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Hydrology of deltas

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6-14 May 1969

Hydrologie des deltas

Actes du colloque de Bucarest
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Volume 2

A contribution to the International Hydrological Decade
Une contribution à la Décennie hydrologique internationale

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Hydraulic calculation of water discharge and levels in river deltas

V.V. Ivanov,
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SUMMARY: The method of hydraulic calculation of channel discharge and water levels in river deltas is discussed. The method is a further development of iteration techniques. It amounts to the determination of discharge in anabranches and water levels in the junction nodes. The method does not require the exact assumption of the flow direction in the anabranches. It allows an analytical calculation of the corrections to the stage in the junction nodes and it converges the solution for delta forks of any complexity. The calculation is readily automated.

On the basis of the discussed method, a programme of hydraulic calculation of complex braiding of river channels was worked out for an electronic computer of the Ural 2 type in the Arctic and Antarctic Research Institute, Leningrad. The programme provides for any number of anabranches of the delta with the water flow directed in and out of the channel braiding, with the given stage. The relationship between channel discharge and water level in the zone of tidal and surge-back water was investigated by hydraulic theory and electronic computer. Bearing in mind the peculiarities of water regimes in deltas, the requirements for the original data in the hydraulic calculation were considered. A numerical check of the method was carried out on the deltas of the Ob River and the Kolyma. This check revealed the actual possibilities of using this method to calculate water regime elements in real deltas.

RÉSUMÉ : On propose une méthode de calcul hydraulique du débit et du niveau dans les deltas des fleuves étant donné le développement suivant des méthodes d'itération. Le calcul revient à la détermination du débit de l'eau dans les bras et des hauteurs de la surface libre du niveau aux nœuds de jonction. La méthode n'exige pas de connaissance précise de la direction du courant dans les passes et elle permet de calculer analytiquement les corrections des niveaux de la surface libre du courant dans les nœuds de jonction : elle assure la convergence du processus pour les bifurcations de différentes complexités. Le calcul peut être facilement automatisé.

A l'Institut de recherches arctiques et antarctiques à Léningrad, en se basant sur la méthode en question, on a composé un programme de calcul hydraulique des bifurcations de rivière complexes pour la machine à calculer électronique "Oural-2". Une résolution est prévue pour les deltas à n'importe quel nombre de bras par lesquels s'écoule l'eau dans le système des bifurcations de rivière et à n'importe quel nombre de branches sortant de deltas avec des repères fixés du niveau libre. On a aussi élaboré l'algorithme du calcul de la corrélation du débit et du niveau de l'eau dans la zone du remous variable par la méthode hydraulique avec l'usage de la machine à calculer électronique.

On a examiné les exigences envers les données premières pour les calculs hydrauliques sur la base de la particularité du régime des deltas.

Le contrôle numérique de la méthode a été réalisé sur les exemples de deltas des fleuves Ob et Kolyma. On a montré ainsi la possibilité pratique d'utilisation de cette méthode pour le calcul des éléments du régime de l'eau des deltas.

The methods of river hydraulics for the calculation of discharge through the delta anabranches and the gradient of the water surface are complicated by their time-consuming nature, partly due to the inadequate development of the technique for different delta conditions. Additional difficulties arise during the preparation of the initial data for calculation, due to surge and tide effects on these data.

With the electronic computer, the time consuming nature of the calculations is no longer an obstacle, but the methods should need to be adapted for calculation by computer. The initial data for the calculation can be obtained in periods when water flow

The study of modelling the ground water flow in the Nile Delta using the Electrical Analogue Method [1]

Dr. Nabil Rofail[2] and Mrs. Sofia Tadros[3]

SUMMARY: The water bearing formations of the Nile Delta can be considered as a two layered aquifer. The hydraulic parameters of the aquifer determined from the analysis of the pumping test data conformed with those obtained by analysis of the water fluctuation in the wells. Accordingly a hydraulic diffusivity map of the Nile Delta is plotted.

The flow through the aquifer of the Nile Delta is simulated by the flow of an electric current through paper of different values of resistivity used as a conductive material. The head of water in the River Nile Branches and in the main canals is represented by electric potentials.

Thus the ground water of the Nile Delta basin is well understood, and accordingly the water table map is plotted.

RÉSUMÉ : Les formations aquifères du Delta du Nil peuvent être considérées comme étant constituées par deux couches. Les paramètres hydrauliques des couches déterminés par l'analyse des données expérimentales obtenues par le pompage ont confirmé ceux de l'analyse de la fluctuation de l'eau dans les puits, ce qui a permis d'établir la carte de la diffusion dans le Delta du Nil.

L'écoulement dans l'aquifer du Delta du Nil a été représenté sur modèle par l'écoulement d'un courant électrique en utilisant, comme matériel conducteur, des papiers électriques ayant des résistances différentes.

La pression de l'eau dans les bras du Nil et dans les principaux canaux a été représentée par des potentiels électriques analogues aux pressions existantes in situ.

On a donc pu bien représenter les eaux phréatiques du bassin du Delta du Nil, ainsi qu'établir le carte du niveau de la nappe aquifère.

1. THE HYDROLOGICAL CONDITIONS OF THE NILE DELTA [1]

The area under consideration is located between the River Nile Branches (Rosetta and Damietta) and is bounded on the north by the Mediterranean Sea. The area can be considered as a plain, the absolute levels of which vary from zero to 30 m above sea level.

The ground water reservoir mainly consists of Holocene and Pleistocene deposits. These alluvial deposits are essentially developed into gravel and sand facies with lenses of impervious clays. The thickness of these deposits is variable; at Cairo it is about 120 m and increases to the north. There is a cap covering these deposits made up of superficial, alluvial, cultivable soil composed of layers of clay and silty deposits. The thickness of this cap varies from 10-30 m between the Nile branches. Accordingly the water bearing formations of the Nile Delta can be considered as a two layered aquifer (see fig. 1, 2, 3).

The water bearing strata are always fully saturated and under hydrostatic pressure controlled mainly by the River Nile branches and by the main canals since its bed cuts through the sandy layer in many parts of its length [2]. The ground water level ranges from 0-20 m from the ground surface, and the ground water can be considered as fresh water, but in deep horizons the ground water is saline. The fresh water in the Nile Delta can be considered as a large fresh lens over saline water.

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2. Research officer, Hydrology Dept., Desert Institute, Mataria, Cairo, UAR.
3. Research assistant, Hydrology Dept., Desert Institute, Mataria, Cairo, UAR.

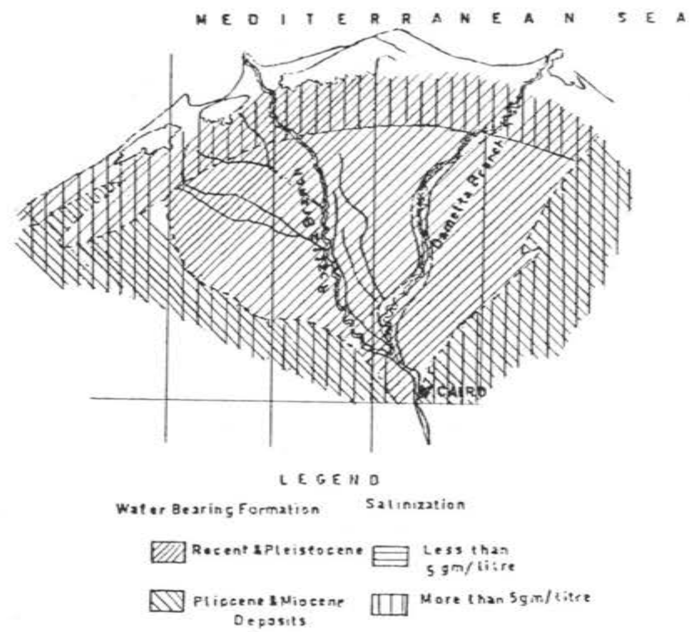

FIGURE 1. *Regional hydrological map of the Nile Delta*

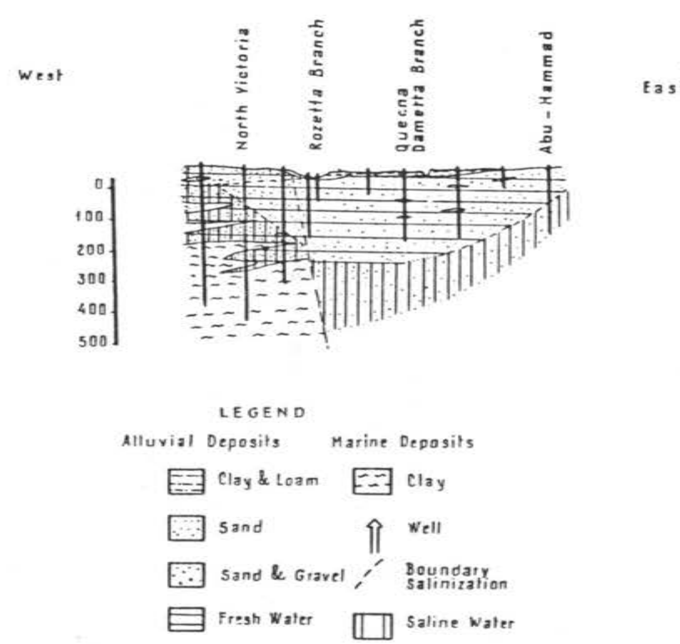

FIGURE 2. *Hydrological section B-B*

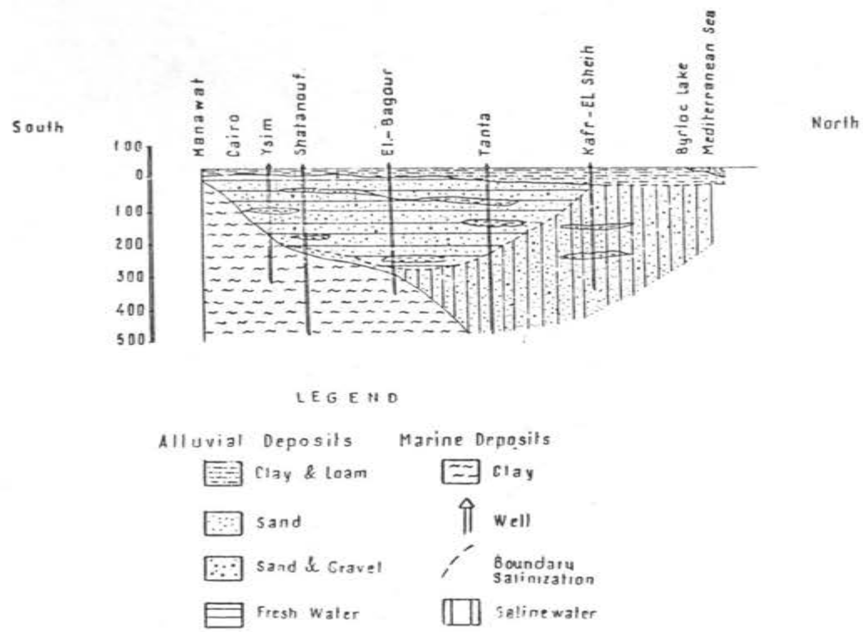

FIGURE 3. *Hydrological section A-A*

2. THE HYDROLOGICAL PROPERTIES OF THE AQUIFER

Pumping tests were carried out at Shebin El-Kom (1, 2, 3), by the Drainage and Ground Water Research Office, Ministry of Irrigation. The data have been analysed by using the Saad (1960) [3] formula for the finite depth of the partially penetrating well. The formula for the solution of the nonsteady state can be written in the following form;

$$s_a = \frac{Q}{8\pi kb} E\left(u, \frac{b}{r}, \frac{b'}{r}\right) \tag{1}$$

where:

$$E\left(u, \frac{b}{r}, \frac{b'}{r}\right) = \left[\int_0^\infty \frac{b+b'}{b'} \cdot \frac{e^{-\beta}}{\beta} \operatorname{erf}\left(\frac{b-b'}{r}\sqrt{\beta}\right) d\beta - \int_0^\infty \frac{b-b'}{b'} \cdot \frac{e^{-\beta}}{\beta} \operatorname{erf}\left(\frac{b-b'}{r}\sqrt{\beta}\right) d\beta\right] \tag{2}$$

As the wells are located near the river, the IMAGE effect has been considered for equation (2). Accordingly the transmissibility and the storage coefficients have been determined. The values of the coefficient of the transmissibility of the aquifer have been checked by analysing fluctuations wells and in the neighbouring rivers. The effects on the ground water flow of the resistivity of the silty materials deposited on the sides and the bed of the rivers have been considered.

Methods of analysis have been worked by using Averyarov's method, that:

$$\frac{\Delta H}{\Delta H_0} = R(\lambda) \tag{3}$$

where:

$$R(\lambda) = (1+2\lambda^2) \operatorname{erf} \lambda - \frac{2}{\sqrt{\pi}} \lambda e^{-\lambda^2} \tag{4}$$

and,

$$\lambda = \frac{x}{2\sqrt{at}} \tag{5}$$

The results have been in agreement with those obtained from the pumping tests.

Accordingly the variations in transmissibility of the Nile Delta aquifer have been determined. Thus maps of transmissibility and hydraulic diffusivity have been plotted.

THE ELECTRICAL ANALOGUE METHOD

This method is based on the mathematical analogy between flow through a porous medium and that through an electrically conducting medium. Many other problems e.g., heat transfer, diffusion of a magnetic field can be solved likewise. As the piezometric head can be represented by the electrical potential, so the difference of pressure head can be represented by the potential difference. Thus the flow lines of the ground water are simulated by those of the electrical flow and the equipotential lines by lines of equal electrical potential.

In case of flow through a homogenous medium, the equations of U, h have the form of Laplace's equations.

$$\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} = 0 \tag{6}$$

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \tag{7}$$

Accordingly the relationship between h and U is linear and relationship can be written in the following form:

$$h = AU + B \tag{8}$$

when A and B are constants.

The boundary conditions of the problem for an aquifer bounded by a river (h = const.), or for an impervious aquifer ($\partial h/\partial s = 0$), can be simulated on the model, by using a conducting material connected to a constant potential of value U, or by using a non-conducting material to get $\partial U/\partial s = 0$.

In the case of flow through a confined aquifer, the relative head h_r is represented by the relative potential in the model.

The head corresponding to a measured potential in the model follows from equation (8).

$$h = (h_{max} - h_{min}) U_r + h_{min} \tag{10}$$

For representation of the flow through the aquifer of the Nile Delta, the following scales have been considered;

(*a*) Scale of resistivity (α_R) which represents the relation between the coefficient of transmissibility of the aquifer (m^2/day) and the electric specific conductivity of the model (ohm/cm) i.e. (α_R: m^2/day/ohm/cm).

(*b*) Scale of length (α_L) which represents the dimension of flow in nature (m) and on the model (cm) i.e. (α_L: m/cm).

(*c*) Scale of potential (α_H) which represents the relation between the drop in nature (m) and the drop in potential on the model (volts), i.e. (α_H: m/volts).

(*d*) Scale of discharge (α_Q) which represents the relation between the discharge of the flow in nature (m^3/day) and the electric current in the model (amperes) i.e. (α_Q: m^3/day amp).

As the flow equation can be written in the following form:

$$Q = -TB\frac{\partial h}{\partial x} \tag{11}$$

Therefore by simulating this flow in the model, equation (11) will have this form:

$$I = -\frac{\alpha_R \cdot \alpha_L \cdot \alpha_H}{\alpha_Q \cdot \alpha_L} C \cdot b_m \frac{\partial U}{\partial x} \tag{12}$$

Accordingly the relationship between the different scales can be written in the following form;

$$\frac{\alpha_R \cdot \alpha_L \cdot \alpha_H}{\alpha_Q \cdot \alpha_H} = 1 \tag{13}$$

or

$$\alpha_Q = \alpha_\omega \cdot \alpha_H \tag{14}$$

Thus this condition should be fulfilled to represent the flow problem in the model.

The representation of the flow of the Nile Delta

The geometric relationships must be mapped to a scale appropriate to the actual aquifer and the model. The aquifer of the Nile Delta is represented by resistance paper of different values of conductivity. The relation between the conductivity of the electric paper of the model and the coefficients of transmissivity of the aquifers should be the same, i.e.:

$$C_1 : C_2 : C_3 : C_4 : = T_1 : T_2 : T_3 : T_4 ;$$

The contact between the zones, which are cut out of the various kind of paper, is made with the aid of conductive adhesive.

The types of boundary conditions that can be imposed upon the model are varied and cover almost any possibility that may be observed in nature.

The River Nile branches and the main canals are represented by electrically conducting material (such as copper sheet) fixed on the model. The head of water along the branches and the canals is produced by hydraulic structures (as barrages, weirs, ...) and due to the gravity flow through the channels. Accordingly the head is divided by a step method into small intervals. The head at each interval is represented by a corresponding potential.

The drop of potential from each interval to the next and between the upstream and the downstream of the hydraulic structures is represented by an electric resistance. (see fig. 4).

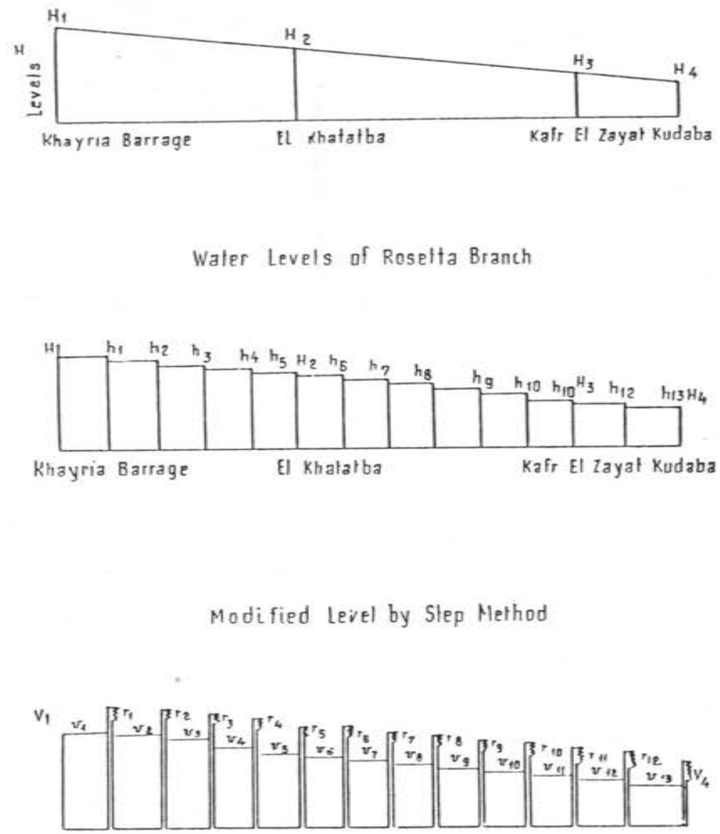

FIGURE 4. *Potential Diagram Representing Modified Levels*

The Mediterranean Sea is considered as a boundary of zero level; thus the zero potential of the model and the terminals of the represented canals of zero level are connected to the represented Mediterranean Sea.

The model is equipped by power supply to feed the model by stabilized D.C. current. It is recommended that potentiometers are used to supply the model. A precise bridge and galvanometer are used in measuring the potential at any point on the model as well as the points of equal potential (see fig. 5).

RESULTS AND CONCLUSIONS

A model of ground water flow of the Nile Delta has been constructed on the basis of the Electrical Analogue. The aquifer and the boundary conditions are represented. The Nile Delta basin is considered fully saturated and under hydrostatic pressure controlled mainly by the head in the River Nile branches and in the main canals. Thus the represented potential of the branches and the canals governs the flow through the represented conductive material of the Nile Delta. The points of equi-potential are determined and accordingly the water table map is plotted. The results from the model compared well with those obtained from the actual water table map.

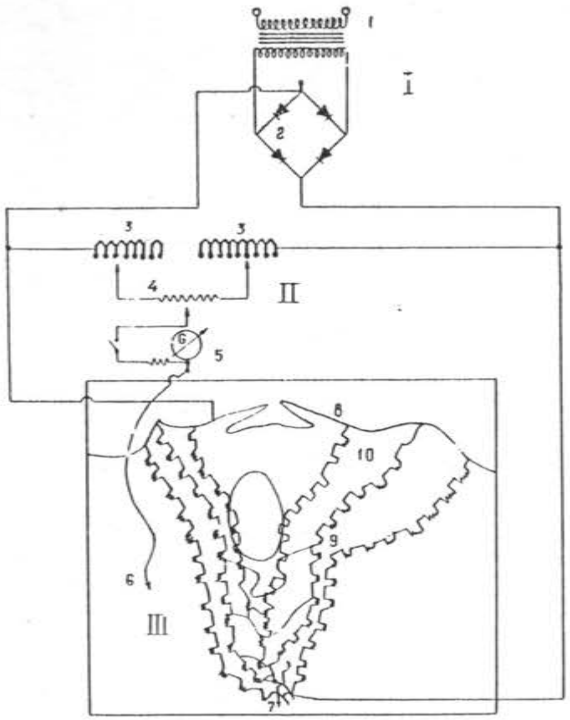

FIGURE 5. *The principal scheme representing the G.W. flow in the Nile Delta: I. Stabilized power supply; II. Measuring unit; III. Model.*

1 — *Transformer* 2 — *Diodes* 3 — *Rheostats* 4 — *Decade Resistance* 5 — *Galvanometer* 6 — *Pointer* 7 — *Upstream of Khayria Barrage* 8 — *Mediterranean sea and main canals* 9 — *Potentials of the River Nile Branches* 10 — *The represented aquifer of the Nile Delta by using the electro-resistance paper*

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Symbols

r Radial distance from the axis of the pumping well to any point in the space;
b Depth of the pumping well below the surface of the impermeable layer;
b' Length of the perforations in observation wells;
s_a Average drawdown in a perforated observation well;
Q Rate of discharge of the well during pumping;
K Hydraulic conductivity of the aquifer;
u Relation $- r^2\, Sc/4Kt$;
t Time since pumping started;
S_c Specific storage;
erf(x) Error function $= 2/\sqrt{\pi}\cdot\int_0^x e^{-\beta^2}\,d\beta$;
ΔH Change of head at a distant X from the river;
ΔH_0 Change of head in the river;
U The potential on the model;
h_1 Relative head;
h_{max} Maximum head in nature;
h_{min} Minimum head in nature;
h Head in nature;
α_R Scale of resistivity;
α_L Scale of length;
α_H Scale of potential;
α_Q Scale of discharge;
T Transmissivity of the aquifer;
B Length of the flow line in nature;
C Electric specific conductivity;
a Hydraulic diffusivity of the aquifer;
b_m Length of the flow line on the model;
I Electric current;
A and B Constant coefficients.

Considérations sur l'interaction entre les eaux de surface et souterraines du territoire du Delta du Danube

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RÉSUMÉ : Ce qui caractérise le territoire du Delta du Danube en matière d'approvisionnement en eau potable des collectivités est le fait que — en raison de la pénurie de puits, ou même de leur absence dans la majorité des localités — la population recourt d'une manière prépondérante à l'eau des bras du Danube.