Study on Return Flow of Farmland and It's Numerical Simulation

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ABSTRACT

Owing to investigate return flow in fields is difficult and influenced by many uncertain factors. This study uses numerical simulation method to calculate horizontal and vertical leakage after irrigation in rice paddy. The three-dimension groundwater flow model 'MODFLOW' which is used for simulating experiment data of sandbox, verifying the application of model and assuming a virtual farmland to estimate horizontal and vertical leakage requirement under different conditions of soil texture, drainage location and surface slopes. Results show that soil texture has the biggest influence on leakage requirement, and get more leakage requirement owing to high hydraulic conductivity of soil that has faster ratio of leakage. Moreover, vertical leakage requirement is larger while vertical drainage location is approaching surface of ground. Finally, considering surface slopes are influencing both on horizontal and vertical leakage, especially for vertical leakage.

Keywords : return flow, hydraulic conductivity, leakage

1. INTRODUCTION

In Taiwan, irrigation water is the most part of agricultural water. Irrigation water, which generally uses rainwater to recycle, and has the feature of combining with the nature. Most of irrigation water are used repeatedly, and will be return into drainages and rivers. The research of return flow is imperative for raising the usage ratio of agricultural water resource and improving the technology and equipments of return flow in farmland.

The rate of return flow requirement in sum of irrigation water will be changed on different periods of crop and areas, and confused to water resource distribution and management. The study will probe in details into all kind consumptive use of agricultural irrigation and transport path lines of visible and invisible return flow. Purposes of this study are preparing perfect irrigational plans and achieving effective usage of water resource by estimating reusable return flow requirement on different irrigational operation by model.

2. LITERATURE REVIEW

There are many connected researches about usage of return flow recently, and its research objects are irrigation of paddy fields more than upland crops. As factors which influence

return flow requirement are numerous, they are classified according to research methods as following, For experiments in fields, Kan (1969), Yunlin Irrigation Association (1991), and Agricultural Engineering Research Center (1996) used historical data such as, water intake, crops area records, irrigation plans of irrigation association and rainfall records to proceed investigations of return flow resource in irrigation canals. For tank models, Liu (1997) and Kan et al.(1998) used observation in field, water budget balance, and cooperated with series tank models to probe into return flow between upstream with downstream irrigation system. For numerical simulation, Lin (1998) and Huang (1999) probed into influence of different parameters on return flow requirement, groundwater flow under saturated and unsaturated layers by experiments, numerical models, such as MODFLOW or FEMWATER. For water budget balance theorem, Luo (1961), Li (1970), Water Conservancy Bureau (1972), and Lin (1997) probed into characteristics of irrigation consumptive use based on different units of field lots, rotation blocks and whole rice zone of agriculture by water budget balance theorem. For sandbox experiments, Liu (2001) and Lin (1998) used soil, different slopes, and irrigation application conditions to estimated horizontal and vertical leakage.

3. SIMULATION OF VIRTUAL SITE

The proof of numerical simulation results, which is according to Liu (2001) data of sandbox experiments. We choose a groundwater flow model, MODFLOW, to simulate a virtual site. Furthermore, added conditions as plow sole and ridges to simulated horizontal and vertical leakage of farmland based on numerical simulation method. To expected have a further comprehension about characteristics of return flow requirement and simulated horizontal and vertical leakage under different conditions by changing soil texture, drainage location, and surface slopes.

3.1 Introduction of Virtual Site

At first, the study assumed a virtual farmland, which use MODFLOW numerical model to simulate leakage of the farmland and estimate horizontal and vertical leakage requirement. Then changed soil and boundary conditions of virtual farmland to simulate the influence of leakage on different conditions which can be an analysis foundation for qualitative characterization of leakage.

In the period of land grading and cultivation, owing to plowing and land leveling repeatedly, soil under plow pan received energy made by animals force or mechanical methods, caused air that inside on soil pore drain out and decrease void ratio. Especially paddy fields plowing and land leveling repeatedly become mud status under intake and saturation conditions, and dynamic load causes soil compressed and density increased, called as compaction soil. In above process, it would likely cause deposited and compression phenomenon of clay on plow pan, which is usually called hard pan (Mooremannand and Breeman, 1978). Design principles of virtual site were based on approached to present farmland in order to be confirmed the practicability of numerical model that we choose. I.e. rectangular farmland, sand clay loam, hydraulic conductivity is 0.471 cm/day, paddy field length is 1,000 m, the width is 200m, and the surface slope was 1/150 by investigation.

The surface slope is consisted of three paddy fields and ridges. Owing to long-term cultivation, there is a plow pan with thickness of 20 cm located at 40 cm under ground (Huang, 1991). The field is stairway status and divided into three sections from upstream to downstream. The initial head is depth of 6 cm for once irrigation depth and height of ridges

is 10 cm. The profile diagram is shown in Fig. 1, and the section surrounded by dotted line is the range of simulation model.

3.2 Numerical Simulation of Virtual Site

For grid separated, field length is 1,000 m, and is uniform separated into 20 grids while simulating; the width of 200 m is also uniform separated into 20 grids; for the depth, this study simulated until 30 m under ground, but a plow sole, which is 20 cm thickness and 0.0942 cm/day of hydraulic conductivity, is located at 40 cm under ground. Considering location of plow sole, the depth was nonuniform separated into 32 grids. Besides, there were 10 cm high ridges in field at intervals between 300~350m. Grids separated diagram show as Fig. 2.

To simulate the situation of leakage after irrigation in paddy field, the initial condition of soil layers is assumed saturation in virtual site; the boundary condition is assumed the initial head is 6 cm, which is once irrigation depth; upstream, downstream and bottom layer boundaries are all assumed as free drainages in order to simulate leakage after irrigation.

In this model, many choose items will be setting. This study used the item of initial head to simulate the surface accumulated water on farmland. Drainage height is assumed based on central point characteristics of model grids while setting drainage height. And all hydrogeological parameters in each layer showed as Table 1. In Table 1, specific yield (S_y) is that moisture per unit volume in saturated layer of groundwater is drained out by pump head or gravity. Specific yield is defined as water volume of drainage over leakage volume and expressed with percentage. The conditions of soil, groundwater status and the specific storage of coefficient are assumed respectively as following: sandy clay loam, unconfined aquifer and the specific storage of coefficient is 0.03 cm^{-1}.

Finishing setting above data and parameters, we can obtain the result of horizontal leakage, vertical leakage and total leakage requirements after irrigation by simulating and result showed as Table 2. In accord with Table 2, the total leakage requirements in farmland increase gradually after irrigation first, and then decrease stably. The reason is that water head increases after irrigation and decrease gradually after drainage. Estimating total leakage requirements, there are approximately 12,000 m^3 surface water, and water requirement exists inside soil and drain out are approximately 1,500,000 m^3. According to the variation of vertical leakage, results show that drainage requirement increase gradually in initial 25 days owing to surface pressure increases, and reaches maximum value on the 25th day. Otherwise, leakage requirement is decreased gradually after the 25th day.

The tendency of drainage requirements show that, the drainage requirement from drainage canal increased quickly before the 25th day. On the contrary, the drainage requirement is decreased slowly after the 25th day. According to the variation of horizontal leakage, results show that drainage requirement keep increasing with time even after the 150th day. Above phenomenon are owing to longer transverse distance of drainage, horizontal leakage is slower while leaking into plow sole below.

In order to observe variation of horizontal and vertical leakage under different conditions, this study completed the analysis of variance among three cases with distinct virtual sites, and discussion the analysis of variance on different conditions of hydrogeological parameters, drainage location and surface slope separately.

3.3 Analysis of Variance

3.3.1 Hydraulic Conductivity Change

In order to observe the variation of horizontal and vertical leakage of hydraulic conductivity changes, this study assumes hydraulic conductivity of field extends 10 times the initial hydraulic conductivity in field from 0.471 cm/day to 4.71 cm/day, and the hydraulic conductivity of plow sole in field from 0.0942 cm/day to 0.942 cm/day. However, the surface slope is kept 1/150 and the setting of grids divided and initial head are kept constant. The simulation results of horizontal, vertical leakage and total leakage requirement are shown as Table 3.

Table 3 shows that the total leakage requirement, contains horizontal and vertical leakage increases obviously after irrigation under condition of hydraulic conductivity becomes 10 times in virtual site, and the maximum daily total leakage occurs on the 9th day. To estimate the multiple relationships between initial leakage with simulated leakage in virtual farmland, horizontal leakage increases 15 times on the first day and increases 12 times on the 100th day. Vertical leakage is got the maximum on the 9th day, it is approximately 10 times of that in virtual farmland. For horizontal leakage, the side drainage canal above the plow sole drains out completely on the 63th day. At the same time, soil above the plow sole is in unsaturated condition, and all side drainage is drain out from the bottom of plow sole.

3.3.2 Vertical Drainage Location Changes in Field (Estimation of Groundwater Table)

If we change the location of vertical drainage in field from 30 to 20 meters underground, it means we estimate vertical leakage under the condition of 20 meters underground, and cause the result is leakage recharge into groundwater directly. Other geometry conditions, such as length, width, location of plow sole, hydraulic conductivity, surface accumulated water, height of ridges are the same as initial virtual site. After once irrigation for the simulated site in 150 days, leakage drained out from each drainage canal is shown as Table 4.

Table 4 shows that leakage increases from horizontal drainage with time. Owing to the quantity of horizontal drainage and drainage area are decreased, the total leakage is relatively smaller than that of initial virtual site; however, horizontal leakage above the plow sole is still kept constant even the location of vertical drainage changes. Comparing vertical leakage with that in initial virtual site, the total vertical leakage increases faster after changes the location of vertical drainage and gets the maximum on the 15th day. Then the vertical leakage is getting decreasing after the 15th day. As a result of the vertical drainage distance is shorter after once irrigation depth.

In the simulation, we assume that if leakage is on certain particular depth, it means groundwater full-recharge. Therefore, by changing location of vertical drainage, the result shows that vertical leakage is bigger than that in initial virtual site if we change the location of vertical drainage in field from 30 to 20 meters underground. Above all, the groundwater table has some particular influences on vertical leakage.

3.3.3 Surface Slopes Change

In order to probe into the influence of changing surface slopes on irrigation leakage, we change surface slopes in the virtual site to simulate. This study adjusts the surface slopes in initial virtual site from 1/150 to 1/100, i.e. the upstream elevation is 10 m higher than that of downstream. Other conditions such as plow sole, once irrigation depth, hydraulic conductivity and drainage boundaries are the same as the initial virtual site. Besides, all

fields are level, and the ponding depth is still kept in 6 cm for once irrigation. Results of vertical and horizontal leakage after simulation are following as Table 5.

In Table 5, comparing leakage from each direction with that of the initial virtual site, the total leakage of horizontal and vertical both increase faster than that of the virtual site. Results show that obvious variation especially occurs in vertical direction. Horizontal leakage above the plow sole is drained out faster under the condition of steeper slope. In general, plow sole exists under the farmland; therefore, changing surface slopes will lag vertical leakage into groundwater.

3.3.4 Results of Analysis of Variance

For discussing leakage difference, we change the conditions of simulation as following: hydraulic conductivity, location of vertical drainage, surface slope, and leakage changes after once irrigation depth in the initial virtual site. Simulative results show that between variation of horizontal and vertical leakage with time are following as Fig. 3. and 4.

Fig. 3. and 4. show that, hydraulic conductivity changes causes obvious variation of leakage. I.e. the vertical and horizontal leakage increases approximately 10~11 times while changing the hydraulic conductivity to 10 times, and getting the maximum very soon. Above all, the influence of hydraulic conductivity on leakage is the most important. Others parameters such as changes location of vertical drainage and surface slopes has less influence on the horizontal and vertical leakage variation.

Figs show that, the maximum of leakage not that occurred immediately, but that at certain period after irrigation under initial conditions are once irrigation depth and the soil is saturated. As a result of irrigation water needs to lag a period of time and drain out from soil after irrigating on the surface.

4. CONCLUSIONS

Numerial models could be used to simulate different geometry conditions and irrigational behaviors of each irrigation area, also used to simulate different boundary conditions and initial conditions of saturation degree. The most differences between models simulation and experiments in field were models simulation could be economized more time than experiments in field but also disregarded other influence factors on simluation processing.. Above all, the conclusions of this study were as following:

(1) Owing to experiments in field were usually affected by farmers' irrigational behaviors and the weather conditions, sandbox model experiments were chosen to simulate return flow. However, sandbox experiments were needed too much time and energy to simulate but couldn't reacted actual fields completely. Therefore, this study used numerical models to offset insufficient data of sandbox experiments. As a result, we could be simulated leakage behaviors after irrigation rapidly by getting accurate hydrogeological parameters data.

(2) Soil texture influences the most on leakage requirement. The soil with bigger hydraulic conductivity gets more leakage in short time. Such as the vertical and horizontal leakage requirement increases 10~11 times than that in initial virtual site while hydraulic conductivity becoming 10 times, and arrives the maximum very soon.

(3) The larger vertical leakage is obtained with the location of vertical drainage is getting more approached surface, that is the height of groundwater table influenced on the vertical leakage.

(4) The vertical leakage, horizontal leakage and total leakage requirement is larger with a steeper slope. Otherwise, plow sole, which is existed under the surface of farmland could lagged the vertical leakage recharge into groundwater.

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Tables and Figures

Table 1. Table of hydrogeological parameters in virtual site

vertical hydraulic conductivity (Kv)	0.471 (cm/day)
horizontal hydraulic conductivity (Kh)	0.471 (cm/day)
vertical hydraulic conductivity in Plow Sole	0.0942 (cm/day)
horizontal hydraulic conductivity in Plow Sole	0.0942 (cm/day)
specific yield (Sy)	0.25
specific storage of coefficient (Ss)	0.03 cm^{-1}

Table 2. Leakage in virtual site

leakage / time(day)	total horizontal leakage (m^3/day)	horizontal above plow sole (m^3/day)	horizontal below plow sole (m^3/day)	total vertical leakage (m^3/day)	horizontal : vertical (ratio)	total leakage (m^3/day)
1	49.78	0.00416	49.78	959.29	0.05	1009.07
2	79.95	0.00416	79.95	1427.74	0.06	1507.69
3	108.55	0.00416	108.55	1895.51	0.06	2004.06
5	150.64	0.00416	150.64	2732.67	0.06	2883.31
7	205.79	0.00416	205.79	3589.79	0.06	3795.58
9	278.51	0.00416	278.51	4493.65	0.06	4772.16
10	324.42	0.00416	324.42	4789.34	0.06	5113.76
15	377.15	0.00416	377.15	5449.98	0.07	5827.13
25	482.49	0.00416	482.49	6064.27	0.08	6546.76
50	558.48	0.00415	558.48	5109.83	0.11	5668.31
75	588.11	0.00413	588.11	4353.38	0.14	4941.49
100	604.99	0.00411	604.99	3840.63	0.16	4445.62
125	616.53	0.00408	616.53	3471.24	0.18	4087.77
150	624.57	0.00404	624.57	3190.17	0.20	3814.74

Table 3. Leakage of changing hydraulic conductivity in virtual site

leakage / time(day)	total horizontal leakage (m^3/day)	horizontal above plow sole (m^3/day)	horizontal below plow sole (m^3/day)	total vertical leakage (m^3/day)	horizontal : vertical (ratio)	total leakage (m^3/day)
1	759.84	0.08640	759.75	9857.54	0.08	10617.38
2	1521.55	0.08541	1521.46	15873.19	0.10	17394.74
3	2258.81	0.07563	2258.73	19647.86	0.11	21906.67
5	4081.51	0.06998	4081.44	29011.81	0.14	33093.32
7	5854.63	0.05985	5854.57	36719.50	0.16	42574.13
9	6958.54	0.04853	6958.49	46276.59	0.15	53235.13
10	7361.45	0.03900	7361.41	44578.54	0.17	51939.99
15	7625.58	0.03800	7625.54	43028.51	0.18	50654.09
25	7895.46	0.03700	7895.42	40574.68	0.19	48470.14
50	8045.65	0.01250	8045.64	37845.19	0.21	45890.84

75	7915.51	0	7915.51	33544.54	0.24	41460.05
100	7798.65	0	7798.65	29875.48	0.26	37674.13
125	7687.15	0	7687.15	25478.45	0.30	33165.60
150	7568.54	0	7568.54	21265.99	0.36	28834.53

Table 4. Leakage of changing the location of vertical drainage

leakage / time(day)	total horizontal leakage (m^3/day)	horizontal above plow sole (m^3/day)	horizontal below plow sole (m^3/day)	total vertical leakage (m^3/day)	horizontal : vertical (ratio)	total leakage (m^3/day)
1	31.56	0.00416	31.56	1125.45	0.03	1157.01
2	48.67	0.00416	48.67	1645.85	0.03	1694.52
3	66.42	0.00416	66.41	2004.54	0.03	2070.96
5	103.27	0.00416	103.26	2883.60	0.04	2986.87
7	135.26	0.00416	135.25	3987.65	0.03	4122.91
9	188.56	0.00416	188.56	5024.54	0.04	5213.10
10	205.69	0.00416	205.69	5654.95	0.04	5860.64
15	239.19	0.00416	239.18	5655.58	0.04	5894.77
25	305.92	0.00416	305.92	5510.25	0.06	5816.17
50	354.13	0.00415	354.13	5398.47	0.07	5752.60
75	373.05	0.00414	373.05	5125.38	0.07	5498.43
100	384.19	0.00411	384.19	4897.54	0.08	5281.73
125	392.12	0.00408	392.12	4755.19	0.08	5147.31
150	398.34	0.00404	398.34	4611.54	0.09	5009.88

Table 5. Leakage of changing surface slopes

leakage / time(day)	total horizontal leakage (m^3/day)	horizontal above plow sole (m^3/day)	horizontal below plow sole (m^3/day)	total vertical leakage (m^3/day)	horizontal : vertical (ratio)	total leakage (m^3/day)
1	49.78	0.00418	49.78	1058.44	0.05	1108.22
2	81.25	0.00418	81.25	1530.79	0.05	1612.04
3	111.16	0.00418	111.16	1908.73	0.06	2019.89
5	171.59	0.00418	171.59	2789.54	0.06	2961.13
7	234.53	0.00418	234.53	3604.57	0.07	3839.10
9	293.46	0.00418	293.45	4511.56	0.07	4805.02
10	330.14	0.00418	324.40	4987.54	0.07	5317.68
15	378.98	0.00400	377.26	5500.87	0.07	5879.85
25	495.45	0.00393	482.49	6178.98	0.08	6674.43
50	560.14	0.00392	558.48	5207.19	0.11	5767.33
75	594.14	0.00391	588.11	4487.74	0.13	5081.88
100	614.46	0.00397	604.99	3917.64	0.16	4532.10
125	620.58	0.00386	616.30	3571.54	0.17	4192.12
150	628.54	0.00380	624.57	3357.84	0.19	3986.38

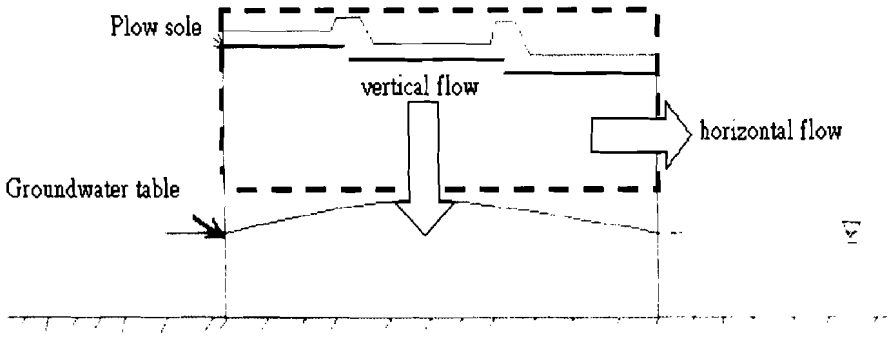

Fig. 1. Diagram of virtual farmland

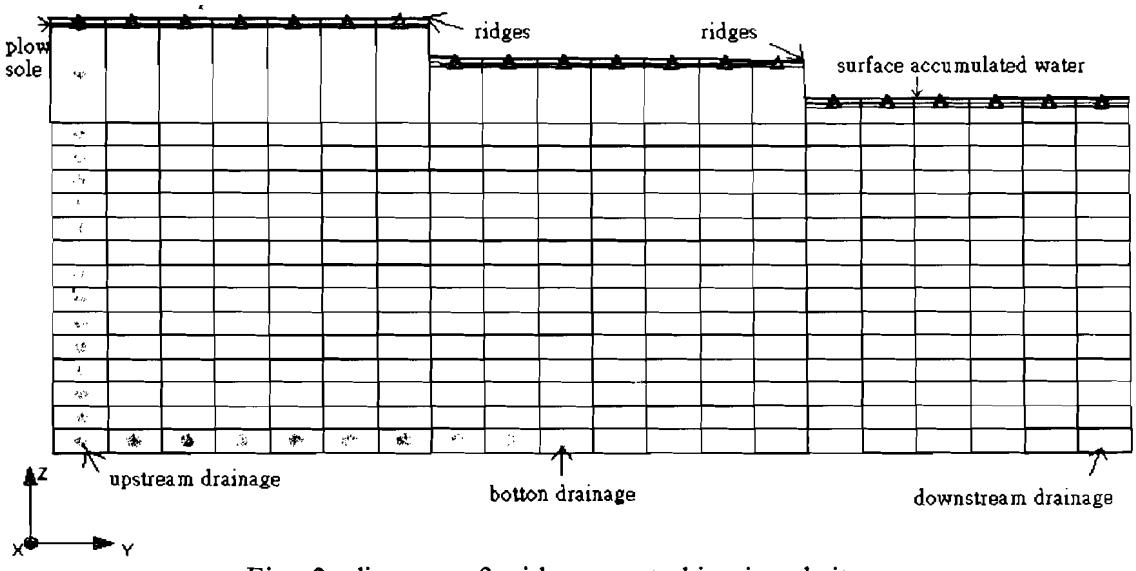

Fig. 2. diagram of grids separated in virtual site

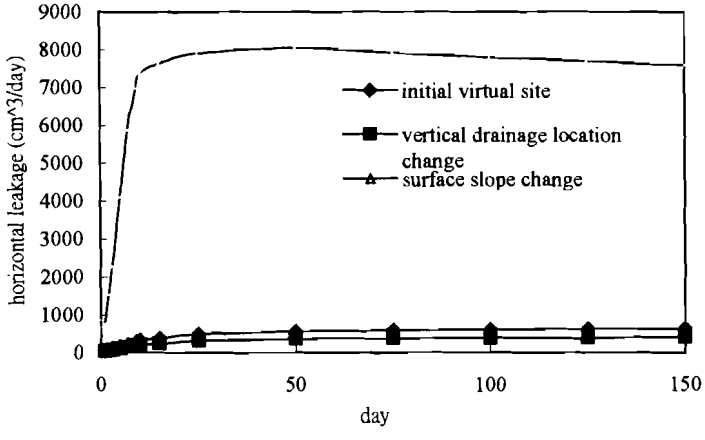

Fig. 3. Total horizontal leakage requirement on different conditions

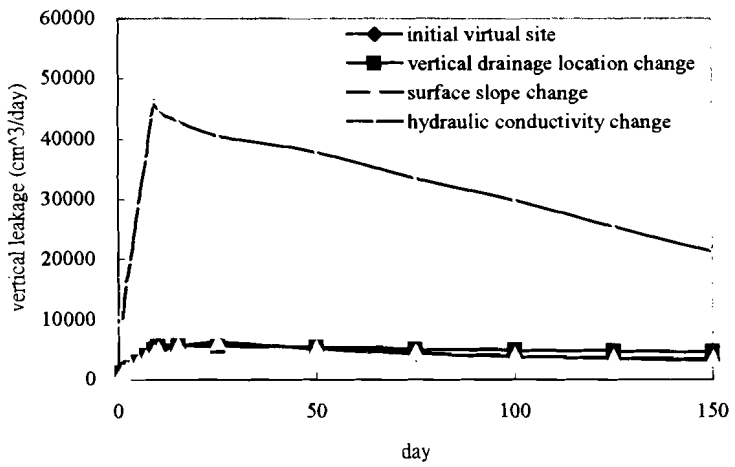

Fig. 4. Total vertical leakage requirement on different conditions