Case Study of the Emergency Operation Model in Upstream Pools of the Accident Pool of the Middle Route of South-to-North Water Diversion Project

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Abstract. In order to apply the emergency operation Model in Upstream Pools of the Accident Pool of the Middle Route of South-to-North Water Diversion Project we have developed, a one-dimensional hydraulic model was developed and a case study was carried out. The results showed the emergency operation model can determine reasonable emergency operation measures in the upstream pools. In addition, some suggestions were put forward to help deal with the emergency operation measures in the upstream pools.

1. Introduction

The strategically important Middle Route of South-to-North Water Diversion project (MRP) was built for solving water shortage issue in North China (Shang et al., 2011), but without any reservoir in-line. The MRP passes through a lot of roads, bridges and is along with many chemical factories, making it potential for sudden water pollution accidents to occur, for example, traffic accidents may cause toxic substance loaded by vehicles going into the canal (Tang et al., 2014). If emergency accidents occur, the main channel can be divided into three sections - upstream section of accidental pool (upstream pools), accident pool and downstream section of accidental pool (downstream pools; Figure 1).

Emergency operation of upstream pools is very important and difficult. We have developed an Emergency Operation Model in Upstream Pools of the Accident Pool of the MRP to determine reasonable emergency operation measures in the upstream pools (Quan et al., 2014). In order to apply this model, this study firstly developed a hydraulic model, and then carried out a case study to show the application process and this model’s applicability.
2. Hydraulic model
A one-dimensional hydrodynamic model for the MRP was developed in our previous study. The complex interior hydraulic structures (e.g., gates, aqueducts, inverted siphons, etc.) were generalized, and then the solution relationships were built in accordance with Saint-Venant equations (Shang et al., 2011; Tang et al., 2014). The Saint-Venant equations were scattered using the Preissmann four eccentric space-time format (Abbot M B, 1991), and then solved using the double sweep method (Vion, 2014). This model was realized with C++ programming language, which can simulate hydrodynamic process of the canal under normal operation and emergency regulation.

The unsteady flow is calculated by employing the Saint-Venant equations that consist of continuity equation and momentum equation:

\[
\begin{align*}
0 & \frac{\partial (AQ)}{\partial t} + \frac{\partial}{\partial x} \left( Q \frac{Q}{A} + \alpha \frac{Q^2}{2A^2} \right) + g \frac{\partial Z}{\partial x} + g(S_f - S_o) = 0 \\
\end{align*}
\]

Where \(x\) and \(t\) are the spatial and temporal coordinates, respectively; \(q\) is the lateral inflow; \(\alpha\) is the momentum correction coefficient; \(Q\) and \(A\) are the cross-section discharge and area, respectively; \(Z\) is the water level; \(S_f\) is the friction slope; \(S_o\) is the canal bottom slope.

The steady flow model can calculate the canal non-uniform steady surface profile under the conditions of steady flows. The steady flow equations can be obtained by setting the temporal items \(\frac{\partial A}{\partial t}\) and \(\frac{\partial}{\partial t} (\frac{Q}{A})\) of equation (1) as zero:

\[
\begin{align*}
\frac{\partial Q}{\partial x} &= q \\
\frac{\partial}{\partial x} \left( \alpha \frac{Q^2}{2A^2} \right) + g \frac{\partial Z}{\partial x} + g(S_f - S_o) &= 0 \\
\end{align*}
\]

Equation (2) was scattered and solved using the same method as equation (1), which made unsteady flow converging into steady flow. Non-uniform steady water surface profile is the initial and final state of hydraulic control transient process.

3. Case Study

3.1 Scenario
In the initial state, the discharge of Taocha Gate was set as 200 m\(^3\)/s, all the escape gates were closed, the upstream water levels of check gates were design water levels, and the discharges of diversion gates were almost the current values (Table 1). The 10\(^{th}\) pool was assumed to have emergency accidents, then the upstream section of accidental pool was the first 9 pools. In the final state, discharges of diversion gates in the upstream pools were unchanged, so the discharge of Taochao Gate would be decreased to 38 m\(^3\)/s, and other check gates’ discharges were listed in Table 1. There were only diversion gates but no escape gates in the 4\(^{th}\) pool and 7\(^{th}\) pool, which means water can only be drained out through the escape gates of the 5\(^{th}\) and 8\(^{th}\) pool, respectively.

| Pool Number | Check gate Number | Coordination (km) | Pool length (km) | Initial upstream water level of check gate (m) | Initial discharge (m\(^3\)/s) | Final discharge (m\(^3\)/s) |
|-------------|-------------------|------------------|-----------------|---------------------------------------------|-------------------------------|----------------------------|
| 1           | K1                | 0                |                 | 148.68                                      | 200                           | 38                         |
|             | F1                | 4.196            | 14.62           | /                                           | 20                            | 20                         |
|             | T1                | 14.538           |                 | /                                           | /                             | /                         |
|             | K2                | 14.62            |                 | 146.8                                       | 180                           | 18                         |
|             | F2                | 22.283           |                 | /                                           | 1                             | 1                          |
|             | T2                | 36.354           | 21.824          | /                                           | /                             | /                         |
|             | K3                | 36.444           |                 | 145.65                                      | 179                           | 17                         |
| 2           | F3                | 44.505           |                 | /                                           | 1                             | 1                          |
|             | T3                | 48.695           | 12.337          | /                                           | /                             | /                         |
|             | K4                | 48.781           |                 | 144.74                                      | 178                           | 16                         |
|             | F4                | 70.562           | 25.859          | /                                           | 1                             | 1                          |
|             | K5                | 74.64            |                 | 143.07                                      | 177                           | 15                         |
|             | T4                | 87.971           |                 | /                                           | /                             | /                         |
| 3           | F5                | 95.005           | 22.393          | /                                           | 2                             | 2                          |
|             | K6                | 97.033           |                 | 141.83                                      | 175                           | 13                         |
|             | F6                | 98.737           |                 | /                                           | 5                             | 5                          |
|             | F7                | 104.287          | 19.413          | /                                           | 2                             | 2                          |
|             | T5                | 115.24           |                 | /                                           | /                             | /                         |
|             | K7                | 116.446          |                 | 139.92                                      | 168                           | 6                          |
|             | F8                | 134.91           | 20.666          | /                                           | 4                             | 4                          |
|             | K8                | 137.112          |                 | 138.73                                      | 164                           | 2                          |
|             | T6                | 147.56           |                 | /                                           | /                             | /                         |
| 6           | F9                | 151.414          | 22.782          | /                                           | 1                             | 1                          |
|             | F10               | 156.815          |                 | /                                           | 1                             | 1                          |
|             | K9                | 159.894          |                 | 137.27                                      | 162                           | 0                          |
|             | T7                | 177.622          | 21.842          | /                                           | /                             | /                         |
|             | K10               | 181.736          |                 | 136.04                                      | 162                           | 0                          |
| 9           | F11               | 195.477          |                 | /                                           | 9                             | /                         |
|             | T8                | 209.339          | 27.697          | /                                           | /                             | /                         |
|             | K11               | 209.433          |                 | 134.60                                      | 153                           | /                         |

Notes: K1-K11 are check gate numbers; F1-F11 are diversion gate numbers; T1-T8 are escape gate numbers.

### 3.2 Feasibility analysis of emergency regulation

The first 10 check gates were assumed to be closed to the final discharges within 10 minutes, and the
worst operation condition was simulated, that was, escape gates were closed during emergency regulation process, because under this condition, canal water level fluctuation was the biggest and water level rise in the final state was maximum. Due to the construction features of the project, if the fluctuation of upstream water level of check gate is not overflowed, then it can be guaranteed that the pool water will not overflow as well. The model calculating step and output step were both 10 minutes. The changing processes of upstream water level of the $2^{nd}$-10$^{th}$ check gates during the 24 hours were shown in Figure 2. The maximum water level, final water level, the differential between initial and final water level and stabilization time during the fluctuation process were listed in Table 2.

![Figure 2. Changing process of upstream water level of check gates.](image)

| Check gate number | Warning level (m) | Maximum level (m) | Final level (m) | Final – initial level (cm) | Stabilization time (h) |
|-------------------|------------------|------------------|----------------|---------------------------|------------------------|
| K2                | 147.66           | 147.359          | 146.876        | 7.6                       | 8.67                   |
| K3                | 146.47           | 146.26           | 145.801        | 15.1                      | 17.17                  |
| K4                | 145.57           | 145.189          | 144.874        | 13.4                      | 8.17                   |
| K5                | 143.88           | 143.92           | 143.392        | 32.2                      | 19.17                  |
| K6                | 142.68           | 142.388          | 142.066        | 23.6                      | 18.33                  |
| K7                | 140.76           | 140.691          | 140.131        | 21.1                      | 15.5                   |
| K8                | 139.57           | 139.364          | 138.937        | 20.7                      | 16.5                   |
| K9                | 138.13           | 137.874          | 137.485        | 21.5                      | 18.67                  |
| K10               | 136.9            | 136.591          | 136.22         | 18                        | 17.67                  |

The variations of fluctuation amplitude of upstream water level of control gates were identical, firstly big followed by a decline, and finally became stable (water level fluctuation less than 1 cm is considered to be stable). The longer the pool length is, the longer stabilization time would be (Figure 3). The differential between the final and initial level was various and the range is from 7.6 cm to 32.2 cm. The maximum water level (Table 2) during the fluctuation process is smaller than the warning water level,
which is the allowable maximum upstream water level of check gate, indicating that water will not overflow during emergency regulation process. The results showed that the fourth constraint condition can be satisfied, proving emergency regulation to be available.

![Figure 3. Graph of pool length and stabilization time.](image)

3.3 Emergency regulation results

After emergency regulation, upstream water levels of control gates (K2-K10) were assumed to increase in the final state. The rise was set as 0 (maintain constant water level), 5, 10, 15, 20 and 25cm to be analyzed, respectively. The initial volumes and final maximum volumes in the pools were listed in Table3.

| Pool number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total abandoned water |
|-------------|---|---|---|---|---|---|---|---|---|------------------------|
| Initial state | 4307802 | 5818310 | 3490017 | 6354034 | 5980187 | 4456528 | 5104943 | 5487340 | 5472742 |
| Level+0cm | 4183122 | 5642959 | 3410593 | 5933655 | 5720215 | 4230110 | 4916919 | 5242170 | 5270720 |
| Level+5cm | 4228707 | 5696394 | 3445775 | 5995574 | 5779422 | 4273152 | 4965993 | 5295686 | 5326639 |
| Level+10cm | 4274531 | 5750045 | 3481119 | 6057763 | 5838890 | 4316378 | 5015267 | 5349428 | 5382819 |
| Level+15cm | 4320594 | 5803909 | 3516623 | 6120223 | 5898619 | 4359786 | 5064743 | 5403396 | 5439259 |
| Level+20cm | 4366896 | 5857988 | 3552289 | 6182953 | 5958609 | 4403378 | 5114421 | 5457591 | 5495961 |
| Level+25cm | 4413437 | 5912282 | 3588116 | 6245953 | 6018860 | 4447152 | 5164300 | 5512011 | 5552924 |

Table 4. Differentials between initial volumes and final maximum volumes in different pools (unit: m³).

| Pool number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total abandoned water |
|-------------|---|---|---|---|---|---|---|---|---|------------------------|
| Level+0cm | 124680 | 175351 | 79424 | 420379 | 259972 | 226418 | 188024 | 245170 | 202022 | 1921440 |
| Level+5cm | 79095 | 121916 | 44242 | 358460 | 200765 | 183376 | 138950 | 191654 | 146103 | 1464561 |
| Level+10cm | 33271 | 68265 | 8898 | 296271 | 141297 | 140150 | 89676 | 137912 | 89923 | 1005663 |
| Level+15cm | -12792 | 14401 | -26606 | 233811 | 81568 | 96742 | 40200 | 83944 | 33483 | 569748 |
| Level+20cm | -59094 | -39678 | -62272 | 171081 | 21578 | 53150 | -9478 | 29749 | -23219 | 242861 |
| Level+25cm | -105635 | -93972 | -98099 | 108081 | -38673 | 9376 | -59357 | -24671 | -80182 | 0 |

Under the condition of the assumed maximum rise of upstream water level of check gates in the final state (i.e. the final assumed maximum rise) to be set as 0, 5, 10, 15, 20, 25cm, the differentials between the initial volumes and final maximum volumes were listed in Table 4.
During the emergency regulation under this scenario, there was linear relationship between the total abandoned water and the final assumed maximum rise in the first 9 pools (Figure 4): $y = -7.8333x + 184.65 (0 \leq x < 25)$, $R^2=0.9878$. The results showed that with the increase of the final assumed maximum rise, the total abandoned water would decrease, and total abandoned water according to any final assumed maximum rise can be estimated by this equation.

![Figure 4. Relationship between total abandoned water and the final assumed maximum rise.](image)

**4. Conclusions**

In order to apply the emergency operation model in upstream pools of the accident pool of the MRP, a scenario was set, and the emergency accident was assumed to occur in the 10th pool. In the emergency regulation of the upstream pools, the final assumed maximum rise was set as 0, 5, 10, 15, 20 and 25cm to be analyzed, respectively. The results showed that, the bigger the final assumed maximum rise was, the smaller the total abandoned water would be. When the assumed maximum rise reached 25cm, through the regulation, the upstream pools would not abandon any water. Besides, the linear relationship between the total abandoned water and the final assumed maximum rise was obtained. Feasibility analysis indicated volumes allocation of different pools in emergency regulation can be realized through gate operations.

Once emergency accidents occur in the MRP, it is suggested that the upstream pools do not maintain constant downstream water levels in the final state after emergency regulation, otherwise, a certain rise of upstream water level of check gates should be allowed after emergency regulation. In addition, allocating volumes in the upstream pools is of significant importance for decreasing abandoned water, saving water resources and playing project benefits.

**Acknowledgments**

This paper was jointly supported by the Major Science and Technology Program for Water Pollution Control and Treatment (2017ZX07108-001).

**References**

[1] Shang, Y., Liu, R., Li T. et al. 2011. Transient flow control for an artificial open channel based on finite difference method. *SCIENCE CHINA Technological Sciences, 54*(4):781-792.

[2] Tang, C., Yi, Y., Yang, Z. et al. 2014. Water pollution risk simulation and prediction in the main canal of the South-to-North Water Transfer Project. *Journal of Hydrology, 519*: 2111–2120. https://doi.org/10.1016/j.jhydrol.2014.10.010

[3] Quan J, Zhen H, Cai S, et al. An Emergency Operation Model in Upstream Pools of the Accident Pool of the Middle Route of South-to-North Water Diversion Project. MATEC Web of
[4] Abbot, M.B., Havno, K., Lindberg, S. 1991. The fourth generation of numerical modeling in hydraulics. *Journal of Hydraulic Research*, 29(5):581-600. http://dx.doi.org/10.1080/00221689109498978

[5] Vion, A., Geuzaine, C. 2014. Double sweep preconditioner for optimized Schwarz methods applied to the Helmholtz problem. *Journal of Computational Physics.*, 66: 171-190. http://hdl.handle.net/2268/171493