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Water Management Model for Drainage of Irrigated Lands in Semi-Arid Zones

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WATER MANAGEMENT MODEL FOR DRAINAGE OF IRRIGATED LANDS IN SEMI-ARID ZONES

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ABSTRACT

Notwithstanding an extensive literature on drainage theory, few drainage systems are in fact rationally designed. Recent developments in computer modeling have shown that many of the complications that have prevented routine use of theory in the past can be overcome and Skaggs is currently using these developments to prepare a standardized method for drainage design in humid areas, at the request of and for use by the USDA Soil Conservation Service.

The objective of this proposal is to extend this technique for use of drainage design in irrigated areas. This extension will require adaptation of the computer programs to account for the differences in conditions encountered, reevaluation of the criteria chosen for assessment, repackaging of input parameters to meet the data base expected to be available, and testing the product against field data.

In addition, the modified program will be compared with other approaches, specifically the design procedure of the U.S. Bureau of Reclamation.

The close interaction between irrigation water management and drainage suggests that, if this project is successful, it will be especially useful in both the Western United States and in Israel in providing not only a tool for rational design of drainage system for irrigated lands, but also in providing an analytical tool to aid in improving the total water management system for agricultural production.

Objectives

(i) Development of model(s)

- (a) To extend the water management model developed by Skaggs, that concurrently is being tailored for use by U.S. action agencies in humid areas, for use in semi-arid, irrigated conditions.
- (b) To compare this model with the model currently in use by the U.S. Bureau of Reclamation.
- (c) To determine the input parameters needed for each model.

(ii) Application to particular cases

To test the model against field data in Israel and California, to the extent such data can be obtained.

(iii) Validation by field experiments

In Israel to conduct field experiments under commercial crop growing conditions. This will require measurement of the pertinent components of the water balance, as well as determination of the soil hydraulic properties.

(iv) Model packaging

Assuming successful attainment of the foregoing objectives, to package the model in simple enough format that it be useful as a routine design tool by technicians of the USDA and Israeli Ministry of Agriculture.

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Water Management Model for Drainage of Irrigated Lands in Semi-Arid Zones

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1. ABSTRACT

This research has extended the use of DRAINMOD (a computer model for the design of drainage systems) to use in irrigated areas. The reliability of the model for irrigated cropland was tested with field data from California and Israel. Water table elevations predicted by DRAINMOD agreed reasonably well with measurements obtained from five experimental locations differing in soil texture, in the San Joaquin and Imperial Valleys, U.S.A. Water loss by deep seepage there was found to be a significant component in soil water balance of irrigated cropland. When water table drawdown exceeds 150 cm, the model tends to overestimate the depth of the water table.

A drained, trickle-irrigated, banana field in the Jordan Valley, Israel, has been intensively studied for the verification of DRAINMOD during 1980-83. Actual measurements generally agreed with water table elevation predicted by DRAINMOD. The model, however, overestimates water table depth, and this is believed to be due to considerable lateral and deep seepages present in this field. Therefore, the model can be used for simulation of drainage systems in irrigated lands only if lateral and deep seepages are taken into account.

2. Results of Research

2.1 In Israel

2.1.1 Field Experiment (See also Sinai et al. 1983a).

One of the objectives of this project is to establish a field experiment in irrigated cropland in the semi-arid region for testing DRAINMOD.

A full scale field experiment has been established in a 27-hectare banana field near Kibbutz Degania A in the Jordan Valley south of Lake Kinneret (Fig. 1). This field can be considered typical of the dry-hot semi-arid region in the Middle East. The field is drained by a deep (2.8-3.0 m) and wide-spacing (120-180 m) subsurface drainage scheme / It is irrigated by a fully automated drip irrigation system with a high leaching fraction.

The experimental set up includes: some 87 piezometers at different depths (2.5m - 8m) and 4 automated water-level recorder type piezometers; computer-based irrigation timings and volume recordings; automated recording of drainage flow measurements in several field drains and at the collector drain outlet. In addition, a complete data set of climatological conditions is provided by an official weather station in Degania-A, some 400m from the field. Crop requirements and ET estimates are provided by the regional experimental station located in Zemach about 1.5 km from the field.

Data are weekly collected from the field (data are mostly continuous due to automated recording), then processed and analysed at the Technion for comparison with simulated data by DRAINMOD.

Besides, a soil survey has been conducted in the field, layered profile found and hydraulic properties of soils measured. More details are available in the enclosed report (Comprehensive Report, Part II).

2.1.2 Validation of DRAINMOD by Field Data

In order to attain our prime objective (i.e., validation of DRAINMOD), we have analysed data collected in the years (1980-83) from the field. Water level contours and observation of drainage flow in manholes indicate that only about half of the 27 hectare field is actually drained by the

Fig. 1- Site of the Test-Field.

Fig. 2 - Experimental field and the drainage system.

Fig. 3 - Actual contributing areas to the drainage system on three different dates

drainage system. Maximum flow and water level heights have been observed in August. We investigated this phenomenon both in the field and on a larger (regional) scale. Our major conclusion is as follows: since during 1972-76 the irrigation method in this region has gradually shifted from the surface (border) method to sprinklers and later on to the drip methods, irrigation efficiency has increased from about 0.5 to about 0.9, and the leaching fraction decreased dramatically for the same leaching requirements which are governed by the crop, irrigation water salinity and soil.

This hypothesis is also supported by a drastic decrease in the total drainage flow of the regional scheme (from some 28,000 m³/day in 1971 to about 4000 m³/day in 1981 for an area of about 400 hectares). We therefore suggest that the drainage scheme at Degania A which was installed in 1965 was originally designed for a higher leaching fraction that might have led to a higher water table. Since water table is much lower now due to a lower leaching fraction and higher irrigation efficiency, only the eastern part of the drainage system is at the saturated zone and in operation. The dashed lines in Fig.3 mark the estimated border of the saturated zone in different periods.

This finding has bothered us immensely because reality in the field is quite far from the idealistic assumptions built in DRAINMOD. The major difficulty comes from the fact that DRAINMOD assumes symmetry in flow conditions with respect to the drain direction. It uses one-dimensional water balance for a soil column located midway between two parallel field drains and this is not a realistic assumption for the Degania case-study. However, this problem has been discussed with Dr. Skaggs during his visit at the field in July 1981. We came to the conclusion that one, plots B & J, out of the 10 drainage treatment plots of the 27 hectare field, is suitable for simulation, as very little lateral flow was observed in this plot. Thus the assumptions regarding symmetry, built in DRAINMOD, can be considered practically valid.

The observed water table hydrograph of October 1980-July 1983 for location J 14, which is the midpoint of plot J, has been compared with the simulated hydrograph by DRAINMOD. Although data are incomplete, we can conclude that the result of simulation come close to the observed data

There is however a significant deviation of the observed W.T. hydrograph from the simulated one (Figs. 4,5,6,7,8,9). Standard error estimates of 30,30,25 cm were found in the years 1981,82,83. Moreover, the comparison shows a significant over-estimation of W.T. hydrograph as simulated by DRAINMOD. This can be attributed to lateral and deep seepage components that were found in the field and are missing in DRAINMOD.

Fig 4 Comparison of simulated and observed water table at J14 location for the year 1981.

Fig 5 - Comparison of simulated and observed water table at J14 location for the year 1982.

Fig. 6 -- Comparison of simulated and observed water table at J14 location for the year 1983.

Fig. 7 Comparison of simulation and observed water table depth for the year 1981 at J14 location.

Fig 8. 1- Comparison of simulation and observed water table depth for the year 1982 at J14 location.

Fig 9.10 - Comparison of simulation and observed water table depth for the year 1983 at J14 location.

2.2 In U.S.A.

2.2.1 Field Evaluation of DRAINMOD in Irrigated Areas (Chang et al. 1983)

The objective, i.e., to test the model DRAINMOD against field data from irrigated areas in California, has been achieved by Profs. Skaons and Chang in North Carolina and is reported in full in Part II of the Comprehensive Report of this BARD project.

Data from two subsurface drainage experiments in California were selected for testing the applicability of DRAINMOD to irrigated cropland. These experiments were: (i) the San Joaquin Valley Drainage Investigation which was conducted by Johnston and Pillsbury (1965). and (ii) the Imperial Valley field study in California which was conducted by USDA researchers of the Imperial Valley Conservation Research Center at Brawley.

Five sites were selected for simulation purposes: four sites in San Joaquin and one site in the Imperial Valley. Lateral spacing ranges from 61 to 244 m and depth of drains ranges from the relatively shallow 1.22 m to the deepest 2.10 m interval.

On comparison, predicted and observed water table responses to irrigation show good agreement. (See Figs. 10-13) It was therefore concluded that DRAINMOD could be used to simulate the water balance in an irrigated cropland. Water table elevation predicted by DRAINMOD agreed well with the field measurements for 5 experimental locations of different soil texture, drain spacings and depths. Standard errors were found in the range of 24-26 cm (Table 1).
however,

It has been observed that water loss through deep seepage and lateral water movement may be significant components in a soil-water balance for irrigated cropland in semi-arid regions. When the water table draw-down exceeded 1.50m the model tended to overestimate the water table depth. The error was apparently due to the model assumption related to the drain and equilibrium of the soil-water distribution above the water table.

Fig. 10 Comparison of predicted and observed water table elevations (cm above the restrictive layer)—without correction for deep seepage loss.

TABLE 1 STANDARD ERROR (S) AND AVERAGE DEVIATION (A.D.) FOR THE COMPARISON OF PREDICTED AND MEASURED WATER TABLE ELEVATIONS (ALL VALUES IN CM).

Drainage system	1960		1961			
	S	a.d.	S	a.d.		
No. 4	24	20	23	18		
No. 6	18	12	17	16	13	15
			(cotton)	(rice)	(cotton)	(rice)
No. 5	12	8	11	10		
No. 9	6	4	23	19		

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Fig. 11—Comparison of predicted and observed water table elevations (cm above the restrictive layer) for a tile drained field in Imperial Valley.

Fig. 12 Comparison of predicted and observed water table elevations (cm above the restrictive layer) for four model testing sites in San Joaquin Valley—1960.

Fig. 1.3 Comparison of predicted and observed water table elevations (cm above the restrictive layer) for four model testing sites in San Joaquin Valley—1961.

Model Packaging

Several efforts have been made to improve the execution of DRAINMOD, both in the U.S. and in Israel. In North Carolina the model has been arranged in several formats suitable for different tasks, e.g., format for simulation where climatic data is available in the form of a magnetic tape, card deck, or disk file; another format for the comparison of simulated water table hydrograph against observed hydrograph. Some special computer programs were written to aid preparation of input data for DRAINMOD, among them program for calculation of drainage volume-water table depth relationships; program to calculate upward flux and program to predict unsaturated hydraulic conductivity. Although some of the efforts conducted in North Carolina were funded by other sources, the methods developed as a result of these efforts are available for us and are routinely used while executing DRAINMOD.

A very practical, engineering-oriented user's guide has been written for DRAINMOD. (See SCS 1983). This operation was funded from another source, however; but the availability of this user's guide, which is very helpful, will hopefully simplify the use of this model.

DRAINMOD has been adopted by the U.S. Dept. of Agriculture's Soil Conservation Service, as a computerized design and analysis tool for water management of agricultural fields. The model can be secured from every State office in the U.S. and is being used by engineers, planners and service agencies.

In Israel, a special program has been developed, which converts irrigation data in the form of intensity, duration and schedule, to the input format used by DRAINMOD (i.e., 0.01 of inches in hourly volumes). This program, GENIN, also combines irrigation data with rainfall in periods where the two occur. (For more detail, see enclosed Suppl. I Sinai et al. 1983b). In addition, several service subroutines have been added to DRAINMOD to allow simple and fast plotting of hydrograph outputs, statistical comparison between observed and simulated data, etc.

Since some of the potential users in Israel do not fluently read English, Hebrew versions of the user's guide, one for DRAINMOD (Supplement III, Sinai & Rubinfeld '83 encl.) and one for GENIN (Supplement II, Sinai & Haramati 1983) have been written.

In view of local circumstances in Israel where the Soil Conservation and Drainage Expt. Station in Midreshet Rupin lacks access to a fast computer (i.e., IBM 370 series), we decided to continue using the computer services at the Technion which is located only 60 km north of Midreshet Rupin. It is anticipated, however, that by the end of the second BARD project US-442-81, two or more scientists (Dr. Yoram Benjamini and Ing. Zvi Revhon) of the Israeli SC&D will be routinely working with this model either at the Technion or at their own premises.

2.4 Comparison of DRAINMOD with other models.

This was one of the objectives of this project. It has taken the form of two earlier M.Sc. theses and was published in Holsambre and Sinai (1980), Suryawanshi and Sinai (1980). Major findings indicate the superiority of DRAINMOD and the concepts employed in this model in comparison with alternative drainage design methods. The "successive steady state" and "drain to equilibrium" concepts which are employed by DRAINMOD were found to give realistic and accurate enough simulations. The incorporation of objective functions in DRAINMOD has been found advantageous.

3. Evaluation of Research Achievement with Respect to Original Research Proposal

3.1 Validation of DRAINMOD (# iii & ii in the Proposal)

The model has been tested against 6 sets of data in irrigated cropland; 4 sets from San Joaquin, 1 from the Imperial Valley, U.S.A., and 1 from the Jordan Valley in Israel. The general conclusion is that the model could be applied to such cases. We can therefore conclude that the task is almost complete. The model, however, fails to predict W.T. hydrographs in cases of deep and lateral seepages.

3.2 Application to Particular Cases (# ii in the Proposal)

This task can also be considered as achieved since, in the process of model validation, the model was successfully applied to the above-mentioned 6 specific cases.

3.3 Development of Model (# i in the Proposal)

This objective has already been reached partially in the first year and has been reported in Parts I and II of the first annual report.

3.4 Model Packaging (# iv in the Proposal)

Several supporting programs have been developed for DRAINMOD. This activity is reported in Section 2.3 of this report, and we thus consider it fulfilled.

4. COOPERATION - Description and Results

Activity in North Carolina, headed by Prof. R. W. Skaggs, included the collection of field data from various sites in California and the use of this data to verify DRAINMOD. Dr. Skaggs and G. Sinai had travelled to California during the summer of 1980 and were introduced by J. van Schilfgaarde to irrigated farming practices of drained fields in both the San Joaquin and Imperial Valleys. Dr. van Schilfgaarde secured published and unpublished data of drained fields from L. Hermsmeier and W. R. Johnston who were very cooperative in that respect. In September 1980 working sessions were held in Raleigh, N.C., by the three concerned scientists, viz. J. van Schilfgaarde, R. W. Skaggs and G. Sinai; they were later on joined by Dr. A.C. Chang who was in Raleigh at that time, on sabbatical leave. He joined the project of his own interest, and his experience in California's agriculture was very useful for the interpretation of the field data.

Progress was reported by G. Sinai in the installation of the field experiment in Degania Alef, Israel. Both J. van Schilfgaarde and R. W. Skaggs recommended useful methods for measurement techniques used in Israel, especially concerning automatic water table recording and flow measurement in drain tubes. Previously, in Raleigh, G. Sinai had become familiar with DRAINMOD and various field and lab measurement techniques in drainage and water management through Dr. R. W. Skaggs. Subsequently, during his trip in Israel in July 1981, Dr. Skaggs visited the Degania Alef (Jordan Valley) experimental field and made useful suggestions regarding measurement and data collection techniques.

We revised the operation of DRAINMOD on the Technion computer and investigated possibilities to improve its execution and usefulness. The validity of some of the basic assumptions in DRAINMOD for the irrigated field case, specifically the absence of salt balance submodel and the inaccuracy in the calculation of mass balance at midpoint in the non-uniform boundary case, were put to test during this visit. The results were also supported by J. van Schilf-gaarde and A. C. Chang. Consequently, we outlined a new research project, for BARD, aimed at studying these aspects (BARD project No. US-422-81, approved). R. W. Skaggs was introduced to the drainage problem in Israel by Ing. Ezra Henkin, Chief of the Soil Conservation and Drainage Div., Israel Ministry of Agriculture. The application of DRAINMOD to some future large drainage project in the Dead Sea, Arava and Jordan Valley areas was discussed.

Dr. J. van Schilf-gaarde met G. Sinai in Israel during his TAC meeting in 1980. He also visited the field experiment in Degania Alef and the Technion in May 1982. This visit was arranged by Ezra Henkin. Work progress in Israel was reported by Prof. B. Zur, Dean of Agric. Eng., who replaced G. Sinai as Principal Investigator during part of 1982 when the latter was absent on sabbatical. Ph.D. students, P. K. Jain and S. Wollman, reported to Van Schilf-gaarde about their Ph.D. projects. Both visits were not funded by this BARD project.

A final working meeting was held in Riverside, California on September 1982, with J. van Schilf-gaarde, R. W. Skaggs, A.C. Chang and G. Sinai as participants. Progress was reported, especially in the evaluation of DRAINMOD in the case of the 5 irrigated sites in California and the site in Israel. Future modifications in DRAINMOD and the work plan for the new BARD project No. US-442-81 were also

discussed. The presence of G. Sinai became possible due to his stay in Riverside during part of his sabbatical. His visit was not funded by BARD.

Cooperation with both the Soil Conservation Service of the USDA and the Israeli SC&D has been very positive. It is carried out on a routine basis in view of the original objectives.

5. THESES

The present BARD project (No.I-46-79) has partially supported two M.Sc. projects, of Mr. D. G. Holsambre and Mr. S. Suryawanshi, while they were studying at the Technion's International Graduate Course on Water Resources Engineering and Management. These theses were submitted to BARD as part of the Initial BARD Report on August 10, 1980, and are entitled

i) A water balance model for drainage of fine textured soils.

M.Sc. thesis of D. G. Holsambre;

ii) Use of transient flow concept and crop needs in the design of subsurface drainage systems. M.Sc. thesis of S. Suryawanshi.

Two Ph.D. projects have also been partially supported by this BARD project: Mr. S. Wollman conducted his Ph.D. research at the Technion on the subject of "A rational model for drainage design in irrigated fields", passed the candidacy examination but had to discontinue his project due to personal reasons. Mr. P. K. Jain has conducted his Ph.D. research at the Technion on the subject of "Drainage design for sequentially irrigated areas". He has already completed 3 years of his Ph.D. program and has benefited by the field results of the Kibbutz Degania Alef experiments. Although Mr. Jain was very much involved in conducting this BARD project, his major objective in his Ph.D. project was to work on the non-uniform boundary conditions problem which is currently under study with the new BARD project No. US-442-81. His thesis, therefore, will be reported in BARD project No. US-442-81.

6. BENEFIT TO AGRICULTURE

Irrigation and drainage systems are the two major water management facilities in cropped lands. The interaction between these two systems has not yet been fully understood. Moreover, successful operation of irrigation and drainage systems requires development of analytical tools which can quantify the effect of changes in the design and operational variable on the objectives of these water management facilities. This type of analysis can be conducted by the computer simulation model DRAINMOD originally developed by R. W. Skaggs in North Carolina. As such, the computer model serves as a sophisticated and reliable tool for analysis of the operation of existing drainage and irrigation systems as well as for Computer Aided Design (CAD) of water management facilities in agricultural fields. Already adopted by the SCS of the USDA for this purpose, the model now serves engineers, agronomists and other experts from every state office in the USA for drainage and subirrigation systems design. The Israeli counterpart, SC&D Div., can have access to the model at the Technion computer, and plans are currently underway to use it for current drainage projects in the Arava and Dead Sea areas.

DRAINMOD was not originally designed to be used for irrigated areas in semi-arid condition. As a result of this BARD, though, we have developed the confidence that this model can simulate with reasonable accuracy and reliability water table fluctuations in semi-arid conditions. Components should be added to quantify deep and lateral seepage; experience with the California data showed that such components can be added, at least on a site specific basis, and will improve accuracy of the predictions. In many irrigated areas in semi-arid zones, drainage facilities are required to remove excess water from fields and allow preparation for soil leaching.

In some of the most productive areas in both the USA and Israel (Imperial and San Joaquin Valleys in California, and Jordan, Arava and Jezreel Valleys in Israel) the skillful operation of irrigation and drainage systems is essential in order to ensure long and short term high soil productivity levels. It is believed that the use of DRAINMOD by SCS, SC&D and other experts in these regions is a necessary step to maintain the soil productivity level or even to increase it.

The present BARD project, therefore, is an important step forward in the application of DRAINMOD to irrigated lands in semi-arid areas for which it was not originally meant.

7 - LIST OF PUBLICATIONS OF BARD PROJECT I-46-79

1. Suryawanshi, S. and G. Sinai (1980). Use of transient flow concept and crop needs in the design of subsurface drainage systems. Faculty of Agric. Eng. Public. No. 319. Technion, Haifa, Israel (Encl. with Initial Report to same BARD project as Part I), 106 pp.
2. Holsambre, D.G. and G. Sinai (1980). A water balance model for drainage of fine textured soils. Faculty of Agric. Eng., Publ. No. 320, Technion, Haifa, Israel (Encl. as Part II of Initial Report to same BARD project), 103 pp.
3. Chang, A.C. and R. W. Skaggs (1981) Field evaluation of a water management model under irrigated conditions. Dept. of Bio. & Agric. Eng., N. Carolina State Univ., Raleigh, N.C. (Encl. as Part II of the comprehensive report to same BARD project) 58 pp.
4. Sinai, G., P.K. Jain and S. Wollman (1983) A field study for verification of DRAINMOD - Degania A banana field. Faculty of Agric. Eng. Publ.No.336, Technion, Haifa, Israel (encl. as Part I of comprehensive report to same BARD project) 61 pp.
5. Sinai, G., S. Wollman and P.K. Jain (1983) GENIN - A computer program for processing of raw data for input to DRAINMOD. Faculty of Agric. Eng. Publ.No. 337, Technion, Haifa, Israel (Encl. to final report of same BARD project as Suppl.I), 36 pp.
6. Sinai, G. and A. Haramati (1983). Hebrew user's guide to GENIN - a computer program for processing of raw data for input to DRAINMOD (encl. to final report of same BARD project as Suppl.II) 45 pp.
7. Sinai, G. and S. Rubinfeld (1983). Hebrew user's guide to DRAINMOD - water management computer model for high water table soils. Faculty of Agric. Eng., Publ. No. 339, Technion, Haifa, Israel (encl. as Suppl. III to final report to same BARD project.) 95 pp.
8. Chang, A.C., R. W. Skaggs, L.F. Hermsmeier and W. R. Johnston (1983) Evaluation of a water management model for irrigated agriculture. Trans. of the ASAE 26(2): 412-418 & 422 (encl. to final report of same BARD project as Suppl. IV).

8 - LIST OF SUPPLEMENTS TO THE FINAL REPORT

1. Sinai, G., S. Wollman and P. K. Jain (1983). (See no.5 of List of Publ.)
2. Sinai, G. & A. Haramati (1983). (See no. 6. of List of Publications).
3. Sinai, G. and S. Rubinfeld(1983).(" no.7 " " " ").
4. Chang, A.C., R.W. Skaggs,(See no.8 " " " ").

9 - LITERATURE CITED IN THE FINAL REPORT

1. SCS (1983) DRAINMOD User's manual - Interim Technical Release. USDA, August 1983.
2. (See No. 8 of List of Publ.)
3. (See No. 2 of List of Publ.)
4. Johnston, W. R. & A. F. Pillsbury (1965). Tile drainage in the San Joaquin Valley of California. WRC Contribution No. 97. Univ. of Calif. Water Resour. Center, 245 pp.
5. (See No. 4 of List of Publications)
6. (See No. 5 of List of Publications)