ANALYSIS OF TILE DRAINAGE DESIGN POLICIES IN EGYPT

Kenneth M. Strzepek

April 1981
WP-81-46

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

Recent field studies have shown that in some cases tile drains have been ineffective in increasing crop production. This paper examines the effect that the policies of 40 meter minimum spacing and aggregating large areas under a single drain design may have upon the effectiveness of tile drains. An approach that synthesizes crop yield response, the physics of drainage and economics is used to determine the possible cost of these two policies. A case study from the Nile Delta is examined.

The paper shows that these policies can have a great effect upon the efficiency of tile drain performance under certain conditions.

CONTENTS

ANALYSIS OF TILE DRAINAGE DESIGN POLICIES IN EGYPT

Kenneth M. Strzepek

Since the completion of the High Aswan Dam in 1965, the Nile's flood waters have been stored in the Lake Nasser Reservoir and are available for distribution over the entire year. The year-round availability of water has led to more land being brought under multiple crop cultivation. This gradually created the situation where the present cropping intensity in the Nile valley is approximately one hundred ninety percent.

This intensive irrigation then created a problem. In the past, with both wet and dry periods, the initial flood waters provided a mechanism for flushing away any salts that might have built up in the soil, and the groundwater table had time to recede slowly after the flood. Now, due to year-round irrigation, the water table is constantly high and salts are not flushed. The result is that crop yields have been severely affected by waterlogging and salinity. These problems are due to irrigation practices and the soil properties of the Nile valley.

It is possible to alleviate the problems of waterlogging and salinity by introducing better farm water management and/or agricultural drainage systems. Drainage systems allow the groundwater table to be controlled, preventing waterlogging and allowing for sufficient leaching of excess salts from the crop root zone.

The widespread adaptation of new farming techniques is decades away. Therefore, the Egyptian government has embarked upon a monumental project of improving agriculture drainage on most cultivated land in Egypt.

The drainage improvement project is composed of two parallel tasks. Task one is the remodeling of open drains and construction of pumping stations, and Task two is the installation of tile drains on cultivated lands.

To date, there have been four World Bank funded Drainage Projects with a total investment of the equivalent of 329 million US dollars. These projects implemented throughout Egypt will provide for the remodeling of open drains which serve an area of 2 460 000 feddans and installation of tile drains on 2 150 000 feddans of cultivated land. The execution of these projects overlap, and at present, approximately fifty percent of the targets have been met. A fifth project for an additional 600 000 feddans of tile drains is presently under study by the World Bank.

The reasons for investing such a large amount of resources in improving drainage conditions were to prevent the continued decline in crop yield and attempt to increase yield to the maximum possible, given the other inputs into agriculture. Approximately thirty percent of Egyptian GNP comes from agriculture, and agricultural exports are a valuable source of foreign exchange. Thus, the decline in yields is a serious problem for the Egyptian economy. During the economic evaluation phase of these projects, it was projected that potential economic benefits of improving agricultural production by improving drainage conditions were greater than the costs of the drainage projects. Thus, each project was implemented. These economic analyses were based on the assumption that the drainage systems upon which the costs were estimated would provide the improvement in drainage conditions to produce the benefits which were projected.

Recently, there have been some who are questioning whether the projected agricultural production is actually occurring and whether the investment in drainage is economically feasible.

Data from experimental studies show definite increases in yields due to tile drainage, while evidence from field surveys of drained land show in some cases yield increases and in others no effects upon yield. It would seem from what was said above and from worldwide evidence, that drainage is beneficial to crop yield when affected by waterlogging and salinity. Why then, are some areas in Egypt exhibiting little or no increase in yields? The answer may be that the drain systems that are being installed are not achieving the necessary improvement in soil water levels that are required for increased yields. The drainage systems may not be functioning due to: (1) poor installation; (2) failure of the system (silting, blockage, etc.); (3) improper design; and (4) farmer practices (blocking drains, etc.).

The goal of this paper is to examine the question of tile drain design from a theoretical viewpoint. It is hoped to provide insight into whether the practices or policies of drain design in Egypt may be leading to a situation where some fields may be improperly designed producing ineffectual drainage.

Since, on the whole, drainage is welcomed by the farmer and field experiments show positive benefits from drainage, drainage must be working in many cases. However, there may be conditions where the current practices fail resulting in no benefits from drainage.

The analysis in this paper will be based upon an approach developed by Strzepek et al., (1980), to measure drainage performance. This approach synthesizes crop response to dewatering zone, the physics of groundwater flow and the economics of crop production and drainage installation into a single measure of drain performance. This approach will not be presented in detail, but the reader is referred to the reference above.

Based upon this approach, Strzepek et al., (1979, 1980), developed a procedure for the optimal design of tile drains using mathematical programming. This optimal drain design procedure will be used in the analysis as well to help illustrate the magnitude of losses due to certain policies. The next section will examine the current policies of drainage design in Egypt.

CURRENT DRAINAGE DESIGN POLICY IN EGYPT

To undertake the enormous task of implementing drainage over almost 5 million feddans of Egyptian agricultural land, the Egyptian Public Authority for Drainage Projects (EPADP) was established within the Ministry of Irrigation. The roles of EPADP are to perform investigations, planning, design and coordination of implementation of all drainage projects in Egypt. This is quite a large task and EPADP has done a good job considering the constraints of man-power, budget, and shortage of resources. In the process of undertaking all these tasks, certain procedures had to be adopted for drain design. Some of these procedures were adopted from different climatic and agricultural regions where they function well. Therefore, some of the procedures may not be appropriate for Egyptian conditions and should be scientifically tested in the field. This is very difficult given the tasks which lie before the EPADP, thus the use of theoretical methods to provide insight into the applicability of untested procedures is a useful exercise.

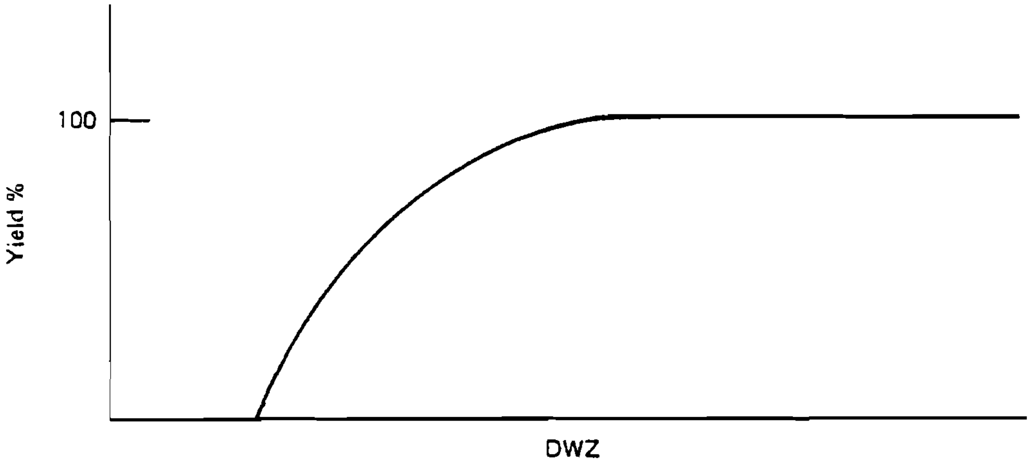
This paper will examine two such procedures that may account for cases where tile drainage is ineffective.

1. The implementation of tile drains with a minimum design of 40 meter spacing with 1.5 meter depth.
2. The implementation of a fixed drain design over a large area.

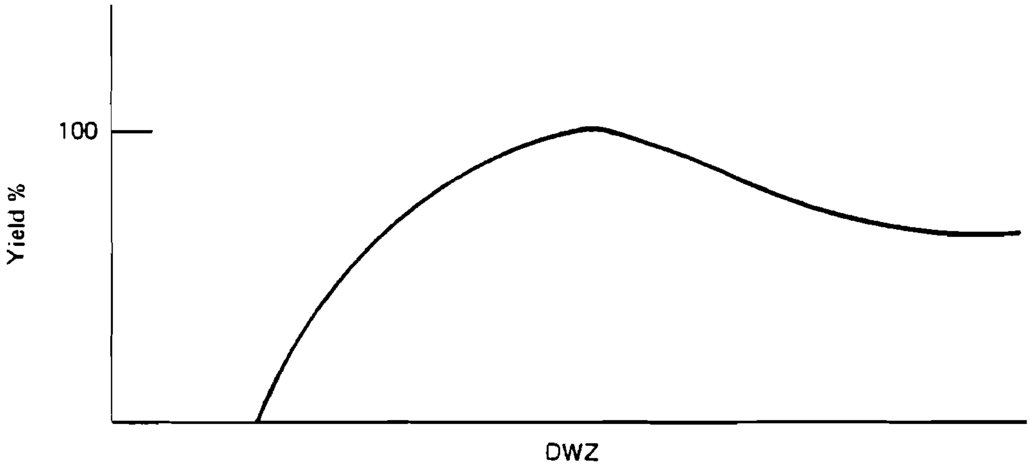
Minimum Spacing

EPADP has adopted a policy of imposing a minimum of 40 meter spacing design for tile drains based upon an assumption that crop yield response to dewatering zone is a linear or concave function. This assumption allows one to claim that the benefits of drainage to crop production over an area of two drains providing 50% of the optimal dewatering zone is equivalent if not greater than the benefits to crop production of an area of one drain provided with optimal dewatering zone. If this assumption holds true, then it is quite logical to propose a design value of a water table that is less than the optimal to exploit the properties of the response function, not a minimum spacing, which is a function of soil permeability, drainage rate, and other parameters.

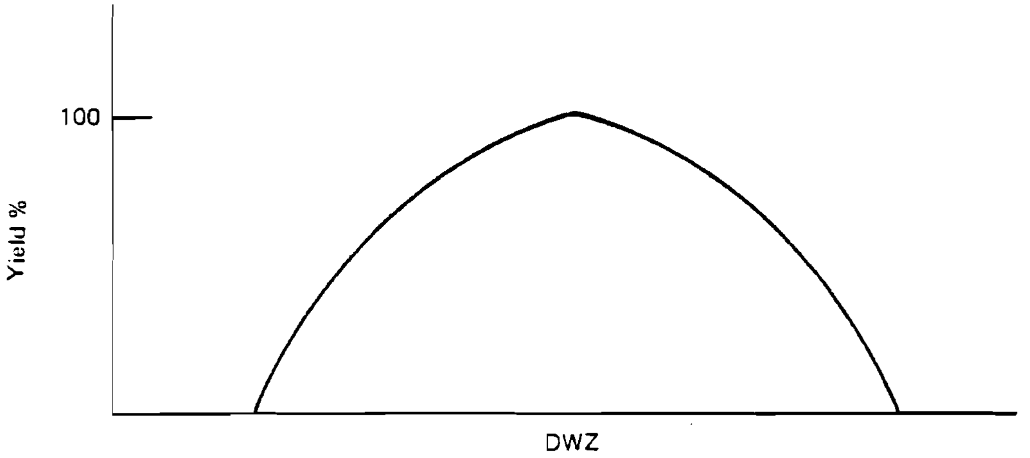
The reason why a minimum spacing approach fails is that dewatering zone is not linearly related to drain spacing; that is, a function of spacing and depth of drains, depth of soil layer, soil permeability, drainage rate, and irrigation practices, all of which change greatly over the regions of Egypt. The goal of an efficient drain design is to find the spacing that provides the dewatering zone where the marginal cost of increased drainage equals the marginal benefits of drainage to crop production. In that way, the capital resources allocated to drainage will be utilized in an efficient manner. The other reason that a minimum spacing approach can fail in certain circumstances is that the crop yield function is not linear or concave. Figure 1 is a plot of the range of possible crop yield functions feasible in Egypt. One can see that although the functions rise concavely from the abssisa, there is a threshold value which does not pass through the origin which makes the function non-concave. These functions also exhibit non-concave features beyond the optimal, further complicating the analysis. Strzepek et al., (1980), have developed a method to determine the optimal design of tile drains for multiple crops even under conditions where the input parameters are uncertain. Based upon the above method, this paper will show the cost associated with applying a minimum spacing approach under conditions where it is inappropriate.



Case I



Case II



Case III

Figure 1. Case study yield functions.

Large Scale Areal Homogenity

The policy of EPADP in many cases is to design large areas under a single tile drain design, in effect, assuming large scale spatial homogenity of drainage properties. This policy is based on a property that as soil permeability varies in space the variation in design spacing will be less, due to the non-linear relationship between spacing and permeability. Therefore it is easier to lump areas together since the magnitude of variation in spacings are less. Especially in the areas of greatest concern, where there are low permeabilities such as the Nile Delta Clays, the designs all show a need for spacing under 40 meters, but due to the minimum spacing policy described above, a whole region will drain at 40 meter spacing. Thus, within that region there will be many areas where the drains are totally ineffective. Even in areas where the minimum spacing policy does not come into effect, the incorporation of spatial variability of soil permeability into drain design will provide a more efficient total system as was demonstrated in Strzepek et al., (1980).

The next section will present the basis of the approach of analysis of economic response to drain design under uncertain input conditions.

ECONOMIC MEASURE OF DRAIN PERFORMANCE

The Hooghoudt equation for tile drain design is presently used by the EPADP, based upon a deterministic mean value approach. Strzepek et al., (1979), have applied the First Order-Second Moment (FOSM) analysis to this equation to provide a probability distribution of the dewatering zone as a function of the uncertainty in the soil permeability and drainage coefficient in the design area. With a probability density function of the dewatering zone from the FOSM analysis and a crop yield response, an expected crop yield as a function of drain design can be calculated. This expected yield can be transformed into an expected economic loss and combined with the capital cost function for drain design to provide a measure of the true total cost of each drain design.

The field level drain design problem can be cast into a formal Mathematical Programming Problem under uncertainty to provide the optimal tile drain design. The stochastic programming approach to uncertainty is possible if there exists a relationship between economic response and system output (the crop yield function).

The Stochastic Programming Model will minimize the total cost of drain installation plus the value of crop loss over the life of the drain, subject to physical constraint on the drain system. This approach provides a design where the marginal cost of improved drain performance (capital cost) is equal to the marginal value of the crop loss over the life of the drain due to better system performance. This analysis provides for the efficient utilization of capital which is a scarce resource in many agricultural economies.

Since this method is based upon economic rather than physical criteria, it is straightforward to extend the method to a multiple crop formulation (Strzepek et al., [1980]).

The stochastic programming model requires statistical information about uncertain parameters as one of its inputs. The important question for lateral drain design using this model is over what area, size and location, is the design to be assumed constant. The spatial variability of the permeability of the soil is a random process and as such permeability will vary from point to point although it may possess some underlying trend. Therefore, the lateral field drains ideally would be designed such that the design would differ for each set of lateral drains. However, this is quite impractical and would add costs. Therefore a design area over which lateral spacing and depth would be kept constant must be selected. The area must be small enough to reflect local conditions but large enough to be practical.

For practical reasons the minimum area over which a constant lateral drain design is feasible is the area drained by a single collector. The reason a single collector area is selected for lateral design is that each lateral must be connected to the collector. Lateral connections that are randomly placed on either side of the collector add to the number of pipe fittings and labor required.

It was shown in Figure 1 that crop yield functions are nonlinear with respect to the dewatering zone. Due to these nonlinearities, accounting for spatial variability in soil permeability as a mean value of sample values within a collector will not take into account the true economic costs of the spatial variability. Ideally, a drainage system in which lateral drain design varied at each point in space where data existed would reduce this problem. This is impractical from an installation point of view. However, it is quite simple to develop a design for each point in space for which permeability data exists. In the same way it is possible to analyze the economic response to the depth and spacing of lateral drains at each point for which permeability data is available. This response will reflect the capital cost as well as the crop yield due to depth of the dewatering zone, which is a function of the lateral design.

Such a function has been developed for multiple crops which gives the economic consequence of a choice of lateral drain depth D, and drain spacing L. So that at each point in space where data is available on permeability K, and drainage coefficient N, and economic response can be defined as a function of D and L.

It is assumed that there must be only one design over the collector area. To determine this design a new cost function for the collector area is defined which is the summation of all the economic responses for each sample point. Within the collector, the "optimal" drainage design can then be found by installing this function in the multi-crop stochastic programming model for a collector system, rather than a single lateral drain. The basis of this model is that the spatial variability of the parameters are reflected in their true economic consequences rather than being described by a set of statistical values.

Now it is possible to analyze the effect of certain policies by comparing the economic response of these design policies to the response of "optimal" design using Mathematical Programming. The following section will provide results based upon data obtained from the Embabe region in the Nile Delta. The "optimal" designs that are found using the Stochastic Programming approach are not necessarily the correct design due to assumptions that are made about crop yield function, but they do provide a good basis upon which to compare the expense of present policies which do not examine total system costs.

ANALYSIS OF POLICIES

A region along the Embabe Drain in the Nile delta was selected as being representative of conditions throughout the Nile delta. Data was provided by the Ministry of Irrigation that would normally be used to design the drains. This includes soil permeability data, drainage rate, depth of soil layer and crops grown. Since the exact form of the crop yield function was not known for this region, the three that represent the range found in Egypt were used to examine the sensitivity of results to each.

The area selected for study was 2 kilometers by 1.4 kilometers and it was assumed it be drained by five parallel collectors which define the homogenous design units.

Minimum Spacing

To study the effect of a 40 meter minimum spacing a single collector area was selected. It was 400 meters wide and 1400 meters long and covers an area of 133.3 feddans. There were 11 soil permeability samples found in this collector region. For this analysis it was assumed that the data samples were without error as is the practice of the EPADP. However, the drainage rate was assumed to be normally distributed with a mean of 4 mm/day, with a standard deviation of 4 mm/day. This value came from the study of the Embabe region, the crops considered for this case study were wheat, maize, cotton, vegetables and berseem. A constant drain depth of 1.5 meters was assumed.

Table 1 provides the results of running the design model for the three types of crop yield function shown in Figure 1. The results show the dramatic effect that the policy of 40 meter spacing can have under these conditions. In all three cases the drain design provided by the model gives a spacing about one-half of the 40 meters. This smaller spacing requires approximately a 100% increase in the capital costs of the tile drain installation. However, the savings in expected losses over the life of the drains, assumed to be 50 years with an interest rate of 10%, is startling for the type 1 crop function. The expected losses with a 40 meter spacing are about 14 times greater than optimal design, resulting in a total cost over the life of the drain of the 40 meter spacing being 3 times greater than optimal design provided by the model. For type 2 and 3 cases, the increased losses for 40 meter spacing were 4 and 3 times greater, respectively. This results in the total costs for both type 2 and 3 being approximately 2 times greater than the design from the Mathematical Programming model.

Although the data used may include some assumptions and extrapolation for this region, it does show that for this data set, the adoption of a minimum spacing policy is very costly in the long run. Even if the losses are 100% over-estimated, it would not change the result. This is due to the fact that for a more costly drain design, less than 40 meters, the present values of expected losses are greater than the additional capital in-

Table 1. Results of analysis of effect of minimum drain spacing.

Crop Yield	Type 1		Type 2		Type 3	
Drain Design	Minimum	Optimal	Minimum	Optimal	Minimum	Optimal
Depth (meters)	1.5	1.5	1.5	1.5	1.5	1.5
Spacing (meters)	40.0	18.05	40.0	19.40	40.0	19.22
Costs:						
Capital Costs (LE)	10115.10	22419.6	10115.10	20861.0	10115.10	21047.29
Expected Losses (LE)	71241.46	4897.52	80822.42	21441.33	93422.49	30335.32
Total Costs (LE)	81356.56	27317.12	90937.52	42302.33	103539.54	51382.61

vestment in drains. Although this is looking at losses rather than actual yields, it may explain why certain drained fields are not exhibiting any increases in yields.

Spatial Variability of Soil Permeability

The procedure of aggregating large areas of land under a single tile drain design is made for ease of installation. It is proposed in this paper that a single collector area be the maximum area under which drain design is held constant. Then each independently designed collector area can be aggregated into a drainage system with little effect on the installation process.

As was demonstrated above, the ignoring of spatial variability of soil permeability within a single collector can have large costs. This section will examine the costs of ignoring spatial variability on a large field level which may span many collectors.

Table 2 presents results of an analysis of this problem for the case study field which is drained by 5 collectors. The analysis examines the effect of assuming a 40 meter minimum spacing over the entire field. The effect of the different crop yield functions are illustrated as well. The results provide the drain spacing for each collector designed using the Spatially Distributed Multiple Crop Stochastic Programming Approach Policy and compares this with the fixed design. The capital cost, expected losses and total cost for the total 5 collector system are presented. The costs resulting from assuming a 40 meter spacing over the entire field are also shown.

Table 2. Effect of spatial variability of system design.

Crop Yield	Type 1		Type 2		Type 3	
Drain Design	Min 40	Optimal	Min 40	Optimal	Min 40	Optimal
Spacing* (m) Collector						
1	40.	29.61	40	32.46	40	31.89
2	40.	18.16	40	20.47	40	20.51
3	40.	20.42	40	23.82	40	23.79
4	40.	18.05	40	19.40	40	19.22
5	40.	25.18	40	27.68	40	27.54
System Costs						
Capital (LE)	50575.48	94244.68	50575.48	84694.79	50375.48	85156.02
Expected Losses (LE)	201040.44	28041.38	256861.34	115645.30	312065.34	161366.88
Total (LE)	251615.92	122286.06	307436.82	200340.09	362640.82	246522.90

* Depth for all designs 1.5 m

In Table 2, the range of values for the spacing of drains for each collector can be seen. These different values are a result of the variability of the soil permeability found among the collector regions. Strzepek et al., (1980), have shown that in this region the scale of variability of soil permeability is between 300-700 meters. This means that little can be inferred about the value of permeability (beyond a distance of 300-700 meters) from the value at a certain point. This is demonstrated in the results as well, since collectors 1 through 5 are continuous but show varying designs.

Table 2 also shows the economic results of ignoring this variability in soil permeability. For a type 1 crop yield function, the expected losses over the entire field are seven times greater with a 40 meter fixed design compared to the spatially varying design. The capital costs are 86% greater for the spatial variability case; even so, the total costs are less than 50% of those for the fixed 40 meter design. For the type 2 and 3 crop yield functions, the expected losses are approximately 2 times greater for the fixed design versus the spatially varying. This results in total costs for type 2 and 3 spatial varying design of approximately 65% of the total costs of the fixed 40 meter design.

These results are quite substantial and a spatial varying design policy should not require much more cost in installation except for the fact of the 40 meter minimum spacing that was discussed above.

CONCLUSIONS

The results of this paper have shown that under certain conditions the policies of ignoring spatial variability of soil permeability and adopting a minimum spacing design of 40 meters can have quite substantial costs over the life of the drain.

This analysis shows that areas where the permeability varies greatly and conditions call for a drain spacing less than 40 meters, tile drainage will not be as effective as projected in the economic analysis phase. In some cases, the tile drains may be ineffective. This is not saying that the only reasons that some areas are not exhibiting benefits from drainage are due to these policies, but this analysis does provide some insight.

It would be possible to examine this hypothesis. By retrieving the design data for the areas that are not showing benefits from drainage, one could see if this data called for design of spacing less than 40 meters and whether the soil permeability is highly variable. It would be possible to examine the actual installation and see if large areas are under a single drain design at 40 meter spacing.

This type of analysis could provide information about these policies from an empirical basis to supplement this theoretical analysis.

Another possible cause that should be examined is whether the area was suffering from salinity problems rather than waterlogging, and whether the tile drains that are designed for waterlogging are also addressing the problems of salinity.

It is clear that tile drainage is beneficial to irrigated land when designed and installed properly.

The question currently being asked in Egypt as to whether tile drainage is effective should be restated so as to ask: "Why in certain cases are tile drains not providing the benefits projected?". The evidence in Egypt and elsewhere shows that tile drainage can be effective. What must be addressed is why certain studies reveal no effect.

REFERENCES

Strzepek, K.M., D.H. Marks, and J.L. Wilson. 1979. Design of agricultural drainage under uncertainty. Proceedings of the Conference on Water Resources Planning in Egypt, Cairo, Egypt.

Strzepek, K.M., D.H. Marks, and J.L. Wilson. 1980. Planning and design of agricultural drainage systems under uncertainty: A dynamic multi-level approach. Technical Report, Ralph M. Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.