Analysis the Operational Performance of Outlet Structures of a Secondary Level Irrigation Canal Using the SIC-Model with the Kifil-Shinasiya Project as a Case Study

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Abstract: The analysis and evaluation of actual hydraulic operation at the level of a distributary canal (secondary level) and its related outlets is based on suitable hydraulic indicators such as equitability ($P_e$), dependability ($P_d$), adequacy ($P_a$), and flexibility (F); this is the basic goal of the present study, which uses the hydrodynamic Simulation Irrigation Canal model (SIC) for the first time in an analysis in Iraq. One of the distributary canals in the Kifil-Shinasiya project (KSP), located at the middle of Iraq, was selected for the study of these indicators by evaluation of the gaps between demand flows and actual deliveries at the outlet structures along the canal. The selected canal serves an area of 710 hectares with, alongside the head regulator, sixteen outlet structures and two cross regulators. The study includes a range of field measurements such as the actual water levels and the actual corresponding discharges at outlets for twenty-four months, covered four cropping seasons, over two years, as eight measurements were taken per month at each outlet from October 2014 to September 2016. The maximum measured discharge at the head regulator during the study period was smaller than the design discharge. The results showed that the equity indicator ($P_e$) was generally good, except for the months of May and October; while the dependability indicator ($P_d$) was good in all head outlets but it was only fair for other outlets. The adequacy indicator ($P_a$) was poor throughout the study period. The dependability and adequacy indicators in the winters were seen to be better than in the summers.

Keywords: distributary canal; equitability; Simulation Irrigation Canal (SIC); outlet; flexibility; Kifil–Shinasiya project.

1. Introduction

The first construction of irrigation projects in Iraq began in the British and Royal periods under the adoption of a strategy of protecting urban and the agriculture lands against the dangers of flooding. After the 1960s, the water discharges of the Tigris and the Euphrates rivers and their tributaries lessened such that there was no actual danger of flood; thus, the Iraqi irrigation authorities adopted another strategy that was designed to overcome water scarcity (drought) especially in summer (Wahad, 1999).

As part of this strategy, the Ministry of Water Resources in Iraq (MoWR) mandated a design manual of irrigation and drainage works and created an administrative structure for water management in all irrigation systems. The operation and maintenance in all parts of the main irrigation system, ending only at the offtakes of the watercourse canals (outlets), are thus the responsibility of the Water Resources Directorate (WRD) in each Governorate, while the operation and maintenance of watercourse canals downstream of the outlet structures are under the responsibility of the farmers themselves.

The present study aims to examine these stages of operation by monitoring and measuring the flow parameters in the KSP project, using several indicators with the aid of a one-dimensional hydrodynamic model (SIC) to determine the actual flows in the distributary canal and through the outlets. These can then be compared with the design flows to help the project manager to distribute the irrigation water among the outlets in a more equitable, proportional, and dependable manner. The study thus aims to answer the following questions:

1. What is the best irrigation outlet in the distributary canal for distributing water among watercourse canals based on equitability ($P_e$), dependability ($P_d$), adequacy ($P_a$), and flexibility (F)?
2. Can the effects of any change in geometry, hydraulics, and location of any outlet structure upon the hydraulic parameters of flow and distribution of water among the outlets be quantified by the appropriate managers?
3. What improvements can best be done in terms of the existing distibutary canal to enhance operation and maintenance practices?
4. What are the best field methods to measure flow velocity and to survey the distributary canals both geometrically and hydraulically with minimum error?

2. The study area

The Kifil-Shinafiya Project (KSP) extends along the Euphrates River from Kifil city in the Babylon governorate, passing through the Najaf governorate towards Shinafiya city in the Diwaniya governorate. KSP is designed for a water allowance of 2.19 l/s ha and the gross area is 203,660 hectares (the net area is 96,000 hectares) distributed between the Governorates of Al-Najaf, Babil, and Diwaniya. Its geographic coordinates are latitude 31º 15' 00" to 32º 35' 00" and longitude 43º 00' to 55º 00' (GESD, 1986).

The first construction stage in KSP was begun in the Najaf Governorate in the middle of Iraq in November 2007. This sub-stage began by implementing the main channel, 1MC, which was designed for a discharge of 20.99 m³/s, with a length of 13,886 m from kilometric station 00+00 to kilometric station 13+886. It has two main cross regulators at stations 0+400 and 5+250. This sub-stage also included the construction of five distributary canals, 1-0-1C through 1-0-5C. The selected distributary canal was 1-0-5C, which is the longest canal.

3. Outlet structures

The outlet or offtake of a watercourse canal may be defined as the hydraulic structure that withdraws the required discharge from a parent (distributary) canal to the inlet of a watercourse canal. The outlets used by State Commission of Irrigation and Reclamation Projects in Iraq (SCRIP) are designed according to the design manual of irrigation and drainage works as adopted by the General Establishment of Studies and Design (GESD). SCRIP adopted three outlets types, A, B and C. Outlet type A can be used if the difference of head between the basin water level and the watercourse water level on the downstream side is small. It consists of the one basin of a certain depth, H, with a net length of 0.80 m and a net width of (B₀ + 0.50 m), where B₀ is the width of weir towards the watercourse canal. Outlet type B is recommended if the head difference between basin water level and the watercourse water level on the downstream side is relatively high (SCRIP, 1983). It consists of two neighbouring basins at the same bottom floor level. The purpose of this configuration is to avoid erosion in the first reach of the watercourse canal. The existing outlets in KSP are all A or B types.

In the present study, it was found that all outlets worked under submerged flow. The discharge was calculated in the field using the area velocity method, and the head difference was calculated between the distributary water level and the basin water level using levelling instrument. Thereafter, head difference and discharge were used to calibrate the outlets and to calculate the coefficients of discharge. All outlets were provided with a measuring weir at the downstream basin, but most of these had been damaged by farmers or had defects from the construction stage. In the damaged weirs, the head difference was out of engineering requirements, requiring maintenance to make them sufficiently efficient in controlling water distribution. All outlets, pipes and gates worked under submerged flow as non-modular devices, and the main parameters for
calculating their discharges were the head differences between upstream and downstream water levels and the pipe diameter.

### Table 1. Geometric and operational survey of the outlet structures along the distributary canal 1-0-5C in KSP.

| No | Distance (km) | Outlet | Outlet Discharge (m³/s) | Type of Outlet | Pipe diameter (m) | Design Gate width (m) | Pipe invert level (m) | pipe Length (m) | Hydraulic Modes of pipe barrel | H Type of gate | Hydraulic Modes of gates |
|----|---------------|--------|-------------------------|----------------|-------------------|----------------------|---------------------|----------------|---------------------------------|--------------|-----------------------------|
| 1  | 0+030         | 1L     | 0.048                   | B              | 0.3               | 0.3                  | 22.77               | 6.0            | Cancelled                       |              | Cancelled                    |
| 2  | 0+262         | 1R     | 0.078                   | B              | 0.3               | 0.3                  | 22.51               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 3  | 0+262         | 2L     | 0.108                   | A              | 0.4               | 0.4                  | 22.43               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 4  | 0+718         | 2R     | 0.105                   | B              | 0.4               | 0.4                  | 22.42               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 5  | 0+718         | 3L     | 0.108                   | B              | 0.4               | 0.4                  | 22.29               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 6  | 1+301         | 3R     | 0.110                   | B              | 0.4               | 0.4                  | 22.97               | 6.0            | Submerged flow                  |              | Damaged                      |
| 7  | 1+301         | 4L     | 0.108                   | B              | 0.3               | 0.3                  | 22.03               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 8  | 1+310         | CR.1   | 0.980                   |                 |                   | 1.0                  |                     |                | Free flow                       |              |                             |
| 9  | 1+614         | 4R     | 0.115                   | A              | 0.4               | 0.4                  | 21.60               | 8.0            | Submerged flow                  |              | Submerged flow               |
| 10 | 1+721         | 5L     | 0.100                   | A              | 0.4               | 0.4                  | 21.65               | 8.0            | Submerged flow                  |              | Damaged                      |
| 11 | 2+189         | 5R     | 0.120                   | B              | 0.4               | 0.4                  | 21.52               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 12 | 2+189         | 6L     | 0.100                   | A              | 0.3               | 0.3                  | 21.30               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 13 | 2+615         | 6R     | 0.078                   | A              | 0.3               | 0.3                  | 21.36               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 14 | 2+615         | 7L     | 0.100                   | A              | 0.3               | 0.3                  | 21.15               | 6.0            | Submerged flow                  |              | Submerged flow               |
| 15 | 2+675         | CR.2   | 0.350                   |                 |                   | 0.8                  |                     |                | Free flow                       |              |                             |
| 16 | 3+106         | 7R     | 0.078                   | A              | 0.3               | 0.3                  | 20.7                | 8.0            | Submerged flow                  |              | Submerged flow               |
| 17 | 3+106         | 8L     | 0.100                   | A              | 0.3               | 0.3                  | 20.6                | 6.0            | Submerged flow                  |              | Submerged flow               |
| 18 | 3+557         | 8R     | 0.110                   | A              | 0.4               | 0.4                  | 20.6                | 6.0            | Submerged flow                  |              | Submerged flow               |
| 19 | 3+557         | 9L     | 0.058                   | A              | 0.3               | 0.3                  | 20.6                | 6.0            | Submerged flow                  |              | Submerged flow               |
| 20 | 3+563         | TE     | Overflow                |                 |                   | 0.6                  | 0.45                |                | Free flow                       |              |                             |

5. **The field measurements**

Sets of 192 discharges and corresponding water level measurements, at eight measurements per month, were done at the head regulator, the two cross regulators, and 16 outlets throughout the study period (24 months) from October 2014 to September 2016. The head difference between the water surface in the distributary canal upstream of the outlet and downstream of it towards the watercourse canal was measured using a levelling instrument due to damage to all staff gauges in
the watercourse head regulators. An electromagnetic current meter was used to measure the velocity in both the distributary and watercourse canals. All outlets were operated under submerged flow with a head difference (ΔH).

6. Theoretical review: a one-dimensional hydrodynamic model (SIC)

SIC software branches into three basic units, which work either separately or in a sequential manner. Unit I is specialised to describe, verify, and process the topology and geometry of systems, Unit II performs steady flow calculation, and Unit III performs unsteady flow calculation. The SIC model offers high accuracy compared with other relevant models. The mathematical derivations and equations were discussed in detail by Baume et al. (2003) and Baume et al. (2005). This study is, however, the first application of the SIC model in Iraq, and it represents collaboration between the University of Technology (Water and Hydraulic Structures Engineering Branch) and the GESD in the Ministry of Water Resources, with the aim of simulating the actual canal operation in KSP in the middle of Iraq.

6.1 Model calibration

Model calibration is defined as the process of calculating the parameters of a model by comparing the model outputs under a certain condition with measured data taken under the same circumstances (Moriasi et al., 2007). Some indicators which were previously adopted by numerous researchers have thus been adopted and inserted into the SIC model in order to group the performance of structures measured. The performance of the SIC model was judged according to the RMSE-observations standard deviation ratio (RSR), Nash-Sutcliffe efficiency coefficient (NSEC) and the Percent bias (PBIAS) based on Gupta et al., (1999); Singh et al. (2005); Moriasi et al. (2007); Chu and Shirmohammadi (2004) and Tariq & Latif (2010), as detailed below:

6.1.1 Percent bias (PBIAS)

Percent bias (PBIAS) determines the tendencies of the calculated or simulated data to be higher or lower than the related measured or observed readings (Gupta et al., 1999). The optimum limit of PBIAS is 0.0, with very close values in either direction illustrating an accurate simulation of the model. Where PBIAS > 0.0, this indicates a model bias for underestimation, and where PBIAS < 0.0, this indicates a model bias for overestimation. PBIAS is determined as;

\[
PBIAS = \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})(100)}{\sum_{i=1}^{n}Q_{obs}}
\]  (1)

PBIAS was selected as a statistical measure because it is recommended by ASCE (1993) and thus widely used to calculate water balance errors; it also has the ability to illustrate the poor performance of a model where applicable (Gupta et al., 1999).

6.1.2 RMSE-observations standard deviation ratio (RSR)

RMSE is an error index statistic (Chu and Shirmohammadi, 2004); the smaller the value of RMSE, the better the performance of the model. Singh et al. (2005) developed criteria for an RMSE-observations standard deviation ratio (RSR), which considers standardisation of RMSE by utilising the standard deviation of all observations or measurements. This therefore works as an error index as well as providing additional information. RSR is thus the ratio of the RMSE to the standard deviation of measurements;

\[
RSR = \frac{RMSE}{STDEV obs} = \frac{\sqrt{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2}}{\sqrt{\sum_{i=1}^{n}(Q_{obs} - Q_{mean})^2}}
\]  (2)

In general, a lower RSR means a lower RMSE, and this in turn implies better performance of the model simulation.

6.1.3 Nash-Sutcliffe efficiency coefficient (NSEC)

4
The Nash-Sutcliffe Efficiency Coefficient (NSEC) is a normalised statistic used to calculate the relative amount of residual variance by comparing it with the variance of the measured data (Nash and Sutcliffe, 1970). NSEC is a dimensionless index and indicates how well the scattering plot of measuring data versus simulated data fits with the perfect line. NSEC can be calculated as:

\[
NSEC = 1 - \frac{\sum_{i=1}^{n}(Q_{i}^{obs} - Q_{i}^{sim})^2}{\sum_{i=1}^{n}(Q_{i}^{obs} - Q_{mean})^2}
\]  

where \(Q_{i}^{obs}\) is the observed or measured discharge at the outlet, \(Q_{i}^{sim}\) is the simulated discharge at the same outlet at the same time, \(Q_{mean}\) is the mean of measured discharges, and \((n)\) is the number of measurements.

NSEC values within 0.0 to 1.0 indicate acceptable performance of the model. If NSEC equals 1, this indicates optimal performance of the model, whereas NSEC values < 0.0 indicate unacceptable performance of the model. This statistic is important and widely used because it is recommended by ASCE (1993) and presents a lot of information about the measured values. NSEC is the best function of the fitness of simulated data as compared with measured data.

SIC Model calibration was implemented in the following steps:
First, the hydraulic parameters of the hydraulic structures (head regulators, cross regulators and outlets) were measured in the field to compute the coefficients of discharge (Cd). The actual canal dimensions (bed width, total height, longitudinal slope, and the roughness coefficient) for each canal reach were calculated in the field by maintaining steady uniform flow condition at each test during the study period. The discharges and the corresponding water levels were periodically monitored and recorded at the nodes (head regulator, cross regulator, outlets, and tail escape). The results of this SIC calibration for different operational scenarios are listed in table 2.

| Scenario   | PBIAS     | NSEC     | RSR       |
|------------|-----------|----------|-----------|
| 100 % Q    | 0.004819  | 0.932118 | 0.252269  |
|            | v. good   | v. good  | v. good   |
| 80 % Q     | 0.000753  | 0.915663 | 0.426152  |
|            | v. good   | v. good  | v. good   |
| 70 % Q     | 0.001721  | 0.878251 | 0.541323  |
|            | v. good   | v. good  | Good      |
| 60 % Q     | -0.01715  | 0.859    | 0.565142  |
|            | v. good   | v. good  | Good      |

Using the general criteria, the model simulation can be considered to be satisfactory if NSEC >0.50 and RSR < 0.70, and if PBIAS ± 25% for canal or streamflow, based on the degree of uncertainty in the measured data illustrated in table 3.

| Scenario   | PBIAS     | NSEC   | RSR       |
|------------|-----------|--------|-----------|
| 100 % Q    | 0.004819  | 0.932118 | 0.252269       |
|            | v. good   | v. good  | v. good       |
| 80 % Q     | 0.000753  | 0.915663 | 0.426152   |
|            | v. good   | v. good  | v. good       |
| 70 % Q     | 0.001721  | 0.878251 | 0.541323  |
|            | v. good   | v. good  | Good        |
| 60 % Q     | -0.01715  | 0.859    | 0.565142   |
|            | v. good   | v. good  | Good        |

Using the general criteria, the model simulation can be considered to be satisfactory if NSEC >0.50 and RSR < 0.70, and if PBIAS ± 25% for canal or streamflow, based on the degree of uncertainty in the measured data illustrated in table 3.

Table 3. Recommended Statistics for a Monthly Time Step for Model Calibration and Validation (Gupta et al., 1999; Moriasi et al., 2007; Singh et al., 2005; Chu and Shirmohammadi, 2004; Tariq and Latif, 2010).
| Performance   | RSR          | NSEC          | PBIAS (stream flow) |
|---------------|--------------|---------------|---------------------|
| Very good     | 0.00 ≤ RSR ≤ 0.50 | 0.75 < NSEC ≤ 1.00 | PBIAS < ±0.10       |
| Good          | 0.50 < RSR ≤ 0.60 | 0.65 < NSEC ≤ 0.75 | ±0.10 ≤ PBIAS < ±0.15 |
| Satisfactory  | 0.60 < RSR ≤ 0.70 | 0.50 < NSEC ≤ 0.65 | ±0.15 ≤ PBIAS < ±0.25 |
| Unsatisfactory| RSR > 0.70    | NSEC ≤ 0.50    | PBIAS ≥ ±0.25       |

The discharges of outlets of distributary canal 1-0-5C for different simulation scenarios using the SIC model are listed in table 2 for the 95% confidence level. Based on the criteria listed in table 3, the model gave good simulations for DPR, ranging from 60% Q to 100% Q at the head regulator of distributary canal 1-0-5C, where NSEC was very good for all scenarios. The RSR ratio was very good in two scenarios (100% Q, 80% Q) and good in scenarios for 70% Q and 60% Q at the head regulator.

6.2 Model validation

Model validation is the process of running the model using the measured data as input to make sufficient simulations for a local or complete network and minimising the differences; before using any model, it must be tested using several techniques. Moriasi et al. (2007) recommend using three main statistical techniques to evaluate model validity. The first one is the Nash-Sutcliffe efficiency coefficient (NSEC), the second is percent bias (PBIAS), and the third one is ratio of the root mean square error to the standard deviation of measured data (RSR).

The discharges of outlets of distributary canal 5C for different validation scenarios within the SIC model at the 95% confidence level are listed in table 4. It is evident that the model gives very good validation for a DPR of 90% Q and 85% Q, where the NSEC was very good (93% and 92.7%, respectively) for both scenarios and the RSR was also very good (28.5% and 33%, respectively). The model also gave good validation for a DPR of 60% Q where the NSEC was very good (89.7%) and the RSR was good (56%). The model further gave satisfactory validation for a DPR of 55% Q where NSEC was very good (82%) and the RSR was satisfactory (66%). It was thus confirmed that the SIC model gives good predictions for withdrawal discharges by canal outlets and water levels both upstream and downstream of all outlets for scenarios larger than 60% Q at the head regulator of the distributary canal, without using rotational bases. Where Q is less than 60% of its design value, the irrigation project management must use a rotational schedule.

### Table 4. Model Validation Statistics of SIC model for Distributary Canal 5 C with Different Scenarios at Confidence Level 95 %.

| Scenario        | PBIAS       | NSEC       | RSR        |
|-----------------|-------------|------------|------------|
| Scenario 90 % Q | -0.00332    | 0.93314    | 0.285252   |
| v. good         | v. good     | v. good    |            |
| Scenario 85 % Q | -0.018427   | 0.92720    | 0.329945   |
| v. good         | v. good     | v. good    |            |
| Scenario 60 % Q | 0.002002    | 0.89706    | 0.562554   |
| v. good         | v. good     | Good       |            |
7. Performance indicators.

7.1 Equity indicator \((P_E)\) for discharges at the outlet structures

Equity in any irrigation system refers to the degree of variability in water delivery; it can be defined as the provision of an equal proportion of water to all users reliant on the irrigation system. Another definition of the equity indicator states that it is the average of spatial variations of the ratio of delivered water to required water over a specified time period. This indicator \((P_E)\) is calculated as

\[
P_E = \frac{1}{t_1} \sum_{t=1}^{n} CV_R \frac{Q_d}{Q_r}
\]  

(4)

Where \(CV_R\) is the spatial coefficient of variation of the ratio \((Q_d/Q_r)\) over the region \(R\), \(Q_d\) is the delivered discharge and \(Q_r\) is the required discharge during the time period \(t\). If the value of \(P_E\) approaches zero, this suggests a high degree of equity. The limits of the Indicators of Water Delivery Performance were recommended by Molden and Gates (1990), and these are listed in table 5.

Table 5. Limits of Indicators of Water Delivery Performance (Molden and Gates, 1990)

| Performance Indicator | Poor  | Fair  | Good  | Excellent |
|------------------------|-------|-------|-------|-----------|
| \(P_D\)                | >0.20 | 0.11-0.20 | 0.00-0.10 |          |
| \(P_A\)                | <0.80 | 0.80-0.89 | 0.90-1.00 |          |
| \(P_E\)                | >0.25 | 0.11-0.25 | 0.00-0.10 |          |

7.2 Dependability indicator for discharges at the outlet structures \((P_D)\)

The dependability indicator \((P_D)\) can be defined from the farmers' point of view as the ability to obtain irrigation water at the desired time and in the required locations along the canal. Another definition of \(P_D\) is the temporal uniformity of released or delivered water discharge, \(Q_d\), against the intended or scheduled design water discharge, \(Q_r\), over region \(R\). This indicator is thus expressed as

\[
P_D = \frac{1}{R} \sum_{R=1}^{R} CV_T \frac{Q_d}{Q_r}
\]  

(5)

Where \(CV_T\) is the coefficient for temporal variation of the ratio \((Q_d/Q_r)\) during a time period \(t\) over a region. According to Molden and Gates (1990), and as shown in table 5, if the values of \(P_D\) are bounded within 0.00 to 0.10, this indicates the release of irrigation water at the specific period of time will be better and more dependable, whereas values within 0.11 to 0.20 indicate only fair performance of the canal system; where \(P_D > 0.20\), poor performance is implied.

7.3 Adequacy indicator \((P_A)\)

Adequacy specifies the range for which the total water releases or deliveries are sufficient to match the water requirements in specific cropping seasons. It deals with the ratio of actual delivery to the required amounts of water for effective crop irrigation. This indicator expresses the ability of an irrigation canal network to match the required or design water quantity:

| Scenario 55 \% Q | -0.03257 | 0.82114 | 0.660911 |
|------------------|----------|---------|----------|
| v. good          | v. good  | Satisfactory |
he actual delivery performance ratio to decide whether the deliveries (75% of total period) and fair in 2 month (17% of the year). In the second year, the equity was good for 10 months (83% of the year) and fair in 2 months (17% of the year). Equity, as measured by \( P_E \), was thus good in 18 months (75% of total period) and fair in 6 months (25% of total period). Figure 1 explains the variation of the equity indicator \( P_E \) for discharges of distributary canal 1-0-5C during the period Oct. 2014 to Sep. 2016. The main conclusion derived from the figure is that the equity indicator \( P_E \) was good in general except for May and October each year.

**Table 6. Classification of Outlet Structures in Distributary canal 1-0-5C based on the Monthly Equity Indicator \( P_E \) for the study period (Oct. 2014 to Sep. 2016).**

| Study period | Good Equity | Fair Equity | Poor Equity |
|--------------|-------------|-------------|-------------|
| Winter (Oct. 2014 - Mar. 2015) | 5 | 1 | 0 |
| Summer (Apr. 2015 – Sep. 2015) | 3 | 3 | 0 |
| Whole Water year (2014 -2015) | 8 | 4 | 0 |
| Winter (Oct. 2015 - Mar. 2016) | 5 | 1 | 0 |
| Summer (Apr. 2016 – Sep. 2016) | 5 | 1 | 0 |
| Whole Water year (2015 - 2016) | 10 | 2 | 0 |
| Whole study Period (Oct. 2014 - Sep. 2016) | 18 | 6 | 0 |
| Ratio % | 75 | 25 | 0 |
8.2 Dependability indicator ($P_D$) of discharges at the outlet structures

The values of the dependability indicator ($P_D$) of discharges at the outlets were measured as a function of the temporal coefficients of the variation indicator $CvT(q_a/q_d)$, where $q_a/q_d$ is the ratio of actual discharge to the demanded discharge at the outlet structure. Similarly, $Q_a/Q_d$ is the ratio of actual discharge to the demanded discharge at the head regulator of the distributary canal. Monthly as with the equitability indicator ($P_e$), the dependability indicator ($P_D$) was best in the months of November and December in winter, and June and July in summer; the months of October and May showed minimum dependability in terms of water delivery. The best dependability was 5.6% at outlet 3L, located in the head reaches, seen in the first season (Oct. 2014 to Mar. 2015), whereas the lowest dependability was, 16.8% at outlet 9L located in the tail reaches, in the second season (Apr. 2015 to Sep. 2015).

Table 7 summarises the seasonal and annual values of the dependability indicator ($P_D$) for discharges of outlets in distributary canal 1-0-5C during the study period (Oct. 2014 to Sep. 2016). The values of the dependability indicator were classified based on the scale of $P_D$ suggested by Molden and Gates (1990).

| No. | Outlet | Design discharge of Outlet (m$^3$/sec) | Mean $P_D$ / Outlet (Winter (Oct. 2014 - Mar. 2015) and Summer (Apr. 2015 - Sep. 2015)) | Mean $P_D$ / Outlet (Average annual) | Mean $P_D$ / Outlet (Winter (Oct. 2015 - Mar. 2016) and Summer (Apr. 2016 - Sep. 2016)) | Mean $P_D$ / Outlet (Average annual) |
|-----|--------|----------------------------------------|---------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------------------------------------|-----------------------------------|
| 1   | 262-1R | 0.078                                  | 0.082 0.109 0.096 0.100 0.121 0.111 0.103                                      |                                   |                                                                                 |                                   |
| 2   | 262-2L | 0.108                                  | 0.072 0.093 0.083 0.102 0.119 0.111 0.097                                      |                                   |                                                                                 |                                   |
| 3   | 718-2R | 0.105                                  | 0.063 0.101 0.082 0.078 0.073 0.076 0.079                                      |                                   |                                                                                 |                                   |
| 4   | 718-3L | 0.108                                  | 0.056 0.078 0.067 0.071 0.077 0.074 0.071                                      |                                   |                                                                                 |                                   |
| 5   | 1301-3R| 0.110                                  | 0.076 0.092 0.084 0.072 0.111 0.092 0.088                                      |                                   |                                                                                 |                                   |
| 6   | 1301-4L| 0.108                                  | 0.083 0.095 0.089 0.071 0.086 0.079 0.084                                      |                                   |                                                                                 |                                   |
| 7   | 1614-4R| 0.115                                  | 0.096 0.118 0.107 0.105 0.096 0.101 0.104                                      |                                   |                                                                                 |                                   |
| 8   | 1721-5L| 0.100                                  | 0.086 0.144 0.115 0.121 0.118 0.120 0.117                                      |                                   |                                                                                 |                                   |
As shown in Table 7, the dependability in winter was better than in summer in both years because of the availability of irrigation water in the winter season. The dependability indicator was within 5.6% to 13.8% in the first season (Oct. 2014 to Mar. 2015); 7.1% to 16.8% in the second season (Apr. 2015 to Sep. 2015); 5.7% to 13.5% in the third season (Oct. 2015 to Mar. 2016); and 5.8% to 13.2% in the fourth season (Apr. 2015 to Sep. 2016). Annually, the second year (Oct. 2015 to Sep. 2016) had an average PD equal to 9.7%, which was better than that for the first year (Oct. 2014 to Sep. 2015), which had an average PD equal to 9.9%.

The dependability indicator (PD) was classified as good for nine months in the first year (75.5% of the year), fair in two months (16.7% of the year), and poor in 1 month (about 8% of the year). Again, the dependability indicator (PD) was good in nine months of the second year (75.5% of the year), fair in 2 months (16.7%) and poor in 1 month (about 8%). The noticeable conclusion from Figure 2 is that the dependability indicator (PD) was good in all head outlets except outlets 5L and 6L in the middle reaches, and fair in all outlets in the tail reaches (7R, 8L, 8R, and 9L).

![Figure 2](image)

**Figure 2.** Dependability indicator (PD) of the discharges at the outlets of distributary canal 1-0-5C for the study period (Oct. 2014 to Sep. 2016).
8.3 Adequacy indicator at outlets ($P_A$)
Table 8 summarises the seasonal and annual values of the adequacy indicator ($P_A$) for distributary canal 1-0-5C during the study period. Based on the scale suggested by Molden and Gates (1990), as shown in table 5, the values of the adequacy indicator ($P_A$) were classified and are listed in table 9.

Table 8. Seasonal and annual means of adequacy indicator ($P_A$) of discharges at the outlets of distributary canal 1-0- 5C during the period (Oct. 2014 to Sep. 2016).

| No | Outlet | Design discharge of Outlet (m³/sec) | Mean $P_A$ / Outlet | Mean $P_A$ / Outlet | Mean $P_A$/outlet / Study period |
|----|--------|------------------------------------|---------------------|---------------------|---------------------------------|
| 1  | 262-1R | 0.078                              | 0.980               | 0.834               | 0.907                           | 0.889                           | 0.833                           | 0.861                           | 0.884                           |
| 2  | 262-2L | 0.108                              | 0.906               | 0.772               | 0.839                           | 0.789                           | 0.749                           | 0.769                           | 0.804                           |
| 3  | 718-2R | 0.105                              | 0.905               | 0.770               | 0.838                           | 0.877                           | 0.743                           | 0.810                           | 0.824                           |
| 4  | 718-3L | 0.108                              | 0.852               | 0.827               | 0.840                           | 0.826                           | 0.756                           | 0.791                           | 0.815                           |
| 5  | 1301-3R| 0.110                              | 0.968               | 0.980               | 0.974                           | 0.940                           | 0.839                           | 0.890                           | 0.932                           |
| 6  | 1301-4L| 0.108                              | 0.966               | 0.907               | 0.936                           | 0.997                           | 0.844                           | 0.920                           | 0.928                           |
| 7  | 1614-4R| 0.115                              | 0.674               | 0.564               | 0.619                           | 0.677                           | 0.671                           | 0.674                           | 0.646                           |
| 8  | 1721-5L| 0.100                              | 0.722               | 0.586               | 0.654                           | 0.755                           | 0.717                           | 0.736                           | 0.695                           |
| 9  | 2189-5R| 0.120                              | 0.695               | 0.622               | 0.658                           | 0.727                           | 0.713                           | 0.720                           | 0.689                           |
| 10 | 2189-6L| 0.100                              | 0.795               | 0.777               | 0.786                           | 0.768                           | 0.788                           | 0.778                           | 0.782                           |
| 11 | 2615-6R| 0.078                              | 0.948               | 0.865               | 0.907                           | 0.959                           | 0.891                           | 0.925                           | 0.916                           |
| 12 | 2615-7L| 0.100                              | 0.927               | 0.917               | 0.922                           | 0.987                           | 0.922                           | 0.954                           | 0.938                           |
| 13 | 3106-7R| 0.078                              | 0.673               | 0.540               | 0.607                           | 0.712                           | 0.547                           | 0.629                           | 0.618                           |
| 14 | 3106-8L| 0.100                              | 0.563               | 0.497               | 0.530                           | 0.648                           | 0.545                           | 0.597                           | 0.563                           |
| 15 | 3557-8R| 0.110                              | 0.552               | 0.418               | 0.485                           | 0.572                           | 0.519                           | 0.546                           | 0.515                           |
| 16 | 3557-9L| 0.058                              | 0.675               | 0.517               | 0.596                           | 0.618                           | 0.570                           | 0.594                           | 0.595                           |
| Max|        | 0.980                              | 0.980               | 0.974               | 0.997                           | 0.997                           | 0.922                           | 0.954                           | 0.938                           |
| Min|        | 0.552                              | 0.418               | 0.485               | 0.572                           | 0.519                           | 0.546                           | 0.546                           | 0.515                           |
| Average|       | 0.800                              | 0.712               | 0.756               | 0.796                           | 0.728                           | 0.762                           | 0.759                           |                                  |

Table 9. Classification of the Outlet Structures in distributary canal 1-0-5C based on Monthly Adequacy Indicator ($P_A$) for the study period (Oct. 2014 to Sep. 2016).

| Study Period          | Good Adequacy | Fair Adequacy | Poor Adequacy |
|-----------------------|---------------|---------------|---------------|
| Winter (Oct. 2014 - Mar. 2015) | 7             | 1             | 8             |
Table 8: Adequacy of discharges of distributary canal 1-0-5C during the study period

| Season                  | Months   | Adequacy Indicator (PA) | Ratio |
|-------------------------|----------|-------------------------|-------|
| Summer (Apr. 2015 – Sep. 2015) | 3        | 3                       | 10    |
| Whole Water year (2014 -2015) | 10       | 4                       | 18    |
| Winter (Oct. 2015- Mar. 2016) | 4        | 3                       | 9     |
| Summer (Apr. 2016 – Sep. 2016) | 1        | 4                       | 11    |
| Whole Water year (2015-2016) | 5        | 7                       | 20    |
| Whole study Period (Oct. 2014 - Sep. 2016) | 15       | 11                      | 38    |
| Ratio                   |          |                         |       |
|                         | 23.4 %   | 17.2 %                  | 59.4 % |

As with the dependability indicator, the adequacy indicator (PA) was best in November and December in the winter and June and July in summer; in October and May, the adequacy indicator (PA) recorded minimum values of adequacy, as shown in table 8.

Seasonally, as shown in table 8, the adequacy in winter was better than in summer for the whole period because of the availability of irrigation water in the winter season. The adequacy indicator was within 0.552 to 0.98 in the first season (Oct. 2014 to Mar. 2015); 0.418 to 0.98 in the second season (Apr. 2015 to Sep. 2015); 0.572 to 0.997 in the third season (Oct. 2015 to Mar. 2016) and 0.519 to 0.922 in the fourth season (Apr. 2015 to Sep. 2016).

From table 9, the adequacy indicator (PA) in the first year was good in about four months (31.25% of the year), fair in about one month (12.5% of the year) and poor in about seven months (56.25% of the year). The adequacy indicator (PA) in the second year was good in about two months (15.62% of the year), fair in about three months (21.87% of the year) and poor in 62.5% (about 7 months) of the second year. For the total period, the adequacy indicator (PA) was good in about 6 months (23.4% of the period), fair in about four months (17.2% of the period) and poor in 14 months (56.4% of the period). The noticeable conclusion from figure 3 is that the adequacy indicator (PA) of discharges of the distributary canal was generally poor (below 0.80) during the whole study period (Oct. 2014 to Sep. 2016).

9. Conclusions
The following conclusions can be extracted:
1. The analysis and evaluation of equitability (PE), dependability (PD), and adequacy (PA) of the discharges of the outlet structures at the distributary canal level showed a large gap between demand flows and the actual delivery of the outlets; this may cause problems in terms of water

![Figure 3. Adequacy indicator (PA) for the discharges of distributary canal 1-0-5C during the study period](image)
distribution, especially where the discharge at the distributary head regulator is less than 0.70 of the design discharge.

2. The discharge measurements at the head regulator of the distributary canal were less than design discharge; however, the outlets did not display the same behaviours. In general, the equity indicator (PE) was good for the distributary canal except for May and October each year. Equity was good in 18 months (75% of the total period) and fair in six months (25% of the total period).

3. The dependability indicator (PD) was good in all head outlets, but only fair for middle outlets (5L and 6L) and all tail outlets. The dependability indicator showed an increasing trend from head to tail outlets due to the high variation of discharges in that direction. The dependability was better in winter seasons than summer seasons for both years.

4. For the total study period, the adequacy indicator (PA) was good in about six months, fair in about four months, and poor in 14 months. The adequacy indicator (PA) of the discharges of the distributary canal was poor in general during the study period. The adequacy in winter was better than in summer for the two years because of the improved availability of irrigation water in the winter season.

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