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Optimal Water Abstraction Infrastructure in Yarmouk River Basin

Prepared by: Amin Shaban

Contents

Executive Summary

Water resources are under stress, notably in those resource located in arid and semi-arid regions where water is scarce enough to cope with the demand of the inhabitants. This has been exacerbated with the dramatic increase in the population size, new human aspects of water consumption, and the changing climatic conditions with a special emphasis on the increased temperature and evapotranspiration rates, as well as the turbulences in the rainfall patterns and intensity.

The issue of water resources management is often hindered when these resources are shared between more than one country; and therefore, the responsibility on water supply will be undefined, notably when geo-political conflicts exist between these countries. This is exactly the case for the Yarmouk Tributary of the Jordan River Basin (YTJRB), where three countries are sharing this major water source.

Since early 1950s, a number of bilateral agreements and treaties have been elaborated between these countries (Syria and Jordan, Jordan and Israel). Yet, the YTJRB including all its water resources (surface and subsurface) are still under severe conditions and stress, and even the established infrastructures are now partially and sometimes totally destructed, and most of them are not functional since tens of years ago.

There are many studies and research projects done on the YTJRB where the largest part of these studies was on the hydro-political situation. However, the exaggerated stresses on water resources in this basin makes it necessary to emphasis on searching for new and alternative methods to conserve (qualitatively and quantitively) the available water resources and look for new resources in order to balance the supply/demand.

This will include, in a broad sense, identification of the existing challenges and trends, addressing major infrastructure and biophysical challenges, water and wastewater reclamation and reuse, assessing the environmental flow requirements, and then propose best practices and solutions.

This report, as a part of the ‘Infrastructure Prefeasibility’ discusses all these themes. It is, in-depth, analyze and diagnose the existing water resources problems as well as the most feasible approaches to be followed in order to reach an optimal abstraction of water resources in this basin as well as new recommendations for infrastructure managements.

In the context of Task KA-1 on "Infrastructure Prefeasibility", emphasis will be mainly on identifying solutions required to enhance the situation on water resources and the related disciplines in the Yarmouk Tributary of the Jordan River Basin (YTJRB), aiming to reach optimal water abstraction infrastructure. This has been achieved through five consequent objectives including: knowledge mapping, treatment, proposing management approaches, sustainable flow and expectations and visions. Thus, each of these objectives is consistent with proposed activity (Fig.1).

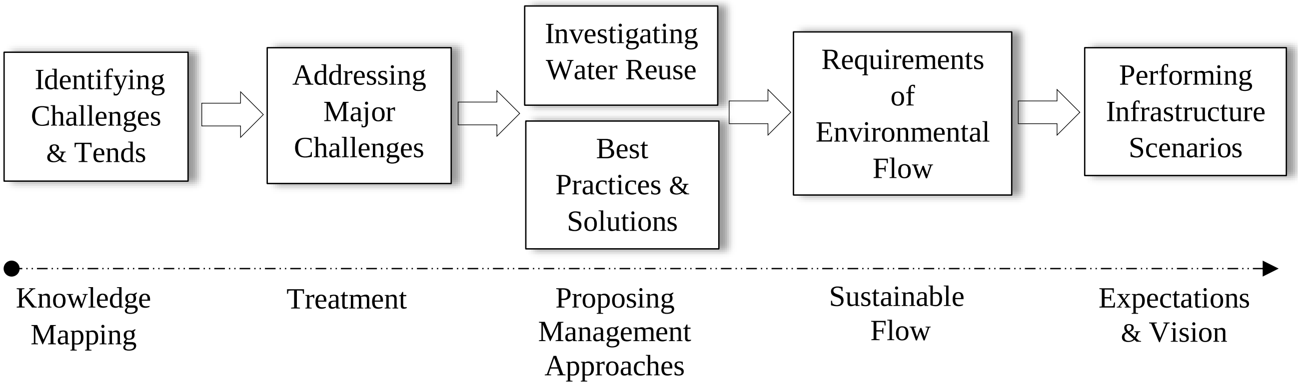

Figure 1: Major objectives and their activities of Task KA-1.

1. Water in YTJRB: Challenges and Trends

It is significant to identify the existing challenges, their trends even the influencer in order to propose the optimal water abstraction infrastructure. However, the existing challenges, on water resources in YTJRB, have diverse origin, mechanism and solutions; therefore, these challenges must be initially categorized according to the theme they belong to.

Usually transboundary water resources are known with poor management and imprecise hydrologic measurements, and this can be refereed to several reasons, in particular the lack for coordination between riparian countries, notably when geopolitical conflicts exist between these countries and then water exploitation becomes messy competitive. This is well pronounced in the Arab Region where debates often exist, especially this region occupies 27 shared watersheds and 41 transboundary aquifers.

Transboundary water resources, mainly those with geopolitical conflicts, are often witnessing uncontrolled impacts, specifically the chaotic water abstraction whether from surface of groundwater resources. Yarmouk River, is a typical example where its location between three political entities ensures its water resources are always under scrutiny.

In the 7378 km^2 area of the YTJRB (Zeitoun et al., 2019), there are dozens of dams along its tributaries, plus thousands of drilled boreholes in the basalt and carbonate aquifer. Hence, overusing of water resources has been exacerbated lately, and it has been increased with changing climate and the increased population. In addition, there is obvious perturbation in the hydrologic system due to the destruction in land cover components and then resulting changes in the hydrologic regime (e.g. diverting direction of tributaries, reducing infiltration due to urban expansion, human interference-induced erosion, etc.).

1.1. Geopolitical Challenges

Many political entities controlled the territory of the YTJRB, including Ottoman, British, French, Arab, Zionist, Syrian, Jordanian or Israeli. This has been accompanied with geopolitical conflicts, which resulted in loss of the identity of the infrastructures established to exploit water from the basin over the sovereignty of the diverse entities.

The YTJRB is shared between two Arab countries (Syria 80%, and Jordan 19.7%); whereas, the rest 0.3% is shared with Israel. The YTJRB is a sub-set of the broader Jordan River Basin, which also includes the Hasbani, Dan, Golan etc. Even though the percentage of the YTJRB shared with Israel is very small in terms of area, it has hydrological significance since it represents the outlet zone of the entire basin. In this – and despite the existence of two bi-lateral international treaties (Jordan-Syria in 1987, Jordan-Israel in 1994) regard, the entire infrastructure of the YTJRB has developed in a totally uncoordinated manner, and perhaps this was anticipated since three hydrocracies are differently operating according to their interests and the changing political situations.

No treaty has been done between Syria and Israel, and the situation remain tense, while there is ambiguous coordination between the Israel and Jordan. Besides, subsequent bilateral agreements have been signed between Syria and Jordan since 1953, and then 1987, and 2001(Borthwick, 2003). Consequently, the final agreement was signed in 2003. Nevertheless, the cooperation between the two countries remains with intermittency and the analysis of the texts shows a significant imbalance (Haddadin, 2014).

No doubt, this unfavorable situation of the YTJRB, notably the violation of treats and disrespect of international agreements impacted the development in the region, and this has been exacerbated due to the increased water scarcity which exhausted the existing agreements.

1.2. Climatic Challenges

Lately, the existed global meteorological phenomenon implies oscillating climate and, to a limit, changing in climatic trends. This is well pronounced in several regions worldwide including the Middle East Region. Amongst many weather variables, much perturbation exists in rainfall and temperature which represent the major two meteorological variables.

YTJRB is located in a semiarid region where the climate is mainly altitude-related. Thus, the altitude ranges between 200 m below sea level and above 1150 m, and this in turn results diverse annual rainfall rate measured between 133 and 486 mm (i.e. averaging 319 mm), and it might reach about 775 mm in Al-Qunaitra (in the proximity of the basin), northwest of the YTJRB (Husein, 2012).

According to the elaborated rainfall patterns (Zeitoun et al., 2019), which have been generated by data combination from 13 ground stations and CHRIPS (remotely sensed product) between 1981 and 2016, there is no remarkable change in amount of rainfall on the YTJRB; however, there is increased rainfall intensity (i.e. torrential rain) in the entire region which often results floods and reduces the infiltration rate, and this has been mentioned by IPCC (2007).

The recorded temperature, which were as acquired from the thermal Landsat 5 and 8 satellite images, showed that the maximum near-surface temperatures were approximately 28 °C between 1985 and 1987 and it has been increased to about 33 °C between 2014 and 2016. Yet there are obvious oscillations in recorded temperature, and even though it has been decreased by 2.9 °C between 1980 and 2010, but there is overall increase which was estimated at 4.5 °C (1985-2016). This increased the evapotranspiration rate, and anticipated to result drought conditions for the Middle East under 1.5 °C of global warming according to Koutroulis et al. (2016).

1.3. Hydrological Challenges

Factors influencing water volume in the hydrologic system are always determined, and this assists proposing optimal solutions in the developing projects. Thus, one of the fundamental concerns for the YTJRB implies the sustainability of its water, and particularly the surface water (i.e. stream flow). This flow is abruptly changing as a result of feeding water sources including precipitation rate and patterns, as well as due to abstraction processes; therefore, the averages annual flow is oscillating between 50 and 250 million m^3, it may reach above 450 million m^3/year during flood flow, thus reflecting a high senility to meteoric water sources and minimal groundwater contribution.

There are 30 gauges installed along the major tributaries of the YR, which is a sufficient number to assess the stream flow. Hence, all studies and surveys indicated that there is obvious decline in the stream flow of the YR. Thus, records show that in early 1970s, the average annual stream flow was about 495 million m^3 (Hoff et al., 2011), and then it was decreased to about 288 million m^3 in 1985s and then to 75-100 million m^3 in 2015 (Zeitoun et al., 2019).

The majority of the decline in stream flow of the YR implies: intensive irrigation and agricultural purposes, impacts of infrastructures (i.e. dams, boreholes, etc.) and the oscillating climatic conditions.

1.4. Geological Challenges

Geology can be a challenge when the existing geological features negatively act. In particular, the geological deformations often mislead the hydrological mechanism and mainly in groundwater flow and storage. They also threat the positioning of infrastructures (e.g. dams). This can be the case in the YTJRB where there are significant geological features which should be considered in order to appraise water resources mechanism and terrain stability. These following are the most challenging geologic features in the YTJRB:

1. Heterogeneity of lithologies, and specifically the presence of carbonate rocks (i.e. limestone) underlying igneous rocks (i.e. alkali olivine basalt). This results in a great amount of uncertainty about the origin of groundwater (Rosenthal et al., 2020).

2. The basalt rocks cover more than over > 67% of the YTJRB is characterized by tremendous fractures, including multi-sets joints and faults. This diffuses water flow into uncertain directions and then creates instable terrain.
3. The dominance of alluvial deposits and soil cover, overlying the basalt pavements, hide the existing rock deformations in these volcanic rocks, and this in turn hides the identification of fracture systems there.
4. The Dead Sea-Jordan Valley Rift System, where the YTJRB is located at its margin, resulted several major faults. These faults, which are described as active faults (Al-Homoud, 1995), threat the stability of the region, notably that the seismic activity is well pronounced in the region. This in turn affects the rigidity of dams and then results leakage in the stored water in these dams, notably all dams, except Al-Wehdah, are earth dams.

1.5. Anthropogenic Challenges

Human interference composes a significant challenge for optimal water use. Thus, the YTJRB reveals typical example for anthropogenic challenges. These can be summarized as follows:

1. Surface water contamination: As a result of human activities including wastewater disposal and crop and animal cultivation; in partial surface water contamination by nitrate is widespread; especially that the half of the YTJRB is known by agriculture activities. Example: the content of Co, Cr, Ni, Ag, Zn and S in YR exceed the permissible limited (Nazzal and Ghrefat, 2001).
2. Groundwater contamination is common in the YTJRB. The major sources of contamination are: wastewater, discharge of olive presses, fertilizers, pesticides, and herbicides. The vulnerability of the exposed rock for groundwater contamination; presumed that groundwater is under risk. There are signs of groundwater pollution in the YTJRB as mentioned by (Orient 2011). While, Awawdeh and Jaradat (2010) states that the depth to water table in northern Jordan is deep (> 30 m) and decreasing gradually northward, which makes the northern part of the YTJRB more susceptible to contamination.
3. Water is abstracted beyond their sustainable limits. Thus, there is over-pumping of groundwater from the major two aquifers (shallow Basalt Aquifer mainly in Syria) and A7/B2 Aquifer). Magane (1995), reported that the excessive groundwater withdrawal caused a severe lowering of the water table estimated at more than 2 m/year in some boreholes within the Jordanian part of the YTJRB. This resulted the lowering of water table, decreased pumping rates. Moreover, salinization has become a common criterion in the YTJRB (Obeidat et al., 2012).
4. The discharge of many springs decreased, and some springs are completely dried (Youmans, 2016). Moreover, many springs (e.g. Ein Zeyzoun, Ein Al

Azal, Ein Khanzir, Ein Umm Qais, Ein Makla, and Ein Reach) show chemical or bacteriological contamination (Chilton 2006), which is mainly from wastewater sources (Al-Yazeji et al., 2004). While nitrate concentrations exceed 100 mg/*l* (Margane et al., 1999).

1.6.Technical Challenges

Technical issues always hinder the progress of implementing optimal water abstraction infrastructure. Even though, some of them can be simply resolved; however, others cannot be addressed unless the decisions taken within the context of integrated strategies. The following are the main technical challenges for the YTJRB:

1. Data availability and creditability (e.g. contradictory in dimensions, gaps in stream flow, dams' actual retention, pumped groundwater volume, etc.).
2. Unavailability of studies, especially those on morphometric and aquifer characteristics and monitoring systems.
3. Lack of detailed thematic maps, in particular faults (lineaments) and other rock deformations map.
4. Lack of derailed thematic analysis, such as morphometric and geometric analysis, aquifer characteristics, etc.
5. Lack to integrated monitoring systems for water nodes and clusters. This can include, for example, quality control, flow-meters, remotely sensed systems, etc.
6. The YTJRB, with its crucial geopolitical and anthropogenic challenges, still in need for sustainable land management to be elaborated.

2. Addressing Major Infrastructure and Biophysical Challenges

Other than the generally existed challenges discussed in previous section, there are specific infrastructure challenges which can be addressed to significantly enhance water supply system and increase the efficiency of water management and use. These challenges are viewed mainly from the volumetric point of view, notably that the amount of water in the YTJRB showed considerable regression over the past few decades, and this includes the surface water and groundwater resources as it was mentioned previously.

2.1. Leakage from drinking water pipelines

Water loss is always a major problem where considerable amounts of water is wasted without any benefit, and sometimes it remains unknown phenomenon. This is well pronounced in the YTJRB where loss of water has several aspects and dimensions of leakage from water supply systems, specifically the old drinking water infrastructure e. This includes water leakage from transmission pipelines (i.e. subsurface networks that span for long distances between major cities and the conveying pipes from dams and tanks), and transmission pipelines (i.e. subsurface networks within cities and towns). In many cases, no measurements have been applied to monitor these aspects of water loss, and if flow monitoring instruments (e.g. flow-meters) are installed, they do not define whether the water in pipelines; however, leakage is always accounted while calculating water balance whether in Syria or in Jordan. Typical examples can be illustrated as follows:

1. Leakage of water from pipelines in the municipal water supply in Jordan is approximately 51% (Ministry of Water and Irrigation, 2015),
2. For example, the leakage is about 27% in Damascus.
3. The mixing the leakage from water pipelines and sewage pipeline systems, which have been constructed more than 50 years ago, resulted severe contamination in domestic water supply in Syria.

Leakage from pipelines usually occurs at pipes connection, also where internal corrosion patches exist and among the longitudinal split in the PVC pipes. Therefore, pipelines leakage may cause: damage to the entire infrastructure, consumer inconvenience due to low water pressure and excessive costs, increased loading on sewers due to infiltration, as well as air intrusion in pipes will result damage to gauge-meters, and over-measurement and then errors in water bills.

In addition, their old and flabby system, most infrastructure supply systems in the YTJRB were improperly installed in terms of its shallow depth, pipes connection and even types of used pipes. They were not also put in a way that allows periodic monitoring and to facilitate the process of detecting damage and applying maintenance approaches.

The identification of water loss in water supply systems remains a crucial issue, notably in a time of worsening water scarcity accompanied with the rapidly increasing of water demands. In this regard, there are several methods and technologies (e.g. Supervisory Control and Data Acquisition - SCADA, Laser technology, etc.) applied to evaluate the amount of water leakage where most of them account mainly on pressure and pipe length.

The following are most commonly applied methods to detect water leakage in pipes:

1. Acoustic pressure test where an acoustic ground microphone with a count-meter is used to detect the loudness of the noises and pinpoint the leak.
2. Tracer gas is applied after draining water from pipes and then fill with pressurized gas which begins to escape when it reaches the crack in the pipe.
3. Thermal imaging can be also applied for leaks in hot water pipes where infrared camera can be used to produce thermal images which are able to delineate any hot water escaping from the pipes.

The efficient and reliable infrastructure is essential to ensuring long-term access to pure water and sanitation services in the YTJRB, with emphasis to the large cities and towns, notably those located away from water sources, such as As-Sanayman and As-Sweida.

Based on the current situation, it can be said that the current status in water supply systems is unfavorable in the YTJRB emphasizing to the leakage from water pipeline. In this respect, Table 1 illustrates the proposed solutions, with their geographic and temporal dimensions, to address this challenge and reach high water use efficiency and reliable water supply:

Table 1. Proposed solutions to address water leakage in pipelines for YTJRB.

Proposed solution	**Geographic and spatial dimensions**
1. Applying integrated survey (using the most efficient detection technologies) for the most accessible pipelines	This can be carried out separately from Syrian and Jordanian sides. Thus, between 60 and 80% of the supply systems must be investigated within one year time period.
2. Adopting appropriate techniques and engineering controls (e.g. depth of pipes and their passageway, etc.) for the new proposed water supply systems	This should be considered for all new supply systems, within a define framework, notably for the interfered towns with rapid population growth
3. Strengthen water sector through staff training on smart metering and rapid leak detection	Periodical trainings and field campaigns over different periods and in different regions
4. Securing financial resources to replace old supply systems with new ones whenever it is possible.	Financial resources should be continuously sought to improve the efficiency of supply systems.

2.2. Seepage from dams

Water seepage from dams is usually a matter of discussion, and it is often viewed from the point of structural soundness rather than as an aspect of water loss (i.e. seepage failure). This must be emphasized in the YTJRB, the region which can be described as "dam-crowded" area, notably there are about 40 dams there and most of them have been constructed on the brittle basalt rocks. This in turn raises the probability cracking and then seepage failure in these dams.

Normally, there are no measurements applied in the YTJRB to monitor seepage failure in dams, and if monitoring instruments are installed, they do not define whether the decrease in the amount of water is due to leakage or it represents a part of the convey of the stored water in dams. In addition, the lack for evaporation measurements is also confusing the amount of water lost from the reservoirs located behind dams.

Most of the dams in the YTJRB included grouting work in the foundation and abutments. However, the proposed treatments are often less than optimal insights. This is due to the fact that the rock beds are disrupted by tremendous rock deformations where the largest part of these deformations are invisible due the dominance of basalt lava which composes a compacted pavement, as well as the widespread alluvial deposits (Al-Homoud, 1995).

The construction of dams in YTJRB has been started since 1964, while the bulk of the dams currently standing were built in the 1980s. Since then, there are many problems in these dams have been reported. As an example, in 2000 considerable leakage has been reported in the partially collapsed Al Mafraq Dam (in Jordan south of the YTJRB), and then it resulted a spill of about 50000 m^3 of sewage which were flowed towards to Yarmouk River.

There are 50 dams constructed in/in the YTJRB. They can be allocated as follows:

- 40 dams are operational (& partially operational) and located within the hydrological boundary of the YTJRB.
- 33 of these dams situated on the basalt rocks,
- 4 are on the limestone at the Jordanian side, whereas,
- 3 dams are located close to the boundary between the basalt plateau and the incised limestone plateau to the south of YTJRB (in Jordan).

Even though slopes orientation is the main controlling factor for the flow direction of tributaries in the YTJRB, yet most of the tributaries in the YTJRB have been generated due to one or more of the following processes:

- Pull apart movements which took place in the consolidated basalt (i.e. basalt pavement split) and then created surfaces of weakness along which water flowed and resulted the existing tributaries.

- Faulting processes, due to the seismic effects in the region, which created large cracks often with mono-set rock breaks, and therefore, created passageway for surface water to flow.

- Building up of rock discontinuity (i.e. abrupt contacts) due to heterogeneous rocks between the consolidated basalt and the moderately hard to soft limestone (deep in

Syria) and marly facies. This slightly represents the primary tributary of the Yarmouk River itself. The Jordan Rift Valley lies to the west, and the Yarmouk River has developed as a drainage marginal to the Syrian basalt lava field.

Other than the probable errors which might resulted from the engineering aspects in the construction of dams, the majority of natural threats for the dams in the YTJRB implies mainly their situation in the proximity to the zone of high activity that parallels the Dead Sea-Jordan Valley Rift System where active seismicity is well pronounced. This has been reported in several studies on the region. Hence, the most dangerous earthquake epicenter is approximately 17-25 km west of the outlet of the Yarmouk River. Therefore, the maximum credible earthquake would probably occur on one of the faults within the Jordan Valley Rift. System, and the likely magnitude of this earthquake is estimated to be with magnitude between 7.5 and 8 on Richter scale (Harza, 1983).

For seepage failure from dams, there are enormous methods for testing probable leakage from reservoirs behind dams. Whereas, in-situ investigation and periodical testing is a major aspect of identification. The following are the most efficient ones:

1. Geophysical sounding is used to investigate the rigidity of dams, and it can provide data on leakages across and in proximity to dams. In this regard, numerous geophysical methods can be applied, namely the seismic propagation, ground penetrating radar (GPR), echo sounding (ES), and Lidar. In addition, the use of different types of Terra-meter proved their reliability (Berhane et al., 2017), where they are able to elaborate vertical electrical sounding (VES), induced polarization (IP) and spontaneous potential (SP) and Electrical Profiling (EP).

2. Isotope techniques are applied by using natural and artificial isotope tracers (e.g. ^{14}C, ^{6}Li, ^{13}N, ^{15}O, etc.) to follow the movement of water. For this purpose, the isotope-ratio mass spectrometer (IRMS) can be efficiently used.

3. Remote sensing can be applied to detect any seepage failure from reservoirs. In particular, the Borehole Radar (BHR) is an effective imaging tool for the subsurface detection where it is uses single or cross-hole reflection radar tomography which enables recognizing any leakage paths since they are characterized by high electromagnetic attenuation.

Even though the regional seismicity has been analyzed for the region where the YTJRB is located, and dams' sites have been designed to withstand earthquake movements, the consolidation of dams must be considered, notably that the dams are aging (> 40 years) and the number of high-hazard dams is on the rise. Therefore, considerable amount of water is being lost by seepage failure in the YTJRB causing: dissolution of soluble rocks, leaching of grout curtains, and wash out in-filled joints, resulting erosion and piping.

Table 2 shows this study’s rough estimate of the probability of leakage (also viewed from dam rigidity point of view) for each dam, and this estimation was based on: lithologies, structural geology, seismic activity and life-span of these dams, regular maintenance of these dams, as well as some dams were destroyed during the war.

Table 2. Rough estimate of probability of leakage in dams in the YTJRB, and proposed YTJRB interventions.

Dam	Construction date	Leakage probability*	Proposed intervention**
Abeedeen	1989	H	PTM, PF
Adwan	1986	L	PTM, DP,
Al Asleha	1968	H	PTM, IR, SR
Al Ain	1965	H	PTM, IR,
Al Bouwayda	1967 (Jordan)	VH	PTM, IR, SR
Al Butmieh	1974	M	PTM, IR,
Al Ghaydha	1988	M	PTM, CES
Al Hujah	1982	H	PTM, IR,
Al Mafraq	1966	VH	PTM, IR, CES, SR
Al Mantara	2001	M	FER, PF
Al Mushanaf (South)	2002	L	CES, PF
Al Mushanaf (North)	1980	L	PTM, IR,
Al Mutaaiyah	1967	VH	PTM, IR,
Al Raha	2000	H-M	PF, CES
Al Raqqad	1991	M	FER, DP, PF
Al Rom	1977	H	PTM, IR,
Al Tiba	1989	H	PTM, CES
Al-Wehdah	2004	H	FER, CES, PF
Al Zolf	1985	M	PTM, FER, PF
Burayqah	1987	H	PTM, IR
Dar'a Al Sharqi	1970	VH	PTM, IR, DP
Ghadir Al Abyad	1972 (Jordan)	M	PTM, IR, SR
Ghadir Al Bustan	1987	M	PTM, FER, PF
Ghadir Al Suf	1968	M-H	PTM, IR,
Gharbi Tafs	1982	L-M	PTM, IR, DP
Herban	1980	M-H	PTM, IR, DP
Jowayleen	1988	M	PTM, IR
Kheital	1970	H-H	PTM, IR, SR
Kudnah	1994	H	FER, PF
Meitsar	1994	VH	DP, FER
Merom Golan	1968	VH	PTM, IR, SR
Qanawat	1991	H	CES
Rasas	1964	H-VH	PTM, IR,
Ruwayhaniyah	1982	H	PTM, IR,
Saham Al Golan	1995	VH	FER, PF
Sahwet Al Blata	1979	H	PTM, IR,
Sahwet Al Khodor	1968	M	PTM, FER,
Sama Al Sarhan	1966	VH	PTM, IR, SR
Shahba	1986	M	PTM,
Taseel	1982	M	PTM, IR,
Uthman	1998	VH	PF, CES

*VH= very high, H= high, M=moderate, L= low, **PTM = periodical testing and maintenance, PF= piping (& cracking) fill-up, DP= depollution (& waste removal), IR = integrated rehabilitation, SR = sedimentation removal, CES= compacting embankment sides, FER = flow energy reduction.

Moreover, Table 2 shows the proposed implements and approaches to address dams' rigidity in general and leakage reduction in particular. The proposition of these implements is based principally on the estimated leakage probability, positioning (e.g. geography, geology, etc.) and type of engineering properties and practices (e.g. capacity, dam types, etc.).

It is obvious from Table 2 that periodical testing and maintenance and the integrated rehabilitation are the most proposed implements to be applied in the YTJRB, while other recommended ones are also significant for specific dams.

2.3. Evapotranspiration loss

Evapotranspiration (ET), including direct evaporation from surface water bodies and soil as well as transpiration form plants, is a significant aspect of water loss, and it is one of the utmost acting components in the water cycle, notably it represents the largest outgoing water flux from the Earth’s surface. Particularly in the semi-arid climate that characterizes most of the YTJRB, and which results in long hot and dry summers. Thus, ET has the most essential deal in crop yield and water productivity, whereas crop ET is usually used in empirical crop coefficients to non-standard conditions.

Lately, ET rates have been increased under global warming; however, the temporal and spatial distribution of ET remains uncertain everywhere, notably in arid and semiarid zones where temperature and sunlight radiation are known with high rates. Hence, the applied projections to the annual ET showed strong ET increase in MENA Region for future periods (Terink et al., 2013).

The impact of ET (& evaporation) are well pronounced in Syria and Jordan, where the YTJRB is situated. According to Hamid et al., (2008), the irrigation schemes of the conveyance efficiency still does not exceed 60-70% in Syria due to evaporation and poor maintenance. While, the estimated long-term average of ET in Jordan is over 90% of the total precipitation (Hamdi et al., 2008). Whereas the estimated ET rates in Jordan, as based on measurements of soil moisture change, ranges between 6 and 10 mm per day (Suleiman et al., 2008).

For the YTJRB, ET (& evaporation) were commonly mentioned in many studies. For example, Siebert et al. (2014) reported that the isotopes ($\delta^{18}O$ and $\delta^{2}H$) deviation from the Hermon Mountain indicates evaporation of the precipitated water before recharging. While, the applied calculations, by numerous studies, estimated that ET for the YTJRB was 55% (of the total volume of precipitated water), 49% and 64% for the years 1986, 2009 and 2015; respectively, where it averages about 55% which is equivalent to 1268 million m^3/year in the entire YTJRB (Zeitoun et al., 2019).

There are several approaches to calculate and estimate evapotranspiration where ground devices and remote sensing tools are always applied. The majority of measuring ET implies the use of "Lysimeters" where various physical parameters and the soil water balance are calculated. However, these devices are not always available or cannot cover large areas;

therefore, remotely sensed products are utilized. The most commonly used methods and tool to measure ET are listed in Annex-1.

Crop land area has been increased from 3631 km^2 to 3719 km^2 between 2009 and 2020; respectively (Zeitoun et al., 2019). Thus, about 99% of absorbed water by plants are lost in transpiration; therefore, many methods used to reduce ET rate, but all these methods are applied in cultivated lands, specifically in crop fields, while naturally cultivated areas and forests remain untreated. These methods can be applied by framers and inhabitants who suffer from water shortage or irrigation.

The following are the most effective methods done to reduce ET rates directly or through evaporation reduction:

1. Mulching: Evaporation can be reduced by covering the surface of soil by grass clippings, plastics, organic residues, straw, leaf debris, stones, etc. However, the mulch types have no discernible effect, but its thickness is a major factor. For example, each 10 cm mulching can reduce can reduce surface evaporation to 50% compared to the water losses from bare soil (McMillen, 2013).

2. Shelterbelts and windbreaks: These are used mainly in arid and semiarid regions where wind is a major factor inducing the loss in soil moisture by evaporation.

3. Tillage: The thin soil layer formed by tillage influences aeration, thermal and mechanical processes of soil impedance to root penetration. This layer restricts the upward movement of water to soil surface by reducing the diffusivity gradient (McMillen, 2013).

4. Transpiration control: These are materials used to reduce water loss from plants, and they can be as: a) stomatal closing by phenyl mercuric acetate for example, or growth retardant, such as Cycocel, b) film forming by plastic or waxy materials that put on leaf surface and c) reflective which is white materials used to be as a coating on leaves and increases it reflectance (albedo).

5. Deficit and scheduled irrigation: This almost represent an irrigation system where irrigation depth, timing, etc. are considered. However, this system requires a better understanding of crop response (Oweis et al., 2011).

6. Dimensions control: This is usually applied to lakes and reservoirs where the surface area is often minimalized wand depth is increased; therefore, same water volume can be sorted by with minimal evaporation.

7. Evaporation barriers: It is commonly used approach where water surfaces in lakes and reservoirs are covered by materials and it proved to reduce evaporation to about 50%. Examples of these materials are: Ag Floats (recycled objects of polystyrene), Aqua-cap and Evap-cap (rounded and sheet floating of polypropylene) (Fig. 2), Aquitaine (silicone based liquid that is spread on top of bodies of water), PV panels (floating solar power plant), Water Saver (powder that is spread over the surface of the water) floating plants, etc. (Clarke, 2019).

Figure 2. Evap-cap, a barrier to reduce evaporation rate.

For the YTJRB, measures to address the problem of evapotranspiration (including evaporation) can be adopted. This is expected to save considerable portion of water estimated at least 50% (evaporation for example) according to different mentioned references (Hamdi et al., 2008; Suleiman et al., 2008 and Zeitoun et al., 2019). Since, the annual average estimated evapotranspiration volume is 1268 million m^3 (Ionides, 1939; Burdon et al., 1954; Energoprojekt, 1964; MWI and GTZ 2004; MWI, Hoff, 2011; 2015; Youmans 2016; Tawil, 2017); therefore, if proper evapotranspiration (& evaporation) measures are applied including barriers and agricultural practices, etc.; the anticipated conserved volume of water will be:
1268 x 50/100 = 634 million m^3/year of the total evapotranspirated water from within the YTJRB

Table 3 shows the applicable methods to reduce evapotranspiration (& evaporation) in the YTJRB. The selection of these methods considered mainly the ease of use and cost effectiveness, and all these methods are emphasized to be applied in dry seasons.

Table 3. Proposed measures to reduce ET in the YTJRB.

Geography of application	**Proposed measure**	**Efficiency***
Agricultural lands (*with different areal extent*)	Mulching (using organic residues, straw, leaf debris, stones)	H
	Shelterbelts and windbreaks on lands' surroundings	L-M
	Tillage, notably in soils with high clayey content	M
	Deficit and scheduled irrigation (considering, depth, timing, irrigated water volume, irrigation system)	M
Crop lands has been increased by about 2.4 % between 2009 and 20202 (Zeitoun et al., 2019)		
Dam reservoirs	Dimensions control, notably surface area versus depth	M-H
	Evaporation barriers (Aqua-cap and Evap-cap and floating plants)	H

*H=high, M=moderate, L=low

3. Water and wastewater Reclamation and Reuse

Water reclamation and reuse assist different communities, notably large urban clusters (i.e. urban centers) to significantly manage the supply/demand of locally available water resources in order to secure optimal water quality and quantity.

Reclaimed water, as a nonconventional water resources, can be adopted either for direct reuse to meet non-potable water needs such as for irrigation and industrial purposes, or indirectly reused to feed surface or groundwater resources. Yet, there is still a debate about the use of reclaimed water, especially the degree to which people are willing to use this water and willingness to purchase produce irrigated with recycled water.

It must be made clear the difference between water treatment, reclamation and purification. The process of water treatment is the converting water from the source into water that can be used for different purposes such as domestic and agriculture. Water and wastewater reclamation is the treatment of used water (including sewage) and reclaimed it for reuse. Beside, water purification is the removal of impurities and diseases-prone bacteria, and thus making water safe even for drinking. The processes of wastewater reclamation different according to geography, technology used and degree of pollution in the water that needs to be treated; however, the basic principles remain the same.

As a strategic tool for water management, water reclamation is adopted in regions with scarce water resources and unassured supply sustainability, such as in YTJRB where water exploitation and consumption is still uncontrolled and unwisely used, plus of declining groundwater levels in aquifers, water discharge from spring, whereas the available water per capita has been sharply regressed and deterioration of water quality became dominant and reached the produced crops.

Down-scaling to the region surrounding the YTJRB; the adoption of reclaimed water proved its reliability and it can at least partially fill the problems created by the imbalanced supply/demand. In this regard, Israel recycles and reuses approximately 60% of wastewater, which represents between 80 and 90% of water used in the agriculture sector. While, Jordan uses about 51 million m^3 (i.e. roughly 10%) per year of recycled wastewater for irrigation, and still planning to reach 60% reuse by 2025 (MWI, 2015). Whereas, between 273 and 550 million m^3 (40% of wastewater) is treated in Syria, and all of this amount is reused for irrigation (FAO, 2008), and thus this reclaimed water irrigates about 31850 ha (Anderson, 2003; MWI, 2015; IDA, 2020).

For water reclamation, it is usually adopted after diagnosing the water budget and determining the volumetric elements of the available water resources as well as the supply/demand balance. For the YTJRB, in spite that the storage exceeds the volume of existing water resources (i.e. 248 million m^3); however, there is still a deficit in the volume of water consumption in different sectors by about 71 million m^3.

The demand for water in different water sectors in the YTJRB is till exacerbating while drought conditions are widening in space and time, and population growth is fast. Therefore, reuse of reclaimed water can be an optimal solution in the YTJRB.

For the YTJRB, there are several methods and technologies that can be adopted to benefit from the nonconventional water resources and mainly the reclamation of water at different scale. Therefore, the proposed technologies for water reclamation in the YTJRB can be either on community-scale (large-scale), enterprise (moderate-scale) and household-scale (small-scale) where all of them must be integrated with each other. They can be summarized as follows:

3.1. Community-scale water reclamation

On the community-scale, water reclamation is typically carried out in a large water treatment plants (WTPs) which uses many processes inapplicable to the home scale or by the individuals. These plants are used either to clean water from their sources (e.g. groundwater, springs, etc.), reclamation of wastewater (black water) which was used in order to reuse it again, or in treating swage water for further usage. However, WTPs are usually built within an integrated scheme that connected to the end-use systems (Fig. 3).

Wastewater reclamation passes by number of technological processes as follows:

- Coagulation (flocculation) is the adding of liquid aluminum sulfate or alum and/or polymer to untreated water; thus dirt particles in the water are coagulated, and then forming larger particles (i.e. flocs) which can be removed by filtration or settling (SWR, 2020).
- Sedimentation in which water and flocs are put into sedimentation basins; and therefore, heavy floc particles settle to the bottom as sludge.
- Filtration to remove microorganisms by size exclusion. It is done using filters, which can be of gravel and sand or sometimes crushed anthracite.
- Disinfection of water (using chlorine or iodine for example) is the inactivation and destruction of microorganisms in the system to a safe level, by eliminate disease-causing bacteria, parasites and viruses.

As another aspect of water reclamation is from sewage water by applying: the primary, secondary and tertiary treatments. Thus, primary treatment is to remove coarse solids and the associated organic and inorganic materials; secondary to remove smaller particles dissolved or suspended, while, tertiary treatment is an advanced secondary treatment where more than 99% of impurities from sewage can be removed.

3.2. Industrial-scale water reclamation

Water treatment in Small and Medium Enterprises (SMEs) is rarely tackled while large volume of wastewater results from these firms. Thus, there are several SMEs which produce wastewater in the YTJRB, namely different manufacturing companies, construction materials production, agronomical establishments, farms, fuel station, and quarries.

SMEs followed conventional methods to reclaim wastewater whereas technology is almost present in these methods as a supportive tool controlled by the availability of financial resources. Thus, the commonly applied methods for wastewater reclamation in SMEs are:

- Open reservoirs (OR) to aerate and expose wastewater to sun radiation. This is applied to remove microbes in MSEs where water will be touched by people. In some instances, this treated water or part of it is redirected into groundwater through shallow boreholes (Fig. 3).

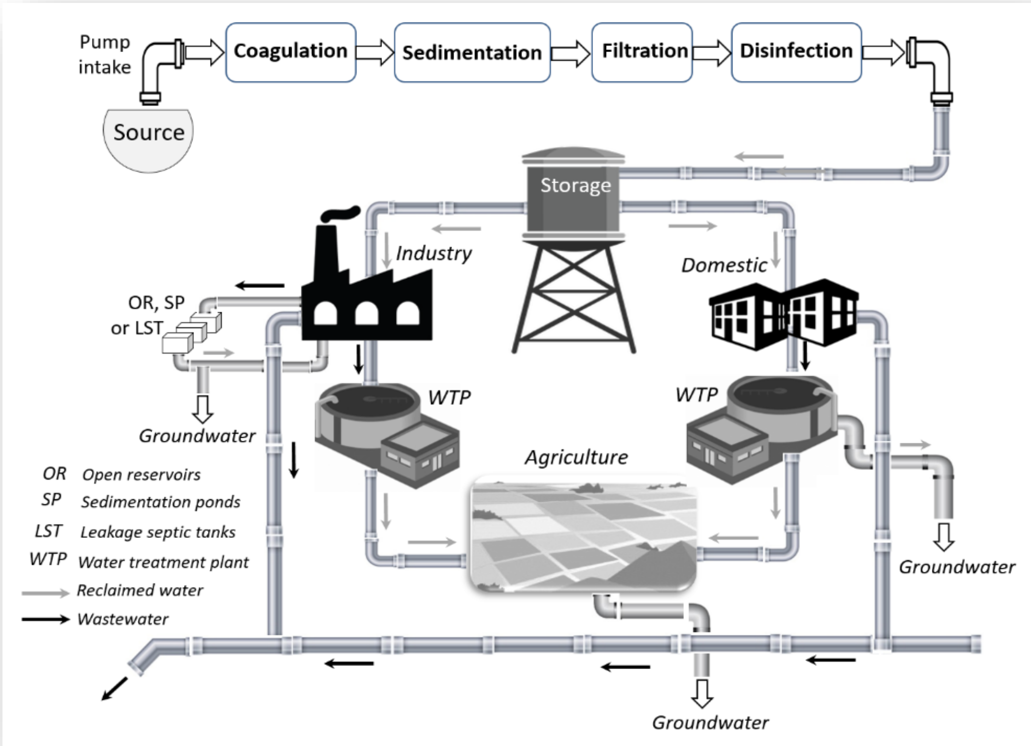

Figure 3. Virtual scheme for water reclamation and the related conveys systems.

- Sedimentation ponds (SP) which are open ground ponds at gradual levels, and these ponds are connected with each other by filters or screens. This common in industrial firms, such as in construction materials production where the largest portion of wastewater is reclaimed and then reused (Fig. 3).

- Filters and Reserve osmosis for the treatment of wastewater, and this needs high to moderate capacity filters (> 20 m^3 per day) that can be fixed in MSEs.

- There are several aspects of leakage septic tanks (LST) which are underground container made of concrete, fiberglass or plastic. Thus, sewage or domestic wastewater is treated by settling and anaerobic reduction of solids and organics. Hence, reclaimed water constitutes integral part in industrial and manufacturing activities (Fig. 3).

- Mixing of water with good quality to reduce salinity, and this is often used in agricultural purposes where soil salinity is high. Then diluted water may have injected into groundwater reservoirs (Fig. 3).

3.3. Household-scale water reclamation

This is point-of-use (POU) water treatment which is commonly utilized using technologies which are typically user-friendly, low cost, low maintenance, and grid-independent. The common available technologies of POU are adopted not to reclaim water, but also in the purification of drinking water. Hence, water treatment on household-scale includes mainly filters, water boiling, ultraviolet light, Reverse Osmosis devises and adding disinfectants (e.g. chlorine, iodine, etc.).

Wastewater from different domestic uses is either conveyed into WTPs to be reused in other purposes (i.e. mainly in agriculture or to a limit in domestic uses) or it is connected directly to the sewage pipeline system (Fig. 3).

For the YTJRB, water reclamation and reuse can be considered as one the most significant tool for water management. Based on different estimates from several sources (Anderson, 2003; MWI, 2015; FAO, 2008, IDA, 2020), this unconventional water is now representing about 16% (82 million m^3) of water demand in the YTJRB.

Large amounts of water in the YTJRB is polluted, notably in the surface water resources including the Yarmouk River tributaries, and they are possibly with extreme hazards. The pollution sources and aspects can be well noticed, such as the chaotic disposal of solid waste and landfills, abundance sewage outfalls, scattered swamps of black water, salinity, leachate, etc. While, contamination was verified in this water where remarkable increase was reported in the microbiology, (e.g. E. Coli), and chemistry (Chloride, Bicarbonates, Magnesium, total Nitrogen) as well as increased heavy metals content of anthropogenic sources (e.g. lead, cadmium, nickel, zinc, etc. (Abu-Rukah and Ghrefat 2001).

In the YTJRB, there is no inventory for WTPs, while most of the existing ones are not fully functional and managed to treat water to a level acceptable for irrigation, but their capacity is limited. The main treatment plants are located in Al Mafraq, Ramtha, and Banias.

3.4. Type and rough estimate of benefits of water and wastewater reuse in YRTBP

Based on the mentioned methods and technologies used for water reclamation and reuse; therefore, the most feasible of these methods which can be adopted in the YTJRB are summarized in Figure 4. It is obvious from the figure that the dimensional aspects of the proposed methods for the YTJRB are on different scales, and there must be decisions taken whether on the individual level and the governmental level.

Figure 4 shows the benefit of water and wastewater reuse in the YTJRB based on the previous mentioned estimates which were adopted from different sources. The estimates put in bold (e.g. 146 million m^3, etc.) show the volumes of water that can be used if the illustrated approaches are properly applied.

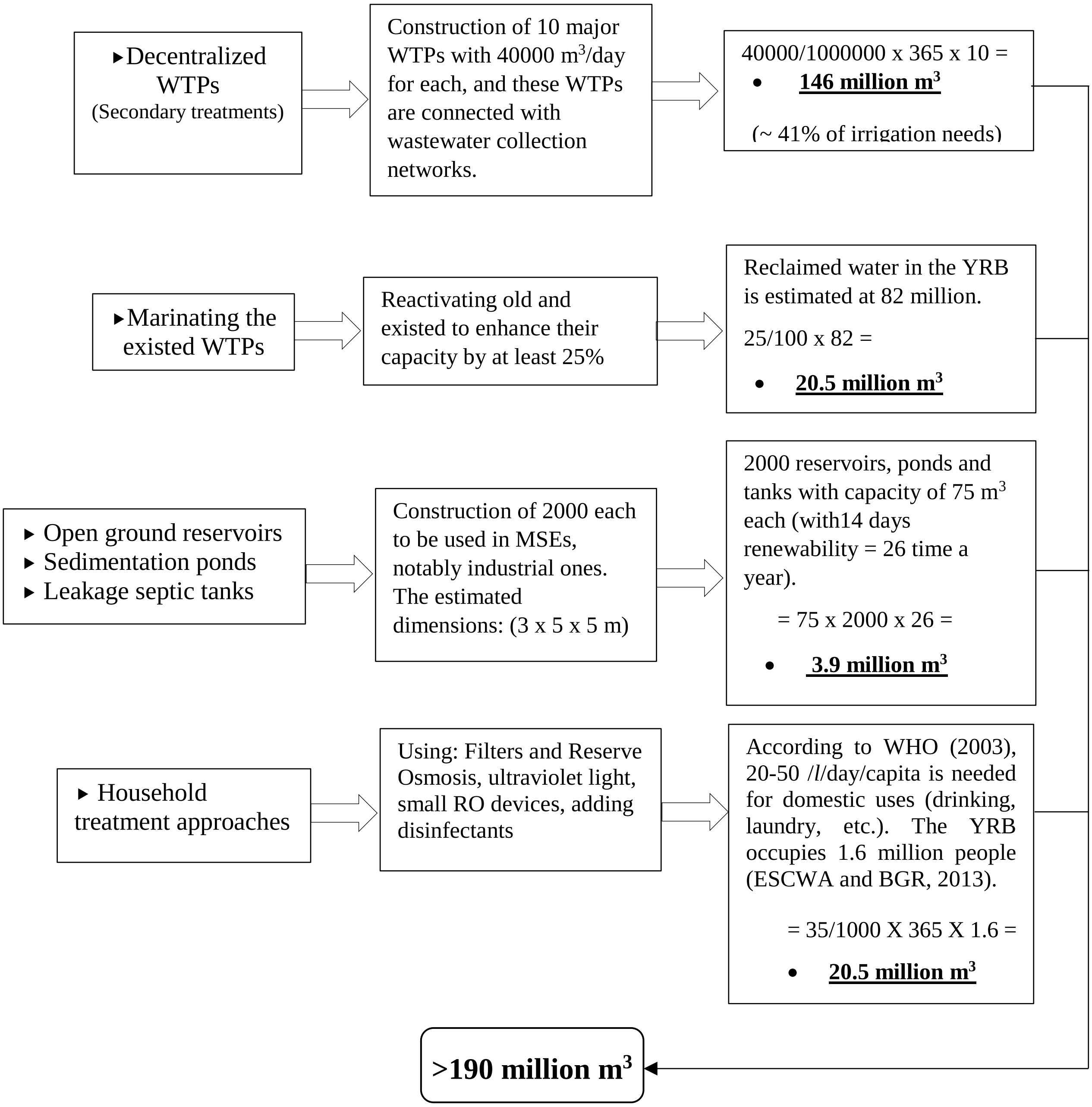

Figure 4. Proposed methods and rough estimate of benefits of water and wastewater reuse in YRTBP.

There are constraints that might hindering the achievement of these methods. They can be summarized as follows:

1. Financial resources are always a problem and they which should be primarily secured. Thus, establishing WTPs on the community-scale can be elaborated within the context of national plans, notably that each of the proposed WTPs costs approximately 2 million \$ if their capacity reach 40000 m^3/day.

Therefore, the proposed 10 WTPs in the YTJRB cost about 20 million $, including supply systems, notably that there are several scattered villages in the YTJRB located far away from the large urban clusters.

2. Operation and management of WTPs are always hindered by the cross-responsibilities between different sectors (e.g. different ministries and authorities), and thus workability often slow and inefficient, notably when technical problems exist and in maintenance.

3. Unavailable money with low-income locals to install filters and other treatment devices at home, especially that no incentives are introduced in this regard.

4. Public acceptance to use reclaimed water is also a problem where many communities do not accept using even crop irrigated by treated sewage water.

4. Environmental Flow Requirements of the YTJRB

Water in rivers (& major tributaries) may be exposed to changes and fluctuations in its volume and quality, and this influences the hydrological regime and the sustainability of stream flow, as well as the fertility of the related ecological systems. Therefore, the quantity, timing, and quality of water flows, required to sustain freshwater and estuarine ecosystems, is described as environmental flow (EF), which is a reflectance for river vitality and its ecological components.

The conservation of water sources (e.g. springs, groundwater, etc.) which feed the river significantly control the EF. Other than these sources, water can be conveyed from dams and weirs to sustain downstream river health for all living and nonliving components. Therefore, the aim of EF management is to mimic natural flow regimes, providing cues for key life cycle events.

The decrease in stream flow in rivers is usually viewed as a major threat in the hydrologic cycle where many aspects of water use/or loss are accounted as influencers on stream flow regression. However, these influencers are different between regions, but climate and human are always considered the major aspects of these influencers. Yet, the enhancement of stream flow remains a fundamental factor to conserve the EF, and it is the clue to the optimal water resources management in any regions where rivers exist.

The management of EF requires primarily identifying the major elements of stream flow regime, and this includes water feeding sources and the influencers (acting factors) where the latter can be natural or man-made. They can be simply described in Figure 5.

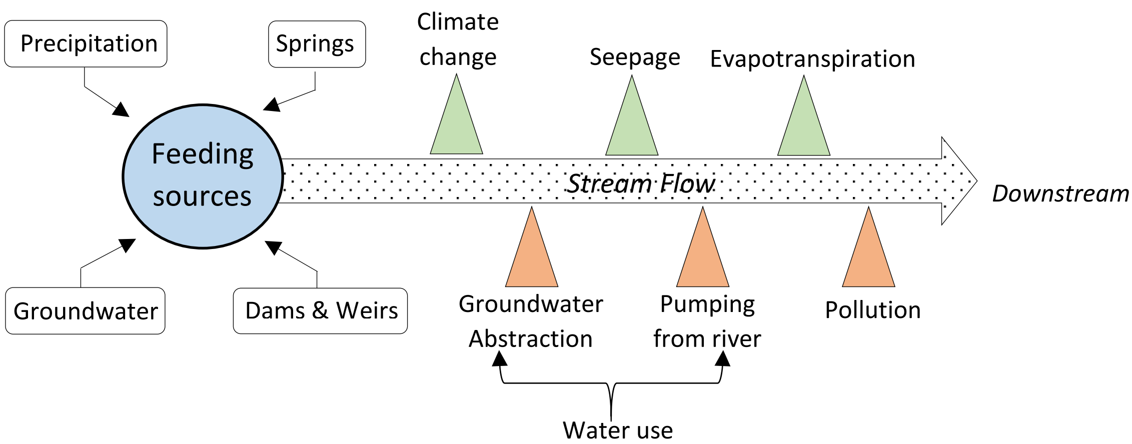

Figure 5. Major elements of stream flow regime (i.e. feeding sources and influencer).

There are many methods required to control the elements of stream flow, and this is usually implemented under two management approaches including the sources and influencers.

Added to the components of EF, the minimal investment or unwise use of stream water is also challenging and described as a loss in stream flow.

The Yarmouk River has a total length about 144 km (primary tributary) and approximately 980 km length of the major 6 tributaries (seasonal streams). If the static water volume is calculated, it is therefore equivalent to about 17 km^2 surface area (i.e. total length x stream width), which is exposed to several natural processes and human activities that are acting on its flow regime.

Measurements show that between 1970s, 1980 and 2015, the average annual stream flow of the Yarmouk River has been decreased from 495 then 288 to 88 million m^3 (Hoff et al., 2011; Zeitoun et al., 2019). Even though the hydrology of stream flow has been delineated from the available time series data; nevertheless, the aspects of impact on the EF has not been determined for the Yarmouk River.

4.1. Analysis of EF in the YTJRB

"EF requirements" is a term used to describe the assessment (or method) applied for estimating and stimulating the quantity of water required to sustain the regular flow and then the river health. EF assessment generates descriptions of probable future stream flow regimes where each will be linked to an objective relating to the condition of the riverine ecosystem and it also used for the rehabilitation of this system. For example, a precipitation rate exceeding 900 mm per year is required to assure adequate volume of water in a medium-scale river all year long and to enable supplying water for 1/2 of population situated in the riparian zone of this rivers.

There are many methods used for assessing EF requirements. The most know methods are: Tennant method, Texan method, Annual minima, Flow duration curve, Wetted perimeter and other methods. According to DEID (2003), these methods are mainly based on:

- Simple hydrological indices
- Hydrological simulations
- Consensus and discussion based approaches
- Historical data analysis
- Building block methodology.

Therefore, two main concepts are adopted while making assessment for the requirements of optimal EF; these can be either by studying the hydrological system of the river, or by investigating the ecosystem stability and species richness.

For this study, the EF will be induced from the analysis of the hydrological system for the YTJRB, because hydrologic data is the most available, whereas no data available on the ecosystem components (i.e. species surveying, etc.). Therefore, *Tennant Method* can be considered since it is based on volumetric analysis of stream flow. In this method, the naturalized flow regime is the hydrological regime of the watercourse with the man-made influences (e.g. abstractions, etc.) removed from the stream flow. Therefore, volumetric measurements of stream flow are required to calculate the naturalized flow series (DEID, 2003).

In this study, the general concept of the *Tennant Method* will be integrated with comparative and simulating figures to manipulate the parameters of *inflows* (feeding sources) and *outflows* (influencers) with respect to the optimal stream flow (baseline) in the YTJRB, as sketched in Figure 6.

Figure 6 represents an Enhanced *Tennant Method* to assess impact of each parameter on the baseline volume of stream flow which is a function of an effective EF in the YTJRB; and this enables simulating the volume of each parameter with the baseline stream flow. These parameters are illustrated in Figure 6.

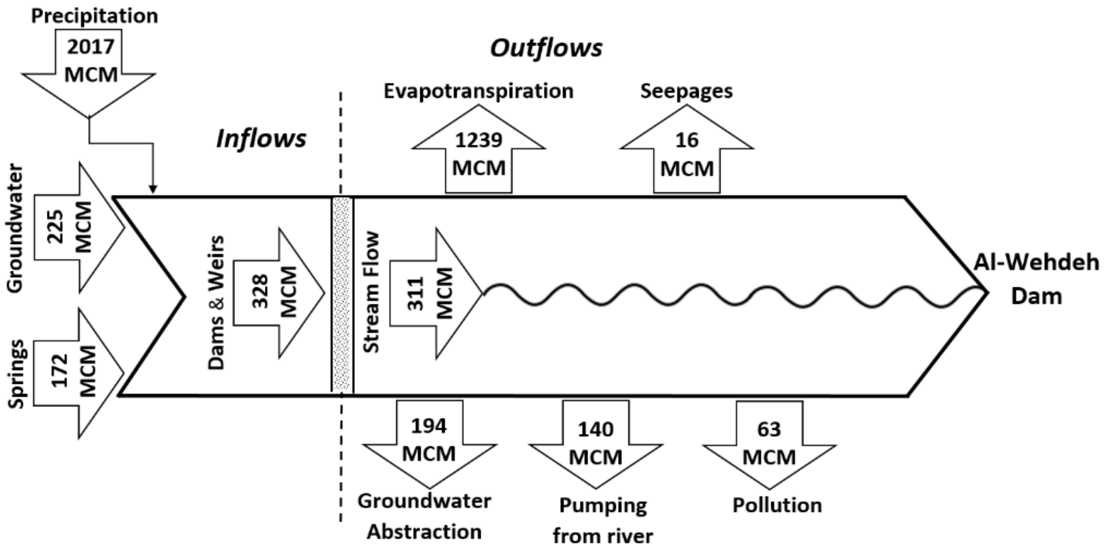

Figure 6. Scheme for the major inflow and outflow parameters versus stream flow in the YTJRB upstream of the Al Wehdeh Dam (Ionides, 1939; Burdon et al., 1954; Energoprojekt, 1964; UN-ESCWA 1993; MWI and GTZ 2004; MWI, Hoff, 2011; 2015; JVA 2016; Youmans 2016; Tawil, 2017; Zeitoun et al., 2019).

For the YTJRB, the water volume for entire hydrologic system (mainstream of the Yarmouk River and the 6 major tributaries) will be calculated. Hence, data on inflows and outflows for these parameters were prepared and this was based on their availability from several sources (Table 4). In this respect, the impact each parameter is investigated separately to assess its impact on the stream flow of the Yarmouk River.

4.2. Stream flow

Measurements on stream flow along the Yarmouk River are almost contradictor, notably if the temporal and spatial dimensions are considered. Thus, many measures were taken at specific tributaries or at different times. This makes it necessary to have creditable measurements by installing more flow-meters along all tributaries of the Yarmouk River.

Figure 7 shows the illustration of the steam flow of the Yarmouk River since 1970s. The used data were from several sources. The figure reveals that there are abrupt fluctuations in stream flow where some years reported about 500 million m^3 beside almost dry years.

Reasons behind these fluctuations are several including mainly the geo-politics, population growth and unwise use of river water as well as the changing climatic conditions.
For the EF assessment, stream flow of the Yarmouk River was being primarily determined, and then the inflows and outflow on the river system were calculated to assume the impact of each parameter on the stream flow and then the sustainability of river water and the related ecosystems.

Table 4. Data on parameters required to elaborate the *Enhanced Tennant Method* for the EF requirement in the YTJRB.

Geographic dimensions	- The catchment of Yarmouk River including 5 major tributaries excluding Raqqad. - End point (outlet): Al-Wehdah Dam at: 32° 44' 03" N and 35° 52' 18" E	
Parameter	**Description**	**Estimated Volume** (Million m^3)
Stream flow	- Maximum average reported stream flow (in 1992).	495
	- Maximum average annual stream flow (after 2015).	80
	- Baseline stream flow.	311
	Inflow	
Precipitation	- Average volume of precipitated water in 1985s.	2275
	- Average (maximum) volume of precipitated water in 2009	2771
	- Average (minimum) volume of precipitated water after 2015.	2015
Groundwater	- Average volume of groundwater reserve in 1985s.	254
	- Average annual volume of groundwater reserve after 2015.	225
Springs	- Average (maximum) volume of water inflow from springs 1954.	254
	- Average (minimum) volume of water inflow from springs in 2013	174
Dams and weirs	- Water capacity that can be retained in dams of the YTJRB in 1985s.	328
	- Average (minimum) water volume in dams and weirs after 2015.	50
	Outflow	
Evapotranspiration	- Average volume of evapotranspirated water in 1985s.	1259
	- Average volume of evapotranspirated water in 2009.	1305
	- Average volume of evapotranspirated water after 2015.	1239
Seepage from dams	- Estimated volume of seeped water from dams (5%).	7
Water abstraction	- Average volume of water abstracted directly from the primary watercourse of the Yarmouk River.	140
	- Average volume of pumped from groundwater.	192
Pollution	- Volumetric estimations of pollution-induced water loss.	63

Sources : (Ionides, 1939 ; Burdon et al., 1954 ; Energoprojekt, 1964 ; UN-ESCWA 1993 ; MWI and GTZ 2004 ; MWI, Hoff, 2011 ; 2015 ; JVA 2016 ; Youmans 2016 ; Tawil, 2017 ; Zeitoun et al., 2019).

To calculate the optimal stream flow (or *stream baseline index SBI*), the extreme (highest and lowest) measurements for the available time series were considered. Thus, the 75% of the difference between the maximum and minimum stream flow is accounted, because it (i.e. 75%) represents an optimal stream flow in the YTJRB.

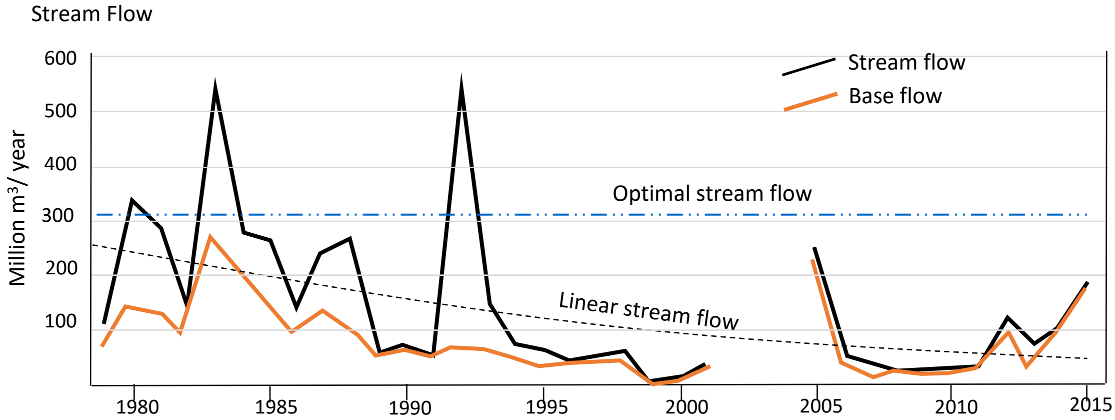

Figure 7. Stream flow and its trending aspects for the Yarmouk River (Modified after Zeitoun et al., 2019).

According to several sources illustrated in Table 4 and Figure 7, the two extreme measurements of stream flow of the Yarmouk River are 495 and 80 million m^3 for the time periods of 1970 and 2015; respectively. Therefore, the *SBI* can be calculated as follows:

$$= \frac{495 - 80}{2} x \frac{75}{100} = 311 \, million \, m^3$$

The resulted *SBI* illustration will be used and an indicative factor where the hydrologic parameters of the inflows and outflows will be compared and simulated with the optimal stream flow. In other words, it expresses how much the volume of each parameter (separately) should be in order to sustain the optimal stream flow which is needed for the required EF in the hydrologic system of the YTJRB.

4.3. Feeding sources (*Inflows*)

Numerous water sources feed the Yarmouk River and its tributaries. Except some of these sources, there is no exact estimations on how much each of these sources is contributing to the stream flow of the Yarmouk River. Thus, all aspect of surface water and groundwater enters the system of the YTJRB are accounted as feeding sources of water (inflows).

1. Precipitation:

The stream flow in the Yarmouk River is highly sensitive to changes in precipitation (Zeitoun et al., 2019), notably that the river spans in diverse geographic aspects including mountainous, plateaus and plains. These aspects govern the volume of precipitated water on the entire YTJRB. Hence, precipitation in the YTJRB implies rainfall and solid precipitation (i.e. snow cover).

Rainfall, as a major inflow in the river, is accounted by using the most available datasets which were reported since 1985s, thus the average annual rainfall rate is about 319 mm and the average total annual volume is approximately 2288 million m^3 (Mourad and Berndtsson, 2011; Obeidat et al., 2012; Zeitoun et al., 2019).

Snow melt affects the flow of the Yarmouk mainstream (Al-Rubeai 2004). However, no estimations have been done yet, but, measurements in the surrounding regions (i.e. Lebanese mountains) were obtained by Shaban et al., (2013, 2014). It was considered that snow cover has considerable accumulations on altitudes above 900 m, and this comprises about 655 km^2 in the YTJRB. Thus, the average snow depth (S_d) on above 900 m was estimated at 0.32 m and snow-water equivalent was (SWE) was 56%. Therefore, the water volume derived from snow (Ws) in the YTJRB will be:

$$Ws = A \times S_d \times SWE = (655 \times 10^6) \times 0.32 \times 56/100$$
$$= 117 \times 10^6 \ m^3$$

All major tributaries are feed from snow in the YTJRB where Raqqad and Allan and Hareer/Arram are fed from snow of Jabal Al-Shaykh; Thahab and Zeidi feed from Jabal Al-Arab/Ad-Druzz and Shaallala tributary feed from Ajloun Heights in Jordan. Therefore, the maximum and minimum measurements of precipitated water were: 2771 (reported in 2009) and 2015 (reported in 2015). These two values were illustrated in the *SBI* and compared with the optimal stream flow as shown in Figure 8.

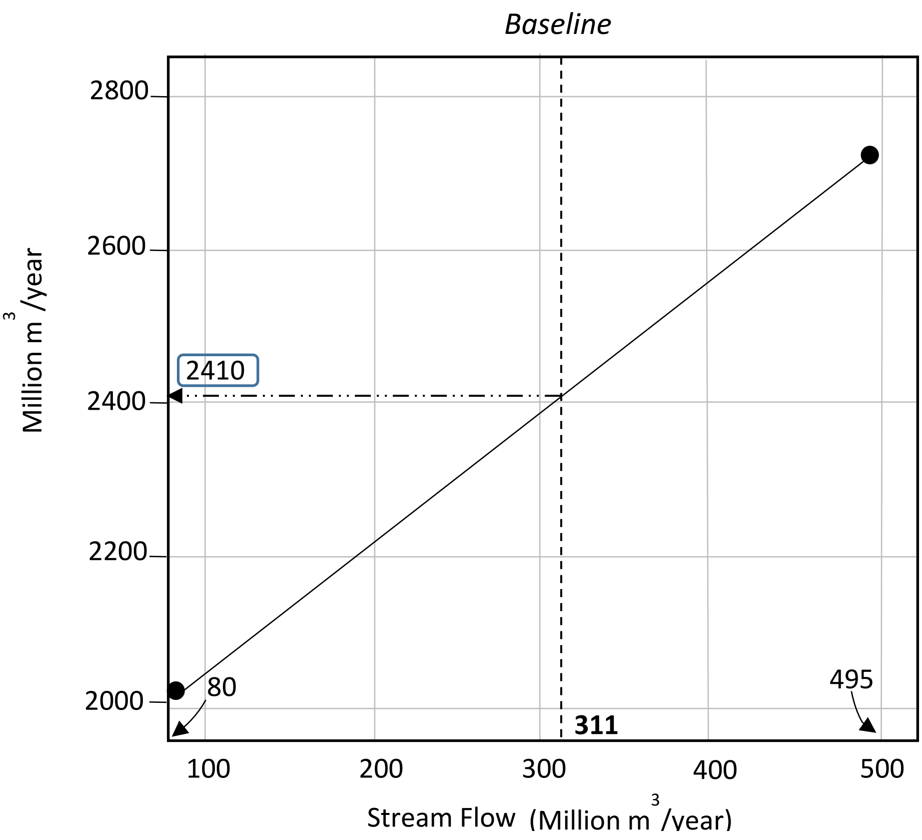

Figure 8. SBI illustration to calculate the required precipitation volume to sustain an optimal stream flow (baseline) in the YTJRB

Therefore, it was resulted that the optimal precipitation rate should be 2410 million m^3 a year in order to sustain optimal stream flow and then effective EF in the YTJRB.

2. Groundwater:

The saturated thickness of the basalt does not exceed 100 m in the fringes and then it ranges between 170 m and 300 m in Jabal Al-Arab. The groundwater exists at shallow to intermediate depths above the water table of the main Basalt Aquifer in the foot slopes of Jabal Al-Arab where groundwater level ranges between 900 m and1300 m; and it exists at about 300 m in Hauran Plain (UN-ESCWA/BGR, 2013).

As an invisible aspect of water, groundwater has been added as inflows to the system of the YTJRB. Therefore, the same concept applied in precipitation was adopted for groundwater. The maximum and minimum reported volumes of groundwater were 254 and 225 million m^3 for 1985s and 2015; respectively. Hence, the illustration of these two values in the *SBI* illustration resulted that about 239 million m^3 will be the needed volume of groundwater for the optimal stream flow, and the related EF in the YTJRB (Fig. 9).

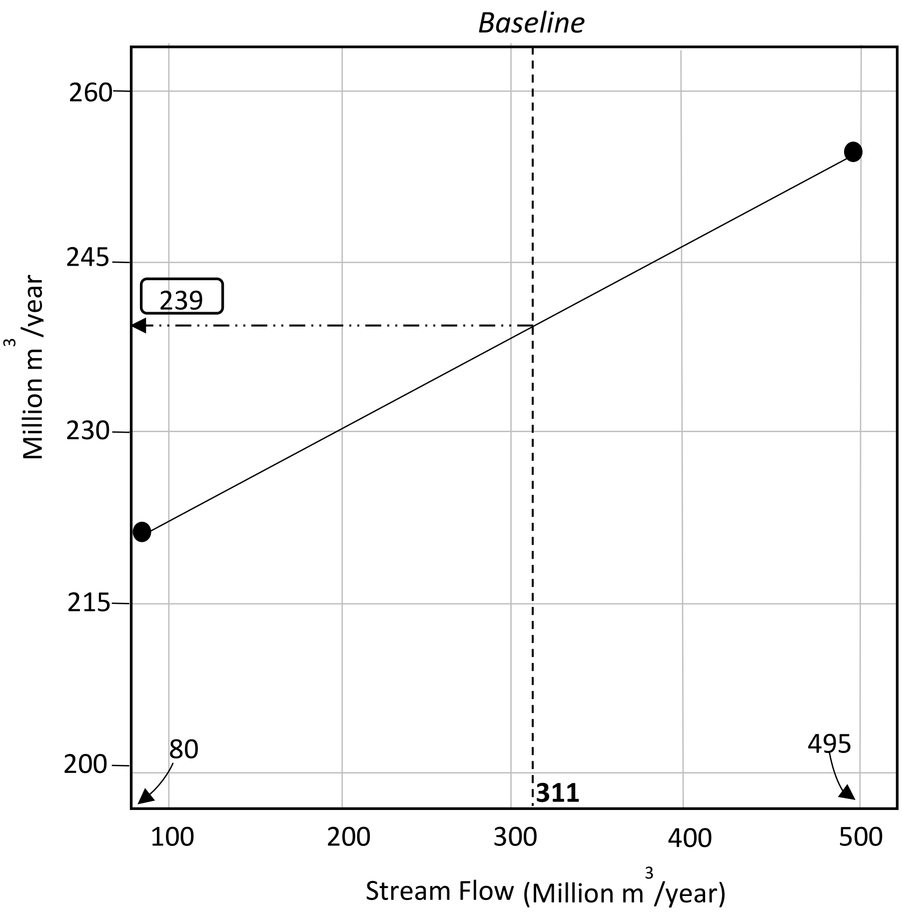

Figure 9. SBI illustration to calculate the required groundwater volume to sustain an optimal stream flow (baseline) in the YTJRB.

3. Springs:

In the YTJRB, a total number of 172 springs were identified which have a total average annual discharging of about 242 million m^3 (Burdon et al., 1954). The largest volume of water from these springs discharges from the basalt aquifer with a total discharge of about 174 million m^3 a year. There are also 5 geothermal springs (e.g. Ein Himma; 42°C) issuing from basalt rocks. No detailed investigations have been done on springs in the YTJRB, but the decline in their discharge is well pronounced.

Springs constitute a hydrologic linkage between groundwater and surface water where they, in both cases, add considerable volume of water to the stream flow. Thus, the maximum and minimum water inflows from springs were 254 and 174 for 1954 and 2013; respectively. Then, putting these volumes on the *SBI* illustration; therefore, approximately 217 million m^3 is required from spring's inflows to sustain the optimal stream flow with the related EF in the YTJRB (Fig. 10).

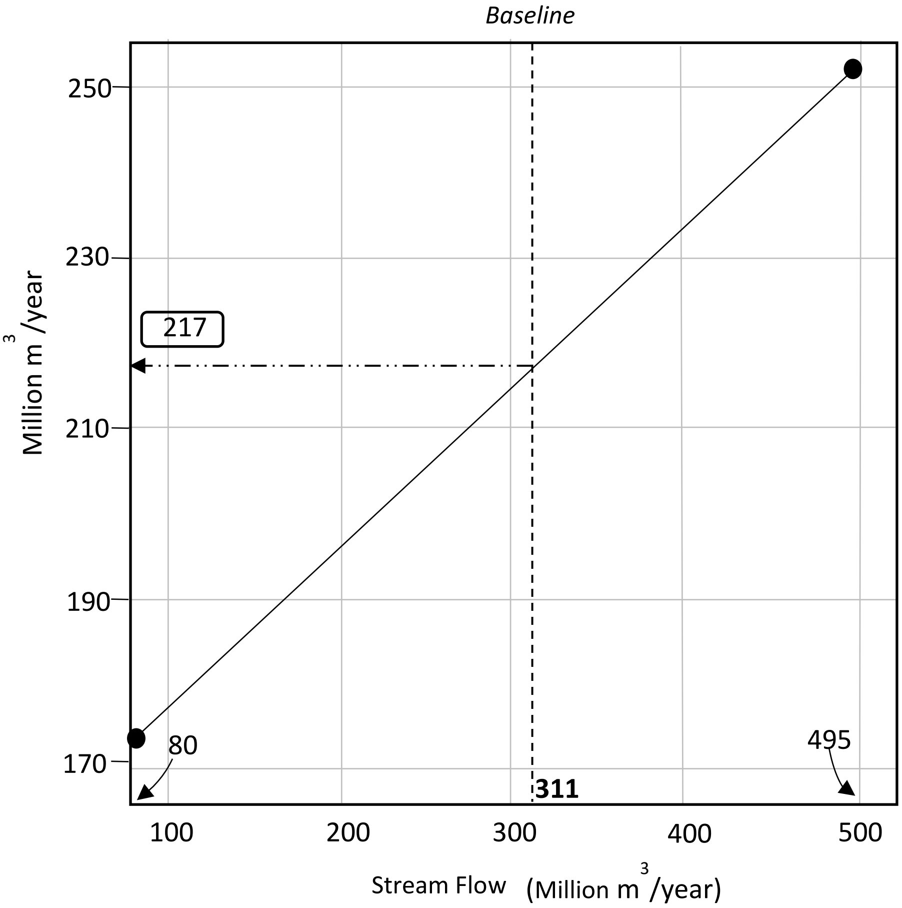

Figure 10. SBI illustration to calculate the required water volume from springs to sustain an optimal stream flow (baseline) in the YTJRB.

4. Dams and weirs:

Water harvesting, in reservoirs behind dams, is induced by the integrated cycle of water sources (i.e. precipitation, springs and groundwater), plus the artificial regulatory for water storage/convey behind and in front of these dams. It is; therefore, a principal component in stream flow and the resulted EF viability.

The operational 40 dams and weirs within the YTJRB comprise significant aspect of water management, and without these dams an estimated water volume of about 328 million m^3 would otherwise flow downstream to Adassiyeh Weir, whereas, 21 of these dams store about 92% of the total dams' storage. However, some dams reached their full capacity only twice over 20 years, while their actual retention in other years ranged from 20 to 40% of their capacity (Zeitoun et al., 2019). Thus, the general trend is almost below the actual retention capacity, with some exceptional years, and it shows that dams in Syria were never filled to their full theoretical capacity.

The actual retention of dams reached to reach a maximum of 78% (>140 million m^3) in 2012 before they declined. This was attributed to the changed agricultural practices due to the Syrian crisis, lack of maintenance in the dams and electricity cuts (Avisse, et al., 2017).

The maximum storage capacity of dams is about 328 million m^3, while the actual retained volume of water is about 50 million m^3 after 2015. Using the *SBI* illustration, therefore, the estimated required inflow from these dams will be about 193 million m^3 in order to regulate the stream flow to its optimal level which can sustain a vital EF in the YTJRB (Fig. 11).

4.4.Influences (*Outflows*)

Other than the feeding sources of water to replenish stream flow and sustain its continuity, there are also the acting forces (i.e. influencers) on this flow which may be act either directly on these sources or on the stream water itself. This implies both the influences on volume and on quality of stream water which were embedded within the discussion of the feeding sources in the previous section.

1. Evapotranspiration:

The high temperature that characterizes the YTJRB results high evapotranspiration rate where evaporation constitutes the substantial part of this aspect of water outflows. In this regard, the annual potential evaporation in Jordan varies from 1900 mm and 4400 mm (NCARTT, 2004). If these measurements are applied to the YTJRB; therefore, the average volume of water that might be evaporated from the Yarmouk River (as a separate water body) and its major tributaries will be:

Surface area x Average Potential evaporation

$$17\ km^2 \times 10^6 \times 1900+4400/1000 = 53.5\ \text{million}\ m^3/\text{year}.$$

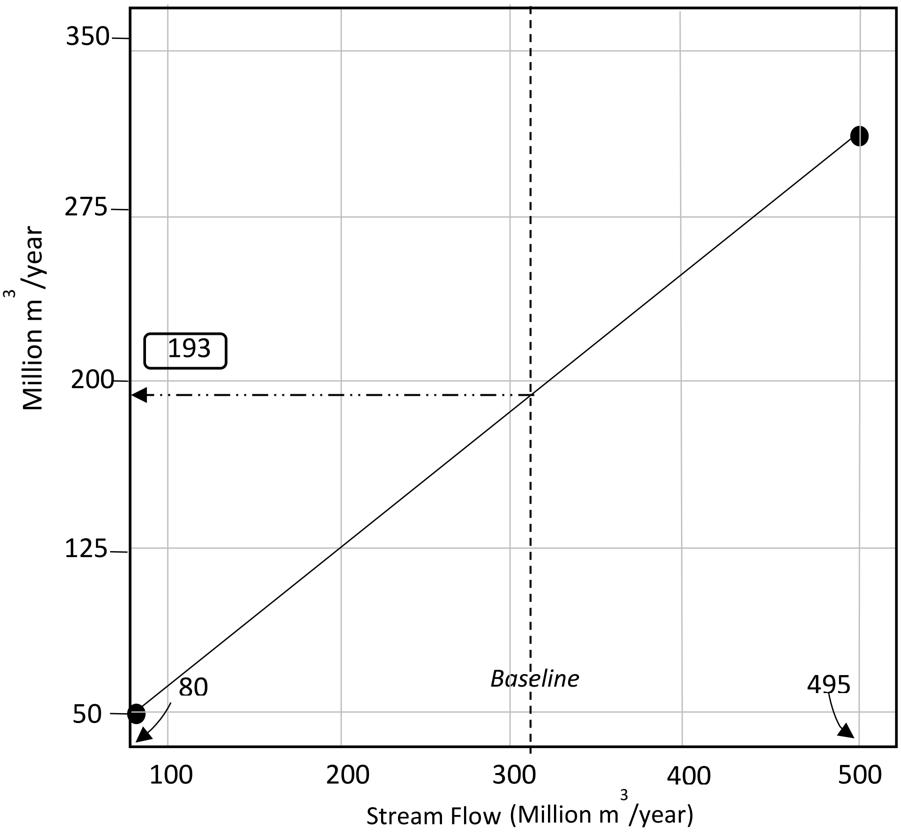

Figure 11. SBI illustration to calculate the required water volume in reservoirs behind dams to sustain an optimal stream flow (baseline) in the YTJRB.

Thus, there are three indicative measurement of Evapotranspiration for the YTJRB as illustrated in Table 4. These are: 1259, 1305 and 1239 million m^3 for the years 1985s 2009 and 2015; respectively. The maximum and minimum values were plotted in the *SBI*. Thus, about 1275 million m^3 can be a satisfactory volume for acceptable EF in the YB (Fig. 12). In this respect, controls to reduce evaporation were mentioned in section 2.3.

1. Water abstraction:

The pumping of water from feeding sources should not exceed the limits of water storage and not from the bulk of water needed to flow the stream regularly. This is well reflected in the YTJRB where demand for water has been exacerbated due to many reasons including population growth and the unaccounted-for water, and thus chaotic water abstraction became dominant.

The flow in the Yarmouk River is highly sensitive to water abstraction, and thus the reduction in the mainstream, as measured at Adassiyeh prior to development in the basin, changed from 450 to about 50 million m^3 per year as it was reported between 2008 and 2015 (Zeitoun et al., 2019).

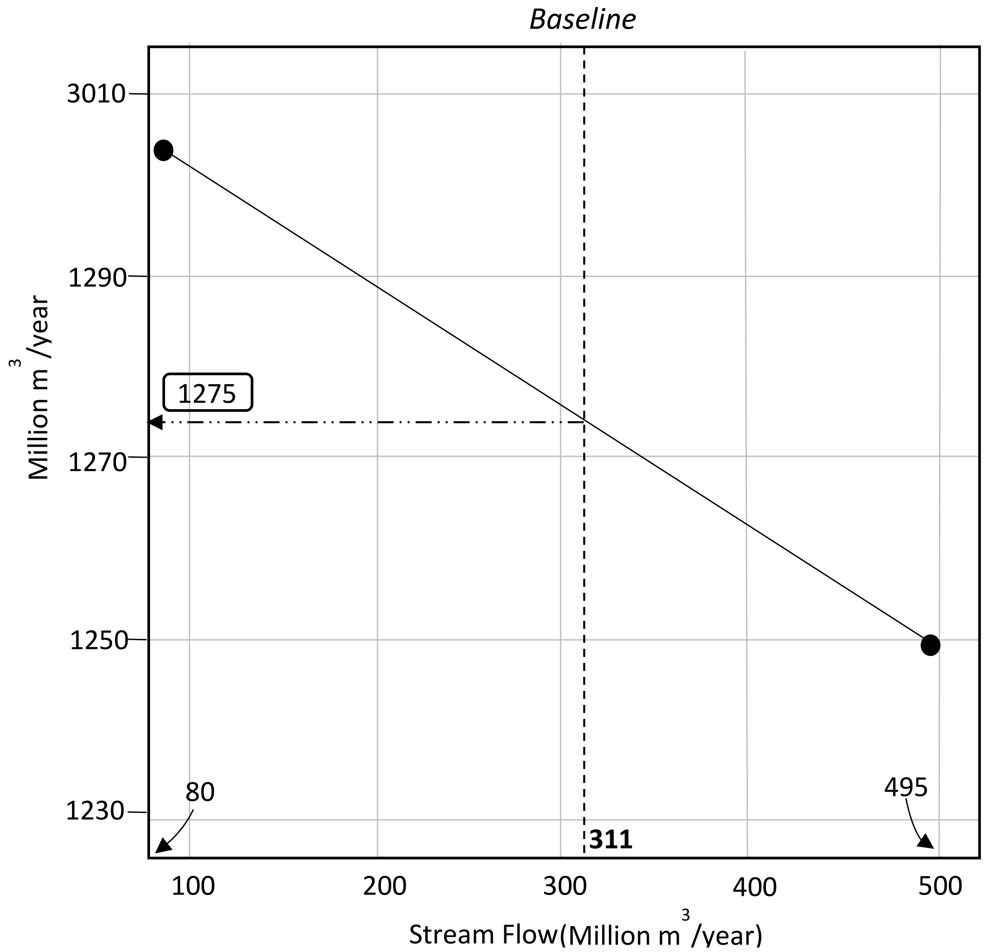

Figure 12. SBI illustration showing the satisfactory water volume from evapotranspiration on stream flow of the YTJRB.

Even though, creditable measurements are still unavailable, but the most common estimates showed that water abstraction is being exacerbated with the increased demand for water in the YTJRB. For groundwater abstraction, there are more than 5000 wells in the YTJRB where 4000 of them are located in Syria (Al-Husein (2007). Thus, the total estimated volume is approximately 192 million m^3 (32 million m^3 in Jordan). While there is about 140 million m^3 abstracted from surface water resources (Table 4).

Thus, if pumped water from the river and its tributaries and water withdraw from groundwater are calculated; therefore, 332 million m^3 is lost annually from the Yarmouk River and its tributaries, which exceeds the baseline stream flow (i.e. 311 million m^3).

Figure 13 shows an illustration for the man-made and technical outflows from the YTJRB, including the abstracted water from groundwater and surface water resources, versus the baseline stream flow in the YTJRB. It is obvious that the impact of all these outflows together, will significantly influence the stream flow of the Yarmouk River, and this in turn will be reflected on the EF in the river and its tributaries.

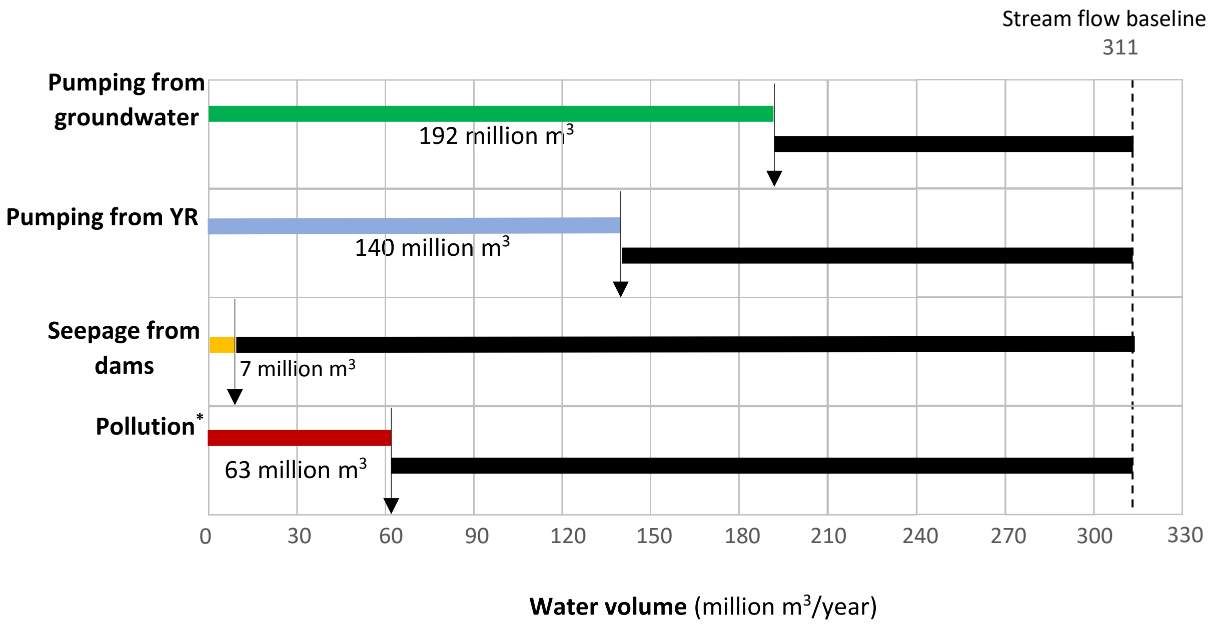

Figure 13. Man-made and technical outflows versus the baseline stream flow of the Yarmouk River (* pollution refers to the volume of flows which are known to be heavily polluted).

2. Seepage from dams:

The loss of water from dams (i.e. seepage failure) due to technical/or geological reasons is well pronounced in the Yarmouk River. This also was discussed in Section 2.2 where the seepage rate differs between the 40 dams and weirs, notably most of them are older than 40 years. However, seep water from dams is either percolated again into ground and then it feeds the rock stratum, transport to the other side of the dam (almost downstream ward), or it evaporates.

There are no measurements, or even engineering assessments, have been done to determine the expected seepage from dams and weirs located in the YTJRB. However, a literature survey was obtained on many studies done on old dams in different regions. Hence it was concluded that dams similar to those in the YTJRB, with more than 40 years old, are anticipated to loss 5% of the total dams` capacity each year (Global Water, 2020).

Considering the water capacity that can be retained in dams of the YTJRB (~ 228 million m^3) and the average (minimum) water volume in dams and weirs after 2015 (~ 50 million m^3); therefore, the volume of seepage water from dams of the YTJRB will be approximately:

$$= \frac{228 + 50}{2} x \frac{5}{100} = 7 \; million \; m^3$$

This rough estimation was illustrated on Figure 13, which is a remarkable loss of water from dams that can affect the stream flow and then the EF.

3. Pollution:

All previous mentioned water sources (inflows) and influencers (outflows) described the volumetric measurements that entre and exist from the Yarmouk River system. However, water impurity and unsafe water resources are also affecting the EF whether directly on the contamination of the ecosystem health including human life, or by assuming the contaminated water as unusable source with no zero benefit.

In this regard, pollution is well pronounced in the water sources and infrastructure of the YTJRB. This can be summarized as follows:

- Contamination of groundwater as a result of random digging of agricultural (private) wells in the areas surrounding the water harvesting, springs, lakes, and even dams.
- Pollution with wastewater resulting from the irrigation of farms with wastewater, and the pollution of dams with water emitted- owing in the tributaries, resulting in the inoperability of the Abta’ al-Kabir and Abta’ al-Saghir dams, and pollution with the remnants of bombardment and ammunition in the waterways of the valley (Etana, 2015).
- The uncontrolled irrigation of farms with dams’ surface water and groundwater, and the waste of large amounts of water in the watercourses (Etana, 2015).

For the YTJRB, no volumetric measurements have been calculated neither for the sources of pollution no for the volume of contaminated water. Nevertheless, the only one estimation has been plotted which for the pollution of water in dams; thus approximately 60 million m^3 of water is polluted in 13 dams located among the YTJRB (Al-Husein, 2007; Youmans, 2016; JVA, 2017; MWI, 2015; UN, 1995; UN-ESCWA and BGR, 2013). This contaminated water if used, it will be harmful for the living organisms and if it is ignored, it will constitute water loss from the YRS, specifically from the stream flow rate.

5. Best Practices and Solutions

The unfavorable situation in infrastructure of the YTJRB requires optimization and restructuring which must be based on the considerations of the available water resources and urban settlements, as well as and caving to the international conventions on transboundary water resources. Hence, optimized investments are needed not only in new infrastructure but also in the maintenance and operations of the existing stock in order to improve their efficiency and reduce water losses. In this regard, two scenarios will be elaborated, one to optimise the current suite of infrastructure and the other to propose a newly conceived optimised suite of infrastructure.

Water demand in the YTJRB is being increased while this geographic cluster naturally constitutes a renewable water system where a major tributary of the Jordan River with six primary watercourses branch out over rock bodies with overlaying groundwater reservoirs.

In paradox, the flow of the Yarmouk mainstream has been oscillating since 2011, due at least in part to reduced agricultural activity in Syria following the start of the crisis (Zeitoun et al., 2019). However, this highlights that water consumption, notably for irrigation, is a major reason behind the decrease in the stream flow the existed or at least fluctuations.

Besides, increased water demand is anticipated with the return of Syrian farmers to their regular livelihoods on the Hauran Plain, and then the stream flow in the Yarmouk mainstream is expected to drop (Muller et al., 2016). In addition, the excessive exploitation of water in the Jordan River has totally exhausted these resources, and this in turn will increase demands from the river tributaries in general and the Yarmouk River in particular.

There are several studies and research projects done on the Yarmouk River and the related hydro-agronomical systems. Most of these studies focused on: limited geo-spatial analysis, water chemistry and pollution, status of the existing infrastructures, dialogues on transboundary water and many other topics where the technical solutions were almost absent, such as Margane et al., (1999); Al-Yazeji et al., (2004); Hamdi et al., (2008); Awawdeh and Jaradat (2010); Obeidat et al., (2012). Whereas, Zeitoun et al., (2019) put an overall vision of complimentary solution for the River basin which can be summarized as: a) the feasibility of equitable and sustainable distribution, b) improving the efficiency of infrastructure and c) the improving the transboundary water agreements.

There are a number of solutions and best practices can be adopted within the context of bilateral cooperation treaties between the riparian regions of the YTJRB and the related hydrological systems downstream. In addition, practices within the national context are significant to assure the success of the optimal water supply and these practices can be either on governmental level or on individual level.

5.1. Proposed solutions within bilateral context

The geopolitical situation, of the Yarmouk River sharing between two non-harmonized countries with water continuing to flow downstream to third dominant country, makes it crucial and embedded with hydrocracies and inequitable water use, and in some instances controlled by the violation of sovereignty. Eventually all riparian countries are losers in front of the limited water resources and lowering-level in the stream flow of the river.

When riparian countries are accorded and greedy is put aside, thus proper solutions can be implemented by adopting innovative and advanced approaches to invest water resources as much as possible. Nevertheless, if this is not the case; therefore, solutions will be sought only to balance the supply of the available amount of water, and "equity" in water distribution will be the only target.

The system builds on the ideas proposed by engineers in the 1950s, and seems inefficient and un-necessarily complicated over half a century later. As we will see in the following sections, there are more optimal ways to make the best use of the precious water. Thus, the controversy (or unsatisfactory) on water consumption by riparian counties of the Yarmouk River resulted dispute between the three countries. This can be viewed from two hydrological aspects: Addressing overexploitation from feeding sources, improving the transboundary water agreements and equitize the distribution.

In addition, there must be supporting tools to sustain the effectiveness of the proposed agreements. This can be achieved by:

- Establishing a roadmap to be followed by the two countries, where periodical meetings can be done within an agreed timeframe.
- Sharing database is a must, where climatological and hydrological measuring/monitoring networks can be established for the benefit of the two countries.
- Developing joint water and agronomical projects considering the balanced water between upstream and downstream with equity in water supply according to land area in each country
- Joint monitoring of water use and availability.

1. Addressing overexploitation from feeding sources:

This has been mentioned before (in section 1.5 and section 4.4) where chaotic water abstraction, whether directly from surface water or from groundwater, is well pronounced in the YTJRB. Thus, there are numerous aspects of unlicensed water pumping and convey channels from surface water distributed in the two parts (Syrian and Jordanian) of the YTJRB (Fig. 14). In addition, some authors have estimated that there are more than 5000 wells in the YTJRB where 4000 of them are located in Syria and about 1000 in Jordan (Al-Husein, 2007).

In order to treat the unmanaged and uncontrolled aspects of water pumping, effective bilateral agreements must be adopted and the existed agreements should be empowered between Syria and Jordan to stop the chaotic pumping of water (surface and groundwater). Thus, combined strategic plans to construct water channels can be achieved and this can be based on hydrologic studies done to equitably convey water between different regions in both countries.

Figure 14. Examples of water abstraction from the Yarmouk Rivers and its tributaries.

2. Improving the transboundary water agreements:

In spite of signed agreements and treaties, multiplicity of geopolitical entities on lands often results conflicts on managing water resources. This will be exacerbated when challenges on water exist, specifically the increased demand for water. Therefore, water projects and works are being done solitarily, overriding the agreements done between riparian countries.

Many bilateral agreements on the equity of water supply in the YTJRB and the downstream lands have been signed between the riparian countries. Thus, Syria and Jordan have signed many agreements since 1953 until 2003 (and notably the 1987 Syria-Jordan Yarmouk agreement) (Borthwick, 2003); while, the Israel-Jordan Peace Treaty in 1994 significantly embedded an article on Water-related Matters (Hof, 1995). AS the YHPB report shows, both the 1987 Agreement and 1994 Treaty do not reflect current water availability or needs, are very rigid, and do not benefit from the equitability principles of International Water Law. There is furthermore some ignorance for these agreements and geopolitical conflicts often exist, notably with the OSol (Occupying State of Israel) who used many times the military force to illegal dominance on water resources in the region.

Many projects have been done to exploit water resources from these countries regardless of the accordance of other concerned countries. These projects and works, which were done either on governmental level or individually, impacted the international infrastructures which were built on transboundary watercourses and resulted harms on many regions, specifically in Syria and Jordan. Some examples can be illustrated as follows:

- The Israeli farmers of the "Yarmouk triangle" extended a rudimentary rock weir along the river length in order to ensure a stable flow for their use downstream lands (Haddadin, 2006). While, the Jordanian utilization of some Yarmouk flows to the East Ghor Canal through a sandbar at Adassiyeh in order to divert flow southwards, resulted thick sedimentation in the river bed.

- The occupation of West Bank, enabled Israel controlling of Banias River and new frontage on the lower course of the Jordan, and an extended frontage on the Yarmouk River and the Golan Heights up to Wadi Raqqad, the major tributary of winter floods.
- Israel was adamantly opposed to the damming of the Yarmouk at Maqarin Station and to the construction of a diversion weir at Adassiyeh, and it bombed the Jordanian dam under construction at Mukhaybah in 1960s (Hof, 1995).
- The excessive damming in Syria makes it utilizes more Yarmouk water than do Israel and Jordan combined.

The non-agreeable situation for the Yarmouk River and the related downstream hydrologic systems must have solved within a context of the international treats and conventions which clearly illustrate water rights for the transboundary water resources based on the equity and integrity in water use between the riparian countries.

Figure 15 reveals the main international treats to regulate water use effectively and their relationship to the situation in the Yarmouk River and its hydrologic systems.

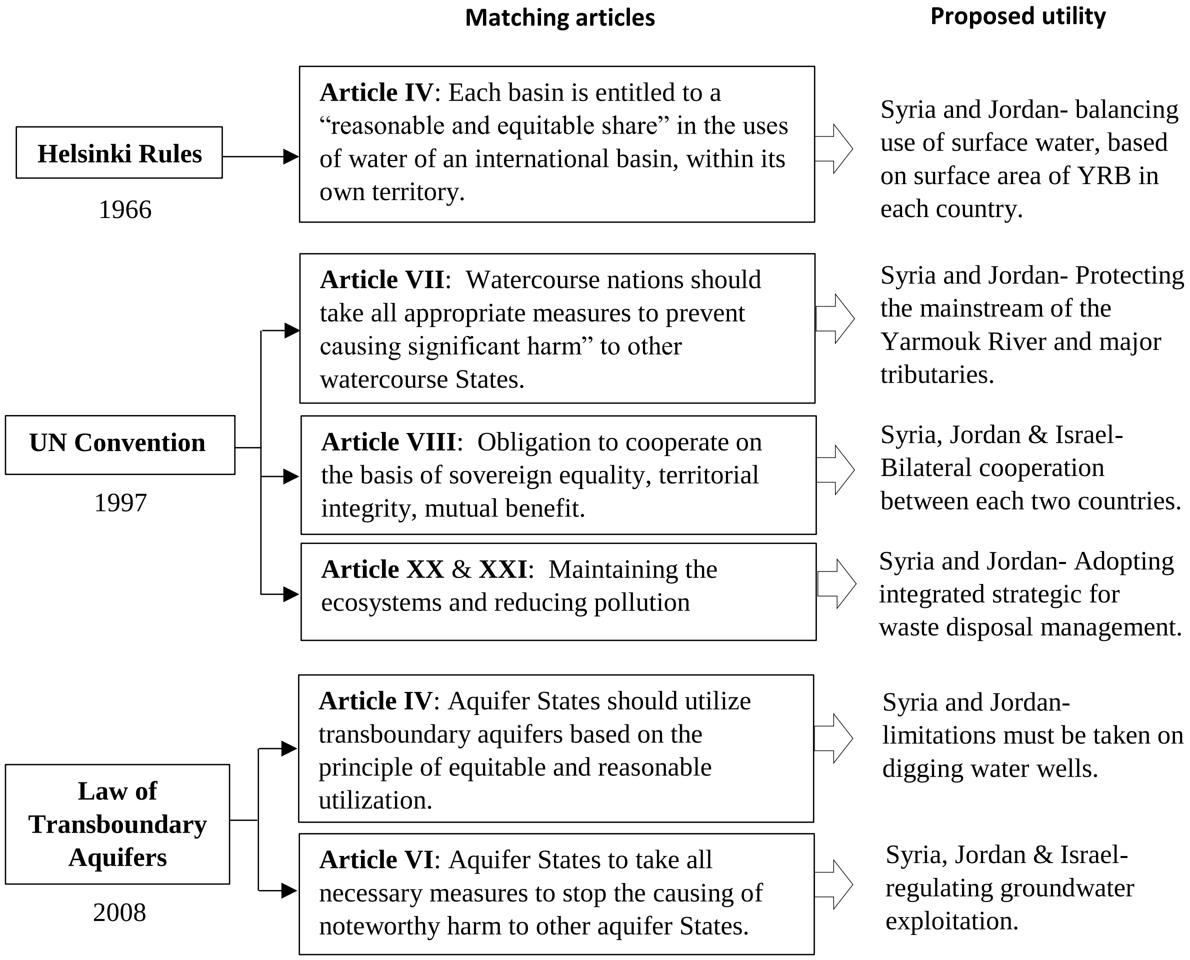

Figure 15. Matching articles from international treaties and their proposed utility for the YTJRB and its downstream hydrologic systems.

3. Make the distribution more equitable:

Considering the volumetric dimensions; however, the case in the downstream regions of the YTJRB is not much better than that in the upstream region. At downstream and then outlet points, the surplus amount of water is derived from the entire basin, among the major tributaries, is accumulated primarily at Al-Wehdah Dam which has never reached its full capacity (i.e. 110 million m^3), and it often witnesses abrupt changes in the volume of retained water which ranges between 29% and 75%.

For the YTJRB, emphasis is on the Jordanian-Syrian Al-Wehdah Dam and the Jordanian-Israeli Adassiyeh Weir, plus the unorganized construction of water dams and weirs as well as the chaotic pumping of groundwater from the entire YTJRB.

The reservoir of Al-Wehdah Dam (established in 2006), with the oversized dimensions, controls the flow to the downstream where it stores water collected from five major streams and then supplies this water to Adassiyeh Weir (established in 1999). Therefore, water from Adassiyeh Weir is diverted into two main destinations; one towards Tiberius Lake and the other along the King Abdallah Canal (Fig. 16).

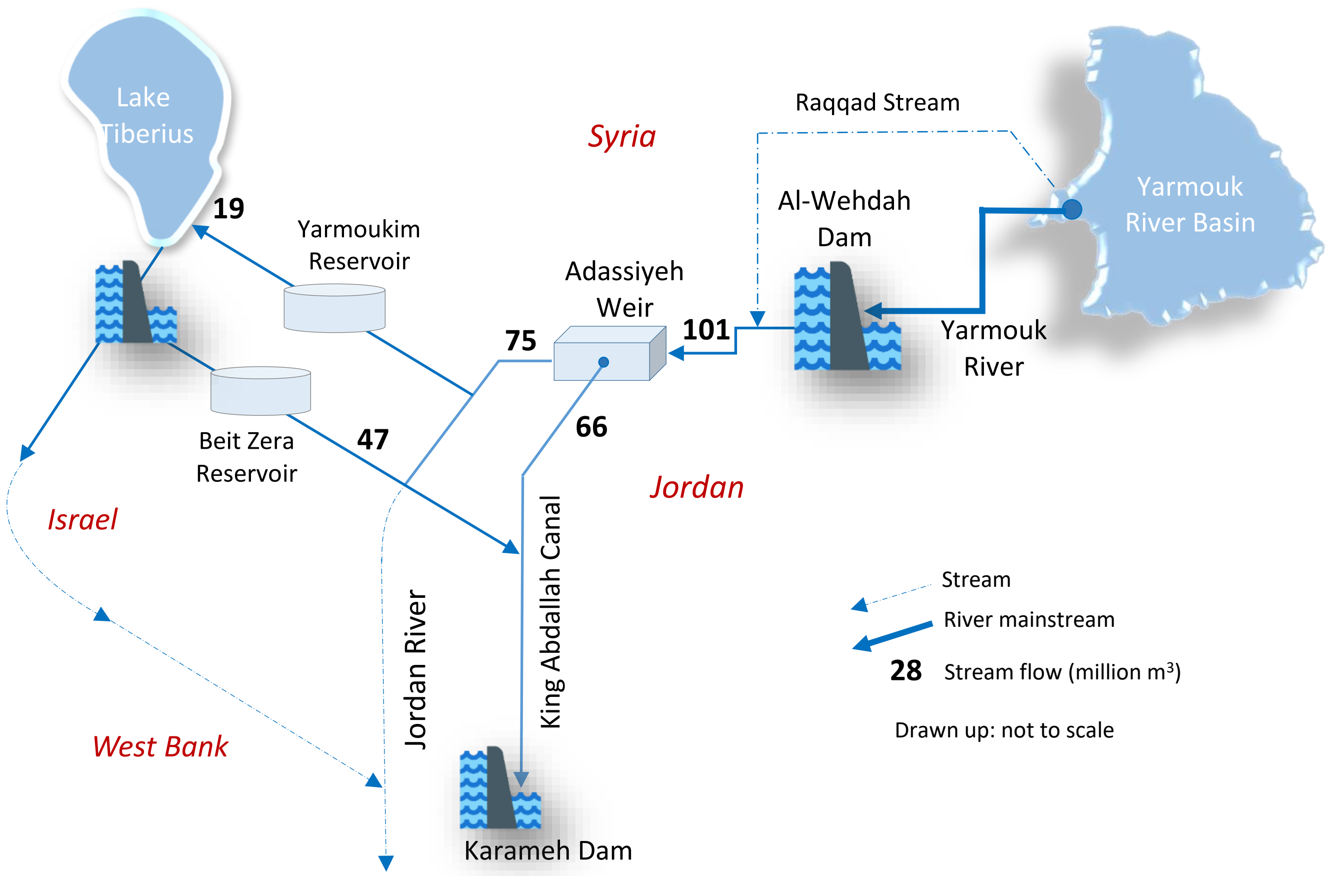

Figure. 16. Schematic figure for the YTJRB and its downstream hydrologic systems including water convey systems (Modified after Zeitoun et al., 2019).

The average volume of water reaches at Al-Wehdah Dam is about 60 million m^3 (before 2015), and it is conveyed downstream to Adassiyeh Weir. There is about 41 million m^3 of water derived along Wadi Raqqad, the tributary spans from the foot-slope of Jabal Al-Sheikh (in the northern Golan Heights, this water joins the mainstream of Yarmouk after the Al-Wehdah Dam and then totaling about 101 million m^3 (Fig. 16). Therefore, a part of this water (28 million m^3) is diverted along King Abdallah Canal, and the rest 73 million m^3 flows back into the river bed to be pumped out at the Yarmoukim Reservoir by OSoI, and towards the Tiberais Lake (occupied by Israel).

Water along King Abdallah Canal flows to Karameh Dam in Jordan, while the volume of water pumped to Tiberais Lake reaches to Yarmoukim Reservoir and then it is divided in its way as: 36 million m^3 to 5 kibbutzim, 16 million m^3 for irrigation purposes in Mevo Hama and Meitsar plain, 19 million m^3 outlets into the Tiberais Lake, whereas very little amount of water continues flowing to the Yarmouk River (Fig. 16). While, water from Tiberais Lake is conveyed to Degania Dam from which about 47 million m^3 is re-joined with the King Abdallah Canal.

It is obvious that this volumetric scheme lacks to creditable and equitable allocation of water distribution. These chaotic aspects of water supply seem complicated and not satisfactory enough to reach typical transboundary water resources including mainly the Yarmouk River and the related hydrologic systems.

The system ofdistribution appears as chaotic as it is asymmetric . Table 5 reveals the key components for water allocation and the related inequitable distribution of water resources of the Yarmouk River, it is basin and the related downstream hydrologic systems.

Table 5. Key components of water allocation for the YTJRB and the related downstream hydrologic systems.

Key components	**Syria***	**Jordan**	**Israel** (OSol)**
Area of YTJRB (%)	5900 km^2 (80%)	1450 km^2 (19.7%)	420 km^2 (0.3%)
Water sources	70%	20%	10%
Groundwater abstraction (million m^3)	160	32	20
Surface water abstraction (million m^3)	112	28	18
Al-Wehdah Dam (& Raqqad Stream) (million m^3)	0	30	0
Adassiyeh Weir (million m^3)	0	28	73
Total exploited water	272	118	111
Exploitation versus area	4.6	8	26.4
Presumed allocated volume with respect to area and source (million m^3)	366	97	39
ratio of the allocated volume to exploitation	0.74	1.21	2.85

**Including the occupied Golan Heights which is a Syrian territory.*
***Occupied territories (Between YTJRB, Tiberais Lake and Karameh Dam).*

Even though, the measurements and estimations plotted in this table are almost rough and they found to be contradictory between different sources; however, they could introduce a rough idea about water allocation by each of the riparian countries.

It can be concluded from Table 5 and the surveyed literature reviews that:

- Syria occupies the largest area of the YTJRB and the downstream hydrologic systems, and the volume of water, from different sources, is also the biggest (about 70%) between the riparian countries. In addition, the total exploited volume of water by Syria is about 272 million m^3. The theoretical allocated water volume, as based on the area of the hydrologic system in Syria and the contribution from different sources, is presumed to be approximately 366 million m^3, which points out that Syria is exploiting 0.74 times of its quota (Table 5).
- If similar theoretical calculations are applied to Jordan and Israel; therefore, Jordan exploits 1.21 times of its water quota while Israel exploits 2.85 times (Table 5).
- Except the hydropower generation, Syria does not benefit from Al-Wehdah Dam. However, this dam serves mainly to collect water for the downstream region.
- Water diverted from Adassiyeh Weir is not equitably allocated between Jordan and Israel, and Israel exploits about 72% of water in this weir.
- Due to the minimal amount of water delivered from Adassiyeh Weir to the Jordan River; therefore, the low-level stream flow cause bad environmental flow conditions and thus impacts the existing ecosystems.

Based on the above mentioned findings; therefore, an integrated solution can be proposed and based on the elaboration of a strategic plan between the riparian countries under the patronage of the international community, and this can assure equitable water supply and to conservation of the ecosystem in the region. Figure 17 reveals a schematic illustration for the proposed strategic plan which implies the following:

- Increasing the capacity Al-Wehdah Dam by:
  - Adoption of new proposed measures (to be discussed in the next section),
  - Regulating and monitoring water abstraction (discussed in Section 5.1, point 1).
  - Establishing canal to convey water from Raqqad stream to Al-Wehdah Dam (Fig. 17). Then, all volumes of water supply after Al-Wehdah Dam will be changed accordingly. This would be tedious to be applied due to the Israeli occupation who will not allow any works in the area, as well as the lack to pumping stations along the slopes.
- Water from Adassiyeh Weir is released to King Abdallah Canal and towards the Jordanian River, with no more water convey towards Tiberais Lake.
- Reservoirs in the Israeli side can be filled from the Tiberais Lake (Fig. 17).
- Therefore, the 75 million m^3 is required for or environmental flow, elimination of energy-intensive pumping uphill to Tiberais, more equitable distribution.

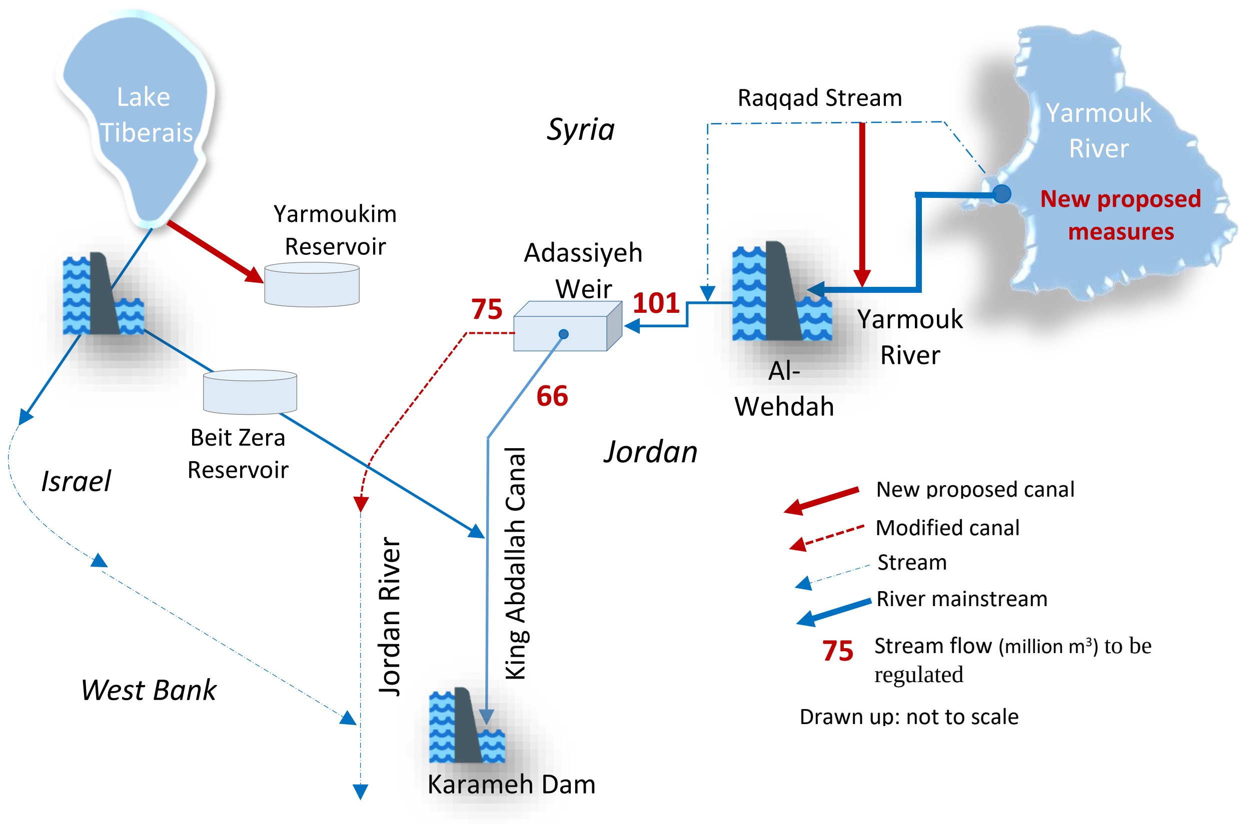

Figure. 17. Schematic figure for new proposed supply scheme and measures for the YTJRB and its downstream hydrologic systems.

5.2. Proposed solutions within the national context

Best practices and solutions, within bi-lateral context, cannot be done separately through the coordination between riparian countries and without the reliance on measures taken by each country individually. Nevertheless, the proposed practices and solutions mentioned in Section 5.1 may not find their way due many reasons, specifically the geopolitical conflicts. Therefore, a count on the national actions to be done on governmental or individual level are a must, whereas incentives and support from the governmental sector remains necessary to promote the application of these solutions. This section is dedicated for Syria and Jordan.

1. Proposed solutions on governmental level:

- Emphasis should be placed for the reduction of leakages and seepages from supply pipes and from dams specifically in the Syrian part of the YTJRB. Thus, methods to determine leakage from pipes and seepage failure seepage from dams must be primarily applied in order to follow maintenance approaches needed (discussed in Sections 2.1 and 2.2 & Tables 1 and 2).

- Water reclamation should be adopted on community-scale level, by establishing new WTPs, notably nearby the urban clusters of the YTJRB. This can be taken from the context of national waste management plan for Syria and Jordan (discussed in Section 3).
- Reducing evapotranspiration, especially in reservoirs behind dams, needs technical experience and financial resources, thus it can be implemented on the governmental level for dams with relatively large surface area with respect to depth. This can be determined for all constructed dams in Syria and Jordan (discussed in Sections 2.3).
- Promoting economic policies including water tariffs, liability for damage to waters, water abstraction charges, as well as environmental legislations should be adopted to support water quality conservation.

2. Proposed solutions on household or farm level

- Enhancing water recharge into substratum, and this can be either in the basalt and limestone rocks or along the stream courses. This follows techniques in localities where surface water is usually accumulated or rapidly runs off, notably after rain storms. They can be applied also in stream beds and beside dams. The most applicable techniques are:
    a) Detention ponds to collect surface water (Fig. 18), and then permits time to infiltrate (Freeborn at al., 2020).

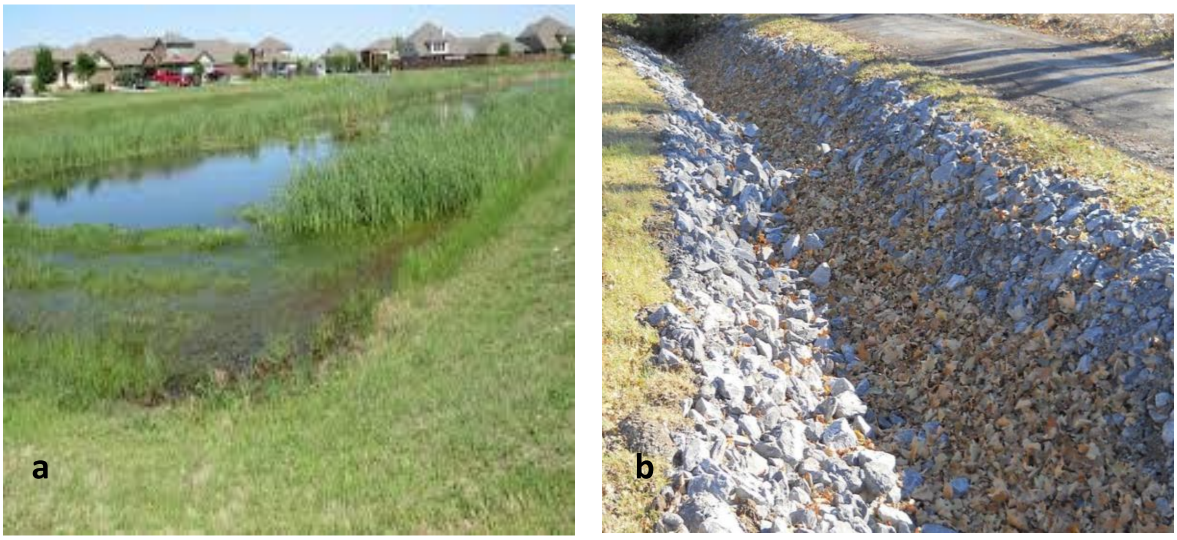

Figure 18. Examples of water recharge enhancement techniques a) detention pond and b) Stone channel lining.

b) Terrain trenching where water can be accumulated for further infiltration and reduce erosion (Harrington, 1989).

c) Stone channel lining (Fig. 18), where the channel sides are covered by stones from which water infiltrates and reduce the flow energy and flooding (NHI, 2005).

d) Terrain cracking is technique where terrain surface in cracked using localized explosions to enhance fractures and infiltration rate, as well as reduce runoff energy. It is often applied behind dames as a flood control.

- Following efficient agricultural methods to reduce water loss and excessive use of fertilizers. Thus, efficient irrigation systems (e.g. drip irrigation schemes implemented in Daraa, Syria), planting drought-tolerant crops, etc. However, this requires empowering the knowledge of farmers and locals on how to use water efficiently, notably in agricultures, and the public sector is in-charge for this purpose.
- Construction of mountain lakes in the mountainous regions, notably along the slopes of the mountain chains covered by snow, with a special emphasis to those chains of Jabal Al-Shaykh; Jabal Al-Arab/Ad-Druzz and Ajloun Heights in Jordan. Similar geomorphologic regions located in Lebanon show efficient aspect of water harvesting from snowmelt (Shaban, 2020).
- Rooftop harvesting can be a simplified and useful method for water management in the YTJRB, notably that urban clusters occupy about 6 % of the basin according to (DOS, 2014; CBS, 2016) and satellite images (e.g. Ikonos). Whereas the average rainfall rate of 273 mm over the entire basin. Therefore, the amount of water that can be captured from rooftop can be calculated as follows:

$$\text{Total area of the YTJRB (km}^2\text{)} \; x \; \text{urban clusters (\%)} \; x \; \text{average rainfall rate (mm)}$$

$$7378 \text{ x } 10^6 \; x \; 8/100 \; x \; 273/1000 = 121 \text{ million m}^3$$

If this volume is divided on the total population in the basin (1.6 million); therefore, the per capita from the rooftop harvesting will be increased by about 76 m^3/year.

6. Performing Infrastructure Scenarios

Water infrastructure broadly represents any system for water supply and transport, treatment, storage, harvesting, flood control and hydropower. Thus, infrastructure is a tool to assist water convey and management and it is applied in regions under diverse water needs (i.e. water-rich or water-scarce region).

For the YTJRB, the increased population is gradually affecting water resources, and this was exacerbated by the continuous expansion of urbanization, changing climate and the deterioration in water quality. Therefore, water infrastructure has been built and changed over different entities controlled the region. However, more technically-developed infrastructure found its ways since1960s when dams, with different dimensions and types, were constructed. Along with these dams, other aspects of infrastructure were put to e integrate water systems in the basin, specifically canals, reservoirs and supply pipes. Nevertheless, the unsettled framework of these dams affected the related water systems.

Dams, as the vital nodes of the YTJRB, are relatively old and were principally constructed during 1960s when the population was less 20% of the current number (Fig. 19).

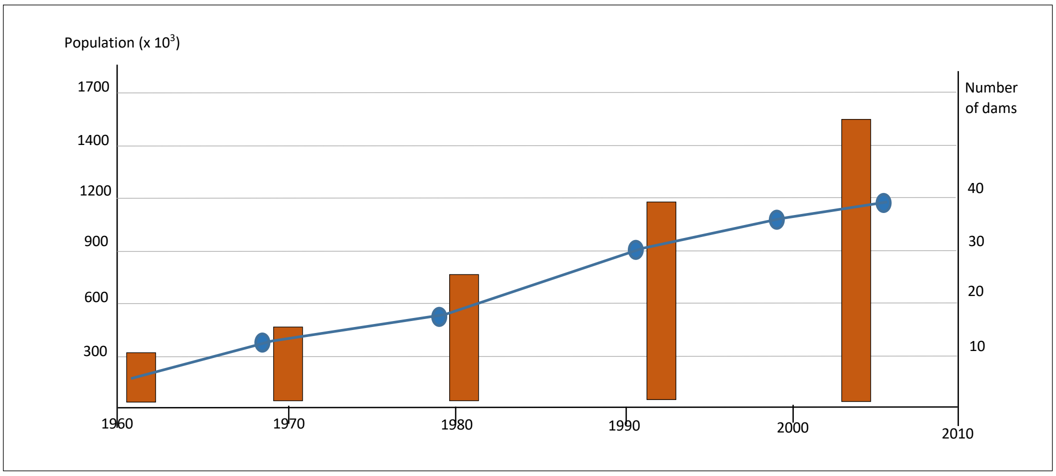

Figure. 19. Population and number of dams in the YTJRB
(Population data adapted from: DOS, 2014; CBS, 2016).

The number of dams was 30 before 1990, and then it was increased with population unless it reached to 40 operational or partially operational dams (& related water systems), where 16 of these them are polluted. In addition, the actual retained volume of water is only about 15% (50 million m^3) of the total capacity (328 million m^3) of these dams (YHPB, 2017)

6.1. Optimizing current infrastructure

The concept of the optimization of the current infrastructure implies adopting enhancement tools and measures for the existing infrastructure. Therefore, all existed water systems to be tweaked to improve their efficiency and to reach the objectives they were built for.

For the YTJRB, the optimization of the current infrastructure can be inspired from the discussion in the previous sections. Nevertheless, financial resources, responding from key actors and from inhabitants is essential to achieve an optimized infrastructure. The components of optimizing the current infrastructure are:

1. Reducing leakages from pipelines was estimated at 51% and 28% in Jordan and Syria; respectively (Section 2.1). Thus, the average leakage can be roughly estimated at 40 %. According to UN-ESCWA (1993), MWI and GTZ (2004), MWI (2015) and Youmans (2016); the volume of water supply is about 422 million m^3/year. Therefore, the volume of leaked water from pipelines (at 40 %) will be 167 million m^3/year.

   Figure 20 illustrates the leaked water versus the percentage of leakage from pipelines. If an optimistic level is sought at 10%; therefore, only 50 million m^3 of water will be lost. Whereas, slight optimization is presumed to be between 10 and 20% where water lost will be between 50 and 90 million m^3, and so on (Fig. 20).

2. Minimize the seepage from dams is also accounted for better optimization. It was estimated at 5% (Table 4). Hence, the approaches to reduce the seepages from dams were discussed in Section 2.2 and Table 2. It was estimated that 5% of seepage in dams will result 7 million m^3 of seeped water. Therefore, an illustration was plotted to presume different scenarios of seepage percentage versus volume of seeped water from dams (Fig. 21).

   In this regard, it is presumed that 2.5% would be reasonable value for seepages from dams where only 3.5 million m^3 of water will be lost then; whereas other percentages can be simulated for different volumes of water (Fig. 21)

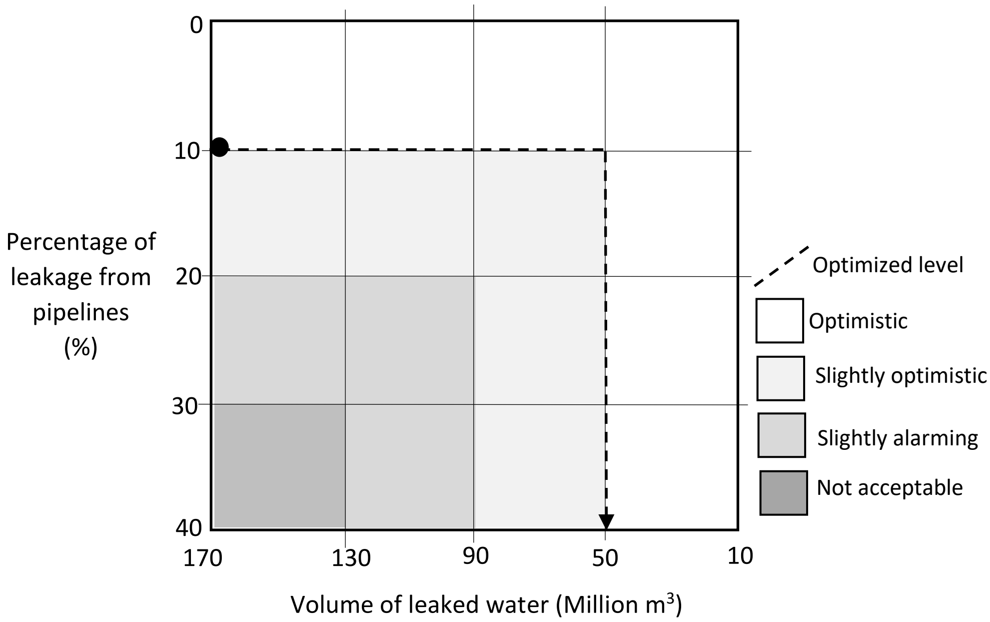

Figure 20. Optimization scenario for different percentage of leakage versus the leaked water from pipelines in the YTJRB.

3. Reducing evaporation, as a part of evapotranspiration which is reported at 1268 million m^3 per year (section 4.4). Even though it is not simply achieved, but measures can be taken as it was mentioned in Section 2.3. Hence, if all measures are properly applied, including putting barriers on reservoirs and using effective irrigation and plantation methods (e.g. mulching, shelterbelts, etc.); therefore, 50% of evapotranspirated water would be saved, which is equivalent to approximately 790 million m^3.

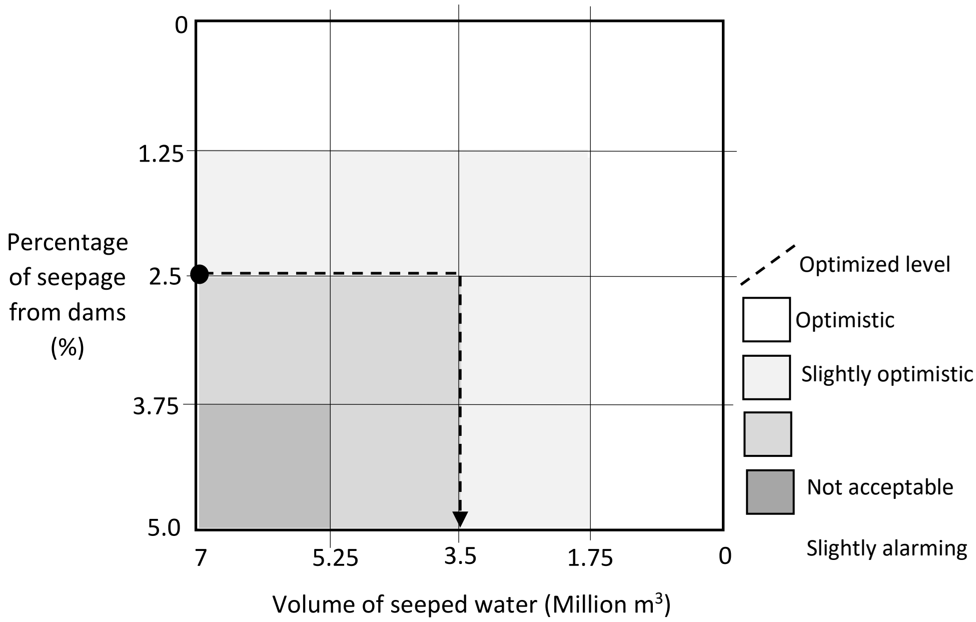

Figure 21. Optimization scenario for different percentage of leakage versus the leaked water from pipelines in the YTJRB.

It would be significant even if 40% of evapotranspiration reduction is reached whether directly from the evaporation from dams' reservoirs or in agricultural and irrigation methods. Hence, Figure 22 reveals a scenario where the 50% will reduce the calculated volume (i.e. 790 million m^3) and if the presumed (optimal) percentage is reach 40% and thus a volume of 640 million m^3 can be saved.

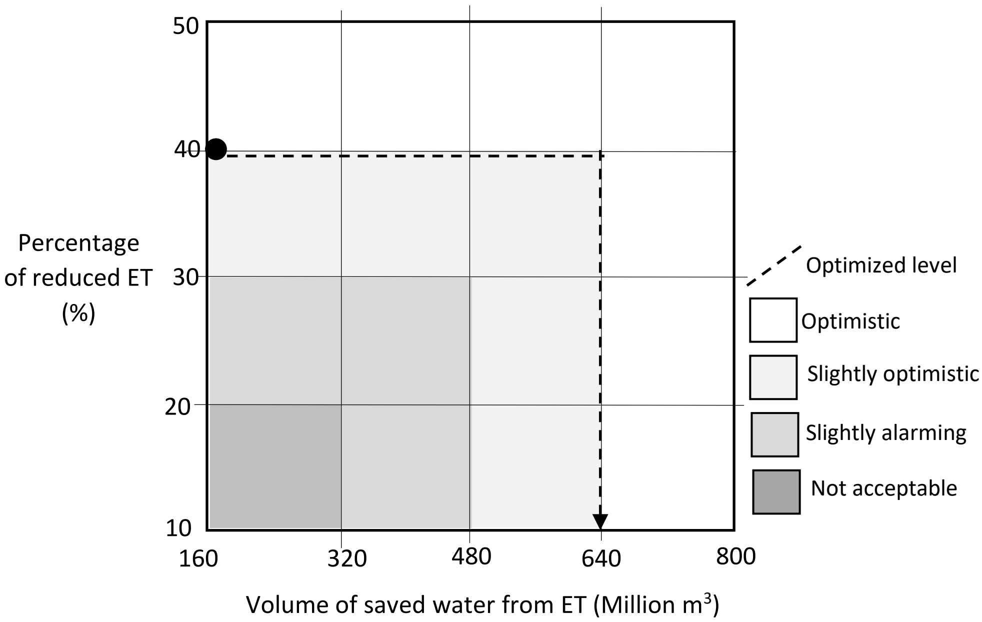

Figure 22. Optimization scenario for different percentage of EV reduction versus the saved water from ET in the YTJRB.

4. Regulating water abstraction from surface water (140 million m^3) and groundwater (192 million m^3) is a feasible to enhance the budget of surface and groundwater resources. They two volumes (332 million m^3, as mentioned with UN-ESCWA, 1993; UN-ESCWA/BGR, 2013) can be reduced if several measures are applied (as mentioned in Section 5.1).

   It can be presumed that abstraction reduction below 10% is not acceptable and the volume of abstracted water will be about 300 million m^3, while a reduction of more than 50% will begin as slightly optimistic and gradually reaches the optimistic level (Fig. 23).

5. Adopting water reclamation and reuse is one of the major optimizing methods applied in many regions and proved their reliability, notably for irrigation. The calculated water volume which can be reclaimed in the YTJRB was estimated to be 190 million m^3 (as illustrated in Fig. 4). This can be reached if proper water treatment approaches are applied including the water treatment on community, enterprises and household levels. In other words, if integrated water reclamation management is adopted, thus a total volume of 190 million m^3 will be reused and annually.

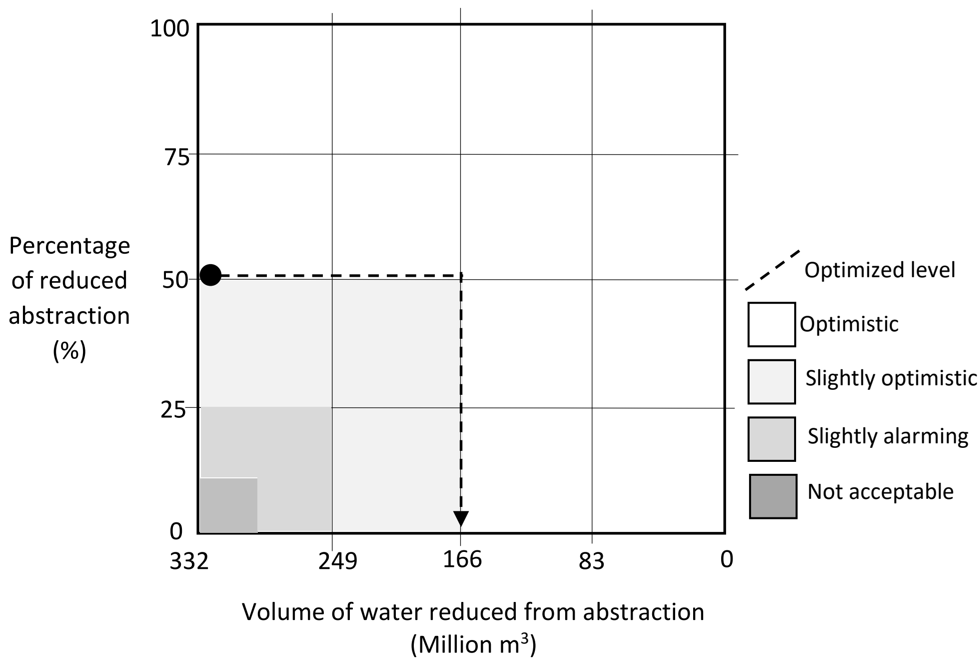

Figure 23. Optimization scenario for different percentage of reducing water abstraction versus the volume of water saved in the YTJRB.

It was reported that ratio of 60% and 40% of water is reclaimed in Israel and Syria While Jordan is planning to reach 60% reuse by 2025 (Anderson, 2003; FAO, 2008; MWI, 2015; IDA, 2020). From this point of view, it is presumed that if at least 75% of wastewater is reclaimed in the YTJRB, it would be a successful application and more than 145 million m^3 can be reused (Fig. 24).

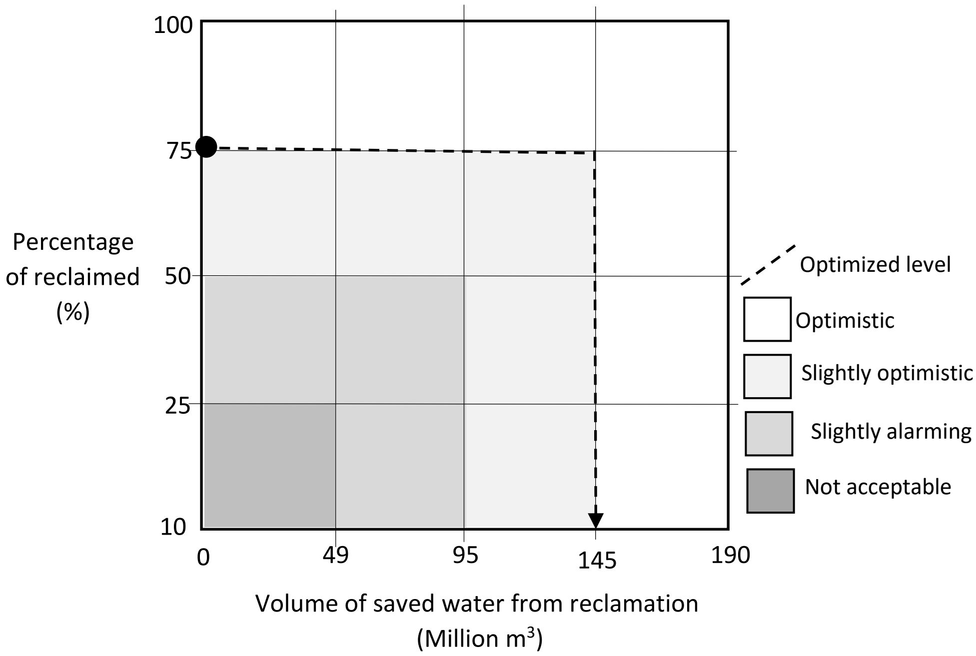

Figure 24. Optimization scenario for different percentage of water reclaiming versus the volume of water reclaimed in the YTJRB.

6.2. Conceived optimised infrastructure

Another scenario of optimized infrastructure for the YTJRB can be applied considering newly conceived optimized suite of infrastructure (i.e. as if there were currently no infrastructure). This understanding implies adding new infrastructure and excluding some of the existing infrastructure in order to reach the most optimized infrastructure that can cope with enhanced water management in the YTJRB. This can be elaborated from different hydrologic components where dams are the utmost significant ones.

1. Dams:

The existing 40 dams in the YTJRB were built for different purposes (Fig. 25); however not all of them are functional or working properly, and even some of them are hindering the hydrologic cycle and the regular stream flow where unfavourable consequences occur. Thus, the current positioning of dams seems unlikely for proper water supply and this is attributed to the following:

- Some dams have become lately with no sufficient volume of water or totally empty.
- A number of dams are polluted, notably those which were built for livestock watering, or old enough and become with no specified rule.
- From the hydrologic point of view, there are many dams were erroneously constructed, such as the proximity to other dams or they are located on the upstream or on reaches where no considerable water volume can be stored.

- Also, successful dams are always located on the confluences of major tributaries, and this was not the case for the largest part of the Yarmouk River.

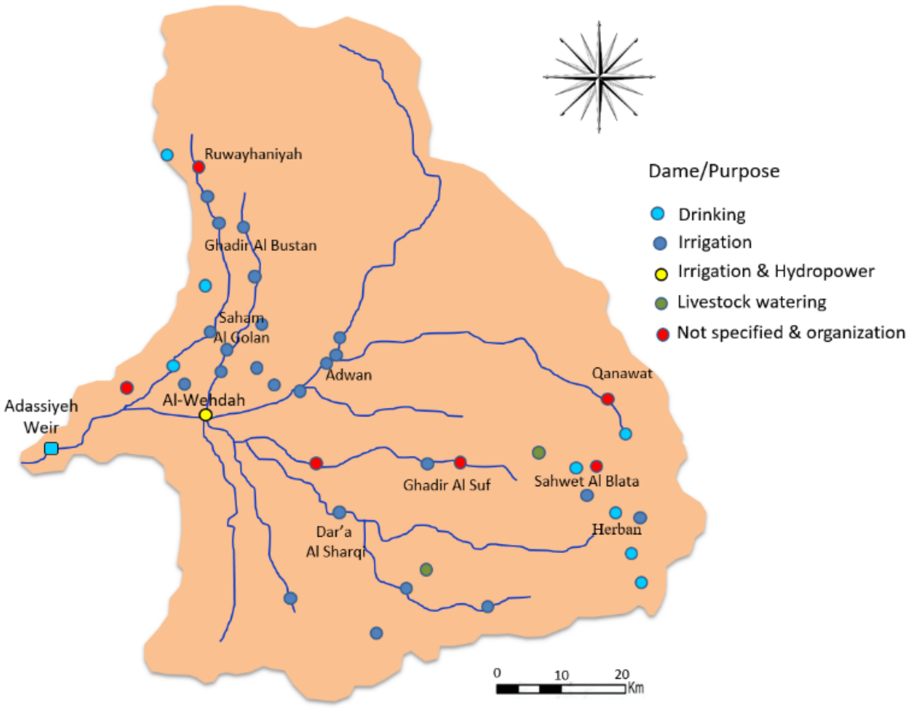

Figure 25. Dams located in the YTJRB and their purposes (Adapted from Zeitoun et al., 2019).

Therefore, the following scenarios were presumed for the exclusion (abandoning) of selected dams. Thus, "abandoning" does not mean necessary the removal of this infrastructure, but it can be excluded as a hydrologic node and might be changed to any aspect of landscapes:

a. Non-functional dams, including those built for livestock watering and those assigned as "not specified" or "organization". Thus, only 32 dams remain and this exclusion facilitates the flow energy and reduce pollution in the stream flow as well as enhance the EF of the mainstream (Fig. 26 a).

b. Dams located upstream (almost the upper parts and reaches), notably these dams are not able to collect considerable amounts of water. The presumed abandoned dams can be used as "detention ponds" which were propose in Section 5.2. Thus, 22 dams were built on these unfavorable localities, and only 18 dams remain (Fig. 26 b).

c. Dams with proximity (< 10 km) can be with minimal and sometime with not function at all. Hence, the positioning of dams with proximity is a result of improper management and can be attributed to the increased needs for water with short periods. If these dams are abandoned; therefore, 22 dams will be excluded from the YTJRB. Similar to scenarios an and b, this will also enhance the stream flow and the EF of the mainstream (Fig. 26 c).

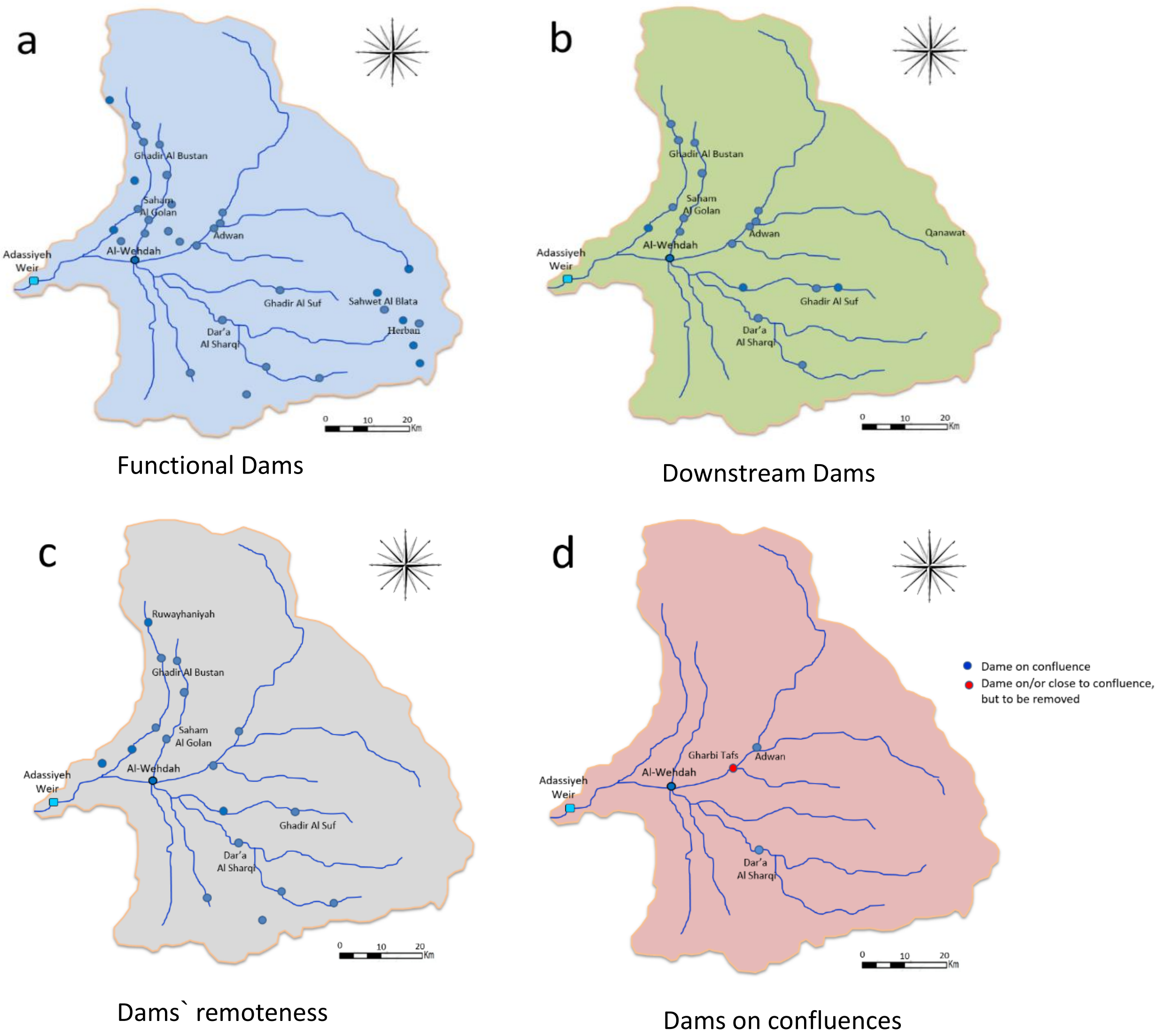

Figure 26. Optimized scenarios for the existence and positioning of dams in the YTJRB.

d. Dams on Confluences would be another and most probable scenarios, notably that most of the existing dams are unlikely working and the majority of stored water in dams in the YTJRB is implied in the Al-Wehdah Dam, which located at the confluence of 5 major tributaries. Whereas another two dams can be proposed; first is the Adwan Dam which is already existed, but the closer dam to it (Gharbi Tafs) to be abandoned. In addition, in spite that Dar'a Al Sharqi Dam is located along a tributary but it is also close to a confluence, and then it can be utilized. Therefore, Adwan Dam will capture stream water from the tributaries of Allan and Hareer/Arram, while Dar'a Al Sharqi Dam from Zeidi tributary, and Thahab and Shaallala tributaries are captured by Al-Wehdah Dam (Fig. 26 d).

2. New suite of infrastructure:

Other than dams, there is another suite of infrastructure that can be elaborated in the YTJRB. These can be done by making new water collection and diversion constructions. However, scenarios on this suite of infrastructure can is elaborated after considering the exclusion of dams with proximity to each other (Scenario c in Fig. 26).

a. Excavation of detention ponds in regions with low-lands are dominant in the YTJRB where the capacity of these ponds varies between 150-250 m^3. These ponds will feed groundwater reservoirs. Figure 27 shows the scenario where these ponds can be excavated in the YTJRB.

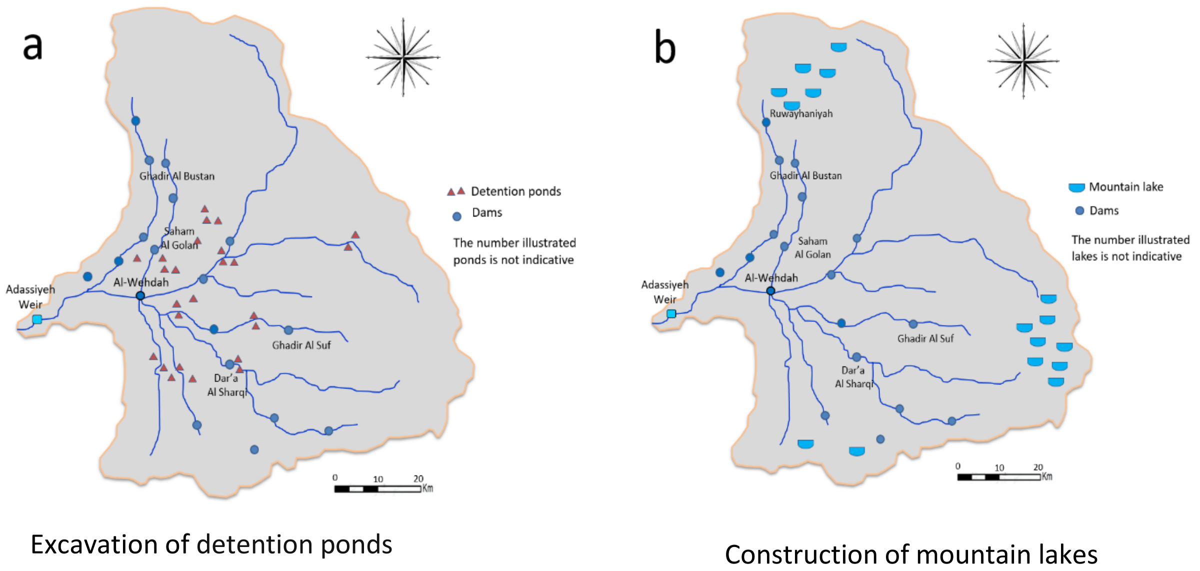

Figure 27. Optimized scenarios for excavating detention ponds and construction of mountain lakes in the YTJRB.

b. Construction of mountain lakes in the elevated regions above 900 m where snowpack is often accumulated (discussed in Section 4.3). The capacity of a mountain lake can vary between 1500 and 5000 m^3. These lakes are significant for water storage from snowmelt, and they can contribute substantially in the allocated water for irrigation by gravity flow, and in enhances creating new and more fertile ecosystems. Figure 27 b shows the scenario where mountain lakes can be constructed in the YTJRB.

c. Constriction of stream diversion from Ghadir Al Bustan Dam (along Raqqad tributary) to be connected Saham Al Golan Dam (along Allan tributary). This was built on the concept that water from Raqqad tributary should be stored at Al-Wehdah Dam. Therefore, a canal is proposed to be executed between both dams as shown in Figure 28.

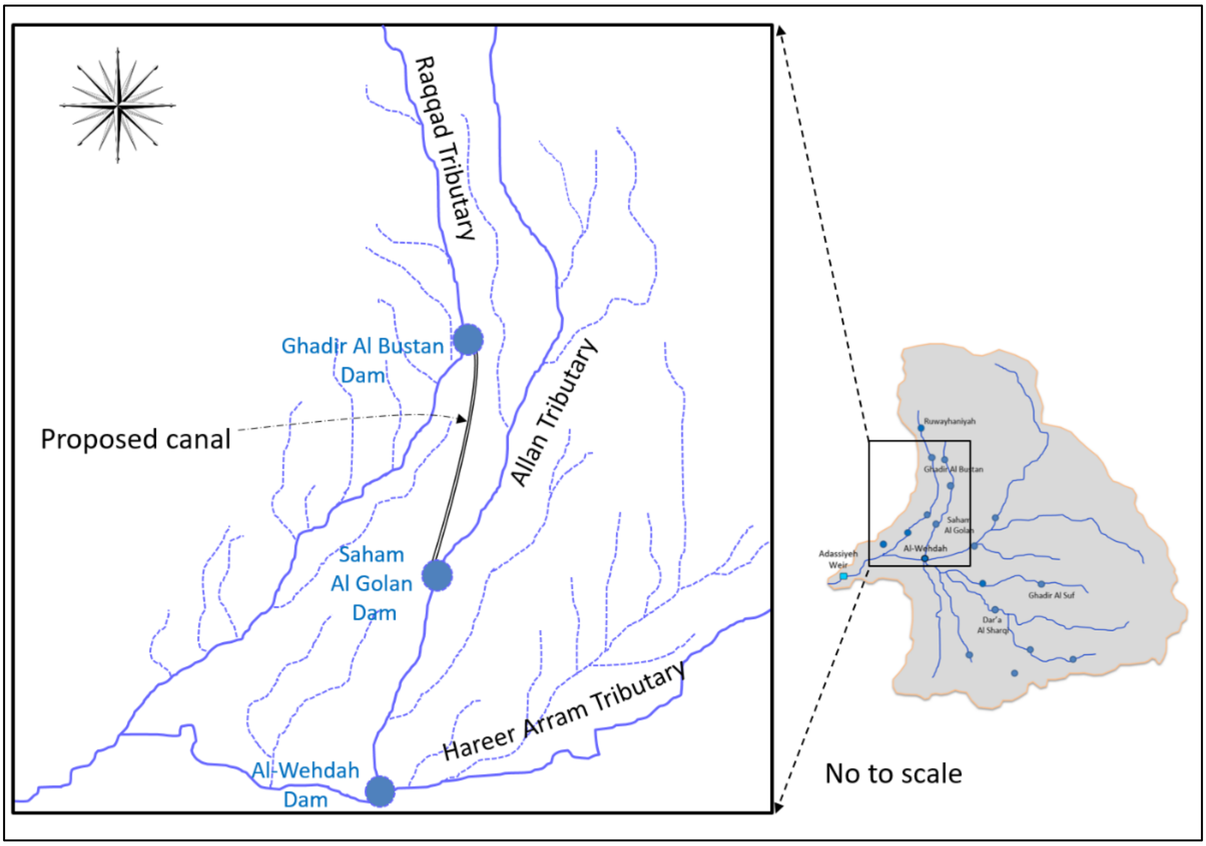

Figure 28. Optimized scenarios for constructing a canal between Ghadir Al Bustan and Saham Al Golan Dams in the YTJRB

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Annex-1

Commonly used methods and tool to measure ET

1. Ground measurements are the most creditable methods to calculate crop or reference crop ET, but they usually applied to limited areas depending on the availability of device and instruments. These measurements include mainly the installation of Lysimeters, Pan Evaporation, Leaf area index (leaf area meter), Bowen ratio stations. Etc.
2. ET can be computed from meteorological data where there are a large number of empirical or semi-empirical equations have been developed for estimating ET (crop or reference crop) from weather data. Examples of these computations are the FAO Penman-Monteith PM-ET◦ method Sargreaves-Samani (HS).
3. Remote sensing has also a wide range of applications in the estimation of ET, and this can be directly deduced or by calculating one or more variables needed for the equations to calculating ET where surface energy balance is the main factor to be determined. In addition, spatially consistent and temporally continuous *E* mapping can be retrieved from remotely sensed products (i.e., surface energy balance-based models, Normalized Difference Vegetation Index (NDVI), land surface temperature (LST) space models, etc.). For these products, a Web-based client interface has been built in order to provide the application with Internet-based accessibility.