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Optimization of wastewater treatment plants in Jordan

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Abstract

This Public-Private-Partnership (PPP) - Project, part-financed by DEG and Public Funds from German Federal Ministry for Economic Cooperation and Development, aims at transferring the know-how in the field of operational optimization of wastewater treatment plants under the administration of Water Authority of Jordan (WAJ) to improve the plants operation and maintenance strategies.As a first step, a survey of the current status of these three wastewater treatment plants in Jordan including data collection, sampling, and analysis has been executed to evaluate the current operational parameters according to the German as well as international standards and norms. The preliminary evaluation showed that all treatment plants exhibits malfunctioning in their unit operations and/or processes. However, in most cases, simple measures and modifications can be implemented to overcome the operational failure.

An example of one of the so many findings at Irbid wastewater treatment plant is the high concentration of COD in the plant effluent (400-500 mg/L) that was attributed to the high influent concentrations and insufficient recirculation rates, followed by breakthroughs at the trickling filter (TF). The option for an additional internal TF-recirculation (as pilot trial for one TF) is proposed.

In this paper the main operation difficulties of the involved and reviewed wastewater treatment plants will be discussed. In addition some results of the ongoing monitoring program as well as first practical proposals for achieving operation improvements will be presented.

INTRODUCTION

Jordan is known to be one of the most water scarce countries in the world. Due to the semi-arid climate of Jordan, compounded with high population growth rates, water scarcity has become of permanent nature and water resources are overstressed. Moreover, Jordan is a relatively small country with limited natural resources which are located in an arid to semi arid climatic region where around 90 percent of the country’s land receives an average annual precipitation of less than 200 mm of rainfall. In addition, approximately 90 percent of the total average rainfall in Jordan is lost by evaporation [World Bank, 2007].

Due to this fact of water shortage in Jordan, many wastewater treatment plants (WWTP) effluents are reused for different purposes, mainly for irrigation. Therefore, discharging high quality water from these plants would further protect the water resources and prevent the increasingly deterioration of groundwater, land, and agricultural quality. On the other hand, many of the existing WWTP facilities suffer from malfunctioning of their unit processes and operations that particularly could happen in case of overloading and lack of operational and maintenance skill.
The PPP-project "TOP - Treatment Optimization for Wastewater Plants in Jordan", part-financed by DEG and Public Funds from German Federal Ministry for Economic Cooperation and Development, aims at transferring the know-how in the field of optimization of wastewater treatment plants to Water Authority of Jordan (WAJ), to apply new technologies and improve their operation and maintenance strategies. Vocational and educational training for public decision makers and operational staff will be a key aspect in raising the awareness and public cooperativeness to accomplish modern and efficient water conservation in Jordan in the future. The implementation of this innovative project, which deals with three different Wastewater Treatment Plants, is considered as a model, which could serve as a multiplication factor at other WWTPs in Jordan.
As a first step a survey of the current status of three wastewater treatment plants in Jordan including data collection, sampling, and analysis has been executed to evaluate the current operational parameters in cooperation with the plant operators and Al-Balqa' Applied University (BAU).

WATER RESOURCES AND WATER REUSE IN JORDAN

Available water resources in Jordan are among the lowest in the world. Water resources consist primarily of surface and groundwater resources, with treated wastewater being used on an increasing scale for irrigation, mostly in the Jordan Valley. Water resources in Jordan are dependent on the rainfall amount. Precipitations range between 50 and 600 mm/year and rainfalls are mostly concentrated in the uplands running alongside the Jordan Valley, in that way, 90 percent of Jordan receives less than 200 mm/year. About 5 percent of the rainwater infiltrates into the ground and replenishes the aquifers while 3 percent is transformed into direct flood flow. The largest share of over 90 percent of annual rainfall is lost by evapotranspiration [MWI, 2007].
The per-capita share of the water resources is estimated at about 150 m³, where as for Germany is more than 1500 m³ [World Bank, 2008]. The current population of Jordan is estimated to be about 5.98 millions with annual growth of 2.1 percent [DOS, 2009]. Moreover, the continual increase in urbanization under the limited available resources create unbalanced situation in water supply and demand. About 80 percent of the current population of Jordan is concentrated on the Jordanian Bank of the Jordan River basin mostly in the cities of Amman, Zarqa, Irbid, Mafraq, Jerash and Ajloun [DOS, 2008]. The agricultural sector using around 64% of the total water resources in Jordan is also mostly located on the Jordanian Bank of the Jordan River basin where the irrigated area in the Jordan valley is about 30300 ha (hectare) and it is about 44 000 ha in the highlands [MOA, 2006]. In spite of that, the output of agriculture only contributes 4 percent to the annual GDP [DOS, 2006]. The municipal or domestic sector (hotels, hospitals, schools, houses, government and private bodies) comes in as the second consumer (32 percent of the total consumption), while industrial sector consumes about 3 percent of the total consumption, see Figure 2 [MWI, 2007].

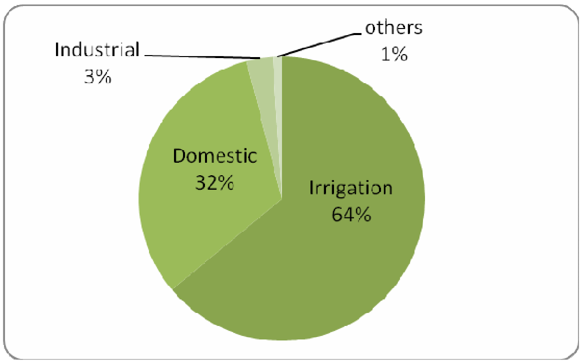

Figure 1: Water Use in Jordan [MWI, 2007]

WASTEWATER TREATMENT IN JORDAN

Currently, there are 24 wastewater treatment plants in Jordan that generate annually more than 110 MCM of treated wastewater, where about 73 percent of wastewater quantity is treated at As Samra wastewater treatment plant [WAJ, 2009]. Many treatment facilities are still operated within the range of their design capacities, whereas some treatment facilities are extremely under designed and the amount of wastewater inflow exceeds the designed flow of more than 100 %, see table 1.

Generally the domestic water consumption in Jordan is low, this results in high organic concentrations. High organic loads impose operational problems where the plants become biologically overloaded with only a portion of their hydraulic loads.
The average salinity of domestic water supply in Jordan is about 580 mg/L of total dissolved solids (TDS). However, the salinity of wastewater is ranging between 800 and 1200 mg/L [WAJ, 2007]. Especially in treatment facilities that use waste stabilization ponds, where part of the water is lost through evaporation, there is a further increase in salinity level in the effluent.

It is estimated that 10 percent of the biological load comes from industrial discharges. Wastewater in Jordan is comparatively low in toxic pollutants such as heavy metals and toxic organic compounds due to the low level of industrial discharges to sewage treatment plants [Uleimat, 2010]. Treated wastewater is discharged to open wadis and flows either to the reuse sites or to dams, where it is mixed with rain water or base flows. There are three main dams (King Talal Reservoir, Shu'aeb, and Kafrain) that receive effluents from some WWTPs. All amounts of water stored in these dams are designated for agricultural use in the Jordan Valley. King Talal Reservoir (KTR) is considered a vital water source for agriculture sustainability in the middle Jordan Valley, since it is the principal recipient of effluents mainly from As'samra, Baq'a, Jerash and Abu-Nusier WWTP's. In addition, many springs and storm water runoff accumulate in the KTR. The total effluent water draining into these dams is around 56 MCM annually, of which 53 MCM is received by KTR alone [WAJ, 2007].

The quality of treated effluent used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant or aquaculture system. In the case of irrigation, the required quality of effluent will depend on the crop or crops to be irrigated, the soil conditions and the system of effluent distribution adopted. Through crop restriction and selection of irrigation systems which minimize health risk, the degree of wastewater treatment can be defined. Figure 2 shows the average chemical characteristics of the wastewater effluents of the main municipal sewage treatment plants in Jordan [WAJ, 2007].

Table 1: Wastewater treatment Plants Profile in Jordan, [WAJ 2007] supplemented

No	Treatment plant name	Start Year	Treatment system	Design m³/d	Act. flow m³/d	Design kgBOD/d	End Use
1a	AS SAMRA	1985	wastewater stabilization ponds	68000	178903	525	Wadies
1b	AS SAMRA new	2008	activated sludge	276000			Wadies
2	IRBID (CENTRAL)	1987	trickling filter and activated sludge	11023	6364	800	Wadies
3	AS SALT	1981	activated sludge	7700	4481	1090	Wadies
4	TAFILA	1988	trickling filter	1600	1181	1050	Wadies
5	WADI AL ARAB	1999	activated sludge	22000	10702	995	Irr
6	WADI HASSAN	2001	oxidation ditch	1600	964	800	Irr
7	WADI MOUSA	2000	activated sludge	3400	1984	800	Irr
8	WADI ALSIER	1997	aerated lagoons	4000	3113	780	Wadies
9	ALEKEDER	2004	wastewater stabilization pond	4000	3700	1500	Irr
10	ALAJOUN	2005	wastewater stabilization ponds	1000	518	1500	Wadies
11	TELALMENTEH	2004	trickling filter and activated sludge	400	290	2000	Irr
12	JARASH(EAST)	1983	activated sludge	3500	3392	1090	Irr
13	AL KARAK	1988	trickling filter	786	1550	800	Wadies
14	KUFRANJA	1989	trickling filter	1800	3931	850	Wadies
15	MADABA	1989	activated sludge	7600	4711	950	Irr
16	MAFRAQ	1988	wastewater stabilization ponds	1800	1991	825	Irr
17	MA'AN	1989	wastewater stabilization ponds	1590	2417	920	Irr
18	ABU NUSEIR	1986	activated sludge and rbc	4000	2358	1100	Wadies
19	RAMTHA	1987	activated sludge	5400	3393	1000	Irr
20	AQABA (old)	1987	wastewater stabilization ponds	9000	5516	900	Irr
21	AQABA(NEW)	2005	activated sludge	12000	7630	420	Irr
22	AL- BAQA (Ain Al Basha)	1987	trickling filter	14900	11714	800	Wadies
23	FUHEIS	1997	activated sludge	2400	1792	995	Wadies

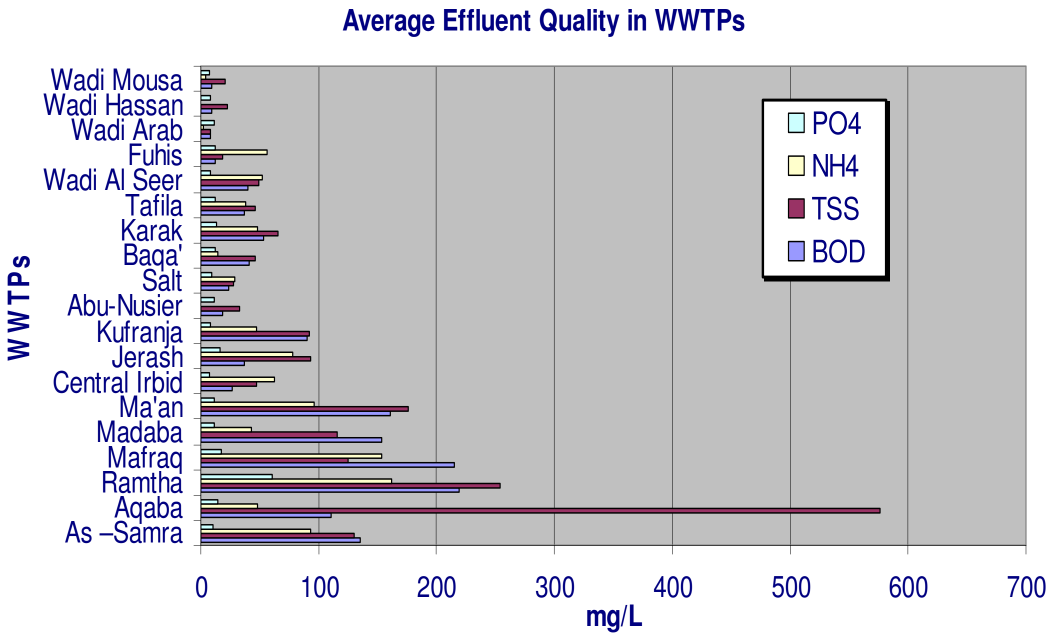

Figure 2: Average chemical characteristics of the wastewater effluents of the main municipal wastewater treatment plants in Jordan [WAJ, 2007].

SURVEY OF THE CURREN WWTP-STATUS

A survey of the current status of the three wastewater treatment plants WWTP Ain Al Basha, WWTP Irbid and WWTP Jerash, including data collection, sampling, and analysis, has been executed to evaluate the current operational parameters in cooperation with the plant operators and Al-Balqa' Applied University (BAU).

WWTP Ain Al Basha

WWTP Ain Al Basha started service in 1988. A flow scheme of WWTP Ain Al Basha is shown in figure 3.
WWTP Ain Al Basha is located near to populated area and adjacent to a major arterial motorway that passes thousands of cars daily, and the WWTP has influent streams of high loaded industrial wastewaters. Odour treatment systems were provided for the liquid stream, not for the solids handling facilities. Because of the frequent odour trouble in the influent the grit chamber is covered and equipped with an odour control unit (air washer with dosing of chemicals: NaOH and NaClO). On our visit the air washer was not in operation. The operational staff mentioned the occurrence of hardly soluble dimethyl sulphide, therefore this washing process is not optimized and not very effective.
The residence time in the primary sedimentation is higher than 3 hours, partially up to 6 hours. To avoid anaerobic digestion processes of the primary sludge, the sludge removal rate is 10 times higher than the surplus sludge produced. This leads to a high internal return flow of sludge liquor.
Trickling filters (TF) typically shed or slough biological solids from the biofilm on the plastic media on a constant basis. To aid the settling of these solids there is a downstream "solids contact stage" (SC) after the trickling filter and before the secondary sedimentation.

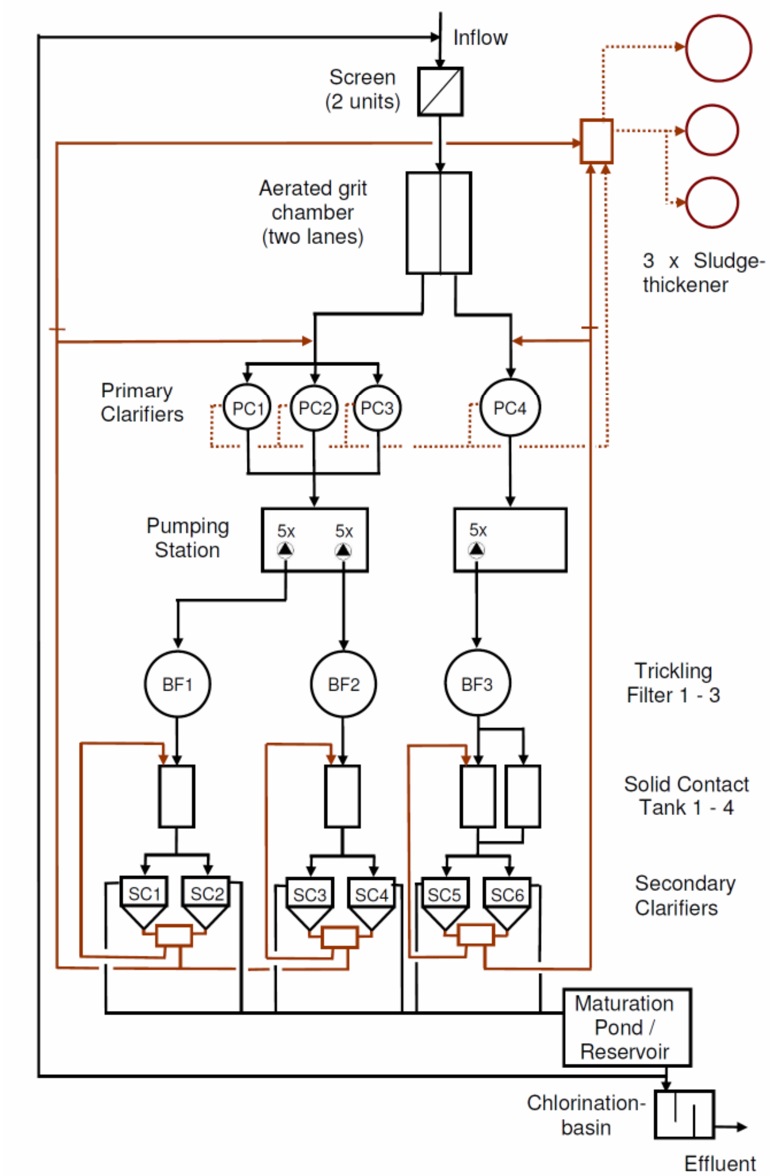

Figure 3: WWTP Ain Al Basha, flow scheme [PIK, 2010a].

Snails can grow in trickling filters. They are flushed into the trickling filter effluent and may accumulate in the SC-tanks: Other TF/SC plants have experienced maintenance difficulties due to substantial accumulations of snail shells in the contact tanks. Snails have been found outside the tank, on the stairs to the SC-tanks, see Figure 4. There is no information available about accumulation in the tanks. A number of sewage treatment plants in Germany that operate trickling filters with synthetic materials have also faced operational problems caused by snails. At the Flensburg sewage treatment plant in northern Germany, this led to the collapse of the downstream nitrification stage. In several large-scale operating trials, a method was developed to kill snails by raising pH-levels and enhancing the formation of ammonia from in-plant sources [Einfeldt et al., 2004].

Figure 4: WWTP Ain Al Basha, snails on the stairs to the SC-tanks [PIK, 2010a].

The disinfection unit is out of operation. The reclaimed wastewater is used locally inside and around the WWTP, as well as it is discharged through a pipe (7.3 km) and then through Al-Seleihi valley. Finally, it ends up at King Talal Dam where it got mixed with the dam's water. The reclaimed wastewater is used for irrigation.

The actual inflow loads as well as the plant operation data have been used for a recalculation of the WWTP-design. The actual BOD_5 volumetric loading of the trickling filters at WWTP Ain Al Basha, based on 85 percentile value, has a value of 0.48 kg/(m³·d). With plastic TF filler material with a specific theoretical surface of more than 100 m²/m³ BOD_5 volumetric loadings of more than 0.4 kg/(m³·d) up to 0.6 kg/(m³·d) are possible [ATV-DVWK-A 281E, 2001].
Recently published investigations show a significantly higher performance at higher wastewater temperatures, reaching volumetric loadings of up to 1.0 kg/(m³·d) at 25°C [Ruhr-Universität Bochum, 2010]. However, at high volumetric loadings the biofilm thickness increases, and the danger of sludge accumulation in the trickling filter rises. To avoid anaerobic zones in the trickling filter at higher volumetric loadings, and to ensure a satisfactory sludge removal the flushing force needs higher values than given in ATV-DVWK-A 281E.

Nevertheless, effluent values of the Ain Al Basha TF reach 200 mgCOD/l. As a rule the BOD_5 concentration at the rotary distributor $C_{BOD,InB,RF}$ is to be set at less than 150 mg/l by return pump operation. For this, as also for a partial balance of large variations of the inflow, a recirculation ratio $RR_{DW} \leq 1$ is sufficient with BOD_5 concentrations in the influent ≤ 400 mg/l. But the actual inflow concentrations range from 510 to 840 $mgBOD_5$/l. Furthermore the actual recirculation ratio with an average value of 0.46 is much lower. Figure 5 shows the diluted biofilter inflow concentrations of BOD_5, all of the values are significantly higher than the proposed 150 $mgBOD_5$/l.

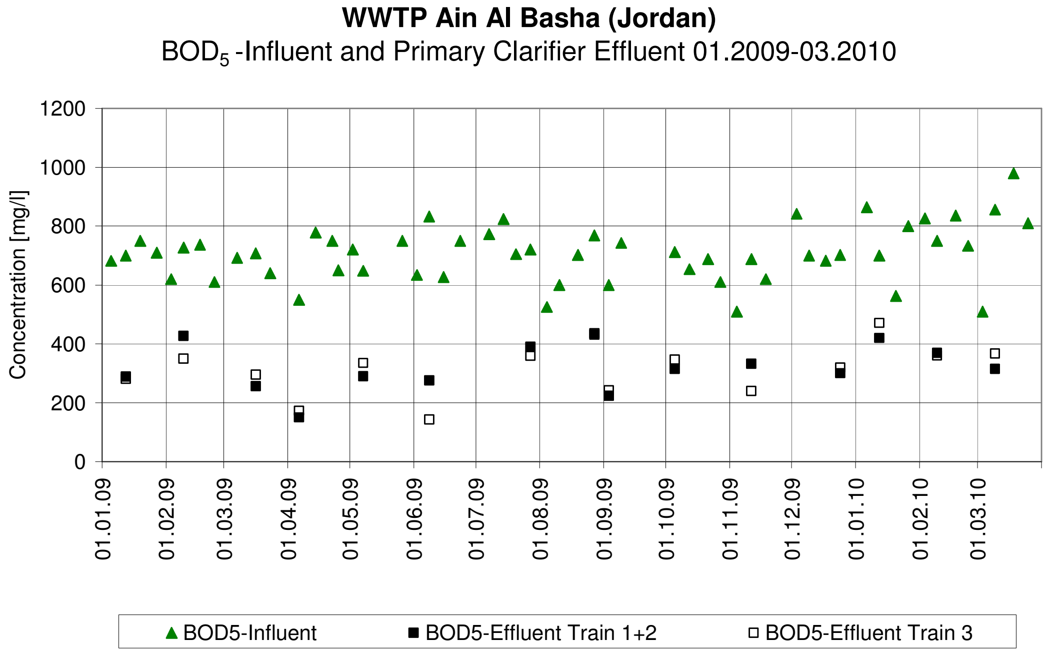

Figure 5: BOD_5-Influent and diluted Primary Clarifier Effluent (01.2009-03.2010)

The recalculation led to a significantly higher required recirculation ratio of 2.1. Some investigations have to be made, how to heighten the recirculation without overloading the secondary clarifier.

For recalculating the secondary clarifier, additional sound actual data on SVI are required, see section monitoring program.

To find out whether the effluent values up to 200 mgCOD/l are depending on high volumetric loadings or insufficient recirculation rates, some further investigations have to be made. Part of the COD effluent concentration is caused by high TSS-values in the effluent, but the remaining COD is still too high. The options for an additional internal TF-recirculation (as pilot trials for one TF) should be evaluated.

The most important problem at the moment is the odour trouble in summer. WWTP Ain Al Basha has influent streams of high loaded industrial wastewaters. Odour treatment systems were provided for the liquid stream, not for the solids handling facilities. It seems that most of the odour trouble in summer results on the load of the influent. Further investigations on the existing indirect dischargers have to be done. That includes the taking of water samples, analyzing and compiling all available information concerning the sewer system.

WWTP Irbid

WWTP Irbid started service in 1986. A flow scheme of WWTP Irbid is shown in figure 6.

WWTP Irbid is located quite near to populated area. Odour treatment systems are not provided

At the trickling filters a fine distribution of wastewater and an as even as possible complete wetting of the filter material surface with wastewater is not ensured: Just 50% of the rotary distributors' openings are unobstructed. The trickling filter operation is without flushing. Every 10 to 12 days a biofilm slough off occurs. The total suspended solid in the activated sludge stage then rises from 5 - 7 g/l up to nearly 15 g/l.

An activated sludge stage is provided for the effluent of the trickling filters. There is a lot of floating sludge on the secondary clarifiers, but the effluent seems clear.

The anaerobic digester is operated without heating. Temperatures reach 15° to 20° in winter and more than 30°C in summer. Wasted sludge from the activated sludge stage is pumped into the digester. In contrast no primary sludge is fed into the digester. The generated digester gas is flared.

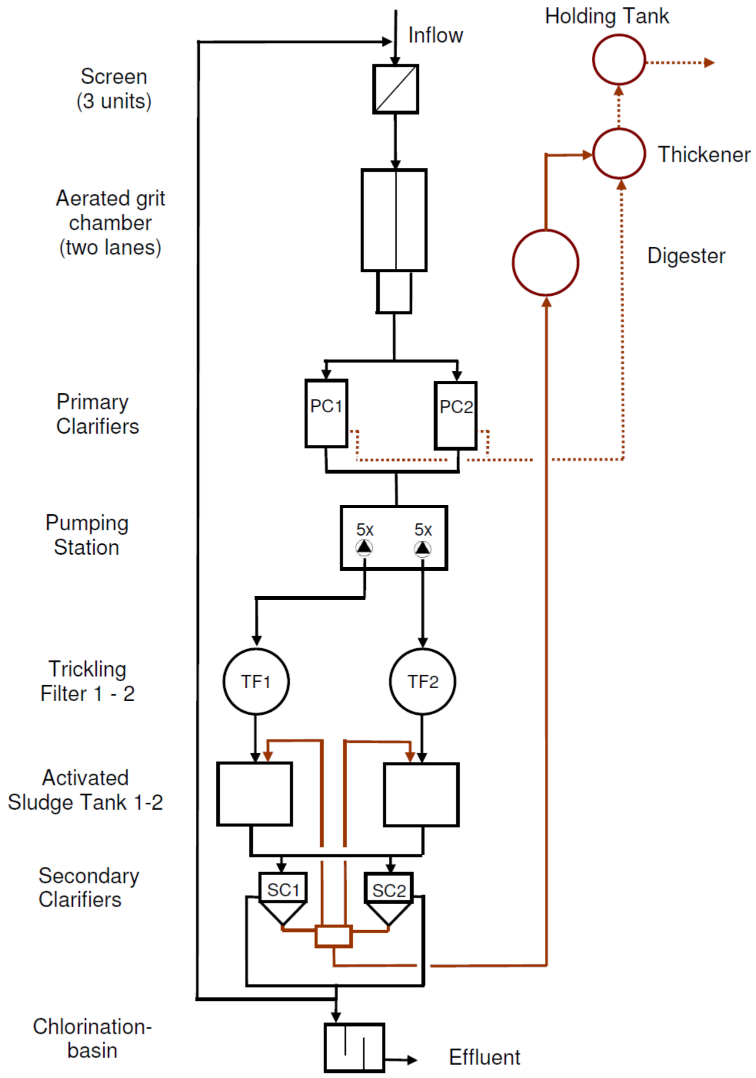

Figure 6: WWTP Irbid, flow scheme [PIK, 2010b].

Together with the digested sludge from the digester the primary sludge is given into the thickener tank (static thickening). No sludge liquor could be seen running over the dentated end sill, and there was a thick layer of floated sludge. From there it is pumped into the holding tank, the generated sludge is transported by tankers to Al-akeder dumpsite. No sludge drying beds in operation because of odour problems.

The disinfection unit is out of operation.

The actual inflow loads as well as the plant operation data have been used for a recalculation of the WWTP-design. The actual BOD_5 volumetric loading of the trickling filters at WWTP Irbid was calculated to 0.8 kg/(m³·d). The acceptable load is 0.4 kg/(m³·d) up to 0.6 kg/(m³·d), if the complete material surface gets wetted (see paragraph WWTP Ain Al Basha).The trickling filter seems to be overloaded, particularly with regard to the uneven distribution of the wastewater over the trickling filter surface.

Though the estimated sludge age of the activated sludge stage seems to be sufficient, the effluent values of WWTP Irbid from 400 up to 500 mgCOD/l in 2009 are much too high (see figure 7). This may be caused by high inflow concentrations and insufficient recirculation rates, followed by breakthroughs at the trickling filter. The options for an additional internal TF-recirculation (as pilot trials for one TF) should be evaluated.

The secondary clarifiers seem to be overloaded regarding to the surface flow rate as well as to the sludge volume loading rate. Additionally from time to time very high concentrations > 7 g/l of suspended solids are observed in the secondary clarifiers inflow, so the situation becomes even more problematic. A high percentage of the COD in the effluent caused by suspended solids may be ascribed to this circumstance. For recalculating the secondary clarifier, additional sound actual data on SVI are required. Appropriate analytics have been induced.
Wasted sludge from the activated sludge stage is pumped into the digester. In contrast no primary sludge is fed into the digester.

Thickening primary sludge in open, not covered basins of course causes odour problems. Investigations should be induced, whether it is possible to feed the primary sludge into the digester. Primary sludge will provide more gas than secondary sludge, so it may be interesting to recondition the heating of the digester and to invest into block heating works or sludge drying technologies.

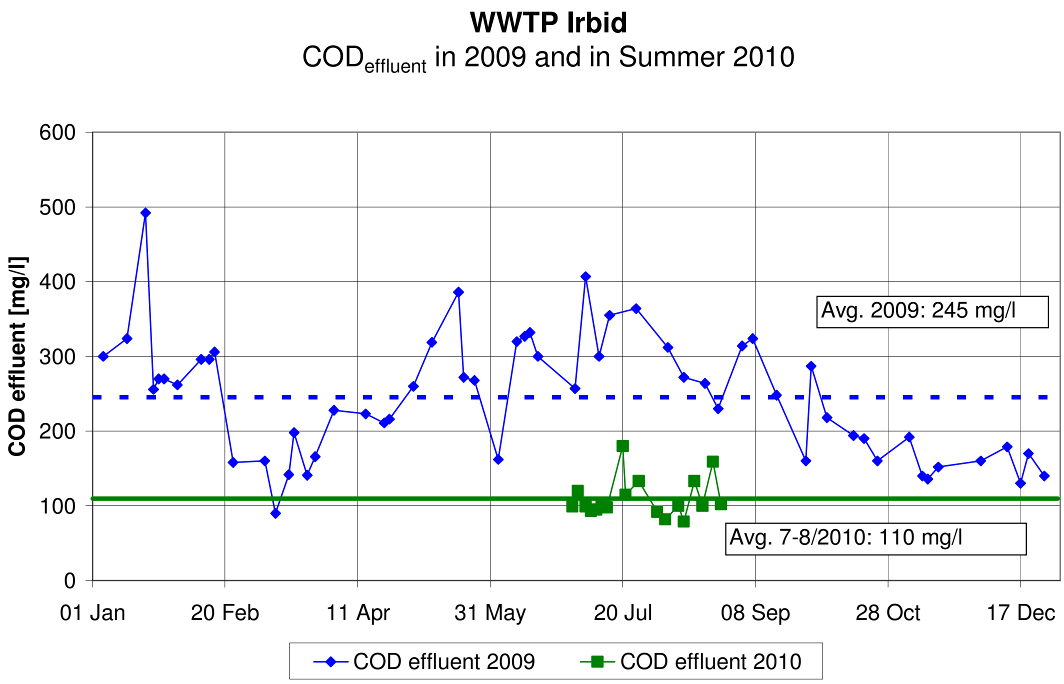

Figure 7: COD-Effluent WWTP Irbid in 2009 and Summer 2010 (monitoring program)

WWTP Jerash

WWTP Jerash started service in 1984. A flow scheme of WWTP Jerash is shown in figure 8.

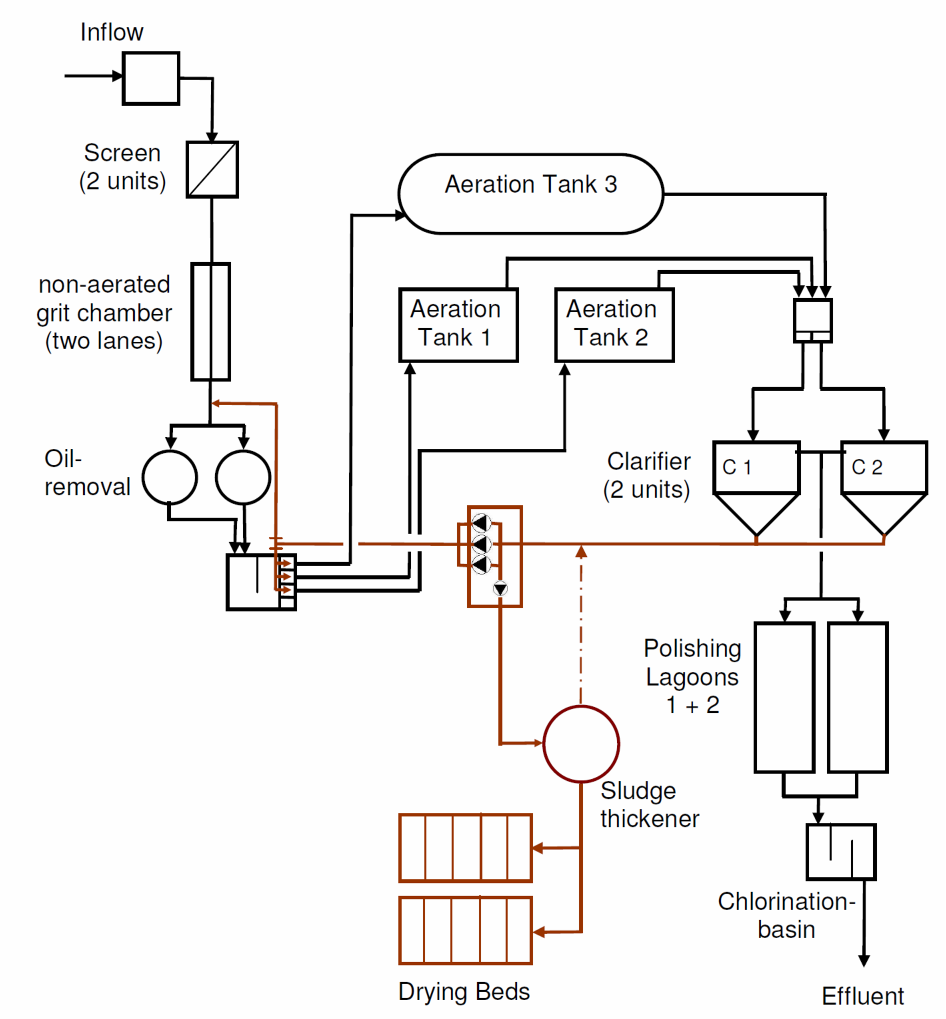

Figure 8: WWTP Jerash, flow scheme [PIK, 2010c].

At present the automatic screenings removal is not working, so 90% of the inflow backwater passes the coarse rack. This leads to an insufficient removal of solids and floating matter. In both grit chambers there is a considerable sedimentation of sand and stones, so there is a reduced free cross section and a raised flow velocity. The sedimentation process is limited. Also there is backwater up to the venturi meter. Measurements are incorrect from time to time, especially at high water quantities, also regarding to the dry weather maximum flow. The main reason seems to be the recirculation of the recycle sludge previous to the oil-removal-chambers with the effect of hydraulic overload in this part of the plant.

As a suggestion dosing of recycle sludge into the existing distribution chamber behind the oil-removal unit was discussed. Because of the present pumping of floating matter from the secondary sedimentation tanks into the recycle sludge stream, an additional removal of floating matter, i.e. by using a screen basket is necessary.

The German dimensioning guideline A 131 stipulates a minimum total depth of the secondary settling tanks of at least 3.0 m at two thirds of the flow path or radius. The side water depth should not be less than 2.5 m. The measured value for the depth at two thirds of the radius is < 2.50 m. The side water depth is 2.2 m. On the other hand a considerable turbidity (non settleable suspended solids) in secondary sedimentation effluent was noticed. Also slight denitrification processes in the clarifiers seemed to be observable.
The disinfection unit (chlorine basin) is out of operation.

MONITORING PROGRAM 2010

Currently the processing and interpretation of the monitoring program (July - October 2010) is in progress. As an example see figure 9. Nearly 50% of the COD effluent values at WWTP Irbid are caused by overloaded secondary clarifiers and the high suspended solids in the effluent.

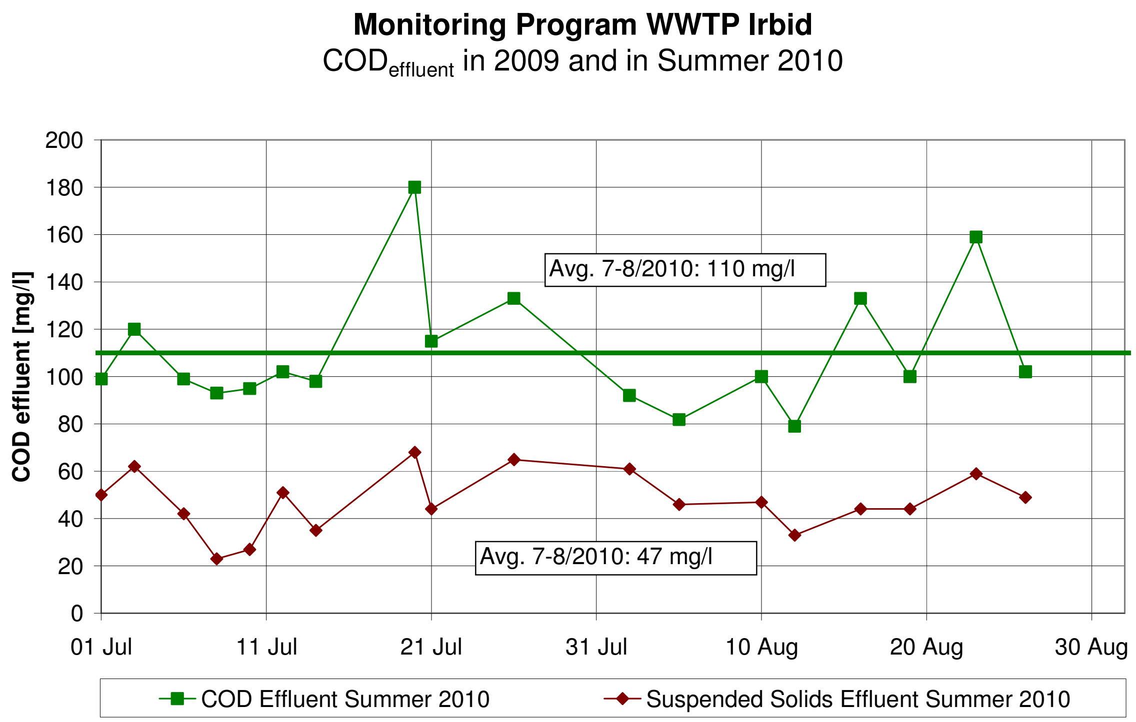

Figure 9: Values for COD and Suspended Solids in the effluent of the activated sludge stage

At WWTP Jerash grab samples from 2009 showed high nitrogen inflow concentrations. With the actual inflow COD-loads the aerobic sludge age was calculated to values between 2 and 5 days. At water temperatures of 25°C and above this should lead to a considerable nitrification [Ruhr-Universität Bochum, 2010]. The values for NH_4-N at WWTP Jerash (samples of the monitoring program) are shown in figure 10. The reduction of ammonia in the biological stage is caused by incorporation into the biomass. Nitrate concentrations as a result of a nitrification process were lower than 1 mgNO_3-N/l, but on the other hand the oxygen concentrations in the activated sludge tanks varied from 0.4 to 0.6 mg/l due to the high inflow COD-loads, so a simultaneous denitrification could be possible. But still there are NH_4-N effluent values in the effluent of the secondary clarifiers of 100 mgN/l and above.

A low sludge activity, caused by a high inactive sludge fraction, could lead to an overestimation of the sludge age. Further investigations on sludge activity are required. Also it is possible, that the given high ammonia concentration leads to an inhibition of the nitrification process, the pH-Value in the activated sludge tank ranges from 7.6 to 7.8.

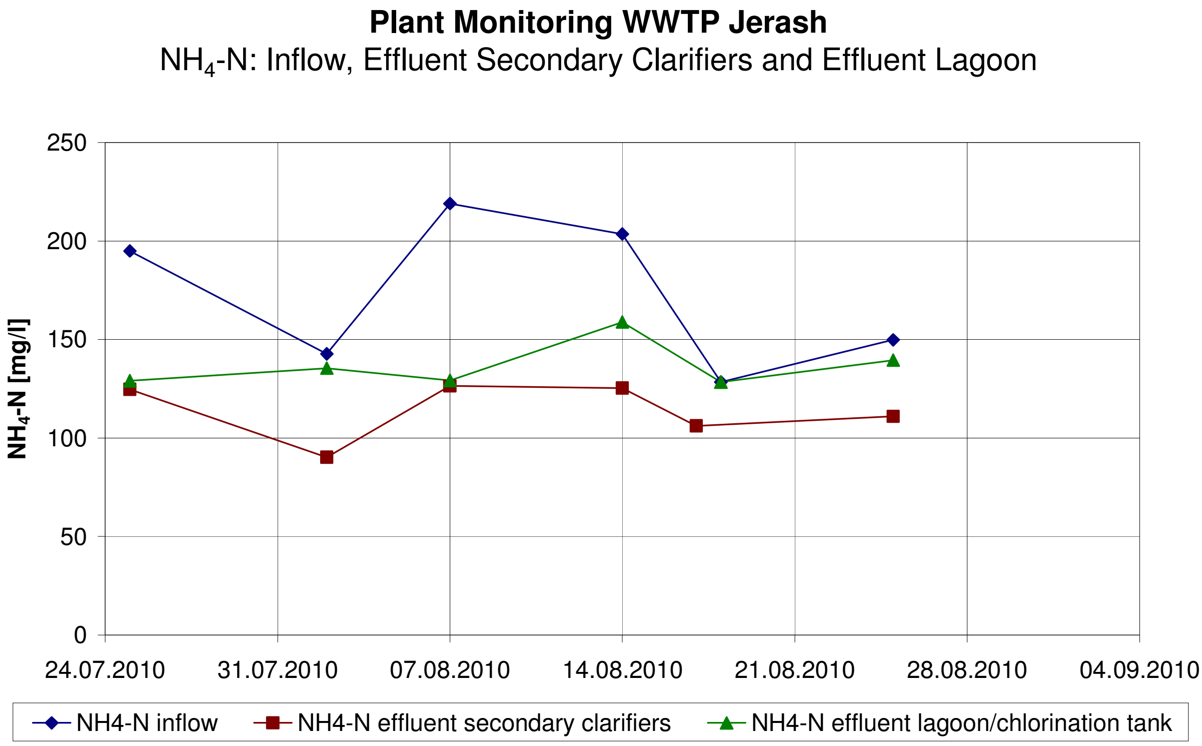

Figure 10: Values for NH_4-N at WWTP Jerash: inflow, effluent secondary clarifiers and effluent lagoon.

In the lagoon the NH_4-N values are rising up to 170 mgN/l, likely caused by redissolution from the high suspended solids concentrations in the lagoon inflow.
Possible causes of the considerable turbidity (non settleable suspended solids) in secondary sedimentation effluent may be the high throttling of the sludge recycle pumps, which leads to a disintegration of the biomass flocs. On the other hand recent investigations show, that a disturbance of the lime-carbonic acid balance could cause floc disintegration (by calcium separation from the activated sludge flocs [Schönherr, 2010]). Further investigation on alkalinity and may be also the lime-carbonic acid balance are needed.

SUMMARY AND FUTURE PROSPECTS

Sewage treatment plants of main cities carry out collection, treatment and disposal which usually are expensive to build and maintain. Collection is accounted for about 80 % of the cost [Alfarra, 2009]. This is known as a centralized WWT system, where volume of the sewage becomes very large and the distance of conveyance is long, as the sewage treatment plants are generally located outside of the cities. In some older cities, storm water is carried in the same sewers as wastewater. Heavy rainfall then may inundate treatment plants and send untreated sewage into down streams. This conventional wastewater management concept has been successfully applied over many decades in densely populated areas of industrialised countries and contributed to a great extend to the improvement of hygienic conditions in these areas.

As a first step a survey of the current status of three central wastewater treatment plants in Jordan including data collection, sampling, and analysis has been executed to evaluate the current operational parameters in cooperation with the plant operators and Al-Balqa' Applied University (BAU). An additional plant monitoring program started in July 2010. The examination and interpretation of the collected data show an improvement in purification performance. An additional enhancement by skilful technical changes and further operation optimization seems to be possible and will be discussed in a workshop held in Amman in December 2010.

The central type of treatment system is difficult to maintain in small remote towns or dispersed suburban areas. Different approaches to wastewater management are required for different regions, rural and urban areas, with different population sizes and different stages of economic governance depending on capacity to manage wastewater and capacity for governance. The new Jordan National Water Strategy has been issued in the late 2009, where it has explicitly indicated the role of decentralized wastewater treatment facilities in extending the sanitation services as well as in recycling (reuse) of treated wastewater in more effective and manageable manner. This is in addition to the role of this new concept of treatment in protecting the environment especially the groundwater.

ACKNOWLEDGEMENT

The authors would like to thank Deutsche Entwicklungsgesellschaft (DEG) and German Federal Ministry for Economic Cooperation and Development for part financing this project.

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