Iraq Salinity Project **Technical Report 6**

Report B1.4: Water and salt trends and balances for the Mesopotamian plain

Reporters:

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The Iraq Salinity Project is an initiative of Government of Iraq, Ministries of Agriculture, Water Resources, Higher Education, Environment, and Science and Technology, and an international research team led by ICARDA – the International Center for Agricultural Research in the Dry Areas, in partnership with the University of Western Australia, the Commonwealth Scientific and Industrial Research organization (CSIRO) of Australia, the International Water Management Institute (IWMI), Sri Lanka, and the International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates.

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This technical report series captures and documents the work in progress of the Iraq Salinity Project, in its seven research themes, working at the regional, farm and irrigation system scales. Technical reports feed into the *Iraq Salinity Assessment*, a synthesis and solutions to solving the problem: Situation Analysis (Report 1); Approaches and Solutions (Report 2) and Investment Options (Report 2).

Key words: southern Iraq, central Iraq, spatial distribution, remote sensing, irrigation, salinity mapping.

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http://icarda.org/iraq-salinity-project/teaser

This report is part of a series analyzing water and salt flow through the Tigris and Euphrates Rivers in the Mesopotamian plain. The series provide an insight in the layout and operation of the water and salt flow to allow a well-founded selection of possible interventions to improve water quality and agricultural production.

Report B1.4 uses water volume and water quality measurements from the Government of Iraq to obtain water and salt mass transport in the Tigris and Euphrates Rivers.

Introduction

A major concern for the future sustainability of irrigated agriculture on the Mesopotamian Plain of Iraq is the long term trends in the salinity of the supply water. There is a great deal of commentary that suggests that the salinity of both the Euphrates and Tigris Rivers is increasing with time, and this is linked to the reduction in streamflow due to the construction of reservoirs along the length of the river system.

Data for both the Euphrates and Tigris Rivers was compiled from published Government of Iraq Ministry of Water Resources reports; with additional data sourced from internal data sheets from recent routine sampling and analysis. The data represented combinations of streamflow volumes and salinity measurements at specific sampling sites (usually gauging stations).

Data

Data was obtained directly from the Water Control Centre, Ministry of Water Resources, summary reports on the flow and salinity of the Euphrates and Tigris Rivers, and associated structures (WCC, 2006). Further data for the period 2005 to 2009 was obtained from University of Baghdad (2011). The data was reported as average monthly values, and covered the period 1976 to 2009. The measurements were assumed to have occurred on the 15th of every month when a monthly value was reported. No details were provided in the two reports that outlined how the average monthly values were derived.

In addition to the data obtained from WCC (2006) and University of Baghdad (2011), further data was obtained from recent sampling programs for water quality assessment in both the Tigris and Euphrates Rivers (unpublished data, Ministry of Science and Technology). This data was generally for the period 2007 to early 2010, was on a monthly basis and had been analysed for full water chemistry.

The data were stored in a simple master spreadsheet database for later analysis. No attempt was made to verify the data apart from simple screening to remove obvious anomalies.

Figure 1 shows the location of all sampling points represented in the database.

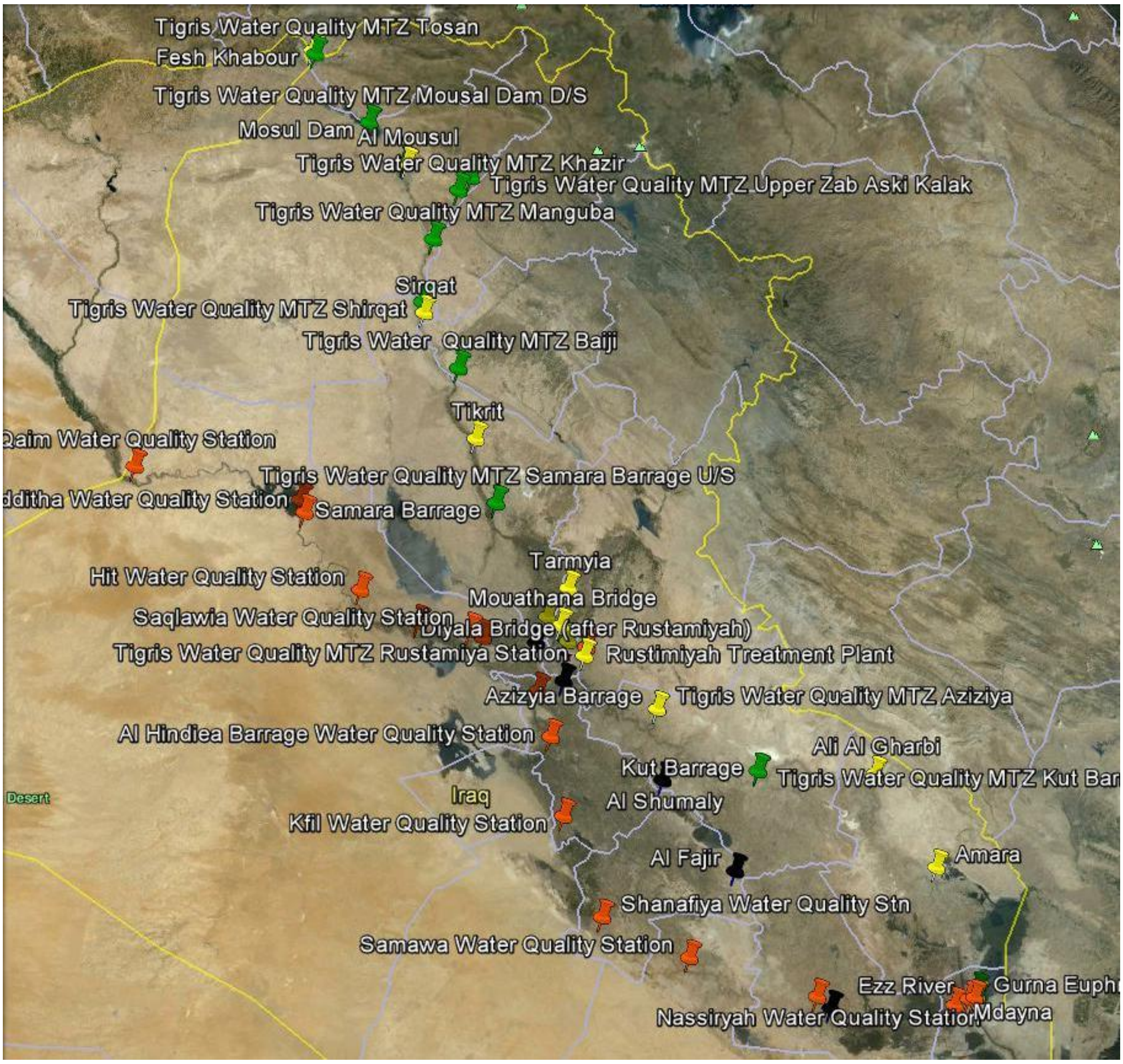

Figure 1: Location of All Sampling Stations used in the Assessment

Data Assessment

The data were assessed in three different tasks. Firstly, the time series trends for each sampling station were reviewed, where data was of a long enough series to make the analysis meaningful. Secondly, the longitudinal profile for the two main rivers was assessed, with a view to understanding the major spatial changes in salinity. Finally, the salinity data was combined with the flow data to assess processes that affect salt load throughout the system. As the flow data was of limited extent, only selected sites were able to be assessed for salt load.

Euphrates

Water in the Euphrates enters Iraq at the border with Syria (Hussaiba) and flows through several water management structures to Qurna, where it meets with the Tigris and flows to the Gulf through the Shat Al Arab. It takes 12 days travel time for the water to move from the border to Qurna (not including residence time in reservoirs).

Longitudinal Salinity profiles

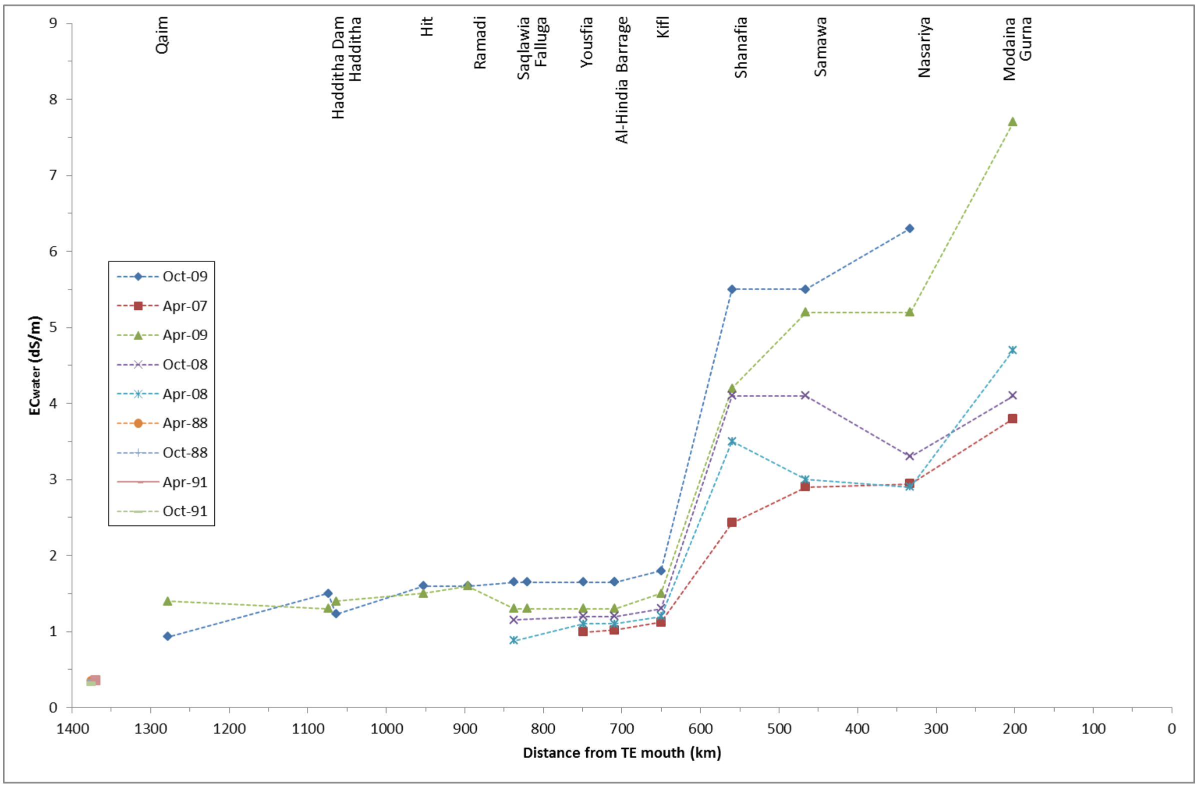

Figure 2: Longitudinal Salinity Profile, Euphrates River

(Source: Ministry of Agriculture and Ministry of Water Resources data)

Figure 2 shows the longitudinal salinity profile for the Euphrates River. The bottom axis shows the distance from the Gulf which increases up to the Syrian border (at about 1300 km from the Gulf). The data shows a gradual increase in salinity throughout the upper section of the river (from the Syrian border downstream to Kfil). This section of the River is that which is most regulated from the point of view of reservoirs and diversions. This is the reach that also receives Tigris water flow from Lake Tharthar. Salinity increases dramatically between the Kfil and Shanafia gauging stations. The salinity increase is substantial, ranging between a factor of two and four between wet and dry years, and wet and dry seasons, the latter correlating with when irrigation deliveries are at a maximum.

The data also show the marked influence of wet years (and higher river flows); April 2007 was wet, whereas October 2009 was dry. This is especially apparent downstream of Kfil. This indicates the importance of dilution flows in controlling river salinity in the lower reaches of the river, as the river is operated to deliver water to the major diversion points all upstream of Kfil. As well, the lower river reaches are subject to major irrigation drain inflows and potentially to saline groundwater ingress.

Limited data is available historically (prior to 2007), however, the scant data shows that salinity hasn’t changed considerably since 1988. In fact, the dry year of 1991 is still typical of river salinities measured more recently.

Water and salt measurements

This section deals with the salinity and flow at each of the major management points in the river based on available water and salinity data.

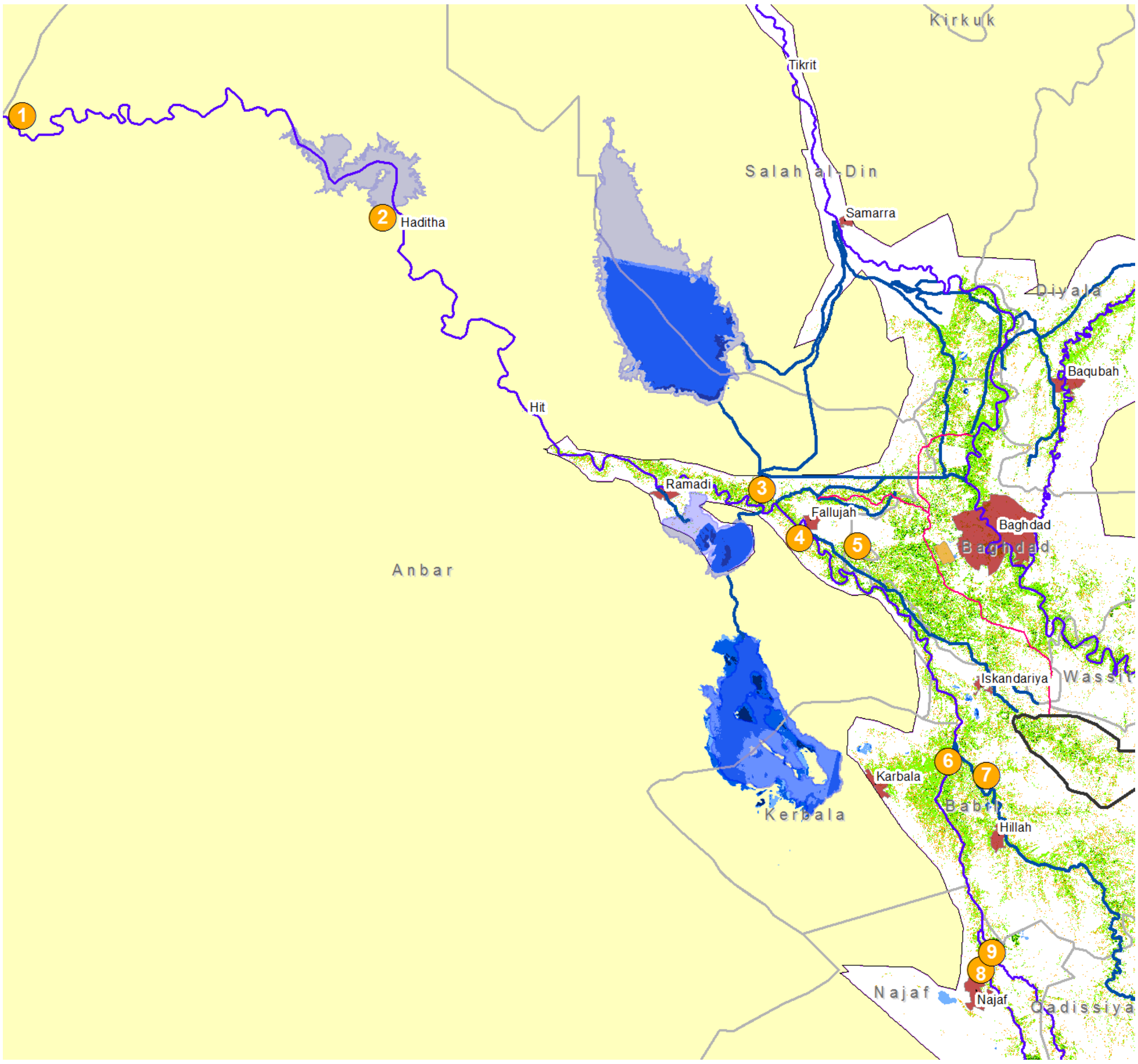

Figure 3: Measurement locations along the Euphrates River.

Figure 3 shows the locations of the sites discussed in this section.

1. Euphrates entry into Iraq
2. Haditha Reservoir
3. Tharthar-Euphrates Canal (inflow of water into Euphrates River)
4. Falluja Barrage
5. Falluja-Iskandriyah Canal (irrigation water extraction from Euphrates River)
6. Hindiyah Barrage
7. Hindiyah Canals (irrigation water extraction from Euphrates River)
8. Kufa Barrage
9. Abassiyah Barrage

Haditha

The Haditha Reservoir is the furthest upstream water storage facility on the Euphrates River in Iraq and regulates flow in the river. The salinity of the water is measured in the reservoir, while the water flow is the water released by the dam into the Euphrates River. It is assumed that the released water will have the salinity of the reservoir water. Figure 4 shows the variability of water flow and water salinity from 1985 to 2005.

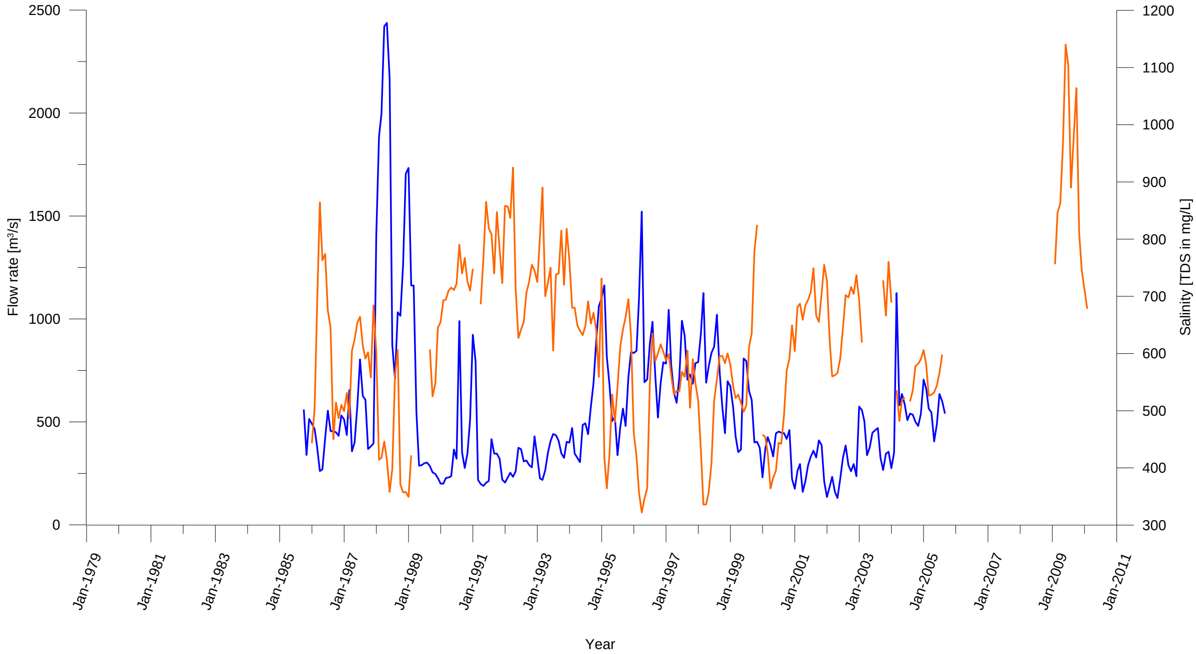

Figure 4: Flow rate (blue) and salinity (orange) of Euphrates River at Haditha.

The data shows that the lowest salinity was recorded in about 1996 related to a moderate flow, and that there has been no systematic increase in salinity over time; the salinity of high flows has remained the same, if not decreased, and the salinity of water related to low flows has decreased from over 900 mg/L to under 800 mg/L. More recent (2009-2010) salinity data show high levels of monthly average salinity levels (up to 1140 mg/L). Flow measurements for that same period were not available at the time of this analysis.

The relationship between water salinity and water flow rate is shown in Figure 5. Note that high salinity levels (600-900 mg/L) correlate with low flow rates (< 1000 m^3/s), and lower salinity levels of 300-400 mg/L correlate with high flow rates (1000-2500 m^3/s). This latter level appears to be the lowest salinity level measured in the Euphrates River near Haditha.

The monthly salt load in the Euphrates for Haditha is shown in Figure 6; salt load is the flux rate of salt per unit time, derived from the flow rate and the salinity level at the same time. Based on the available number of data pairs for flow and concentration, an average monthly salt load of 824,000 tonnes is transported through the Euphrates river at Haditha Reservoir, varying between 2,750,000 tonnes and less than 250,000 tonnes per month. It is not surprising that when the water flow rates decrease, the salt load decreases as well, despite an increase in salinity concentration. At Haditha Dam, the flow rate has a larger impact on salt load than the salinity concentration, which is a common relationship in other river basins.

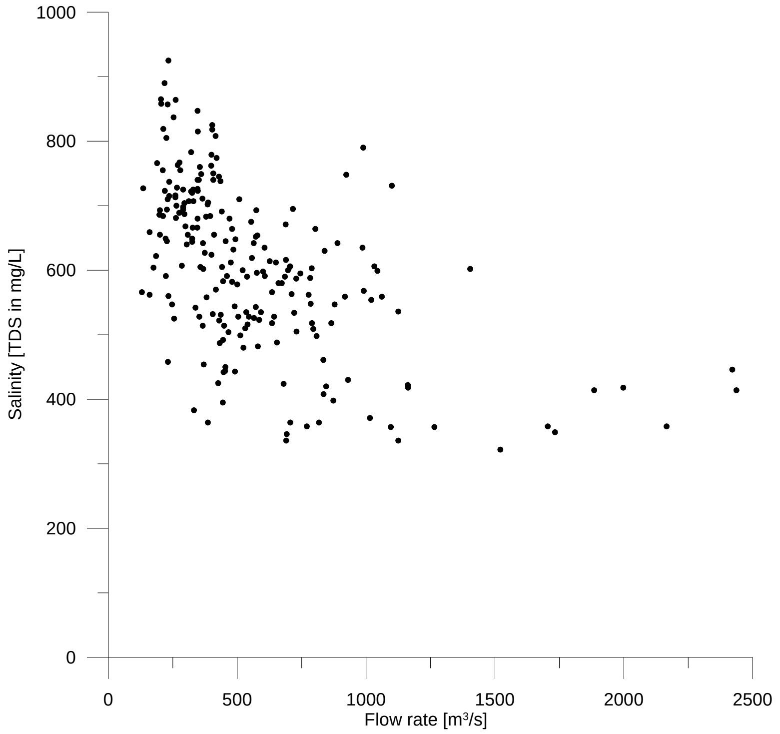

Figure 5: Water salinity and monthly flow rates of Euphrates River at Haditha

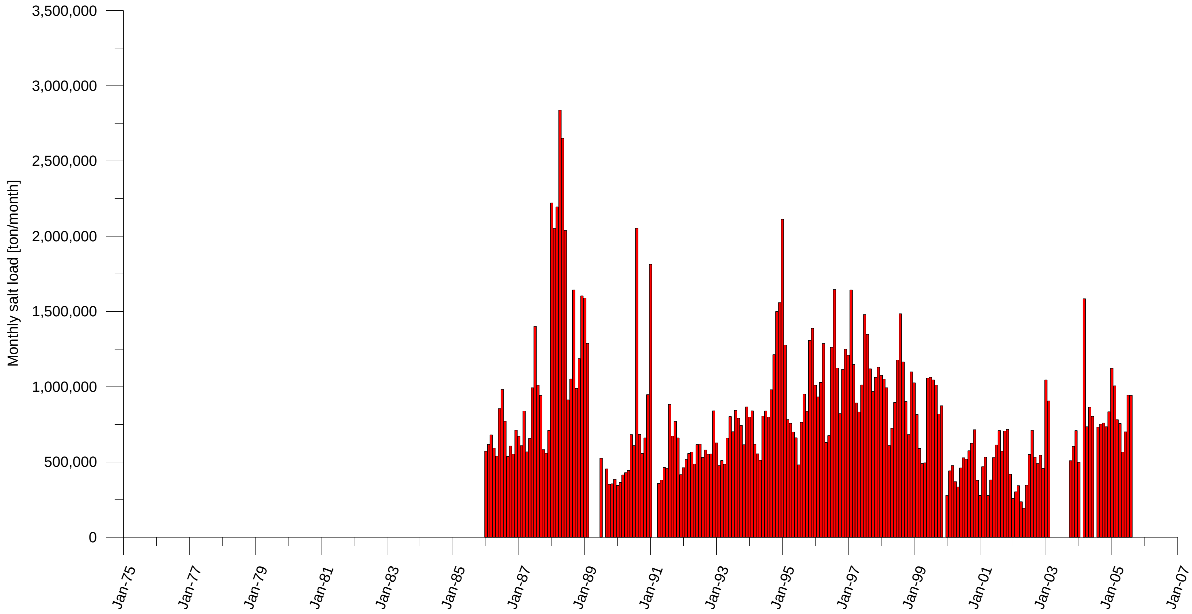

Figure 6: Monthly salt mass transported in the Euphrates at Haditha

Falluja

The Falluja Barrage is the next available measurement point in the Euphrates. The Falluja barrage regulates water flows and feeds its upstream left bank canals to meet required irrigation water, mainly through the main Falluja-Iskandriyah canal. Euphrates River water at Falluja is a combination of water released from Haditha Reservoir and water released from the Tigris River via Lake Tharthar into the Euphrates through the Tharthar-Euphrates canal. Between Haditha and Falluja, some excess flood water is temporarily stored in the Habbaniyah Lake and can be released back into the Euphrates through the Dibban canal.

Water flow rates and water salinity downstream of the Falluja Barrage are shown in Figure 7.

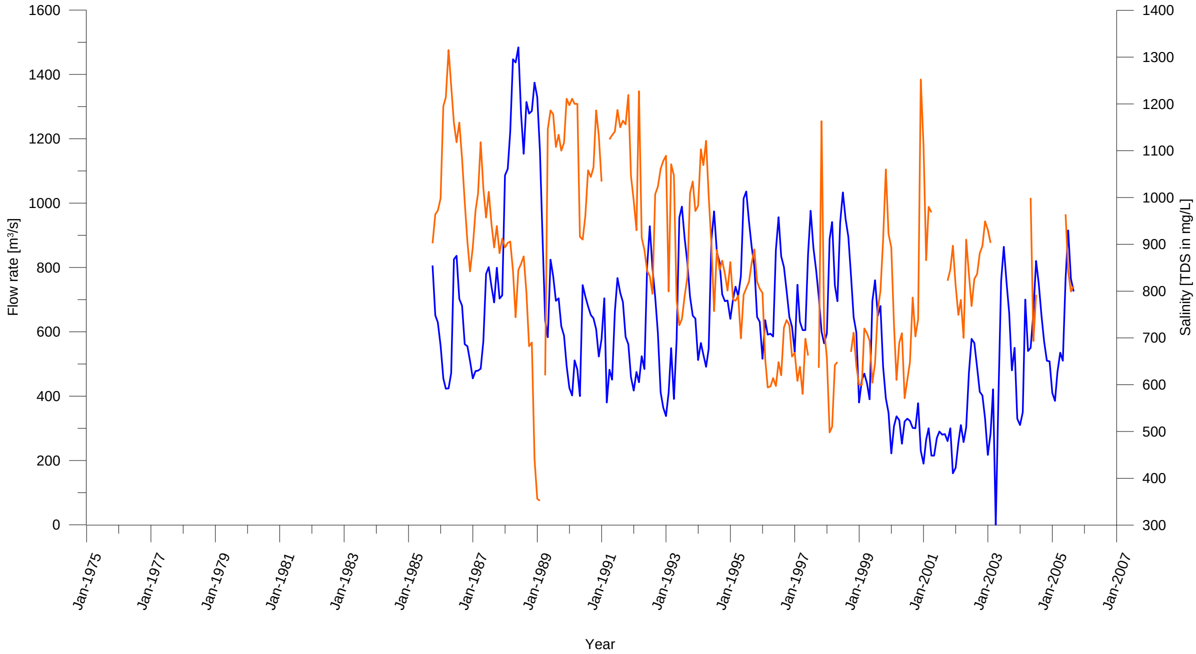

Figure 7: Flow rate (blue) and water salinity (orange) of Euphrates River at Falluja.

The salinity at Falluja is usually higher than in Haditha. The relationship between flow rate and salinity concentration (Figure 8) is less defined for the Falluja barrage than for Haditha Reservoir. This is likely the result of the addition of water from Lake Tharthar into the Euphrates, water from which is the only major addition to the main Euphrates flow and which generally has a higher salinity than from Haditha (Figure 10). The seasonality in the flow data indicates that captured flood waters in Lake Tharthar are released into the Euphrates during the high water demand season (summer). Figure 11 shows the monthly salt load (for months where both salinity and water flow data are available) transported from Lake Tharthar into the Euphrates. Note that peaks of 1 – 2 million tons of salt per month occur, which is a large contribution to the salinity at Falluja Barrage, and thus to irrigation water for the projects Saqlaviyah, Abu Ghreib, Radhwaniyah, Yosafiya, Latifyia and Al-Iskandariyah.

Salt concentration and water flow rate through the Falluja-Iskandria Canal is shown in Figure 23. Due to the low flow volumes, relative to the large water volume flowing through the Euphrates, this extraction of water and salt (salt load) has little influence on the salt balance of the Euphrates. However, the salinity of the irrigation water can have a large impact on the management of crops and soils in the above mentioned irrigation projects, since water is consumptively used, and salts will be deposited unless sufficient drainage is present.

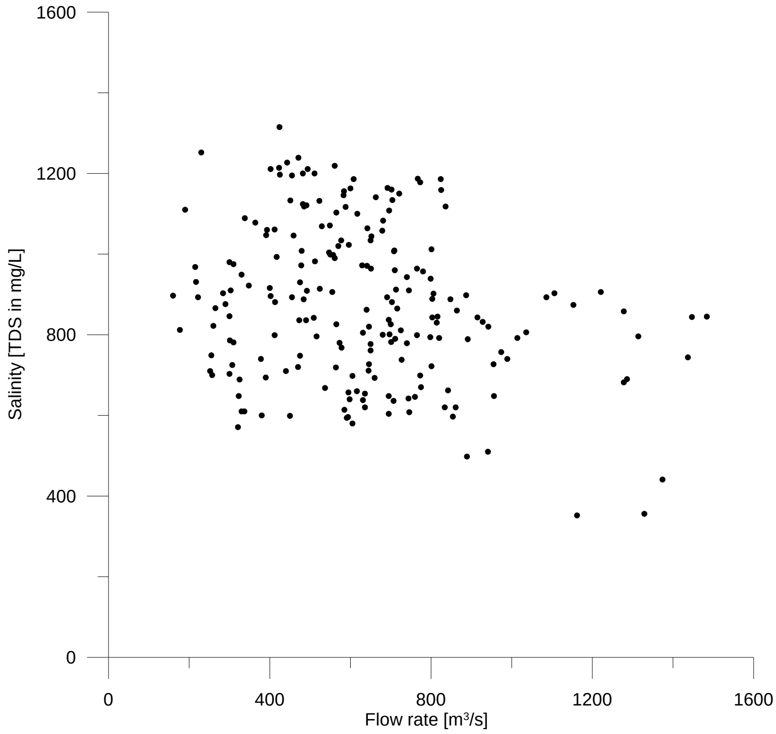

Figure 8: Water salinity and monthly flow rates of Euphrates River at Falluja

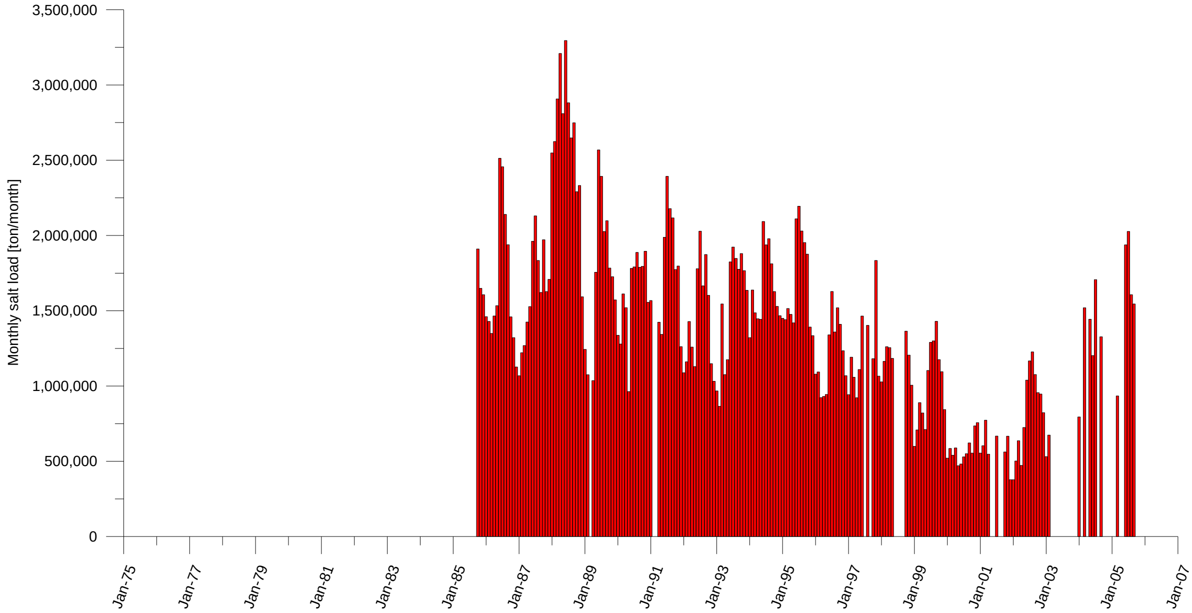

Figure 9: Monthly salt mass transported in the Euphrates at Falluja

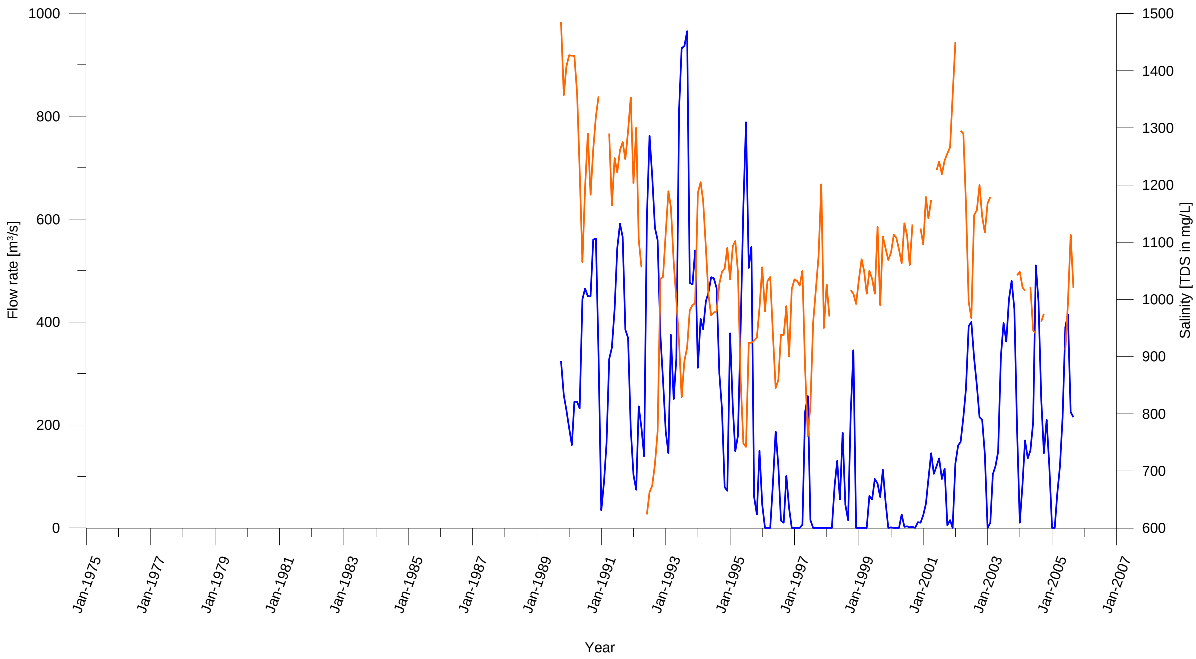

Figure 10: Flow rate (blue) and water salinity (orange) of Tharthar-Euphrates Canal at Tharthar Regulator

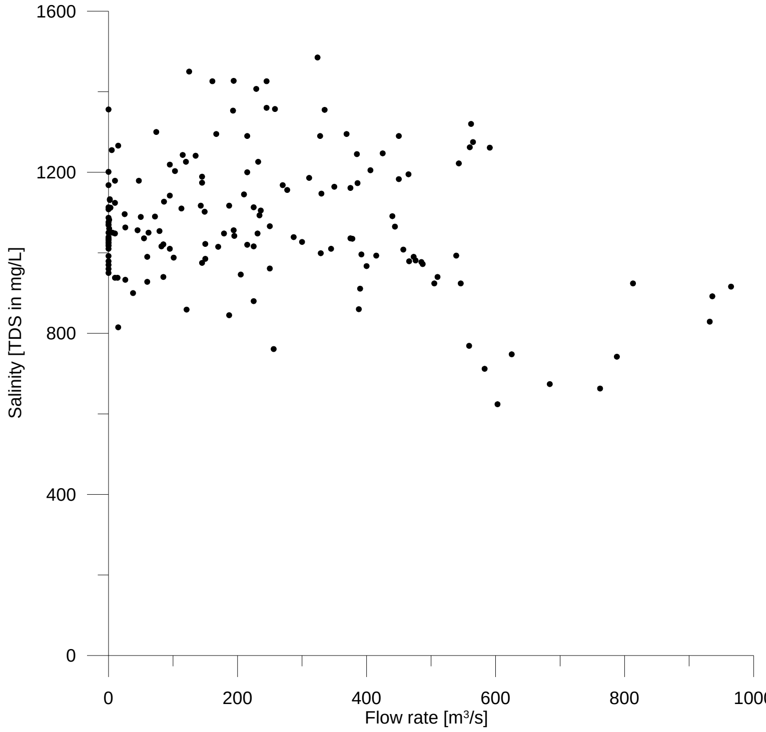

Figure 11: Water salinity and monthly flow rates of Tharthar-Euphrates Canal at Tharthar Regulator

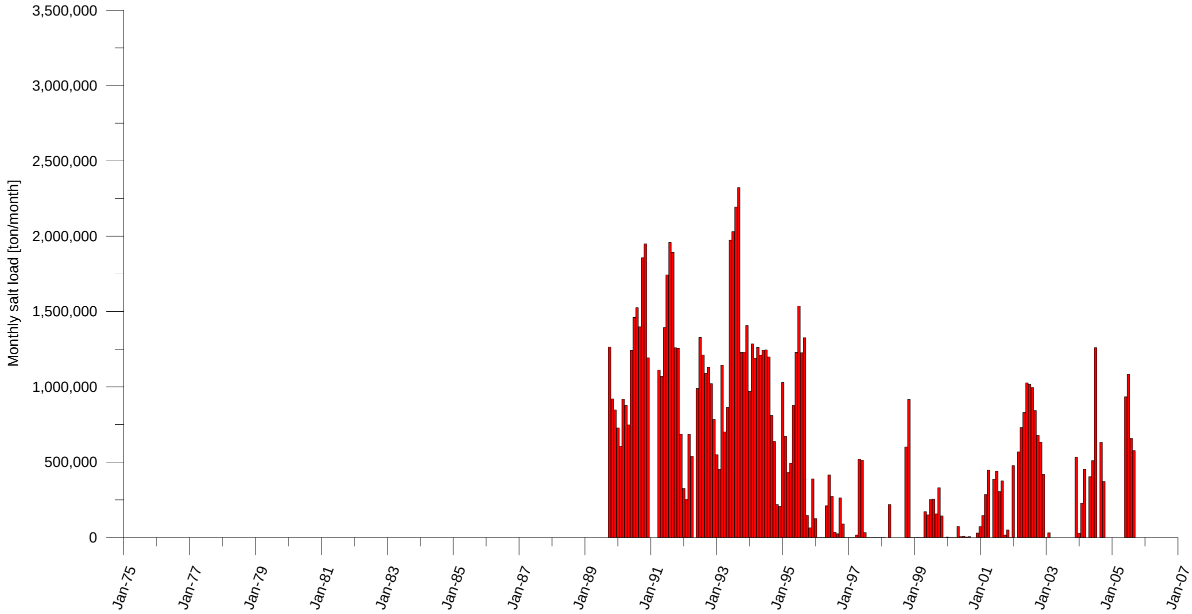

Figure 12: Monthly salt mass transported through the Tharthar-Euphrates canal into the Euphrates at Falluja

The salt loads for both Haditha and Falluja are shown in Figure 13. The plot shows that there is very good correlation and a declining trend over time, with the salt load at Falluja matching closely with that at Haditha. The main difference is in the early years of the plot, and if the salt load from Lake Tharthar is taken into account (which shows a major input up until about 1996), then the load at Falluja can be explained from these two inputs. The water and salt flows through Lake Habanyiah, and the extraction for irrigation has been excluded from the analysis.

If the salinity of the flood water stored in Lake Tharthar could be managed better, the salt load of the irrigation water for several important irrigation projects on the left bank would be improved.

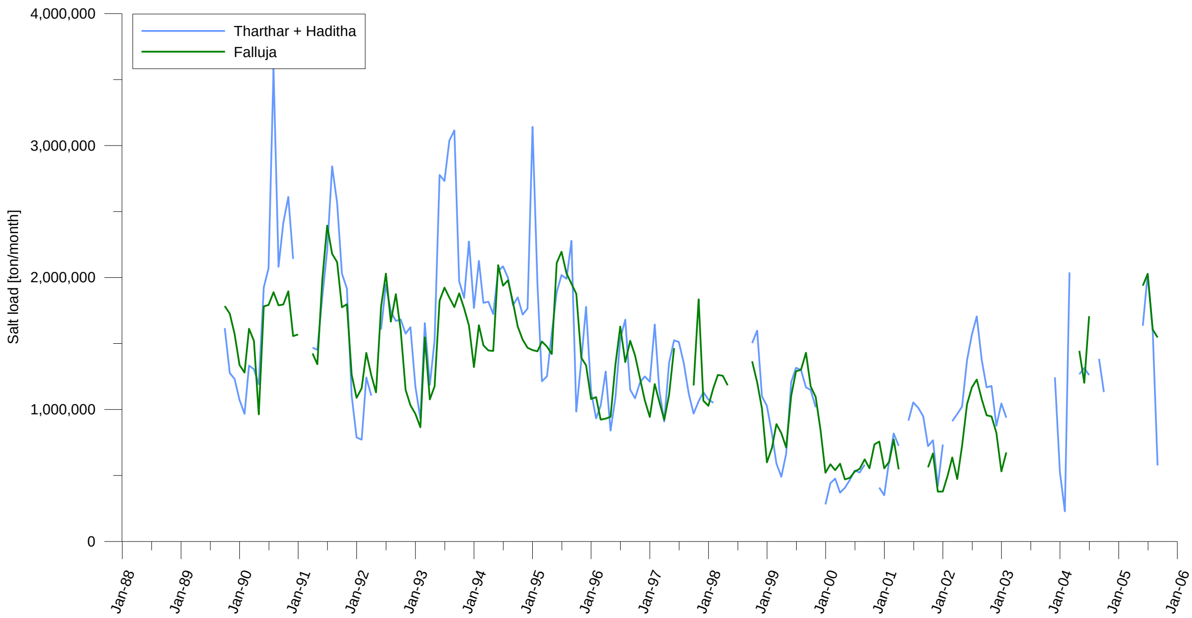

Figure 13: Salt load at Falluja and salt load at Haditha including contribution from Lake Tharthar-Euphrates canal

Hindiyah

The Hindiyah Barrage is located downstream of several irrigation diversion canals. The irrigation projects irrigated with Euphrates water upstream of Hindiyah are Husseinya and Bani Hassan on the right bank, and Musaieb, Kifl and the Shat Al Hillah Canal on the left bank. The regulators for these diversion points were (re)constructed in 1989.

Figure 14 shows the flow rate and salinity concentrations in the Euphrates at the Hindiyah Barrage. Again the high flow rates are showing lower salinity concentrations, and low flow rates show higher salinity concentrations. This relation is graphically presented in Figure 15, and appears closely related to the flow-salinity relation at Haditha (Figure 5) than at Falluja (Figure 8), albeit with higher salinity concentrations than at Haditha. The increase of salinity concentration in the Euphrates at Hindiyah is only due to the increase of salinity from Lake Tharthar, since the salt load at Hindiyah (Figure 16) is very similar to the salt load from the Euphrates at Haditha and the salt load entering through the Tharthar-Euphrates canal (Figure 17).

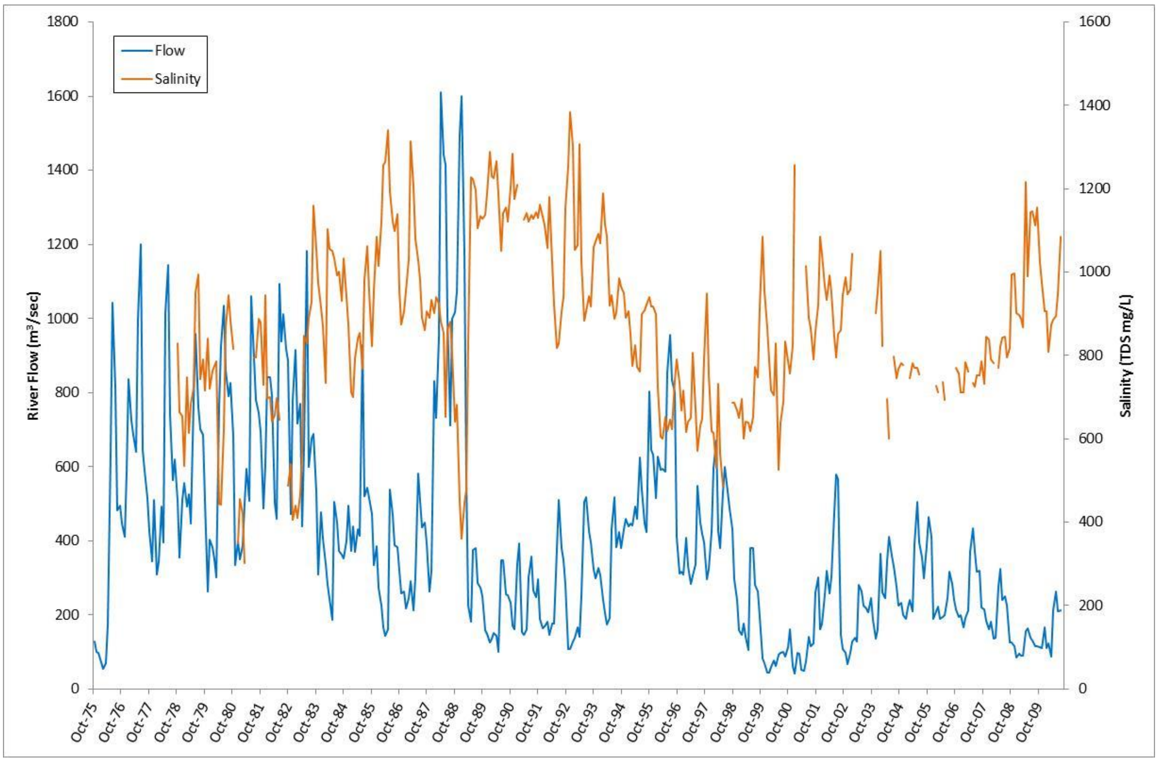

Figure 14: Flow rate (blue) and water salinity (orange) of Euphrates River at Hindiyah Barrage

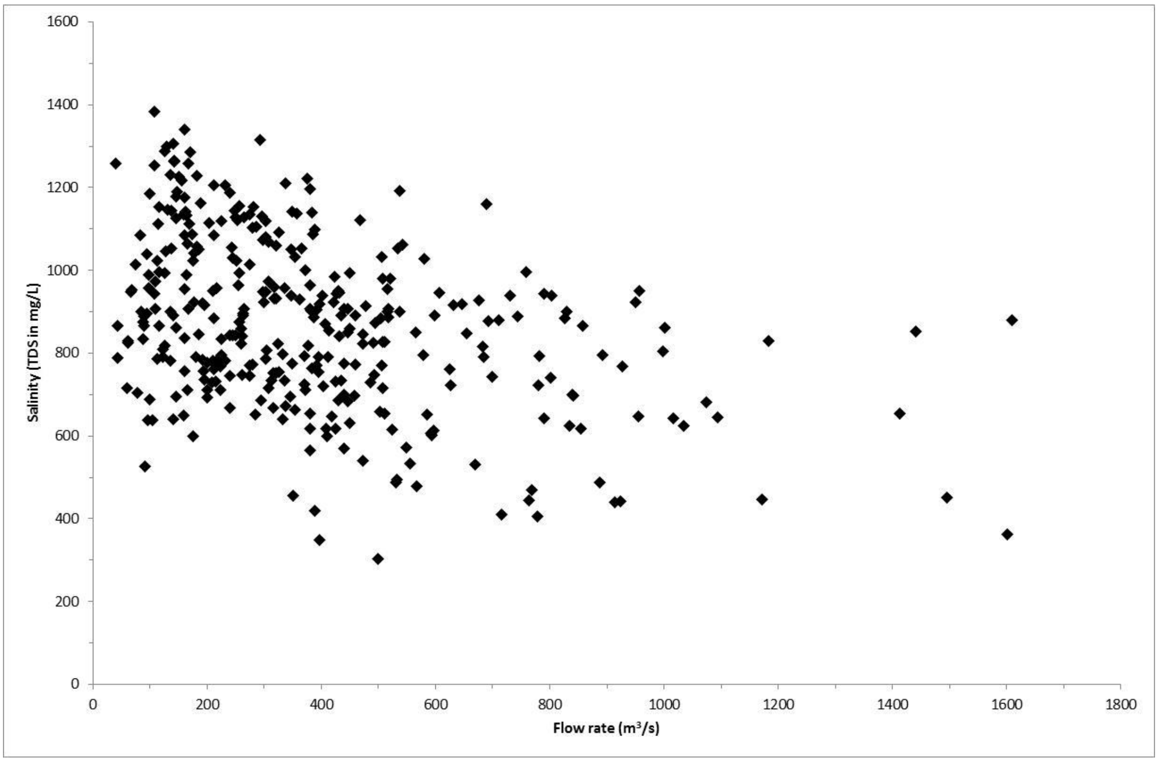

Figure 15: Water salinity and monthly flow rates Euphrates at Hindiyah Barrage

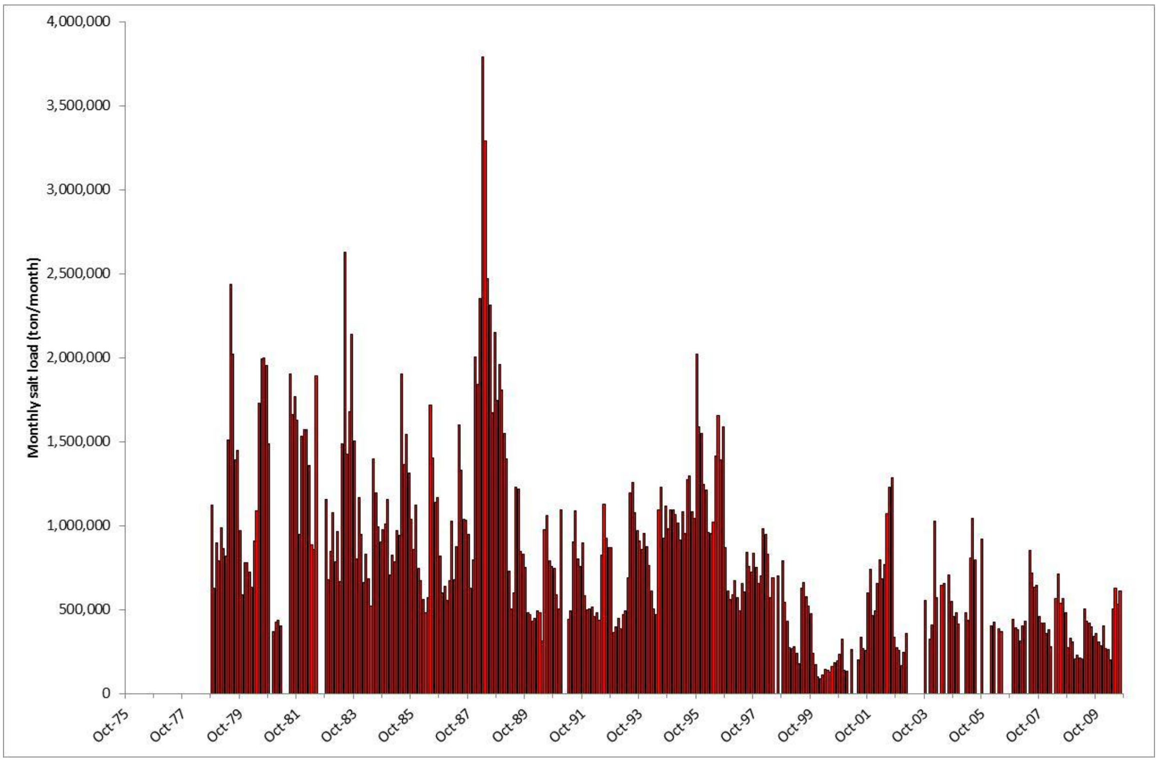

Figure 16: Monthly salt mass transported through the Euphrates River at Hindiyah Barrage

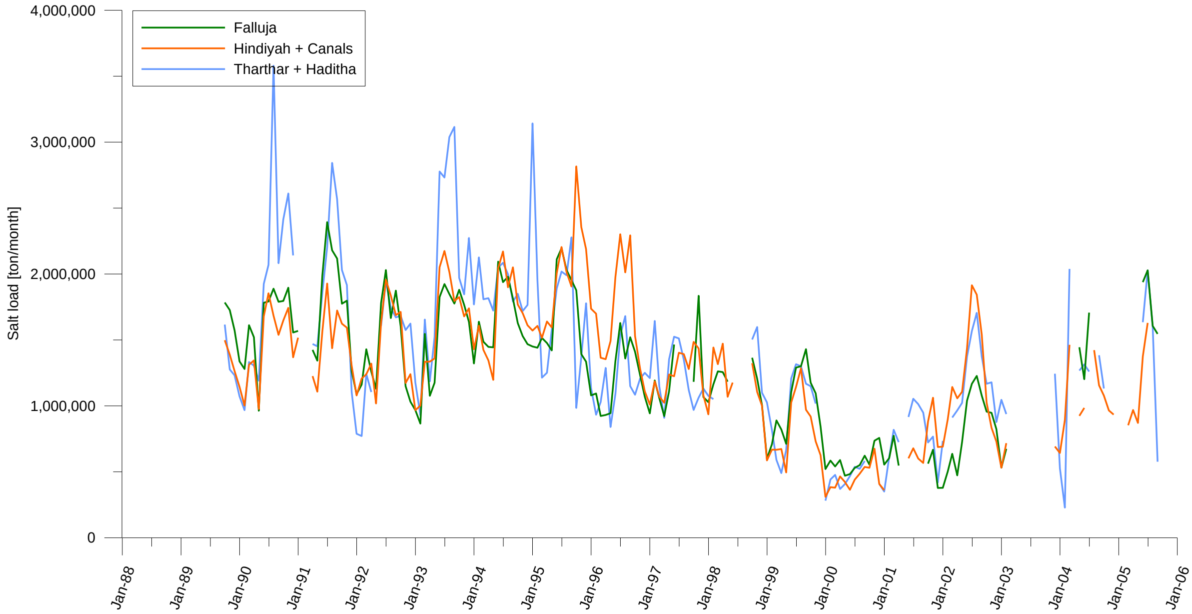

Figure 17: Salt load at Hindiya including salt load lost to irrigation compared with salt load in the Euphrates River at Falluja and salt load at Haditha and Tharthar-Euphrates Canal.

Figure 17 shows the monthly salt load flowing through the Euphrates at Falluja, compared with the salt load delivered to the irrigation canals and flowing through the Euphrates at Hindiyah. The data are very comparable, indicating that there are no major losses or gains of salt in the Euphrates river section between Haditha and Hindiyah. In the schematic diagram for storage and control of water in Iraq (WCC, 2006) no return flow points have been identified. The similarity of salt loads throughout the upper sections of the Euphrates indicates that there is no major recharge or discharge of the river to the groundwater. The water balance between the three monitoring sites is also very close (not shown), indicating that evaporative losses are small relative to the flow volume, and that salinity concentration increases are not due to evaporative losses in the river.

The times series in Figure 17 show two distinct portions. Prior to about 1998, there is a slight but consistent mismatch between the three traces. There is a declining trend with time over this period for Haditha plus Lake Tharthar. However, there is an increasing trend over the same period for Hindiyah plus canals. This means that in the early part of the time series (up until 1993) there is a reduction in salt load as one proceeds downstream, whereas after that point there is an increase in salt load moving downstream. This may be due to floodplain groundwater dynamics related to the major flood that occurred in 1988, the legacy of which lasts for about ten years. After 1998, there is a consistent pattern of salt loads between the three series, showing little difference. This may be due to the generally lower flows recorded over this period.

Kufa and Abassiyah

Downstream of Hindiyah, the Euphrates splits into two arms. The right arm (looking downstream) is regulated by the Kufa Barrage, while the left arm is regulated by the Abassiyah Barrage. The purpose of both the Kufa and Abassiyah Barrages is to regulate the delivery of water for irrigation purposes to Al Najaf and Al-Diwaniyah governorates (WCC, 2006). Both barrages were (re)constructed in 1986.

Water flow data are available for each of the barrages, but salinity data are lacking. Since the water balance between Hindiyah, and Kufa and Abassiyah is comparable (not shown), it is likely that the salinity concentrations at Kufa and Abassiyah are similar to Hindiyah (assuming a similar salt load).

However, it is at about this point, or slightly upstream, that river salinity increases dramatically, as shown in Figure 2.

University of Baghdad (2011) show data that confirms that the increase in salinity is due to the return flows from a number of major drains in this area. This leads to the conclusion that a large proportion of the river flow below this point is in fact irrigation drainage water.

Water and salt flow through the Euphrates River

Data presented in the preceding sections showed that the water and salt balance from Haditha reservoir to the Al-Kufa and Abassiyah reservoir can be well described with the available data. A graphical representation of the annual water volume and salt load for an average year (1990) and a dry year (2001) are given in Figure 18-Figure 21. Note that the data do not result in a closed water balance, partially due to extrapolation of flow rates expressed in m^3/s to a volume on an annual basis. However, the annual totals appear to fall within expected error margins.

The importance of salt load from Lake Tharthar is shown again, especially for an average year (based on the flow rate at Falluja between 1985 and 2005). Figure 20 shows that the salt load inflow from Lake Tharthar is higher than salt load from Haditha, affecting all water consumption below the Tharthar-Euphrates Canal.

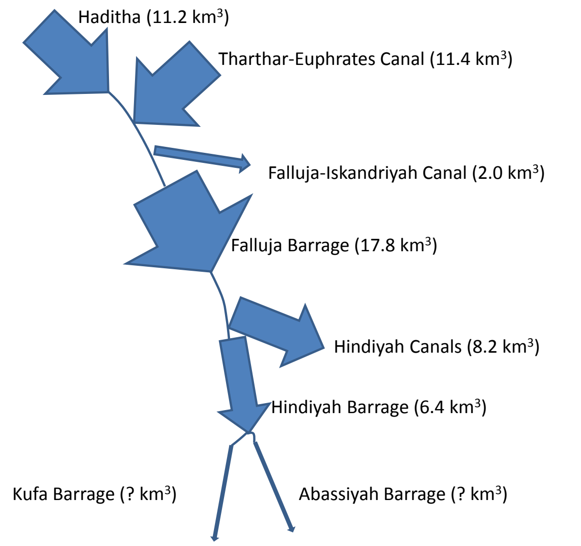

Figure 18: Water volumes for calendar year 1990 in the Euphrates river.

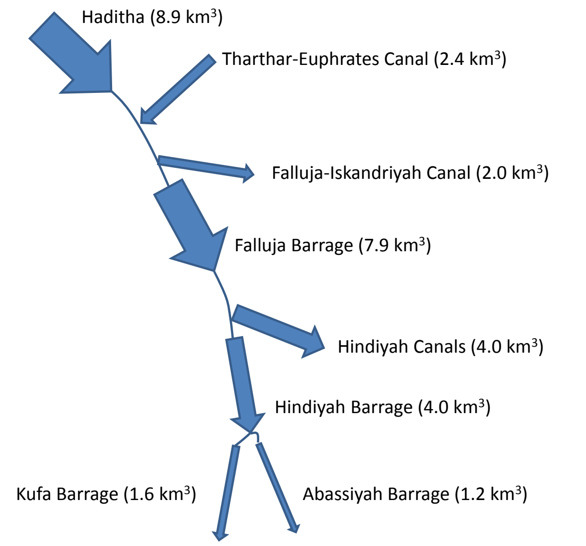

Figure 19: Water volumes for calendar year 2001 in the Euphrates river.

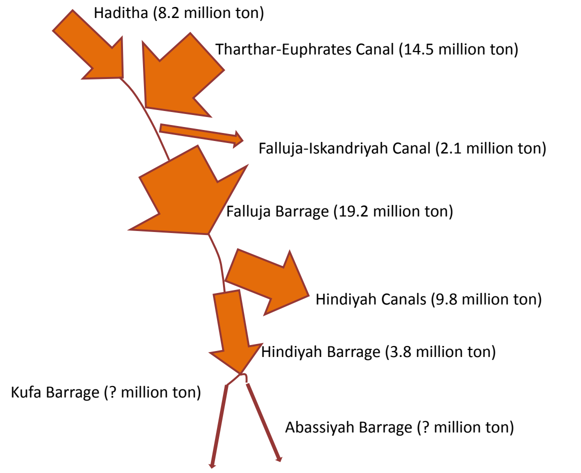

Figure 20: Salt mass for calendar year 1990 in the Euphrates river.

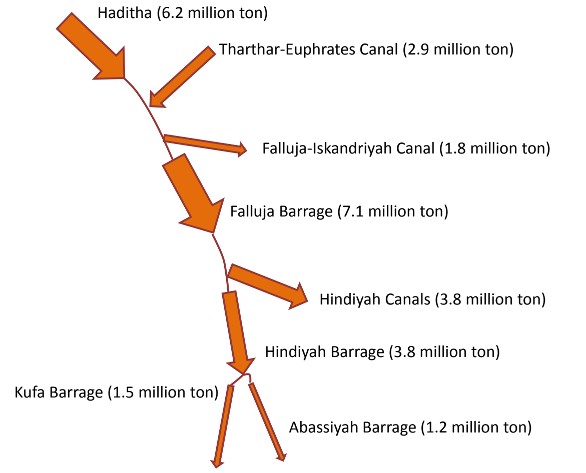

Figure 21: Salt mass for calendar year 2001 in the Euphrates river.

A detailed longitudinal salinity profile for the Euphrates in 2009 is shown in Figure 22 and this can be compared to that for a number years as shown in Figure 2. The former profile shows a large increase in salinity concentration between Kifl and Shanafiya. The schematic operational diagram for the Euphrates (WCC, 2006) shows return flows from the Shamia East drain, the Shamia West drain, the Al-Kasaf drain and the rice-growing area located in this area. This combined return flow contributes substantially to the low flow in the Euphrates, thus increasing salinity concentrations considerably.

The decrease of salt concentration at Qurna is due to a mixing of water between the Tigris and the Euphrates. The first 5 months of 2009 show salinity concentrations similar to Modaina, while the last 7 months show salinity concentrations similar to the Tigris salinity levels.

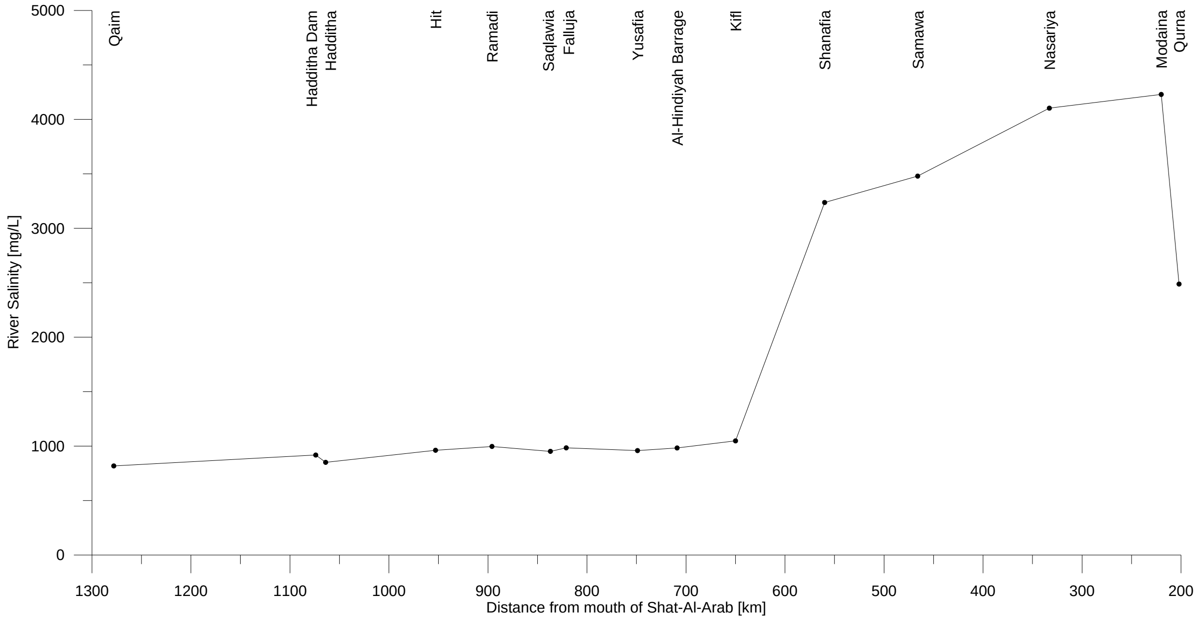

Figure 22: Longitudinal salinity concentration profile in the Euphrates River.

Irrigation from the Euphrates

Three reaches of the Euphrates River are important for irrigated agriculture. The first is upstream of Falluja Barrage, where water is extracted to Saqlawiyah and the Falluja-Iskandriyah Canal for the irrigation projects Abu Ghreib, Radwania, Yusafia, Latifia and Alexandria. The second reach of importance is upstream of Hindiyah Barrage, where Bani Hassan and Husseiniya are irrigated on the right bank, and Musaib, Kifl, and the Shatt Al Hillah Canal are fed from the Euphrates river. The third reach is downstream of Hindiyah, where most of the remaining water is consumed through several off-takes, mainly to irrigate an extensive area of rice. Figure 23 shows the flow rates and salinity levels for the Falluja-Iskandriyah Canal. Peak irrigation flows correspond with lower salinity levels. The flow rate shows a somewhat reliable and constant supply of water. Figure 24 shows the flow rate and salinity at the Hindiyah Canals. The impact of the dry years in 2000 and 2001 is more pronounced, with extraction rates approximately 1/3rd of the normal water extraction. The third reach in the Euphrates that is important for irrigation is where the river splits into two arms. Water flow in the right arm is managed by the Kufa Barrage (Figure 25) and in the left arm is managed by the Abassiyah Barrage (Figure 26).

Salt loads for each of the irrigated areas is shown in Figure 27-Figure 29. The salt load for each area is very dependent on the flow rate through the main irrigation supply canals. Irrigation water through the Hindiyah Canals, and the combined salt load in irrigation downstream of Kufa and Abbassiyah has a similar order of magnitude, while the salt load extracted from the Euphrates River at Falluja is relatively small. Note that the values on the y-axes are almost 3 times lower than the range used to display the salt loads in the Euphrates River. The effect of low flow rates in 2000-2001is clearly visible in the salt load figures for Hindiyah, Kufa and Abbasiyah. The effect on the load at the Falluja-Iskandriyah Canal, which is farther upstream in the Euphrates, is less during these drought years.

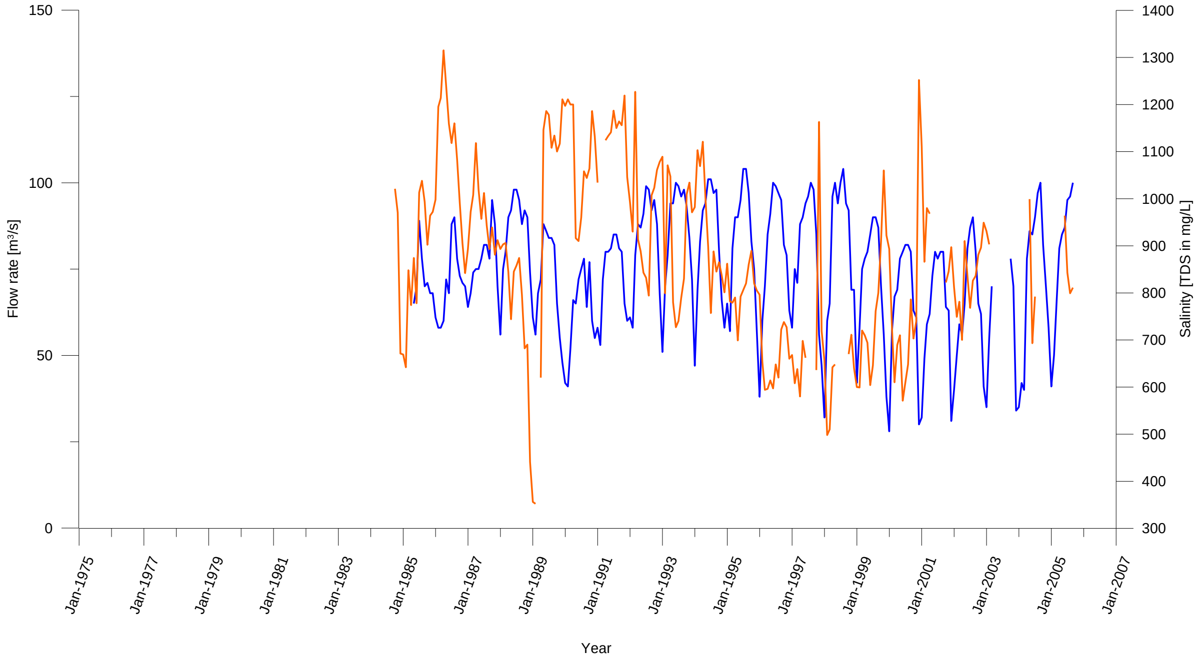

Figure 23: Flow rate and water salinity of Falluja-Iskandriyah Canal at Falluja

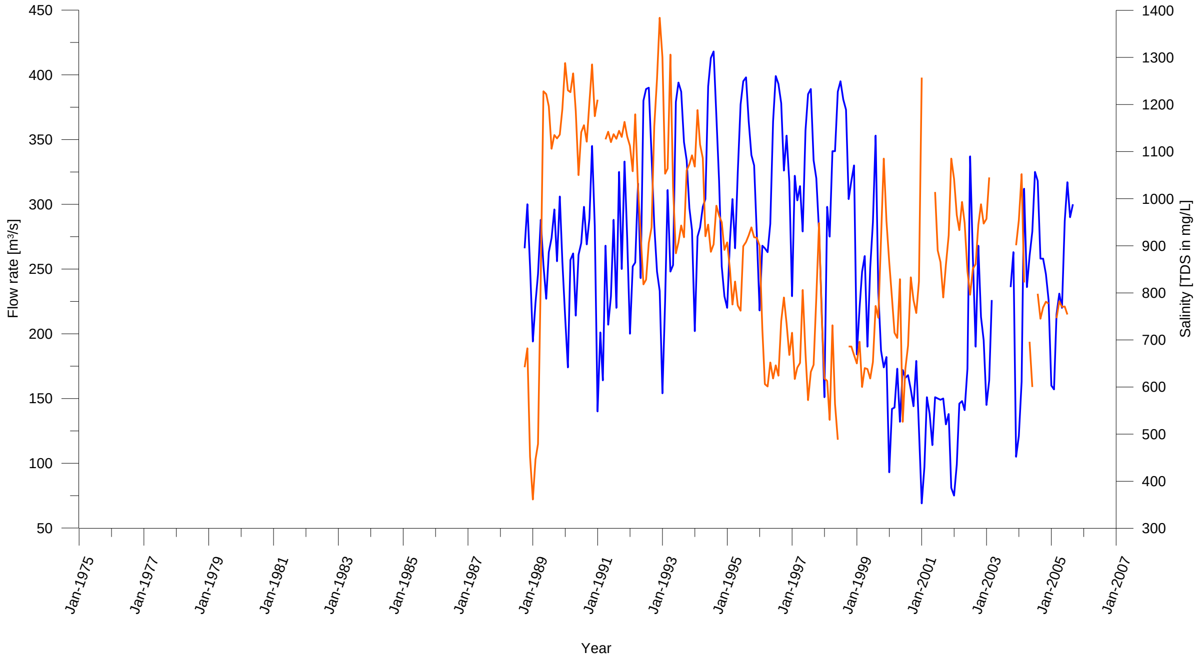

Figure 24: Flow rate and water salinity of Hindiyah Canals.

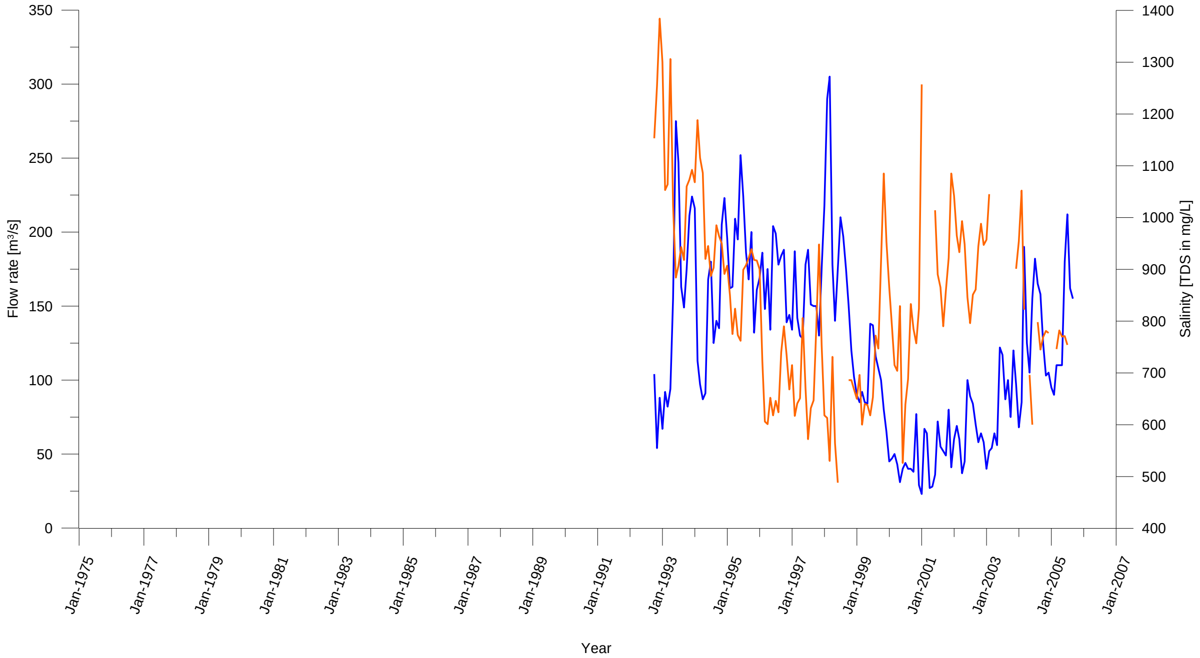

Figure 25: Flow rate and water salinity of Euphrates River at Kufa Barrage.

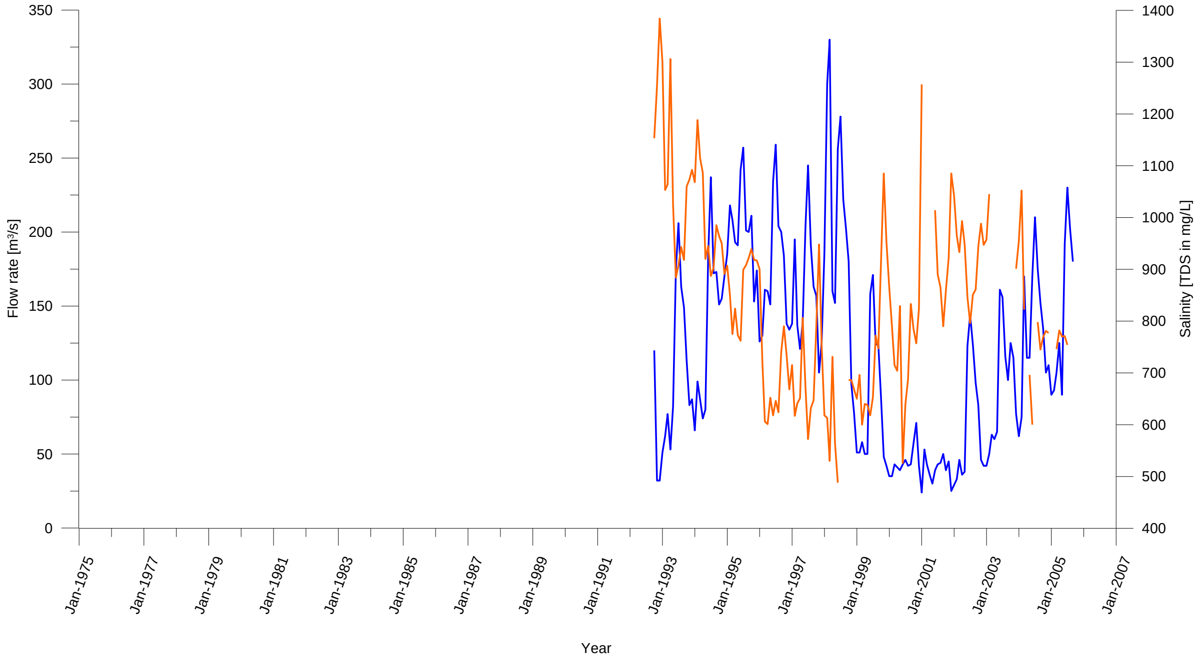

Figure 26: Flow rate and water salinity of Euphrates River at Abassiyah Barrage

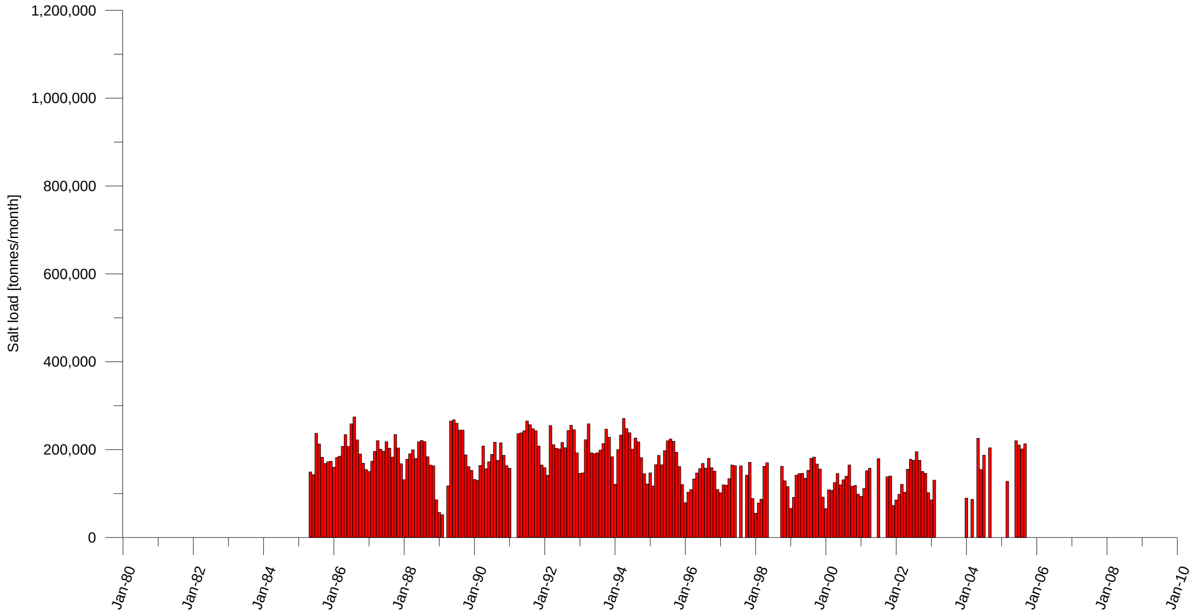

Figure 27: Monthly salt mass transported into Falluja-Iskandriyah Canal at Falluja.

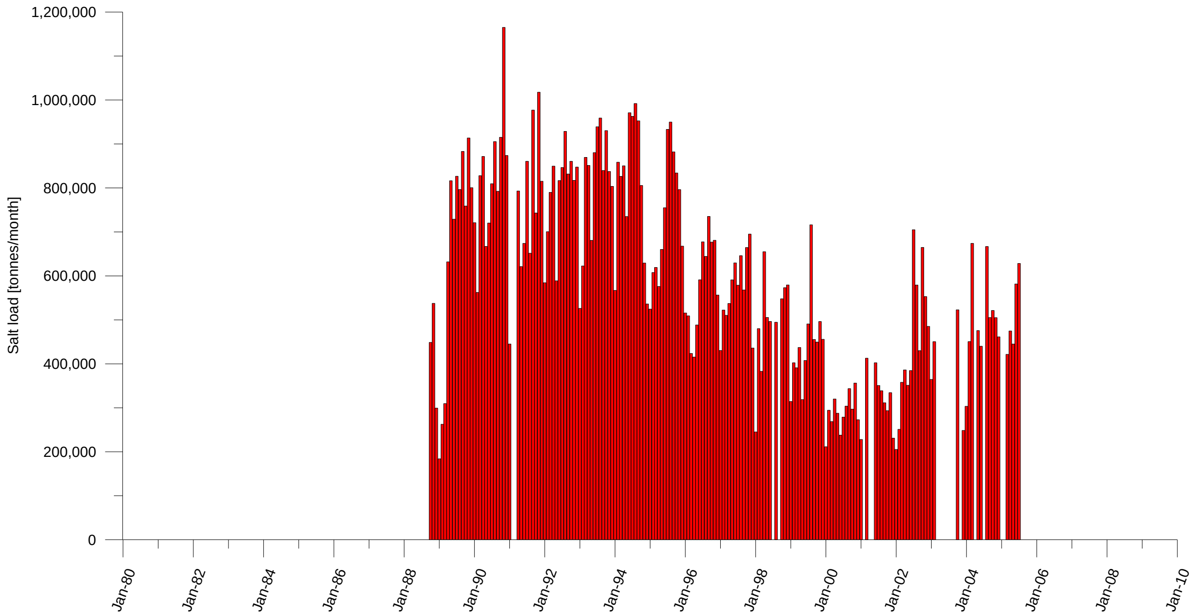

Figure 28: Monthly salt mass transported into Hindiyah Canals.

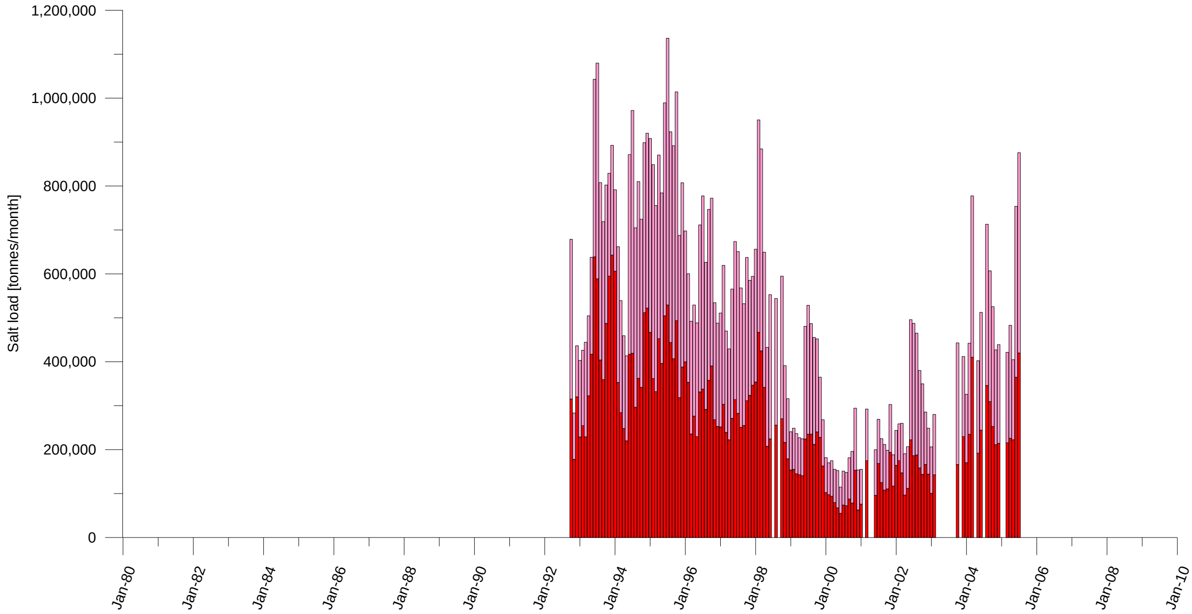

Figure 29: Monthly salt mass transported at Kufa (red) and Abbasiyah (pink).

Tigris River

Water in the Tigris River enters Iraq at the border with Turkey (Fesh Khabour) and flows through several water management structures to Qurna, where it meets with the Euphrates River, and then flows to the Gulf through the Shat Al Arab. It takes about 14 days travel time for the water to move from the border to Amara (not including residence time in reservoirs).

The Tigris River is joined by a number of tributaries entering from the eastern side, many of which originate in Iran. The major tributaries are the Greater Zab, the Lesser Zab, Adhaim, Diyala, Karkah and Karoon Rivers; these inflows are further augmented by small contributions from a series of Wadis downstream of Kut.

Water is diverted into Lake Tharthar at Samara Barrage, and then into the Euphrates River. A return flow from tharthar is also possible via the Tharthar-Tigris Canal that rejoins the Tigris just upstream of Baghdad.

Longitudinal Salinity Profiles

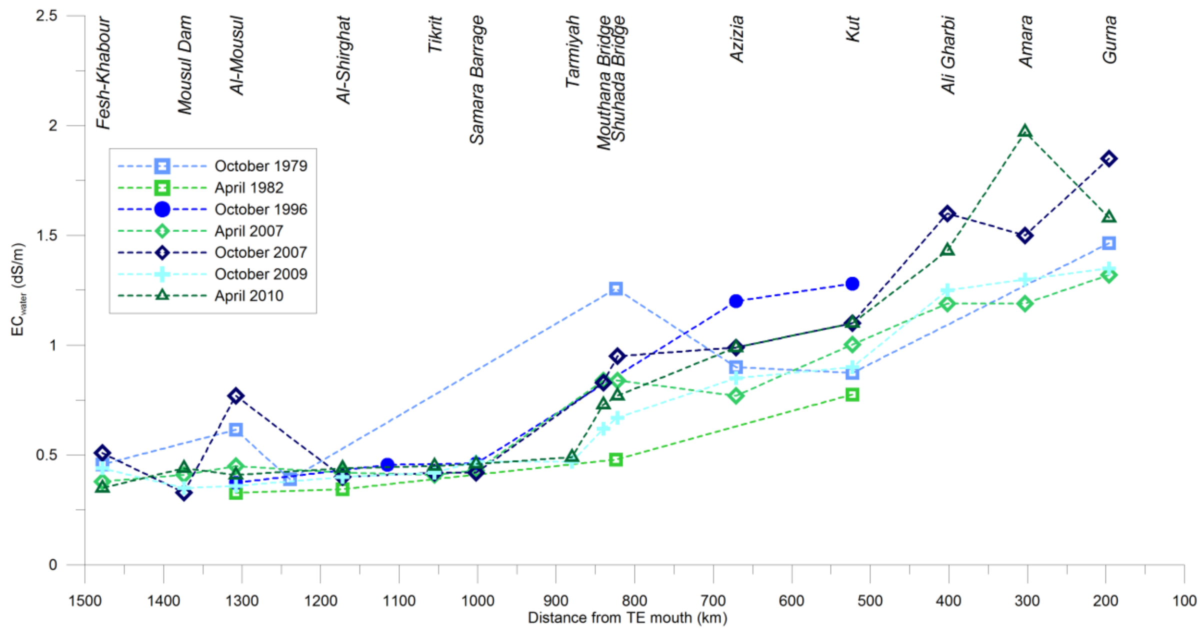

Figure 30: Longitudinal Salinity Profile, Tigris River

Figure 30 shows a longitudinal profile of salinity for the Tigris River for a number of years. The bottom axis shows the distance from the Gulf which increases up to the Syrian border (at about 1500 km from the Gulf). The data show a similar trend as to that for the Euphrates River, that is, an increase in salinity with distance downstream within Iraq. A major change in the rate of increase of salinity is observable downstream from Samara Barrage (about 1000 to 900km river distance) and this coincides with a position just upstream of Baghdad. Between this point and Qurna, there is a fivefold increase in salinity presumably due to a combination of reduced dilution flow from upstream, returned drainage water to the river and from groundwater ingress.

The data shown in the figure comprise different years and seasons, with April and October being chosen to reflect wet and dry season respectively.

Upstream of Baghdad, river salinity is reasonably constant (with some exceptions) across years and seasons, however, downstream of this point, there can be a factor of two difference between seasons and even greater across years.

The data also shows that there is no systematic variation (increase or decrease) in salinity over the period of measurements.

Water and Salt Measurements

This section deals with the salinity and flow at each of the major management points in the river based on available water and salinity data.

These points include:

1. Mosul Dam
2. Samara Barrage
3. Baghdad
4. Kut
5. Lake Tharthar Diversion Canal

Mosul Dam

Mosul Dam provides the main regulation for the Tigris River and is located upstream of the major irrigation developments. The salinity is measured in the reservoir, whilst the flow data is measured immediately downstream as water is released into the Tigris. It is assumed that the released water has the same salinity as the reservoir. Figure 31 shows the variability of water flow and salinity from 1985 through to 2010.

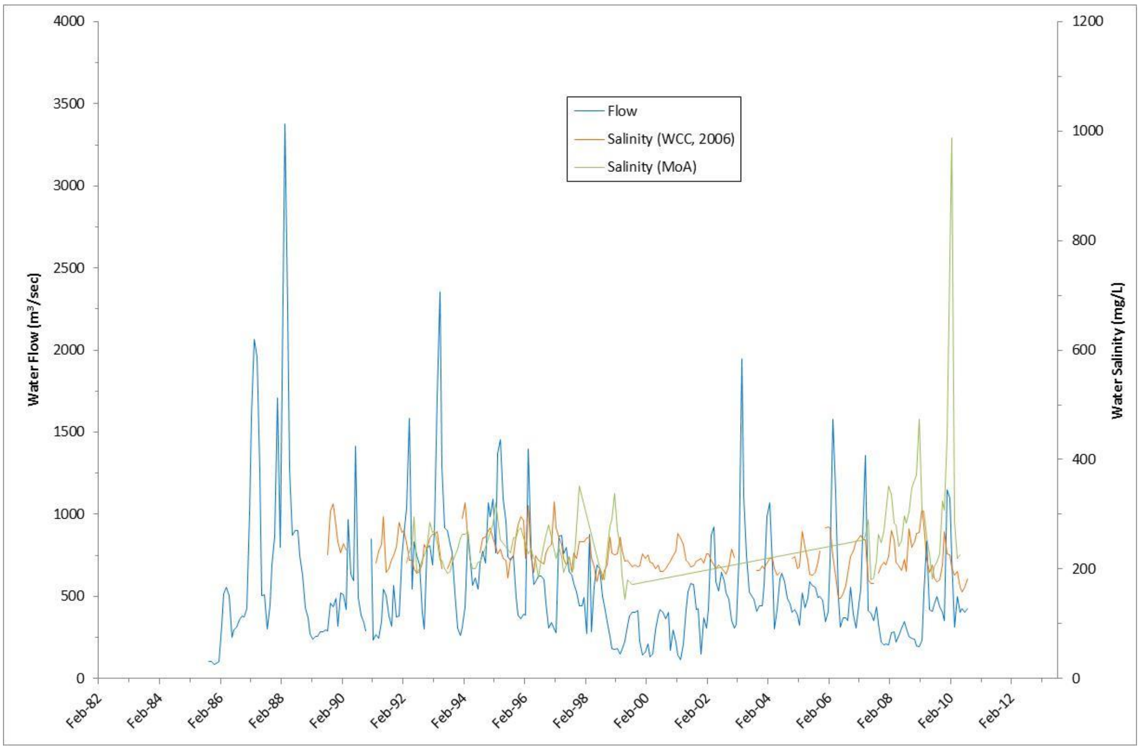

Figure 31: Flow rate and water salinity for Tigris River at Mosul Dam

The data shows that despite highly variable water flow, salinity has remained constant (or decreased slightly). An apparent increase in the last five years or so can be seen in an additional data set, noting that this is different data to the previous set of salinity values and represents individual samples and not average monthly salinity.

The relationship between salinity and flow is shown in Figure 32. As discussed above, salinity varies in a limited range across all flow rates.

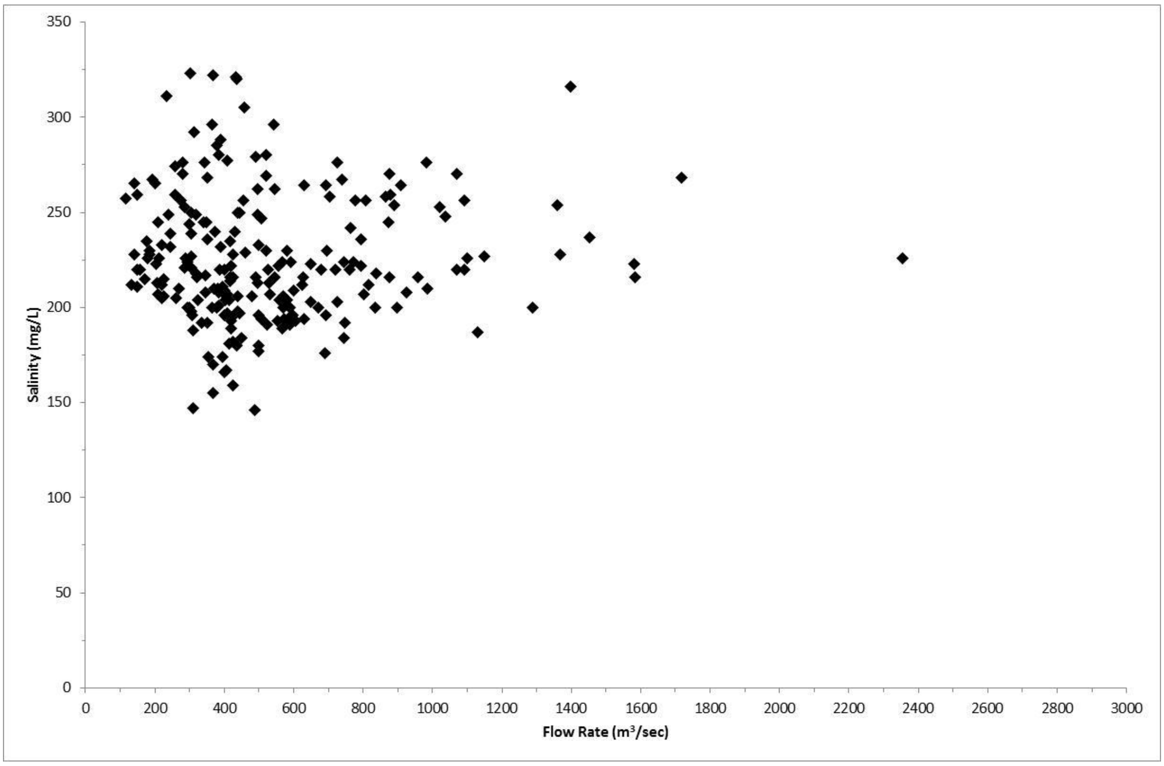

Figure 32: Water salinity and monthly flow rates Tigris River at Mosul Dam

The monthly salt load is shown in Figure 33. Based on the available data pairs for flow and salinity, an average monthly salt load of about 334,500 Tonnes per month is transported via the Tigris River at this point, varying between 1,426,000 Tonnes and less than 150,000 Tonnes. As salinity is reasonably constant, the salt mass transported is almost directly proportional to the flow rate. Hence, during periods of high flow (such as during the 1990s), the salt mass transported was very much higher than for the last decade.

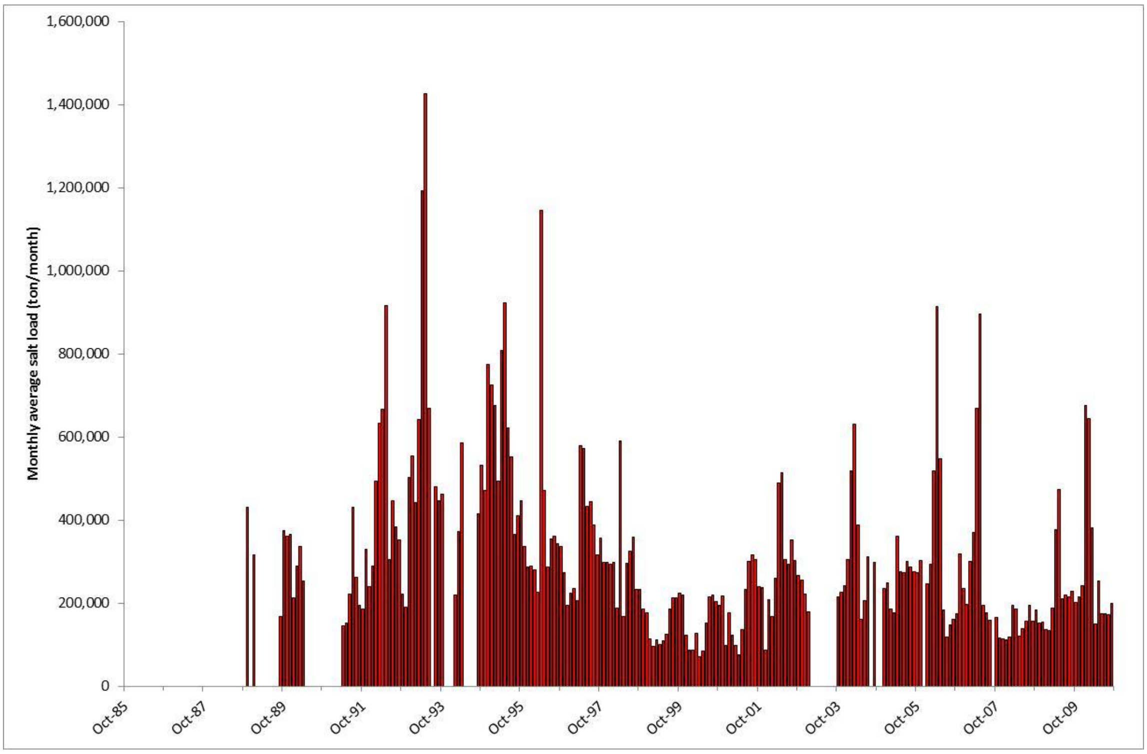

Figure 33: Monthly salt mass transported through the Tigris River at Mosul Dam

Samara Barrage

The Sammara Barrage lies on the Tigris River just upstream of Sammara. The Tigris at this point has been joined by the major east bank tributaries, the Greater and Lesser Zab Rivers. The Barrage regulates water flow primarily to Lake Tharthar (on the west bank), and to the Al-Irwah'iyah Canal and the Al Ishaqy/Al Rasasy Canal also on the west bank.

Figure 34 shows the flow and salinity time series data for downstream of the Sammara Barrage, noting that diversions to Lake Tharthar occur immediately upstream of the Barrage. The flow record shows major seasonality in the 1970s, and that this has disappeared from the record by the 2000s, as well as a general overall decline in flow volume. The salinity changes dynamically over time, but within a narrow range of between about 250 and 400 mg/L. there is a suggestion of a rising trend over time. Compared with the salinity downstream of Mosul Dam, there is an increase of almost double in the Sammara Barrage values. It is also noteworthy, that there is no rising trend in salinity observed in Mosul Dam; hence the causal mechanism may be related to either tributary flows or to salinity ingress to the main Tigris channel between Sammara and Mosul Dam.

The monthly salt load is shown in Figure 36. Based on the available data pairs for flow and salinity, an average monthly salt load of about 567,000 Tonnes per month is transported via the Tigris River at this point, varying between 1,578,000 Tonnes per month and less than 230,000 Tonnes per month. As salinity is reasonably constant, the salt mass transported is almost directly proportional to the flow rate. Hence, during periods of high flow (such as during the 1980s and 1990s), the salt mass transported was very much higher than for the last decade. There is an overall increase in salt mass transported between Sammara Barrage and Mosul Dam.

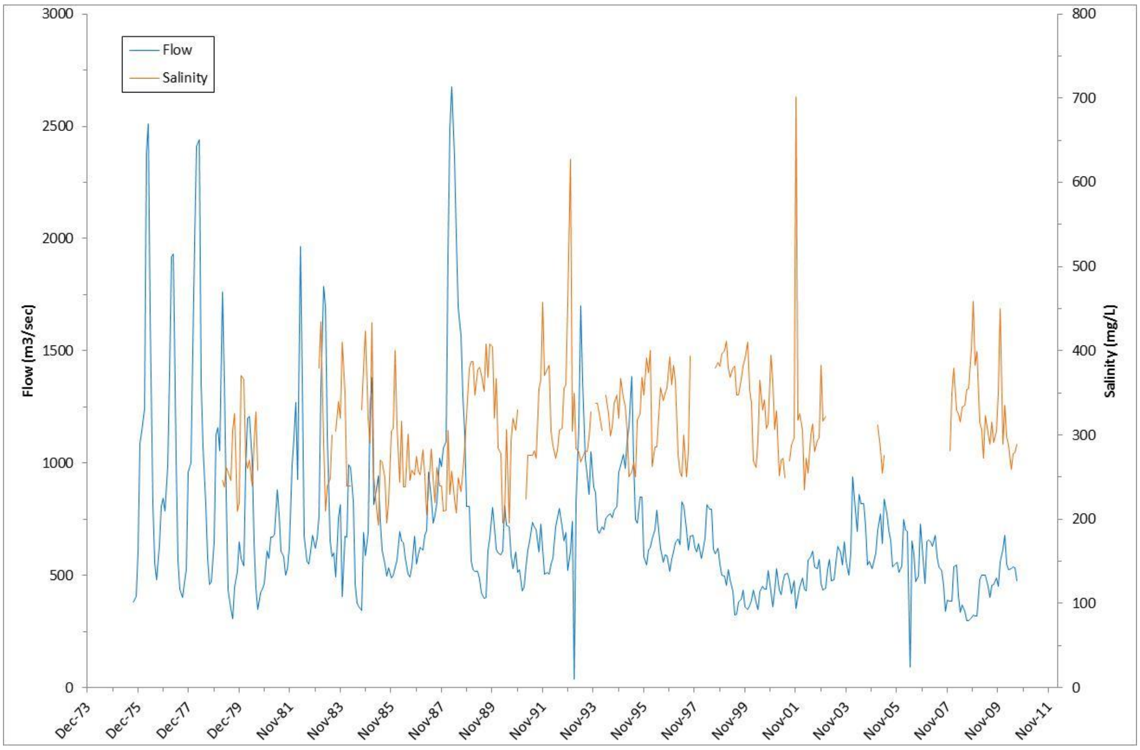

Figure 34: Flow rate and water salinity for Tigris River, downstream Sammara Barrage

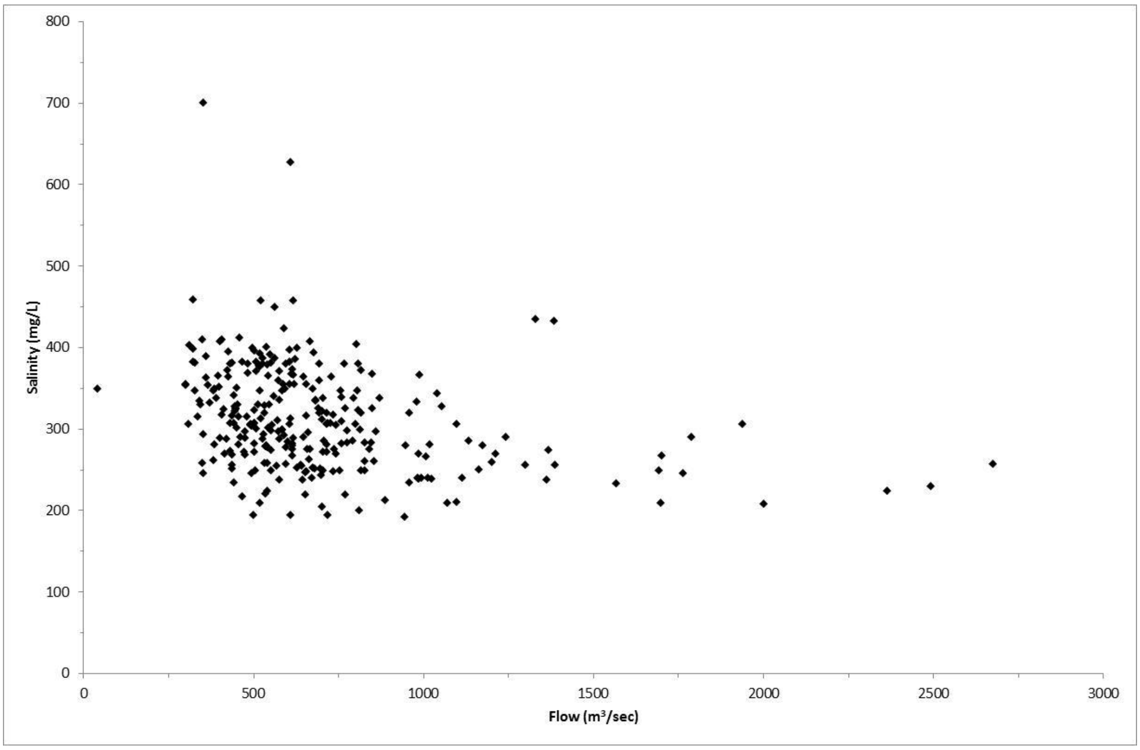

Figure 35: Flow and Salinity relationship for Tigris River at downstream Sammara Barrage

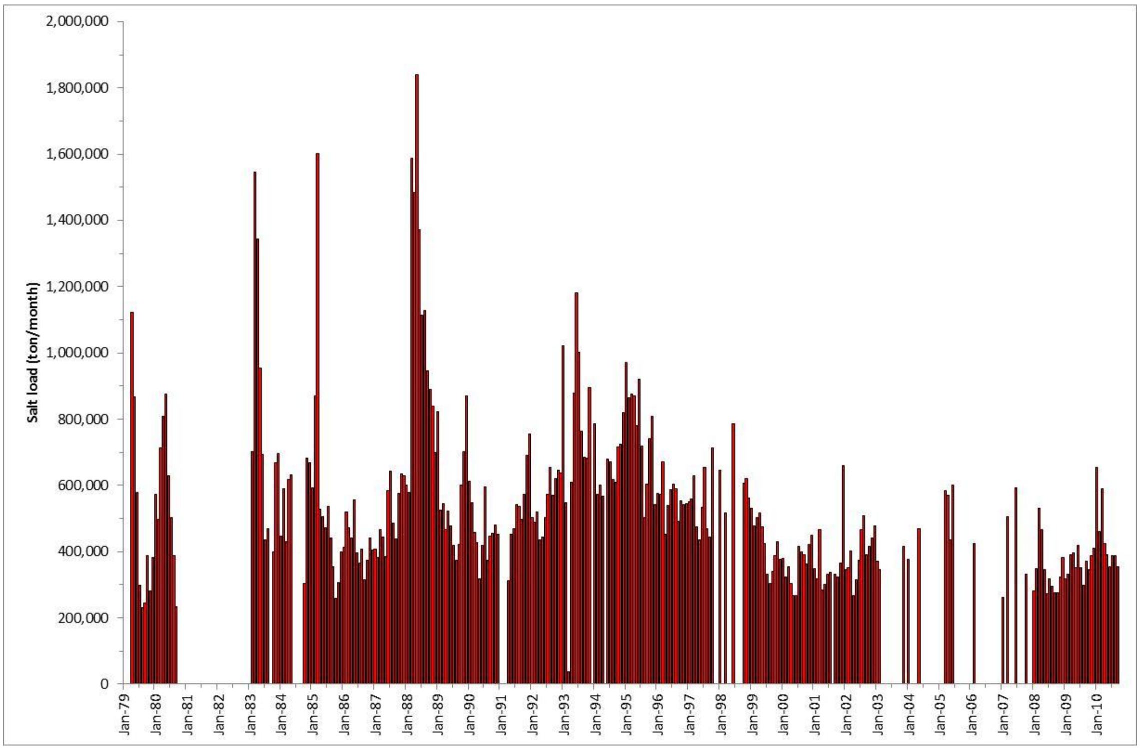

Figure 36: Monthly salt mass transported by Tigris River at downstream Sammara Barrage

Baghdad

The gauging station on Tigris River in Baghdad City provides the next major data point. The site is below the return from Lake Tharthar (the Tharthar-Tigris Canal) on the west bank and also downstream of the Adhaim River tributary on the east bank of the Tigris. There is substantial irrigation development upstream of Baghdad between it and Sammara, and the majority of the Diyala irrigation development is to the north east of Baghdad in higher topographic elevations, even though the main Diyala River junction is further downstream from Baghdad. The Abu Ghraib irrigation area lies to the west and north west, the drainage from which may influence the Tigris River in this locality.

The flow and salinity time series are shown in Figure 37. As with the Sammara flow record, the data show major seasonality through the 1970s and early 1980s. The major change in flow by the 2000s as noted earlier also is apparent. Flow fell abruptly in 1999 and returned to those pre-1999 levels by 2005. The salinity data show an increasing trend from the start of the data observations through until the mid-1980s. The data then show a dynamic variation over the remaining time, varying between 400 and 900 mg/L. More recent data from two other sites in Baghdad have also been plotted. These are for the Tigris at Mouthana Bridge and at Shuhada Bridge. These data show consistency in values and trends when compared with the other historical data set.

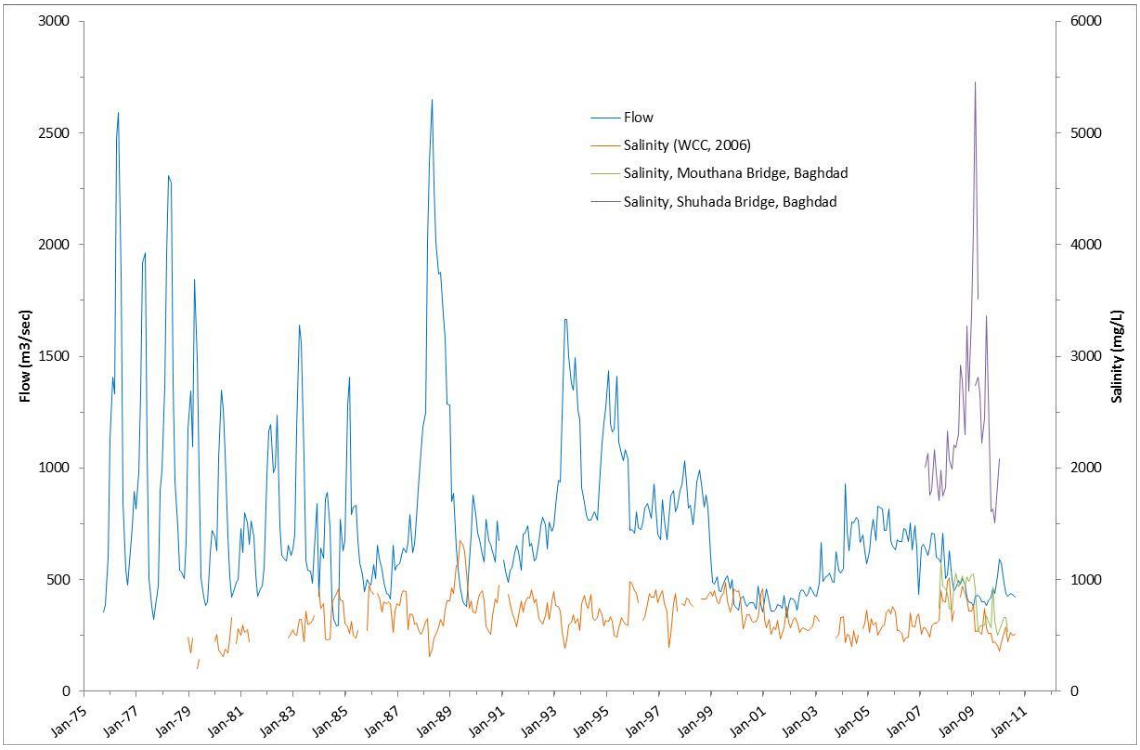

Figure 37: Flow and water salinity for the Tigris River at Baghdad City

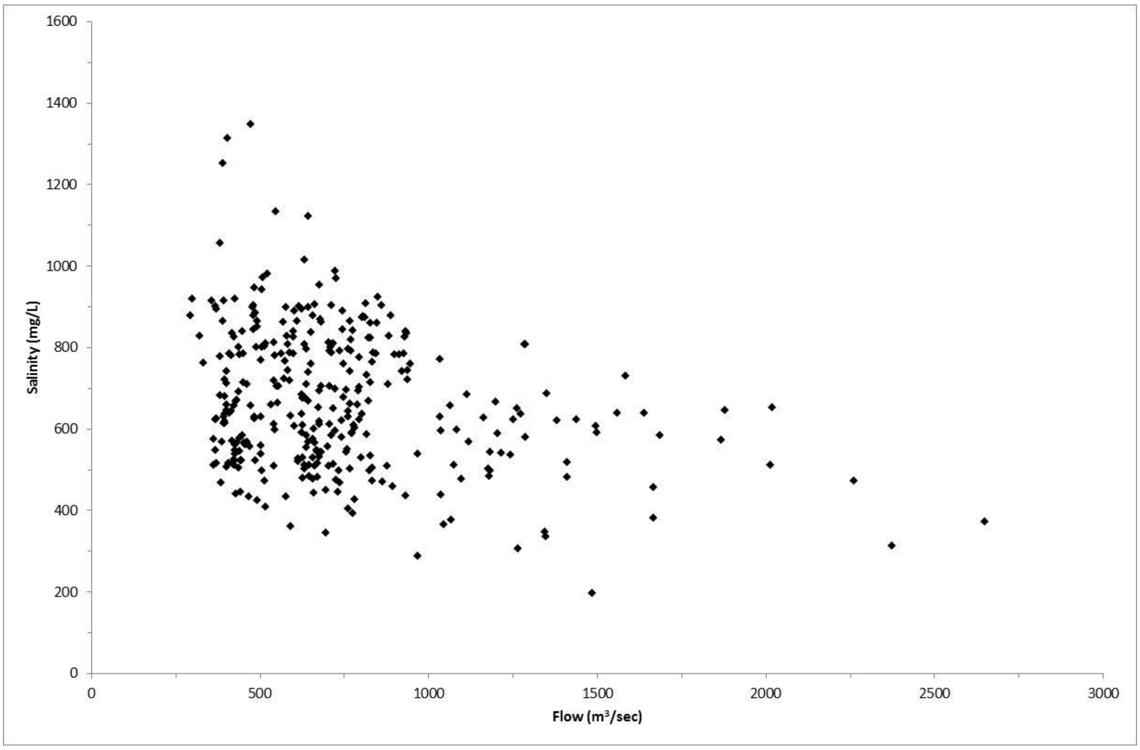

Figure 38: Relationship between flow and salinity for Tigris River at Baghdad City

Figure 38 shows the relationship between water flow and water salinity for available data pairs for the Tigris River at Baghdad City. The plot shows a reasonably constant relationship across most flow values, with a slight decrease at higher flows. The most saline readings are at low flows, consistent with flow and salinity relationships for most rivers.

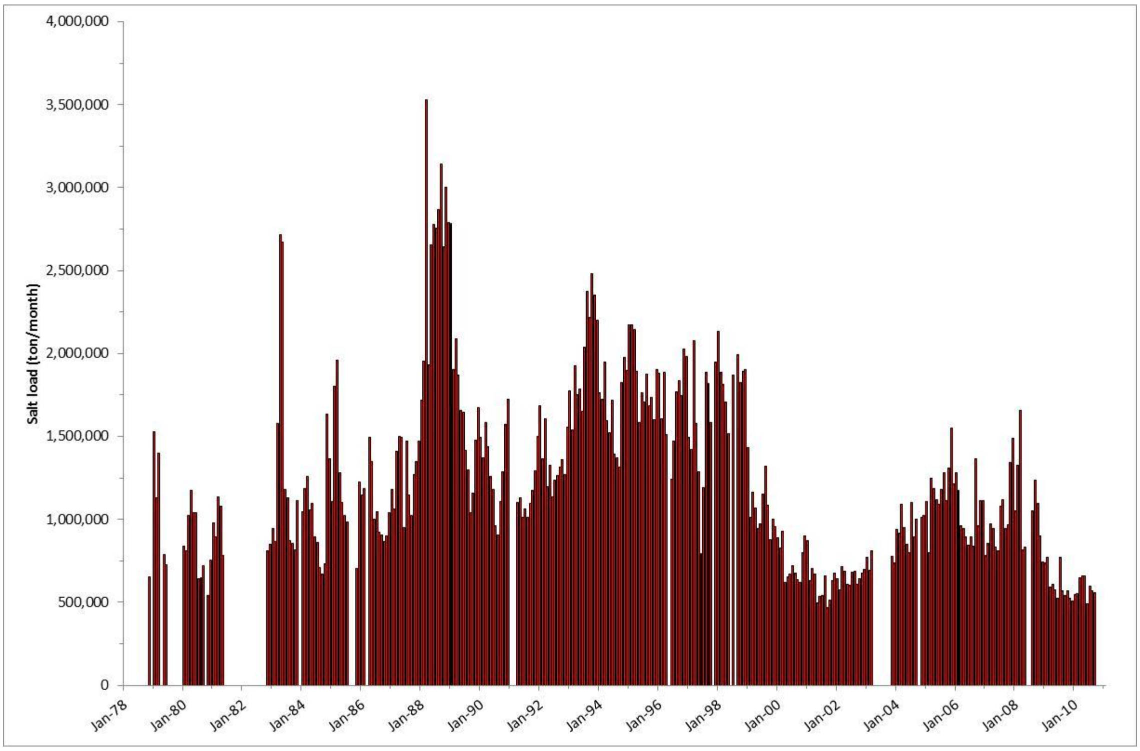

Figure 39: Monthly salt mass transported for Tigris River at Baghdad City

Figure 39 shows the monthly average salt load for the Tigris River at Baghdad City. The average salt load for the period of record is 1,322,000 Tonnes per month, substantially higher than for Sammara Barrage upstream. The maximum salt load was about 3,500,000 Tonnes per month and the lowest was 466,000 Tonnes per month. Salt load peaked during the flood of 1988 and immediately afterwards, it remained at a high level (between 1,500,000 and 2,000,000 Tonnes per month) during the 1990s and at the end of the record was between 500,000 and 1,000,000 Tonnes per month.

A comparison of salt loads for the different stations along the Tigris River will be described in a later section.

Kut

The Kut Barrage lies on the Tigris River in the city of Kut. The weir pool formed by the barrage supplies a diversion to the Gharaf River and also a canal to deliver water to the Dujaila irrigation area. Both of these lie on the west bank of the Tigris. The Diyala River is a major east bank tributary of the Tigris upstream of Kut, between it and Baghdad. There are some small diversions along the length between Baghdad and Kut, and ribbon irrigation is practiced in the riverine strip immediately adjacent the River. There is a transit time for water to move between Baghdad and Kut of about 6 days.

Figure 40 shows the time series of both water flow and salinity at the Kut Barrage. The salinity record is made up of two separate data sets, a data set of average monthly salinity from WCC (2006) and University of Baghdad (2011) and a recent unpublished data set of discrete individual samples from MoA based on routine sampling. Trends in the water flow data are consistent with those for the Baghdad City site reported above, in that they show highly seasonal flow in the early record, then a major change to less variable flows in the 1990s and a further major change to reduced flows in the latter part of the time series. The water salinity data also mirror the trends at Baghdad City. The increasing salinity up until the early 1990s is evident, as is the dynamic equilibrium since that time. Salinity increased from values around 400 mg/L TDS at the start of the record, and has now apparently equilibrated dynamically at values between 600 and 1,200 mg/L TDS. The most recent data show consistency with the previously collected data.

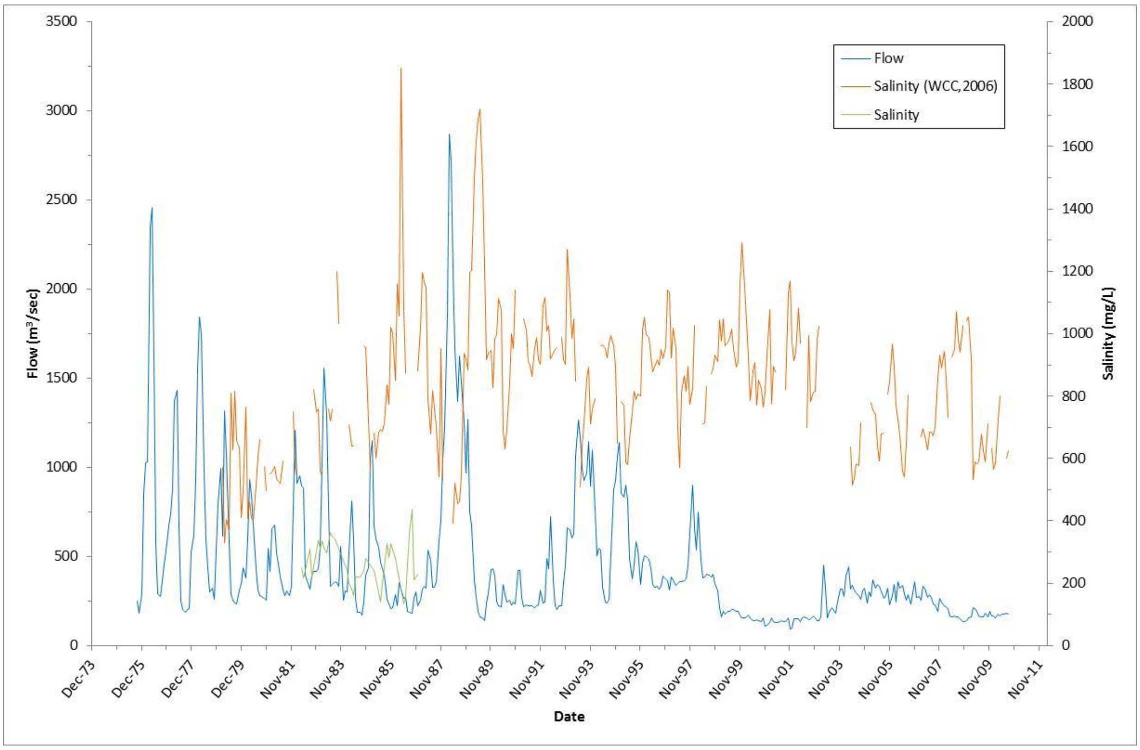

Figure 40: Water flow and water salinity for the Tigris River at Kut Barrage

Figure 41 shows the relationship between flow and salinity for individual pairs of data where available, for Kut Barrage. The relationship is consistent with other sites where the freshest (lowest salinity) water is associated with the highest flow. The reverse is also evident for low flows and high salinities.

The monthly average salt loads (Figure 42) at Kut Barrage are about 890,000 Tonnes per month, varying between a high of 3,000,000 Tonnes per month in 1988 and a low of about 230,000 Tonnes per month in 2000. Of interest is an apparent reduction in salt load at Kut Barrage when compared to the data for Baghdad City; this is discussed in a later section.

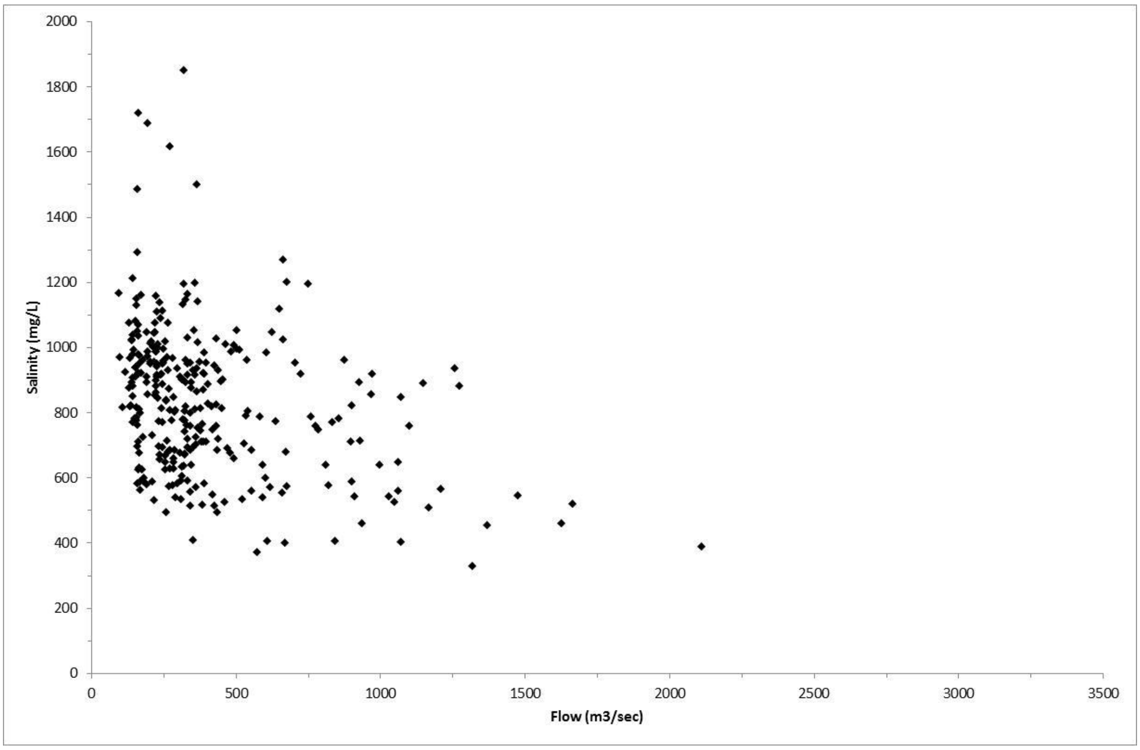

Figure 41: Relationship between flow and salinity for Tigris River at Kut Barrage

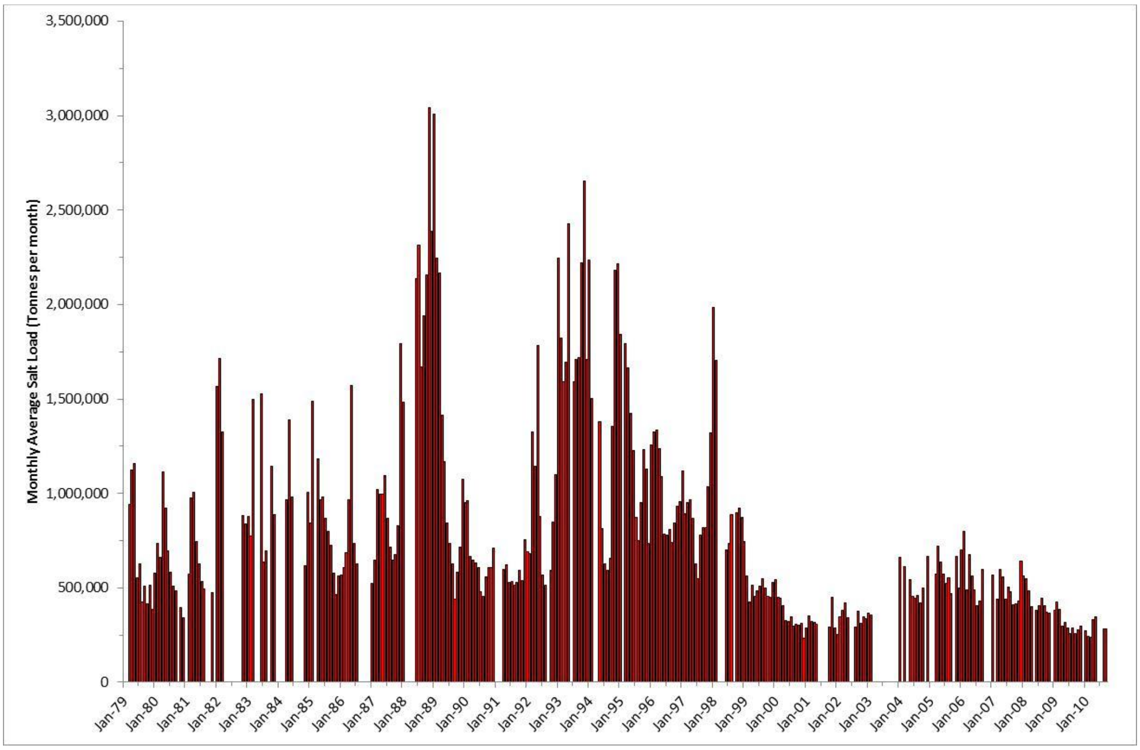

Figure 42: Monthly salt mass transported for Tigris River at Kut Barrage

Al Gharraf River/Canal

The Al Gharraf River/Canal is a west bank diversion from the Tigris River upstream of the Kut Barrage (which was constructed to regulate flow into the River. It is more properly described as a canal in its upper sections. Little information is available to describe the operation of the diversion system, other than it is planned to receive about the same amount of flow as remains in the Tigris downstream of Kut in a normal year, and about 50% of the flow downstream of Kut in a dry year. The water from the Al Gharraf Canal eventually supplies the raw drinking water for Basra.

The monthly average salt load (Figure 43) was derived by assuming that the salinity of the diverted water from the Tigris was the same as that measured downstream of the Kut Barrage. Salt load averages about 400,000 Tonnes per month and varies between 1,100,000 Tonnes per month and 100,000 Tonnes per month.

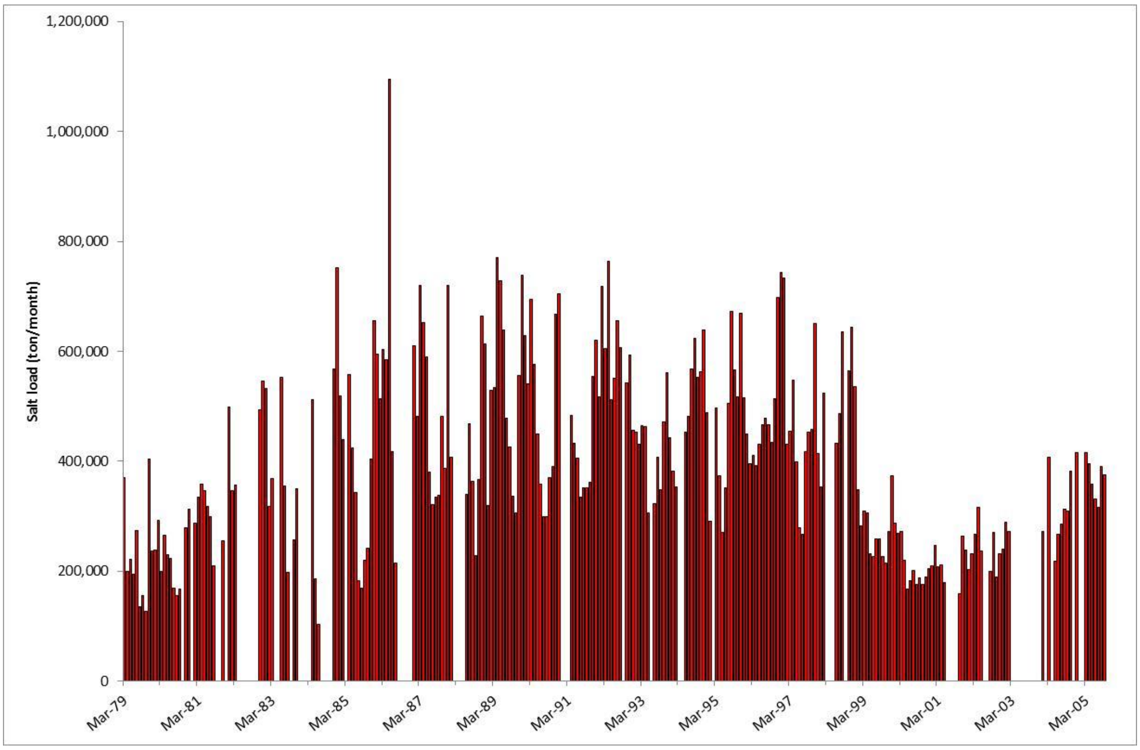

Figure 43: Monthly salt mass transported at the headworks of the Al Gharraf River (derived by assuming salinity of the Tigris River at Kut).

Greater Zab

The Greater Zab River is one of the major east bank tributaries of the Tigris River, joining downstream of Mosul. The River is unregulated and has the Khazir River as a tributary. Little data is available for both flow and salinity in the Greater Zab. Water salinity data has been recorded at Aski Kalak for the period 1979 to 1993, and monthly average flow data is available via the WCC report for the period 1973 to 2005. The data (Figure 44) show a highly seasonal flow pattern that appears similar over the period of record. Water salinity is generally in the range 200 to 400 mg/L TDS, with salinity during the major flood of 1988 falling to less than 50 mg/L TDS.

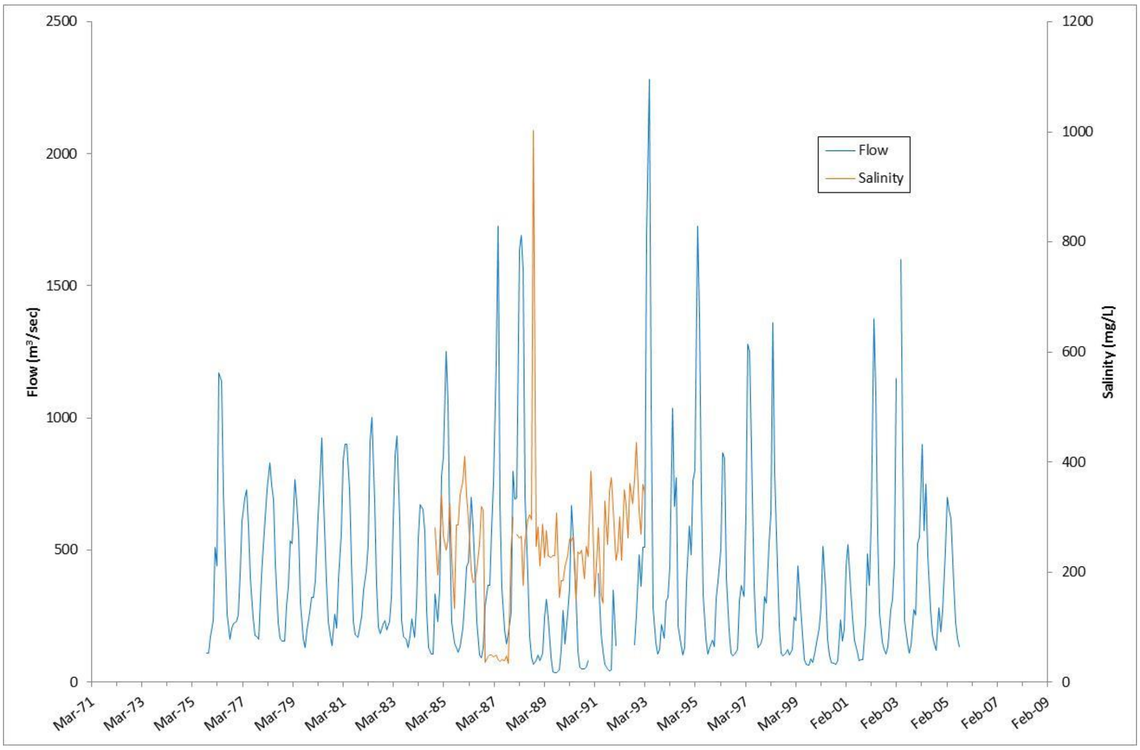

Figure 44: Flow and Salinity for the Greater Zab River at Aski Kalak

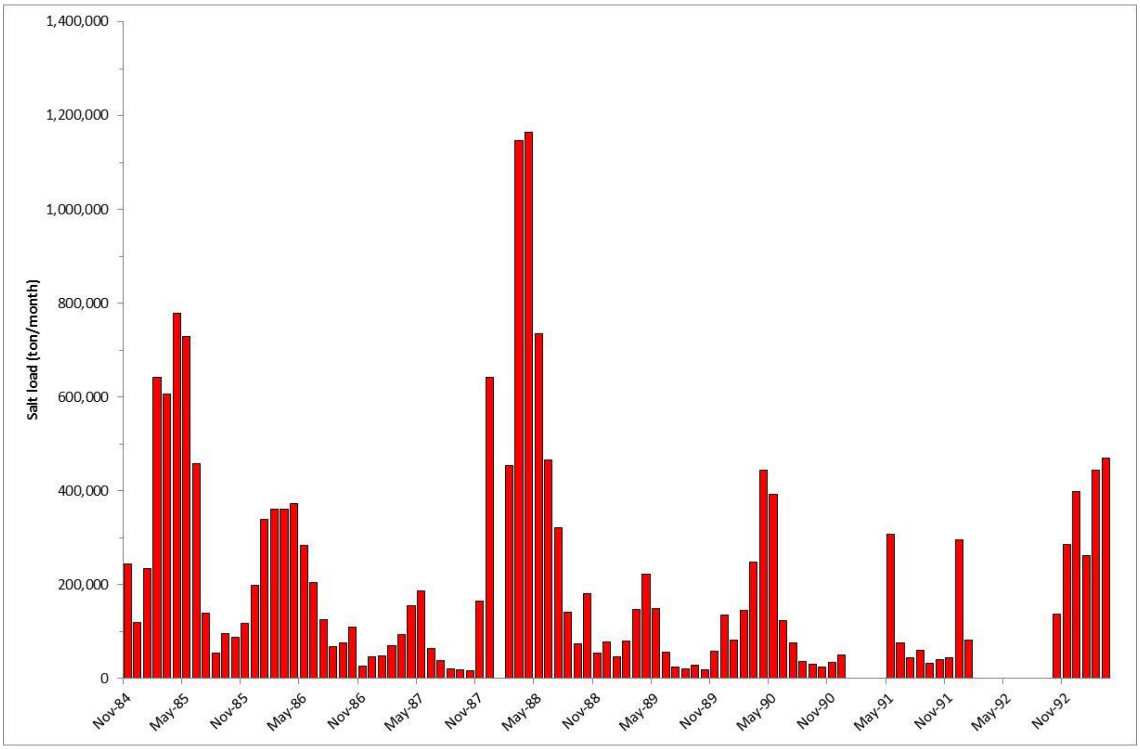

Figure 45: Monthly salt mass transported by Greater Zab River at Aski Kalak

The available data only allows a restricted analysis of salt loads in the Greater Zab. Figure 45 shows that salt load varies according to the seasonal flow pattern, averaging about 215,000 Tonnes of salt per month. The highest salt load occurs at the peek of the floods in 1988 and 1989 at about 1,200,000 Tonnes per month, and the lowest load of 25,000 Tonnes per month occurs in 1990 during low flow periods.

Lesser Zab

The Lesser Zab River is an east bank tributary of the Tigris River, joining downstream of Mosul. The River is regulated via the Dokan Dam and the Dibs Barrage. The Kirkuk Irrigation project is supplied by diversion from the Lesser Zab upstream of the Dibs Barrage. Some data is available for the river at Dokan Dam, but a much abbreviated record only exists for the Dibs Barrage. Data available in WCC (2006) for flow and salinity covers the period 1989 to 2005, and for is shown in Figure 46.

The ddata shows that salinity has remained essentially constant over time, with a possible minor increasing trend evident. Salinity values range between 400 and 500 mg/L (TDS) except for some rare higher values of about 700 mg/L (TDS).

Flow has decreased over the period of record.

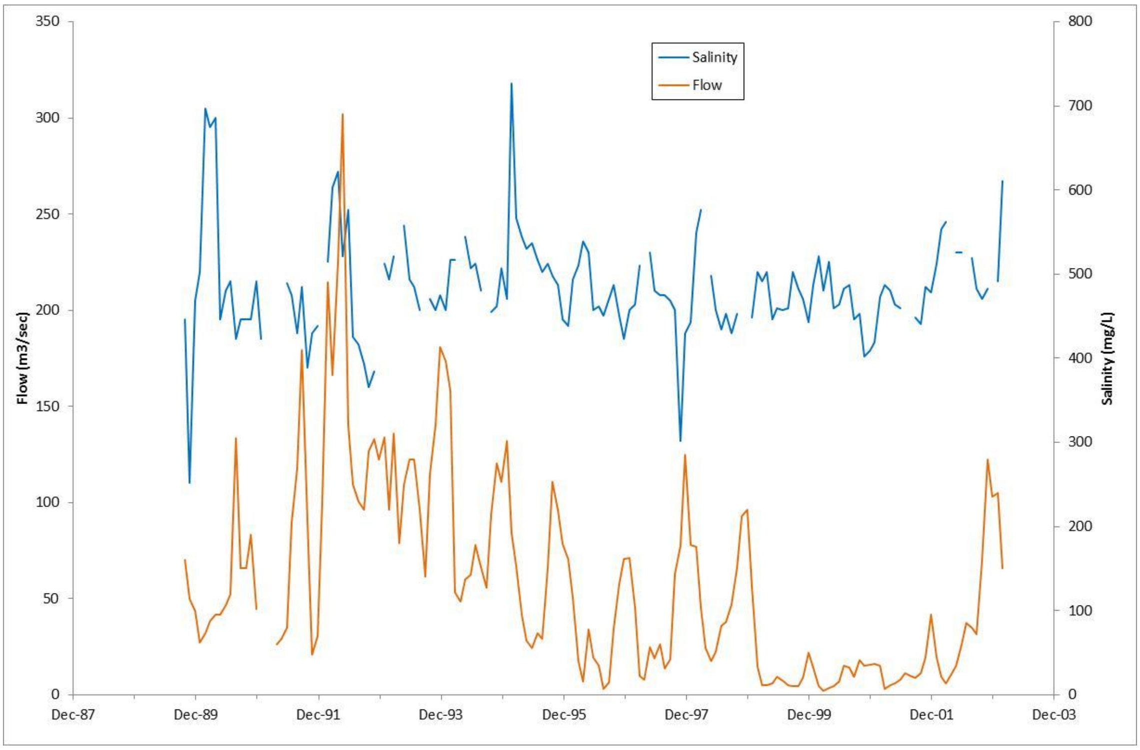

Figure 46: Flow and Salinity for the Lesser Zab River downstream of Dibs Barrage

The relationship between salinity and flow (Figure 47) shows that salinity is almost independent of flow, with little variation based on the size of the flow event.

Figure 48 shows the time series of salt loads at this site and these indicate a very small salt load. Average salt load is about 74,000 Tonnes of salt per month, with the highest salt load corresponding to the high flow event in 1992. Salt loads of less than 5,000 Tonnes per month have also been recorded. This is compared to salt loads at Samara Barrage of between 500,000 and 1,000,000 Tonnes per month.

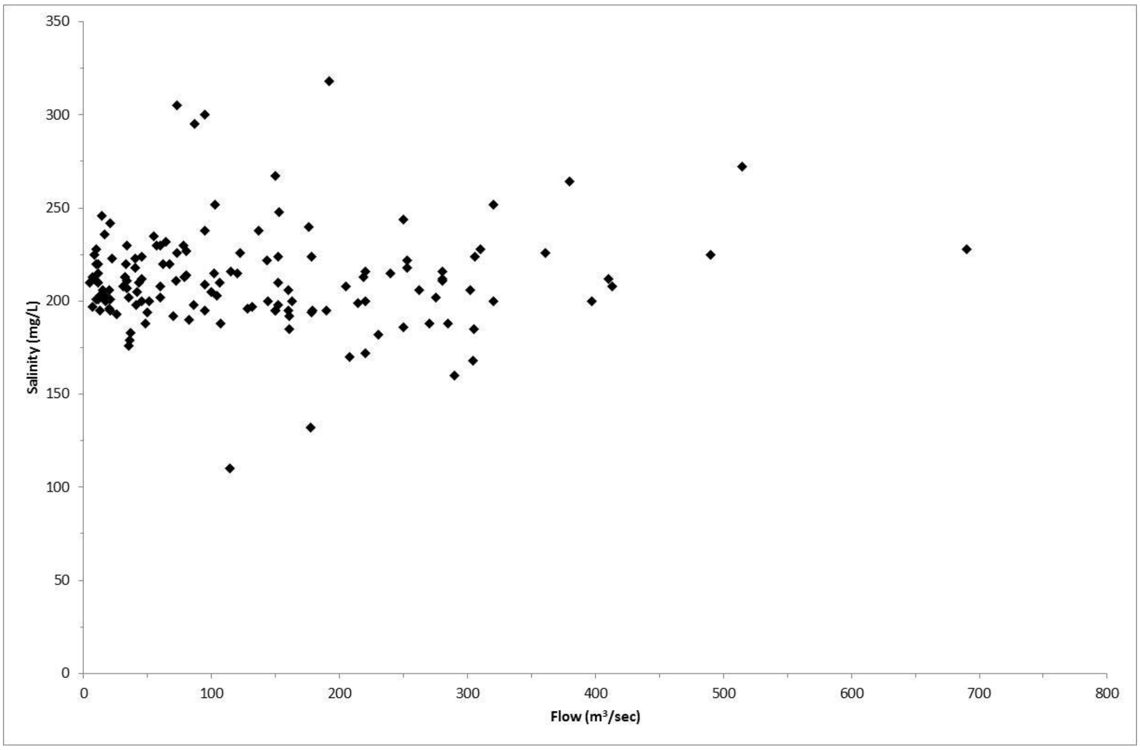

Figure 47: Relationship between flow and salinity for Lesser Zab River downstream of Dibs Barrage

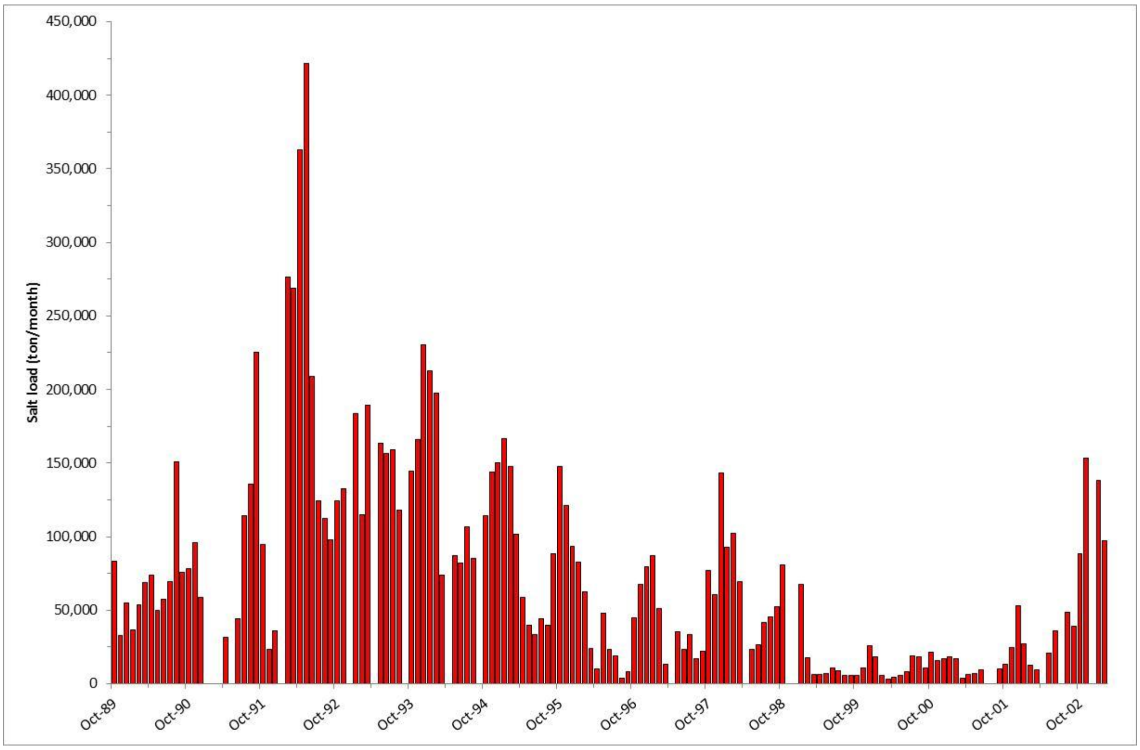

Figure 48: Monthly salt mass transported by the Lesser Zab River downstream of Dibs Barrage

Diyala River at Hemrin Dam

The Diyala River is another east bank tributary of the Tigris rising in the Zagros Mountains. The River is regulated by the Derbendi Khan and the Hemrin Dams, as well as by the irrigation diversion structure at Diyala Weir. Major diversions to the Al-Khalis and Combined Head reach irrigation projects occur at the Weir.

Flow from the Diyala River joins the Tigris just downstream of Baghdad.

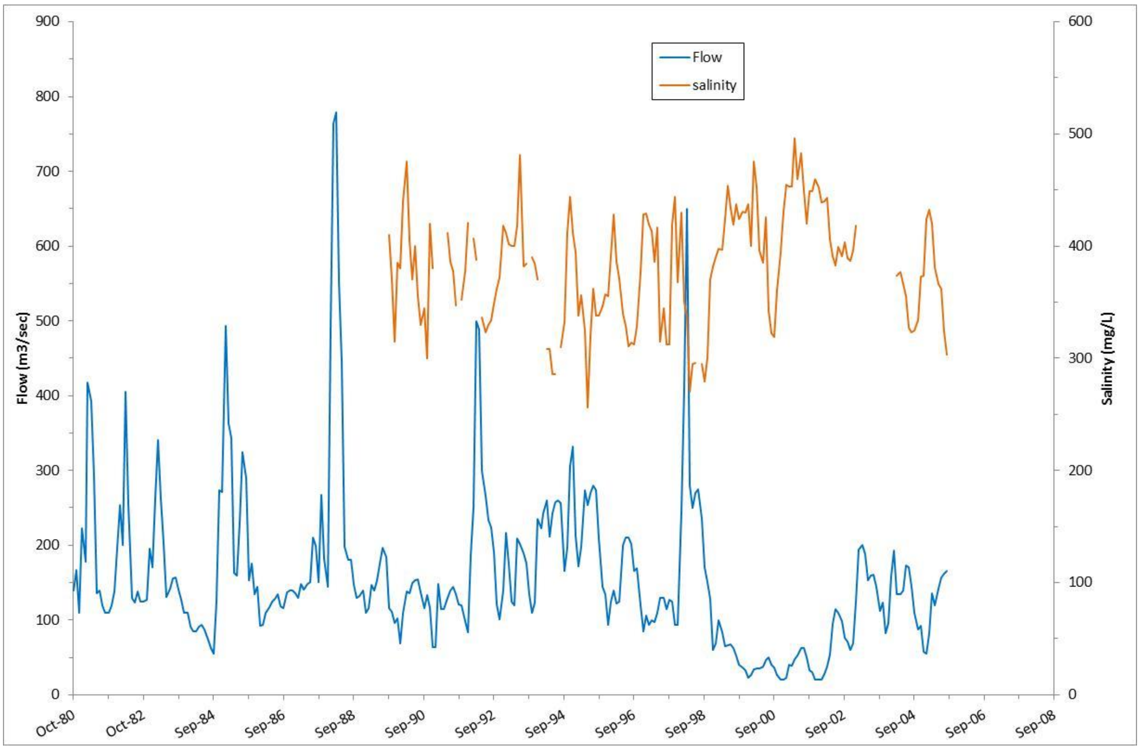

Figure 49: Flow and Salinity for the Diyala River downstream Hemrin Dam

Salinity (Figure 49) time series data shows an essentially constant value varying between 300 and 500 mg/L (TDS) for the period of record. Flow is also essentially constant within a very dynamic range, except there has been no large flood recorded between 1998 and 2005.

Figure 50 shows data obtained from MoA related to monitoring of the Diyala River immediately adjacent to the water treatment plant at Al-Rustimiyah, near Baghdad. The historical data available purportedly shows river salinity downstream of the water treatment plant (Rustimiyah in the Figure) increasing from around 1 dS/m (or about 650 mg/L TDS) in the early part of the record to values of between 1 and 4 dS/m (or between 650 and 2600 mg/L TDS) at the latter part of the record. The data purportedly from the station upstream of the water treatment plant shows, for the period 2007 to 2009, that salinity ranged between 2 and 5 dS/m (or between 1300 and 3250 mg/L TDS). This data, if validated, shows that salinity in the Diyala River increases substantially between Hemrin Dam and the confluence with the Tigris, in some cases, by more than a factor of five. As this is a tributary entering the Tigris in its mid reaches, this represents a point where water quality can be controlled for a major benefit.

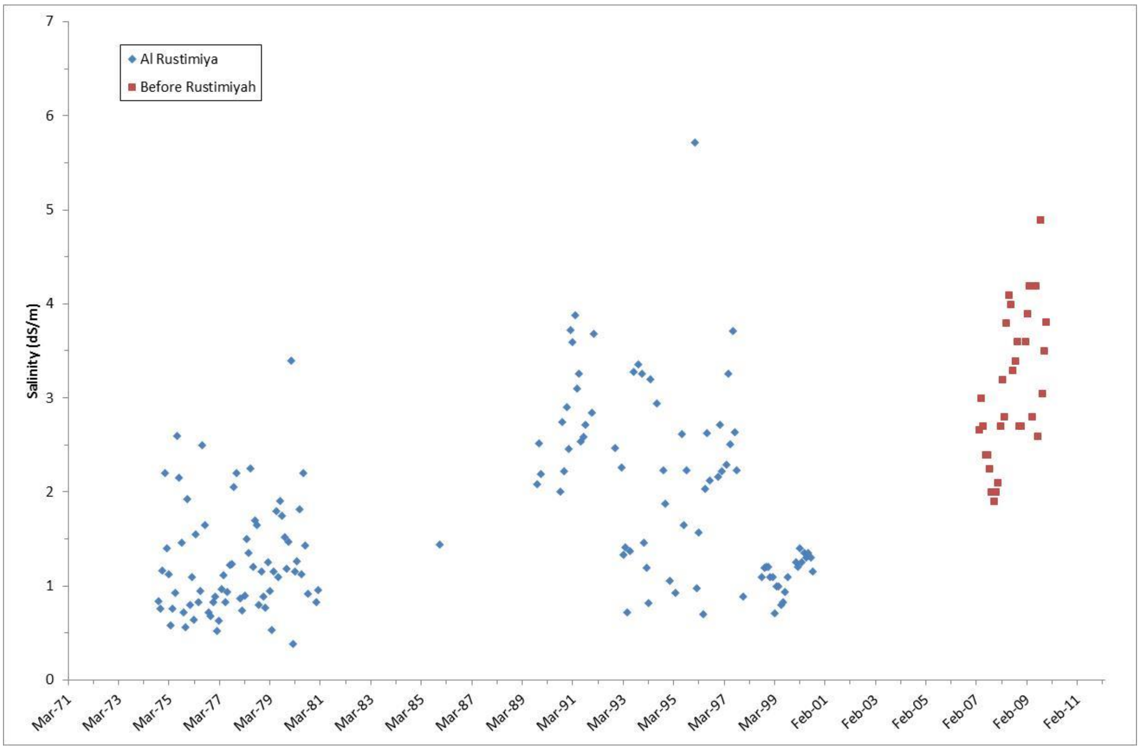

Figure 50: Salinity data for Diyala River at Al-Rustimiyah.

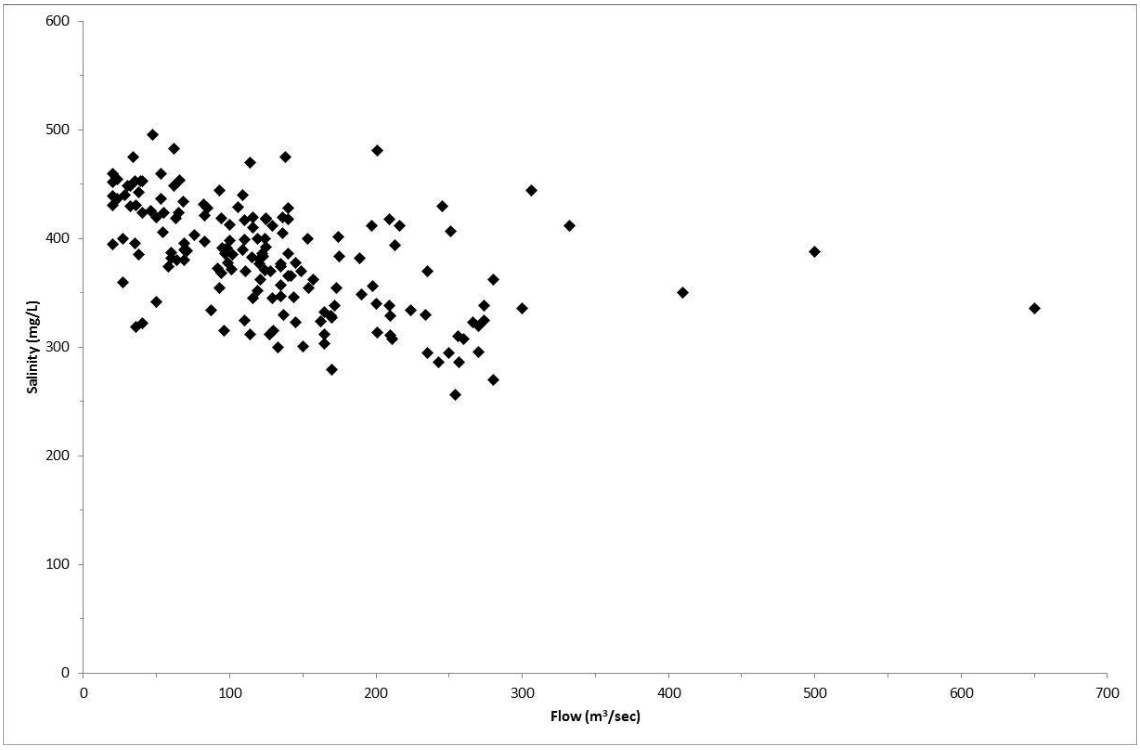

Figure 51: Relationship between flow and salinity for the Diyala River downstream Hemrin Dam

The relationship between salinity and flow is constant within a variable range, with lower salinity values associated with the higher flows (Figure 51).

Salt load (Figure 52) is generally between 100,000 and 200,000 Tonnes per month, except during periods of high flow (for instance, 1998) or low flow (for instance, during the period 2000 to 2002).

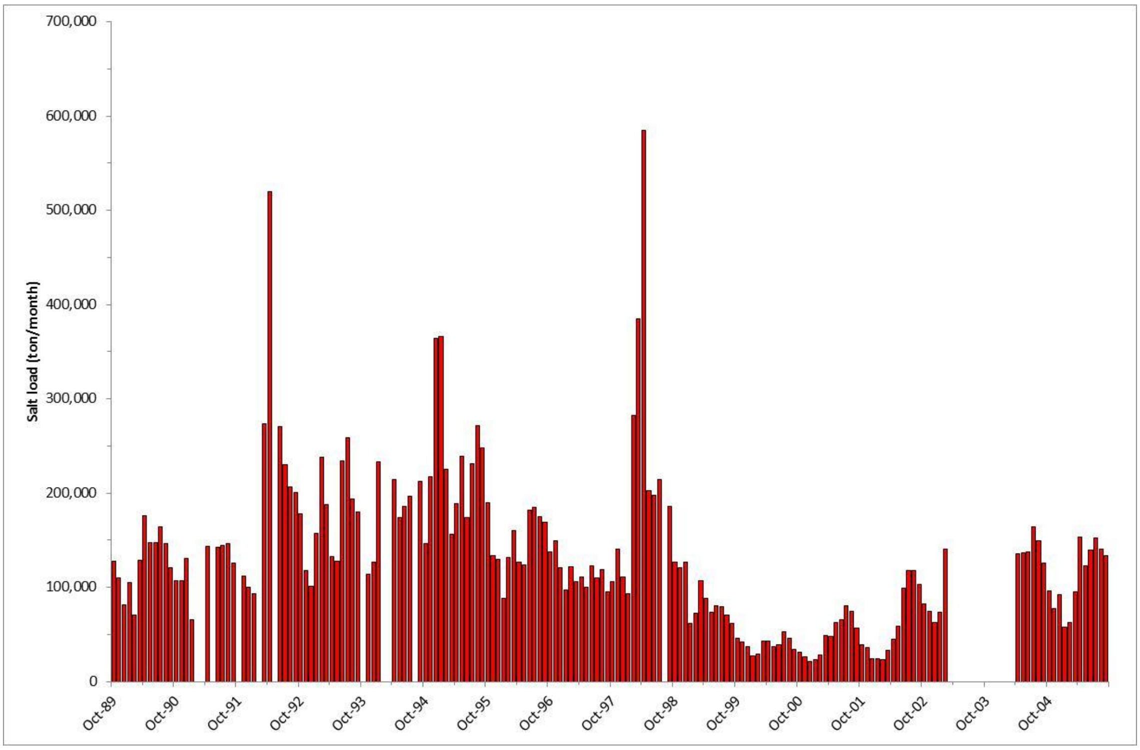

Figure 52: Monthly salt mass transported by the Diyala River downstream Hemrin Dam

Lake Tharthar diversions

Lake Tharthar is a major storage (utilizing a large natural lake) in the upstream section of the Mesopotamian Plain. It lies between the two Rivers to the north west of Baghdad. The lake was utilised as a storage for flood mitigation in the Tigris River. The main inlet structure is the Tigris-Tharthar Canal regulator. The outlet from the Lake is to a main canal that is then regulated to divert water to the Euphrates and/or the Tigris Rivers.

The original objective of construction as a flood mitigation measure has been subsequently superceded by objectives to now operate the Lake as a main storage structure to maintain flows in the Euphrates River. The Lake is large (reportedly 47.3 BCM designed active storage), and the water within the storage is saline. Figure 53 shows the salinity over time for both the input water (as measured at the Sammara Barrage) and the Lake itself. Note the decrease in salinity overtime from the start of observations through to about 1992. The use of the Lake as a balancing storage for irrigation water commenced in 1987 when the main diversion canals to both the Euphrates and the Tigris were constructed. It is likely that the reduction in salinity in the Lake was due to the flushing of the Lake as it started to be used on a regular annual basis.

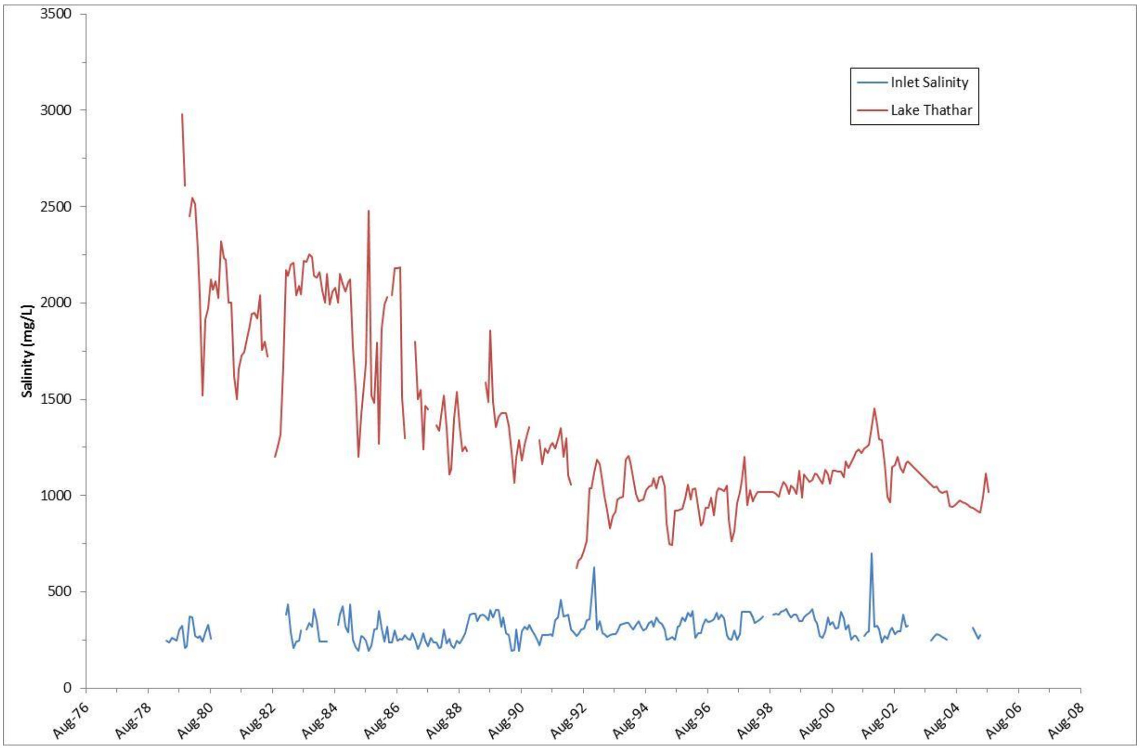

Figure 53: Lake Tharthar water salinity

Figure 54 shows the monthly average salt loads for the input and output from Tharthar Lake during its recent operations. The data shows that the overall input and output has decreased over time, and that inputs appear to balance outputs. However, if the annual salt inputs are compared to the annual salt outputs, it is apparent that in most cases outputs exceed inputs, indicated that the Lake is a net salt source.

The data used to derive the input and output from Lake Tharthar is incomplete. The input salinity data is taken from the Tigris River at Sammara Barrage and has times when now salinity was recorded. Similarly, the salinity record for Lake Tharthar is also incomplete. Where there are short periods of now data, interpolated values have been used to infill the record. In some cases, however, there are longer periods of missing data where interpolation provides values of greater uncertainty. In these cases, the interpolation has been avoided. This occurs for the Lake Tharthar salinity record during 2003 to 2005. The data is also further compromised in that there is no flow record for the Euphrates Tharthar canal prior to 1993. Any salt balances prior to this pint have been ignored in the analysis.

The data was analysed for annual periods (for a June to July accounting period approximating to a water use year). On average, there is about 6,300,000 Tonnes of salt per year exported from the Lake Tharthar system, that is, an imbalance of salt output over input.

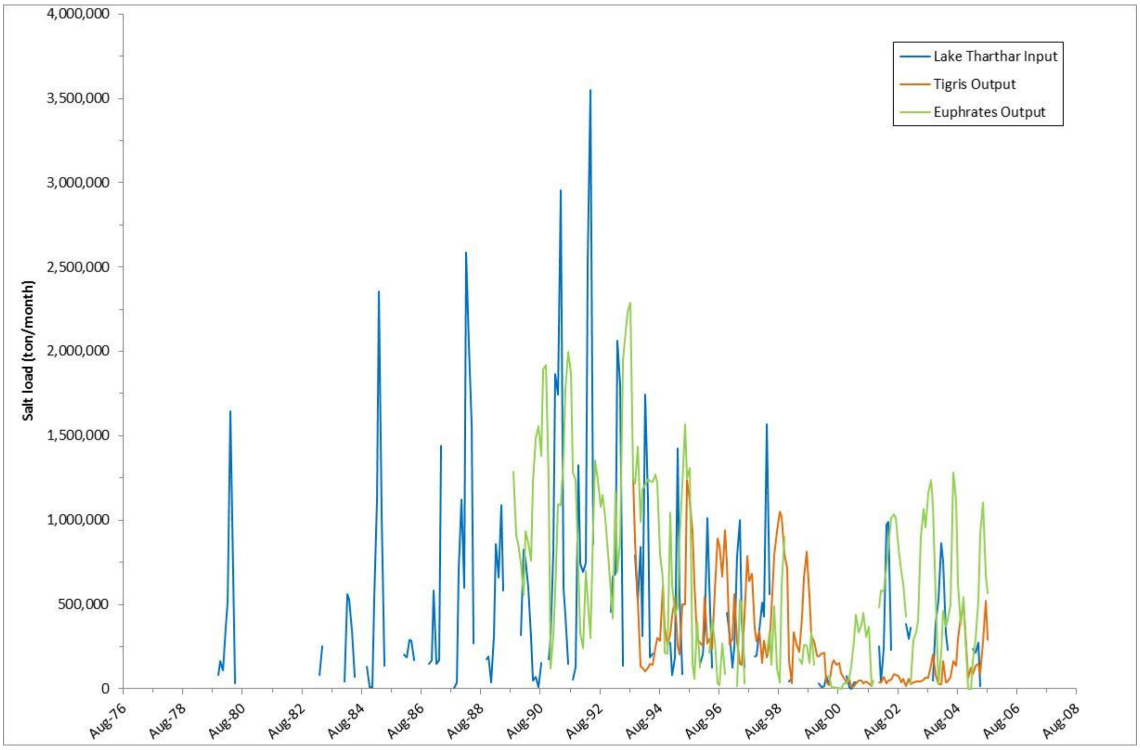

Figure 54: Monthly average salt load for Lake Tharthar inputs and outputs

This is influenced by the three years (2003 to 2005) of poor data record for Lake Tharthar salinity, and so is a slight over estimate. The highest net output was in 1995, with an additional 10,760,000 Tonnes of salt added (followed closely by the output of 1996), and a low of 760,000 Tonnes of salt per year added in 1992. This latter amount may be influenced by the lack of data on flow in the Euphrates Tharthar canal. It is noteworthy that at no time is there an imbalance where the addition of salt to Lake Tharthar is greater than its export from the Lake.

Tigris River Salt Loads

Figure 55 shows the monthly average salt load for the Tigris River at four stations along the length of the Tigris River. There are a number of major tributaries not represented on the plot, including all the major east bank tributaries within Iraq. These will influence the salt load.

There are a number of points that can be deduced from the figure.

There is a noticeable increase in salt load between the Sammara Barrage and Baghdad City. Upstream, the salt load at Sammara is reasonably consistent with that at Mosul Dam, indicating there are no major inputs of salt load in the intervening river reaches. However, this conclusion is modified by the large salt load removed from the river at Sammara Barrage when flow is diverted to Lake Tharthar, and the large salt load returned to the river via the Tigris Tharthar canal. Note that the Tigris River salt load at Sammara Barrage is downstream of the Lake Tharthar diversion point. There also potentially major salt load additions from the Greater and Lesser Zab Rivers unaccounted in this analysis.

It is also apparent that the salt load at Baghdad City is very similar to the combined salt load for Kut Barrage and Al Gharraf. However, there is a major increase in salt load evidenced by the flood peak of 1988 when an additional 3,000,000 Tonnes per month flowed past Baghdad City, and also during the 1990s when there appears to be on average an additional 1,000,000 Tonnes per month flowing past Baghdad City, when compared to Sammara Barrage.

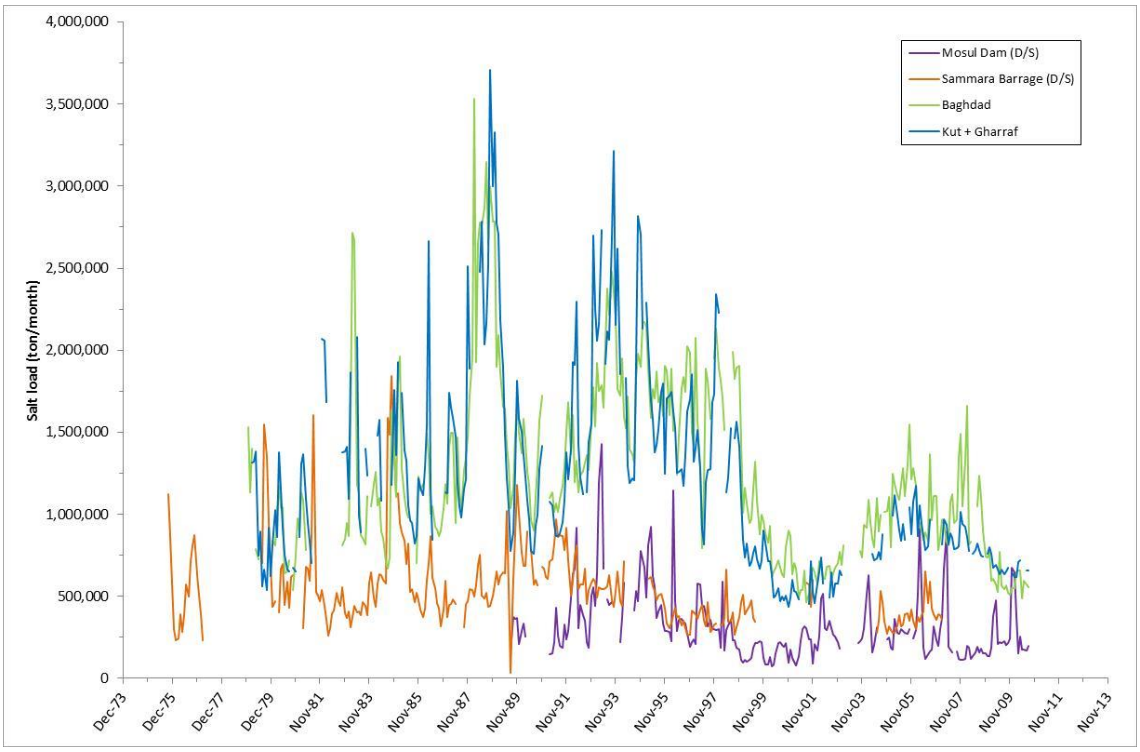

Figure 55: Salt load time series for various stations on the Tigris River

The data also shows that the Kut plus Gharraf salt load doesn't match the salt load at Baghdad. One might expect an increase moving downstream in a major river system such as the Tigris, but the data doesn't bear that out. This is further compounded by the fact that the Diyala River joins the Tigris between Baghdad and Kut and hence there is an expectation that salt load would further increase. The data tends to infer that there is a loss of salt from the river in this reach, possibly due to irrigation diversions.

This additional salt load may be due to the flushing of Lake Tharthar as shown in Figure 56. It can be seen that the time series of salt loads matches trend but the salt load at Baghdad is slightly higher. This indicates that the salinity increase seen at Baghdad during the 1990s may well be due to the increased salt being transported from Lake Tharthar. However, it is also obvious in the plot that the salt load at Baghdad is increasing at the end of the time series, indicating that a further different process is operating, perhaps from the Greater and Lesser Zab Rivers.

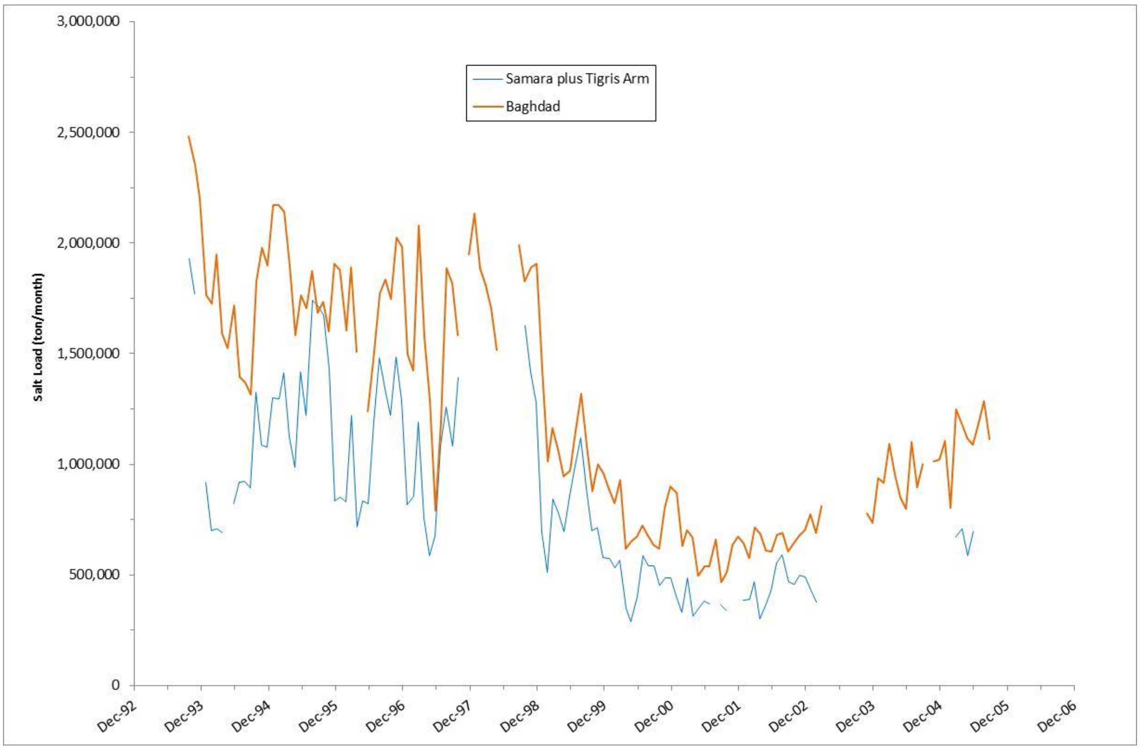

Figure 56: Salt Load at Samara Barrage and Lake Tharthar Tigris Arm compared with Baghdad

Irrigation from the Tigris River

Irrigation diversions from the Tigris River are not as large as from the Euphrates. As well, the Tigris River has additional flow added to it as it traverses within Iraq, from its major east bank tributaries.

In the upper parts (above Mosul upstream of the Mesopotamian Plain) water is diverted to the various Jazira Irrigation developments (East, North and South). Downstream of Baiji, large diversions occur to Lake Tharthar (and hence the Euphrates system), as well as to the Al Rawaieh and Ashati Irrigation (via the Al Ishaqy and Al Rasasy Canals) areas on the west bank and to the Door Irrigation area on the east bank.

Return flows from Lake Tharthar, via the Tharthar-Tigris Canal feed back to the Tigris upstream of Baghdad. The Diyala Irrigation Area to the east of Baghdad accepts water primarily diverted from the Diyala River downstream of Hemrin Dam. The lower parts of the Diyala scheme and irrigation close to the river between Baghdad and Samara are also fed by minor diversion directly from the Tigris.

The next major diversion occurs at the Kut Barrage, where water is channeled to the Al Gharaf River/Canal, and to the Dujaila Irrigation area. The Al Gharaf Canal eventually supplies minor irrigation in its lower reaches, and provides the water supply to Basra. Ribbon irrigation development along the Tigris River downstream of Baghdad is supported by minor diversions directly from the River.

There is diminishing irrigation along the river downstream of Kut, and none downstream of Amara. The flow of the river in these downstream reaches is managed in a complex fashion to supply diversions into the lower Marsh areas. The Tigris eventually joins the Euphrates River at Qurna.

There is little data available in WCC (2006) to quantify the irrigation diversion volumes to the main irrigation development.

Water and salt flow in the Tigris River

The previous sections outlining the salt and flow characteristics at various points along the Tigris River system and its tributaries has shown a complex pattern of flow and associated river salinity. A graphical representation of the annual water volume and salt load for an average year (1990) and a dry year (2001) are given in (Figure 57, Figure 58,Figure 59 and Figure 60). Note that the data do not result in a closed water balance, partially due to extrapolation of flow rates expressed in m^3/s to a volume on an annual basis. However, the annual totals appear to fall within expected error margins. Note also that the salt load downstream of Mosul Dam is incomplete due to missing data.

The figures show that river flow in 2000 is lower than in 1990, and that there is a corresponding reduction in salt load. The figures also show that a large proportion of the salt load in the Tigris River is generated between Sammara and Baghdad, a minor proportion of which comes from Lake Tharthar. In fact, the salt load between Sammara and Baghdad increases by a factor of between two and three. The processes by which this happens are known.

There is also a major reduction in flow between Baghdad and Kut, presumably due to diversions. There is also anecdotal evidence from unpublished MoWR and MoA reports that irrigation drainage water discharges to the river along this reach, so it is likely that i) the water flowing past Kut is comprised predominantly of drainage water, and ii) that the diversions from this reach are greater than the apparent volume indicated in the figures (the data is showing the net change in flow volume). Given that the Gharraf Canal provides good quality water for drinking and irrigation in the lower Euphrates region, the management of water quality in the Tigris River downstream of Baghdad is an important task.

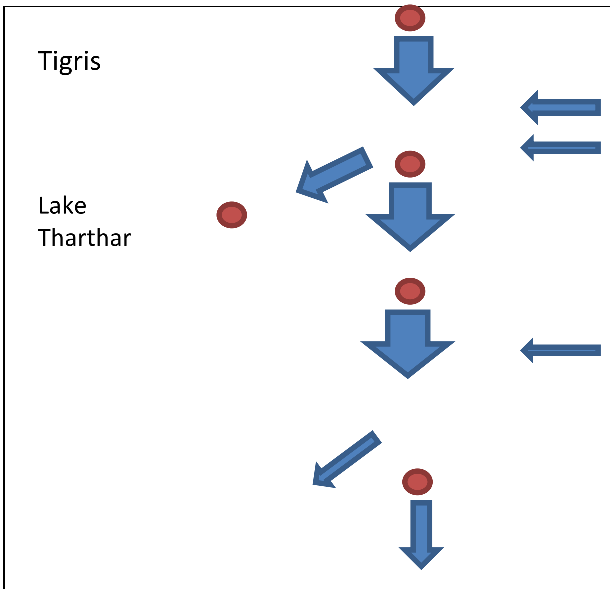

Figure 57: Water volumes for calendar year 1990 in the Tigris river

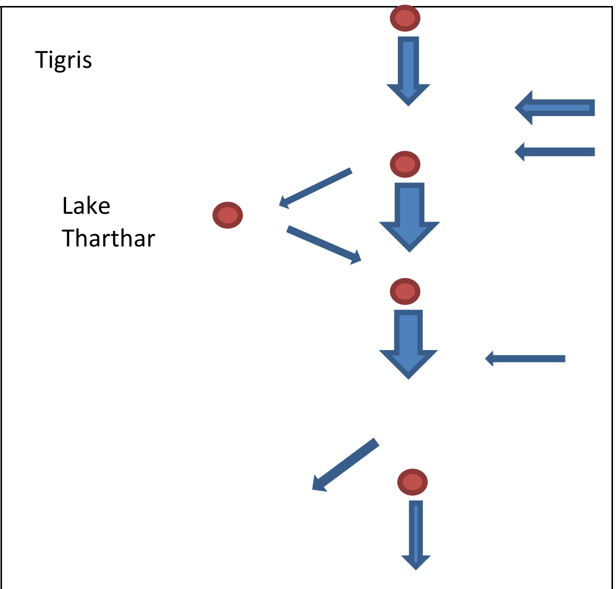

Figure 58: Water volumes for calendar year 2000 in the Tigris river

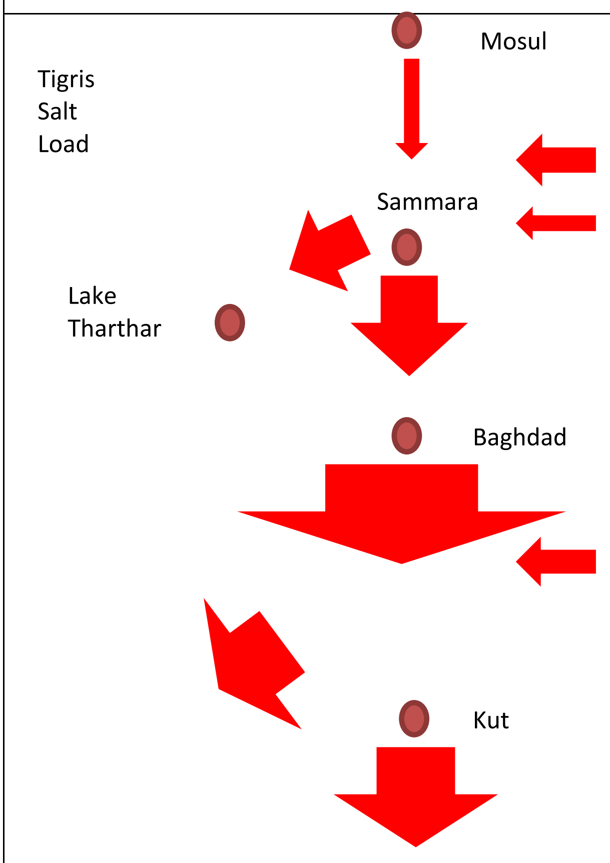

Figure 59: Salt Load for calendar year 1990 in the Tigris river

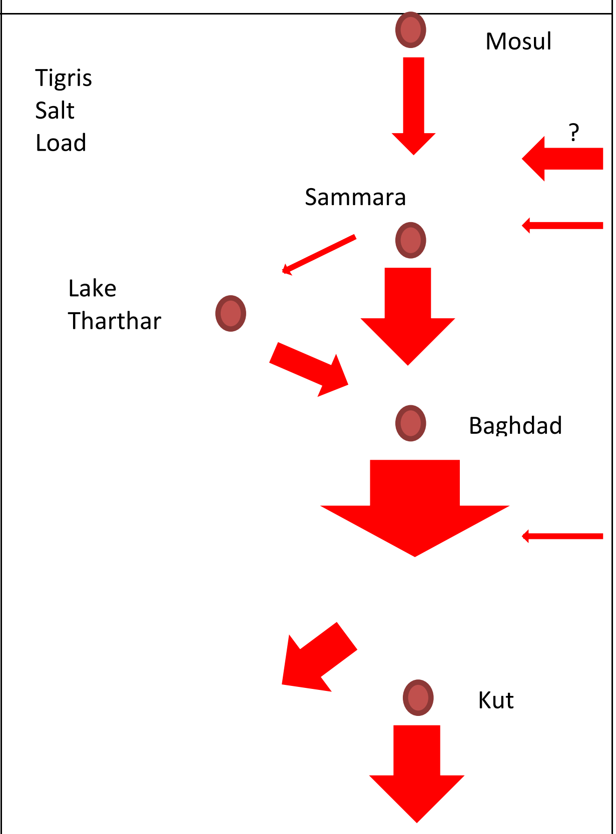

Figure 60: Salt Load for calendar year 2000 in the Tigris river

Notes: Salt load from Greater Zab in 2000 is unknown due to no data; Salt load below Mosul Dam is incomplete for 1990 due to missing data; Diyala River data are for below Hemrin Dam, not at the confluence with the Tigris River, thus flow and salt loads mat be substantially different.

Main Drain

Known as 'The third river', the Main Drain, was first suggested by British engineers in 1951 as a means of removing highly saline irrigation drainage water from 1.5 million hectares of agricultural land between the Tigris and Euphrates Rivers. Parts of the Main Drain were begun in 1950's and more work was completed in the 1960's but the entire project was not completed until December 1993.

Nearly 565 km in length, the drain runs south from the end of Ishaki Drain near Baghdad at nearly 35m above sea level. It continues south on the western side of Dalmaj Lake, (having both an inlet and outlet with the lake). It continues down the west bank of the Shatt Al Gharraf and crosses the Euphrates via a large inverted siphon beneath the riverbed just east of Nassiriya. The drain then runs parallel to the Euphrates until it changes direction and joins up with the Shatt Al Basra canal, finally discharging into Khour Abdulla and then the Persian Gulf.

Salinity data is available at five sites along the drain for the period January 2009 to February 2011 (Figure 61); Abu Gharieb, Mahmudiyah, Al Shumaly, Al Fajir and Nassariyah (from upstream to downstream respectively). The data shows that salinity of the drainage water generally varies between 2,000 and 7,000 mg/L over that period, with a period of very high salinity recorded at Al Fajir during early 2009. It is also apparent form the data that salinity of the water increases slightly from upstream to downstream (though during 2010 Nassariyah recorded the lowest salinity indicating a more complex relationship dependent presumably on local factors), and that summer salinity recordings are higher than those for winter.

There are no flow records available to this project for the Main Drain, so no salt load calculations are possible.

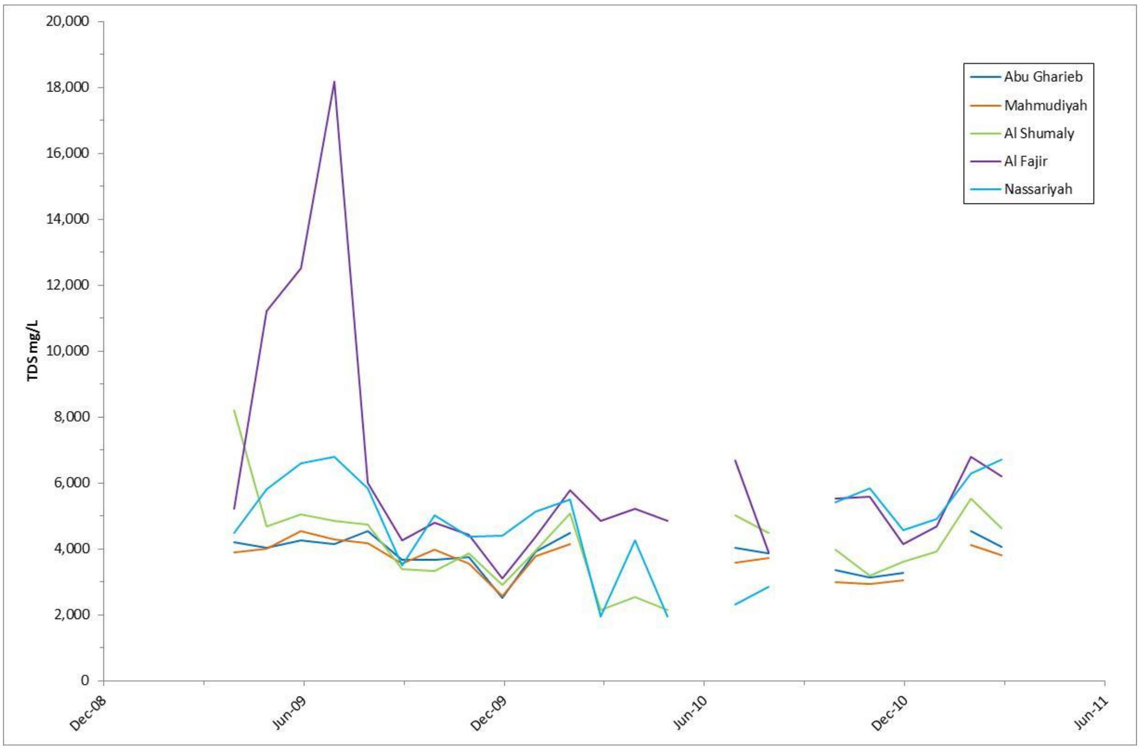

Figure 61: Salinity (TDS) data for the Main Drain

Conclusions

This report suffered from the lack of access to the key data held in the Ministry of Water resources, and would benefit from further analysis of the daily time series data that is available. The analysis has relied on monthly average flow and salinity data sourced through one or two key unpublished reports. The raw data obtained from the MoA has not been validated or verified, and so caution is required in using these results as strict facts. However, enough data exists to provide a pattern of occurrence, and this internal consistency of conclusion allows some confidence in our results. As well, the results of this study accord reasonably well with conclusions from other work.

The distribution of river flow and salinity concentration is complex across the Euphrates and Tigris River Basins. The system is highly regulated in its upper parts within Iraq (that is, upstream of K'fil on the Euphrates and upstream of Kut on the Tigris). River flow volumes have substantially reduced as has been shown by a number of published reports and papers.

The salt load carried by the Rivers is large, with the Tigris transporting 15 million Tonnes in 1990. Together these represent the transport of between 30 and 40 million Tonnes of salt for that year; this is a substantial mass of salt and needs to be managed explicitly.

There are issues with the influence of the reduced flows on the salinity of the water that is available for irrigation in Iraq, and whether the reduction in flow has caused an increase in salinity. The data analysed for this report does not show an increasing trend at the Iraqi border upstream on either the Euphrates or Tigris Rivers. This data extends back to the middle 1970s and since the upstream regulation commenced in 1973, it would seem on face value that increasing salinity trends have not occurred. Within Iraq, however, it is a different matter. There is a clear increasing trend in salinity for the Tigris River at Baghdad, and part of this is probably due to the influence of Lake Tharthar and its use as an off-stream flood mitigation storage. At the moment the River seems to have reached a dynamic equilibrium with Lake Tharthar inputs, but future trends cannot be predicted based on the available data.

There is a clear increasing trend in salinity with distance downstream on both the Euphrates and Tigris Rivers. This is most pronounced in the Euphrates River where salinity increases by a factor of about five. The increase is characterised by a rapid rise in salinity at the point in the River where regulation for irrigation diversion ceases. That is, the rivers seem to be operated for irrigation deliveries above key points (K'fil and Kut) and below those points it is essentially unregulated in that there are no flow objectives. It is concluded here, in line with other reports and studies, that the increase in salinity is due to the return flow of major irrigation drains and ingress of saline groundwater. A further conclusion from this is that the delivery of good quality water below these points would appear to be a major challenge, and hence any irrigation activities downstream would need to accommodate saline agriculture.

Clearly, if salinity in these middle to lower reaches is to be reduced, management of drainage water will be a key aspect. The Main Drain is an obvious disposal point for the drains discharging back to the Rivers, but there is an added complication that removing the drainage water may stop the salt load, but it will also divert the majority of flow from the rivers, essentially ensuring that both major Rivers would almost cease to flow.

Careful management and adoption of flow objectives for the downstream reaches will be required.

References

WCC, 2006 Technical Data for Dams, Reservoirs and Main Control Structures with mean monthly flow rates and water quality for Main Water Resources (1976 – Sep 2005). General Directorate of Water Resource Management, Ministry of Water Resources, Republic of Iraq.

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