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第 **5** 屆亞洲區域研討會論文發表

The potential of developing agriculture return flow in Taiwan

作者：Hung-Kwai Chen, Kuo-Liang Wang, Po-Wen Wen, Chi-Mei Wang and Ray-Shyan Wu

（陳弘凷所長及吳瑞賢教授等）

60th International Executive Council Meeting &

5th Asian Regional Conference, 6-11 December 2009, New Delhi, India

THE POTENTIAL OF DEVELOPING AGRICULTURE RETURN FLOW IN TAIWAN

Hung-Kwai Chen
Director, Water Resources Planning Institute, Water Resources Agency, MOEA, 1340 Chung-Cheng Rd, Wufeng country, Taichung, Taiwan,
Kuo-Liang Wang
Chief, Water Resources Planning Institute, Water Resources Agency, MOEA, 1340 Chung-Cheng Rd, Wufeng country, Taichung, Taiwan
Po-Wen Wen
Post doctor researcher, Dept. of Civil Engineering, National Central University, 300 Chung-Da Rd, Chungli city, Taoyuan, Taiwan,
Chi-Mei Wang
Ph D student, Dept. of Civil Engineering, National Central University, 300 Chung-Da Rd, Chungli city, Taoyuan, Taiwan
Ray-Shyan Wu
Professor, Dept. of Civil Engineering, National Central University, 300 Chung-Da Rd, Chungli city, Taoyuan, Taiwan

Abstract *In Taiwan, industry water demand has been increasing gradually. Due to the difficulty of finding new water resources and the negative impact on ecological environment from establishing new reservoir, developing agriculture return flow as diversification water resources is very important. To analyze the potential volume of agricultural return flow, XinHuei Creek branch canal and XinLuchangke canal sites were chosen as study and demonstration areas in Yunlin, which is located in meddle of Taiwan. The potential volume of agricultural return flow is quite different between plenty or low water year. Therefore, the study years 2004 to 2007 included both plenty water year, ordinary average year, and low water year. The minimum potential agricultural return flow can be seen as the condition of steady water sources. In low water year (2004), average return water was 0.83 CMS (72 thousands cubic meter) in XinLuchangke canal and 1.54 CMS (133 thousands cubic meter) in XinHuei Creek branch canal. The volume of agricultural return flow will help offshore industry park to solve the problem of water insufficiency.*

1. INTRODUCTION

Due to the changes of industry structure composition, water using types and demands have been increasing gradually. The traditional water resource development becomes difficult. In order to keep sustainable use of water resource, to maintain living, economical and ecological environment, and to protect land and soil, developing diversification water resources in order to replace the traditional types are constructive process. In Taiwan's policy, except for water saving processes study, reuse water resource is opening up and developing as a stable water supply choice. According to the conclusion of "Taiwan Hydraulic Congress" in 2003, it suggested that: "......irrigation associations were encouraged to diversification management. To drew on water resource, irrigation system, organization, and manpower more efficiently into all targets of water supply enterprises, such as agriculture, industry, people's livelihood, and hydraulic. Creative business and benefits, serve the peasantry and society." Therefore, develop and reuse of agriculture irrigation water will not only make water resource using efficiently but also decrease the loading of water resource exploitation. The benefits can help agriculture pursuit refinement and make the peasantry have better life.

In all types of regeneration water resource, the agriculture irrigation return flow has the richest volume and potential recycle possibility. Return flow development is one item of the newly risen hydraulic industry. It can increase surface water supply and decrease groundwater demand. It also conforms to the policies of water source, hydraulic industry, and land subsidence prevention during present phase. Currently there is no reservoir in Yunlin area of Taiwan. River water supply of agriculture irrigation is often adjusted by ChiChi weir. The Hushan reservoir engineering project is set to constructive action to increase water demand in this area for the future.

Before the reservoir begins operating, the shortage demand in this period must be solved. According to the result of "The research of retrieving useable agricultural return flows", "Revalue and recycling assessment of agricultural irrigation in Yunlin irrigation association" and some researches about agricultural irrigation flow the formula of agricultural return flow, the object of this research tried to analyze the volume of agricultural return flows and choose some suitable sites as demonstration areas.

2. CONCEPTS OF RETURN FLOW & PAST STUDY

2.1 Return Flow

The return flow comes out from both rainfall and irrigation water. The rainfall will lost with evapotranspriation, leakage and crops use. Most of them in the irrigation area will flow back to canal or river as return flow. The return flow may also result from excessive or surplus irrigation water, field slope, ridge breaches and hydraulic structures leakage, and underground water.

As showed in Fig.1, when rain falls (R) on the soil surface, some of it infiltrates into the soil (P), some stagnates on the surface (D), while some flows over the surface as runoff (D1, D2). When the rainfall stops, some of the water stagnating on the surface evaporates to the atmosphere (ET_{crop}), while the rest slowly infiltrates into the soil. From all the water that infiltrates into the soil, some percolates below the root zone, while the rest remains stored in the root zone. When paddy field water keeps in balance, the sum of rainfall (R), surface inflow (D1) and lateral leakage inflow (P_{h1}) will equal to the sum of surface outflow (D2), lateral leakage outflow (P_{h2}), evapotranspriation (ET_{crop}), and vertical leakage flow (P_v).

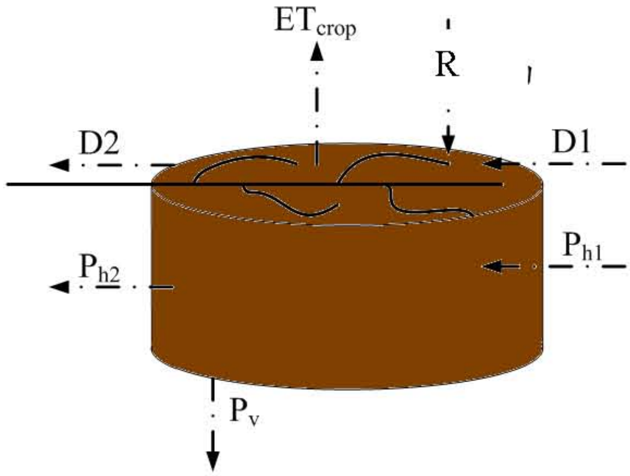


Fig.1. The hydrologic components for crop land

Kan (1969, 1998) indicated that the vertical leakage flow (P_v) is much less than the lateral leakage outflow (P_{h2}) in large area fields. The outflow may complete recycle as return flow under a suitable geology condition. Japanese research even suggested that the proportion of vertical and lateral leakage flow is 3:7. But the ratio had a wide variation range, which is depended on the influence of land, soil, geology, and hardpan.

2.2 Literature Review

The issue study of return flow started in 1960s. Based on the Water Balance theory, the methods could be separate into field investigation, Tank Model, and numerical model.

Oad et.,al. (1997a, 1997b) used Lysimeter to measure the return flow of Colorado Springs city. The result showed that 37% of total water amount were return flow, which was higher than the estimated 15% of with Cottonwood curve method. It was helpful for local agriculture to apply sufficient water rights. Chen (1999) and Liu (2001) observed the variation of field return flow in cultivation period and established the estimation curve of return flow which tested and verified with experiments. The proportion of return flow would increase with irrigation water. Chien (2003) used both field and sand box experiments to discuss the infiltration and to establish the irrigation water balance system optimization model in Taoyuan area. The result showed that the whole study area can save irrigation water up to about 21% with return flow.

Zulu (1995) used water balance and Tank model to simulate the paddy field daily return flow. There were about 14.5% of irrigation water which can be reused in Kaliyada, Japan during year 1991 to 1993. Liu (1998) separated the Ja-nan irrigation area into three irrigation systems: upstream, midstream and downstream. Each irrigation area could be seen as a tank to estimate the return flow. The estimation showed that the total volume of return flow was 2.54×10^9 in Janan irrigation area during the first-season period. The 70 to 80 percent of return flow belonged to depth leakage.

Lin (1999) used both experiment data and MODFLOW 3D underground flow model to investigate the effect of return flow with different factors in Yunlin area. The result showed that the average volume of return flow was about 24% of the sum of rainfall and irrigation water during year 1988 to 1997.

3. RETURN FLOW SYSTEM MODEL

3.1 Study Area Description

The study area is Yunlin area, which is located in meddle of Taiwan. The total irrigation area is 64,807 ha.. The main industry in Yunlin County is agriculture. The main agricultural products are rice, sugar can, earthnut, garlic, and fruits. The Jhuoshuei River, Cingshuei River and Beigang River are main irrigation rivers. The year average rainfall is between 1,000 to 1,500 mm in this area, but the rain spell appears during May to September.

Because of the water supply was very unstable, the Yunlin irrigation association developed return flow volume and pumped groundwater from deep or shallow wells to help irrigation. Insufficient water resources could not fully irrigate due to river property limit. Therefore, most fields in irrigation area still maintain the operation of rotation system.

After the establishment of offshore industry park, tech-industry parks and the No. 6 Naphtha Cracker Complex of Formosa Petrochemical Corp. set up in Mailiao in recent decade, the material change of industry structure not only helped economical income and employment opportunities but also increased the water demand sharply.

3.2 System Model

According to the water equilibration principle of the hydrologic cycle which calculates water output subtracted from water input, which is equivalent to the changing volume of water storage. The mechanisms of the paddy field water equilibration is analyzed in this study, such as rainfall, evapotranspiration, irrigation routing water, etc.. The return flow formula for water equilibration for a specified period is shown below:

$$RF = D + P_h = I/(1+S_2) + ER - ET_{crop} - P_v \tag{1}$$

Where, the RF is return flow (mm/day), D is field outflow (mm/day), P_v is vertical leakage (mm/day), P_h is lateral leakage (mm/day), I is irrigation inflow (mm/day), ET_{crop} is evapotranspiration (mm/day), ER is effective rainfall (mm/day), and S2 is the ratio of water conveyance loss (%).

3.3 Estimation of Evapotranspiration

The crop water requirement can be decided by direct measurement or through indirect calculation. Although direct measurement can obtain an actual water requirement, it costs more money and labor due to morphological constraints. Instead, the indirect calculation is usually used by researches. The calculation equation is expressed as below:

$$ET_{crop} = K_c * ET_0 \tag{2}$$

Where ET_{crop} is the crop water requirement, K_c is the dimensionless crop coefficient which varies with season and wind speed, approximately 0.95~1.35 for paddy rice. The ET_0 refers to the reference evapotranspiration of standard crop canopy, which is often estimated of using the Penmen-Monteith method (Monteith, 1994; Kan et al., 1996). According to the growing seasons of all crops (paddy rice) (Masakazu, 1999; Chang et al., 2001), one can determine the total crop water requirement for any period.

3.4 Estimation of Water Conveyance Loss

Water conveyance loss means the water loss during the transportation process. Water conveyance loss (S2) used in this study was identified by FAO. The calculation equation is showed as below:

$$S_2 = \frac{Q_{in} - Q_{out}}{Q_{out}} \quad (3)$$

$$Q_{in} = (1 + S_2) \times Q_{out} = K \times Q_{out}, \quad K=1+S_2 \quad (4)$$

Where Q_{in} is irrigation inflow, Q_{out} is irrigation out flow, and K is loss factor. According to the investigation, the estimation of water conveyance loss in Yunlin area was about 38%. The loss of canal, branch, sub-branch, and medium to small ditches were 10%, 8%, 7% and 20%, respectively (Table 1). The data of Yunlin irrigation association annual irrigation schedule showed that the loss of main canal is in between 29.5% to 61.5%. The reason of huge gap was that some old canals were without repair.

Table 1. The percentage of water conveyance loss of irrigation canal in Yunlin area

Data source	**Coarse grains irrigation handbook**			**The investigation report of the reasonable irrigation water volume and resource in association**				
ratio / association	Above sub-branch level	ditch	ditch (association)	canal	branch	sub-branch	medium to small ditch	system
Yunlin	14%	15%	20.6%	10%	8%	7%	20%	38%

4. RESULT AND DISCUSSION

The measure station must conform to the conditions or standards of water quality, volume, transportation, water right, and location. Based on researchers and data from Water Resources Planning Instituted Water Resources Agency MOEA and Yunlin irrigation association, this study appraised the stations to measure agricultural return flows. Therefore, two stations, (1) Downstream of XinHuei Creek- air support dam in Mailiao (A) and (2) Midstream of XinHuei Creek- Nanzi work station (B), were chosen as water taking sites in the study (Fig.2).

Fig. 2. The location of Xinhuei Creek in Yunlin County

According to the suggestion of the research in Water Resources Agency in year 2006, the study checked water quality and analysis at those two stations for one year. In this study, not only sampled both upper and lower stations but also analyzed eleven water properties. They were water temperature, pH, water depth, water velocity, turbidity, suspended solid, dissolve oxygen, COD, ammonia nitrogen, nitrite nitrogen, phosphorous etc. Each sampling dates were 2007/8/28, 2007/11/1-2 and 2008/3/5-6. The results showed in Table 2 and Table 3. Although the water flow was huge at downstream (point A) and middle at midstream (point B); in average, the water quality at midstream (point B) was better than at downstream (point A).

Table 2. Sampling analysis result at downstream of XinHuei Creek (point A)

location item	96/08/28		96/11/01		97/03/05	
	upper	down	upper	down	upper	down
temperature (°C)	30.4	30.2	24.4	24.5	20.8	20.5
pH	6.8	6.6	7.0	7.1	7.1	7.2
depth (m)	-	0.11	-	0.14	-	0.07
velocity (m/s)	-	1.22	-	1.24	-	0.73
volume (m^3/s)	-	6.05	-	7.55	-	2.32
turbidity (NTU)	18	30	29	63	23	10
SS (mg/L)	51.4	37.2	58.8	85.0	30.6	14.8
DO (mg/L)	3.76	3.58	6.24	6.21	6.36	6.25
COD (mg/L)	38.8	32.0	33.6	14.1	15.4	16
NH3-N (mg/L)	2.65	16.0	0.30	0.70	3.3	5.7
nitrite nitrogen (mg/L)	0.34	1.96	0.30	0.44	0.20	0.17
phosphorous (mg/L)	0.29	0.30	1.07	0.62	0.62	0.65

Table 3. Sampling analysis result at midstream of XinHuei Creek (point B)

location item	96/08/28		96/11/01		96/11/02		97/03/05		97/03/06	
	upper	down	Upper	down	upper	down	upper	down	upper	down
temperature (°C)	29.6	29.2	24.4	24.1	22.3	22.4	21.5	21.4	18.5	18.6
pH	6.7	6.6	7.4	7.5	6.5	6.4	7.2	7.2	7.2	7.21
depth (m)	0.63	1.67	1.15	1.88	1.1	1.88	0.53	1.14	0.47	0.82
velocity (m/s)	0.89	0.18	1.28	0.44	1.28	0.42	0.42	0.13	0.16	0.07
volume (m^3/s)	2.92	2.93	8.3	8.35	7.92	8.03	1.24	1.23	0.43	0.43
turbidity (NTU)	38	60	100	100	500	400	24	49	19	19
SS (mg/L)	67.2	45.7	142	122	712	490	30.6	120	40.0	46.2
DO (mg/L)	4.51	3.29	7.06	7.12	7.15	7.18	7.24	7.21	7.64	7.34
COD (mg/L)	34.0	28.8	7.76	12.8	16.1	27.8	14.8	17.1	20.8	16.1
NH3-N (mg/L)	1.55	19.9	2.70	0.40	0.60	0.40	5.1	3.5	11.6	5.2
nitrite nitrogen (mg/L)	1.59	1.64	0.13	0.15	0.10	0.10	0.18	0.16	0.26	0.32
phosphorous (mg/L)	0.26	0.36	0.24	0.19	0.36	0.35	1.00	0.60	1.47	1.37

According to the result of "The research of retrieving useable agricultural return flows", "Revalue and recycling assessment of agricultural irrigation in Yu-Lin irrigation association" and some researches about agricultural irrigation flow, the formula of agricultural return flow derived from paddy field water balance. Using that formula to count agricultural return flow in Yunlin area during year 1995 to 2004, it showed that the potential agricultural return flow was plenty from June to October, and appeared shortage from November to May.

To estimate the minimum potential agricultural return flow under the condition of steady water sources, it showed that potential agricultural return flow has a huge difference between low water and full water. It explained that developing agricultural return flow was changeable in Yunlin area. Supplying water steadily is important for all industries and it is also necessary for improving productivity and competence. Collection of agricultural return flow should be built up while it is considered as the water source of industries. Surplus water can compensate the lack of irrigation flow by managing or attemper in Yunlin area during fallow period is suggested here.

Fig.3 showed the distribution of average potential agriculture return flow in year 2004-2007 in Yunlin area. Under the condition that water conveyance loss was 38%, estimating return water was 1.61 m^3/day by average available return flow in Yunlin. Estimating return water raised to 1.79 m^3/day under the condition that water conveyance losses reduced to 30%. It showed that improving water conveyance loss could make stationary of return flow better. Cost-benefit relation should be considered in this case.

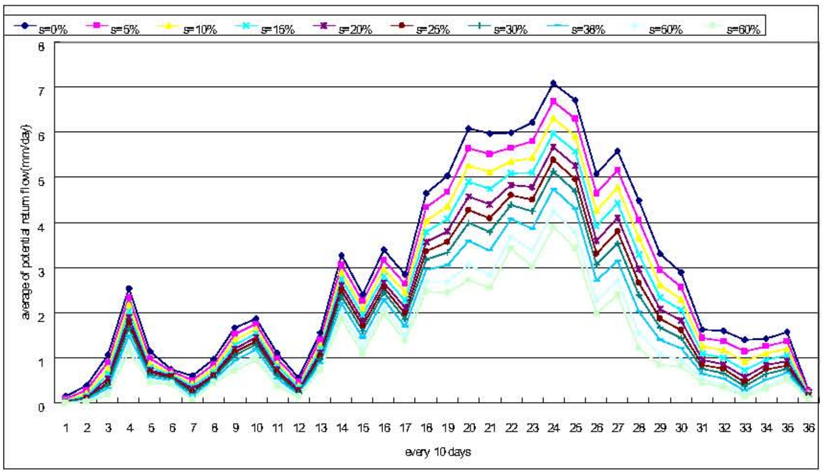
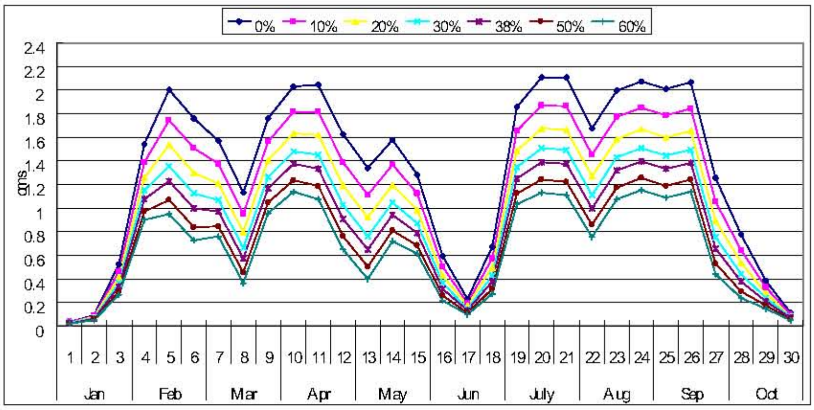


Fig. 3. The distribution of average potential agriculture return flow in year 2004-2007 in Yunlin area

By estimating return flow in XinLuchangke canal and XinHuei Creek branch canal separately, the study analyzed Xinhuei Creek agricultural return flow. According to irrigation area, agricultural return water estimated during year 2004 to 2007. Those four years could be distinguished into three parts which were plenty water year, ordinary average year, and low water year by total rain fall. Year 2004 was the low water year, year 2005 was the plenty water year, and year 2006 and 2007 were ordinary average years.

In XinHuei Creek irrigation area, full water period was during May to October, and low water period was during November to April. One thing that should be considered, XinHuei Creek branch canal area irrigated that return water were in full water period. Under the condition that water conveyance loss was 38%, average return water was 0.83 CMS (72 thousands cubic meter) during full water period, and return water was 0.84 CMS (72 thousands cubic meter) during low water period in XinLuchangke canal in 2004. Average return water was 0.91 CMS (79 thousands cubic meter) during full water period, and return water was 0.95 CMS (82 thousands cubic meter) during low water period in XinLuchangke canal in 2005. Average return water was 0.92 CMS (80 thousands cubic meter) during full water period, and return water was 0.84 CMS (74 thousands cubic meter) during low water period in XinLuchangke canal in 2006. Average return water was 0.90 CMS (76 thousands cubic meter) during full water period, and return water was 0.83 CMS (72 thousands cubic meter) during low water period in XinLuchangke canal in 2007.



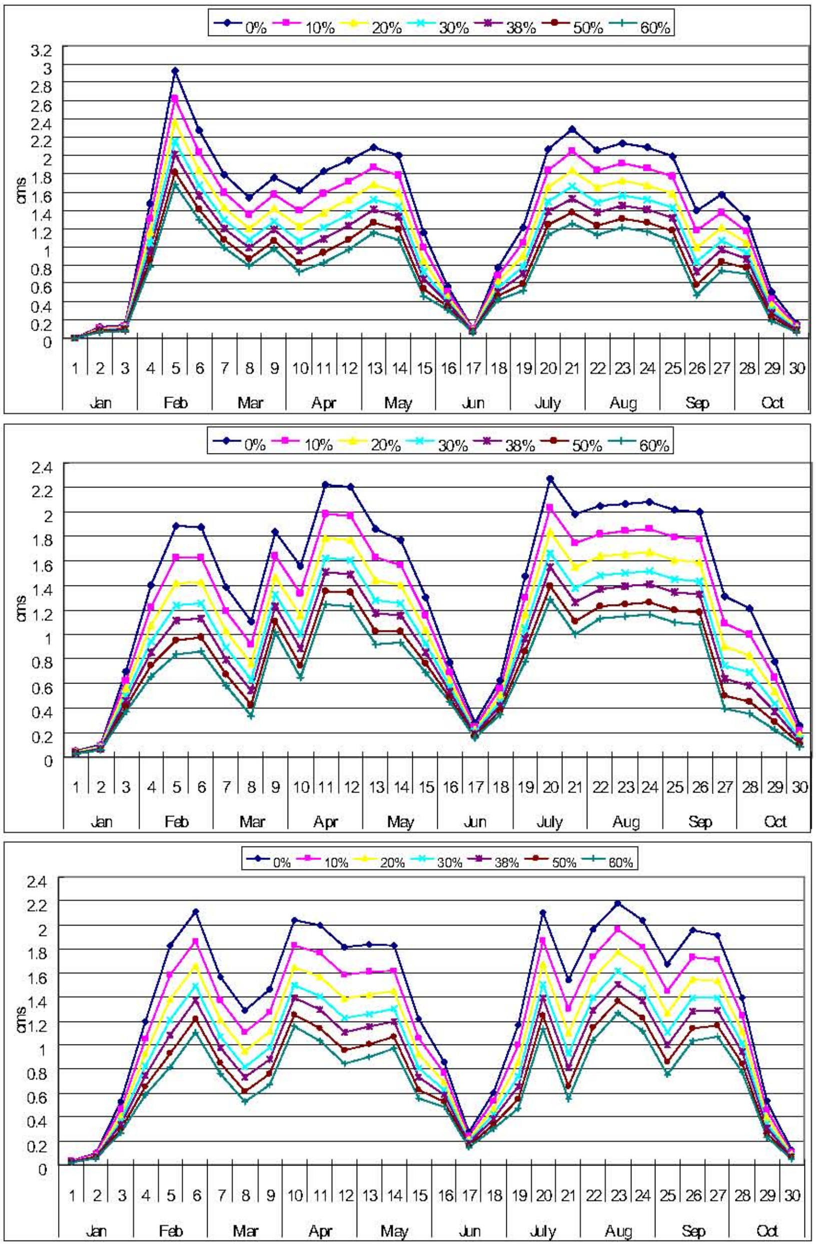


Fig. 4. The return flow of different water conveyance loss in 2004-2007 in XinLuchangke canal

Average return water was 1.54 CMS (133 thousands cubic meter) during full water period in XinHuei Creek branch canal in 2004. Average return water was 1.60 CMS (138 thousands cubic meter) during full water period in XinHuei Creek branch canal in 2005. Average return water was 1.41 CMS (122 thousands cubic meter) during full water period in XinHuei Creek branch canal in 2006. Average return water was 1.56 CMS (135 thousands cubic meter) during full water period in XinHuei Creek branch canal in 2007.

This study estimated that conveying return water in different capacity of conveyance canal and efficient rate (efficient rate = conveying water / canal capacity) each ten days. In XinLuchangke canal, the result showed that efficient rate is 73.7% while canal capacity is 1.0 CMS. Efficient rate is 58.4% while canal capacity was 1.5 CMS. Efficient rate was 44.1% while canal capacity was 2.0 CMS. In XinHuei Creek branch canal the result showed that efficient rate was 78.2% while canal capacity was 1.0 CMS. Efficient rate was 72.9% while canal capacity was 1.5 CMS. Efficient rate was 67.4% while canal capacity was 2.0 CMS.

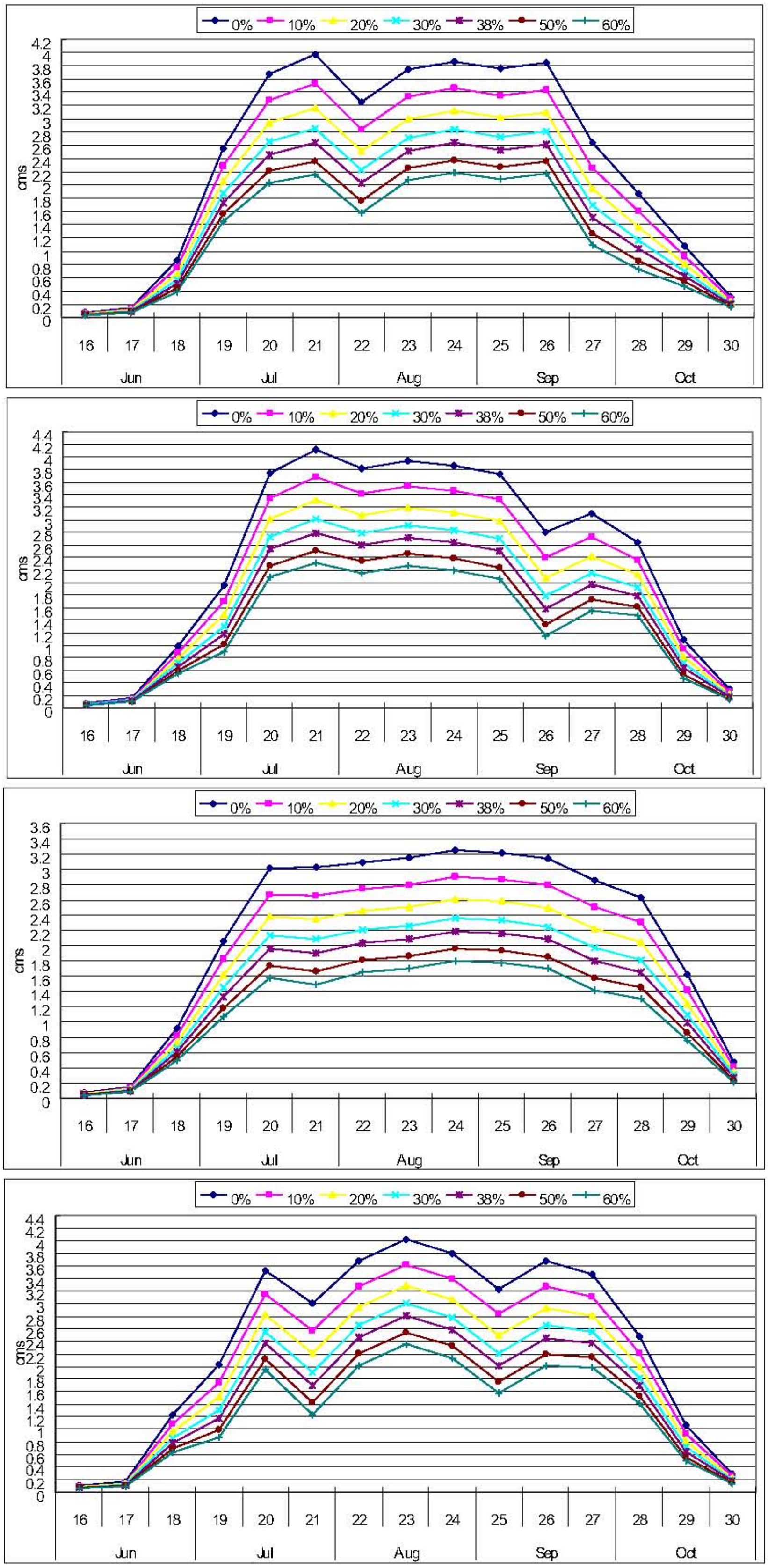


Fig. 5. The second-season period return flow of different water conveyance loss in 2004-2007 in XinHuei Creek branch canal

Table 4. The return water volume of XinLuchangke canal and XinHuei Creek branch canal

Canal	Year	Full water period m^3/s ($10^4 m^3$)		Low water period m^3/s ($10^4 m^3$)	
		Average	**Standard deviation**	**Average**	**Standard deviation**
XinLuchangke canal	2004	0.83(7.2)	0.49(4.3)	0.84(7.2)	0.48(4.1)
	2005	0.91(7.9)	0.50(4.3)	0.95(8.2)	0.61(5.3)
	2006	0.92(8.0)	0.47(4.0)	0.84(7.4)	0.49(4.3)
	2007	0.90(7.6)	0.45(3.9)	0.83(7.2)	0.47(4.1)
XinHuei Creek branch canal	2004	1.54(13.3)	1.03(8.9)	-	-
	2005	1.60(13.8)	1.04(9.0)	-	-
	2006	1.41(12.2)	0.80(6.9)	-	-
	2007	1.56(13.5)	0.98(8.5)	-	-

5. CONCLUSION

The purpose of this study is trying to analyze the volume of agricultural return flows which choose XinHuei Creek branch canal and XinLuchangke canal sites as demonstration areas in Yunlin. Under the condition that water conveyance loss in Yunlin is 38%, estimating return water was 1.61 m^3/day by average available return flow. Estimating return water cloud raise to 1.79 m^3/day under the condition that water conveyance loss reduces to 30%. It showed that improving water conveyance loss can make stationary of return flow better. However, cost-benefit relation should be considered in those cases.

The potential agricultural return flow in Yunlin was plenty from June to October, and appeared shortage from November to May. It also has a huge difference between low water and full water. In low water year (2004), average return water was 0.83 CMS (72 thousands cubic meter) in XinLuchangke canal and 1.54 CMS (133 thousands cubic meter) in XinHuei Creek branch canal. In XinLuchangke canal, when canal capacity was 1.0 CMS, the result showed the best efficient rate of 73.7%. In XinHuei Creek branch canal indicated the best efficient rate of 78.2% at the same canal capacity. On the list of main industry water demand users, under the situation of water insufficient, offshore industry park has high desire and possibility of using agricultural return flow.

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