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ground-water abstraction by gravity from sand rivers

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GROUND-WATER ABSTRACTION BY GRAVITY FROM SAND RIVERS

L. Horst,
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July 1975.

ABSTRACT

In many of the dry regions in the world, an adequate supply of water during the dry season constitutes a problem of paramount importance. Creation of surface storage reservoirs is often restricted by lack of suitable dam sites, by streams carrying heavy sediment load and by high rates of evaporation. Recovery of water from ground-water aquifers generally requires pumping with consequent problems of financing, maintenance and repair. One source of water, which in many dry regions is not, or scarcely developed, is the flow of water through sandy riverbeds (called "sand rivers " or " underflow"). This source, although relatively small, is dependable, annually replenished, and free from pollution; while, evaporation losses are limited. The principles of development of these sand rivers are discussed with special reference to abstraction and diversion by gravity by means of a collector.
Such a collector could be placed by modern machinery used for laying deep horizontal well-point de-watering pipes. Preliminary cost estimates for this method compare favourably with conventional methods of water abstraction (pumped wells and boreholes). The great advantage of this method is that, once installed, very little maintenance and operation and no treatment are required. The discussed method may well be applied for rural water supply schemes for small communities(1000 - 4000 inhabitants).

CONTENTS

GROUND-WATER ABSTRACTION BY GRAVITY FROM SAND RIVERS

1. INTRODUCTION

The basic problem of water resources development in dry regions in the world consists of short rainy seasons with erratic rainfall and flashy surface-water flows of short duration and varying magnitudes, followed by a long dry season with no or little rain. During the dry season many rivers cease flowing and water during that period could either be obtained from surface-water reservoirs or ground-water aquifers where excess water of the rainy season is stored either naturally (lakes, aquifers) or artificially (man-made reservoirs). Surface-water storage in these regions often implies problems with respect to lack of favourable dam sites, heavy sediment load reducing the lifetime of the reservoir, high evaporation rates (often in the order of 3 m/year) and contamination (by cattle and insects). Consequently, ground water constitutes an important source of water in these regions. Apart from the relatively rare instances of natural recovery of ground water in the form of springs, it is generally recovered artificially by means of dug wells and tubular wells. In some special cases, such as the famous abstraction of ground water by underground tunnels (kanats) in Iran or the constructed sand-filled reservoirs in South West Africa, the ground water flows from its source to the point of use by means of gravity.

In most cases in the dry regions, however, wells are used and the water has to be abstracted by pumping or other water lifting devices (animal traction or windmills).

People living in those dry regions often constitute the poorest part of the population. Lack of surface water and unreliable rainfall limit agriculture and animal husbandry. Development of ground water by means of pumping often results in failure due to lack of financing and/or inadequate operation, maintenance and repair of the pumping installation. Trained pumping operators are scarce;while, in many regions a large variety of types of pumps and engines hampers adequate spare part supply.

In many instances introduction of water-lifting devices by animal traction appeared unsuccessful due to various reasons (local population not familar with using animals, maintenance of lifting device, etc.).

The use of windmills is restricted to areas with favourable wind conditions. Furthermore, they are generally limited to small supplies and require, due to their irregular supply, large water-storage facilities.

In view of the above and in light of the rapidly increasing prices of fuel for motor driven pumps, the question of tapping ground water by gravity comes to the fore.

Gravity abstraction of ground water could only be considered where topography and slope of the ground-water table and water-bearing capacity of the aquifer render suitable conditions.

One of the possibilities of creating such a suitable condition artificially is to make a "sand dam". In the course of years a weir is built in stages across the valley bottom followed by the silting up of the reservoir. The water stored between the pores of the sand in the reservoir is practically free from losses by evaporation and could be tapped at the toe end of the dam. This method is limited by the availability of a suitable dam site and, in addition, is dependent upon the "erosion yield" of the catchment.

Another possibility is to make use of the ground water stored in the so-called "sand rivers" (or "underflow") constituting the aquifer of the sandy deposits of river valleys.
The following sections will deal with the possibilities of making use of these sand-river aquifers by means of gravity abstraction.*

In Chapter 2 the phenomena of the sand river will be described.

Chapter 3 outlines the possible means of water abstraction from these sand rivers; while, the theory will be given in Chapter 4.

In Chapter 5 the question of construction of gravity-abstraction works is discussed.

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*Note: These possibilities are often also found at alluvial fans where rivers suddenly change from steep to shallow slopes.

For the case of gravity abstraction by means of a collector constructed by "horizontal well-point method" the costs are compared with conventional (pumped wells and borehole) methods in Chapter 6.

Surveys and investigations required for choice of site and applicability of the discussed method are indicated in Chapter 7.

A review of the proposed method, its applicability, costs, advantages and disadvantages is presented in Chapter 8.

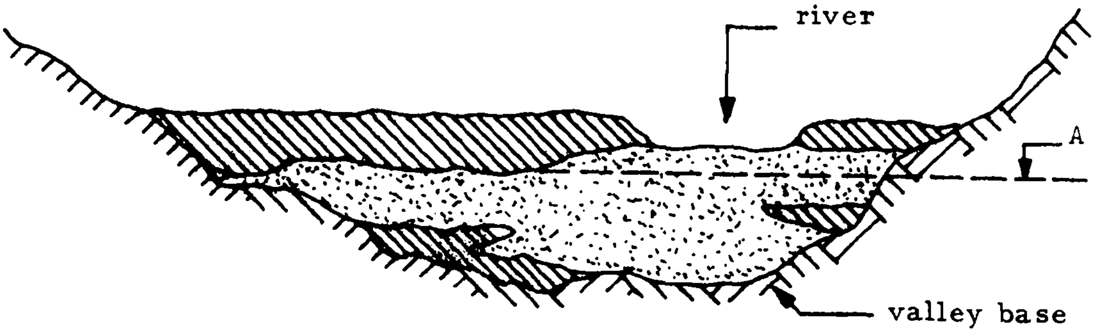
2. THE SAND RIVER

2.1. Climatic regions

Gravity abstraction from sand-river aquifers is only feasible for those rivers where sufficient surface-water flow ensures annual replenishment of the aquifer. Areas where the rainfall does not sustain a sufficiently long period (at least some weeks) of surface flow are excluded from the following considerations. The climatological area where these rivers could be developed constitutes a very large portion of the semi-arid/semi-humid regions of the world.

2.2. Description

Depending on geological history, many valleys in dry regions are filled with large deposits of coarse sands and gravels. In cross section these deposits are often bounded by impervious layers consisting of clay deposits and/or bedrock. See fig. 1.



▨ Fine deposits

░ Coarse deposits

A = Water level at the end of the dry season

Fig. 1. Valley cross section.

The rivers flowing ephemerally through these valleys often show very wide beds and rather low banks. These wide riverbeds, constituting the upper boundary of the pervious valley deposits, form an excellent surface for infiltration during the short duration of river surface flow. Therefore, surface flows of only short duration suffice, in many cases, to replenish completely the coarse valley deposits.

The effluent stream from bank storage into the river is, in general, negligible due to the low banks. Once the surface flow ceases, the groundwater aquifer below the riverbed (= sand river) could be considered as an entity, independent from the river itself. The sand river follows the general direction of the valley and not necessarily the present course of the riverbed.

Starting with a fully replenished aquifer, the sand river will be depleted during the dry season due to evaporation and evapotranspiration by vegetation in the valley and by the difference of inflow from the higher reaches and outflow into the lower reaches. The resulting drop of ground-water level due to this depletion, however, amounts often to not more than $1\frac{1}{2}$-2 m below riverbed level at the end of the dry season , usually constituting depletion of only a relatively small percentage of the total ground-water storage (see fig. 2).

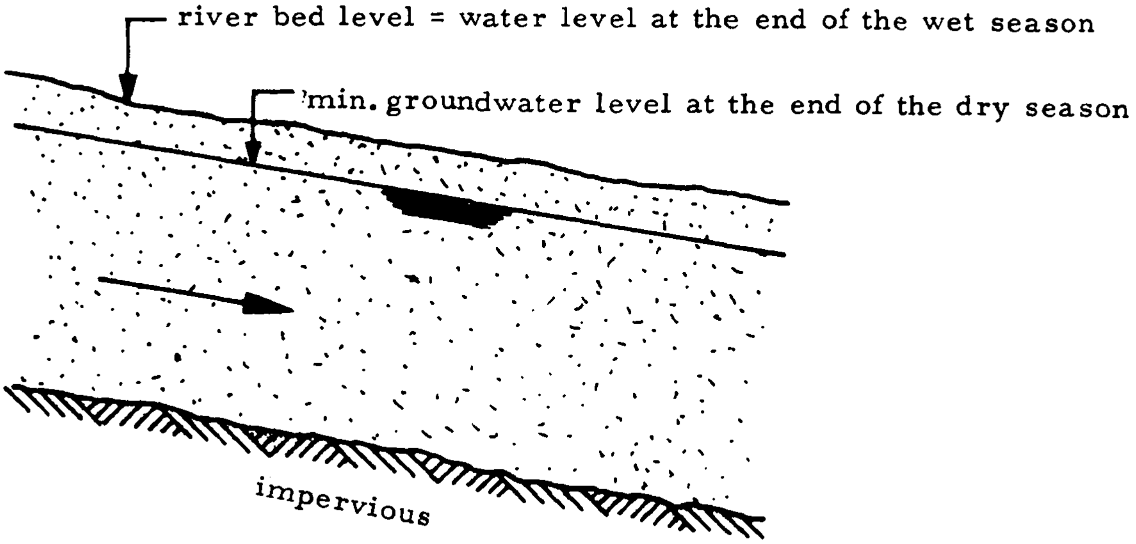


Fig. 2. Longitudinal section.

The sand river, therefore, could be imagined as a long shaped aquifer under a certain slope, yearly replenished and yearly only partly naturally depleted.

2.3. Ground-water potentials

The flows of sand rivers are relatively small when compared with surface flows. However, this type of water source could be of importance on a local scale as drinking water for man and beast and possibly for small-scale irrigation. The order of magnitude of water stored in a sand river could be visualized by considering the storage of a typical medium-sized sand river:

average depth of sand layers = 5 m
average width " " " = 50 m
losses by evaporation and evapotranspiration during
the dry season = 1.5 m
effective porosity 25%

When considering a stretch of sand river of 2 500 m, the water stored at the end of the dry season amounts to:
$3.5 \times 50 \times 2\,500 \times 0.25 = 110\,000 \text{ m}^3$.

Assuming abstraction of only $\frac{1}{4}$ of this water, to be supplied as an evenly distributed flow over 8 months of dry season:

$$\frac{110\,000}{4 \times 8 \times 30} = 115 \text{ m}^3/\text{day}$$

On the basis of 25l/person/day for domestic water supply, or 1 l/sec/ha for irrigation, this flow could serve either 4 500 persons or $1\frac{1}{2}$ ha under irrigation.

2.4. Gravity abstraction development

The abstraction of ground water from sand rivers is based on the difference in slope of the aquifer (following the slope of the valley and generally in the order of 0.02 to 0.003) and the slope required for the supply line (horizontal or very small).

The advantages of gravity abstraction are:

- Reliable source of water as a result of the yearly replenishment of the aquifer.
- In many cases the sand river already supplies the basic needs for drinking water for man and beast in the form of shallow holes dug in the riverbed. Often, therefore, a relatively dense population does already live in the vicinity rendering supply easier.
- Pollution of the water is reduced to a minimum due to the filter effect of the sandbody and the location of consumption being a long distance from point of abstraction.
- Once a gravity supply system is installed, neither fuel nor skilled operation and maintenance is required.

3. METHOD OF ABSTRACTION

3. 1. Introduction

In the following, only methods by means of gravity will be considered.

The principle of gravity abstraction is to place an interception drain (collector) across the sand river at a certain depth below the ground-water table. The relatively steep slopes of the sand river make it possible to divert the water intercepted by the collector by means of a gravity conduit under a small slope to a certain command level downstream at the bank of the river. The collector is able to capture the water due to its position well below the ground-water table and/or due to blockage of the flow by means of a cut-off wall.

3. 2. Abstraction by collector and cutt-off wall

One possibility of gravity abstraction is to block the flow of water through the sand river by means of a cut-off wall, screen or underground dam. A collector could be placed at the upstream side of the cut-off wall to divert the inflowing water.

The cut-off could either be complete (fig. 3) or partial (fig. 4).

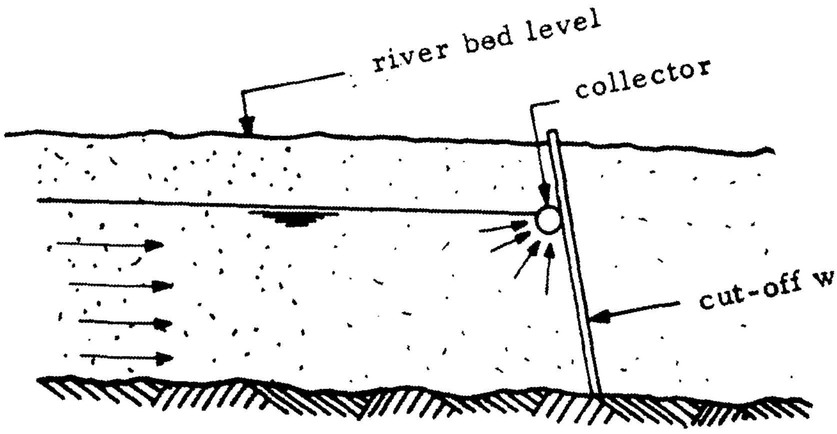


Fig. 3. Complete cut-off.

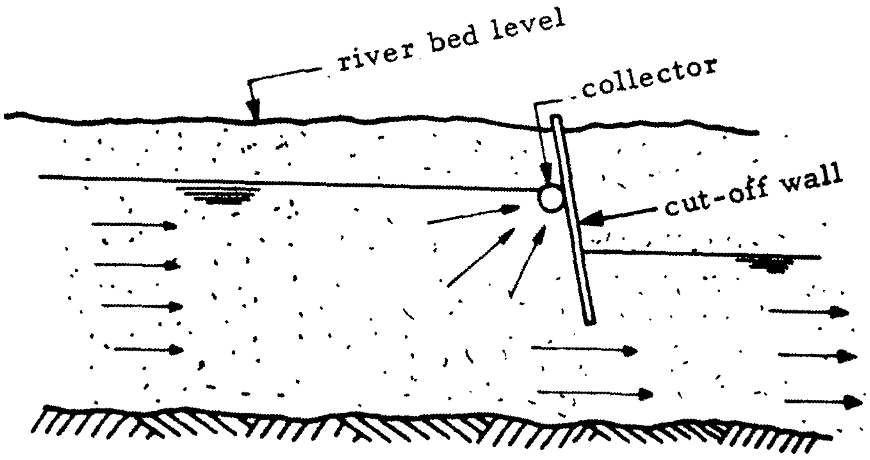


Fig. 4. Partial cut-off.

Recent model test investigations [1] indicated that the influence of the cut-off wall only becomes noticeable over the last one-tenth of the depth (see sketch fig. 5).

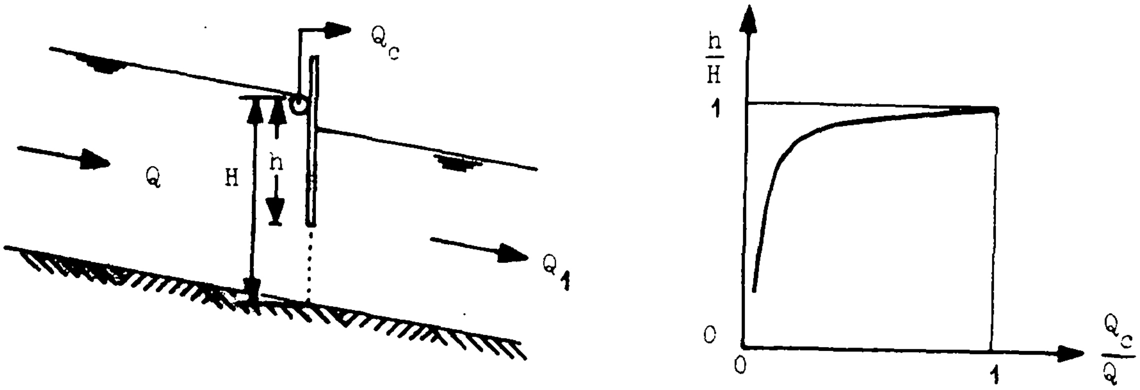


Fig. 5.

This entails in practice that a cut-off wall will only be effective if the whole valley will be closed off. (See also fig. 1).

In view of the relatively large dimensions of those valleys and the many problems which may be encountered, the costs of such a cut-off wall are in most cases expected to become prohibitive.

This method is therefore no longer pursued.

3. 3. Abstraction by collector only

In fig. 6a and b a layout and longitudinal section is schematically presented of a gravity abstraction by means of a collector placed at a certain depth below the water level perpendicular to the valley direction. A gravity conduit conveys the intercepted water under a small slope to the required command level A at the river bank.

The length of the conduit depends on:

- slope of the river
- depth of the collector below bed level
- required slope of the conduit
- required command level A

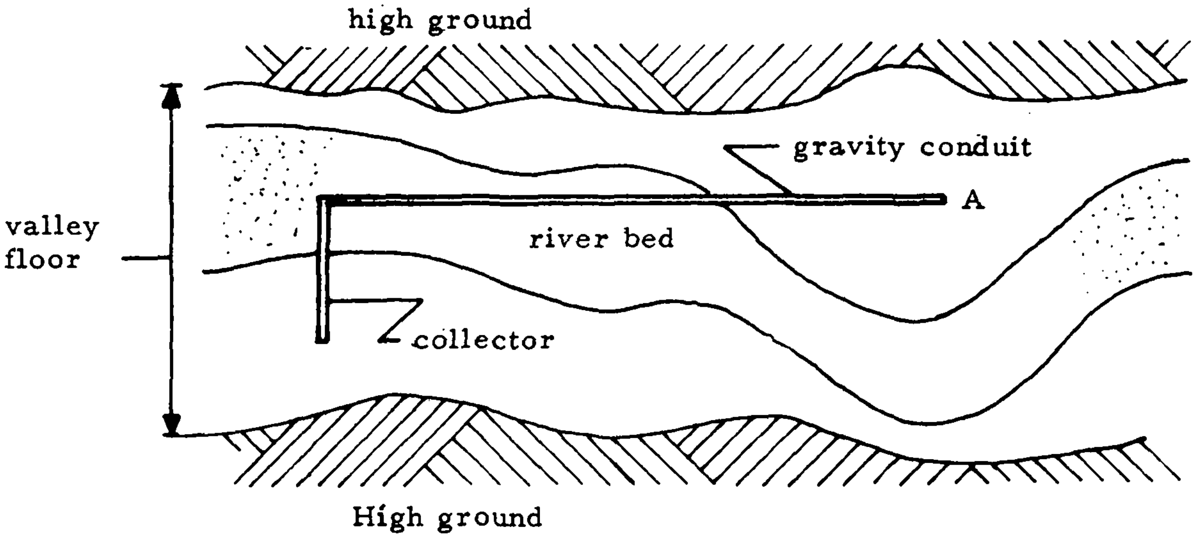


Fig. 6a. Layout of collector and gravity conduit.

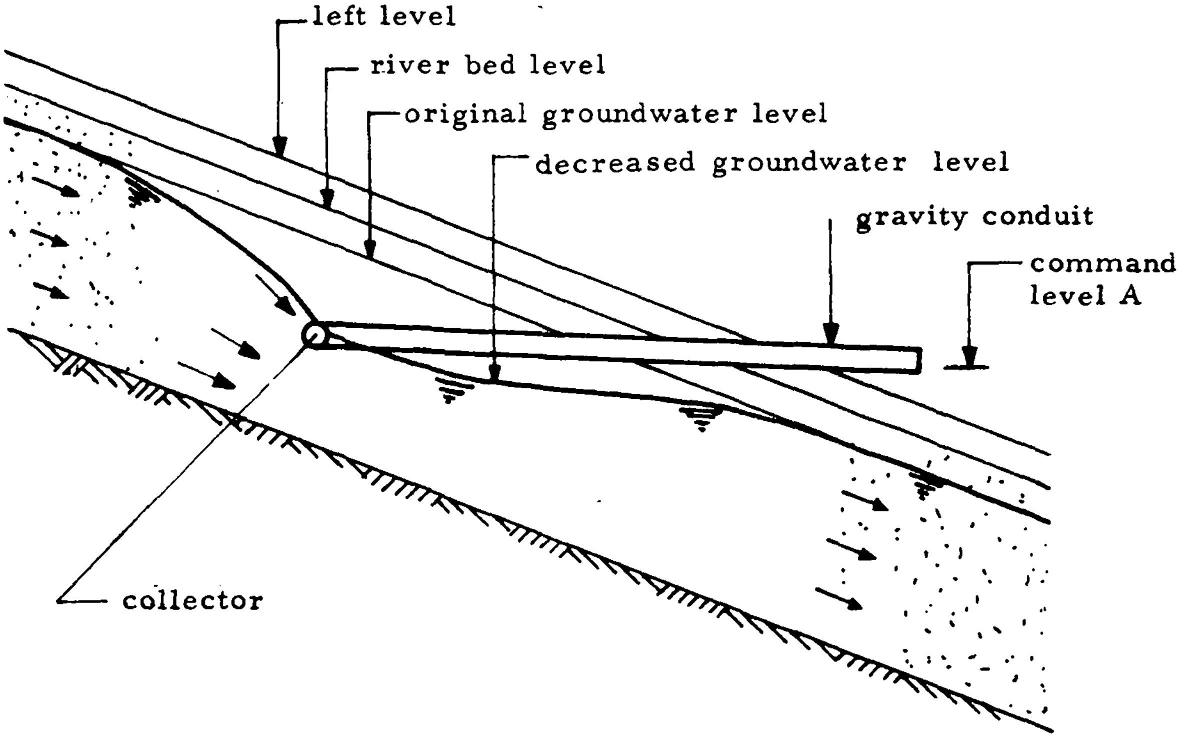


Fig. 6b. Longitudinal section collector and gravity conduit.

4. GROUND-WATER FLOW TOWARDS A COLLECTOR

4.1. Introduction

The phenomena of a ground-water flow towards a collector has been studied by various authors [2] [3] [4] from a point of view of the theory of interceptor drains on sloping lands for agricultural purposes.

These studies, however, were mostly concentrated on questions such as depth of drain, effectiveness of drain, shape of drawdown curve, etc.

In the present case of a collector for supplying water, however, the major question is : how much will be the discharge in time through a collector in relation to permeability, slope and depth of a collector (drain)? Little research in this field has been carried out.
Leaving this question open for future research workers, an attempt has been made in the following to assess the phenomena of ground-water flow towards a collector, drawing heavily on the theories of drainage of sloping lands. The interpretation of these theories for the case of a collector is therefore, rather qualitative in nature.

4.2. Flow towards one collector

In the following the sand river is schematized by an infinitely long homogeneous aquifer which is rectangular in cross section and under a uniform slope. (fig. 7)

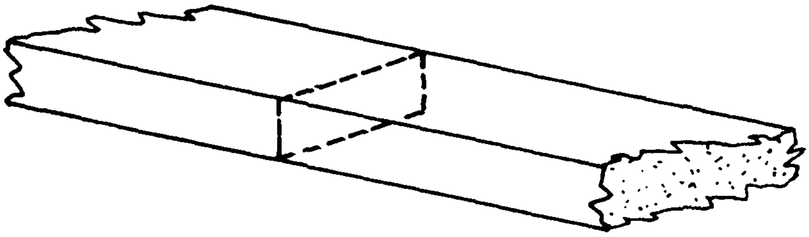


Fig. 8.

Most formulas for ground-water flow towards a drain, as given by various above referred authors, differ only in their choice of coordinate system and appear to render approximately equal results.

Two important questions could be solved by these formulas:

1. How much of the total flow will be intercepted?
2. How far upstream will the influence be felt by the drain(collector)?

Donnan [2] presented the formula of Glover describing the water level depths above the impervious base in relation to the distance from the drain for steady flow conditions:

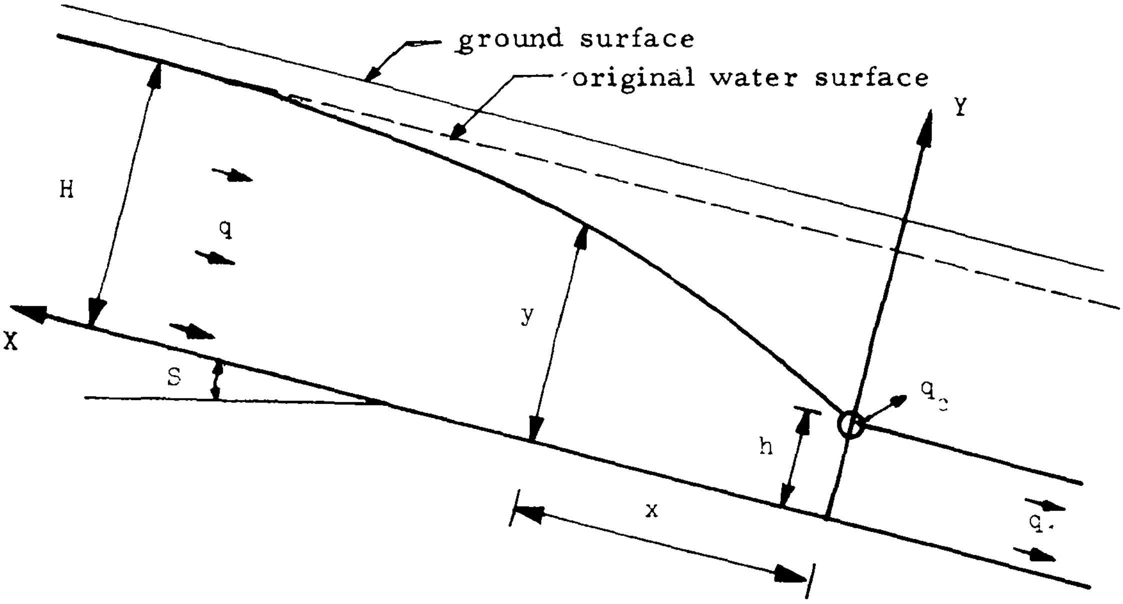


Fig. 9.

$$x = \frac{1}{S}\left[H.\ \ln\frac{H-h}{H-y} - (y-h)\right] \qquad \text{...............(1)}$$

where (see also fig. 8):

x = distance from the drain
H = thickness of original water-bearing layer
h = depth from drain to impervious base
y = water-table height above impervious base
S = slope of original water-table surface.

This formula shows that the drain has an infinite influence on the upstream part.

A point could be assumed arbitrarily of "significant" drawdown where
$y = 0,9\ H$
Substituting this value of y in formula (1) it appears that the result could be approximated by:

$$x = \frac{4}{3}\cdot\frac{H}{S} \qquad \text{................(2)}$$

for values of $h < 0.5\ H$

The significance of formula (1) is that the slope of the drawdown curve (and therefore effective length) is independent from hydraulic conductivity and from quantity of flow.

In case of low radial resistance into the drain, the downstream drawdown could be approximated by the height of the water in the drain. Therefore:

$$q_c = \frac{H-h}{H}\cdot q \qquad \text{.................(3)}$$

where (see fig. 8):

q_c = discharge of the drain (collector) per unit width
q = inflow upstream of the drain per unit width
q could be expressed (Darcy) as:

$$q = K.S.H \qquad \text{.................(4)}$$

where

K = permeability coefficient
S = hydraulic gradient (= slope of aquifer)
H = depth of water-bearing layer

(3) and (4) give:
$q_c = K.S.\ (H-h)$

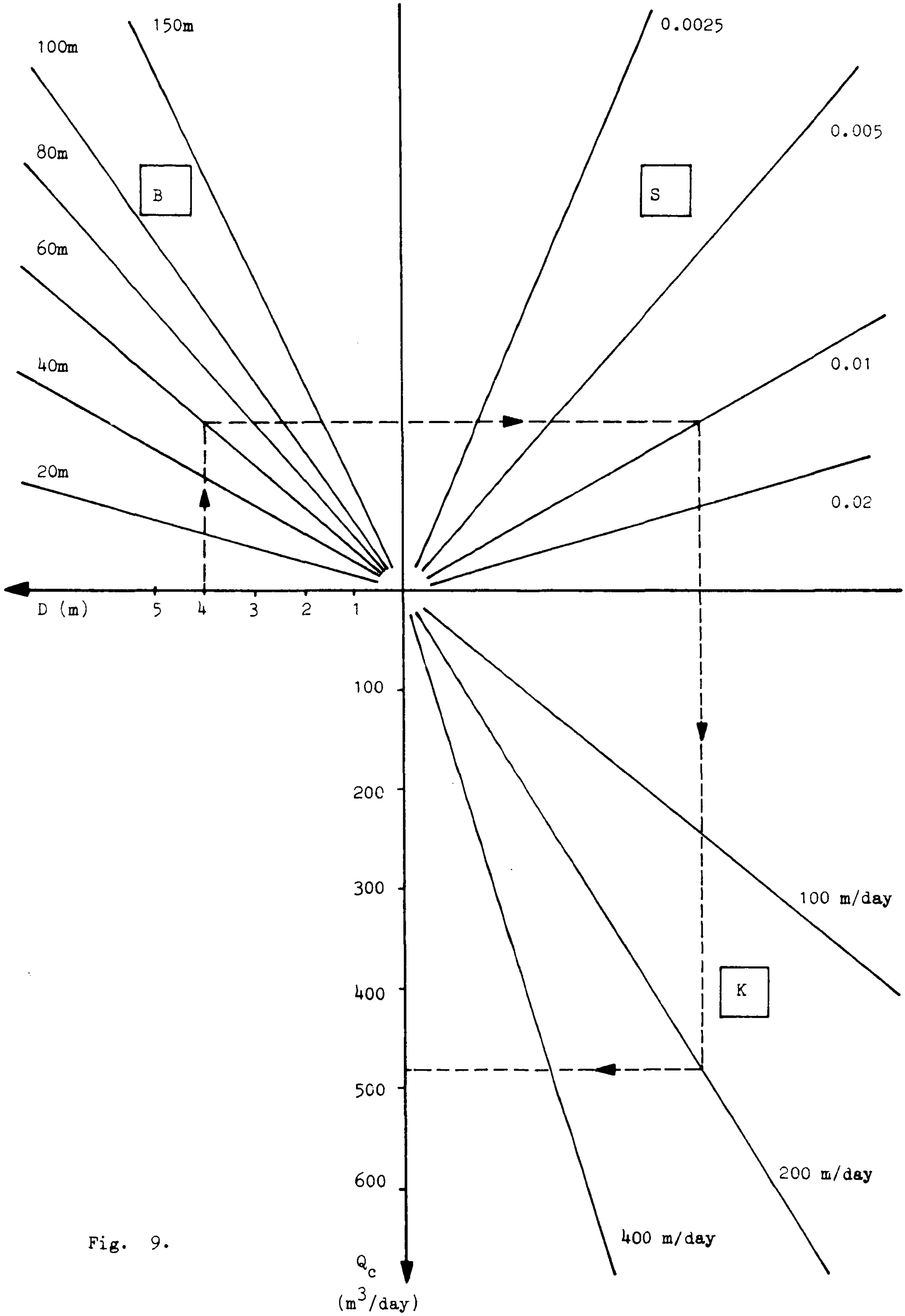

150m
100m
80m
60m
40m
20m
B
0.0025
0.005
0.01
0.02
S
D (m)
5
4
3
2
1
100
200
300
400
500
600
100 m/day
200 m/day
400 m/day
K
Q_c
(m^3/day)

Fig. 9.

or for a width B of the aquifer and substituting D=H-h= depth of drain (collector) below original ground-water level:

$$Q_c = K.\,S.\,D.\,B. \qquad \ldots\ldots\ldots\ldots (5)$$

The relation between the various variables of eq. (5) is presented in the nomogram on fig. 9 for values generally encountered in sand rivers.

It should be kept in mind that eq. (5) represents the situation at a steady flow condition; i. e. for the collector at the end of the dry season. The discharge Q_c will be considerably higher at the beginning of the dry season when the aquifer is replenished.

4. 3. Flow towards several collectors

Unlike the case with a single drain where the depletion curve representing the drain discharge assymptotically nears the level of the upstream inflow, (fig. 10 case a) several spaced drains will influence each other (fig. 10 case b). The result will be that the discharge from each drain individually will decrease to a level lower than the single drain. (The rate of depletion is dependent primarily on the permeability of the aquifer). See fig. 10.a and b.

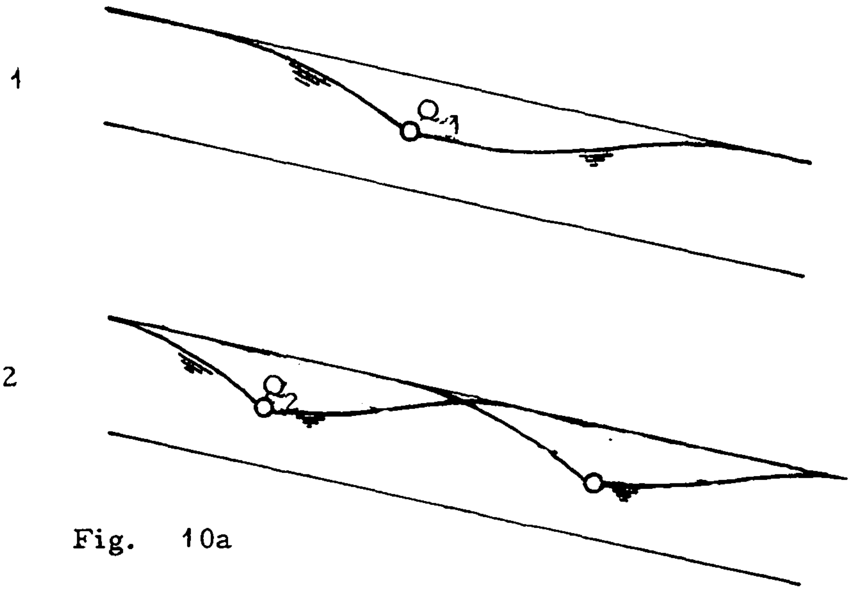


Fig. 10a

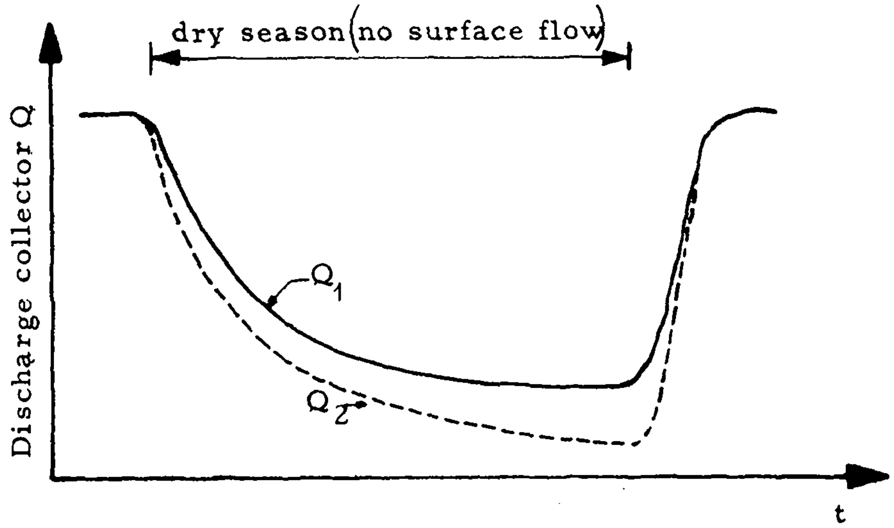


Fig. 10b.

4. 4. Regulation of the outflow

In case of unregulated (free) outflow of the collector system the discharge will follow a depletion type of curve as sketched in fig. 11.

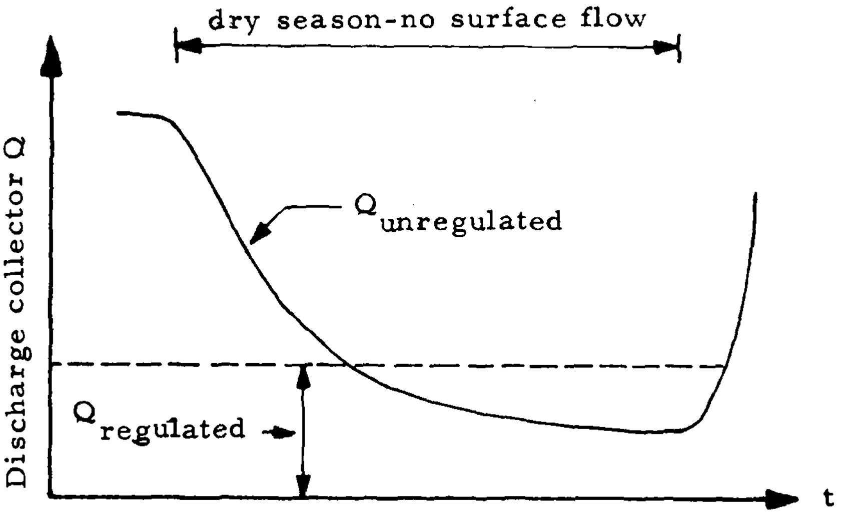


Fig. 11.

The shape will depend on characteristics of the sand-river aquifer (dimensions, K value etc.).

Just after the rainy season the aquifer is replenished and, due to the high potential, the flow in this first period will be much higher than towards the end of the depletion period.

In case of a regulated collector flow (e. g. constant over the dry period), the depletion will be retarded and the flow at the end of the dry season could be expected to be higher than in the case of the unregulated flow - see sketch fig. 11.

4. 5. Example for a typical sand river

In the following an example is worked out for a medium-sized sand river under average conditions:

Characteristics:

- slope S = 0. 005
- $K = 10^{-3}$ m/s
- average depth sand river 10 m
- average width B = 50 m
- natural drawdown at the end of the dry season: 1. 50 m below bed level
- depth of collector below water level D = 5 m
- dry season: 8 months without surface runoff
- effective porosity: 25%

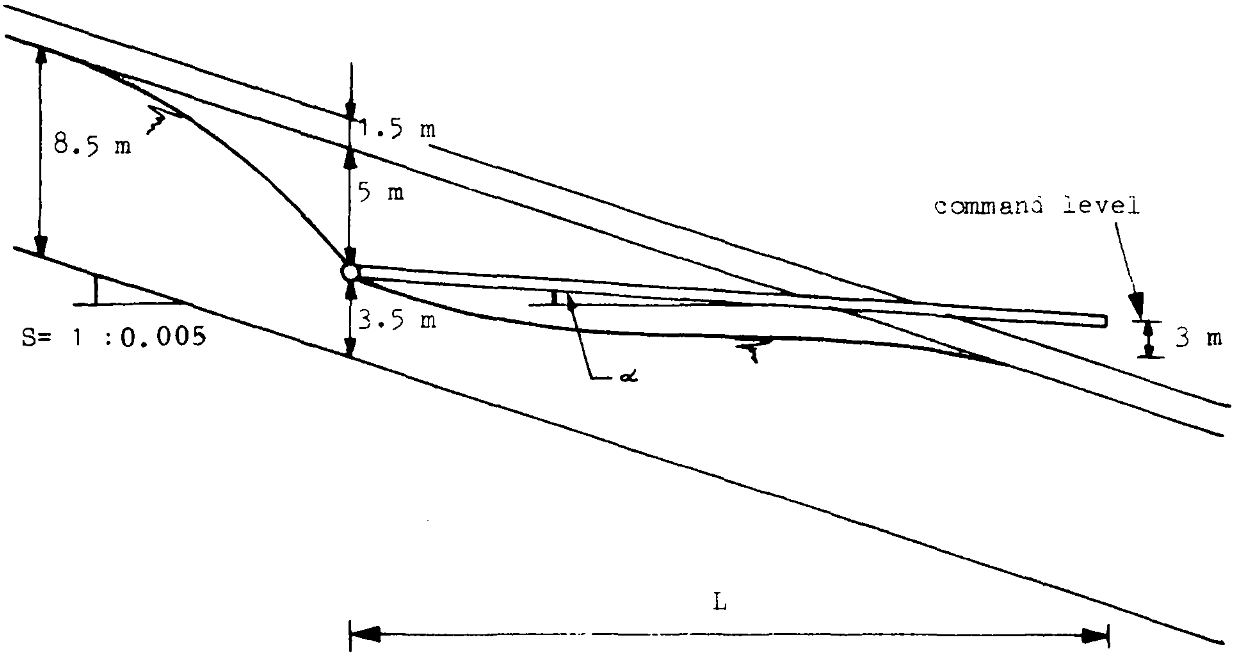


Fig. 12.

Discharge collector

It is assumed that at the end of the dry season the flow conditions are in equilibrium (steady flow) and the natural depletion is reached(1. 50 m below bed level).

Assuming no radial resistance into the collector, the discharge into the collector is - see equation (5):

$$Q_c = K. S. D. B$$

or

$$Q_c = 10^{-3}. \ 0.005 \ . \ 5 \ . \ 50 = 1.25. 10^{-3} \ m^3/sec = 1.25 \ l/sec$$

Upstream and downstream influence

"Significant" influence on drawdown upstream - see equation (2)

$$x = \frac{3}{4} \cdot \frac{H}{S} = \frac{3}{4} \cdot \frac{8.5}{0.005} = 1\ 300 \ m$$

The average flow velocity through the sand river under natural conditions during the dry season $v = K. S = 5. 10^{-6}$ m/sec.
The distance travelled during 8 months: $5. 10^{-6}. 8. 30. 24. 3600 = 100$ m.
Assuming the same "significant" influence downstream as upstream (1300 m), the total influence of the collector on the natural flow in the sand river becomes:

1300 + 100 + 1300 = 2700 m.

Length of conduit

Assuming the slope of the conduit = 0 the length of the conduit will be

$$\frac{(5 + 1.5 + 3)}{0.005} = 1900 \ m$$

Q_c = 1.25 l/sec
L = 1900 m
∅ pipe = 0.10 m.
roughness (PVC) = 0.02 - 0.05 mm

From conventional pipe flow formulas appears loss of head:

$4. 3. 10^{-4}$ m per m length, or over the total length L approx. 0.80 m.

In order to establish a condition of free inflow into the collector, the conduit pipe could be laid under a slope of $\alpha = 0.0004$. The length of the pipe will be then increased to approximately 2100 m.
(It could be considered to lay the conduit pipe horizontally. This would mean, however, a loss of head of 0.80 m at the collector. Since the depth of the collector of 5 m below the water table is a limiting factor - see para 5.3 - a sloping conduit pipe would be, in most cases, preferable).

In figure 13 the relation between slope S, depth of collector D and length L_c is presented for a horizontal counduit pipe.

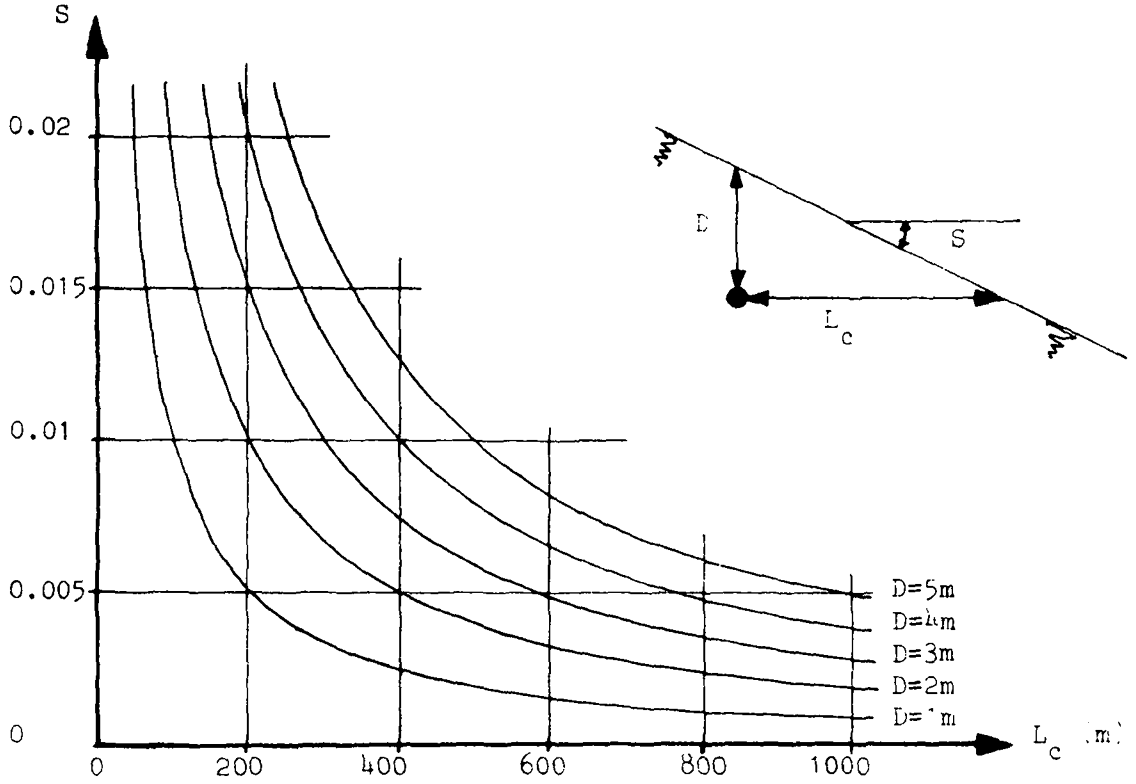


Fig. 13.

4.6. Conclusions

From the previous discussion the following conclusions could be drawn:

- The discharge from a single collector placed at a depth D below the ground water table will follow a depletion curve from the time of total replenishment (end of rainy season) to the end of the dry season.
- This depletion curve will approach a discharge value which is linearly related to the depth D.
- The rate of exhaustion will primarily depend on the permeability of the aquifer (K).
- Regulation of the outlet could result in an average supply over the dry season considerably greater than the flow value at the end of the depletion period in case of free flow.
- The total volume of water abstracted by a single collector constitutes only a part of the total water stored. This part could be increased by placing more than one collector.
- In the case of more than one collector, a more efficient use could be made of the water stored. The collectors will influence each other, however, resulting in smaller discharges from each collector individually. This could be compensated by regulation of the outflows.

5. CONSTRUCTION OF A COLLECTOR SYSTEM

5.1. Introduction

A collector could consist of a pipe (concrete, slotted metal or P. V. C.) packed in a gravel or in another type of filter. (A collector in the form of a gallery of larger dimensions has not been considered in view of the required special skills and expected problems regarding construction at greater depth below the ground water table in sandy-gravelly material).

The collector should be placed below the ground water table at a depth depending on the water requirements and local conditions of the sand river(e. g. depth of aquifer). This type of construction normally requires temporary drainage of the ground water along the construction alignment to enable excavation to the required depth. (Considerations could be given to excavate a trench with bottom level equal to collector level starting at the downstream end. This trench could then be self-draining. No experience is known with this type of construction. It is surmised, however, that with greater depth, problems will be encountered regarding stability of the trench slopes. Although this method deserves to be tested in practice, it will not be looked into further). This temporary type of drainage could be carried out by well-point de-watering method.

By the conventional vertical well-point method a row of vertical risers is placed parallel to the collector line. The risers are connected to a pump and the ground-water table lowered to a level below the envisaged collector level.

By the horizontal well-point method, the water table is lowered by means of a horizontal slotted pipe laid by a special deep digging horizontal well-point machine. See fig. 14.

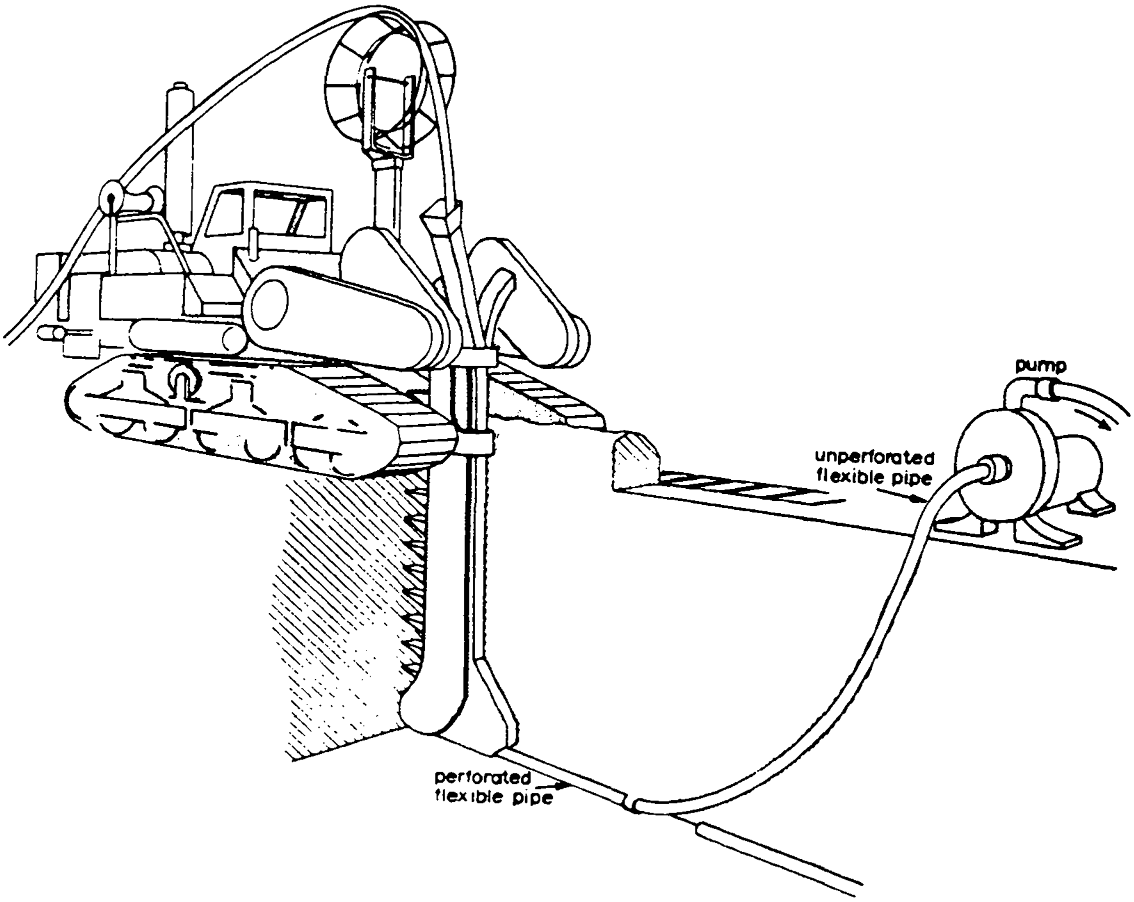


Fig. 14. Principle of installing deep drains for horizontal pumped well drainage. REF. (5)

In both cases the trench (up to a depth of 5-7 m) has to be made and the collector placed in the dry.

The following should be noted:

- Due to the high permeability of the aquifer, a relatively large pumping capacity is required to lower the water table to the required depth.
- For deeper trenches (5-7 m) large volumes of excavation are required.

In the following, therefore, the solution is proposed to use the horizontal well-point method not for temporary drainage but for the construction of the collector proper.

5.2. Horizontal well-point method - see fig. 14

During recent years the horizontal well-point de-watering method has been rapidly developed. [6]

The specially constructed deep digging machines are able nowadays to lay horizontal pipes till a depth of approximately 5 meters.

To drain construction sites in the Netherlands, PVC pipes are used with diameters of 80 and 100 mm. The perforated part of the tube is brought in situ with a nylon cover to prevent intrusion of particles of sand and silt.

The cost of the deep digging pipe laying machine is around $ 200 000(DG 500 000); while, for Dutch conditions the cost per meter pipe laid amounts to around $ 4-5 per meter (DG 10-12/m) all-in, including amortization, operation, cost of pipe, etc. The cost of the PVC pipe (100 mm) is approximately $ 1.40 per meter (DG 3.50/m).*

The speed of the pipe laying operation is in the order of 60-80 m per hour in wet sandy conditions.*

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* Personal communication with Mr.J.de Weerd, Lareco, Arnhem, the Netherlands.

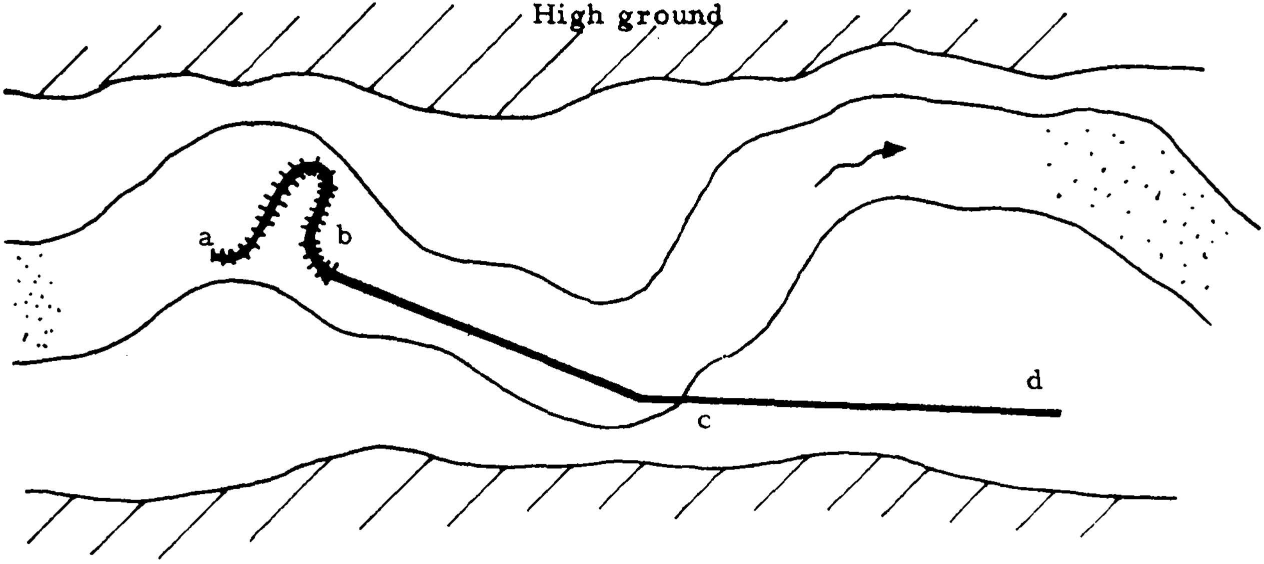
5. 3. Applicability of horizontal well-point method for sand rivers

The deep digging pipe laying machine, normally used for horizontal well-point drainage, is able to lay pipes of 80 or 100 mm diameter at a maximum depth of 5 m below ground surface in-alluvial soil.

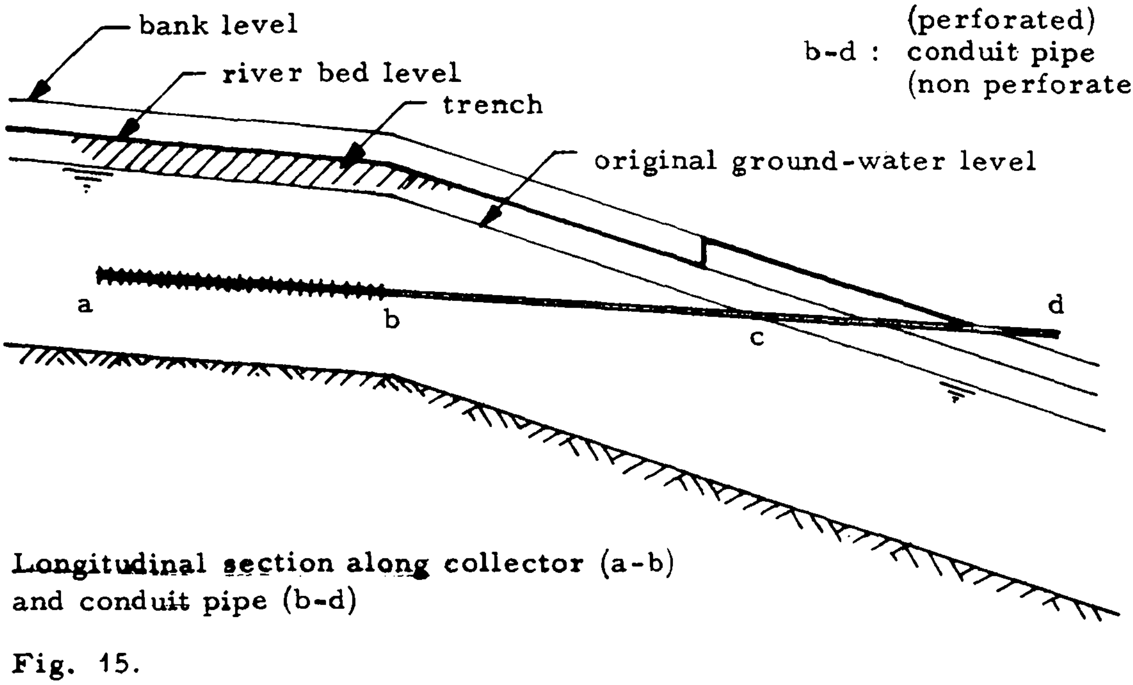
The use of this machine for placing a collector in a sandy riverbed amounts to exactly the same procedure as placing a drain(drain = collector).

In the next para 5. 4. some questions regarding construction are discussed; while, in Chapter 6,the costs of this method and conventional water supply systems are compared.

Within acceptable limits regarding loss of head and length of pipe, a 100 mm diameter pipe could convey maximum 1-2 l/sec or 80-170 m^3/day.



Layout:
a-b : collector (perforated)
b-d : conduit pipe (non perforated)



Longitudinal section along collector (a-b) and conduit pipe (b-d)

Fig. 15.

5.4. Construction procedures - see fig. 15 -

In order to achieve the largest possible yield, the collector should, in most cases, be placed as deep in the sand river as possible. Since the deep digging pipe laying machine has a limit of reach of approximately 5 m below ground level, the following measures should be considered:

- Construction of deep collectors should be carried out preferably towards the end of the dry season.
- In order to enable a deeper reach for deep collectors and also to save on the length of machine laid pipe, a trench following the alignment of the collector pipe should be dug until just above ground-water level(normally up till 1.5 - 2 m below riverbed level) - see fig. 15. The machine could lay the pipe at the required depth by following the bottom of the trench.
- This trench should be excavated in the riverbed.
  At the place where the pipe emerges from the ground water table (point c, fig. 15) the rest of the pipe could be placed in a trench in the riverbank. This part of the pipe could be hand laid in the dry. A too shallow depth below the riverbed level should be avoided due to possible damage during floods. For the last part of the pipe (hand laid) a different type and size of pipe could be considered depending on the costs.
- The collector part a-b should be slotted and could be laid in loops (fig. 15) in order to enlarge the length of the collector.
- For sand rivers with a large ground-water potential, several collectors could be placed parallelly.

It is expected that the disturbance of the sand layers by the digging of the machine will have a favourable influence on the permeability.

5.5. Regulation device

As has been discussed in para 4.4, regulation of the outflow could increase the minimum dependable flow at the end of the dry season.

The following measures could be considered:

1) Storage reservoir at supply point with a simple automatic regulation device at the inlet.
2) Valve to be closed when the storage reservoir becomes full. It could be considered to place this valve at the point where the machine laid PVC pipe is connected with the lower hand laid part of the conduit pipe(point c fig. 15).

6. COSTS

6.1. Introduction

In order to financially assess the feasibility of the above proposed method, cost comparisons are made between the above proposed collector system and a traditional scheme comprising a river well, pumping station and distribution system.

Most of the cost figures used for the traditional system are derived from recent studies in Tanzania [7] , [8] , [9] .

Regarding this cost comparison the following should be noted:

1. In view of the different operation and maintenance factors of the two types of schemes, not only the capital investments are compared but also the total annual costs.
2. It is evident that for the collector scheme, where the water is free flowing from source to public taps, the site of the public taps is limited by the topography. Pumped supply could cover a larger area around the well; whereas, the collector system is restricted to the valley bottom.
3. The quality of water is not taken into account. In both cases no water treatment is assumed.

6.2. Cost comparison

In the following, two schemes have been compared: one with a collector system and one with a well and pumping arrangement. Both schemes are supposed to deliver 25 m^3/day, serving 1000 persons on the basin of 25 l/caput/day from two public taps.

Project 1 Well + pumping unit

Assumption:
- well constructed in the sand river
- safe yield : 25 m^3/day

Costs for such a project have been taken from recent investigations [7] [8] [9] . Especially the recent water supply survey by NEDECO for the Shinyanga region in Tanzania provides valuable detailed cost estimates for an area with many sand rivers.

The costs are expressed in US$ (1972)

Net construction cost	$
- river well	1 000
- distribution system	900
- ground storage tank	1 000
- rising main (750 m)	700
- pump house	1 700
- pumping equipment	1 300
Total net construction cost:	$ 6 600

Capital investment: Total net construction cost + 25%: $ 8 200

Total annual costs (depreciation, interest, operation and maintenance)

Depending on the economic lifetime of the construction components and on the operation and maintenance percentages, reference [7] arrived at the following annual costs as percentages of the net construction costs (n. c. c.) (based on an interest rate of 8%)

- river well, storage tank, pump house	11.5 % of n. c. c.
- distribution system and rising main	12.8 % " "
- pumping equipment	33 % " "

Furthermore, a flat rate of \$ 600/year has been assumed for the wages of the pump attendant.

- river well	115
- distribution system	115
- ground storage tank	115
- rising main	90
- pump house	195
- pumping equipment	430
- wages for pump attendant	600
Total annual cost \$	1 660

Cost price of water: $\frac{1660}{25 \times 365} = \underline{\underline{\$\ 0.18/m^3}}$

Project 2 **Collector**

Assumptions: - see fig. 16 -

- slope river S = 0.007
- width B = 20 m
- depth collector D = 2 m
- depletion at the end of dry season : 1.5 m below bed level
- bank level 1.5 m above riverbed
- supply point 2.0 m above bank level
- permeability coefficient $K = 10^{-3}$ m/sec.

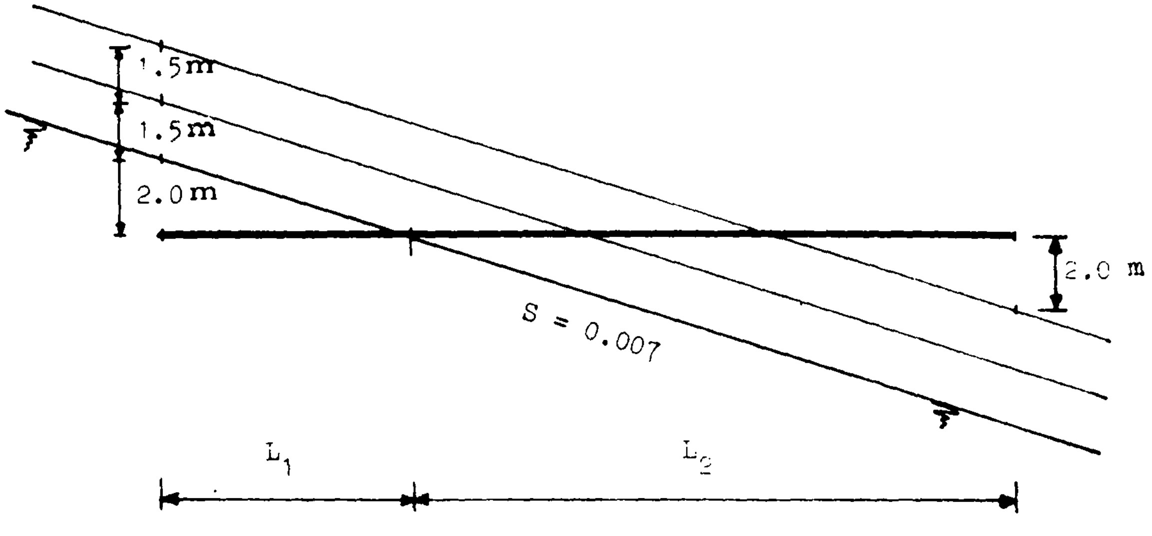


Fig. 16.

Minimum discharge collector $Q = D.B.K.S$ or

$Q = 2 \times 20 \times 10^{-3} \times 0.007 = 28 \times 10^{-5}$ m/sec

or approximately <u>25 m^3</u>/day

$L_1 = \frac{2}{0.007} = 286$ m say <u>300 m</u>

$L_2 = \frac{5}{0.007} = 714$ m say <u>750 m</u>

L_1 is the distance over which the collector and supply line will be laid by machine

L_2 to be laid by hand in an open excavated trench.

<u>Unit costs:</u>

The cost in the Netherlands of laying a horizontal drain by special machinery is around DG 10-12/m or US$ 4-5/m. This is all-in including depreciation of the machine, cost of the pipe, etc. Assuming the cost in developing countries as double, the rate has been taken as $ 10./m.

In comparison with Project 1 the length L_2 could be considered as the "rising main" conveying the water collected to the storage tank. This length of pipe could be of the same diameter (P.V.C. 10 cm) as the collector. The net construction cost per m under normal conditions including 10% for fittings, excavation and back filling could be taken as in the order of $ 2.50/m. In view of locally deep excavation the net construction cost has been assumed as $ 3.00/m.

<u>Net construction cost</u>	$
- machine laid pipe; length 320 m ; $ 10/m	3 200
- hand laid pipe; length 750 m ; $ 3/m	2 300
- distribution system (same as project 1)	900
- storage tank (" " " ")	1 000
Total net construction cost $	7 400

<u>Capital investment:</u> total net construction cost +25%: $ 9250

Total annual costs (depreciation, interest, operation and maintenance)

Assuming the same economic lifetime as for project 1 for the comparable cost components and an economic lifetime for the collector as 20 years, the annual costs will be:

		$
- collector	(12.8 %)	410
- supply pipe	(12.8 %)	295
- distribution system		115
- storage tank		115
Total annual costs $		935

Cost price of water : $\frac{935}{25x365}$ = $ 0.10/m^3

6. 3. Conclusions

- From the above it appears that capital investments(= net construction cost + 25 %) for the two projects with the same daily supply lay in the same order of magnitude (around $ 8-9/caput); while, the cost of water for the collector project is nearly half the cost of water for the traditional project. The reason for this could be attributed to maintenance, operation and amortization of the pumping unit.
- It is evident that the cost of the collector scheme is directly related to the depth of collector, width and slope of the river and permeability. The most favourable conditions exist at places where the sand river is relatively wide and steep and the permeability is high (see fig. 9 and 13).
  It appeared that with different slopes, widths and depth of collector, the cost price of water per m^3 varies between in the order of $ 0.02 and $ 0.30.
- It is expected -see para 4.4. and 5.5 - that regulation of the outflow will decrease the cost price of water per m^3.

7. REQUIRED SURVEYS AND INVESTIGATIONS

7.1. Choice of abstraction site

The choice of a gravity abstraction site in relation to supply area is governed by the following considerations:

a. command level of supply area (this could be the elevation of a water-supply reservoir, drinking reservoir for cattle or a headwork of an irrigation area)
b. water requirement of the supply area
c. topographical and morphological conditions of the river: slope of the valley, slope of the water table, depth and width of the aquifer, changes of the cross section of the aquifer, permeability, etc.
d. possible depth of the collector below the valley floor
e. the slope of the gravity conduit. The favourable factor of the abstracted water being silt-free renders the possibility of a conduit with very small slopes. The slope could, therefore, be determined by the required loss of head in the relatively long feeder pipe.

7.2. Determination of sand river potentials

Determination of the potential water resources in sand rivers should be carried out for some kilometers upstream and downstream of the supply area in view of existing and future use of this water source along the river valley.

Prospecting should, furthermore, be extended over the whole valley width and not be confined to the riverbed since the aquifer can be considerably stretched out (see fig. 1).

A preliminary assessment of the potential could be made by the following office and field procedures:

1. A study of available maps and aerial photographs with special attention to river morphology (existence of rockbars, widening and narrowing of the valley, stability of the bed, etc.), existing population, agricultural practices, types of vegetation, present use of water, etc.

2. If hydrological records are available, the periods of replenishment (surface flow) should be studied.
3. Where no topographical information is available, a rough levelling should be carried out to determine the general slope of the valley, riverbed and ground-water table.
4. To investigate existing wells in the valley in respect of abstraction and water level fluctuation.
5. Where the local population uses the water from the sand river by digging holes in the riverbed, the deepest level of digging in an extremely dry year could be assessed by questioning the local inhabitants. This can give an indication of the order of magnitude of maximum natural depletion in dry years.
6. Information (thickness of aquifer and physical and chemical properties) concerning the water bearing layer could be assessed by auger drilling. This often poses problems where in coarse layers the auger hole keeps caving in.
7. The quality of the water should be tested in regard to biological and chemical properties.
8. A preliminary geo-electrical survey to assess the depths of the coarse layers.
9. During the dry season, the direction and actual velocity of the ground-water flow near the surface can be determined by inserting a tracer, e.g. fluorescein at various points in the riverbed and by determining the path followed by the tracer with respect to direction and length over a certain time.
   By determining the slope of the water level a rough estimate of the permeability coefficient K for the upper layers could be made. It should be noted that permeability estimates derived from sieve analysis (disturbed samples) give, in general, much lower values than in reality. This is due to the layered pattern of the sandy aquifer.
   -See fig. 17 -

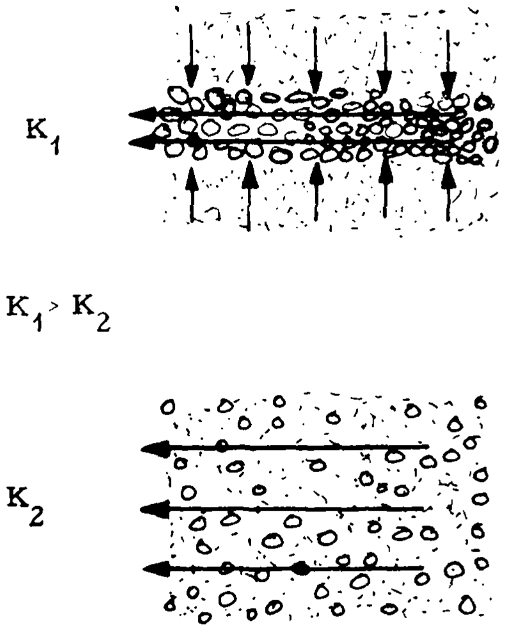
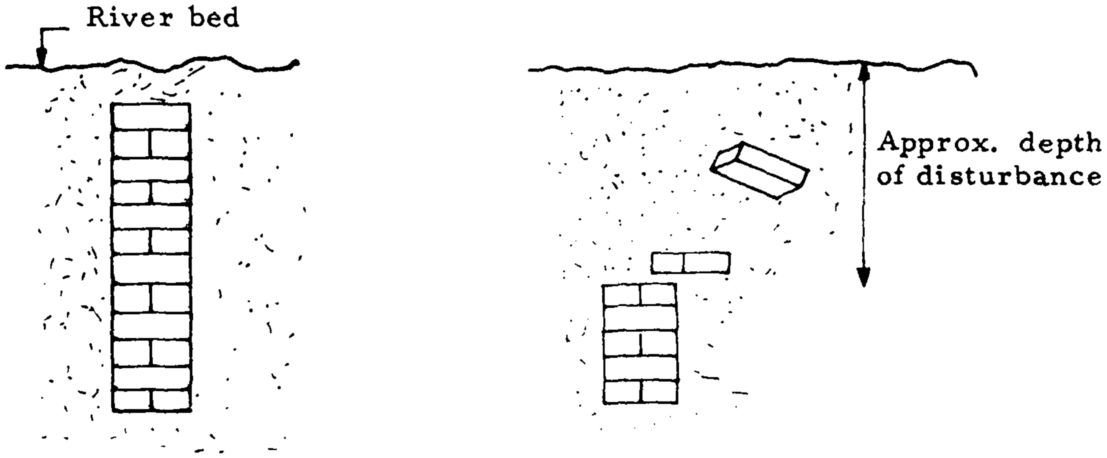


Fig. 17.

10. During at least one dry season the drop in water level should be followed by installing water level gauges in temporary holes dug in the riverbed or by water level observation in temporary standpipes.

11. The depth of disturbance of the riverbed by floods should be assessed for at least one high flood occurrence. This could be carried out by method of loose piles of bricks buried in the bed before occurrence of the flood and determination of the influence after the flood period. (See fig. 18)



Before flood

After flood

Fig. 18.

If, after these preliminary findings, the prospects of water abstraction from the sand river look promising, and one or more abstraction sites are chosen, further details of the thickness of the water-bearing layers at these sites could be assessed by more detailed geo-electric or seismic prospecting. When the project is of importance, pump-tests should give the final answer to the expected capacities.

8. CONCLUSIONS

1. Sand rivers - sandy alluvial valley aquifers - form in many dry regions in the world relatively important underground water reservoirs. This source of water is dependable due to annual replenishment by surface water flow.
2. Abstraction of water from this source by means of pumping often raises considerable problems with regard to requirements for skilled operators and maintenance being hampered by lack of spare parts. Furthermore, the annual cost appears to be strongly augmented by the short economic lifetime of the pumping equipment, operator wages and fuel.
3. Other means of abstraction (animal traction, windmill) often appear to have limitations regarding small supply, animal traction not being known, etc.
4. In the previous chapters a method of gravity abstraction by means of a collector conveying the water from sand-river aquifers to points of supply by free flow has been described. Such a collector system could be constructed by a deep digging pipe laying machine as used for horizontal well-point drainage.
5. Applicability of this method depends on the characteristics of the sand river: dimensions and permeability of the aquifer, slope of the river, natural depletion of the aquifer, etc.
   A proper survey of the sand river is therefore required prior to construction.
6. A proper cost comparison between the collector method and a traditional pumping scheme is difficult to make due to factors such as dependability (breakdown) and purity of water being an

asset for a collector system and larger flexibility in layout being an asset for a pumped scheme. Disregarding these factors, rough cost comparisons reveal that the capital investment of a collector system and a pumped system do not differ greatly. The annual costs, however, appear to be considerably less for a collector system due to the absence of pumping, operator and fuel requirements.

7. Advantages of a collector system:

   - Annual costs are generally low compared with pumping systems.
   - Supply is reliable (aquifer is annually replenished and no sudden breakdown could be expected).
   - The system has no mechanical parts requiring operation, maintenance and fuel.
   - In most cases the quality of water could be expected to be excellent (filtration of the water by the sand layers and source of water a long distance from the users tap).
   - Construction of the collector is rapid.

8. Disadvantages of a collector system:

   - Reach of supply is limited by topography of the area.
   - The supply should be restricted to public taps. The low pressure in the supply pipe does not allow for house connections.

9. In spite of its relatively limited applicability, it is believed that the described collector method could, in many places in the dry regions of the world, constitute an important tool for rural water supply schemes.

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