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# Flushing Time of Shatt Al-Arab River, South of Iraq

**S.S. Abdullah*, A.A. Lafta, S.A. Al-Taei, A.H. Al-Kaabi**
*Marine Science Centre, University of Basrah, Basrah-Iraq*
**e-mail: sadiqsalimunibasrah@yahoo.com*

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**Abstract -** Flushing time for tidal rivers and estuaries is of great benefits for those involved in taking appropriate decisions in water resources management. Shatt Al-Arab River is the main and only source of fresh water to Basra City, South of Iraq. Unfortunately, this river is facing an environmental deterioration as a result of presence of many pollution sources. The calculated flushing time of the river helps to estimate the expected time needed to renew the river water. Fresh water fraction method was used to calculate flushing time. The results showed that three factors are responsible for affecting the value of flushing time. These factors are upstream coming flow discharge, phenomenon of tide and lastly the location distance from the estuary. The results also showed that the flushing time of the northern part of the river from Maqal port until the confluence with Karun River are much more than that of southern part. Results also showed that the flushing time for the whole parts of the river was 2.4 months.

**Key words:** Flushing time, River, pollution and environmental deterioration.

## Introduction

In estuaries, the mutually interfere water masses between sea and rivers are transferring substances (suspended or dissolved) such as salts or contaminants. Some of these contaminants are hydrocarbon or toxins or even radioactive materials from nuclear power plants or algal growth like Red tide. The longer time these substances were stayed in the tidal rivers, and results in more negative impacts by causing deterioration in the quality of its waters. As this time become less as the tidal river be able to dispose these undesirable substances to its neighboring seas.

According to this situation, the idea of flushing time came. The flushing time can be defined as the time required to replace the available freshwater in the estuary as a whole or part by a new freshwater coming from the upstream (Bowden, 1967; Fischer *et al.*, 1979). Previous studies have used several different terminology within this concept for this time such as Renewal time, Residence time, Detention time, Turnover time, Exchange time and Transit time (Costa *et al.*, 1999; Choi *et al.*, 2004 ;Wang *et al.*, 2004). In estuaries, the flushing time, when it is to be exchanged between previously available and the newly coming freshwater depends mainly on tidal flow discharge coming from the sea and fresh water discharge coming from river upstream (Kumari *et al.*, 2009), as well as the flow circulation fields (Wang *et al.*, 2004).

Knowing the flushing time helps to estimate the allowed materials loads in the estuaries, as well as a helpful guide to take emergency measures in cases of spills of harmful substances or disasters. Also, it is an important tool to manage estuarine areas.

Global warming and climate change impact in temperature rise and in expected sea water level rise up of 30-40 cm in the next hundred years (Wu *et al.*, 2008), as the coast areas affected, including estuaries. Studies of Bhuiyan and Dutta (2012) and Rice *et al.* (2012) showed that the increase in sea level affects the amount of salt, stratification, residence time and the transfer of materials in the estuaries. The predictive study of Liu *et al.* (2004) showed the impacts of increased sea water level on the flushing time, and they concluded that the flushing time increases at low fresh water discharges while decreases at high fresh water discharges in comparison with sea level as the tidal discharges change the level difference.

The calculation of flushing time becomes more important due to the reduction in upstream coming fresh water discharge, and also the salinity increase in tidal rivers water from sea intrusion upstream. As Shatt Al-Arab River characterized in such cases, many salt sources from the upstream (marshlands) and the downstream (Arabian Gulf) as well as being located at the oil resources and the ports of export.

In addition to this the sharp decline in coming upstream fresh water discharges from time to time results in a deterioration in the quality of river water, all of this calls to estimate flushing time of Shatt Al-Arab River. No studies have been done in this area except for a short length part in the study of Albadran *et al.* (2001), in their study the amount of flushing time of Shatt Al-Arab River was calculated to be approximately 3.64 day.

## Materials and Analysis

### The Study Area:

Shatt Al-Arab tidal river starts from the confluence of the Tigris and Euphrates Rivers in the town of Qurna, north of Basra then continues to the south-east direction before flowing in the Arabian Gulf South of Faw city. The total length of this river comes to 204km (Fig. 1). Karun River is another source of fresh water coming from Iranian territory at a distance 93.5km from the gulf. The flow of Karun River increases the Shatt Al-Arab River discharge in Faw city to be less or more than 1000$m^3$/sec (Al-Mansory, 1996), this was the situation of the river in the last century. The present situation was completely different.

Storage dams built in the trans-boundary countries of Turkey and Syria on Tigris and Euphrates Rivers had prevailed in the years of the last century which led to the gradual decline in Shatt Al-Arab River discharge in Qurna to become 50$m^3$/sec (Al-Taei *et al.*, 2014). The new situation now of disruptions of Euphrates River discharge and Karun River discharge not coming to Shatt Al-Arab River changes the hydrological situation as Tigris River become the only source of fresh water to Shatt Al-Arab River. A 400m top width and depths ranging between 8-15m are the main geometrical features of Shatt Al-Arab River. The source of tide is Arabian Gulf.

The tide type is of mixed-semidiurnal dominant (Abdullah, 2002). The average tidal range is 1.84, 1.75 and 1.18m (Abdullah, 2014) in the outer bar, Faw and Basra stations respectively, in some times the water level reaches 3m at the flood and fall up to 0 meters at the ebb in Outer Bar and Faw stations (Abdullah, 2014).

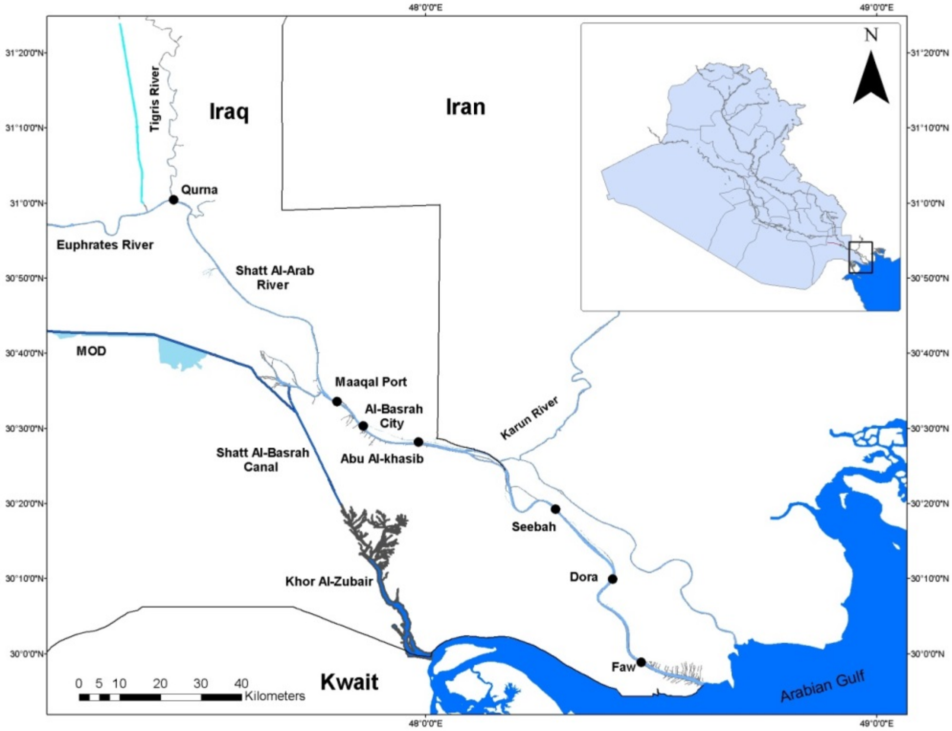


Figure 1. Study Area.

**River Flow Hydrodynamics:**

The Bathymetric and Topographic survey data of Shatt Al-Arab River from Maqal Port to south of Faw city (the study area up to 100 km) which was carried out by Marine Science Center of Basra University in 1998 and 2005, as it has been the source of data to build the geometry in Mike II model. Mike II, of the Danish Hydraulic Institute (DHI) was used to simulate flow hydrodynamics in Shat Al-Arab River (DHI, 2007).

This software is in the form of a one-dimensional flow, solving Saint Venant equations of river flow. This governing equation represents the mass and momentum equations. The dispersion-advection differential equation was also part of the governing equation. The solution was numerically stable using implicit finite differences scheme (Kawachi *et al.*, 1982). A 13 cross-sections of the study area of Shatt Al-Arab River with 1km minimum space interval were fed to the cross section Module of Mike11 as in Figure (2). To calculate the total water area in each cross-section using Mike11, the model was run for Shatt Al-Arab River for a period of six months. The upstream boundary condition was fixed as constant discharge while the downstream boundary conditions were the tidal fluctuations of water level in the Gulf as in Figure (3). The total water area of each cross-section of the river was calculated through the model run, the values of these areas are very precise so as to take the consideration of the impacts of the phenomenon of tide (water level at both cases of high and low ebb).

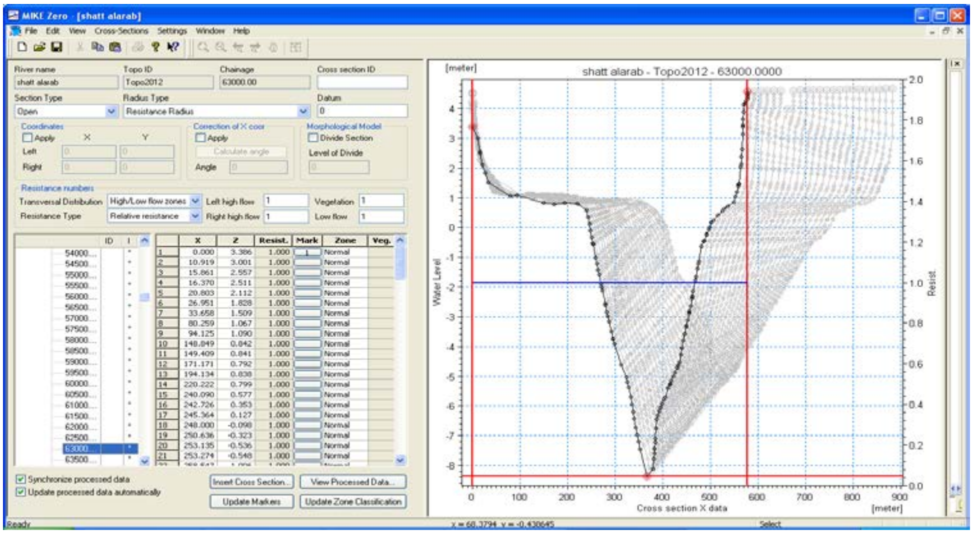


Figure 2. Mike II Front Page showing cross-sections of the river.

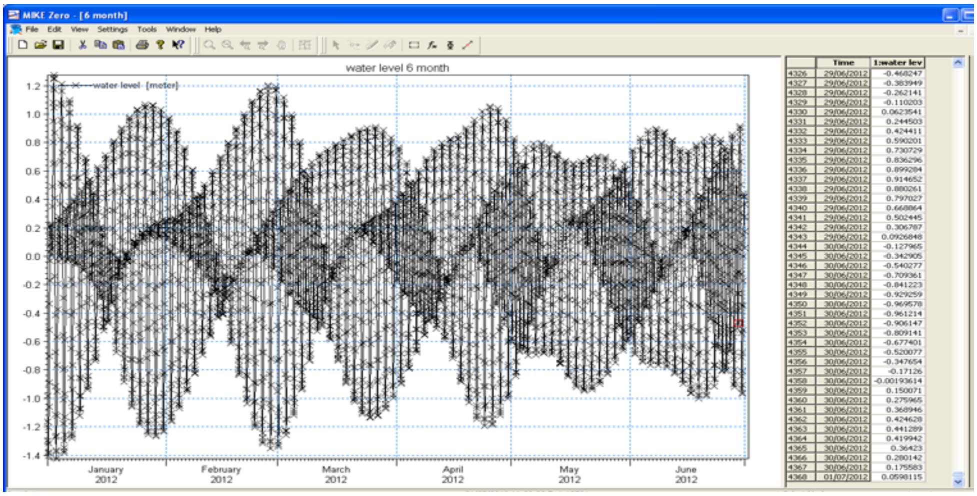


Figure 3. Mike II FrontPage showing time sequences.

## Fresh Water Fraction Method:

Fresh Water Fraction Method proposed by Dyer (1973) was used in steps to calculate flushing time as following:

1. Divide the tidal river into segments. The volume and salinity of each segment are to be calculated.
2. Calculate the fresh water part using the following relationship:

$$f_i = (s_0 - s_i)/s_0 \quad (1)$$

Where: $f_i$ is the fresh water part in the segment $i$ and $i = 1,2,3,\ldots\ldots,n$

$n$ is the total number of segments of the river.
$s_i$ is average of salinity in each segment along the reach, it was calculated as flow, first determine the cross-section average salinity every hour ,then calculate the hourly average of cross-section average salinity for the tidal cycle period and this hourly average was represented the $s_i$.
$s_0$ is the salinity of local marine water from the downstream end.

3. Calculate the volume of fresh water in each segment ($W_i$) using the equation:

$$W_i = \mathrm{V_i} \times f_i \qquad (2)$$

Where: $\mathrm{V_i}$ represents Mean Tidal Volume in each segment.

4. Calculation of Flushing Time in each segment according to the equation:

$$T_i = \frac{W_i}{R_i} \qquad (3)$$

Where: $R_i$ represents mean fresh water volume inside each segment for a one tidal cycle (T.C.) i.e. the flow discharge in units of $m^3$/tidal cycle. The upstream segments (1-5) have tidal cycle time of 12 hours while segments (6-13) have tidal cycle time of 11.5 hours.
When there is a tributary inflows to a main river, the coming discharge was added to the discharge of segment downstream of the confluence as was the case for the Karun River, which its flow discharge was added to the discharge of segment number 5.

5. Flushing Time was calculated for the river as a whole ($T_f$) by summing up all of the segments flushing time:

$$T_f = \sum_{i=1}^{n} T_i \qquad (4)$$

Where: $i$ = 1, 2, ......, $n$ represents the number of segments.

## Results and Discussions

As required by Fresh Water Fraction Method to calculate Flushing Time, the river was divided to segments of length up to approximately 10km. Considering the form of the river reach whether it was bend or straight or braided as in Seebah or Dora locations north of Faw City, segment length may be less or more than 10 km. Running Mike11 model using high tide (HW) and low ebb (LW) water levels had resulted in water volumes data ranged between 0.01422-0.05087 $km^3$ as shown in Table (1), which represents the state of the river at discharge 50 $m^3/s$. The highest output volume value was at segment number (13), this was due to the highest river top width in the reach at this location. The Flushing Time was calculated using different scenarios of fresh water supply discharge. These scenarios are using range of discharges (10 $m^3/s$ to 800 $m^3/s$) of fresh water that reaches Shatt Al-Arab River from a collection of different sources (Tigris, Euphrates and Karun Rivers) as in Table (2). The salinity data used in this study are part of measurements done by Marine Science Centre of Basrah University and Al-Mansory (1996). The scenarios are:

Table 1. Segments characteristics at HW tide and LW ebb.

| Segment No. | C.S. Area at low water ($m^2$) | C.S. Area at high water ($m^2$) | C.S. Area Average | Volume ($m^3$) |
|---|---|---|---|---|
| 1 | 1090.935 | 1754.908 | 1422.9215 | 14229215 |
| 2 | 2695.938 | 3660.328 | 3178.133 | 31781330 |
| 3 | 2871.727 | 3563.644 | 3217.6855 | 32176855 |
| 4 | 2283.768 | 3314.145 | 2798.9565 | 27989565 |
| 5 | 3157.068 | 4936.334 | 4046.701 | 40467010 |
| 6 | 1836.262 | 2581.063 | 2208.6625 | 22086625 |
| 7 | 1952.377 | 2566.781 | 2259.579 | 22595790 |
| 8 | 3138.174 | 4195.559 | 3666.8665 | 36668665 |
| 9 | 2002.942 | 2767.465 | 2385.2035 | 23852035 |
| 10 | 1711.921 | 2525.872 | 2118.8965 | 21188965 |
| 11 | 3596.909 | 5104.503 | 4350.706 | 43507060 |
| 12 | 2100.85 | 3418.622 | 2759.736 | 27597360 |
| 13 | 4004.231 | 6212.999 | 5108.615 | 51086150 |

Table 2. Scenarios details.

| Scenario No. | Fresh Water Source | Discharge ($m^3$/sec) | Calculated Flushing time |
|---|---|---|---|
| First | Euphrates, Tigris and Karun | 800 | 8 day |
| Second | Karun | 100 | 1.5 month |
| | Tigris | 50 | |
| Third | Tigris | 50 | 2.4 month |
| Forth | Tigris | 35 | 3.3 month |
| Fifth | Tigris | 10 | 6.9 month |

**The First Scenario:**

This scenario presents the nature of the river in the end of last century, as the amount of discharge of 800 $m^3$/sec was the average annual discharge. The coming fresh water discharge exceeds sometimes the 1000 $m^3$/sec at Faw city coming from the three rivers (Tigris, Euphrates and Karun Rivers). As in Figure (4), the water volume of the segments varies from the minimum 0.0153 $km^3$ at segment 1 to the maximum 0.0512 $km^3$at segment 13. This variation was accompanied with a salinity values come to 1.5 (ppt) in the last segment, and therefore influences the values of fi, Wi for each segment, as the fi values are affected by the tidal discharge per tidal cycle (Samano *et al.*, 2012). The Wi values in this scenario was large compared with other scenarios, it is 1220000$m^3$/h and 33120000$m^3$/h for the segments located upstream and downstream the river respectively.

Segment number (5) has the largest flushing time. Here in this scenario is approximately 2.4 tidal cycle. This was due to the large volume of this segment. The segment (10) has the lowest flushing time of almost 0.6 tidal cycle time, this was a result of the impact of the small size of the segment with a lower value $W_i$. Total flushing time for the river in this case was 8 days. This was reflected to sustain the vitality of the river in spite of any exposure to pollutants whether it was spilled oil or salinity. A prosperity of agriculture on both sides of the river was noticed and the river was a good source for the presence of fish not only in Shat Al-Arab River but extending to marshlands areas in the upstream.

**The Second Scenario:**

This scenario applies the case of discharge 50 $m^3$/sec from Tigris River plus an extra 100 $m^3$/sec from Karun River, when the Karum River was opened from the Iranian side. The positive impact of Karun River flow discharge was positive by reducing the salinity values in each segment, as shown in Figure (5). In this Figure the output results of flushing time showed a variation between segments where values ranged between 9.0-17.1 Day. The effects of Karun River discharge was obvious in reducing the flushing time for the segments located downstream the Karun River confluence (Segment 6) compared with the segments located upstream where flushing time results become less than two days, as in the segments (6, 7, 9 and 10). Downstream segments are affected by the phenomenon of the tide and ebb, causing a slight increase in the flushing time, compared with above segments. In general, the flushing time in this case was 1.5 months for the whole river.

**The Third Scenario:**

This scenario represents the current situation of Shatt Al-Arab River, where the coming discharge is only from the Tigris River of 50 $m^3$/sec. The fact that the Euphrates and Karun Rivers are in the event of closure. This is what caused the deterioration of water quality of the arrival of salts from the Arabian Gulf to the river upstream (Al-Tai *et al.*, 2014). The Figure (6) shows the variation of flushing time values in segments as in the previous scenario and the segments have more flushing time as so in segments (5), (8) as results show more than 8 days. And the lowest flushing time for so is the segment (1) with a time amount of 3.1 days, which was approximately the same as of the segments (10, 12 and 13). The influence of the tides on flushing time of each segment are mainly located near the tidal energy source, as confirmed by (Wang *et al.*, 2004) and (Kumari *et al.*, 2009) that flushing time changes with the locations in accordance with the change in a difference between segments themselves in the study area. Results show that the segments located downstream the river has less flushing time than those located upstream. The flushing time of the river as a whole was 2.4 months.

**The Fourth Scenario:**

This scenario uses the event of a suitable upstream discharge during the running of the newly constructed Kteiban irrigation canal which takes 15 $m^3$/sec freshwater from the Shatt Al-Arab at Kteiban 20km north of Basra city, to deliver freshwater to the south of Basra at Abu Alkhaseeb and Faw area. Accordingly, it has been assumed that the remaining discharge was 35 $m^3$/s. This has influenced the water quality, especially in the downstream segments, as shown in Figure (7). The lowest flushing time was at segment (13) influenced by the tides and influenced also by the increase in salinity, the flushing time reaches a value of 2.7 days. The second segment of lowest flushing time is number (1) influenced by the discharge value and small segment volume, to be (4.4) day. And the highest flushing time was the segment (4) influenced by its large volume of 40440490 $m^3$. In general, the flushing time in this scenario was 3.3 month.

**The Fifth Scenario:**

This scenario adopted discharge of 10 $m^3$/sec, which is the least ever occurred discharge in Shat Al-Arab River, as it was in this situation in 2009. The resulted situation in this case incursion salinity to distance and reached Basra city (Al-Tai *et al.*, 2014). The results as in Figure (8) showed a disparity between the segments area which reflected in the volumes of the segments ranged between (14177105 - 51082965) $m^3$ of Segment No. 1 to segment No. 13, respectively. According to the decrease in discharge, salinity will have incursion in the river upstream direction to reach in segment (1) a value of 12 g/liter, while reaching the highest values in the last segment of the river which is number (13) to a value of 37 g/liter of being close to the sea. The effect of this variation in salinity on the parameter value fi values as a value between 0.26-0.69 was clear on segments 13 and 5 respectively. The amount of water (Wi) vary between the segments due to the segments volume and the coefficient fi.

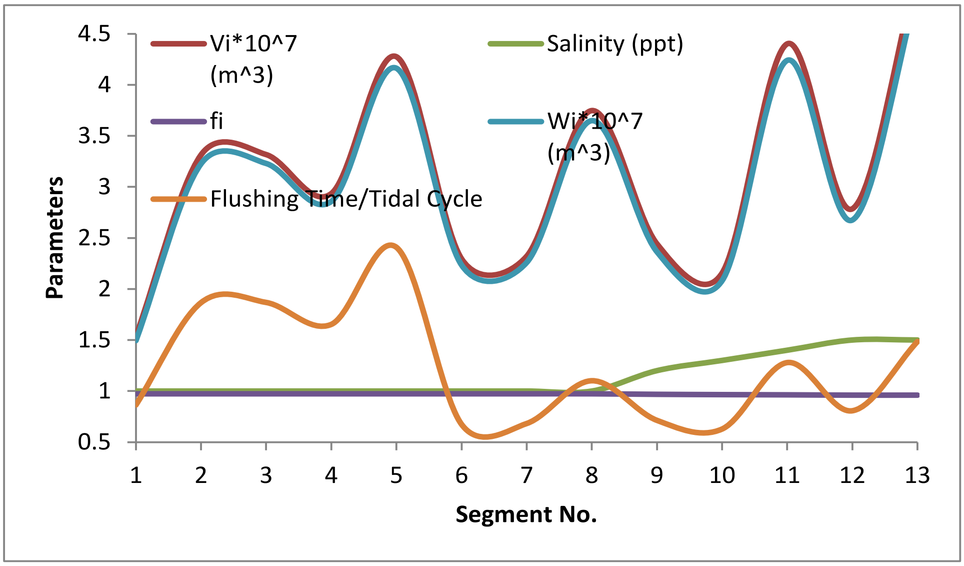


Figure 4. Variation of parameters in first scenario (Q=800$m^3$/sec).

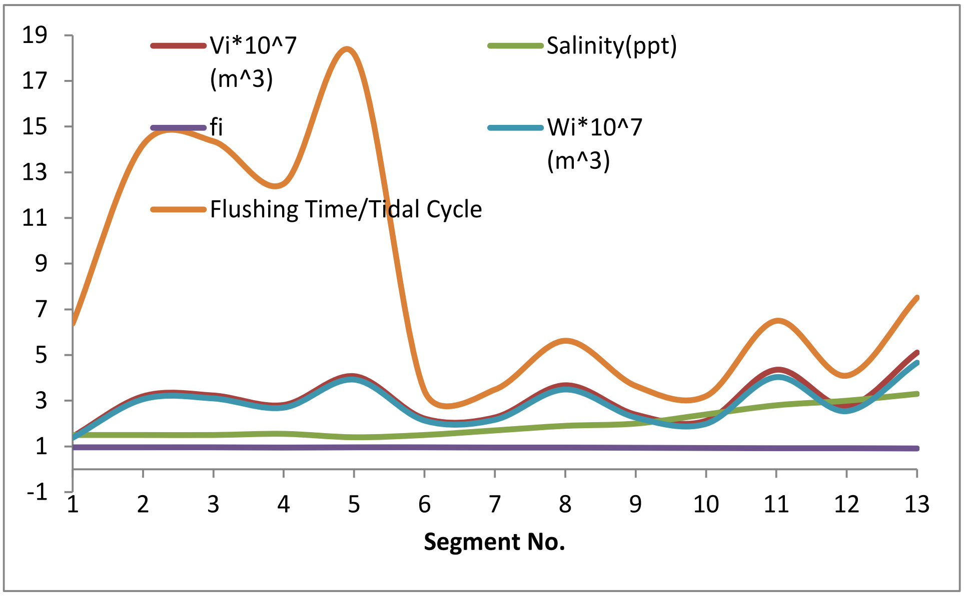


Figure 5. Variation of parameters in second scenario (Q=150m$^3$/sec).

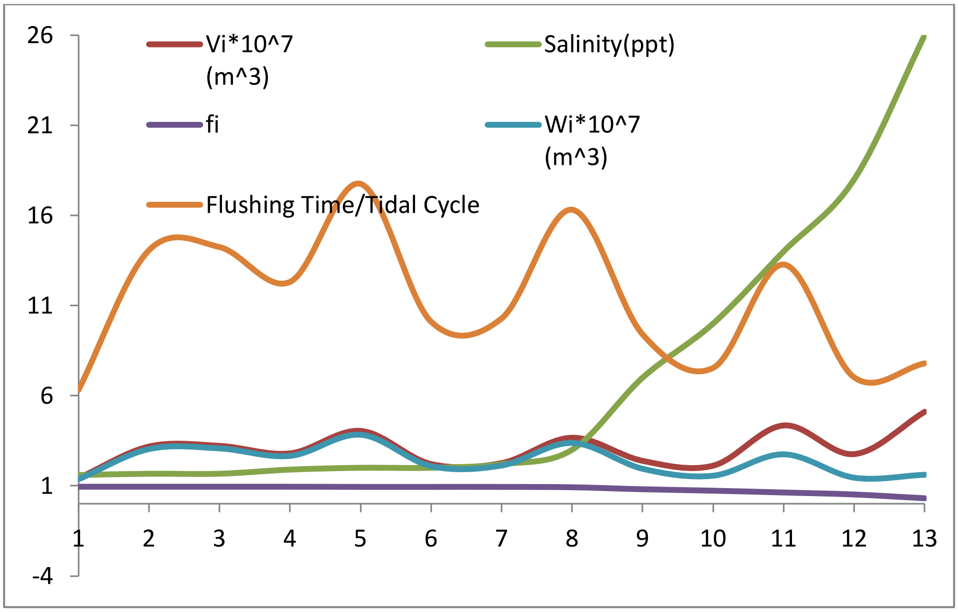


Figure 6. Variation of parameters in Third scenario (Q=50m$^3$/sec).

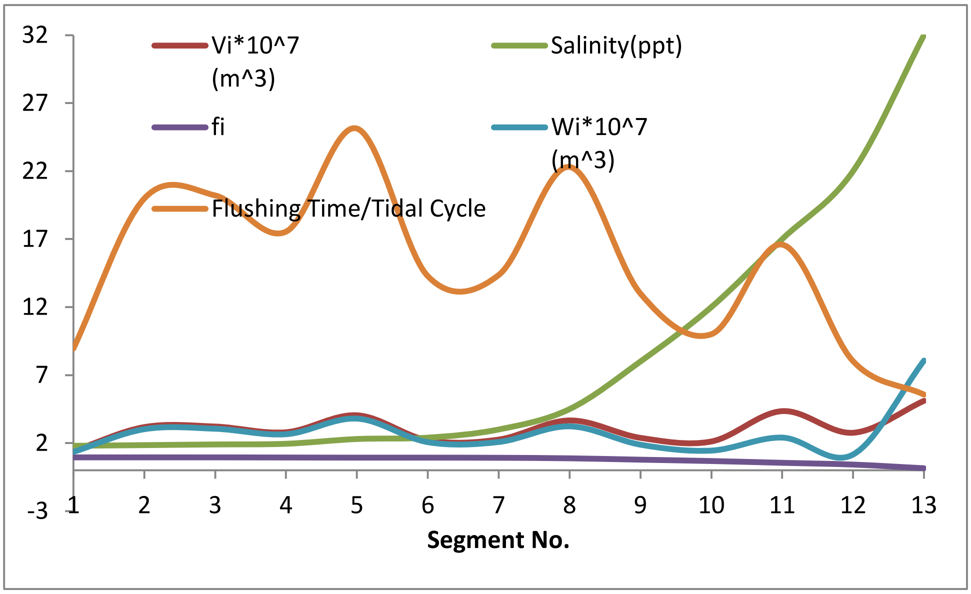


Figure 7. Variation of parameters in Forth scenario (Q=35m³/sec).

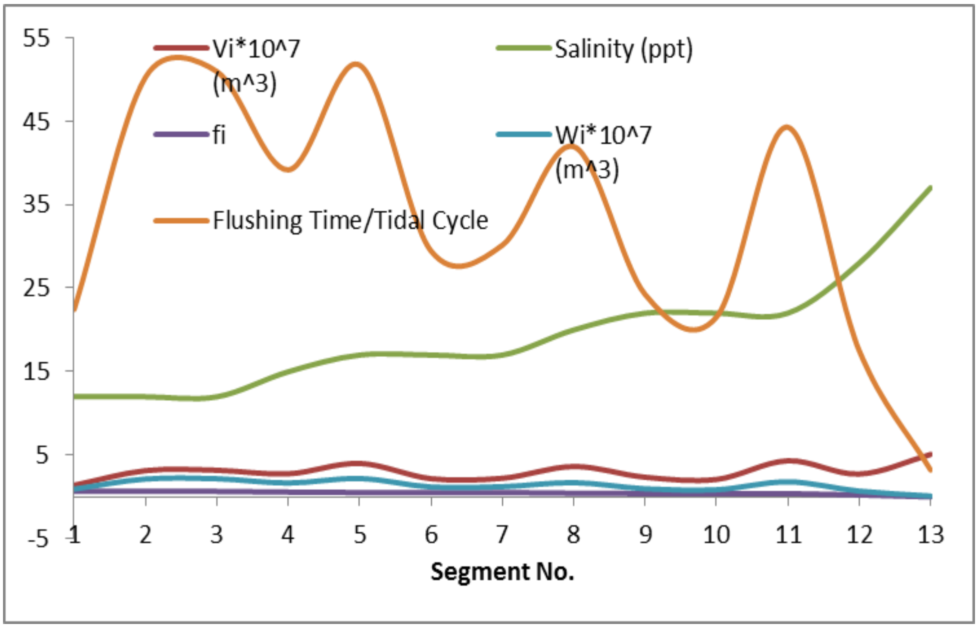


Figure 8. Variation of parameters in Fifth scenario (Q=10m³/sec).

Consequently, there is a large disparity among the segments as shown in Table (1). The amount of fresh water entering each segment was constant among the segments and the only influential factor was the tidal cycle time, which divides the river into two tidal cycles. The upstream segments (1-5) have tidal cycle time of 12 hours while segments (6-13) have tidal cycle time of 11.5 hours.

The impacts of the above variables on the values of the flushing time make the range of 3.24 hour to 51.67 hour at segments 13 and 5, respectively. And the flushing time of the total river reaches in this case was 6.9 months, which is a high value if compared with the previous scenarios where the discharges decreased as the flushing time increased (Liu and Liu, 2014). This confirms that the application of the Fresh Water Fraction Method in Shatt Al-Arab River gave convincing results.

Hartnett *et al.*, 2003 affirmed that the application of this method on rivers with relatively small areas be useful compared with that applied on large areas may cause significant errors.

### Segments Behavior:

To give a clear picture of what is ongoing in the thirteen segments consisting of the river reach and how they behave individually, Figure (9) showing that in segment (1) the flushing time was decreasing as the discharges increasing as well as salinity decreases with increasing discharge but differences of salinity range (1.0-1.8) g/l and 12.1 g/l at the discharge of 10 $m^3$/sec. Segment (2) has the same discharge of segment (1), but the flushing time was larger as it has in the segment (1), this was due to the fact that volume of this segment was larger. Segment (3) has the same discharge as in segment (2), segment (4) has the same discharge as of segment (3) but the flushing time was less because of their small volume as compared with the volume of segment (3). The segment (5) has the same discharge as of segment (4) but the flushing time was higher than the segment before. The segment (6) has the same behavior (flushing time was decreased with increasing discharges) but less than the upstream segments and it seems that this was due to the volume was less than the volumes of them. The segment (7) was behaving the same where flushing time was reduced with discharge increase, but the flushing time is larger than that of segment (6). The Segments (5), (3) and (2) have similar flushing time. Segments (8-13) flushing time was reduced with the increased discharges. In segment (11), flushing time was larger than segments (10), (9) and (12) and it seems that was due to the impact of its Volume. The impact of increasing salinity was lowering flushing time, as it was clearly seen in downstream segments (12), (13). Increasing discharge and lowering salinity cause reduction in flushing time in all segments.

## Conclusions

Due to the results, it can be conclude as the flow:

1. The flushing time depends on the fresh water discharge coming from upstream. It has non-linear inverse proportional relationship.
2. The flushing time depends on the volume of the segment where the relationship was positive.
3. The flushing time inversely depends on the salinity where flushing time decreases when increasing salinity to be compared to the biggest salinity, especially in the vicinity of the sea segment.

4. High discharge and low salinity cause a decrease in the flushing time per segment.
5. Flushing time decreases as flow discharge increases and vice versa.

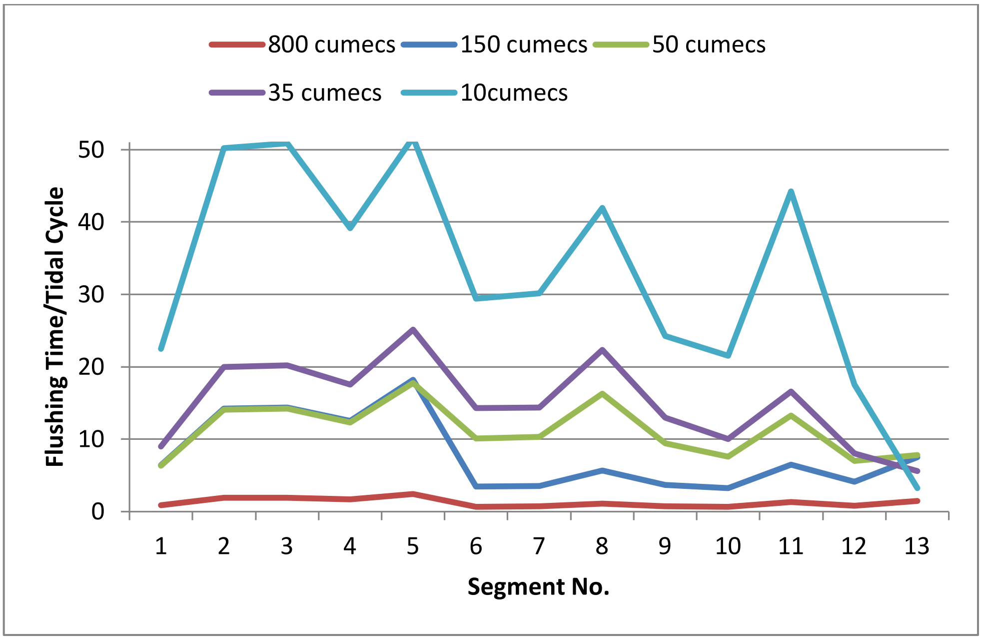


Figure 9. Flushing Time for all Scenarios and all segments.


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# زمن التبديل لمياه شط العرب – جنوب العراق

**صادق سالم عبدالله، علي عبدالرضا لفتة، سامر عدنان الطائي و عبدالكريم غيلان**
*مركز علوم البحار / جامعة البصرة، البصرة - العراق*

**المستخلص -** يعد حساب زمن التفريغ للأنهار المدية والمصبات ذو فائدة كبيرة للمعنيين بإدارة المياه لما يتخذوا من قرارات مناسبة وفقا لمعرفتهم بزمن التفريغ، شط العرب أحد الأنهار المدية وهو المصدر الرئيسي والوحيد للمياه العذبة في البصرة ويتعرض النهر بصورة مستمرة للأضرار البيئية نتيجة لوجود مصادر عديدة للتلوث منها الطبيعة وأخرى بشرية وحساب زمن التفريغ للنهر يساعد على تلافي أخطار التلوث قدر الإمكان. تم أستخدام طريقة جزء المياه العذبة لحساب زمن التفريغ لشط العرب، تبين إن لتصريف المياه العذبة وظاهرة المد والجزر والمكان دوراً في تحديد قيمة زمن التفريغ. زمن التفريغ لجزء النهر العلوي من المعقل حتى نهر الكارون اكثرا زمناً للجزء السفلي المتمثل من نهر الكارون حتى نهاية النهر وبشكل عام ووفقا للظروف الهيدرولوجية الحالية التي تسود النهر يكون مقدار زمن التفريغ بحدود 2.4 شهراً.