STRATEGIES FOR IMPROVING THE WATER SUPPLY SYSTEM IN HCID, UPPER REACHES OF THE YELLOW RIVER BASIN, CHINA

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ABSTRACT

This paper analyzes the irrigation water supply system in Huinong Canal Irrigation District (HCID), Yellow River basin, China, evaluates the conveyance efficiency (seepage loss) in the main canal, investigates a method for seepage calculation, and develops a water supply framework and a conveyance—allocation simulation model. Based on the investigations and modeling results, strategies for improving the water supply system are suggested.

Keywords: Water supply, Efficiency, Irrigation, Canal, Yellow River

1 INTRODUCTION

In this paper, the water supply system is studied starting from the main canal system. The design, construction and operation conditions will have important impacts on reliability and rationality of irrigation water allocation and irrigation water use efficiency. In the Qingtongxia irrigation system, upper reach of the Yellow River basin, Ningxia Autonomous Region, China, there is a large water supply potential from the Yellow River. With the current water system conditions and the existing water management practices, this region's water intake from the Yellow River is more than double of the theoretical irrigation water requirement for the 417,000 *ha* irrigated area, from which nearly 34% is drained back to the Yellow River by surface and sub-surface drainage. This situation has resulted in problems of waterlogging and large-scale salinity as well as huge water resources waste.

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The present study was carried out within the framework of the European Union funded project YELLOWATSAVE (policies for water saving in the Yellow River basin: a Decision Support System - DSS applied to Ningxia and Shandong) (Pereira *et al*., 2000). Main objectives of this project include the identification of possible water saving irrigation methods and the definition of improved water management strategies. The study focused on two irrigated areas, Huinong Canal Irrigation District (HCID, part of Qingtongxia irrigation system) in the upper reach and Bojili Irrigation District (BID) in the downstream reach. Within this project a water supply framework and simulation model was developed. The present paper analyzes the water supply system in HCID, evaluates the conveyance efficiency (seepage loss) in the main canal and investigates the method for seepage calculation. Then a conveyance—allocation model was developed. Based on the investigations and modeling results, strategies for improving the water supply system were suggested.

2 GENERAL INTRODUCTION OF WATER SUPPLY SYSTEM IN HCID

2.1 Description of the study area

In Ningxia, there are two main irrigation districts that divert water from the Yellow River: Weining Irrigation District and Qingtongxia Irrigation District. The Qingtongxia Irrigation District (about 330,000 *ha*) is supplied water from the Qingtongxia dam through 10 main canals. Each of these 10 canals has a head gate, which are managed by the Head Gate Department (HGD) while each specific canal departments manage the canals.

The Huinong canal is the second big canal in terms of capacity in the Qingtongxia Irrigation District. Huinong Canal Irrigation District (HCID) begins just after the Huinong canal head gate located 30 *km* downstream from the Qingtongxia dam and on the western bank of Yellow River. The HCID is about 140 *km* long in the direction of south to north and 10 *km* wide on the average in the direction of east to west. The canal command area is 150,000 *ha* but the actual irrigation area is 75,000 *ha*. The HCID is in the alluvial plain of the Yellow River with major soil types of silty clays to silty sands, originated from fluvial deposits of sediments from the Loess Plateau. The elevation ranges from 1100 to 1150 m with a slope about 1/6000-1/8000 from southwest to northeast generally. The total length of Huinong main canal is 171 *km* with designed intake discharge of 110 m^3/s. There are three sub-main canals with a total length of 90 *km*: Changrun canal; Pang canal and Guansi canal. The schematic diagram of main and sub-main canals in HCID is illustrated in Figure 1. These canals pass through Qingtongxia city, Yongning county, Yinchuan city, Helan county, Pingluo county and Shizuishan city. Although the irrigation canal system is adequate, the surface and subsurface drainage system is imperfect which results in high groundwater table and secondary salinization. Most of the drainage flows through the Fifth Main Drain and comes back to the Yellow River.

The main Huinong canal can be traced back to 1729 although most of the irrigation canal system was built in 1963. There are few improvements since that time. The canal shape is trapezoidal without lining and the shape of canal cross section has changed with time due to sediment filling and cleaning, erosion and collapsing of side slopes. In some place the canal bed is more than two times wider than its design width, which makes it looks like a river instead of canal.

The weather is typical continental climate. It is arid and windy with big temperature differences and strong evaporation rates. The annual rainfall is 190 *mm* with an uneven distribution in a year as shown in Table 1. It shows 76% of annual rainfall occurs during June to September, which is the rice irrigation season. Also there is uneven rainfall distribution between different years with a minimum of 78 *mm* and a maximum of 420 *mm* during 1988 to 1997. The annual evaporation from free water surface is around 1817 *mm* with a monthly distribution as shown in Table 1.

Table 1 - Annual rainfall, evaporation and their distribution in a year in HCID

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall(mm)	0.8	2.4	3.9	5.7	11.4	14.4	40.8	60.0	29.0	14.3	6.3	1.2	190
Percentage(%)	0.4	1.3	2.0	3.0	6.0	7.6	21.5	31.6	15.3	7.5	3.3	0.6	100
Evaporation(mm)	43.0	61.0	133.2	238.4	280.6	256.2	243.6	200.2	146.4	117.4	55.4	41.3	1817
Percentage(%)	2.4	3.4	7.3	13.1	15.4	14.1	13.4	11.0	8.1	6.5	3.0	2.3	100

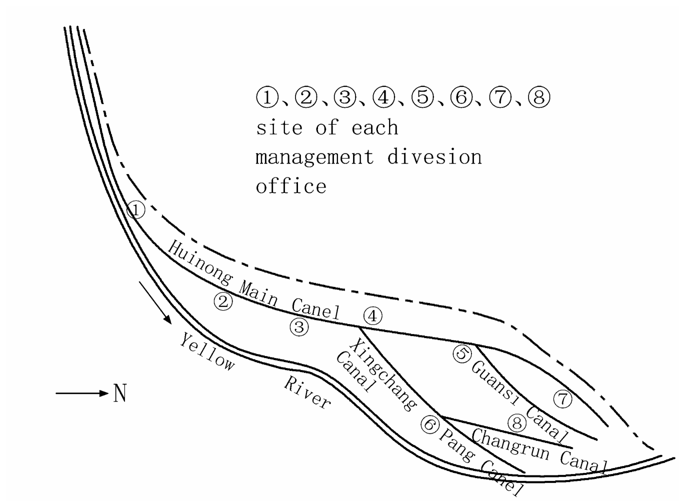

Figure 1 - Schematic diagram of main and sub-main canals in HCID

The major subsistence crops are spring wheat, paddy rice, maize and Chinese sorghum. The cash crops include jute, sugar beets, vegetables and fruits. The crop intensity is around 1.4. The planting area of spring wheat and rice makes up about 90% of the farmlands, where rice accounts for 15%. At present, spring wheat and rice are rotated yearly in the upper reaches from division 1 to division 4. Rice cannot be grown in the lower reaches from division 5 to division 8 because of water shortage imposed by the limited canal capacity.

The HCID is managed by Huinong Canal Irrigation Management Bureau through its 8 divisions. Each division is responsible for about 20 to 30 *km* of main canal. The 8 divisions are interconnected as shown in Figure 2.

The Huinong canal management bureau allocates water in the 8 divisions according to the planned demands. Then, the divisions are responsible for sharing the allocated discharge between the different branch canals according to a planned demand defined the year before. The divisions must respect the discharge out of their district. Therefore, each boundary between two divisions has a measurement station.

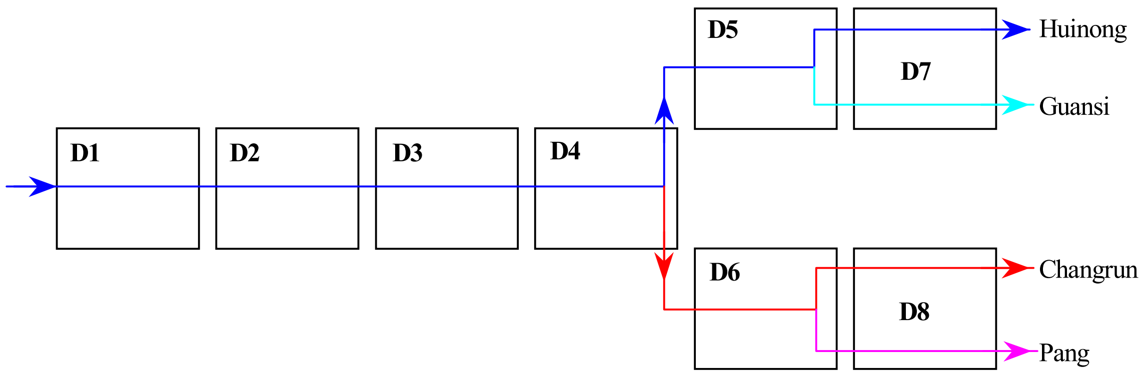

Figure 2 - Links between the different divisions and canals (Where D1 ..D8 are Division 1 .. Division 8)

The Huinong canal management bureau made irrigation demand each year before irrigation season. At present, planned demand is estimated for the next year based on the mean value of the actual allocation for the recent 3 years. These demands are calculated without taking into account the potential rainfall, which is considered too small to be included in the calculation. This indicates planned demand does not consider the weather conditions and was very rough. These demands are sent to the Ningxia water resources bureau, which makes some adjustments and approves it according to the Yellow River Conservancy Commission (YRCC, which takes charge of water resources management in the Yellow River) recommendations or requirements as well as considering balance among different irrigation districts. Once this is done, any change of water allocation because of unforecasted heavy rainfall or other reasons must be reported to the provincial bureau. Generally, the demands are accepted without any modifications because there is abundant water from the Yellow River in Ningxia. Therefore, allocations are known one year in advance and followed day by day without any modifications if the resource is enough. In fact, the planned demands become planned allocations.

In a similar way, the water allocation follows the planned demands even if it rains. It is only after several days of heavy rain and an expressed demand from the townships to the Province, via the management bureau, that the planned allocation can be changed. If such requests are accepted, orders are given to the HGD to reduce the discharges. Otherwise, the management bureau has to follow the planned allocation. Sometimes, when the intake reduction has been refused by the HGD or it arrives too late, farmers tend to close some branch canals gates and therefore endanger the canal security (possible overflow downstream). In such a situation, the management bureau has no other choices than to manage security by using the escape gates, returning the excess water to the Yellow River.

2.2 Comparison between diverted and consumed Yellow River water in Ningxia Autonomous Region

Table 2 gives the comparison between diverted and consumed Yellow River water in Ningxia from 1988 to 1997 (Zhao 1999), where consumed water is equal to the difference of inflow between XiaheYan and ShizhuiSan measurement station. In these ten years, only about 28.6% of the water diverted was actually consumed by crops, and 71.4% was returned to the Yellow River or lost in other ways such as non-productive evaporation and recharge to deep aquifer. In 1992 only 19% was consumed, but in 1997, about 40% was consumed when the policy came from the Central Government of using Yellow River water more fairly among all provinces located along the Yellow River. All the time, the maximum consumed water volume never exceeds 4,000 $M.m^3$, which is the allotting quota (maximum consumed value) for Ningxia decided by the Central Government in 1998. It can be noted that about 75 to 80% of all the water diverted is used in Qingtongxia irrigation district and comes from the Qingtongxia dam.

Table 2 - Comparison between diverted and consumed Yellow River water in Ningxia region ($M.m^3$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	mean
Water in and out Ningxia in Yellow River											
XiaheYan	23000	39100	30300	24200	22700	28900	27800	25300	21200	19500	26200
ShizhuiSan	20800	35700	27800	22100	21200	25700	26100	23700	19600	16300	23900
Consu. water	2200	3400	2500	2100	1500	3200	1700	1600	1600	3200	2300
Diverted water from Yellow River in Ningxia											
Weining	1780	1730	1830	1850	1850	1870	1860	1760	1840	1860	1823
Qingtongxia	5720	6200	6030	6030	6160	6560	6250	6225	6300	6590	6206.5
Diverted water	7500	7930	7860	7880	8010	8430	8110	7985	8140	8450	8029.5
Ratio of consu. water to diverted water (%)	29.3	42.9	31.8	26.6	18.7	40.0	21.0	20.0	19.7	37.9	28.6
Ratio of diverted water to inflow (%)	32.6	20.3	25.9	32.6	35.3	29.2	29.2	31.6	38.4	43.3	30.6

It can be observed that the total annual volume diverted in the Ningxia irrigation district represents about 30.6% of the total annual volume flowing in the Yellow River. As only 28.6% of the diverted water is actually used, the consumed water in this district represents about 8.7%

of the total annual volume flowing in the Yellow River. The average annual depth of applied water over the irrigation area is 1881 *mm*.

All this data shows that in Ningxia too much water was diverted compared with its actual demand for irrigation, thus resulting in huge water losses. The reasons for system water losses include:

- too much irrigation by faulty irrigation methods and technique e.g. the average rice field irrigation depth was around 1405 *mm* with the continuous deep flood irrigation method, which leads to huge deep percolation and tail run off in paddy fields (Dong *et al*. 2000);
- the planned demand and the operation of canal system not based on the actual crop water requirements, climate, soil moisture and hydraulic structure's conditions;
- losses in the water supply system such as main canal seepage, operational and management losses;
- water lost due to uncompleted irrigation distribution system and faulty irrigation scheduling which leads to canal seepage, canal escape and high field runoff.

2.3 Causes of escape water in water supply system

In order to prevent some overflows, the divisions must sometimes open escape gates. Note that the four end gates also work as escape gates. The excess water flows into the Yellow River through these gates results in a lot of water loss as described below:

a) Problem of critical branches (especially during rice irrigation)

The canal bed is much lower than the irrigated field from division 1 to division 4. To optimize the distribution efficiency, each division has to manage both a minimum water level in order to reduce losses and secure the canals, and a maximum water level in order to allocate all the branches without any restriction, especially concerning allocation duration. The difference between these two water levels is in general not more than 0.5 to 0.7 *m*. For most of the time, water levels are maintained by using the check gates. However, their influence is not more than 3 to 5 *km* upstream, which represent about 50% of the distance between two check gates (about 1 check gate every 7 *km*).

Escape gates are used because of the critical branches (branch with a high intake gate soleplate, which can not intake water when water level in the main canal is low). A high discharge is needed in order to have a high water level and push the water in all branch canals at the same time. As no water is needed in downstream of the gate, the excess water returns to the Yellow River through the escape gates.

In HCID, rice is planted only in division 1 to division 4. During the rice irrigation season (from end of May to end of October), the demand is very high in division 1 to 4 and it is difficult to push the demanded water in the branch canals due to the height of the branch gates (critical branches). Therefore, to be able to supply water to these branches, Huinong canal management bureau intakes a very high discharge, and then uses the escape gates to release the excess water into the Yellow River in order to secure the downstream reaches.

b) During rainy periods

As mentioned before, at present, planned demand is estimated without taking into account the potential rainfall, which has been considered too small to be included in the calculation. In the same way, the allocation must follow the planned demands even if it rains. It is only after several days of heavy rainfall that the planned allocation can be changed. But this request should be accepted by the HGD via the provincial bureau before decreasing intake discharge. When the intake reduction is refused or the information arrives too late, farmers do not need water, they tend to close the branch gates and endanger the canal security. In such situation, the management bureau has to use the escape gates and release the excess water to the Yellow River.

c) At the beginning of the first irrigation season

The entire irrigation system should be checked in the first week of irrigation season without allocating any water. Therefore, all water flowing in the canal during this time returns to the Yellow River through the escape gates. Adding to this, it also seems that at the beginning of an irrigation season all the farmers are not ready to irrigate at the same time (they are late in land preparation) when HCID begins to deliver all the planned demands, so farmers close the gates themselves and endanger the canal security.

3 CONVEYANCE EFFICIENCY (SEEPAGE LOSS) OF MAIN CANAL

3.1 Efficiency evaluation

It is assumed that if a 10-day time computation step is used, time lag between inflow and outflow in a canal reach can be ignored and seepage can be calculated with Eq. 1.

$$S = Q_{in} - Q_{out} - Q_a - Q_r \tag{1}$$

where S is canal seepage (only include losses from the canal bed and bank); Q_{in} is inflow; Q_{out} is outflow; Q_a is allocation; Q_r is return flow to the Yellow River. All units are m^3/s.

According to this balance, three indices of efficiency can be defined:

a) Effective conveyance ratio EF_c

$$EF_c = \frac{Q_{net}}{Q_{gross}} = \frac{Q_{out} + Q_a + Q_r}{Q_{in}} \tag{2}$$

It represents the capability of a canal reach to carry water with seepage. As the seepage $S = (Q_{in} - Q_{net})$, the effective conveyance ratio can also be calculated on the basis of the formula:

$$EF_c = 1 - \frac{S}{Q_{in}} \qquad (3)$$

b) The return flow ratio EF_r

$$EF_r = \frac{Q_r}{Q_{in} - Q_{out}} \qquad (4)$$

It represents the management situation of canal system. A better management condition results in low Q_r and low EF_r. EF_r represents the ratio of diverted water through the escape gates, which returns to the Yellow River Q_r with the gross consumed in a division.

c) The effective allocation ratio EF_a

$$EF_a = \frac{Q_a}{Q_{in} - Q_{out}} \qquad (5)$$

It allows assessment of the relative importance of non-allocated water compared with allocated water. EF_a represents the ratio of actual allocation water Q_a with the gross consumed in a division. Because water charge was collected according to total allocation in each division, high EF_a indicates high water use efficiency from the point of view in the management agency.

According to daily measurement records from 1992 to 1998, the calculated three indices are given in Table 3 and Table 4. Table 3 shows that the actual allocation represents 81% of gross water consumed. In the losses of 18.9%, return flow through escape gates represents 3.4% of gross water consumed and canal seepage represents 15.5% of gross water consumed. As for the return flow, it represents 7% to 8% of gross water consumed in division 3 and 4, although in system average it is only 3.4%. The reason is that in these two divisions rice were planted in a large area (39.6% and 33.8%, respectively) and during rice irrigation season huge amounts of water were drained to the Yellow River through escape gates.

Table 3 - Three indices in different years

Indices	1992	1993	1994	1995	1996	1997	1998	Average
EF_c	0.83	0.84	0.84	0.82	0.86	0.83	0.89	0.844
EFr	0.02	0.02	0.05	0.04	0.03	0.03	0.03	0.033
EF_a	0.81	0.82	0.79	0.78	0.82	0.81	0.84	0.811

Table 4 - Three indices in different divisions

Indices	Div.1	Div.2	Div.3	Div.4	Div.5	Div.6	Div.7	Div.8	Average
EF_c	0.94	0.98	0.96	0.98	0.96	0.95	0.90	0.92	0.949
EFr	0.01	0.00	0.07	0.08	0.01	0.03	0.03	0.03	0.034
EF_a	0.52	0.86	0.73	0.84	0.92	0.86	0.88	0.88	0.811
Objective efficiency	0.55	0.84	0.84	0.84	0.86	0.87	0.9	0.9	

The average effective conveyance ratio EF_c in Table 3 is 0.84. According to Table 4, the average effective conveyance ratio is 0.95. This ratio is high because it only represents the effective conveyance in each division and not at the system level. Table 4 also shows that the effective allocation ratio EF_a is only 0.52 in division 1. It is much lower when compared with other divisions. This is because of the fact that in division 1 the effective irrigated area is only 1,500 *ha*, which is much lower than the average irrigated area of 10,000 *ha* for other divisions, which indicates canals passing through division 1 are mainly conveying water to downstream and the actual allocation is small. With the low allocation and a similar seepage loss rate, the allocation ratio was lower.

In calculating above parameters, Q_{out} at the system scale is considered to be zero. Escape water from the four end gates is also included in Q_r. So at the system scale, the total gross water consumed $Q_{in} - Q_{out}$ is equal to total intake Q_{in}, and the above efficiency ratios are based on the total system intake.

Every year, each division has an objective efficiency (similar to $EF_{a)}$, and it is called *objective efficiency* (also shown in Table 4 for year of 1998). This objective efficiency level is defined to push the divisions to manage the planned allocation with minimum seepage losses. Therefore, the divisions have to manage the check gates with due care to maintain minimum water levels (the seepage is mainly linked with the water levels) while supplying the demands. HCID bonuses or penalties are assessed for the divisions according to whether their actual EF_a is more or less than the *objective efficiency*.

As shown in Table 4, EF_a is almost equal to *objective efficiency* in most division except division 3. This difference is because of use of 7 years daily measurement data in calculated EF_a, but the *objective efficiency* is given every year by HCID according to the canal conditions and here only figure for 1998. So *objective efficiency* is decided by HCID according to the system conditions in each division and EF_a is dependent both on the system conditions and the management condition. That EF_a is bigger than the *objective efficiency*, which indicates better water management.

Based on the above analysis, the conveyance efficiency in the main canal in HCID is only 0.81 which is less than the average efficiency value in most irrigation district in China. The escape return loss (by uncompleted structures and poor management) represents 3.4% of total system intake and 20% of total losses, is more than double of the average value (1~1.5% of total intake) in most irrigation district in China. In 1998, the total system intake in HCID was 1.12 billion m^3, which indicates the total escape return loss was 0.04 billion m^3, it is a very huge loss. In Huinong canal, seepage loss represents 15.5% of total system intake; this is in line with the value for most irrigation districts in China.

3.2 Calibration of seepage calculation equation

Seepage is affected by main factors such as soil characteristics, hydraulic conditions, shape of canal cross sections, water level in canal, ground water table depth, sediment carried by water, velocity and priming time. The widely used empirical formula for seepage calculation in China is Kostiakov equation originated from Russia (Guo 1997)

$$S = r \bullet 0.01 \bullet A \bullet Q_n^{1-m} \tag{6}$$

where S is the seepage in per unit canal length (m^3/s/km); r is the coefficient for no free seepage, expresses the groundwater influence; A and m being given as soil coefficients; Q_n being the net discharge flowing in the canal reach and defined as the sum of the discharge out and the allocation of a division (m^3/s).

Originally this relationship was developed for canal design. This relationship does not include any hydraulic conditions in and around the canal and assumes that seepage mainly depends on the soil type and indirectly the design theory used. It is, therefore, only useable with the design discharge of a canal and, normally, cannot be used with other discharge rates. This type of equation does not allow establishing a complete relationship between seepage and discharge for a given reach. This relationship is mainly used in China to allow a simple computation of water demands (annual value) through a downstream-upstream procedure in order to obtain the total requirement at the head gate including seepage in the different divisions. In such a practice, the aggregated demands are in general very close to the design capacity of the different reaches and calculation is acceptable.

A new empirical formula similar to Eq. 6 for seepage calculation was suggested by the authors, that is

$$S = r \bullet B \bullet Q_{mean}^{L} \tag{7}$$

where B and L are parameters that need to be calibrated for each division (not decided only by soil type like in Eq. 6), these parameters will include the influence of soil characteristics, hydraulic conditions and shape of canal cross section; Q_{mean} being the mean discharge flowing the canal reach (m^3/s); S and r are same as Eq. 6.

Coefficient *r* expresses the groundwater table influence. It mainly depends on soil type and *seepage head*, the difference between water level and groundwater table. According to the previous study (Guo 1997), an empirical relation can be established as

$$r = \min[1; D \bullet gwd^{\alpha} \bullet Q_{mean}{}^{\beta}] \tag{8}$$

Where *gwd* being ground water depth (*m*), it is the distance from the canal bottom to ground water table; α, β, D being calibrated parameters.

The parameters in Eq. 7 and Eq. 8 were calibrated by using the measurement data from 1992 to 1998. The calibration results were given in Table 5. In the calibrating process, data series not influenced by groundwater (such as in the beginning of irrigation season in April or during winter irrigation in November, when the ground water depth was more than 1.5 metre) were first used to calibrate parameter *B* and *L* in Eq. 7. Then data series, influenced by ground water were used to calibrate parameter α, β, D in Eq. 8.

Table 5 - Calibration parameters for different divisions

Parameters	Div.1	Div.2	Div.3	Div.4	Div.5	Div.6	Div.7	Div.8
L	0.37	0.37	0.37	0.36	0.36	0.37	0.42	0.42
B	0.031	0.034	0.035	0.029	0.019	0.016	0.015	0.016
D	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
α	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
β	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18

4 PHYSICAL REPRESENTATION OF THE WATER CONVEYANCE AND ALLOCATION SYSTEM

Figure 3 shows the relationship between inflow (intake) discharge Q_{in} and allocation Q_a in division 4. This relationship illustrates the rule and constraints that each division allocates water among branches and sends water downstream according to its total intake. Figure 3 shows that as long as inflow is less than 20 m^3/s, no more water can be allocated in division 4 because water level in the main canal is too low. At this time division 4 only conveys water downstream. If the total downstream water demand is less than 20 m^3/s subtract seepage in division 4, there will be escape loss. Total inflow never exceeds 65 m^3/s, which is the capacity of the main canal in division 4. Total allocation never exceeds 18 m^3/s, which is the capacity of all branches canal.

To represent the physical capacity to convey water in the main canal and allocate it to branch canals, physical functioning domains were defined for the main canal reaches of each divisions. Each domain globally characterises the main canal reach of a division and the set of related secondary canals. Figure 4 illustrates a typical conveyance and allocation functioning domain, where the x-axis represents the inflow (m^3/s) to the division and the y-axis the total allocation (m^3/s) in the division. The dashed line in Figure 3 and Figure 4 represents a line that has an intersection of zero and a slope of one. The four linear physical constraints bounding this domain are defined below:

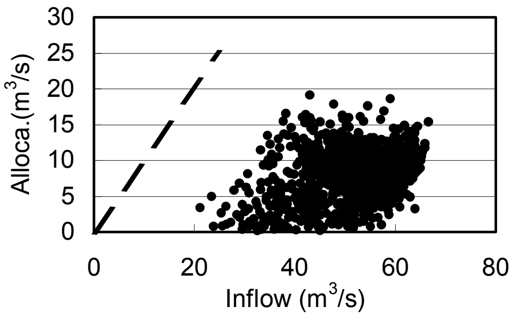

Figure 3 - Relation of intake and allocation

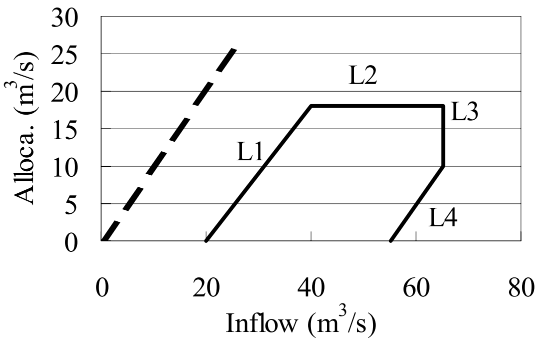

Figure 4 - Allocation domain

a) L1, the maximum possible allocation for a given value of inflow to the division. This constraint accounts for the fact that only some branch gates can be reached with a given inflow and the corresponding water level in the main canal. It can also incorporate the effect of pumping, if pumps are used to allocate water.

b) L2, the maximum possible allocation in the division that corresponds to the total design capacity of the branch canals.

c) L3, the maximum possible inflow to the division, corresponding to the design capacity of the main canal at the head end of the reach.

d) L4, the minimum allocation required above a certain value of inflow to ensure that the maximum conveyance capacity in the downstream division is not exceeded.

These constraints bound a single, global physical domain of water conveyance and allocation. With these four constraints (Figure 4), functions (model) were developed to simulate water conveyance and allocation at the main system level (Lance *et al*. 2000; Roost *et al*. 2000, 2001). This model has been primarily developed to perform water allocation from the main canal network, considering the division water demands, the physical characteristics of the main canal reaches, the water resource availability and the water allocation rules. Due to the selected 10-day time step, hydrodynamic behavior was not dealt with and emphasis was mainly on a water balance approach based on mean flow conditions in main canal reaches. This approach is not appropriate to support real-time operation but well suited to the purpose of strategic analysis at the system scale. In addition, it is flexible and only requires limited amount of information.

Three scenarios were used in the simulation:

- *S0*, current situation of supply system and demand;
- *S1*, improvement to the supply system, consists in building enough check gates to achieve an optimal control of the water level and thus solve the problem of 'critical branch gates'. From a modelling point of view, this means modifying the first conveyance and allocation constraint (L1) of each division by setting an intersect of zero and a slope of one (see Figure 4). This indicated allocation is possible as soon as there is water flowing in a division;
- *S2*, improvement to the distribution system and on farm irrigation practices thus decreased demand (Gonçalves *et al*. 2002).

These simulated results are given in Table 6. It can seen from the results of scenario *S0* that although only 88% of the overall demand could be satisfied, about 31% of the diverted water is returned to the Yellow River through escape gates. This situation is very illustrative of the conditions in HCID, where the resource is abundant but the physical characteristics of the system (primarily high branch gates) constrain allocation/use. In particular, high inflow rates are required to have a sufficient water level and thus be able to allocate some water in the upstream divisions. Then in the downstream, extensive escape gates are used for getting rid of the excess water flow.

Table 6 - Simulation comparison among three Scenarios ($M.\ m^3$)

Scenario	Demand	Inflow	Allocation	Seepage	Return flow
S0	836	1208	738	90	380
S1	836	805	738	67	0
S2	369	870	369	83	418

For scenario *S1*, there is no return flow to the Yellow River and the inflow is about one third less than those of scenario *S0*. Despite these improvements, the demand could not be better satisfied than those of *S0* (the volume allocated only represents 88% of the demand). This is a clear indication that the deficit occurs because of limiting main canal capacity in some reaches.

For scenario *S2*, although demand only represents 44% of the demand than that for scenarios *S0* and *S1*, the system inflow still represents 72% of the previously computed inflow. This is again a consequence of the 'critical branch gates' problem, which leads the system to be over-supplied for providing allocated water to the upstream divisions.

5 DISCUSSION AND CONCLUSIONS

According to analysis in previous section, strategies for improving the water supply system in HCID include:

a) Rebuilding and rehabilitation of canal system

As already mentioned, the Huinong canal was built in 1963 and received few improvements since that time. The shape of canal cross section has changed significantly. This influences the water flow and results in huge water loss at the beginning of the irrigation season. At the same time, wide canal bed also increases the seepage loss during the irrigation period. So strategies of rebuilding and rehabilitation of canal system should be adopted. These strategies may include: removal of the sediment, side slope defending, rehabilitation of canal system, and lining of the canal system.

b) Completion of hydraulic structure

With the problem of critical branches, in order to control water level, one of main strategies is to build enough check gates on the main canal and thus avoid escape loss and improve reliability for branches allocation. This point is very important to solve the water supply problem when the total intake is restricted by Central Government and the discharge is not enough in the main canal.

According to supply simulation, if there are enough check gates on the main canal, the total intake can be decreased by 30% with the same allocation.

c) Establishing a reasonable irrigation water demand plan and improving irrigation water management level

As mentioned above, in HCID the planned irrigation demand is based on a very rough methodology yet the planned demand allocations are followed very strictly during the irrigation season. This results in lot of escape loss as weather conditions change from time to time. Improved strategies are needed to establish reasonably long term and middle term irrigation water demand planning based on weather forecasting, crop irrigation scheduling, irrigation methods etc. This is also a need to establish an information monitoring system of weather conditions, soil moisture condition, crop growing condition which will help revise the planned demand during the irrigation season based on all of this short term information forecasting. Thus, the objective of reasonable water diversion, correct water allocation/delivery, and reduction in water losses could be achieved.

d) Increasing water use efficiency in distribution and on farm system

As shown in Table 3, more than 62% of total intake water was returned to Yellow River even in 1997. The total loss in supply system was 19% according to analysis in section 2.2, which indicates the total losses in distribution and on farm system are more than 43% of total intake. These include seepage in different level of canals, too much allocation in distribution by faulty planned demand, escape water in distribution system by uncompleted hydraulic structures and poor management, field deep seepage and tail water runoff losses due to very high irrigation duty, etc. Therefore, improvement strategies such as better irrigation methods (e.g. observation of shallow water depth for paddy rice), reducing the number of irrigation applications and adoption of new irrigation application calendars according to the depth of water table and the soil salinity conditions, rebuilding and rehabilitation of distribution system as well as better canal operation rules should be adopted in order to increase water use efficiency in the distribution system and at the farm level. At the same time, this will decrease the allocation of supply system and thus decrease the losses in supply system and increase the reliability of water supply.

According to observations during 1998 and 1999, Dong *et al*. (2000) reported the field irrigation depth for rice could decreased from 1405 *mm* to 820 *mm* with a water saving potential of 41.6%, when shallow water depth irrigation method was used instead of farmer's practice of continuous deep flood, the field application efficiency could be changed from 0.58 to 0.88, respectively. The efficiency in distribution system was around 0.57 to 0.60 with the poor canal operation rules with one-day interval between two irrigation events. Cheng et al. (1989) reported a distribution system efficiency of 0.71 to 0.80 in Hetao irrigation districts in Inner Mongolia, which has similar conditions with HCID. If distribution efficiency was increased from 0.60 to 0.71, the overall water saving potential was 440 mm according to Dong's calculation. So in the field and distribution system scale, the total water saving potential was 1025 mm and represents 54% of the average gross irrigation depth, which was a huge amount of water. For dry foot crops, 33% water saving potential at the field and distribution system levels was also reported by Gonçalves *et al*. (2001) and Pereira *et al*. (2000).

e) Changing crop patterns

Changing crop patterns especially the planted area and the distribution of paddy rice based on scientific analysis is good for increasing water productivity in HCID. For example, changing paddy rice to dry foot crops in the command area of critical branches, removing some paddy rice from upstream to downstream. This will solve the problem of escape losses during rice irrigation periods and will lower the ground water table and then solve the problem of salinization.

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