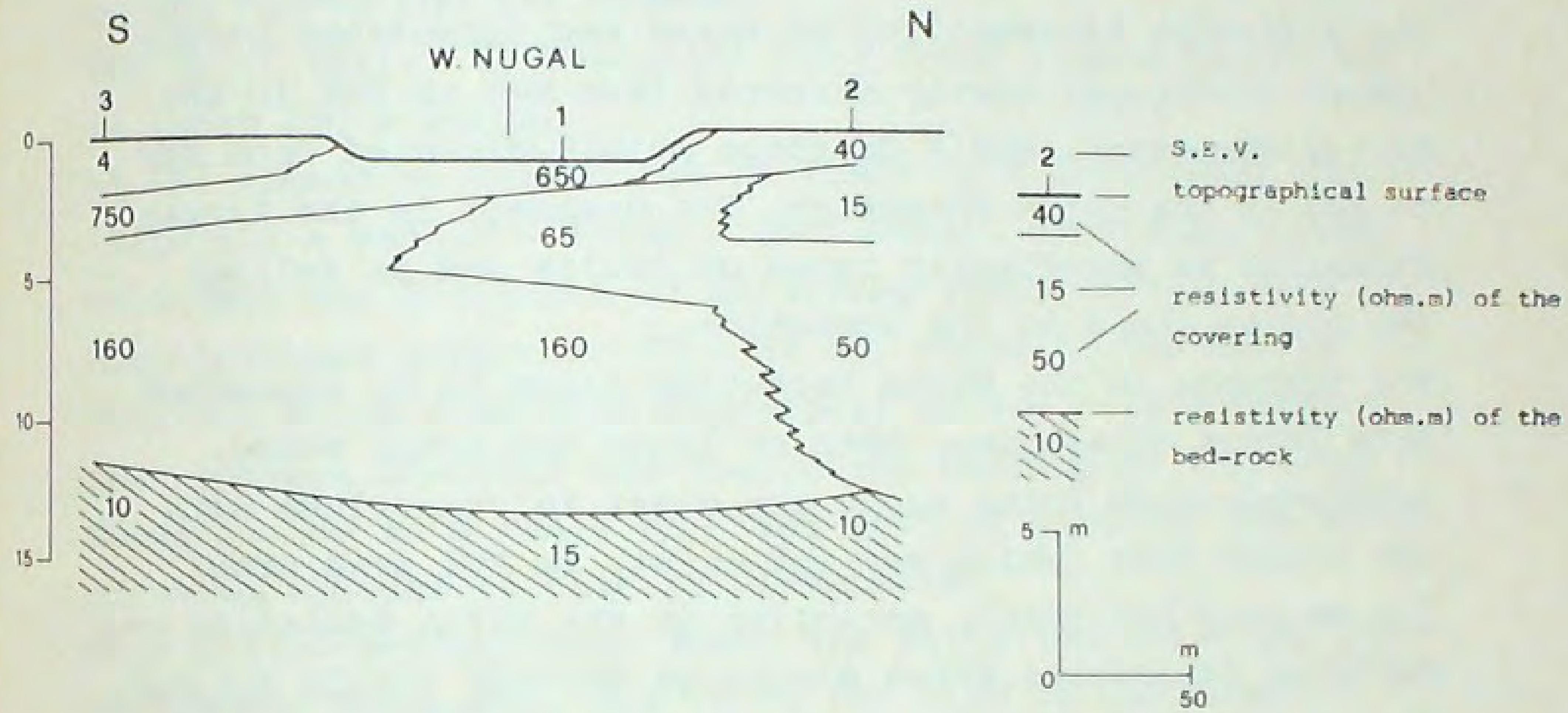
Figure 2. Location of geophysical (electrical methods) surveys in Sinujiif area



from about four S.E.V. 3 ohm.m to about 700 S.E.V. I and 4 ohm.m: pure clay constitutes the conductive electro-stratum, stones and dry sand consist the resistive one. In the lower part there are soils resistive (about 50 and I50 ohm.m) and a thickness of about I5 m. The more resistive terms should accord with sands and stones, the less resistive ones with muds.

- substratum. It is represented with a electrostratum, whose resistivity can be evaluated between I0 and I5 ohm.m and which could identify itself with the Taleh Formation. It is interesting to observe that this formation main-

Figure 3. Electrostratigraphical cross-section of Sinujiif sub-soil



tains electric characteristics, practically exactly alike Garoowe and Sinujiif, far from each other 60 km; the geoelectric section of Sinujiif points out that the resistive zone, possible site for an aquifer, has a notable thickness (8 - I0 m) not only in correspondence with the actual water-course (S.E. I), but also on the right side of the same (S.E. 3); on the left side the ground at 50 ohm.m could be an obstruction, at least partial, to the aquifer contained in more resistive soils.

The Nugal Valley in Eyl area

The low valley of the Nugal, that is 100 km long seawards, is characterized, from the hydrogeological point of view, by the limestones of Karkar Formation which is overlain by the sands, sandstones and conglomerates of the Hafun Formation.

The different permeability of these two formations establishes a drainage mostly directed from NNE to SSW in the Karkar Formation, and a drainage mainly directed from NNW to SSE in the Hafun Formation. The drainage in the Karkar Formation is prevalently based on faults and it follows the softer zones in the formation.

The drainage in the Hafun Formation seems to be connected with facies etheropies, both at large and small scale.

Relatively high rains along the coast in comparison with the inland ones (which may not exist; in Eyl area about 175 mm rain per year), establish in the Hafun Formation remarkable reservoirs which discharge through little springs.

In the topographic maps to the scale 1:100.000 these springs are called as follows:

- Dhinkaad
- Dhagaxlaha
- Bio Kulul
- God cad.

Certainly an important role on the intake area of these springs is played by the regional tectonics and first of all the subvertical big faults (direction NE - SW) that slope like graben, the more ancient formations of Karkar - Taleh, so that they were scaled by the Miocene-Oligocene transgression of the Hafun Formation.

The Togga Nugal outcrops about 10 - 12 km NO of Eyl. Waters outcrop depending on the outcrop of rocky substratum.

The complete exploration of these areas was not possible for time reasons; we can pass through the valley only on foot, from Eyl we can climb up the valley by Land-Rover only for about 2 km.

The bed-rock is formed by lithologic types of the Karkar Formation which lie subhorizontal along all the bed of the Togga Nugal; the more calcareous or marlier zones outcrop on the talweg and its slopes.

The Nugal Valley in Dool-Dool area forms like a canyon and is about 250 m large.

At the moment we cannot say if there is a continuous flow (Sinujiif - Kaalis - Garas - Dool-Dool). From Sinujiif to Dool-Dool the thickness of alluviums seems locally very high (perhaps more than 70 - 80 m), while in the Kaalis area the Taleh Formation crops out; we are of the opinion that between Sinujiif and Kaalis the outcrop of the Togga Nugal is due to a fault NE - SW. East of Sinujiif the sandy alluvium shrinks so that it disappears.

From Kaalis to Dool-Dool there are still the alluviums with remarkable thickness, but we do not know if they contain water. These - as we mentioned above - outcrop to the east of Dool-Dool, but this could be due not to a continuous flow, but only to a local concentration.

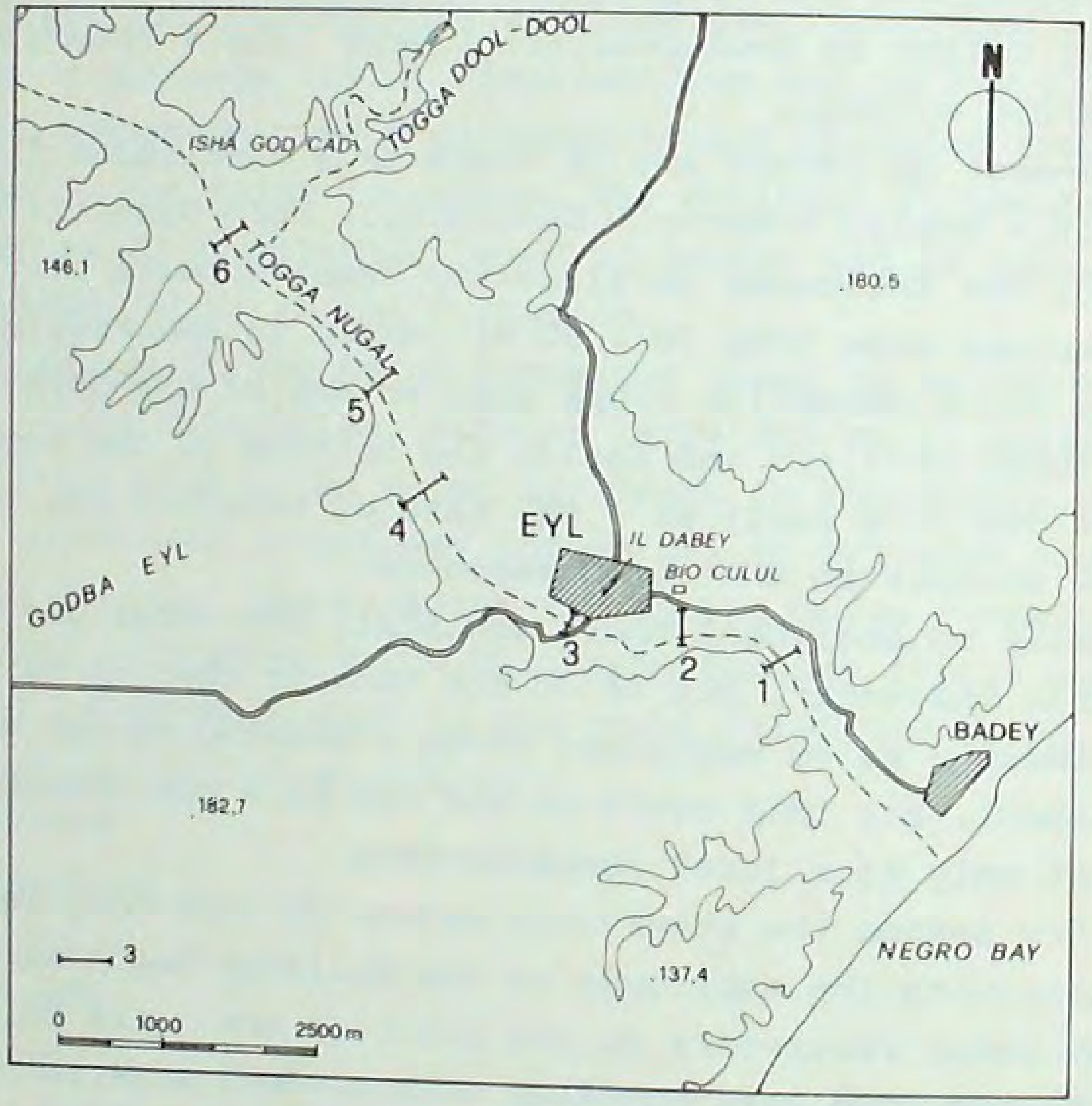
In the dry season the observable amount is very low; in comparison with the amplitude of the drainage basin we can see that water reservoirs in the sub-soil are quite fair in Sinujiif area, and less numerous in Dool-Dool area.

Our reflections get us to think that the outcrop is due to the contact between the Karkar Formation; the latter, in a regional sense, acts as a rock reservoir.

The retined-rocks, locally, are formed only by the Karkar Formation which we see to occupy the low Nugal Valley, about 5 km west of Eyl.

Now we are going to consider the Togga Nugal. We made surveys in 1979 and 1980. The difficulties were great of course, so that data are indicative. They are, however, the first published. The surveys were made along six sections as illustrated in Figure 4.

Figure 4. Surveys in the Eyl area.



Section	Day	Hydraulic Discharge
No. I	May 7, 1980	73.5 I/sec.
No. I	May 8, 1980	490.0 I/sec.
No. 2	May 7, 1980	180.0 I/sec.
No. 3	November I, 1979	18/20 I/sec.
No. 4	November I, 1979	2/4 I/sec.
No. 5	May 8, 1980	1450.0 I/sec.
No. 6	May 8, 1980	700.0 I/sec.

At the same time, we made a survey of the discharge of the Bio-Kulul spring, on May 7 and 8, 1980.

We have to note that all the night of 7th long, there was abundant rainfall and that, the day before, it had rained in the Nugal (mostly in Kaalis area on May 4, 1980).

The hydraulic discharge of the Bio-Kulul passed from I.5 lit/sec on May May 7, 1980 to 3.2 in the night of May 8, 1980.

The collected data let us make some considerations:

- The groundwater flow of Eyl is completely independent from the superficial one and is connected with the quaternary formation, widely cropping in the Eyl area.
- The Il-Dabay spring is connected with drainage of the outcrops from the plateau north of Eyl, and its hydraulic discharge varies from about 9 lit/sec to about 20 - 25 lit/sec.
- In correspondence with Eyl, under the quaternary formation very pervious rocks must exist, which establish a wide loss of the Togga Nugal; it is enough to consider that in about 3 km, the Nugal disperses as far as 2/3 of its discharge.
- The fact that the Togga Nugal discharges are strongly influenced by rains, suggests a very low infiltration.

Eyl springs are quite well-known. There are cold and hot springs (in particular see Popov and Kidnay, 1972).

A typical example is the hot spring of Bio-Kulul, where we surveyed a water temperature of 38° C (being the temperature of air 31° C). The spring is about I km SE of Eyl and the water outcrops, gurgling in pressure, about 10 - 15 m above the Togga Nugal Bed.

The water temperature is in favour of a deep origin of the spring, but the discharge variation following the rain season gets us to think that the same spring has also a more superficial intake area; in fact, an increase of hydraulic discharge is followed by a temperature decrease of about 2^{o} C.

In the same area, we also observed the emergence of two other little hot springs, evidently due to presence of an impermeable bed, just above the Togga Nugal bed.

The groundwater flow of springs is completely independent from the Togga Nugal one.

The origin of these hot springs is possibly connected with deep faults and is due to the geothermal gradient.

The contact-zones between fresh and salt water toward the coast is variable according to the tides, but is meaningful the fact that at Badey there is a dug-well from which people take fresh water. There is, hence, a thin aquifer floating on salt water; we think that the penetration of salt water in the inland is of about 2 km.

From the practical point of view, it is evident that it would be really useful to prevent the loss of Nugal water (NO of Eyl), without compromising or prejudicing the big springs of Eyl.

A plan of utilizing the Togga Nugal plains is being considered by our group.

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