# Analysis of Channel Leakage Law in Piedmont Plain of Haihe River Basin

Jingsi Zhu[1], Zhe Wang[1], Tianyu Hou[2,*] and Yu Li[1]
[1]Hydrology Bureau of Haihe River Water Conservancy Commission, MWR, Tianjin 300170, China
[2]Tianjin Meteorological Bureau, TianJin 300000, China

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Abstract: The channel leakage loss of piedmont plain in north China directly affects the flood evolution law and ecological water diversion, especially in Haihe River Basin. The essay selected three typical river reaches of the basin to analyze the leakage loss of the historical flood processes using statistical method, studying the correlation between the leakage rate per unit river length and the upstream inflow, and the duration of flood under different water storage conditions. Meanwhile, the initial leakage loss rate of flood with different magnitude in each typical reach was estimated. The study results indicated: (1)The upstream inflow is negatively correlated with the leakage rate per unit river length; the leakage rate per unit river length tends to be stable when the upstream inflow increases to a certain value; (2)The duration of flood is negatively correlated with the leakage rate per unit river length when there is bottom water; (3)The degree of dryness in the early stage is one of the main factors affecting the seepage capacity; (4)The leakage rate per unit river length is generally logarithmic or exponential related to the upstream inflow; (5)In Haihe River Basin, the initial loss rate of medium and small water in typical reach is higher, more than 30%, and the initial loss rate of large water is lower than that of medium and small water.

## 1 FOREWORD

The mutual conversion of surface water and groundwater is a common natural phenomenon in nature. The interaction between surface water and groundwater has been regarded as one of the most important and frontier research topics by the major hydrology and water resources research institutions in the world. Channel leakage is an important aspect of surface water and groundwater exchange. The Haihe River Basin (in north China) is semi - humid semi - arid climate zone. There are many seasonal rivers in the basin. The rivers are often dry up in the discontinuous season. The basin has been in the background of less rain since the "1996.08" flood, and parts of the river have dried up for years. Therefore, the flood leakage loss is large during the flood routing, which changes the flood evolution process and law under the natural state. Especially, the plain channel leakage loss leads to prolonged flood propagation time and significant increase of peak clipping rate (Yu et al., 2017). Meanwhile, river seepage is one of the important sources of groundwater resources. Studying the law of channel leakage loss in plain is of great significance for flood evolution, ecological water diversion and groundwater recharge. The research results provided a basis for flood forecasting and management, ecological water replenishment and other important decisions.

At present, the research on channel leakage loss estimation and simulation has achieved some achievements. Boroughs & Abt (2003) evaluated losses of river flows due to evaporation, seepage, and transpiration, and empirical seasonal functions were developed to relate flow loss to the flow rate in the river. Grebenyukov (2002) choosed optimal hydrogeological models for calculating seepage losses from channels and rivers based on data of observations performed in some parts of Kazakhstan. Yu, Ma, & Fan (2017) summarized the research progress in the simulation and calculation of channel leakage. Zhang, Yan, & Cui (2002) analyzed the correlation between the upstream water, the recharge coefficient of river infiltration and the loss rate of channel leakage in the Hebei plain. Lu (2009) analyzed the channel seepage characteristics using statistical method in piedmont plain of Hebei province.



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Currently, hydraulic models or statistical analysis are mainly methods used in the research of channel leakage. But the hydraulic model is often hard to meet the dual requirements of time and accuracy in the actual flood prediction, evaluation of river recharge groundwater, etc. This paper emphasized on the deep integration of scientific research and practice. Therefore, the statistical method was used to analyze the leakage loss of typical river reaches in this paper. This paper calculated the leakage loss per unit river length, researched the correlation of the leakage rate of unit river length and the upstream inflow, the duration of flood under different water storage conditions. Meanwhile, the initial leakage loss rate of flood with different magnitude was estimated. The research result was directly applied in the practical work including flood prediction, evaluation of river recharge groundwater. The flow chart is as follows (Figure 1):

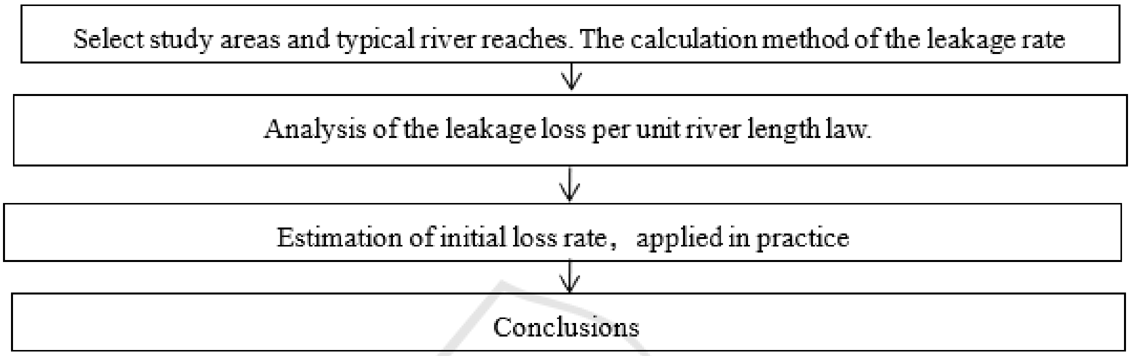


Figure 1: Flowchart.

## 2 CALCULATION METHOD AND DATAUM

### 2.1 Calculation Method

During the evolution of a flood, the water loss includes phreatic evaporation, vadose infiltration, and leakage. Due to the small proportion of evaporation and vadose infiltration in the process of flood evolution, they are ignored in the analysis of water loss. The channel leakage is expressed by the leakage rate per unit river length. When the leakage rate per unit river length is constant, the downstream section flow is calculated using the upstream section inflow and the leakage rate per unit river length (Eq. 1) (Zhang et al., 2002).

$$W_d = W_u (1-\varphi)^L \tag{1}$$

In the formula: $W_u$ —the upstream inflow, Billion cubic meters; $W_d$ —the downstream inflow, Billion cubic meters; $\varphi$ —the leakage rate of unit river length, ‰; L——length of the river, km.

The calculation formula of leakage rate per unit river length is (Eq. 2) :

$$\varphi = 1 - (\frac{W_d}{W_u})^{\frac{1}{L}} \tag{2}$$

### 2.2 Datum

The typical river reach should meet the following requirements:

(1) Representation of reaches. The interval inflow in typical river reach is negligible.

(2) Integrity of datum. The data series is long, and there are several years of flood processes.

(3) Applicability of results. The typical reach of different rivers was compared to analyze the common law of leakage loss under different underlying surface conditions.

Based on the above principles, this paper selected three typical river reaches in the Haihe River Basin. Yuecheng Reservoir~Caixiaozhuang located in Zhanghe River, Huangbizhuang Reservoir~ Beizhongshan located in Hutuo River, Xinle ~ Beiguocun located in Sha River. The positions of the three typical river reach in the Haihe River Basin are shown in Figure 2.

The three river reaches are all located in areas where human activities are concentrated. In recent years, due to the influence of upstream water diversion and impoundment projects, the inflow of

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the river reach has decreased sharply, leading to the increased number of cut off days. All three reaches are wide and shallow sandy beds. The basic information and datum of the three reaches are shown in Table 1.

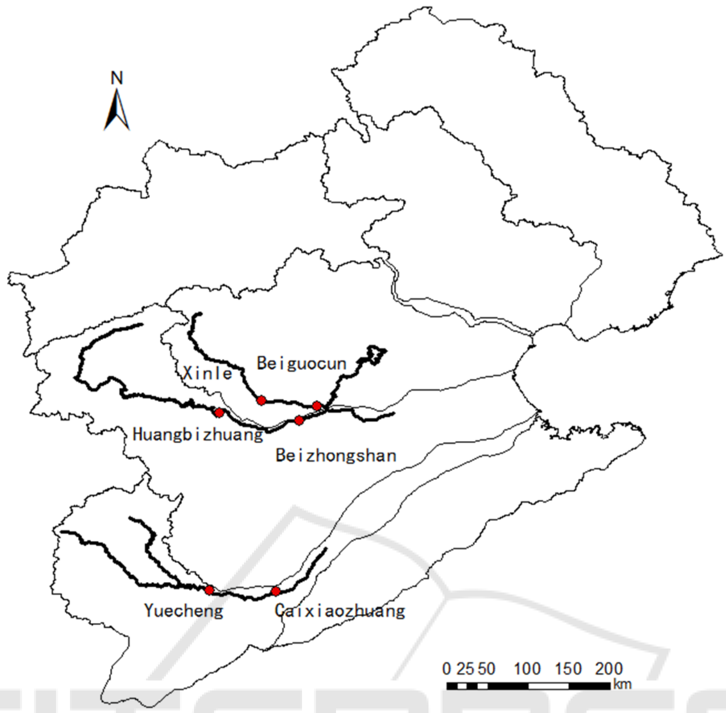


Figure 2: Locations of typical river reaches.

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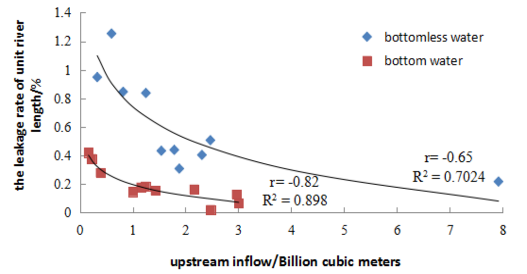
Table 1: The basic information and datum of the reaches.

| The serial number | The name of reach | The length of reach/km | Data time | Quantity of data/groups |
|---|---|---|---|---|
| 1 | Yuecheng Reservoir ~ Caixiaozhuang | 76 | 1967-2016 | 21 |
| 2 | Huangbizhuang Reservoir~ Beizhongshan | 110 | 1963-2018 | 15 |
| 3 | Xinle ~ Beiguocun | 55 | 1965-2013 | 16 |

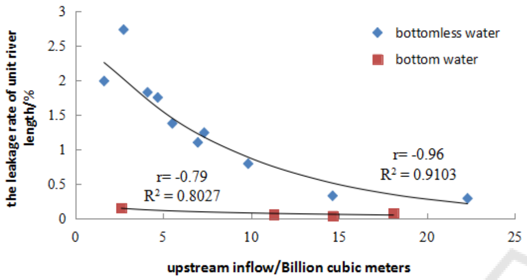
# 3 ANALYSIS OF LEAKAGE LAW

## 3.1 Law of Leakage Loss Per Unit River Length

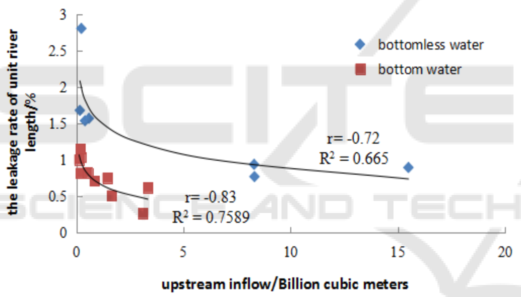
The main factors affecting the leakage rate of unit river length are: the water storage conditions of the channel before flood, the lithology of the riverbed, the size of the inflow, the duration of the flood, and the hydraulic conditions (Qin, 1989; Sun et al., 2010). The water storage conditions of the channel before flood includes bottom water and bottomless water. The channel leakage loss with bottomless water includes initial leakage loss and steady leakage loss. The channel leakage loss with bottom water is steady leakage loss. In this paper, the correlation analysis between the upstream inflow, the duration of flood and the leakage rate per unit river length is carried out respectively under the condition of bottom water and bottomless water. Figure 3 is correlation diagram of upstream inflow and leakage rate per unit river length in three typical river reaches. Figure 4 is correlation diagram of the flood duration and leakage rate per unit river length in three typical river reaches.




(a) Yuecheng Reservoir ~ Caixiaozhuang located in Zhanghe River

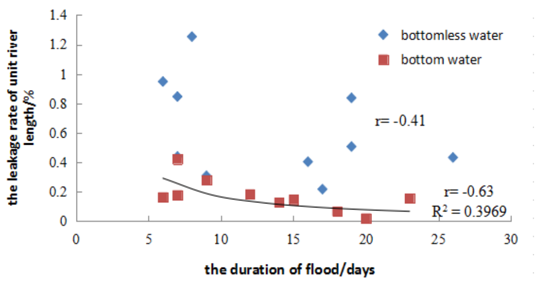



(b) Huangbizhuang Reservoir~ Beizhongshan located in Hutuo River

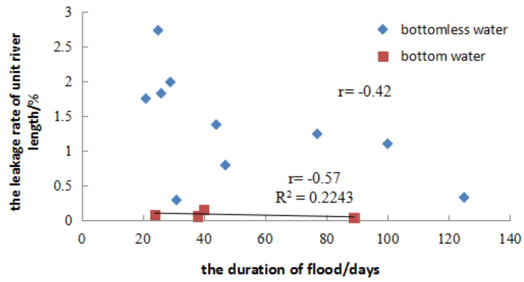



(c) Xinle ~ Beiguocun located in Sha River

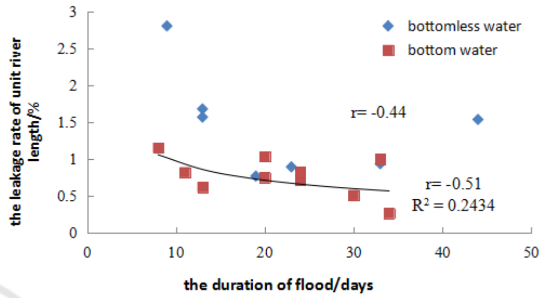
Figure 3: Correlation diagram of upstream inflow and leakage rate per unit river length.




(a) Yuecheng Reservoir ~ Caixiaozhuang located in Zhanghe River




(b) Huangbizhuang Reservoir ~ Beizhongshan located in Hutuo River




(c) Xinle ~ Beiguocun located in Sha River

Figure 4: Correlation diagram of the flood duration and leakage rate per unit river length.

From Figure 3 and Figure 4:

(1) The upstream inflow is negatively correlated with the leakage rate per unit river length. The leakage rate per unit river length tends to be stable when the upstream inflow increases to a certain value.

Generally, the leakage loss is greater with the increase of upstream inflow. But the relationship between inflow and leakage rate is not the case(Lu, S.Y.,2009). There is a significant negative correlation between upstream inflow and leakage rate per unit river length under the conditions of bottom water and bottomless water. With the increase of upstream inflow, the leakage rate per unit river length decreases gradually. The leakage rate per unit river length tends to be stable when the upstream inflow increases to a certain value, which indicated that the channel leakage rate is close to the leakage capacity. Therefore, channel leakage has a greater impact on the evolution of small-sized and medium-sized floods, but less impact on the evolution of large floods. The lower the inflow of upper section is, the higher the leakage rate is, while the inflow decreases along the river, so the leakage rate of the same reach length increases along the river.

(2) The leakage rate per unit river length of bottomless water is obviously higher than that of bottom water.

When there is bottomless water, the initial seepage loss of the channel occurs before the steady seepage loss. Under the present condition, the dry period of most river channels is long in the Haihe River basin. Even if the inflow is consistent with the inflow of historical floods, the leakage is generally higher than the historical situation.

(3) There is a negative correlation between flood duration and leakage rate per unit river length when there is bottom water.

The longer the flood duration is, the more interaction between flood and channel is, but the water-bearing strata tend to be saturated gradually. When there is bottom water, the leakage rate per unit length of three typical river reaches decreases with the increase of flood duration. This indicates that, under the condition of bottom water, the soil moisture content tends to be saturated and the river infiltration capacity decreases with the increase of time. When there is bottomless water, the data points are relatively scattered, without obvious correlation trend. This is due to the previous dry channel. The thickness of the underlying soil aeration zone was different, leading to different water storage capacity and different initial infiltration loss in the river basin. Therefore, when there is bottomless water, there is no obvious correlation between leakage rate per unit river length and flood duration.

(4) The degree of river dryness is one of the main factors affecting the seepage capacity.

The seepage capacity of the three typical reaches is different due to the respectively underlying surface conditions and early water storage conditions. Figure 5 shows the comparison of the leakage rate per unit length of three typical river reaches when there is bottomless water. Under the condition of bottomless water, the leakage rate of unit river length in Huangbizhuang~Beizhongshan and Xinle~Beiguocun is obviously higher than that in Yuecheng reservoir~Caixiaozhuang when the upstream inflow is constant. This was mainly because there were many floods in Yuecheng Reservoir~Caixiaozhuang in recent 20 years, while there were only one or two floods in the other two typical river reaches. The dry period of the channel is long, so the leakage capacity is large. It indicates that the degree of river dryness is one of the main factors affecting the seepage capacity.

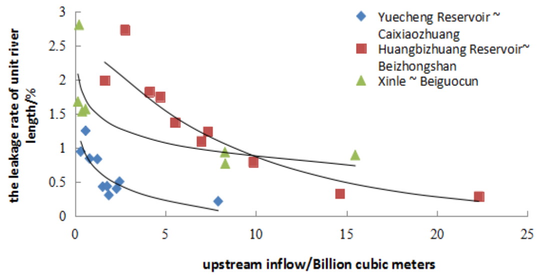



Figure 5: The comparison of the leakage rate per unit length with bottomless water.

## 3.2 Channel Leakage Equation

Through the optimal curve fitting, the calculation formulas of leakage rate per unit length of three river reaches are:

1.Yuecheng Reservoir ~ Caixiaozhuang

$$\varphi = -3.21\ln(W_u) + 0.742 \quad \text{bottomless water} \quad (3)$$

$$\varphi = -1.13\ln(W_u) + 0.195 \quad \text{bottom water} \quad (4)$$

2. Huangbizhuang Reservoir~ Beizhongshan

$$\varphi = 27.29e^{-0.114W_u} \quad \text{bottomless water} \quad (5)$$

$$\varphi = -0.5\ln(W_u) + 0.198 \quad \text{bottom water} \quad (6)$$

3.Xinle ~ Beiguocun

$$\varphi = -3\ln(W_u) + 1.561 \quad \text{bottomless water} \quad (7)$$

$$\varphi = -1.9\ln(W_u) + 0.689 \quad \text{bottom water} \quad (8)$$

$W_u$ and $\varphi$ has the same meaning as Formula (1).

From the above formulas, it can be seen that the leakage rate per unit river length is generally logarithmic or exponential related to the upstream inflow. Bigger $R^2$ is regarded as the criteria of optimal curve fitting when selecting logarithmic or exponential equations. When the upstream inflow is known, the leakage rate per unit river length in the case of either bottom water or bottomless water can be calculated by using formulas (3) ~ (8), and then the downstream inflow can be further estimated by using formula (1).

# 4 ESTIMATION OF INITIAL LOSS RATE

The dry period of most rivers is long in Haihe River Basin, so it is difficult to estimate the initial leakage loss of the first flood in each year. Therefore, this paper analyzed the characteristics of the initial loss rate with different magnitude floods, to provide reference for flood prediction and groundwater recharge evaluation. When there is bottomless water, the channel leakage loss includes initial seepage loss and steady seepage loss. When there is bottom water, the channel leakage loss is steady seepage loss. The estimation method is as follows:

(1) Calculate the steady seepage loss rate. The ratio of the loss of bottom water process to the duration of flood was used as the average steady permeability rate.

(2) Calculate the steady seepage loss. The steady seepage loss in bottomless water process is obtained by multiplying the average steady seepage rate by the steady seepage duration. In recent years, local rainstorms are frequent in Haihe River Basin, and the runoff generation mode is mostly mixed runoff. Therefore, the steady seepage time of bottomless water process is approximated by the total flood duration.

(3) Calculate the initial loss. The initial loss is obtained by deducting the steady seepage loss from the total loss of the bottomless water process.

(4) Calculate the initial loss rate. The initial loss rate is the ratio of initial loss to upstream inflow.

The steady infiltration rate of Yuecheng Reservoir~Caixiaozhuang was calculated by five floods with bottom water since 1982, which was 0.011 million $m^3$/d. The Huangbizhuang Reservoir~Beizhongshan adopted three floods with bottom water since 1964, and the steady infiltration rate was 0.012 million $m^3$/d. The Xinle~Beiguocun used ten floods with bottom water since 1970, and the steady infiltration rate was 0.007 million $m^3$/d. The calculation results of initial loss rate were shown in Table 2~Table 4.

The initial loss rate of medium and small water (upstream inflow less than 150 million $m^3$) in the Yuecheng Reservoir~Caixiaozhuang is 30%~50%, which concentrated in 30%~40%. The initial loss rate of large water is 10%~25%.

The initial loss rate of medium and small water (upstream inflow less than 100 million $m^3$) in Huangbizhuang Reservoir~Beizhongshan ranges from 50% to 80%, which concentrated in 60% to 80%. The initial loss rate of large water is 20%~30%.

Table 2: The calculation results of initial loss rate in Yuecheng Reservoir~Caixiaozhuang.

Unit: The amount of water-billion cubic meters; Duration—day.

| Number | Time | | Flood duration | Upstream inflow | Downstream flow | The initial loss | The initial loss rate/% |
|---|---|---|---|---|---|---|---|
| | Year | Month and Date | | | | | |
| 1 | 1969 | 6.15-7.10 | 26 | 1.54 | 1.11 | 0.15 | 9 |
| 2 | 1970 | 6.18-6.25 | 9 | 1.88 | 1.49 | 0.29 | 16 |
| 3 | 1988 | 8.11-8.17 | 7 | 1.79 | 1.28 | 0.43 | 24 |
| 4 | 1996 | 8.3-8.21 | 17 | 7.92 | 6.72 | 1.01 | 13 |
| 5 | 2001 | 7.3-7.8 | 6 | 0.33 | 0.16 | 0.10 | 32 |
| 6 | 2006 | 4.9-4.15 | 7 | 0.82 | 0.43 | 0.31 | 38 |
| 7 | 2008 | 6.2-6.20 | 19 | 1.25 | 0.66 | 0.38 | 30 |
| 8 | 2012 | 8.2-8.9 | 8 | 0.60 | 0.23 | 0.28 | 47 |
| 9 | 2013 | 7.17-8.1 | 16 | 2.31 | 1.70 | 0.43 | 19 |
| 10 | 2016 | 7.23-8.10 | 19 | 2.47 | 1.68 | 0.58 | 24 |

Table 3: The calculation results of initial loss rate in Huangbizhuang Reservoir~ Beizhongshan.

Unit: The amount of water-billion cubic meters; Duration-day.

| Number | Time | | Flood duration | Upstream inflow | Downstream flow | The initial loss | The initial loss rate/% |
|---|---|---|---|---|---|---|---|
| | Year | Month and Date | | | | | |
| 1 | 1970 | 4.20-6.2 | 44 | 5.53 | 1.2 | 3.80 | 69 |
| 2 | 1971 | 3.15-5.30 | 77 | 7.34 | 1.85 | 4.57 | 62 |
| 3 | 1977 | 5.30-10.1 | 125 | 14.64 | 10.18 | 2.96 | 20 |
| 4 | 1978 | 9.23-10.21 | 29 | 1.65 | 0.18 | 1.12 | 68 |
| 5 | 1979 | 7.7-10.14 | 100 | 6.98 | 2.06 | 3.72 | 53 |
| 6 | 1991 | 6.29-7.24 | 26 | 4.12 | 0.54 | 3.27 | 79 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 1996 | 8.3-9.2 | 31 | 22.31 | 16.18 | 5.76 | 26 |
| 8 | 1996 | 9.4-10.20 | 47 | 9.84 | 4.09 | 5.19 | 53 |
| 9 | 1997 | 4.22-5.16 | 25 | 2.76 | 0.13 | 2.33 | 84 |
| 10 | 2016 | 7.20-8.10 | 21 | 4.70 | 0.67 | 3.78 | 80 |

Table 4: The calculation results of initial loss rate in Xinle ~ Beiguocun.

Unit: The amount of water-billion cubic meters; Duration-day.

| Number | Time | | Flood duration | Upstream inflow | Downstream flow | The initial loss | The initial loss rate/% |
|---|---|---|---|---|---|---|---|
| | Year | Month and Date | | | | | |
| 1 | 1965 | 7.26-8.7 | 13 | 0.17 | 0.07 | 0.08 | 46 |
| 2 | 1968 | 7.18-8.13 | 44 | 0.41 | 0.18 | 0.15 | 36 |
| 3 | 1978 | 5.25-6.16 | 23 | 15.49 | 9.44 | 6.00 | 38 |
| 4 | 1979 | 10.3-10.21 | 19 | 8.31 | 5.43 | 2.84 | 33 |
| 5 | 1988 | 8.3-9.8 | 33 | 8.29 | 4.94 | 3.29 | 38 |
| 6 | 1990 | 7.29-8.10 | 13 | 0.59 | 0.25 | 0.32 | 43 |
| 7 | 2013 | 7.11-7.19 | 9 | 0.24 | 0.05 | 0.17 | 53 |

The initial loss rate of medium and small water (upstream inflow less than 100 million $m^3$) in Xinle~Beiguocun is 35%~55%, which concentrated in 40%~50%. The initial loss rate of large water is 30%~40%.

The initial loss rate of medium and small water in each reach is higher, more than 30%, and the initial loss rate of large water is lower than that of medium and small water. In Yuecheng~Caixiaozhuang section, the initial loss rate of all-range water is lower than that of the other two typical sections. The initial loss rate of medium and small water in Huangbizhuang reservoir~Beizhongshan is higher than that in Xinle~Beiguocun, while that of large water is lower than that in Xinle~Beiguocun.

# 5 CONCLUSIONS

In North China (Haihe River Basin as an example):

(1) The upstream inflow is negatively correlated with the leakage rate per unit river length, and when the upstream inflow increases to a certain value, the leakage rate per unit river length tends to be stable; he leakage loss rate increases along the river course. There is a negative correlation between water duration and leakage rate per unit river length when there is bottom water.

(2) The dryness degree of river channel is one of the main factors affecting the seepage capacity.

(3) The leakage rate per unit river length is generally logarithmic or exponential related to the upstream inflow. Through the optimal curve fitting, the formula for calculating the leakage rate per unit length of each typical reach is obtained by given upstream inflow.

(4) The initial loss rate of medium and small water in each typical reach is higher, more than 30%, and the initial loss rate of large water is lower than that of medium and small water.

This study has innovatively put forward the law of channel leakage in North China (Haihe River Basin as an example). The research results have strong practicability and could really guide the practical work including flood prediction, evaluation of river recharge groundwater, etc.

# ACKNOWLEDGEMENT

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