4.4 Minutes of Discussions for Explanation of Draft Report (March 2005)

MINUTES OF DISCUSSIONS
ON THE BASIC DESIGN STUDY
ON THE PROJECT FOR REHABILITATION OF THE WATER TRANSMISSION TUNNELS
IN DAMASCUS CITY
IN THE SYRIAN ARAB REPUBLIC
(EXPLANATION ON DRAFT REPORT)

In November 2004, the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the Basic Design Study Team on the Project for Rehabilitation of Water Transmission Tunnels in Damascus City (hereinafter referred to as "the Project") to Syrian Arab Republic (hereinafter referred to as "Syria"), and through discussion, field survey, and technical examination of the results in Japan, JICA prepared a draft report of the study.

In order to explain and to consult with the Government of Syria on the components of the draft report, JICA sent to Syria the Draft Report Explanation Team (hereinafter referred to as "the Team"), which is headed by Mr. Kazuhide Nagasawa, Resident Representative, Syria Office, JICA, from March 11 to 17, 2005.

As a result of discussions, both parties confirmed the main items described on the attached sheets.

Damascus, March 17, 2005

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Leader
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The Syrian Arab Republic

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ATTACHMENT

1. Components of the Draft Report

The Government of Syria agreed and accepted in principle the components of the draft report explained by the Team.

2. Japan's Grant Aid scheme

The Syrian side understands the Japan's Grant Aid Scheme and the necessary measures to be taken by the Government of Syria as explained by the Team and described in Annex-4 of the Minutes of Discussions signed by both parties on July 22.

3. Schedule of the Study

JICA will complete the final report in accordance with the confirmed item and send it to the Government of Syria by July, 2005.

4. Other relevant issues

4-1. Project components

Main components of the project are shown in Annex-1.

4-2. Undertakings of the Syrian side

The Syrian side will take the necessary measures, as described in Annex-2, for smooth implementation of the Project, as a condition for the Japanese Grant Aid to be implemented.

4-3. Technical assistance

The Team explained a plan of technical assistance (so-called Soft Component) to DAWSSA. DAWSSA will allocate counterpart personnel for the activities.

4-4. Visibility

DAWSSA will disseminate the Project under Japan's grant aid for public awareness, through a television program and installation of billboards under the expense of DAWSSA. DAWSSA will install display panels disseminating the Project under Japan's grant aid at DAWSSA's tariff paying counter office.

ANNEX-1 : Main components of the project

< Rehabilitation >

Item	Contents
Leakage prevention at the upper part of the Old Tunnel	FRP lining
Repair work for concrete deterioration in the Old Tunnel	Injection of epoxy resin into cracks with at least 0.2mm wide
	Polymer cement mortar filling for concrete exfoliation and falling parts
	Cleaning and polymer cement mortar filling for corroded and exposed reinforcing bars
Measures against surface corrosion of round steel pipes for reinforcing the Old Tunnel	Pipe cleaning, rust scraping, polymer cement painting
Replacement of corroded gates of the Old Tunnel	Replacement of the gates at the entrance and siphon
Measures against structural cracks in the Old Tunnel	Repair by rock bolt
Reinforcing of bridge girder of Aqueduct No.3	Sticking carbon textile on the bridge girder.
Repair work for concrete deterioration in the New Tunnel	Removal of surface deterioration (15 cm), installation of waterproof board, resin mortar filling

< Equipment >

Item	Contents
Equipment for tunnel inspection, repair material	Crack scale Concrete test hammer Convergence tape Water level meter Flow meter Polymer cement mortar waterproof material
Displacement measurement equipment for the Wali underground reservoir	Laser measurement equipment Laser reflector Strain gauge and reading equipment

< Technical Assistance (Soft Component) >

Item	Contents
Tunnel inspection and repair	Preparation of inspection and repair work manuals Institution-building for systematic tunnel inspection Instruction on usage of inspection equipment Instruction on simple repair technique
Displacement measurement of the Wali underground reservoir	Learning of displacement measurement skill by provided equipment Acquisition of recordkeeping method Instruction on appraisal of crack characteristics classification

ANNEX-2 : Undertakings of the Syrian Side

[Construction Stage (Cooperation by the Japanese Grant Aid)]

1. To provide necessary data and information;
2. To obtain permissions, licenses, and other authorization, if necessary;
3. To secure a lot of land (approx. 500 m^2) for a temporary stock yard in DAWSSA Figeh and Wali Office;
4. To provide facilities for distribution of electricity and other incidental facilities necessary for construction work in and around the site;
5. To stop water flow in the tunnels in accordance with construction schedule;
6. To ensure prompt unloading and customs clearance of the construction materials and equipment purchased or brought under the Japan's Grant Aid at ports of disembarkation in Syria;
7. To ensure prompt execution of the rehabilitation work;
8. To accord Japanese nationals whose services may be required in connection with the supply of the products and services under the verified contracts such facilities as may be necessary for their entry into Syria and stay therein for the performance of their work;
9. To bear commissions, namely advising commissions of an Authorization to Pay (A/P) and payment commissions, to the Japanese foreign exchange bank for the banking services based upon the Banking Arrangement (B/A);
10. To exempt Japanese nationals from customs duties, internal taxes and fiscal levies which may be imposed in Syria with respect to the supply of the products and services under the verified contracts;
11. To bear all the expenses, other than those covered by the Japan's Grant Aid, necessary for the Project;
12. To allocate counterpart personnel and necessary budget;
13. To increase the visibility of the Project;
14. To accord the relevant stakeholders and concerned authorities in collaboration with the Consultant and the Contractor;
15. To install measurement devices in the new Wali Reservoir in collaboration with the Consultant;
16. To allow the Consultant and the Contractor to use the two battery cars in the new tunnel, when required;
17. To provide office space for the Consultant members assigned for technical assistance;

[Operation Stage]

18. To ensure that the facilities constructed under the Japan's Grant Aid be maintained and used properly and effectively for the Project;
19. To conduct periodical inspection and repair work of the tunnels; and
20. To continue displacement measurement of the Wali reservoir.

5. References

5.1 Water Leakage Investigation of Tunnel

5.1.1 Background and Object of Investigation

According to DAWSSA, more than 40% of water is leaking out of the old tunnel. On the other hand, leakage out of the new tunnel is very little. It is important to control leakage during tunnels are in service, because it cause instability and waste of precious water resources.

In this investigation, DAWSSA leakage investigations were verified. Also the incoming and outgoing water inside the tunnels were determined through observing the discharges and site inspection. In addition, for the old tunnel, observation at different points were carried out to determine leaking points using gates in the tunnel.

5.1.2 Review of Existing DAWSSA Investigations

DAWSSA documents and reports regarding leakage investigations in old and new tunnels were examined and the methodology and accuracy of the investigations were verified.

5.1.2.1 Results of Existing DAWSSA Investigations

DAWSSA reports on leakage in both old and new tunnels are shown in the following table. In September 2003, DAWSSA had conducted leakage investigation inside the old tunnel and reported that the leakage rate out of the tunnel was 46.7%. Later, in October 2004, another investigation was carried out and the reported leakage rate was 60.3%. This result gave high values of leakage. DAWSSA conducted discharge measurements only between the Figeh entrance and the Wali exit. Therefore, there was no record for leakage out of other locations inside the tunnel.

In 2003, DAWSSA carried out investigations on leakage inside new tunnel and the leakage rate was between 0.1% and 1.5% which was too small to be considered. DAWSSA water leakage investigations along old and new tunnels are shown in Appendix- 1.

Table1.1 Results of DAWSSA Water Leakage Investigation on Old Tunnel

No.	Date	Transferred Discharge from Figeh	Received Discharge at Wali	Amount of Leakage	Leakage Ratio
1.	2003/9/30	1,500 m^3/hr	800 m^3/hr	700 m^3/hr	46.7%
2.	2004/10/23	1,890 m^3/hr	750 m^3/hr	1,140 m^3/hr	60.3%

Source: DAWSSA

Table1.2 Results of DAWSSA Water Leakage Investigation on New Tunnel

No.	Date	Transferred Discharge from Figeh	Received Discharge at Wali	Amount of Leakage	Leakage Ratio
1.	2003/6/23	3.894 m^3/s	3.890 m^3/s	0.004 m^3/s	0.1%
2.	2003/6/25	5.324 m^3/s	5.244 m^3/s	0.080 m^3/s	1.5%
3.	2003/6/26	7.596 m^3/s	7.533 m^3/s	0.063 m^3/s	0.8%

Source: DAWSSA

5.1.2.2 Methodology of DAWSSA Leakage Investigations

Methodology of DAWSSA leakage investigations were grasped out of DAWSSA materials and through DAWSSA counterparts reporting and could be summarized as follows:

Observing Water Transmitted from Figeh

- Water depths were measured by DAWSSA through the readings of calibrated ultrasonic sensor fixed inside the old tunnel at TD223 and a calibrated ultrasonic sensor fixed inside the new tunnel at TD81. Both sensors are installed about 100m D/S of Figeh entrance.
- Rating curves based on Manning equation of discharge were used to calculate the discharges in the tunnels against water depths under the sensors.
- Discharges were determined and recorded during the period of the investigation.

Water Converted out of Old and New Tunnels

- All outlets along old and new tunnels were, completely, shut off except for leaking water.

Measuring Discharge at Old Wali Reservoir (Old Tunnel)

- All water flowing through the tunnel was collected at the old Wali reservoir. During the investigations, other incoming water in the tunnel and also outgoing water from the reservoir were not allowed.
- Water level inside Wali reservoir was recorded every period of time.
- Using the periodical recorded water levels, periodical volumes accumulated during the investigation were calculated and discharges were determined.

Measuring Discharge at New Wali Reservoir (New Tunnel)

- All water flowing through the tunnel was collected at the new Wali connected reservoirs No.1 and No.2 (or No.3 and No.4). During the investigations, other incoming water in the tunnel and also outgoing water from the connected reservoirs were not allowed.
- Water level inside Wali connected reservoirs was recorded every period of time.
- Using the periodical recorded water levels, periodical volumes accumulated during the investigation were calculated and discharges were determined.

As mentioned above, recorded discharges at Figeh entrance and Wali exit were compared and rate of leakage was calculated. Flow chart of DAWSSA leakage investigation in old and new tunnels is illustrated in Figure1.1.

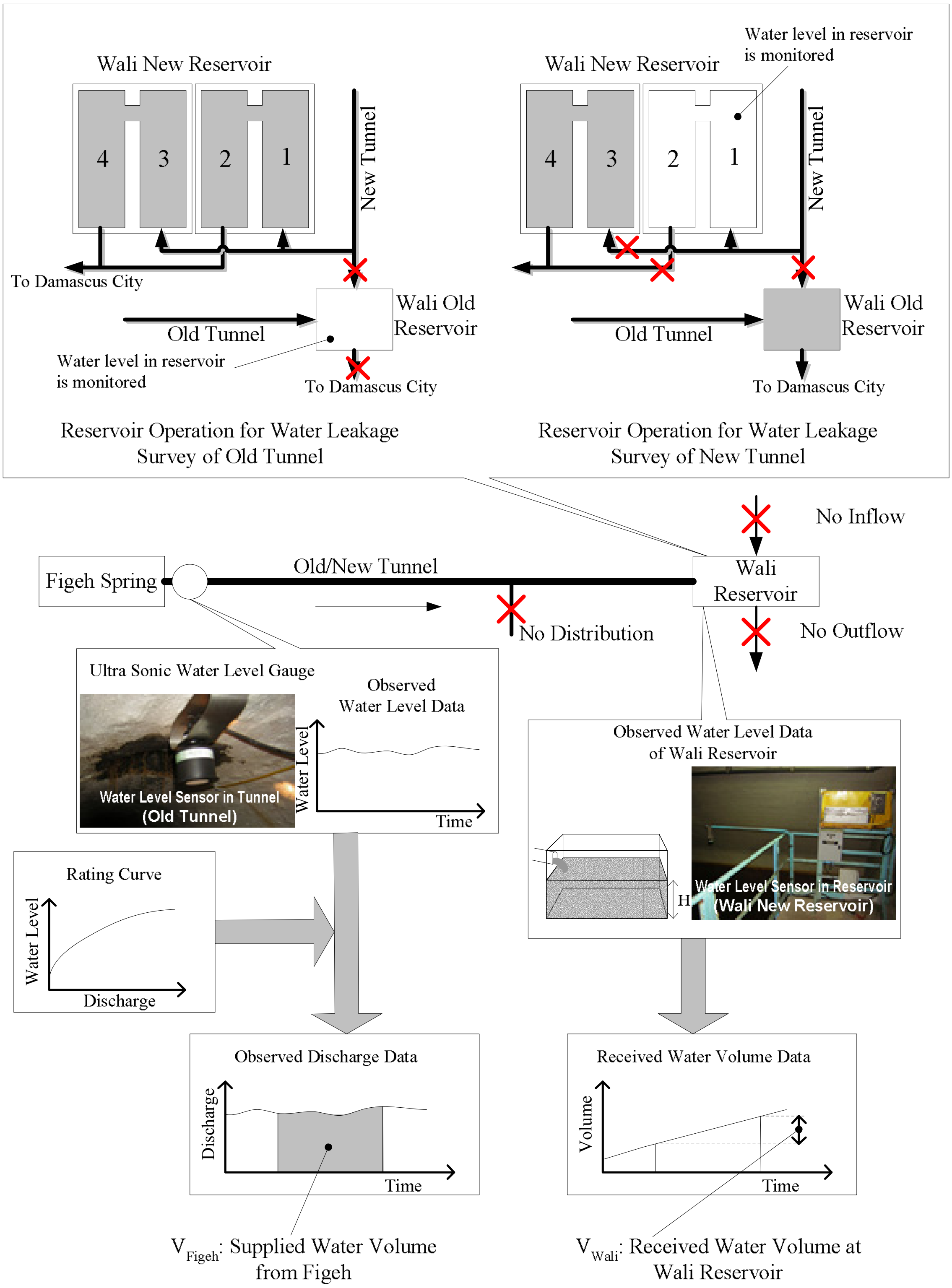


Figure1.1 Flow Chart of DAWSSA Leakage Investigation in Old and New Tunnels

5.1.2.3 Issues on Existing DAWSSA Investigations

According to the result of study on the methodology of DAWSSA leakage investigations, issues on discharge measurement at Figeh in the old tunnel were found as mentioned below.

(a) Issues on Discharge Measurement at Figeh in Old Tunnel

In regard to discharge measurement at Figeh, two issues are considered as follows.

Location of Water Level Sensor

DAWSSA is monitoring water levels inside old tunnel based on the readings of the ultrasonic sensor located at TD223 and estimating discharges. According to the investigation by the study team, flow conditions near the sensor are unstable. In this area, flow condition changes between subcritical and super critical or undular jump. When a flow has a surface like this tunnel, transition of flow condition affects to water velocity or depth, and makes surface is instability. Therefore, measuring discharge at this location is very difficult.

Rating Curves

Manning equation of discharge used by DAWSSA to calculate the discharges in the tunnels against water depth were based on uniform flow.

Manning formula used by DAWSSA is:

$$Q = (86.609 - 10.78h) \times \sqrt{0.0015} \times A \times R^{2/3}$$

Where, h is the water depth (m), A is the cross section of flow (m^2) and R is the hydraulic radius (m). The cross section area and hydraulic radius were calculated taking average tunnel width as 1.3m. Parameters used in the above formula are as listed below. Applicability of rating curve is based on these parameters.

- Bed slope of tunnel : i = 0.0015 (=1/867),
- Manning coefficient of friction : n = 1/(86.609-10.78h)

The bed slope of tunnel around the sensor was 0.0015. However, according to Figure1.2, the bed slope of tunnel is calculated as i=0.00583(=1/171) using bed elevation from TD195 to TD225. The bed slope of tunnel has an effect on flow condition in the tunnel. The flow condition in the tunnel can be estimated theoretically by the Froude number as shown in Figure1.3. It seems that bed slope of i=0.0583 is appropriate around the sensor considering actual condition (30cm of water depth) when the discharge measurement was carried out. In addition, bed slope of tunnel is suddenly changed at this section. Therefore, there is possibility that the uniform flow can not appear at this section.

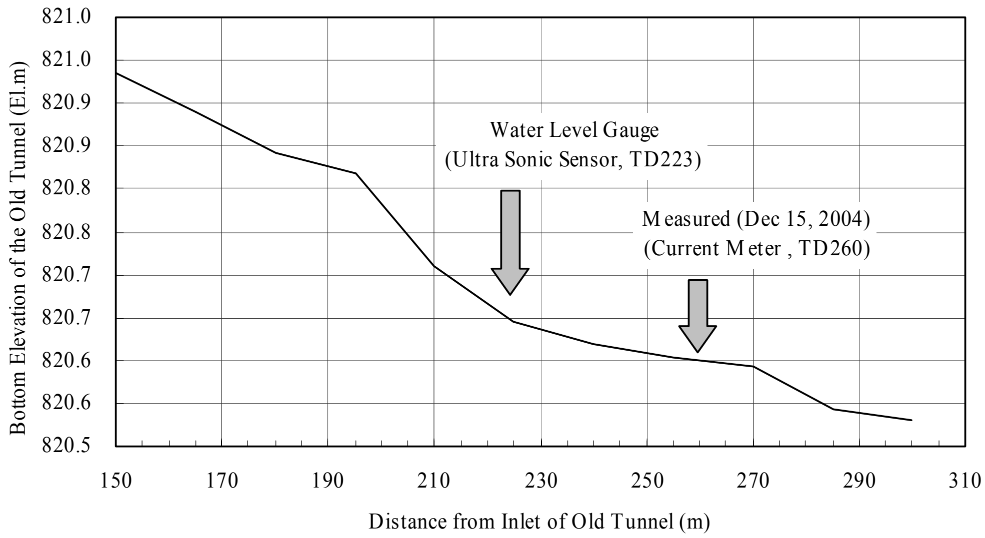
Manning coefficient in the formula depends on water depth. However, nobody recognize in DAWSSA why is this formula was applied.

Study team considers that Manning coefficient can be fixed without any relation with water depth. Because, Manning coefficient is the parameter for roughness of surface. It will increase by any chance as time goes on.

Study team carried out discharge measurement at TD260, where 1) bed slope is steady 2) uniform flow can be applied. Calculation results are shown in Figure1.4. In this figure, following conditions are applied.

- Sectional area and hydraulic radius are calculated based on rectangular section with 1.35m width
- Bed slope of tunnel is calculated as i=0.0008(=1/1250), based on TD240 to TD270
- Manning coefficient is 0.015

When study team carried out discharge measurement, water depth was 0.3m. Therefore, 0.012 is calculated as Manning coefficient applying the formula mentioned above. This value is appropriate as concrete surface. However, considering quality of construction and long lapse of time after construction, this value seems slightly smaller. Therefore, there was possibility that DAWSSA calculated leakage of water rather than actual volume.



Source: Old Tunnel Profile Survey, 1940-41, DAWSSA

Figure1.2 Longitudinal Cross Section of Old Tunnel near Water Level Sensor

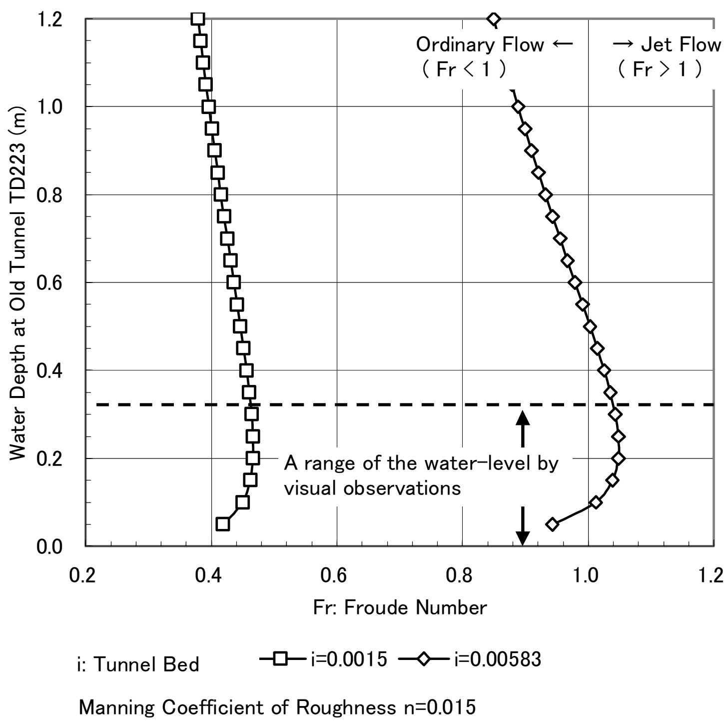


Figure1.3 Specification of Flow around Sensor in Old Tunnel

Time	Observed		Q_{uni} (m^3/s)	dQ = (Q_{uni} - Q_{obs}) (m^3/s)
	h (m)	Q_{obs} (m^3/s)		
11:20	0.320	0.317	0.480	0.163
11:30	0.328	0.328	0.497	0.169
11:40	0.325	0.323	0.491	0.167
11:50	0.322	0.322	0.484	0.163
12:00	0.325	0.325	0.491	0.165
12:10	0.320	0.322	0.480	0.158
12:20	0.330	0.331	0.501	0.170
12:30	0.320	0.320	0.480	0.160
12:40	0.330	0.322	0.501	0.179
12:50	0.325	0.310	0.491	0.181
13:00	0.325	0.313	0.491	0.178
13:10	0.315	0.308	0.469	0.162
13:20	0.322	0.321	0.484	0.163
13:30	0.320	0.305	0.480	0.175
13:40	0.325	0.305	0.491	0.185
13:50	0.325	0.310	0.491	0.180
14:00	0.320	0.309	0.480	0.171
14:10	0.322	0.305	0.484	0.180
14:20	0.320	0.300	0.480	0.180

Average Q_{obs} = 0.316
Average Q_{uni} = 0.487
Average dQ = 0.171

* Note
Q_{obs} : Measured discharge by current meter
Q_{uni} : Estimated discharge by rating curve provided by DAWSSA

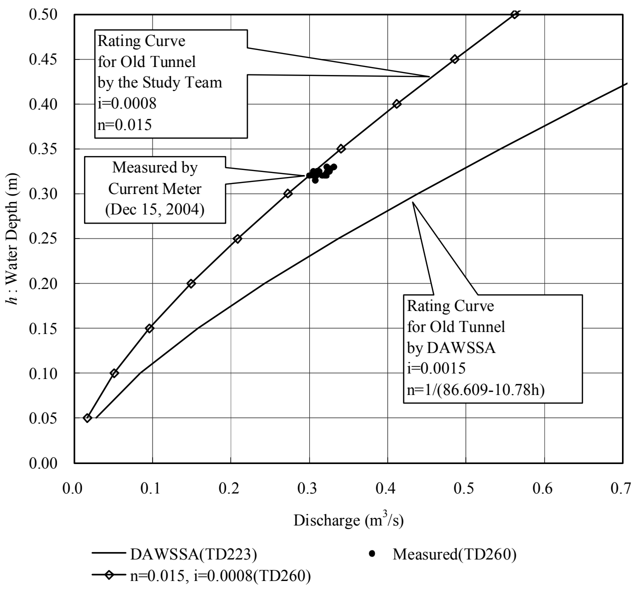


Figure1.4 Comparison between Actual Discharge and DAWSSA Rating Curve

(b) Improvement of Discharge Monitoring Process

The review of DAWSSA leakage investigations clarified that there is a problem in observing the discharge through the old tunnel. Monitoring transmitted discharge from Figeh is not only to determine amount of leaking water but also it is important for daily water supply process as a whole and improvement is highly recommended.

As an improvement measure, installing standard sharp-crested weir downstream of the existing ultrasonic sensor installed at TD223, in order to measure discharge, is to be mentioned. Flow condition at this section is sub-critical flow because bed slope of tunnel is gentle, i=0.00111(=1/900), from TD225 to TD270 as shown in Figure1.2. When a weir locates in sub-critical flow, water surface of upstream makes back water. Therefore, hydraulic jump around the sensor is moved to upstream than present condition, and flow condition around the sensor will be stable. By measuring water depth by the existing ultrasonic sensor, practical discharge can be estimated.

A simple aluminum weir is installed at the downstream of the existing ultrasonic sensor as shown in Figure1.5. According to DAWSSA members, it is not utilized for measuring discharges. However, it is necessary to confirm this weir is useful or not.

Figure1.5 Simple Weir inside Old Tunnel (about TD290)

Application of rating curves is estimated by the bed slope of tunnel and Manning coefficient. Therefore, following investigation is recommended for further maintenance.

- Survey of longitudinal profile to confirm bed slope from Figeh to the existing ultrasonic sensor
- Estimation of Manning coefficient using measured discharge by a current meter and compare with present value.

5.1.2.4 Summary of Review on Methodology of Leakage Investigation in Old Tunnel

Results of review on methodology of leakage investigations in old tunnel are summarized in Table1.3.

(a) Summary

The most important issue concerning the leakage investigations is discharge measurement at Figeh. Flow condition around the existing ultrasonic sensor can not assume as uniform flow, so that it is difficult to apply rating curve. Even the water level was measured at sub-critical flow section in a hydraulic jump, Manning coefficient is calculated smaller than that of estimated value by the study team. Therefore, DAWSSA estimates bigger transmitted discharge from Figeh. In addition, there is possibility that leakage rates reported by DAWSSA were much higher than actual in the old tunnel.

Table1.3 Evaluation of DAWSSA Leakage Investigation inside the Old Tunnel

Measuring Location	Methodology	Comments	Remarks
Discharges from Figeh Entrance	• Measuring water depth by a sensor fixed at TD223. • Discharge is calculated by Manning equation according to water depth.	• Flow conditions near TD223 are unstable and therefore affect flow measurements. In this area, flow condition changes between subcritical and super critical or undular jump. • Tunnel bed slope is not constant and applying Manning equation on the entire tunnel length with same slope is inappropriate.	• High leakage rate is attributed to high evaluation of the discharge from Figeh entrance.
Water Volume Collected at Wali Reservoir	• Measuring the volume of water collected at the old reservoir.	• No problem	• In order to avoid the effect of discharge adits…etc, water level in the reservoir is, adequately, measured within the range 1.5m to 4.0m.
Flow Diverted from the Old Tunnel	• Shut down all intakes from the tunnel.	• No problem	

Other detailed results on methodology of leakage investigations by DAWSSA are mentioned below.

(b) Measurement of Discharges at Wali Reservoir

In order to measure discharge at Wali reservoir, raising water level in the reservoir is observed and accumulated volume of water during the investigation period is calculated. The principle of measurement is rather simple and therefore there is no problem with the measuring methodology. To ensure measurement accuracy, DAWSSA observes water levels inside the reservoir by means of ultrasonic water gauge.

In order to minimize the effect of errors in water level observations, long enough observation period was taken into consideration and, hence, as much water volume as possible can be collected. On the other hand, as the difference between tunnel bed and reservoir bed at the exit is 4.0m and in order to avoid any miscalculation in discharge, accumulated water level in the reservoir should not get above the tunnel bed level at its connection with the reservoir so that no back water would be formed. Also, outlet channel to Damascus city, stairs and other structures exist at 1.5m height from the reservoir bed which make it difficult to calculate accurately water volume within this layer. DAWSSA carried out measurements inside the reservoir within the limit of 1.5m and 4.0m from the reservoir bed.

Figure1.6 shows a photo inside the old reservoir, while Figure1.7 shows the relation between bottom levels of the old tunnel and the old reservoir.

Figure1.6 Old Wali Reservoir (a photo taken from old tunnel exit to the reservoir)

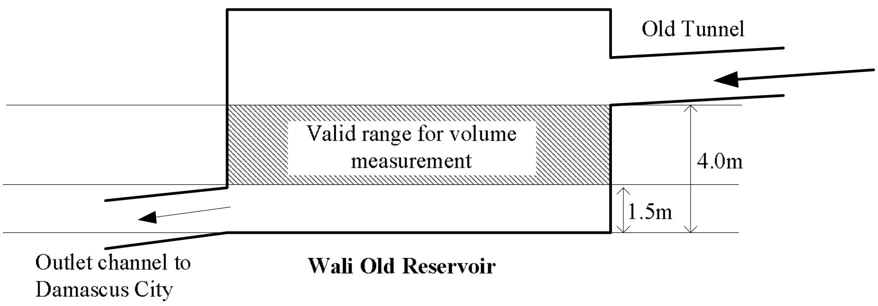


Figure1.7 Sketch of the Connection between Old Tunnel and Old Reservoir

(c) Outlets and Converted Discharges

In order to determine the leakage along the old tunnel and to ensure the accuracy of the measurements, it was adequate that all outlets from old tunnel were cutoff during the investigation period.

At the moment, there are no flow meters installed at the outlets to record the outgoing water from the tunnel and thus it was not possible to observe the water conversion rates during usual operations. For future maintenance management, it is desirable to thoroughly observe continuous discharges and also to install measuring devices along the tunnel.

5.1.2.5 Summary of Review on Methodology of Leakage Investigation in New Tunnel

Results of review on methodology of leakage investigations in old tunnel are summarized in Table1.4.

(a) Summary

Similar to the old tunnel, the water discharge transmitted from Figeh was calculated according to the observed water depth and by using Manning uniform flow formula. It was considered that uniform flow can be applied, since cross section and bed slope within tunnel reaches are constant different from the old tunnel. Specifically, other remarkable issues were not found and DAWSSA leakage investigations along the new tunnel were adequate.

Table1.4 Evaluation of DAWSSA Leakage Investigation inside the New Tunnel

Measuring Location	Methodology	Comments	Remarks
Discharges from Figeh Entrance	• Measuring water depth by a sensor fixed at TD81. • Discharge is calculated by Manning equation according to water depth.	• Manning equation is applicable to calculate discharge.	
Water Volume Collected at Wali Reservoir	• Measuring the volume of water collected at Wali reservoirs.	• No problem	
Flow Diverted from the New Tunnel	• Shut down all intakes from the tunnel.	• No problem	

Other detailed results on methodology of leakage investigations by DAWSSA are mentioned below.

(b) Discharge Measurement at Figeh

Similar to old tunnel, DAWSSA is monitoring water levels and measuring discharges inside old tunnel based on the readings of the ultrasonic sensor located at TD81. Also, a gauge point sensor is installed at TD86 to, automatically, measure water depth and velocity. However, this sensor is no operating recently.

Calculated rating curve is utilized to observe the discharges inside the new tunnel. As, the tunnel bed slope is almost constant and the tunnel cross section is almost uniform, it is appropriate to use the curve in local discharge calculation. The standard cross section of the tunnel at a point close to the water level sensor is shown in Figure1.8.

Figure1.9 shows the rating curve for the discharge in the new tunnel. Appendix-2 gives the values of the discharge in regard to water depth. The parameters used for predicting the rating curve are given here below:

- Bed slope : $i = 0.00127$, and
- Manning coefficient of friction : $n = 0.0116$

The values of the parameters were considered adequate and there was no problem to use the rating curve for estimating the discharge transmitted from Figeh.

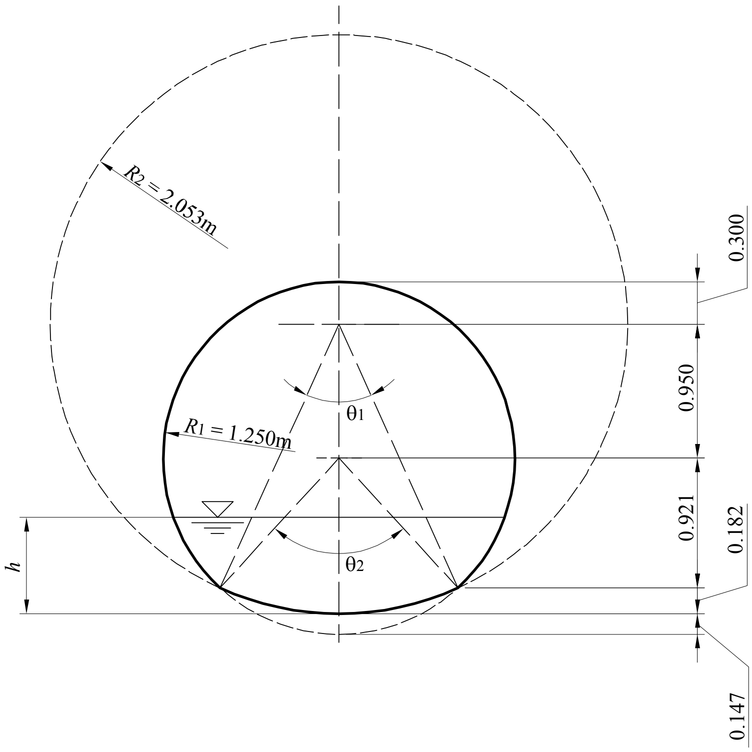


Figure1.8 New Tunnel Standard Cross Section

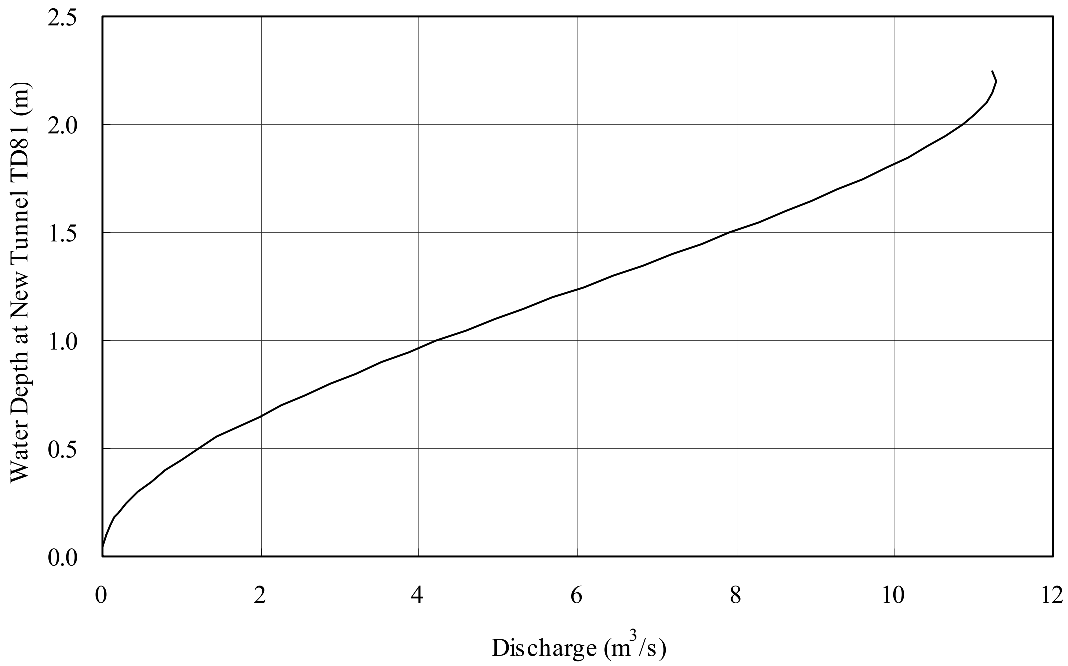


Figure1.9 Rating Curve for New Tunnel

(c) Discharge from Figeh

On the other hand, the study team calibrated the discharge entering the tunnel by measuring the water head on the weir crest, applying the weir discharge equation, compared the results with the discharges given by Manning equation and listed in DAWSSA discharge tables, and confirmed the adequacy of the discharge tables. Appendix- 3 shows the new tunnel weir calibration and hydraulic design.

(d) Measurement of Discharges at Wali Reservoir

In order to calculate the amount of water leaking along the new tunnel, the change in water level in Wali reservoirs was basically observed. The surface area of the connected reservoirs (No.1 & No.2 or No.3 & No.4) is 3840m^2 and therefore maintaining the measurement accuracy was important. Yet, to avoid the effect of water surface fluctuation, ultrasonic water level sensor was installed.

The process of measuring discharge at Wali reservoir is basically simple and the accuracy of observing water levels was high enough so that the measurement process was thought appropriate and accepted.

Figure1.10 shows a photograph of the connection between the new Wali reservoir with the new tunnel exit, while Figure1.11 shows both the plan and longitudinal cross section of the new reservoir.

Figure1.10 Condition of the New Reservoir with the Exit of New Tunnel

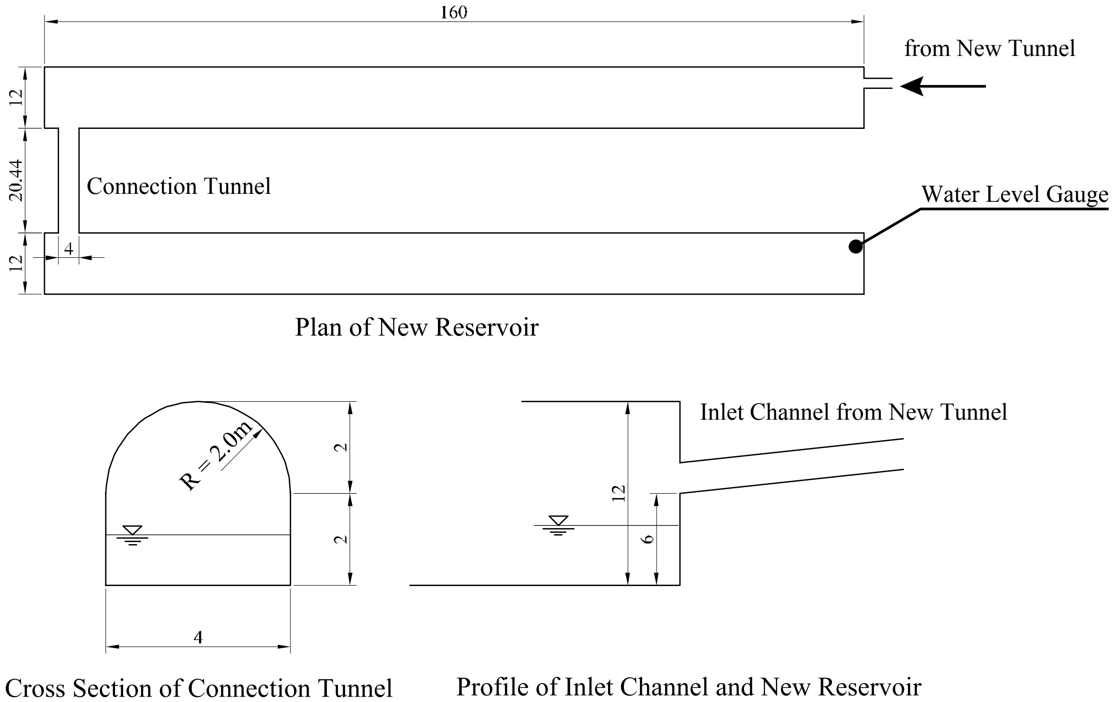


Figure1.11 Plan, Longitudinal Elevation of the New Tunnel and Cross Section of the Connecting Tunnel

(e) Outlets and Converted Discharges

Along the new tunnel, there are only two outlets, Bassima at TD 2490 and Al Ayoun at TD 9475 which were completely closed during the investigation periods in order to maintain an accurate observation for the leakage along the new tunnel.

Meanwhile, discharge out of the two outlets was automatically observed which made it possible to monitor both Figeh entrance and Wali reservoir.

5.1.3 Site Investigation Methodology

The study team carried out leakage investigation to grasp whole quantity of leakage and their location in both old and new tunnels considering methodology of leakage investigation by DAWSSA and review results.

5.1.3.1 Old Tunnel

During field investigations conducted by the study team in December 2004, discharge inside the old tunnel was around 300 *l*/s, water depth was between 25 and 30 cm, velocity of flow was about 0.8 m/s and the conditions inside the tunnel were helpful enough to conduct discharge measurements. In addition, there are nine possible gated accesses to get inside the old tunnel.

The study team grasped leakage longitudinally at each section utilizing water level gauges and velocity meters

(a) Investigation Locations

Accessible locations which were selected for observations inside the old tunnel are shown in both Table1.5 and Figure1.12.

In the preparatory study, leaking was doubted out of siphon reach. On the other hand, mixed tree roots and cracks inside the tunnel along the parts from Figeh entrance to Gate No.7 at TD 3090 and from TD8800 to TD10800 were identified.

Aiming at a detailed observation of discharge fluctuation inside the old tunnel, the above mentioned was considered and the accissable locations were selected.

Table1.5 Investigation Locations

Location (TD)	Access	Remarks
260	Tunnel entrance	
997.5	Entering from Gate No.5 and moving inside tunnel	Water flooding in from a pipe
1,655	Gate No.5	
3,090	Gate No.7	
8,379	Gate No.20	
12,300	Gate No.32 (U/S of Siphon)	
12,620	Gate No.33 (D/S of Siphon)	
16,254	Gate No.38	

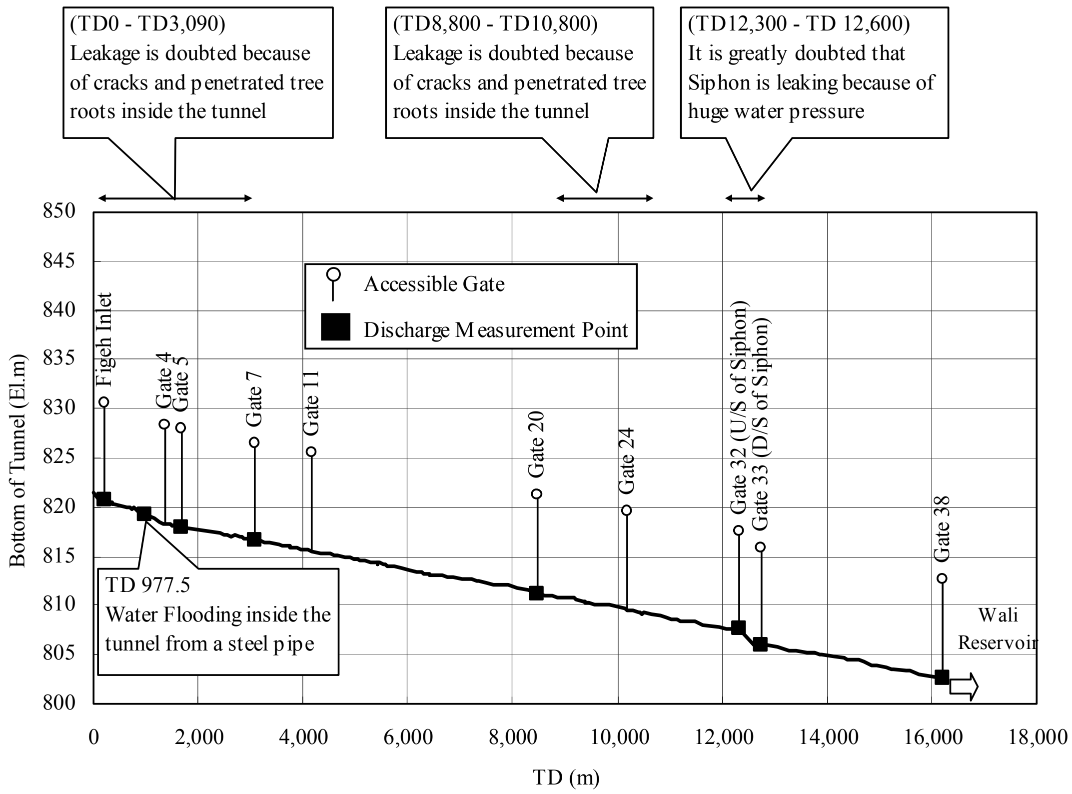


Figure1.12 Accessible Gates and Investigation Locations

(b) Investigation Schedule

With DAWSSA cooperation, the following conditions basically considered for investigations were prepared and seven locations were selected for discharge observations.

- Maintaining constant discharge almost along the old tunnel by fix opening of gate at the diversion weir to the tunnel.
- Closing up all outlets along the old tunnel during the investigation period.

Actually, discharge from Figeh to the diversion weir is not constant, because seepage from underground is not stable all time. Consequently, water depth at upstream of the gate fluctuates sometimes, so that detailed gate operation is necessary to keep steady flow. However, such operation is impossible. Therefore, the study team observed discharge between Figeh and Gate No.5 to grasp difference of discharge from Figeh and estimated quantity of leakage.

Table1.6 shows the schedule of discharge observation along old tunnel.

Table1.6 Schedule of Discharge Observations along Old Tunnel

Date : 13/12/2004

Time	Location of Discharge Observation	Remarks
Till 8:00		All outlets along tunnel are closed
10:40 – 10:50	Figeh	Measurements were not possible at a distance 20m apart from the old tunnel entrance as the flow just after the diversion weirs at old and new tunnels is strongly disordered and because the time to enter and investigate inside the Siphon was limited by the military, re-measurement was considered.
11:45 – 12:15	Gate No.5 (TD1,655)	
12:45 – 13:15	Gate No.7 (TD3,090)	
13:35 – 13:55	Gate No.20 (TD8,379)	
15:05 – 15:25	Gate No.32 (U/S of Siphon, TD12,300)	
15:50 – 16:10	Gate No.33 (D/S of Siphon, TD12,620)	
17:00 – 17:20	Figeh (TD260)	The location was considered suitable for measurements as the flow was far stable than that near the old tunnel entrance.
18:20 – 18:40	Gate No.38 (Wali, TD16,254)	

(c) Methodology of Discharge Observation

Discharge observation was conducted by getting directly in the selected location, measuring the water depth by means of water level pressure gauge (in some cases, water depth was measured directly using a measure) and velocity by electromagnetic velocity meter. Old tunnel cross section and the points at which measurements were carried out are explained in Figure1.13. Discharge observation procedures are as follows:

Discharge Observation Procedures

1. Getting in the tunnel through the selected gate, checking the stability of flow nearby and, accordingly, selecting the most suitable location for measurements.
2. Measuring the width of the tunnel at which the measurements would be conducted and then determining the points where velocity of flow would be observed. As shown in Figure1.13, the points of velocity observations are at distance equal to 0.2 of the width from the wall sides and at the center of the section.
3. Water level was measured at the center of the section.
4. Velocity meter sensor was set at 0.6 of the water depth as shown in Figure1.13.
5. Velocity of flow was observed at the 3 points determined in step 2.
6. Repeating the steps from 3 to 5, five times and taking observation records eventually.

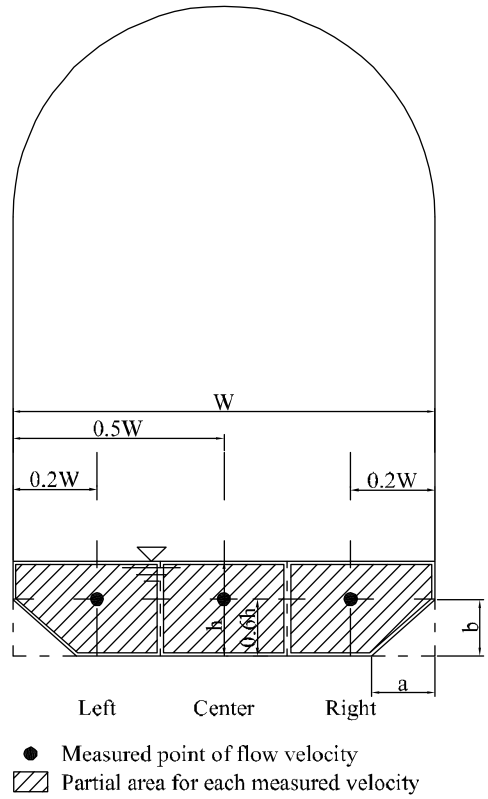


Figure1.13 Old Tunnel Discharge Observation Locations

The discharge was calculated using the recorded water depth and velocity at the 3 points as follows:

$$Q = v_{\mathrm{left}} A_{\mathrm{left}} + v_{\mathrm{center}} A_{\mathrm{center}} + v_{\mathrm{right}} A_{\mathrm{right}}$$

Where, *v*: velocity of flow, *A*: the cross section area at which velocity was observed, and left, center, right indicate the location at which velocity was measured.

The rate of flow at TD 977.5 where water is flooding in the tunnel through an old steel pipe was measured by filling a calibrated bucket by the flooding water and measuring the time.

5.1.3.2 New Tunnel

During December 2004 observations conducted by the study team, the discharge inside the new tunnel was about $5m^3/s$ and the velocity of flow was over 2m/s which made it difficult to measure the velocity through neither propeller type nor electromagnetic type velocity meters. Meanwhile, there is no access along the tunnel to directly observe the velocity of flow, and therefore, DAWSSA observation process was considered to calculate the leakage along the new tunnel.

Table1.7 shows the new tunnel discharge observation process, while Table1.8 shows the schedule of the observations.

Table1.7 New Tunnel Discharge Observation Process

Location & observation	Discharge Measurement Process	Remarks
Discharge at Figeh entrance	• Water level is recorded through the ultrasonic sensor installed at TD81 and the discharge is calculated using • DAWSSA rating curve.	
Outlets discharges Bassima (TD2,485) Al Ayoun (TD9,498)	• All outlets were fully closed during the investigation period.	It was planned to close all outlets completely. However, it was not possible and therefore, monitored and recorded outlets discharge at both Figeh and Wali control center were utilized.
Discharge at Wali reservoir	• Accumulated volume in New Wali reservoirs No.3 and No.4 was observed.	

Table1.8 Schedule of Discharge Observations along New Tunnel

Date：07/12/2004

Time	Location		
	Figeh Water Level Sensor (TD81)	Outlets (Bassima & Al Ayoun)	Wali Reservoir
12:00		• Closing all outlets. • Bassima was fully closed. • Al Ayoun could not be closed.	
12:20	Start of recording water depths (in 10 minutes interval)	Start of recording Al Ayoun discharge (in 10 minutes interval)	
15:20	Recording water levels	Recording Al Ayoun discharge	• Lowering water depth inside Wali reservoirs No.3 & No.4 to 1.5m.
15:25			• Closing outgoing valves on reservoirs No.3 and No.4. • Open all valves only to reservoirs No.3 and No.4 so that all new tunnel flow enters in. • Recording water level every 5 minutes.
16:30	End of water level recording	End of Al Ayoun discharge recording	• Observation was completed when water depth in the reservoirs reached 6.0m.

5.1.4 Investigation Results

5.1.4.1 Results of Old Tunnel Discharge Investigation

Results of old tunnel discharge investigation are shown in Table1.9 and Figure1.14. Figure1.15 also shows the amount of leakage per second for every 100m of the observed location. Appendix- 4 gives the record of water level, velocity of flow and calculated discharges.

The results can be summarized as follows:

- The ratio of the total leakage between Figeh and Wali is 27.5%.
- DAWSSA investigations put total leakage ratio at 46.7% and 60.3%, which were attributed clearly to errors in discharge measuring at Figeh. However, the result given by the study team confirms there was remarkable leakage, which necessitate some restoration.
- Despite DAWSSA assertion and preparatory study report that the Siphon reach is the most leaking location along the old tunnel, the results of the investigations do no support that claim.
- The part of the tunnel between Figeh and Gate No.5 has the highest leakage ratio. It was considered that there were not so many cracks or penetration of tree roots based on the preparatory study. However, the study team found some cracks newly, which seems the origin of leakage as mentioned later.
- The part of the tunnel around Gate No.5 has also the highest rate of leakage per 100m, which is 3.61 l/s/100m as shown in Figure1.15.
- Despite the assertion of big leakage in the area between Gate No.20 and U/S of the Siphon, the leakage ratio was around 2% out of the total. It can be said that there is actually no leakage if the error in measurement is neglected.

Table1.9 Results of Leakage Investigation along Old Tunnel (13/12/2004)

Measurement location	TD	Measured discharge (*l*/s)	Ratio of measured discharge to Figeh discharge	Ratio of discharge loss to Figeh discharge	Rate of discharge loss in stretch between upstream site of measurement	Discharge loss per unit length (*l*/s/100m)
Figeh	260	343.5	100.0%	0.0%		
					-15.3%	3.76
Gate No.5	1,655	291.1	84.7%	-15.3%		
					-7.0%	1.68
Gate No.7	3,090	266.9	77.7%	-22.3%		
					-2.8%	0.18
Gate No.20	8,379	257.2	74.9%	-25.1%		
					-1.8%	0.16
U/S of Siphon	12,300	250.9	73.0%	-27.0%		
					-0.1%	0.07
D/S of Siphon	12,620	250.7	73.0%	-27.0%		
					-0.4%	0.04
Wali	16,254	249.2	72.5%	-27.5%		

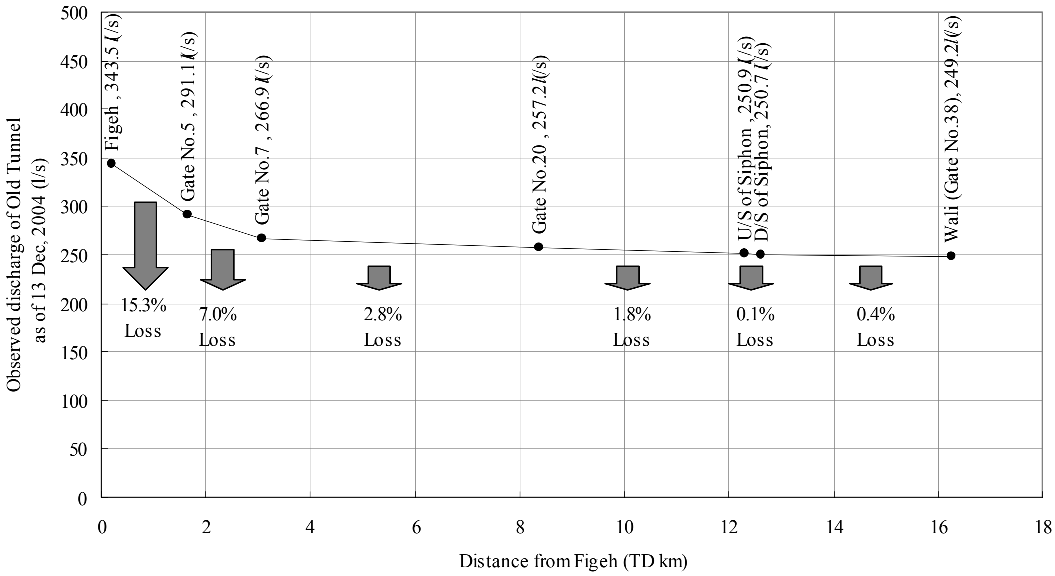


Figure1.14　Results of Leakage Investigation along Old Tunnel (13/12/2004)

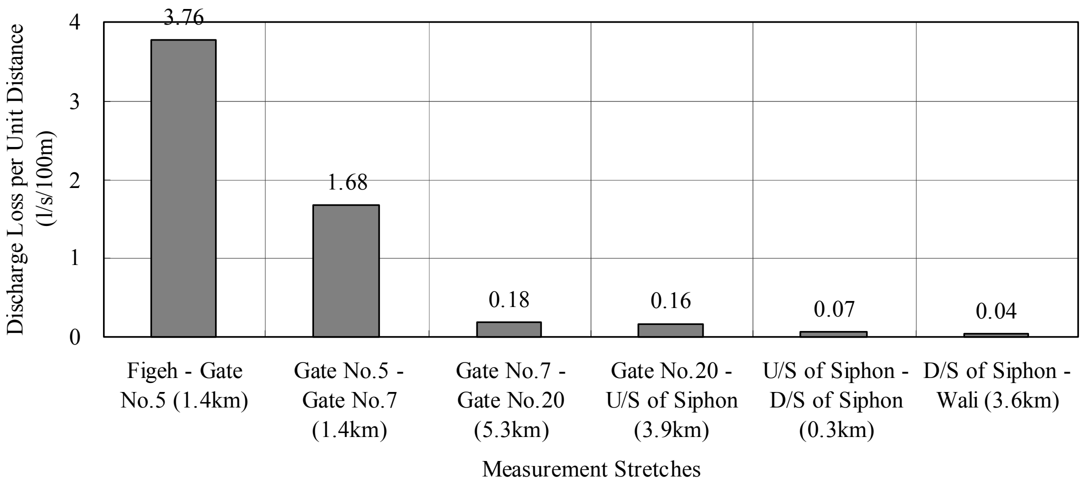


Figure1.15　Local Leakage Rate per 100m

5.1.4.2　Verification Investigations on Old Tunnel

Additional investigations were conducted to confirm results of the old tunnel discharge investigation as listed below.

for further verification.

Table1.10 Verification Investigation on the Results of Leakage Investigations along Old Tunnel

No.	Items to be Verified	Verification Investigation
1.	Confirming the stability of discharge at Figeh.	Simultaneously, discharge at both Figeh & Gate No.5 was re-observed.
2.	Confirming the location of the leakage between Figeh and Gate No.5	Cutoff transmitting water through old tunnel while investigating the tunnel bottom.
3.	Confirming leakage at Siphon	Drying up Siphon and conducting internal check.

(a) Simultaneous Discharge Observation between Figeh and Gate No.5

Simultaneous discharge observation between Figeh and Gate No.5 was conducted aiming at verifying the following,

- Conducting simultaneous discharge observation between Figeh and Gate No.5 and re-confirming the leakage ratio.

(On 13/12/2004, there was five hours difference of observation time between Figeh and Gate No.5 because of military circumstance.)

- Confirming the stability of discharge at Figeh by carrying out discharge observations every 10 minutes for 3 hours.

(Observation was carried out for two hours and 20 minutes at Gate No.5 due to DAWSSA's circumstance)

Results of simultaneous discharge observation are shown in Figure1.16. While, Appendix- 5 gives the record of water level, velocity of flow and calculated discharges. Results of simultaneous discharge observation confirmed the following:

i) Leakage between Figeh and Gate No.5

- Average leakage ratio was 14.9% which is the same ratio obtained out of the results of the investigation conducted on 13/12/2004.

ii) Stability of Discharge at Figeh

- The fluctuation of discharge at Fiigeh was about 30 *l*/s during three hours of investigation period, which is 10% of transmitted discharge. The discharge along the tunnel was decreasing in three hours of investigation.
- Figure1.16 shows the fluctuation in discharge at Figeh and Gate No.5 every 30 minutes. They coordinate with 30 minutes difference. For an average velocity of flow of about 0.8m/s and a distance of 1400m. The traveling time of the flow from Figeh to Gate No.5 is about 30 minutes, which confirm the adequacy of the investigation.

Time	Q_{Figeh} (*l*/s)	$Q_{GateNo.5}$ (*l*/s)
11:20	316.8	
11:30	**327.5**	
11:40	**323.1**	**264.5**
11:50	**321.5**	**280.5**
12:00	**325.4**	**276.3**
12:10	**321.9**	**269.1**
12:20	**331.4**	**265.9**
12:30	**319.8**	**270.5**
12:40	**322.3**	**273.7**
12:50	**310.1**	**281.7**
13:00	**312.7**	**264.3**
13:10	**307.7**	**272.0**
13:20	**321.4**	**273.0**
13:30	**305.1**	**270.5**
13:40	**305.5**	**268.1**
13:50	**310.2**	**265.5**
14:00	309.0	**260.6**
14:10	304.7	
14:20	300.1	

Q_{Max} (*l*/s)	331.4	281.7
Q_{Min} (*l*/s)	305.1	260.6
Q_{Ave} (*l*/s)	317.7	270.4
Q_{loss} (*l*/s)		47.3
Average Loss Ratio (%)		14.9%

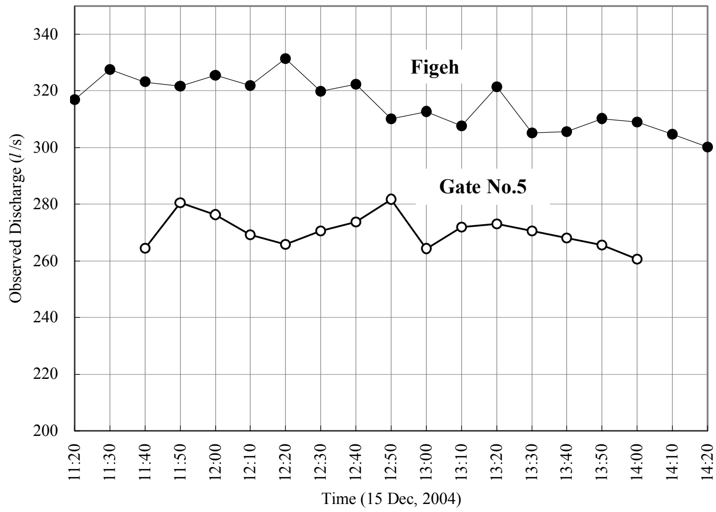


Figure1.16 Results of Simultaneous Discharge Observation (15/12/2004)

iii) Proposal based on results of simultaneous discharge observation

According to the results of simultaneous discharge observation, it is necessary to consider of observation time between investigation points to grasp appropriate discharge of leakage. Therefore, it is recommended to apply simultaneous discharge observation as same as this study for further maintenance.

(b) Investigation on the Section between Figeh and Gate No.5

In order to confirm the location of leakage along the section between Figeh and Gate No.5, internal investigation was carried out on 18/12/2004. In order to conduct investigation on the tunnel bed without difficulties, water running through old tunnel was shut down.

Many small cracks were found along the tunnel bed in the part between TD80 and TD 1200. In particular, there were cracks with about 2mm~3mm width between TD300 and TD330, and between TD1000 and TD1025. On the other hand, penetrated tree roots from a 4cm hole in the section between the wall and bottom of the tunnel at TD 1217 were observed and shown in Figure1.17.

In addition, rather much leakage was observed around the sealing of gate at the entrance of Figeh. The study team proposed to check Manning coefficient and conduct simultaneous discharge observation at each section of the tunnel for further maintenance. To control transmitted discharge from Figeh, it is necessary to replace the gate.

Figure1.17 Penetrated Roots into Old Tunnel at TD 1217

(c) Siphon Internal Investigation

As shown in Figure1.18, Siphon is consisting of four branches and leakage was doubted to be taken place along the asbestos pipe in particular. However, the results of the discharge observation along the tunnel gave little indication of leakage there. On 20/12/2004, water was cut off at the Siphon and the 1400 mm diameter asbestos pipe was investigated.

As a result, the concrete part of the Siphon was remarkably sound and though there were few joints out of place in some points, there was no sign of sand or dust and hence water tightness was maintained. On the other hand, while the surface of the earth part of the Siphon is ravine, there was no indication of water coming out from any location. Figure1.19 shows a photograph inside the asbestos concrete pipe of the Siphon.

As discussed above, the discharge observation investigation was adequate and no leakage was observed out of the Siphon.

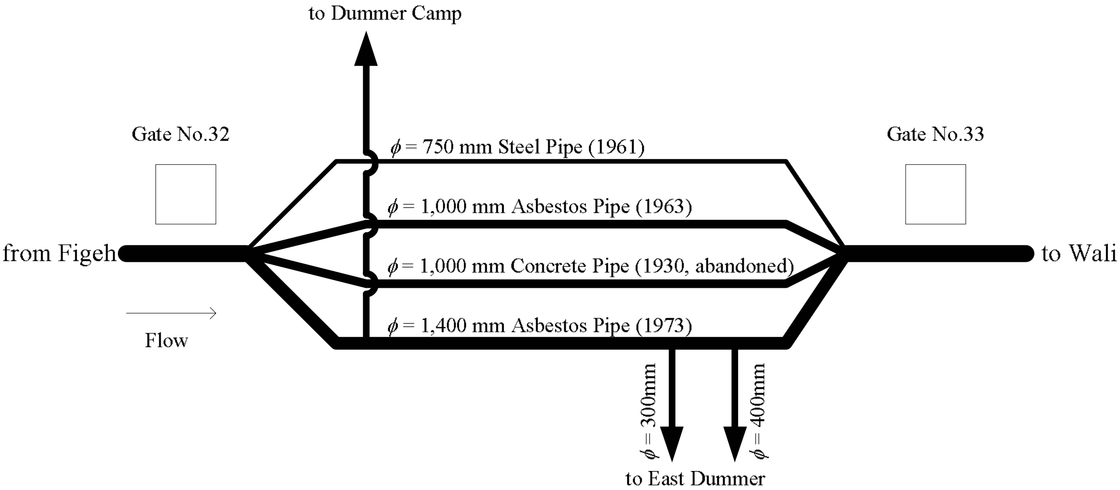


Figure1.18 Siphon

Figure1.19 Inside of Siphon

5.1.4.3 Results of Leakage Investigation along New Tunnel

(a) Results of Discharge Observation

It was planned to cutoff all discharges out f the two outlets along the new tunnel at Bassima (TD2490) and Al Ayoun (TD9475) during the leakage investigation. While, discharge out of Bassima could be cutoff, it was not possible for Al Ayoun. As a result, in order to evaluate the water balance in the new tunnel, the following 3 parameters were observed and the results were obtained as shown in Table1.11.

- Volume of water transmitted from Figeh (V_{Figeh})
- Volume of water out of Al Ayoun ($V_{Al\ Ayoun}$)
- Volume of water collected at Wali reservoir (V_{Wali})

Table1.11 Results of Water Leakage along New Tunnel

Time	Figeh		Al Ayoun	Wali Reservoir	
	Observed Water Depth (m)	Discharge (m^3/s)	Distributed Discharge (m^3/s)	Observed Water Depth of Reservoir (m)	Water Volume in Reservoir (m^3)
13:30	1.13	5.169	0.362		
13:40	1.14	5.243	0.378		
13:50	**1.13**	**5.169**	0.38		
14:00	**1.12**	**5.095**	0.385		
14:10	**1.12**	**5.095**	0.389		
14:20	**1.13**	**5.169**	0.391		
14:30	**1.12**	**5.095**	0.401		
14:40	1.14	5.243	0.403		
14:50	1.13	5.169	0.402		
15:00	1.13	5.169	**0.412**		
15:10	1.14	5.243	**0.422**		
15:20	1.13	5.169	**0.428**		
15:30	1.12	5.095	**0.445**		
15:40	1.12	5.095	**0.463**	2.64	**10,353**
15:50	1.13	5.169	0.464	3.36	**13,168**
16:00	1.13	5.169	0.466	4.09	**15,998**
16:10	1.12	5.095	0.464	4.81	**18,762**
16:20	1.13	5.169	0.464	5.52	**21,489**
16:30	1.13	5.169	0.463	6.23	24,215
16:40	1.14	5.243	0.462		
16:50	1.13	5.169	0.462		
17:00	1.13	5.169	0.463		

(b) New Tunnel Water Balance Calculation

Figure1.20 shows the new tunnel water balance relationship. Average travel time for the flow from both Figeh and Al Ayoun to Wali reservoir was determined. It was found that travel time of the flow from Figeh to Wali is about 110 minutes and from Al Ayoun to Wali was about 40 minutes. Travel time estimate is shown here below:

- Average velocity of flow inside the new tunnel during the investigation was 2.2 m/s
- Travel time of flow from Figeh (TD81) to Wali reservoir (TD14,353)
  = (14,353 – 81) / 2.2 / 60
  = 108 min ≈ 110 min
- Travel time of flow from Al Ayoun (TD2,485) to Wali reservoir
  = (14,353 – 2,485) / 2.2 / 60
  = 37 min ≈ 40 min

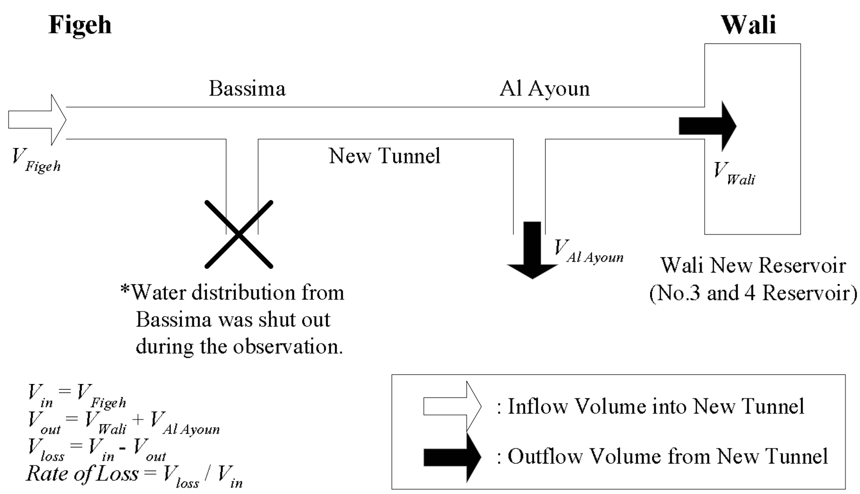


Figure1.20 The New Tunnel Water Balance Relationship

Table1.12 shows water volume calculations, while Table1.13 and Figure1.21 show the leakage ratio calculations. On the other hand, the Wali reservoir water level record at 16:30 was exempt as the water depth record was 6.23m which is over the balanced 6.00m.

Table1.12 Water Volume Calculations

Wali Reservoir		Figeh			Al Ayoun		
Observed Time	Cumulative Inflow Volume (m^3)	Observed Time	Supplied Water Discharge (m^3/s)	Cumulative Supplied Water Volume (m^3)	Observed Time	Distributed Water Discharge (m^3/s)	Cumulative Distributed Water Volume (m^3)
15:40	0	13:50	5.169	0	15:00	0.412	0
15:50	2,815	14:00	5.095	3,079	15:10	0.422	250
16:00	5,645	14:10	5.095	6,136	15:20	0.428	505
16:10	8,410	14:20	5.169	9,215	15:30	0.445	767
16:20	11,136	14:30	5.095	12,294	15:40	0.463	1,040

Table1.13 New Tunnel Leakage Ratio

Elapsed Time	$V_{in} = V_{Figeh}$ (m^3)	$V_{out} = V_{Wali} + V_{Al\ Ayoun}$ (m^3)	$V_{loss} = V_{in} - V_{out}$ (m^3)	Rate of Water Loss = V_{loss} / V_{in}
0:00	-	-	-	-
0:10	3,079	3,065	14	0.4%
0:20	6,136	6,150	-14	-0.2%
0:30	9,215	9,177	38	0.4%
0:40	12,294	12,176	119	1.0%

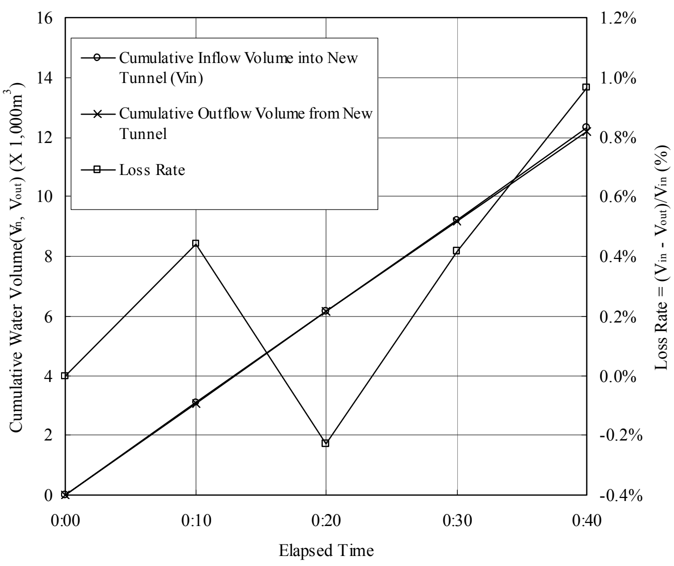


Figure1.21 New Tunnel Leakage Ratio

From the above mentioned, the new tunnel leakage ratio was 1.0% at the end of the investigation, which is approximately the same result obtained through DAWSSA investigation as shown in Table1.2. It can be said that there is no leakage out of the new tunnel if measurement error is considered.

5.1.5 Conclusions

Results of water leakage investigations on both old tunnel and new tunnel can draw the following conclusions.

Leakage Investigations on Old Tunnel

- Overall leakage ratio out of old tunnel reaches about 30%, and therefore rehabilitation is needed.
- Leakage ratio in the part between Figeh entrance and Gate No.5 (TD1655) is, in particular, very high followed by the leakage ratio in the part between Gate No.5 and Gate No.7.
- Despite assertion of big leakage out of Siphon, almost nothing was observed and it was judged as satisfactory due to no harmful damage.
- For further maintenance, following will be needed:
  - Confirmation of bed slope around the ultrasonic sensor located at TD223
  - Periodical estimation of Manning coefficient using measured discharge by a current meter and simultaneous discharge observation along the tunnel, and
  - Confirmation of useful of simple aluminum weir which is installed at the downstream of the existing ultrasonic sensor
- In addition, replacing of gate at the entrance of tunnel is needed to implement maintenance works as mentioned avobe.

Leakage Investigation of New Tunnel

- The leakage out of new tunnel is approximately null.

Appendix- 1 DAWSSA Water Leakage Investigation Results

(1) Old Tunnel Leakage Investigation on September 2003

Memory

Water losses in the old tunnel

According To the most recent leakage mesurment held on the 30/9/2003 Dawssa team discover the following result:

- Sended quantity 1500 m^3/~~day~~ hour ≈ 36000 m^3/day
- Received quantity (the end of the Tunnel) 800 m^3/~~day~~ hour 19400 m^3/day. the lossed water quantity 16600 m^3/day.

the original report is made in arabic by Directorate of production in Dawssa.

Deputy general direction

[illegible] : 1/10/2003 [illegible]

(2) Old Tunnel Leakage Investigation on October 2004

OLD TUNNEL.

Water Leakage Measurement Report.

The Old Tunnel leakage test was conducted on the 24 of October 2004 by following the procedures listed below:

1- Keeping the water level stable, in the old small Wali reservoir, in 150 cm. water depth.
2- Closing the isolating valves which connect this reservoir with the big one.
3- Closing the outlet of the distribution lines Ø1000 - Ø 500.

30 minutes after starting the water depth Measurement, the total measured depth became 250 cm. and when doing the mathematical calculations, the result shows that this is equivalent to a water flow of 750 m3/h.

If we take into consideration the flow sent from Figeh site at the beginning of the old tunnel with 1890 m3/h capacity, we easily found that the water leaks for: 1890 – 750 = 1140 m3/h.

Careful check for the whole existing outlet was conducted.

Notice : This test was conducted on the 23rd of October 2004 with flow around 900 m3/h and no water received in Wali reservoir after 4 hours.

Eng. Mounther AMEEN　　Eng. Faisal ADWAN

Director of exploitation and maintenance dept.

Eng. Marwan SOUMAN

(3) New Tunnel Leakage Investigation on June 2003

SR/4R 002J 5/8

NEW TUNNEL

Date of test	Sended flow m3/sec	Received flow m3/sec	Deference m3/sec	Deference m3/day
25/6/2003	5.324	5.244	0.08	6912
26/6/2003	7.596	7.533	0.063	5443

average quantity of losses
in the new tunnel $\frac{6912+5443}{2}$ =

6200 m³/day.

30/9/2003

Director of studies and design

(4) New Tunnel Leakage Investigation on June 2003

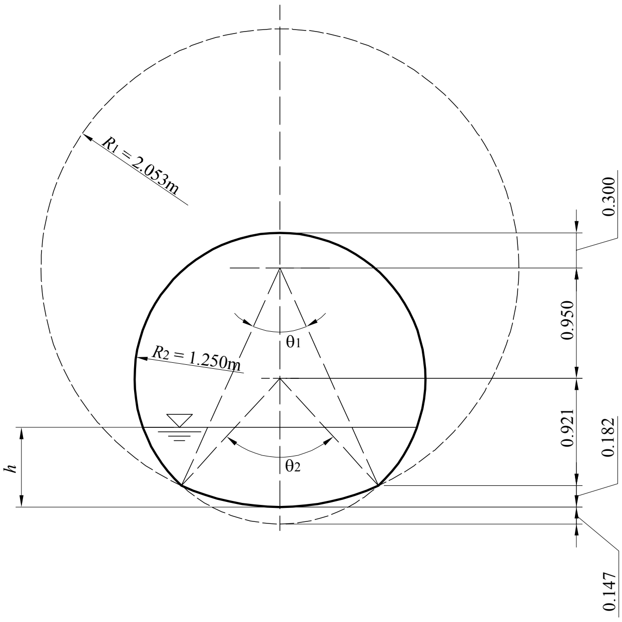
New Tunnel

تجربة تدقيق التصريف في النفق الجديد بالطريقة الحجمية

Date	الابر الهيدرومترية (Point Sensor)	التصريف م3/ ثا (Q m³/s)	معايرة الخزان م3/ ثا (Tank Calibration m³/s)		الفرق م3/ ثا (Difference m³/s)	اليومي م3 / يوم (Daily Discharge m³/d)	العداد الصوتي م3/ ثا (Ultrasonic Sensor m³/s)	ملاحظات (Remarks)
2003/6/22	50.00	2.74	2.58	+	0.16	13824	3.8	التجربة غير دقيقة (Test error)
2003/6/23	67.4	3.894	3.89	+	0.004	346	4.9	
2003/6/25	87.2	5.324	5.244	+	0.08	6912	5.7	
2003/6/26	117.7	7.596	7.533	+	0.063	5443	7.04	

Fish   Wali

As shown in the right hand figure, the new tunnel cross section composes two arches of different radii, R_1 = 2.053m at water depth up to 0.182m and R_2 = 1.250m for water depth above 0.182m



DAWSSA measures the discharge inside the tunnel through Manning equation of discharge where wet section dimensions are calculated according to water depth observed by means of water level sensors installed at TD81 and TD86. Parameters used in Manning equation for calculating discharge are as follows:

- Tunnel Bed Slope : 0.00127
- Manning Coefficient of Roughness : 0.0116 (= 1/86.2)

(i) If $0 < h < 0.182$m

$$\theta_1 = 2\cos^{-1}\left(\frac{r_1 - h}{r_1}\right)$$

Wetted Perimeter $S_1 = r_1\ \theta_1$

Flow Cross Section Area $A_1 = \frac{r_1^{\ 2}}{2}(\theta_1 - \sin\theta_1)$

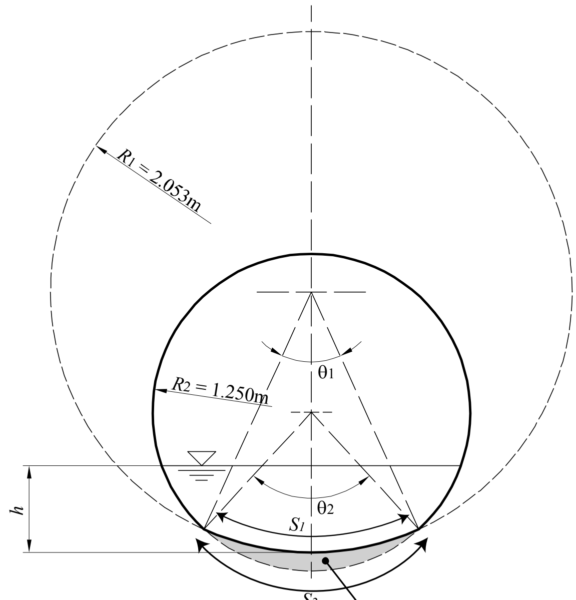
then、Hydraulic Radius R_1: $R_1 = \frac{A_1}{S_1} = \frac{r_1}{2\theta_1}(\theta_1 - \sin\theta_1)$

(ii) If $h \geq 0.182$m

$h' = h + 0.147$

$$\theta_2 = 2\cos^{-1}\left(\frac{r_2 - h'}{r_2}\right)$$

if $dS = S_2 - S_1$, the area between the two arches under the transaction points dA is determined as follows (see figure to the right)



dS = 0.1142m

dA = 0.1748m^2

then, wetted perimeter S_2, flow cross section area A_2 and hydraulic radius R_2 are given as follows:

$S_2 = r_2\theta_2$+0.1142

$$A_2 = \frac{r_2}{2}(\theta_2 - \sin\theta_2) - 0.1748$$

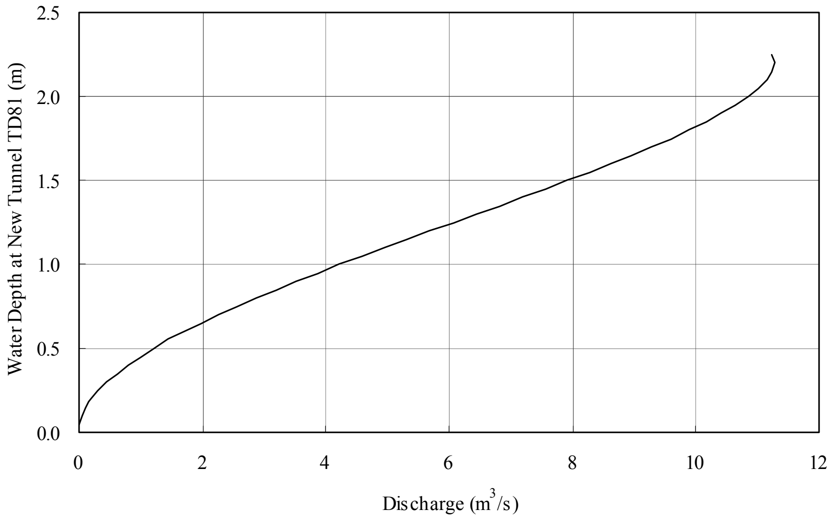
$$R_2 = \frac{A_2}{S_2} = \frac{\frac{r_2}{2}(\theta_2 - \sin\theta_2) - 0.1748}{r_2\theta_2 + 0.1142}$$

Incorporating the above mentioned parameters in Manning equation, the discharge at any depth is calculated as:

$$Q = \frac{A}{n} R^{2/3} i^{1/2}$$

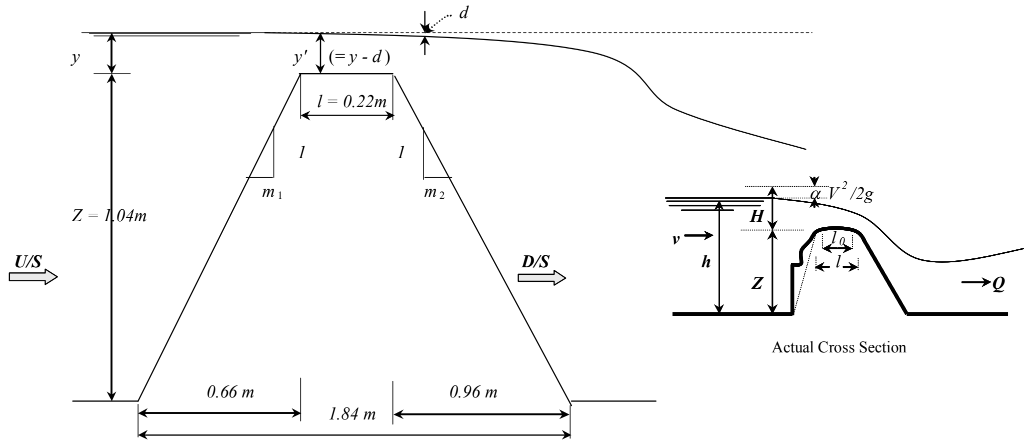
Accordingly, the rating curve of the new tunnel is shown in the next page.

h (m)	θ_1 (rad)	θ_2 (rad)	S_1 (m)	A_1 (m^2)	S_2 (m)	A_2 (m^2)	S (m)	A (m^2)	R (m)	v_{uni} (m/s)	Q_{uni} (m^3/s)
0.05	0.221	0.569	0.908	0.030	1.423	0.180	0.908	0.030	0.033	0.317	0.010
0.10	0.313	0.639	1.287	0.085	1.599	0.251	1.287	0.085	0.066	0.501	0.043
0.15	0.385	0.704	1.579	0.155	1.759	0.329	1.579	0.155	0.098	0.654	0.102
0.182	0.424	0.742	1.742	0.207	1.856	0.382	1.742	0.207	0.119	0.742	0.154
0.20	0.445	0.764	1.827	0.238	1.909	0.413	1.795	0.238	0.132	0.798	0.190
0.25	0.499	0.820	2.047	0.331	2.049	0.501	1.935	0.327	0.169	0.938	0.307
0.30	0.547	0.873	2.248	0.434	2.183	0.595	2.069	0.420	0.203	1.062	0.446
0.35	0.593	0.924	2.433	0.545	2.311	0.693	2.197	0.518	0.236	1.173	0.608
0.40	0.635	0.974	2.607	0.663	2.434	0.795	2.320	0.620	0.267	1.274	0.790
0.45	0.675	1.021	2.771	0.788	2.553	0.900	2.439	0.725	0.297	1.368	0.991
0.50	0.713	1.067	2.927	0.920	2.669	1.008	2.554	0.833	0.326	1.455	1.212
0.55	0.749	1.113	3.077	1.057	2.781	1.118	2.667	0.944	0.354	1.537	1.450
0.60	0.784	1.157	3.221	1.199	2.892	1.232	2.777	1.057	0.381	1.613	1.705
0.65	0.818	1.200	3.360	1.347	3.000	1.347	2.886	1.172	0.406	1.685	1.976
0.70	0.851	1.243	3.495	1.499	3.106	1.465	2.992	1.290	0.431	1.753	2.261
0.75	0.883	1.285	3.626	1.655	3.211	1.584	3.097	1.409	0.455	1.817	2.560
0.80	0.914	1.326	3.754	1.816	3.315	1.704	3.201	1.530	0.478	1.878	2.872
0.85	0.945	1.367	3.879	1.980	3.417	1.826	3.303	1.651	0.500	1.935	3.196
0.90	0.974	1.408	4.001	2.149	3.519	1.949	3.405	1.774	0.521	1.989	3.530
0.95	1.004	1.448	4.121	2.320	3.620	2.073	3.506	1.898	0.541	2.041	3.873
1.00	1.032	1.488	4.238	2.495	3.721	2.197	3.607	2.022	0.561	2.089	4.225
1.05	1.060	1.528	4.354	2.673	3.821	2.322	3.707	2.147	0.579	2.135	4.583
1.10	1.088	1.568	4.468	2.853	3.921	2.447	3.807	2.272	0.597	2.178	4.948
1.15	1.115	1.608	4.580	3.036	4.021	2.572	3.907	2.397	0.614	2.218	5.317
1.20	1.142	1.648	4.690	3.222	4.121	2.697	4.007	2.522	0.629	2.256	5.689
1.25	1.169	1.689	4.800	3.410	4.222	2.821	4.107	2.646	0.644	2.291	6.064
1.30	1.195	1.729	4.908	3.600	4.323	2.945	4.208	2.770	0.658	2.324	6.439
1.35	1.221	1.770	5.015	3.792	4.424	3.068	4.310	2.893	0.671	2.355	6.813
1.40	1.247	1.811	5.121	3.985	4.527	3.190	4.413	3.015	0.683	2.383	7.185
1.45	1.273	1.852	5.226	4.181	4.630	3.311	4.516	3.136	0.694	2.409	7.554
1.50	1.298	1.894	5.330	4.378	4.735	3.430	4.621	3.255	0.704	2.432	7.917
1.55	1.323	1.936	5.433	4.576	4.841	3.548	4.727	3.373	0.714	2.453	8.273
1.60	1.348	1.980	5.536	4.776	4.949	3.663	4.835	3.489	0.722	2.471	8.621
1.65	1.373	2.024	5.638	4.977	5.059	3.777	4.945	3.602	0.728	2.487	8.958
1.70	1.398	2.069	5.740	5.178	5.172	3.888	5.058	3.713	0.734	2.500	9.283
1.75	1.423	2.115	5.841	5.381	5.287	3.996	5.173	3.822	0.739	2.510	9.594
1.80	1.447	2.162	5.942	5.584	5.406	4.102	5.291	3.927	0.742	2.518	9.889
1.85	1.472	2.211	6.043	5.788	5.528	4.204	5.414	4.029	0.744	2.523	10.164
1.90	1.496	2.262	6.143	5.993	5.655	4.302	5.541	4.127	0.745	2.524	10.418
1.95	1.521	2.315	6.244	6.198	5.788	4.396	5.674	4.222	0.744	2.522	10.648
2.00	1.545	2.371	6.344	6.403	5.928	4.486	5.814	4.311	0.742	2.517	10.850
2.05	1.569	2.430	6.444	6.608	6.076	4.570	5.962	4.395	0.737	2.507	11.019
2.10	1.594	2.494	6.544	6.814	6.235	4.649	6.121	4.474	0.731	2.493	11.152
2.15	1.618	2.564	6.644	7.019	6.409	4.721	6.295	4.546	0.722	2.473	11.240
2.20	1.642	2.642	6.744	7.224	6.604	4.785	6.490	4.610	0.710	2.446	11.275
2.25	1.667	2.733	6.844	7.428	6.832	4.840	6.718	4.665	0.694	2.409	11.238



2.5
2.0
1.5
1.0
0.5
0.0
Water Depth at New Tunnel TD81 (m)
0
2
4
6
8
10
12
Discharge (m3/s)

Appendix- 3 New Tunnel Weir Hydraulic Design Using Standard Trapezoidal Weir Discharge Equation



Modified Cross Section

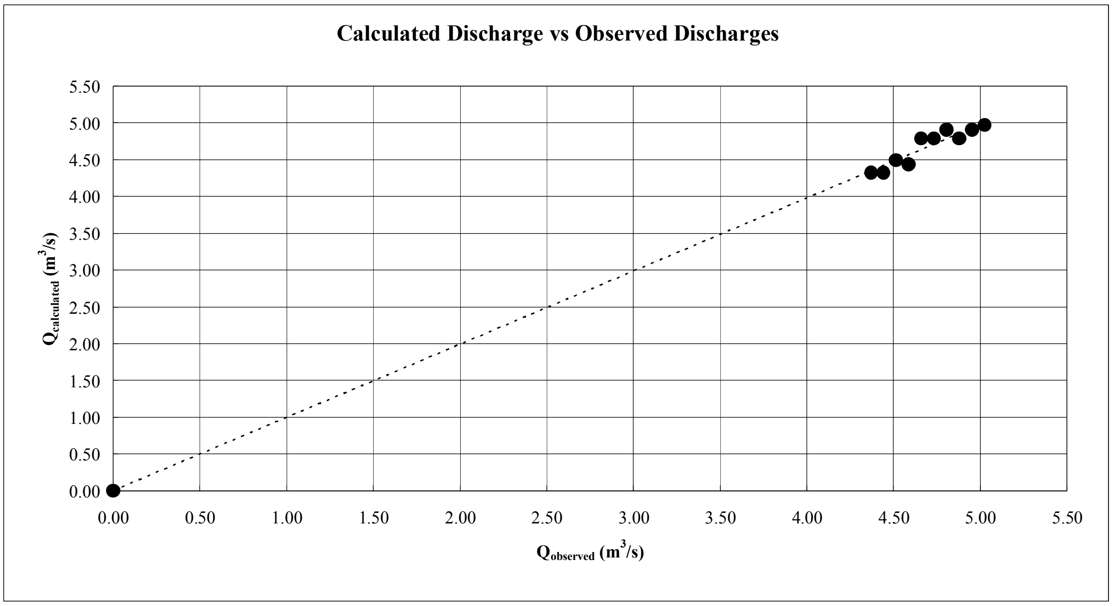
Discharge "$\boldsymbol{Q}$" = $\boldsymbol{C} * \boldsymbol{B} * \boldsymbol{y}^{3/2}$ (m^3/s)

at $\boldsymbol{m_1}$= 0～2/3, $\boldsymbol{m_2}$≒1/1, $\boldsymbol{C}$ = 1.28 + 1.42 ($\boldsymbol{y}/\boldsymbol{Z}$)

where; $\boldsymbol{Q}$ **:** discharge (m^3/s), $\boldsymbol{B}$ **:** weir length (m), $\boldsymbol{y}$**:** water depth over crest (m), $\boldsymbol{Z}$ **:** weir height (m), $\boldsymbol{h}$ **:** U/S water depth (m), $\boldsymbol{C}$ **:** coefficient of discharge ($m^{1/2}/s$), $\boldsymbol{m_1}$ **:** weir U/S side slope and $\boldsymbol{m_2}$ **:** weir D/S side slope.

(Source: Hydraulic Equations Collection, Chapter 1, page 245 (in Japanese)).

Weir Hight "$\boldsymbol{Z}$" (m)	TD100 Sensor Reading (m)	Water Depth at TD100 sensor (m)	Observed Discharge "$\boldsymbol{Q_o}$" (m^3/s)	U/S Water Depth "$\boldsymbol{h}$" (m)	Weir Length "$\boldsymbol{B}$" (m)	Water Head $\boldsymbol{y = (h - Z)}$ (m)	$\boldsymbol{y/Z}$	Weir D/S Side Slope $\boldsymbol{m_2}$	Weir U/S Side Slope $\boldsymbol{m_1}$	Coeffecient of Discharge "$\boldsymbol{C}$"	Calculated Discharge "$\boldsymbol{Q_c}$" (m^3/s)	$\boldsymbol{Q_o / Q_c}$
1.04	0.7409	1.02	4.370	1.780	2.965	0.740	0.712	0.923	0.635	2.290	4.323	1.011
1.04	0.7509	1.03	4.442	1.780	2.965	0.740	0.712	0.923	0.635	2.290	4.323	1.028
1.04	0.7609	1.04	4.514	1.795	2.965	0.755	0.726	0.923	0.635	2.311	4.495	1.004
1.04	0.7709	1.05	4.586	1.790	2.965	0.750	0.721	0.923	0.635	2.304	4.437	1.034
1.04	0.7809	1.06	4.659	1.820	2.965	0.780	0.750	0.923	0.635	2.345	4.790	0.973
1.04	0.7909	1.07	4.732	1.820	2.965	0.780	0.750	0.923	0.635	2.345	4.790	0.988
1.04	0.8009	1.08	4.805	1.830	2.965	0.790	0.760	0.923	0.635	2.359	4.911	0.979
1.04	0.8109	1.09	4.878	1.820	2.965	0.780	0.750	0.923	0.635	2.345	4.790	1.018
1.04	0.8209	1.10	4.952	1.830	2.965	0.790	0.760	0.923	0.635	2.359	4.911	1.008
1.04	0.8309	1.11	5.025	1.835	2.965	0.795	0.764	0.923	0.635	2.365	4.972	1.011

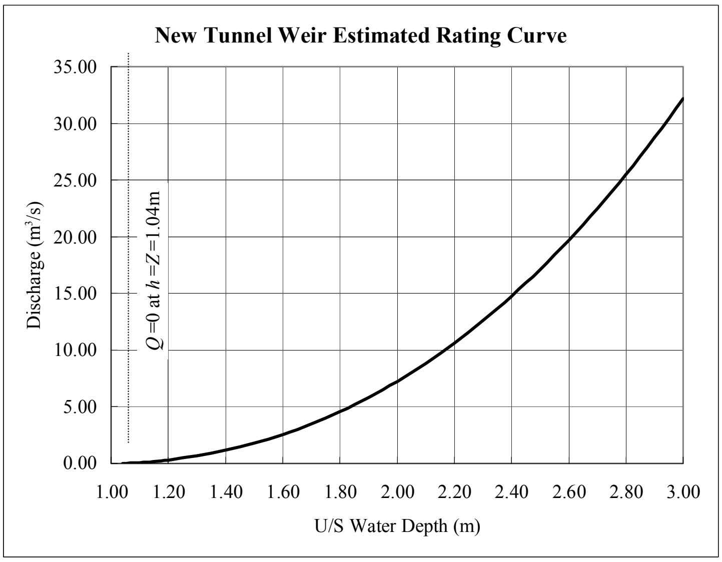


Conditions and Recommendations:

(*) Water head "*y*" should be measured U/S from the weir at a stable surface a sufficient distance to avoid the surface contraction "*d*". If the head measurement is taken just above or close to the weir crest, the recorded head will be "y'" but not "y", which will result in calculation error. In order to assure the point of water head measurement, actual water surface curve should be drawn at different discharges. It is recommended to install a water level guage U/S the weir at a distance to be determined from water surface cuves, in order to calculate actual water head over the weir crest "y".

New Tunnel Weir Estimated Rating Curve

Weir Length "*B*" (m)	Weir Hight "*Z*" (m)	U/S Water Depth "*h*" (m)	Water Head *y = (h - Z)* (m)	*y/Z*	Weir D/S Side Slope m_2	Weir U/S Side Slope m_1	Coeffecient of Discharge "*C*"	Calculated Discharge "Q_c" (m^3/s)
2.965	1.04	1.04	0.00	0.000	0.923	0.635	1.280	0.000
2.965	1.04	1.10	0.06	0.058	0.923	0.635	1.362	0.059
2.965	1.04	1.20	0.16	0.154	0.923	0.635	1.498	0.284
2.965	1.04	1.30	0.26	0.250	0.923	0.635	1.635	0.643
2.965	1.04	1.40	0.36	0.346	0.923	0.635	1.772	1.135
2.965	1.04	1.50	0.46	0.442	0.923	0.635	1.908	1.765
2.965	1.04	1.60	0.56	0.538	0.923	0.635	2.045	2.540
2.965	1.04	1.70	0.66	0.635	0.923	0.635	2.181	3.468
2.965	1.04	1.80	0.76	0.731	0.923	0.635	2.318	4.553
2.965	1.04	1.90	0.86	0.827	0.923	0.635	2.454	5.803
2.965	1.04	2.00	0.96	0.923	0.923	0.635	2.591	7.225
2.965	1.04	2.10	1.06	1.019	0.923	0.635	2.727	8.825
2.965	1.04	2.20	1.16	1.115	0.923	0.635	2.864	10.609
2.965	1.04	2.30	1.26	1.212	0.923	0.635	3.000	12.582
2.965	1.04	2.40	1.36	1.308	0.923	0.635	3.137	14.752
2.965	1.04	2.50	1.46	1.404	0.923	0.635	3.273	17.122
2.965	1.04	2.60	1.56	1.500	0.923	0.635	3.410	19.700
2.965	1.04	2.70	1.66	1.596	0.923	0.635	3.547	22.490
2.965	1.04	2.80	1.76	1.692	0.923	0.635	3.683	25.498
2.965	1.04	2.90	1.86	1.788	0.923	0.635	3.820	28.729
2.965	1.04	3.00	1.96	1.885	0.923	0.635	3.956	32.187



Appendix- 4 Old Tunnel Discharge Observations on 13/12/2004

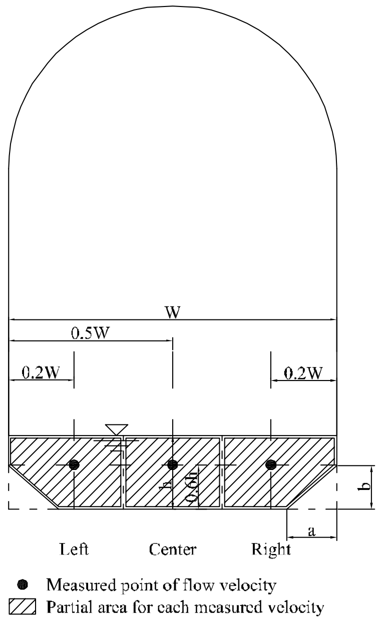
2004/12/13 Discharge Measurement (Old Tunnel) -Figeh

Measurement Location: 20m downstream section of DAWSSA water depth sensor at Figeh (TD250)
Channel Width: 135 cm
Dimension of bottom corner triangle: a = 0 cm
b = 0 cm

Remarks:

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
17:00	0.286	0.855	0.923	0.882
17:05	0.291	0.876	0.889	0.926
17:10	0.290	0.833	0.890	0.885
17:15	0.288	0.869	0.887	0.921
17:20	0.285	0.879	0.879	0.867



Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	A_{total}
17:00	0.135	0.116	0.135	**0.386**
17:05	0.137	0.118	0.137	**0.393**
17:10	0.137	0.117	0.137	**0.392**
17:15	0.136	0.117	0.136	**0.389**
17:20	0.135	0.115	0.135	**0.385**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	Q_{total}
17:00	0.116	0.107	0.119	**0.342**
17:05	0.120	0.105	0.127	**0.353**
17:10	0.114	0.105	0.121	**0.340**
17:15	0.118	0.103	0.125	**0.347**
17:20	0.118	0.101	0.117	**0.337**

Average of $Q_{total:}$ **0.344** m^3/s
= **343.55** *l*/s

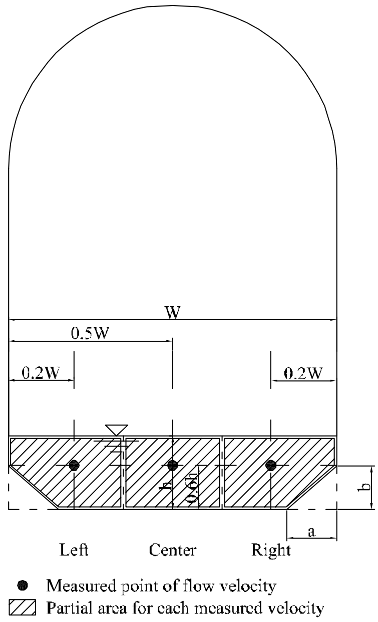
2004/12/13 Discharge Measurement (Old Tunnel) - Gate 5

Measurement Location: Upstream section of Gate No. 5 (TD1655)
Channel Width: 134 cm
Dimension of bottom corner triangle: a = 0 cm
b = 0 cm

Remarks: Observed flow velocity of the left side is faster than that of the right side, and it is conceivable affection of curved allingment of the upstream reach of the measurement site.

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
11:45	0.265	0.891	0.787	0.761
11:55	0.260	0.905	0.829	0.811
12:00	0.260	0.898	0.840	0.782
12:05	0.260	0.891	0.812	0.776
12:10	0.265	0.847	0.805	0.793



Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
11:45	0.124	0.107	0.124	**0.355**
11:55	0.122	0.105	0.122	**0.348**
12:00	0.122	0.105	0.122	**0.348**
12:05	0.122	0.105	0.122	**0.348**
12:10	0.124	0.107	0.124	**0.355**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
11:45	0.111	0.084	0.095	**0.289**
11:55	0.110	0.087	0.099	**0.296**
12:00	0.110	0.088	0.095	**0.293**
12:05	0.109	0.085	0.095	**0.288**
12:10	0.105	0.086	0.099	**0.290**

Average of $Q_{total:}$ **0.291 m^3/s**
= **291.09 *l*/s**

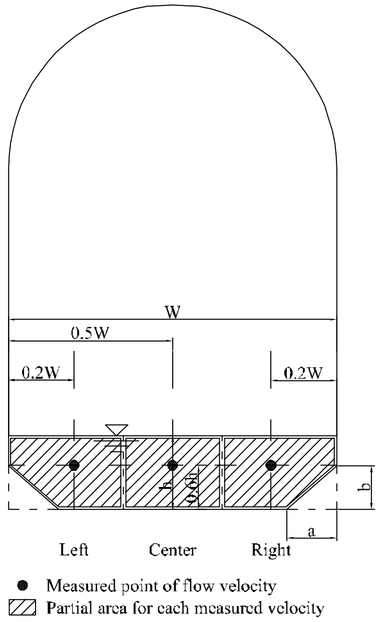
2004/12/13 Discharge Measurement (Old Tunnel) - Gate 7

Measurement Location: Upstream section of Gate No. 7 (TD3090)
Channel Width: 131 cm
Dimension of bottom corner triangle: a = 0 cm
b = 0 cm

Remarks: Observed flow velocity of the right side is fastest among the other measured points, and it is conceivable affection of curved allingment of the upstream reach of the measurement site.

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
12:45	0.265	0.726	0.754	0.773
12:50	0.270	0.751	0.758	0.783
12:55	0.265	0.758	0.772	0.793
13:00	0.265	0.759	0.777	0.791
13:05	0.265	0.747	0.764	0.784



Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	A_{total}
12:45	0.122	0.104	0.122	**0.347**
12:50	0.124	0.106	0.124	**0.354**
12:55	0.122	0.104	0.122	**0.347**
13:00	0.122	0.104	0.122	**0.347**
13:05	0.122	0.104	0.122	**0.347**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	Q_{total}
12:45	0.088	0.079	0.094	**0.261**
12:50	0.093	0.080	0.097	**0.270**
12:55	0.092	0.080	0.096	**0.269**
13:00	0.092	0.081	0.096	**0.269**
13:05	0.091	0.080	0.095	**0.266**

Average of Q_{total}: **0.267 m^3/s**
= **266.94 *l*/s**

2004/12/13 Discharge Measurement (Old Tunnel) - Gate 20

Measurement Location: Upstream section of Gate 20 (TD8379)
Channel Width (W): 135 cm
Dimension of bottom corner triangle: a = 12 cm
b = 10 cm

Remarks:

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
13:35	0.264	0.783	0.753	0.738
13:40	0.254	0.789	0.728	0.705
13:45	0.255	0.777	0.766	0.736
13:50	0.261	0.816	0.766	0.733
13:55	0.266	0.789	0.770	0.729

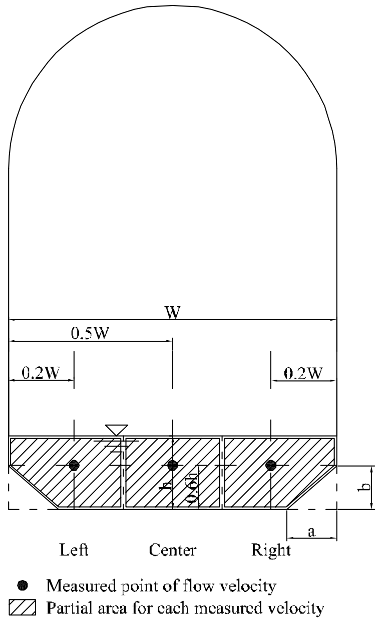
Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
13:35	0.119	0.107	0.119	**0.344**
13:40	0.114	0.103	0.114	**0.343**
13:45	0.114	0.103	0.114	**0.344**
13:50	0.117	0.106	0.117	**0.352**
13:55	0.120	0.108	0.120	**0.359**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
13:35	0.093	0.081	0.088	**0.261**
13:40	0.090	0.075	0.080	**0.245**
13:45	0.089	0.079	0.084	**0.252**
13:50	0.096	0.081	0.086	**0.263**
13:55	0.094	0.083	0.087	**0.265**

Average of Q_{total}: **0.257** $\mathbf{m^3/s}$
= **257.20** ***l*/s**



2004/12/13 Discharge Measurement (Old Tunnel) Upstream of Siphon

Measurement Location: Upstream section of Siphon (TD12300)
Channel Width (W): 137 cm
Dimension of bottom corner triangle: a = 12 cm
b = 10 cm

Remarks:

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
15:05	0.242	0.771	0.758	0.762
15:10	0.244	0.768	0.765	0.769
15:15	0.252	0.790	0.789	0.775
15:20	0.247	0.777	0.777	0.729
15:25	0.255	0.750	0.757	0.748

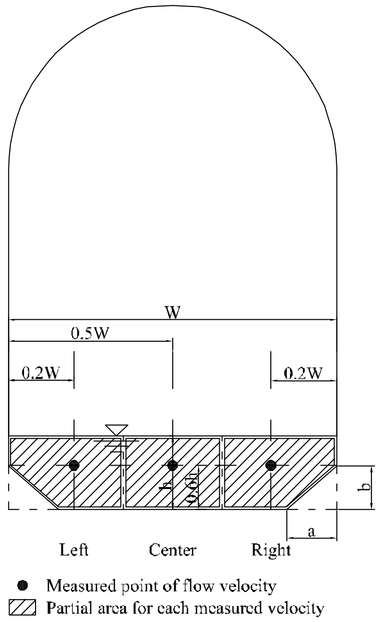
Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
15:05	0.110	0.099	0.110	**0.320**
15:10	0.111	0.100	0.111	**0.334**
15:15	0.115	0.104	0.115	**0.345**
15:20	0.112	0.102	0.112	**0.338**
15:25	0.116	0.105	0.116	**0.349**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
15:05	0.085	0.075	0.084	**0.244**
15:10	0.085	0.077	0.085	**0.247**
15:15	0.091	0.082	0.089	**0.261**
15:20	0.087	0.079	0.082	**0.248**
15:25	0.087	0.079	0.087	**0.254**

Average of Q_{total}: **0.251** $\mathbf{m^3/s}$
= **250.91** ***l*/s**



2004/12/13 Discharge Measurement (Old Tunnel) Downstream of Siphon

Measurement Location: Downstream section of Siphon (TD12620)
Channel Width: 128 cm
Dimension of bottom corner triangle: a = 12 cm
b = 10 cm

Remarks:

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
15:50	0.267	0.770	0.773	0.746
15:55	0.260	0.777	0.758	0.744
16:00	0.270	0.776	0.773	0.773
16:05	0.265	0.770	0.750	0.758
16:10	0.270	0.762	0.747	0.752

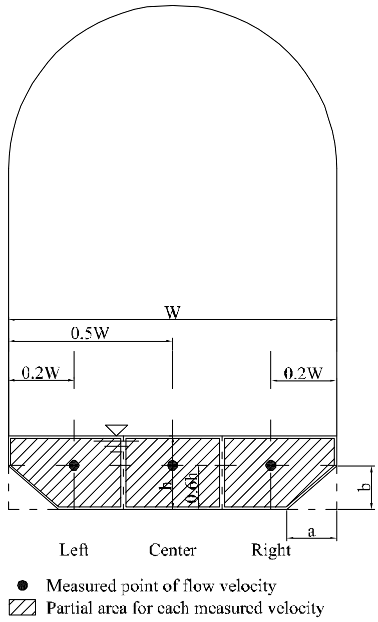
Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
15:50	0.114	0.103	0.114	**0.330**
15:55	0.110	0.100	0.110	**0.333**
16:00	0.115	0.104	0.115	**0.346**
16:05	0.113	0.102	0.113	**0.339**
16:10	0.115	0.104	0.115	**0.346**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
15:50	0.087	0.079	0.085	**0.251**
15:55	0.086	0.076	0.082	**0.244**
16:00	0.089	0.080	0.089	**0.258**
16:05	0.087	0.076	0.085	**0.249**
16:10	0.088	0.077	0.086	**0.251**

Average of $Q_{total:}$ **0.251 m^3/s**
= **250.70 *l*/s**



2004/12/13 Discharge Measurement (Old Tunnel) Gate 38 (Wali)

Measurement Location: Wali, Upstream section of Gate No. 38 (TD16254)
Channel Width: 128 cm
Dimension of bottom corner triangle: a = 22.5 cm
b = 17 cm

Remarks: Measured section is just upstream of constrained section of Gate No.38. Critical flow is observed on the constrained section of Gate No.38.

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
18:20	0.298	0.700	0.723	0.712
18:25	0.307	0.723	0.723	0.732
18:30	0.299	0.708	0.701	0.725
18:35	0.300	0.703	0.721	0.740
18:40	0.304	0.707	0.693	0.736

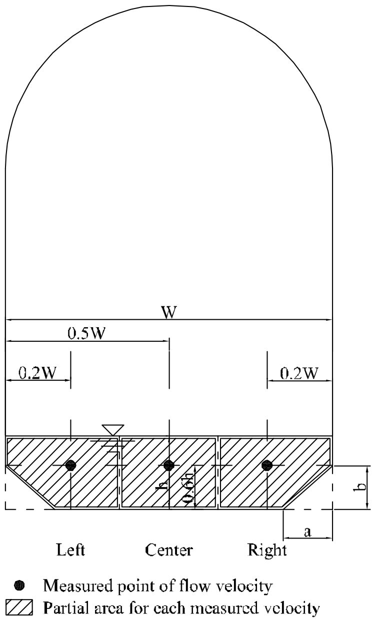
Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
18:20	0.114	0.114	0.114	**0.343**
18:25	0.118	0.118	0.118	**0.393**
18:30	0.115	0.115	0.115	**0.383**
18:35	0.115	0.115	0.115	**0.384**
18:40	0.117	0.117	0.117	**0.389**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
18:20	0.080	0.083	0.081	**0.244**
18:25	0.086	0.085	0.087	**0.258**
18:30	0.081	0.080	0.083	**0.245**
18:35	0.081	0.083	0.085	**0.249**
18:40	0.083	0.081	0.086	**0.250**

Average of $Q_{total:}$ **0.249 m^3/s**
= **249.20 *l*/s**



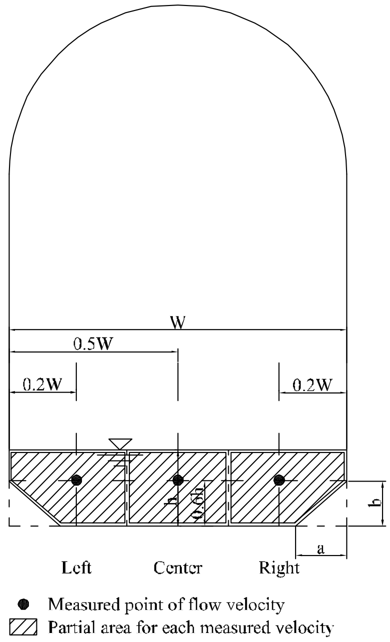
Appendix- 5 Simultaneous Discharge Observations at Figeh and Gate No.5 on 15/12/2004

2004/12/15 Discharge Measurement (Old Tunnel)

Measurement Location 20m downstream section of DAWSSA water depth sensor at Figeh (TD120)
Channel Width: 135 cm
Dimension of bottom corner triangle: a = 0 cm, b = 0 cm
Remarks:

Observed Record

Time	h (m)	Flow Velocity (m/s)		
		v_{left}	v_{center}	v_{right}
11:20	0.320	0.746	0.735	0.720
11:30	0.328	0.741	0.761	0.721
11:40	0.325	0.731	0.757	0.724
11:50	0.322	0.713	0.745	0.761
12:00	0.325	0.729	0.777	0.724
12:10	0.320	0.773	0.720	0.739
12:20	0.330	0.741	0.784	0.713
12:30	0.320	0.773	0.740	0.708
12:40	0.330	0.756	0.729	0.686
12:50	0.325	0.712	0.717	0.692
13:00	0.325	0.737	0.718	0.684
13:10	0.315	0.734	0.733	0.704
13:20	0.322	0.738	0.785	0.702
13:30	0.320	0.687	0.724	0.709
13:40	0.325	0.713	0.677	0.696
13:50	0.325	0.729	0.718	0.676
14:00	0.320	0.727	0.731	0.690
14:10	0.322	0.710	0.691	0.700
14:20	0.320	0.712	0.670	0.699



Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	A_{total}
11:20	0.151	0.130	0.151	**0.432**
11:30	0.155	0.133	0.155	**0.443**
11:40	0.154	0.132	0.154	**0.439**
11:50	0.152	0.130	0.152	**0.435**
12:00	0.154	0.132	0.154	**0.439**
12:10	0.151	0.130	0.151	**0.432**
12:20	0.156	0.134	0.156	**0.446**
12:30	0.151	0.130	0.151	**0.432**
12:40	0.156	0.134	0.156	**0.446**
12:50	0.154	0.132	0.154	**0.439**
13:00	0.154	0.132	0.154	**0.439**
13:10	0.149	0.128	0.149	**0.425**
13:20	0.152	0.130	0.152	**0.435**
13:30	0.151	0.130	0.151	**0.432**
13:40	0.154	0.132	0.154	**0.439**
13:50	0.154	0.132	0.154	**0.439**
14:00	0.151	0.130	0.151	**0.432**
14:10	0.152	0.130	0.152	**0.435**
14:20	0.151	0.130	0.151	**0.432**

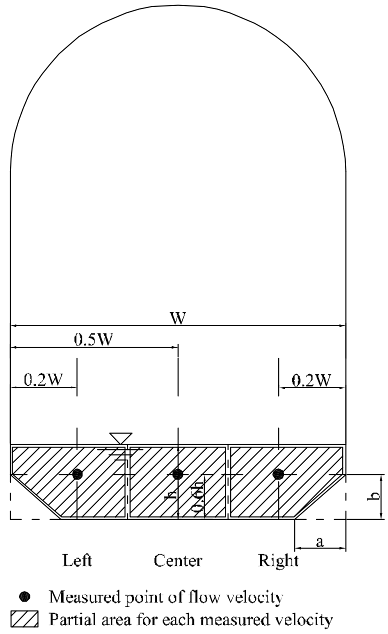
Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	Q_{total}
11:20	0.113	0.095	0.109	**0.317**
11:30	0.115	0.101	0.112	**0.328**
11:40	0.112	0.100	0.111	**0.323**
11:50	0.109	0.097	0.116	**0.322**
12:00	0.112	0.102	0.111	**0.325**
12:10	0.117	0.093	0.112	**0.322**
12:20	0.116	0.105	0.111	**0.331**
12:30	0.117	0.096	0.107	**0.320**
12:40	0.118	0.097	0.107	**0.322**
12:50	0.109	0.094	0.106	**0.310**
13:00	0.113	0.095	0.105	**0.313**
13:10	0.109	0.094	0.105	**0.308**
13:20	0.112	0.102	0.107	**0.321**
13:30	0.104	0.094	0.107	**0.305**
13:40	0.110	0.089	0.107	**0.305**
13:50	0.112	0.095	0.104	**0.310**
14:00	0.110	0.095	0.104	**0.309**
14:10	0.108	0.090	0.106	**0.305**
14:20	0.108	0.087	0.106	**0.300**

Average of Q_{total}: **0.316 m^3/s**
= **315.58 *l*/s**

2004/12/15 Discharge Measurement (Old Tunnel)

Measurement Location Upstream section of Gate No. 5 (TD1655)
Channel Width: 134 cm
Dimension of bottom corner triangle: a = 0 cm
b = 0 cm
Remarks:



Observed Record

Time	h (m)	Flow Velocity (m/s)		
		Left	Center	Right
11:40	0.260	0.727	0.763	0.789
11:50	0.270	0.749	0.731	0.840
12:00	0.270	0.719	0.777	0.797
12:10	0.260	0.732	0.763	0.822
12:20	0.260	0.737	0.745	0.805
12:30	0.260	0.736	0.746	0.843
12:40	0.260	0.757	0.763	0.833
12:50	0.270	0.752	0.772	0.811
13:00	0.260	0.741	0.736	0.796
13:10	0.260	0.764	0.773	0.804
13:20	0.260	0.749	0.760	0.838
13:30	0.260	0.778	0.731	0.813
13:40	0.260	0.720	0.766	0.823
13:50	0.260	0.733	0.754	0.798
14:00	0.250	0.751	0.741	0.837

Partial area of each measured point (m^2)

Time	a_{left}	a_{center}	a_{right}	$\mathbf{A_{total}}$
11:40	0.122	0.105	0.122	**0.348**
11:50	0.127	0.109	0.127	**0.362**
12:00	0.127	0.109	0.127	**0.362**
12:10	0.122	0.105	0.122	**0.348**
12:20	0.122	0.105	0.122	**0.348**
12:30	0.122	0.105	0.122	**0.348**
12:40	0.122	0.105	0.122	**0.348**
12:50	0.127	0.109	0.127	**0.362**
13:00	0.122	0.105	0.122	**0.348**
13:10	0.122	0.105	0.122	**0.348**
13:20	0.122	0.105	0.122	**0.348**
13:30	0.122	0.105	0.122	**0.348**
13:40	0.122	0.105	0.122	**0.348**
13:50	0.122	0.105	0.122	**0.348**
14:00	0.117	0.101	0.117	**0.335**

Partial discharge of each measurement point and calculated discharge (m^3/s)

Time	q_{left}	q_{center}	q_{right}	$\mathbf{Q_{total}}$
11:40	0.089	0.080	0.096	**0.265**
11:50	0.095	0.079	0.106	**0.281**
12:00	0.091	0.084	0.101	**0.276**
12:10	0.089	0.080	0.100	**0.269**
12:20	0.090	0.078	0.098	**0.266**
12:30	0.090	0.078	0.103	**0.271**
12:40	0.092	0.080	0.102	**0.274**
12:50	0.095	0.084	0.103	**0.282**
13:00	0.090	0.077	0.097	**0.264**
13:10	0.093	0.081	0.098	**0.272**
13:20	0.091	0.079	0.102	**0.273**
13:30	0.095	0.076	0.099	**0.271**
13:40	0.088	0.080	0.100	**0.268**
13:50	0.089	0.079	0.097	**0.266**
14:00	0.088	0.074	0.098	**0.261**

Average of Q_{total}: **0.270** $\mathbf{m^3/s}$
= **270.42** ***l*/s**