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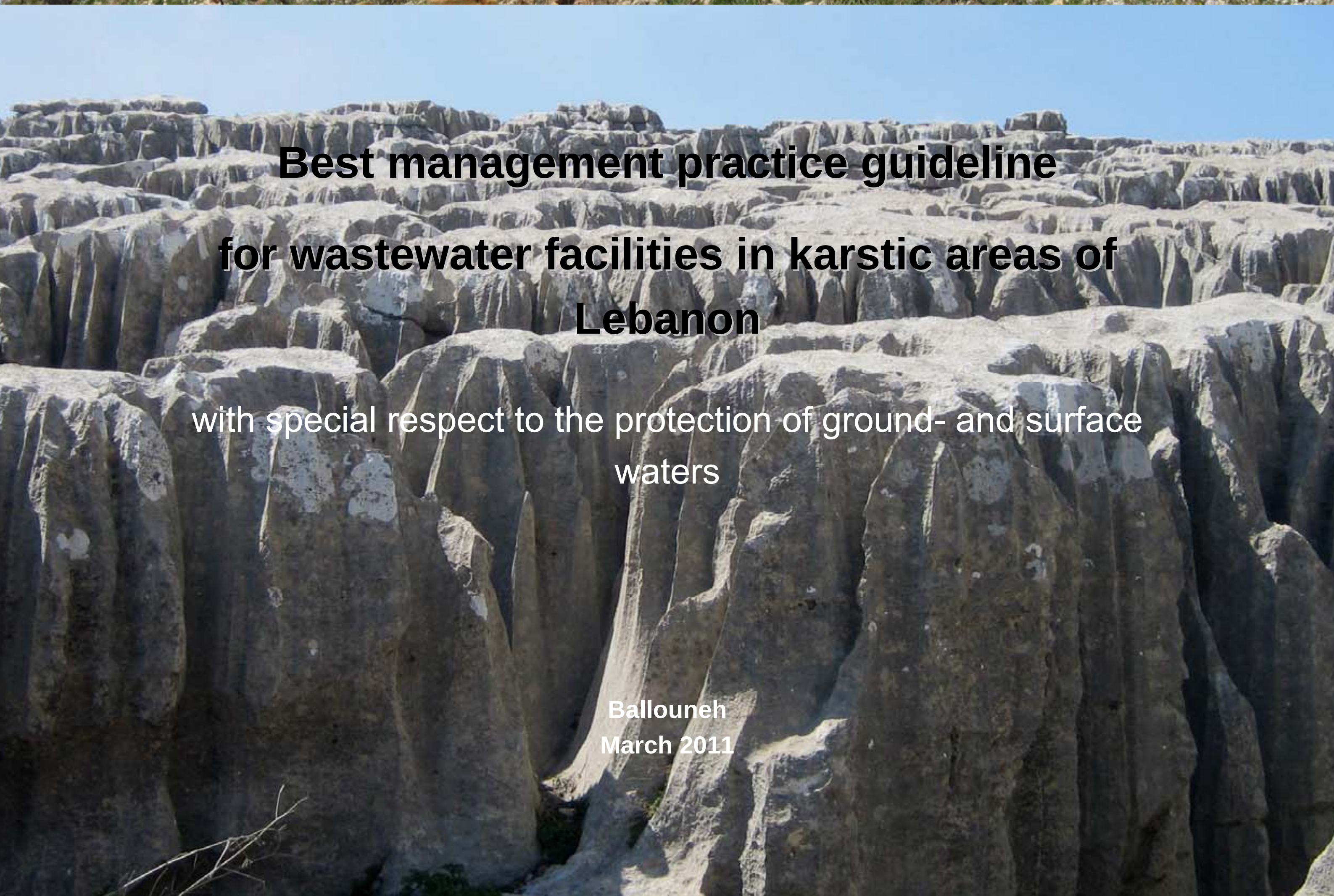

Best management practice guideline for wastewater facilities in karstic areas of Lebanon

with special respect to the protection of ground- and surface waters

Ballouneh
March 2011

Best management practice guideline

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Abbreviations

AOX	organic halogen compounds
BOD	biological oxygen demand
cfu	colony forming units
COD	chemical oxygen demand
DALY	disability-adjusted life years
DO	dissolved oxygen
DW	dry weight
EDC	endocrine disrupting compound
FC	faecal coliforms
HACCP	hazard analysis critical control point
MPN	most probable number
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenols
PCDD/F	polychlorinated dibenzodioxins and – furans
PE	person equivalents
PhAC	pharmaceutically active compound
SAR	sodium adsorption ratio
SAT	soil aquifer treatment
TC	total coliforms
TDS	total dissolved solids
TEq	TCDD (tetrachlorinated dibenzodioxin) equivalents
TOC	total organic carbon
TSS	total suspended solids
WFD	water framework directive (EU)
WWTP	wastewater treatment plant

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Executive Summary

Water resources protection is the main aim for the establishment of wastewater facilities. However, in many cases the planning of wastewater facilities does not sufficiently integrate all geoscientific aspects relevant for their protection. In karst areas, regulations need to be and commonly are much more stringent than in other areas. This Best Management Practice guideline specifically addresses the issues, which have to be considered for the protection of karst aquifers by wastewater facilities.

Wastewater treatment is still in the beginning in Lebanon. However, a large number of wastewater facilities are currently in planning. In order to achieve optimum protection of the water resources in Lebanon one can learn from international and regional experience.

This guideline gives recommendations on the potential impact on water resources with regards to:

- site selection and design process for wastewater treatment plants, collector lines and effluent discharge points
- selection of the optimal treatment method
- criteria for wastewater reuse
- criteria for sludge management
- monitoring of the treated wastewater effluent, sludge quality and effects of wastewater reuse and sludge application

Groundwater protection zones have not been implemented in Lebanon. The delineation of highly vulnerable areas is urgently needed to avoid unsuitable land use in these areas.

Wastewater master plans for the related surface water catchments are still missing in Lebanon. These are urgently needed before any related planning can begin. The main output of those plans is a proposal which and how villages could be meaningfully combined in wastewater schemes, where treated wastewater would be discharged or reused and how sludge will be managed. These proposals must specifically take into account the potentially negative impact on water resources, especially if used for drinking purposes, and the need for protection of those water resources.

A draft guideline for wastewater reuse and sludge reuse has been prepared by the Ministry of Energy and Water. However, currently this guideline does not sufficiently take into consideration the risk for water resources and the fast transfer in karst aquifers. It is recommended to modify the draft guidelines accordingly. Wastewater reuse and biosolids classes should not only be based on health concerns, but also on the hydrogeological and soil characteristics of the area. Karst areas (Mount Lebanon and Anti-Lebanon mountain ranges) have only limited suitable areas for wastewater reuse and biosolids application, while the Bekaa Valley (as a non-karstic area) is more suitable for reuse. Detailed hydrogeological

maps are needed for Lebanon, which would form the basis for reuse decisions. The monitoring of treated wastewater quality, regardless whether they will be reused or discharged into rivers or the sea, as well as the monitoring of wastewater sludge will require a massive increase in laboratory capacities, which needs to be planned for now.

1 Introduction

Clean water is vital to the survival and growth of all life and all economic and environmental processes. In Lebanon, water demand is bound to increase due to population growth (2.5 %) and increase in living standard. In contrast, water supply is likely to decrease due to climate change, overexploitation and pollution (IPCC, 2007; Miller, 2005). It is therefore paramount to protect existing water resources from contamination and increase the use of alternative water resources as new conventional water resources will not become available. The main pollution to water resources results from diffuse pollution like wastewater infiltration through cesspools and septic tanks as well as pesticide and fertiliser use in agriculture (LEDO; 2001). Point source contamination occurs where industrial and domestic effluents are discharged directly into streams or wells.

Building dams or desalination plants are common measures to increase water supplies. Building dams, however, does not increase the total amount of available water, but is only a means of temporary storage that goes hand in hand with increased evaporation losses and detrimental consequences for downstream users und downstream environmental needs (Devine, 1995; Williams and Wolman, 1985). Construction of dams on karstic grounds is impeded by leakage losses and sometimes dam failure due to subsidence or ground collapse (Waltham et al., 2005). They also pose a serious hazard if the dam wall breaks due to earthquakes, landslides or rock falls, which are not uncommon in Lebanon (Elnashai and El-Khoury, 2004). The high energy needs and the problems associated with disposal of highly saline brine make desalination an expensive and environmentally challenging option (Lattemann and Höpner, 2008).

The installation of wastewater treatment plants and the reuse of treated effluent on the other hand are of manifold use:

- By protecting groundwater through the establishment of wastewater treatment plants (WWTPs) and the establishment of groundwater protection zones, the health hazards from pathogens and other substances in drinking water adverse to human health are reduced.
- The increase of surface water quality allows an increase in biodiversity.
- Treated wastewater is an additional water resource, which is available throughout the year, even in drought years, and helps to conserve freshwater resources.
- The recycling of nutrients from treated wastewater reduces the need for fertilisers.

This report discusses the groundwater protection needs with special emphasis on karstic areas, showing examples from other countries (chapter 2.1). A brief introduction to wastewater treatment techniques and associated risks is given (chapter 2.2) and wastewater reuse options and guidelines (chapter 2.3) as well as sludge management option (chapter 2.4) from around the world are presented. After a short description of the current situation in Lebanon (chapter 3) best management practices for Lebanon regarding groundwater protection (chapter 4.1), wastewater treatment (chapter 4.2), effluent reuse (chapter 4.3) and sludge management (chapter 4.4) are proposed. Accompanying measures like public awareness raising (chapter 4.5) and monitoring needs (chapter 4.7) as well as economic considerations (chapter 4.6) are also discussed.

2 International Practices

2.1 Groundwater protection in karstic areas

Karst aquifers occupy large terrains of the earth (about 35 % in Europe, 25 % worldwide) and supply a significant portion of drinking water (up to 50 % in some European countries and regionally up to 100 %) (COST 65, 1995). They are commonly characterised by high heterogeneity and anisotropy. Depending on the karst maturity, either intergranular porosity or preferential flowpaths along solutionally enlarged voids dominates groundwater flow and storage. In mature areas, rapid infiltration and high flow velocities are commonplace. Water levels can hence fluctuate greatly and discharge usually responds rapidly to groundwater recharge events. Contaminants can easily enter karst aquifers through sinkholes and other epikarst features and spread rapidly over large distances in the conduit network (Fig. 1). Natural attenuation processes based on filtration and retardation are often very low, and the main process is only dilution. Due to rapid flow, retention times for degradation processes are low and even particulate matter can be transmitted in turbulent flow. Hence pollution is not treated in the groundwater system but only transferred. These facts make karst aquifers extremely vulnerable to groundwater contamination (e.g. Ford and Williams, 1989). Unfortunately, sinkholes are commonly perceived by the population as suitable for the disposal of storm- and wastewater resulting in widespread contamination (e.g. Emmett and Telfer, 1994; Ford and Williams, 1989), a fact commonly observed in Lebanon.

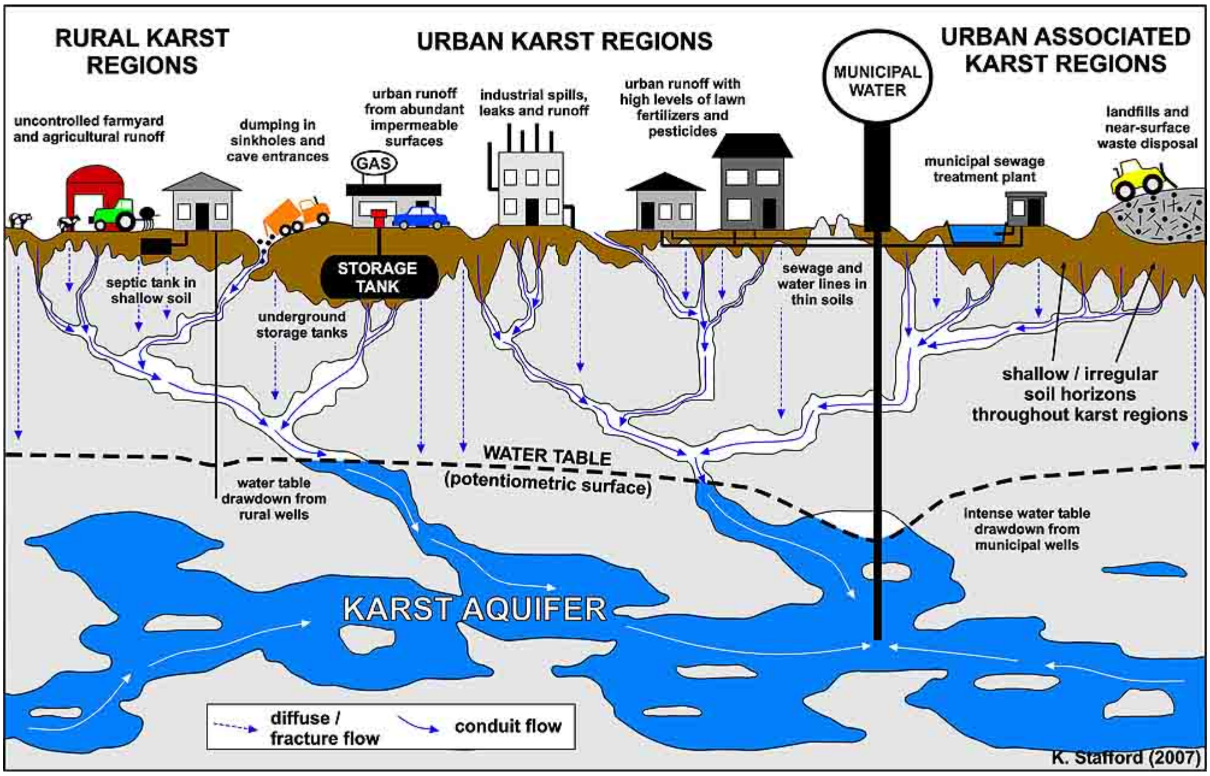

Fig. 1: Potential sources of contamination of groundwater and drinking water supplies due to rural and urban activities (from karstcentral.org).

Due to their complexity and vulnerability, management practices applicable to non-carbonate aquifers are often not appropriate for karst aquifers. The protection zone III (chapter 2.1.1) is not necessarily reflected by the topographic divides as divergent and disjunct flows are possible (Gunn, 2007). Also, the delineation of the protection zone II of a karstic spring cannot easily be defined, as travel times vary greatly from one area to the other depending on the karst features. It is therefore common practice to define the protection zone II as highly and very highly vulnerable areas based on groundwater vulnerability mapping (Margane, 2003a). A variety of vulnerability mapping methods has been developed. For an intrinsic vulnerability mapping parametric systems are mostly employed, while specific vulnerability mapping commonly uses index systems (Zwahlen, 2004; Vrba, 1994). Factors affecting the intrinsic vulnerability are properties of the unsaturated and the saturated zone like porosity, thickness of soil cover and depth to water table. The attenuation capacity of the soil is influenced by properties like pH, oxidation-reduction potential, cation exchange capacity as well as organic matter, clay and metal oxide content. The specific vulnerability is based on the intrinsic vulnerability and adds the properties that affect the attenuation of a selected contaminant like solubility, degradation processes, dispersion/dilution, sorption and complexation behaviour (Margane, 2003a).

While vulnerability maps are commonly used to assist decision makers in the land use planning process and delineation of groundwater protection zones, hazard maps are needed for risk assessment and risk management. Hazard maps include all anthropogenic potential pollution sources like sewer lines, septic tanks, wastewater treatment plants, waste disposal sites, residential areas, petrol stations, industrial sites, roads and agricultural practices etc. (Chilton, 2006). After estimating the likelihood of the occurrence of a hazardous event and assessing the possible consequences (amongst other things based on the distance to the protected resource or target), risk management selects options to avoid the event and/or decrease the consequences (Margane, 2003a). The management options include the restriction of land use practices, building codes and the installation of monitoring networks to detect a potential pollution early. Groundwater protection will become more vital as the pollution potential increases due to urbanisation and intense farming practices.

The quality and scale of available data is critical for the development of vulnerability and hazard maps as the outcome cannot be better than the input. Detailed mapping of karstic features is essential for evaluating preferential flow paths and tracer tests are necessary to estimate the extent of the recharge area and flow velocities.

2.1.1 European Union

The **European Water Framework Directive** 2000/60/EC (WFD) (EC, 2000) is the guiding principle for all European countries. It comprises the groundwater directive 2006/118/EC (GWD) (EC, 2006) and directive for priority pollutants 2008/105/EC (EC, 2008) setting the target for attaining a good groundwater chemical and quantitative status. It is based on a protection zoning system for groundwater resource and drinking water source protection. For porous aquifers protection Zone I (immediate protection zone) is located in a small area around the spring or wellhead, varying from 5-100 m radius. Zone II (inner protection zone) is usually based upon the time of travel, varying between 10 (Switzerland) – 100 (Ireland) days, which should result in pathogen die-off. Zone III (outer protection zone) encompasses the entire catchment or recharge area (Margane, 2003b). For karst aquifers some countries prescribe protection zones around infiltration points or regions without sufficient soil cover and increase the travel time limit.

For karst areas a European karst groundwater protection guideline has been issued by COST 65 (1995) and a new vulnerability mapping and risk assessment approach has been developed by COST 620 (Zwahlen, 2004). The approach is based on an origin (potential contaminant release) – pathway (vertical and horizontal passage) – target (groundwater surface or spring/well) model combining intrinsic and specific vulnerability (Fig. 2). The **COP method** for intrinsic vulnerability evaluates the concentration of flow, i.e. degree of bypassing (C), the overlying layer properties (O) and the precipitation regime (P) (Vias et al., 2006). A karst network development factor (K) was also added, which could be further subdivided (Andreo et al., 2009). Specific vulnerability incorporates the effectiveness of attenuation processes as additional weighing factor for diffuse flow. The new approach has been tested at two sites in Spain, but the validation of vulnerability is difficult (Andreo et al., 2006).

Hazard mapping is based on a 7-step work plan (identifying the hazards (inventory), rating and weighing them etc.) resulting in a map with hazard indices. The risk assessment combines the probability of a hazardous event and vulnerability at the site into a risk intensity index. A risk sensitivity index is derived by incorporating the potential consequences. It is recommended to validate the produced maps with hydrographs, chemographs, isotopic chemistry, tracer tests or numerical modelling and to verify the map through comparison with other methods.

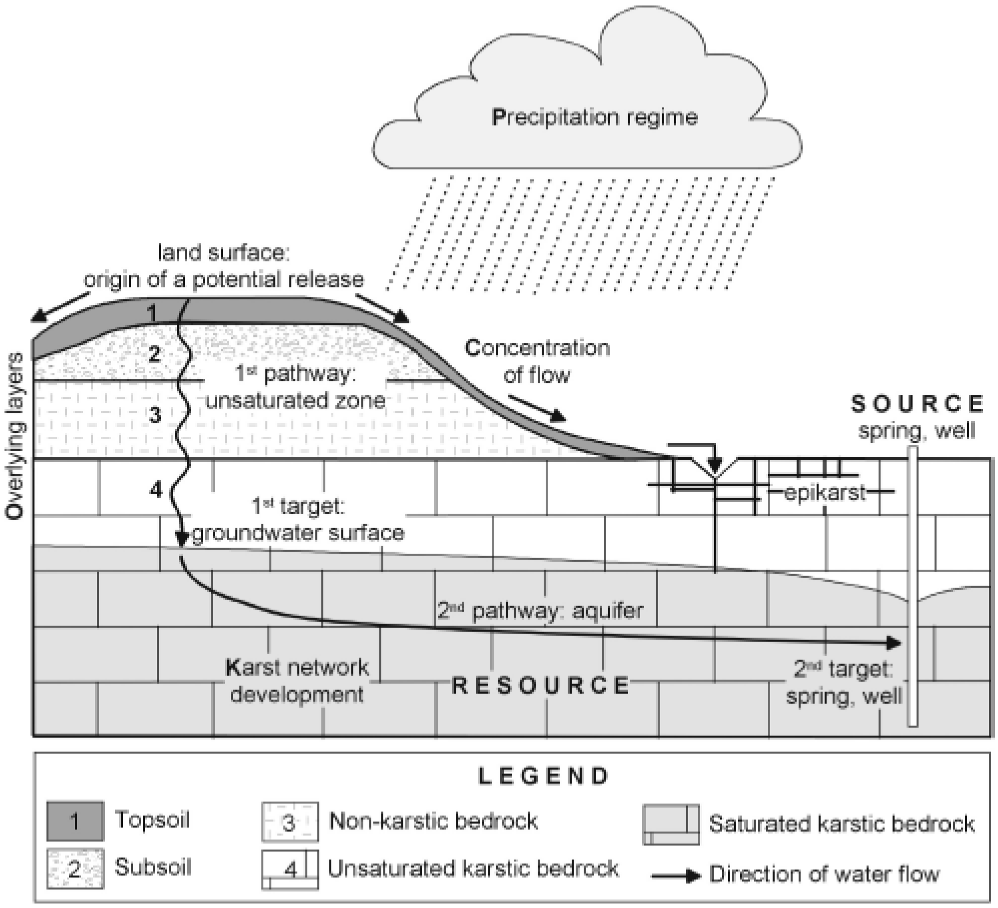

Fig. 2: The European approach to groundwater vulnerability mapping based on the origin – pathway – target conceptual model. For resource protection the groundwater surface is the target, for source protection the spring or well is the target, i.e. the horizontal passage through the saturated aquifer is only included of source protection. The main factors are the concentration of flow (C), the properties of the overlying layers (O), the precipitation regime (P) and the karst network development (K). (after Zwahlen, 2004)

2.1.2 Germany

The legal basis for groundwater protection is the German Water act (Wasserhaushaltsgesetz, Bundesregierung, 2009) and the groundwater ordinance (Grundwasserverordnung, Bundesregierung, 2010). The federal states are responsible for their implementation. The DVGW regulation (DVWG, 2006) is generally accepted, prescribing a minimum of 20 m upstream from the well/spring for protection zone I. Areas of artificial recharge have to be included in zone I as well. A 50 day travel time line (min. 100 m) for protection zone II is prescribed. The standard method includes the use of numerical models or graphical methods in porous aquifers. For karst aquifers zone II might extend to a maximum of 2 km upstream, but should include areas of increased risk like slopes generating runoff, infiltration features, streams, fault zones, areas with thin soils etc. (Hölting et al., 1995; Bolsenkötter et al., 1984). If thick strata of low permeability overlay areas of the catchment, these will be assigned to zone III (Fig. 3; DVGW, 2006). The immediate vicinity of the spring/well has to be fenced in and no actions are permitted that are not essential for the drinking water supply.

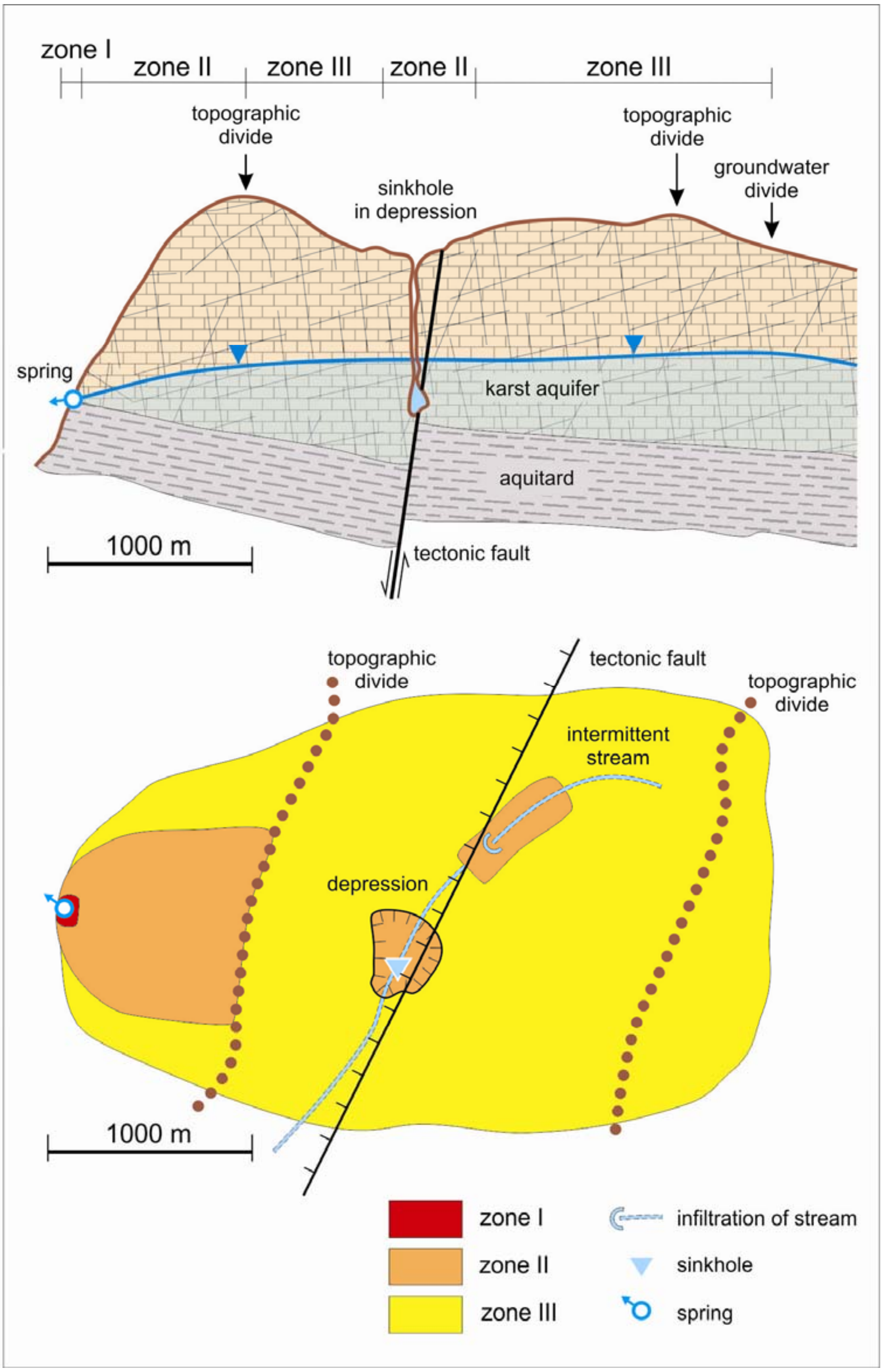

Fig. 3: Example of delineation of groundwater protection zones for a karst spring with high flow velocities: a) cross section, b) top view (after DVGW, 2006)

Restrictions in zone II prohibit any new development or construction, construction of roads, infiltration of sewage, application of pesticides, fertilisers or sewage sludge, use of hazardous substances, mining of mineral resources and use as pasture or livestock husbandry. Groundwater protection zones have to be clearly marked and regularly monitored. This includes water quality measurements at the well/spring and observation bores as well as inspections of the area.

For vulnerability mapping the **GLA method** (Hölting et al., 1995) or the **PI method** (Goldscheider et al., 2000), which is a modification of the GLA method more suitable for karstic environments, are employed. The effectiveness of the protective layers (P) is rated according to thickness and hydraulic conductivity of soil and subsoil, but does not include the thickness of the unsaturated zone. The infiltration conditions (I) indicates the relative degree of diffuse to direct infiltration. Precipitation regime is not included, but detailed knowledge of precipitation intensity and soil saturation to evaluate surface runoff is often not available anyway.

2.1.3 Italy

Each regional government is responsible for the implementation of the EU and state legislation (Italian Government, 2006). A new simple method for delineation of source protection zones especially for karstic springs has been included in the Italian technical standards. It involves the analysis of the **recession curve** of a spring in flood (Civita, 2008). After a rain event, the discharge at the spring rises until a peak is reached. The recession curve describes the decrease in discharge, which is commonly faster shortly after the peak and then tails of into the base flow. The maximum discharge half-time (MDHT) is defined as the time it take after the peak to reach half of the peak discharge. According to peak discharge (Q_{max}) and MDHT the hazard scenario of the spring is evaluated according to Fig. 4. The dimensions of the protection zones are scaled according to the scenarios. For areas with high contamination potential (scenario A and B) zone II encompasses the whole catchment area. For scenario B zone II can be decrease to a 2 km section upstream if a thick protective layer or aquitard provides enough protection. For scenario C and D, the upstream distance of zone II is 400 - 600 and 200 - 300 m, respectively. If sinkholes exist in the area, their vicinity will be one protection zone higher than the surrounding area (Fig. 5). This method only needs a continuous recording gauge or daily discharge records to identify the travel time in the saturated zone and can hence be applied easily.

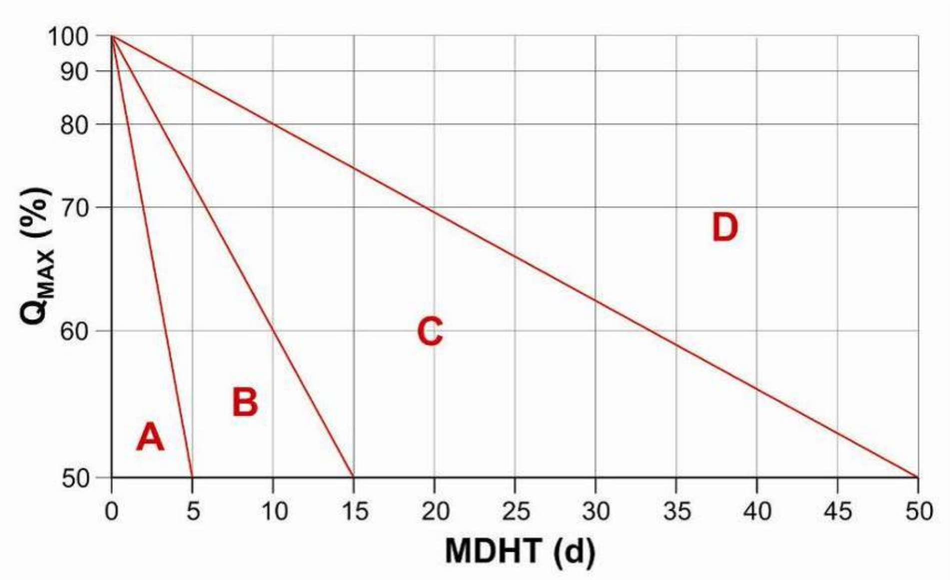

Fig. 4: Nomograph for identification of the contamination hazard base-scenario A-D of karst springs as a function of MDHT (maximum discharge half-time) and peak discharge (Q_{max}) (after Civita, 2008)

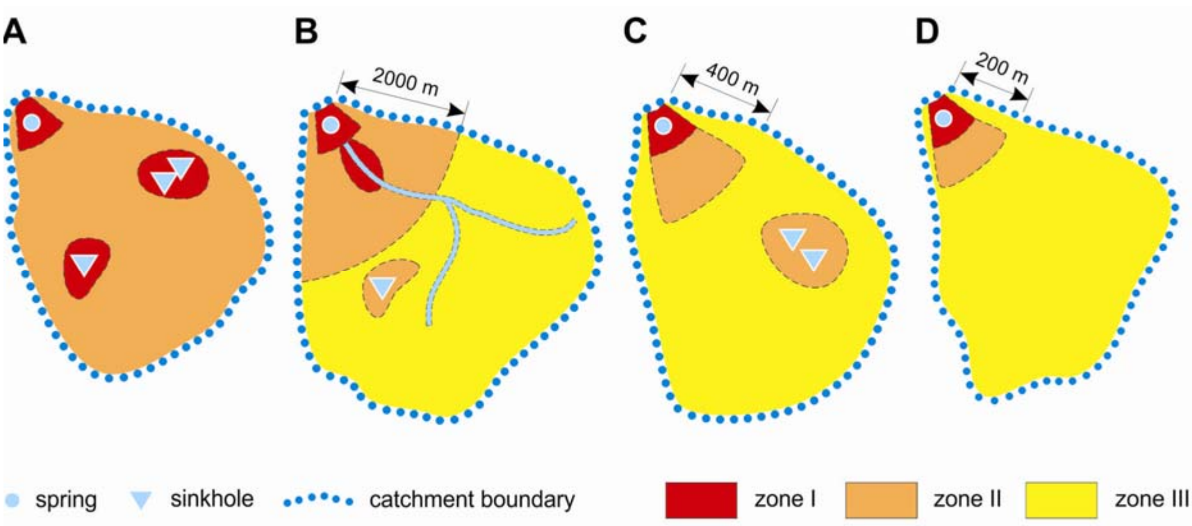

Fig. 5 Dimensioning of protection zones for the vulnerability scenarios A - D (after Civita, 2008)

Protection zone I is defined by a distance of 10 - 40 m upstream and 2 - 10 m downstream of the spring. All human activity is prohibited apart from planting trees. No spillage of polluting matter or release of effluent is allowed in Zone II for scenarios A - C. The outer protection zone restricts the settlement and land use, but a limited efficiency of protection is still unavoidable. Therefore auxiliary safeguarding strategies such as implementation of a monitoring network, installation of a disinfection plant and a linkage to alternative water supplies should be adopted (Civita, 2008).

2.1.4 Switzerland

In Switzerland (not a member of the EU) the Water Protection Law (1991) requires a qualitative and quantitative protection against aquifer overexploitation and impairment for all areas. The 'water protection map' is the central instrument for its implementation (BUWAL; 2004). The protection zone I (S1) around the spring/well and all areas with high vulnerability has a minimum radius of 10 m and has to be fenced and no activities are allowed. The protection zone II (S2) is defined by the 10 day travel time line and a minimum distance of 100 m upstream. If no groundwater table contour map exists, it is determined through tracer tests and the first arrival time of the tracer not the peak time should be used in karst aquifers with high flow velocities. Apart from a general construction prohibition, the restrictions include a prohibition for sewage sludge, liquid manure or pesticide application (ChemRRV, decree to reduce the risk of chemical contamination). The protection zone III (S3) is a buffer zone with the same distance upstream than the distance between S1 and S2. Restrictions in this zone include the prohibition of industrial and commercial enterprises with high groundwater pollution potential or quarrying. The Swiss concept includes further zones for persistent or mobile pollutants: the area with supplies about 90 - 100% of the groundwater flow to the spring (protection zone for groundwater quality restoration) and the total catchment area including all areas which drain into the catchment area either underground or on the surface (Fig. 6). Also potential groundwater resources (conservation areas), which are currently not used, but might be used in the future, are set apart and no buildings or activities are allowed that would impair future protection zone declaration. Even though the Swiss groundwater protection system is very detailed, the protection zones only allow a partial protection of groundwater resources in karst areas and contamination of drinking water is not uncommon (Doerfliger and Zwahlen, 1998). Details of the regulations for selected uses are listed below (Table 1).

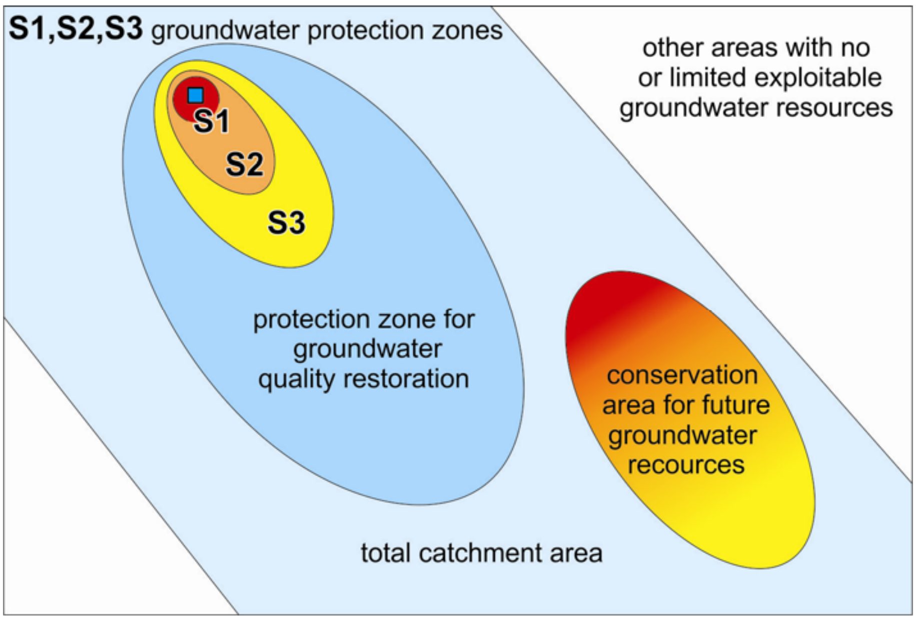

Fig. 6: Elements of the Swiss groundwater protection scheme (after BUWAL, 2004)

Table 1: Prohibitions for selected land uses or activities (after BUWAL, 2004)

land use or activity	S1	S2	S3	future area	catch-ment area	other areas
sewage collectors for domestic effluent	-	-[1]	+b[1]	-[2]	+	+
sewage collectors for industrial effluent	-	-	b[1]	-[2]	+	+
wastewater treatment plants	-	-	-	-	b	+
decentralised biological wastewater treatment plants[3]	-	-	b[4]	-[2]	b	+
septic tanks[3]	-	-	-	-	-	-
infiltration of non-polluted groundwater	-	-	b	-	+b	+
infiltration of non-polluted effluent via soil passage[5]	-	-	-b[7]	-[2]	+	+
infiltration of non-polluted effluent without soil passage[6]	-	-	-	-	b	+
infiltration of treated sewage	-	-	-	-	-b	-b
grassland for hay production	+	+	+	+	+	+
pasture	-	+[8]	+	+	+	+
field	-	+[9]	+[9]	+	+	+
fruit trees, vines, vegetables	-	-	+[9]	b[2]	+	+
irrigation with non-polluted ground- or surface water	-	-b	+	+	+	+
livestock husbandry	-	-	-	b	+	+
pesticide use on fields	-	+[10]	+	+	+	+
pesticide use on fruit trees, vegetables	-	+	+	+	+	+
liquid manure use on fields, fruit trees, vegetables	-	-[11]	+	+	+	
solid manure, compost or mineral fertiliser use on fields	-	+	+	+	+	+
solid manure, compost or mineral fertiliser use on fruit trees, vegetables	-	-	+	+	+	+
mineral resource exploitation above groundwater level	-	-	-	-	b	+
construction of buildings	-	-b[12]	-b	-b[13]	b[13]	+
use of recycled materials in roads	-	-	b	-	+	+
industrial land use with potential groundwater contaminating substances	-	-	-b	-[2]	b[14]	+
land fills	-	-	-	-	+b	+b

+: permitted, - not permitted, b: permission required, -b: generally not permitted, but permission after case specific consideration possible; 1: fulfilling requirements (SIA-Norm 190) with visible pipes inside buildings and inspection every 5 years, double-pipe system might be required in S2; 2: possible with permission in future S3; 3: discharge into receiving stream in accordance with environmental limits; 4: no infiltration of treated effluent; 5: min. distance to groundwater table 1m; 6: artificial filter needed, 7: exception infiltration of clean roof runoff via soil passage; 8: only for extensive use of pastures, 9: only limited percentage of intensive agriculture allowed, 10: not permitted if spring could be affected, 11: permission for a max. of three times 20 m^3/ha during vegetation period with long enough intervals, if groundwater table is 3 m below surface and no surface runoff or fast infiltration is possible; 12: no industrial or commercial buildings with potential groundwater contamination, 13: buildings should not be reaching into the saturated zone thereby impairing more than 10% of the flow to the spring; 14: only above mean groundwater table and no underground storage tanks of hazardous substances

In karst areas with high groundwater velocities the protection zones I - III are delineated by using the vulnerability map: very high vulnerability corresponds with zone I, high vulnerability with zone II and medium vulnerability with zone III. The standard method for vulnerability mapping in karst areas is **EPIK**, a multi-criterion method (Doerfliger and Zwahlen, 1998). It factors in the development of the epikarst (E), the effectiveness of the protective cover (P) (mainly using soil thickness), the conditions of infiltration (I) (including slope, runoff, preferential infiltration, hydrological characteristics, spring discharge) and the development of the karst network (K) (including size and connectivity of conduits, tracer test, flow hydrographs, water quality variability), which are combined by weighing factors to the final score. It involves detailed mapping in the field and high resolution aerial images to determine the epikarst and karst features. Hydrograph separation methods of detailed discharge curves can be used to determine the size of the recharge area. Furthermore, numerical models can be used to evaluate the vulnerability of the spring to diffuse source pollution under variable hydrological input or constant recharge setting (Butscher and Huggenberger, 2009) It does not include recharge or the thickness of the unsaturated zone. It is recommended to install continuous monitoring devices for discharge, turbidity, electric conductivity, UV-absorption and maybe particle distribution. A climate station should be located nearby (Auckenthaler, 2007).

2.1.5 USA

The Water Pollution Control Act also known as the Clean Water Act (1987) and the Water Quality Act (1987) are the main federal law in the USA trying to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Groundwater is not directly addressed in the Clean Water Act but included in the Safe Drinking Water Act (1996), the Resource Conservation and Recovery Act (1976) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund (1986) (LaMoreaux et al., 1997). The states are responsible for the delineation of wellhead protection areas including hazard inventories, contingency plans, land use planning, best management practices for groundwater protection and source water assessment (Margane, 2003b). The guidelines for the delineation of wellhead protection areas (US EPA, 1987) is not very precise but proposes a three zone system as in other countries with a remedial action zone (zone I), an attenuation zone (zone II) and a well field management zone (zone III). Apart from travel time, the delineation could be based on distance, drawdown, flow system boundaries or/and the attenuation capacity of the aquifer. Specific criteria are not set, but are to be developed by the States and commonly involve public participation. For karst aquifers with high flow velocities the delineation of the drainage basin should be undertaken with discharge curves, water table elevations and tracer tests.

The most commonly used method for vulnerability mapping is the **DRASTIC method**, which is based on the seven parameters depth to groundwater table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone media (I) and hydraulic conductivity of the aquifer (C) (Aller et al., 1987). As it does not consider bypassing of the vadose zone or the complexity of karst features, it is not very suitable for karst areas. Due to its simplicity and the limited amount of data needed, it is often applied and suitable for regional scale evaluations, but does not differentiate different vulnerability levels in one karst aquifer (Metni et al., 2004; Goldscheider et al., 2000).

2.1.6 General conclusions

The guiding principle should always be to prevent pollution rather than treating occurred pollution, as remediation is more costly and often not possible ('**precautionary principle**'). The general concept of groundwater protection based on a zoning system with a minimum of three zones can be found worldwide. The number of activities permitted in each zone is decreasing with decreasing distance to the spring/well (Schmoll et al., 2006). A national policy on groundwater protection and regulations detailing the delineation and permitted or restricted activities in each protection zone should be implemented in each country. For a more detailed review and recommendations on how to implement groundwater protection measures see Margane (2003b). A general introduction to water pollution control and case studies are outlined by the WHO (Schmoll et al., 2006; Helmer and Hespanhol, 1997).

Groundwater protection in karst aquifers is commonly based on a **vulnerability map**, where areas of the highest vulnerability are prioritised. Comparison of different methods show a general correlation connected to the mean transit time, but also significant differences in the resulting vulnerability map due to different integrated factors (e.g. Neukum and Hötzl, 2007; Vias et al., 2006; Goldscheider, 2005). The choice of method depends on data availability, the scale and the purpose of the map. For a more detailed review and comparison on methods see Margane (2003a).

Risk management is often based on the hazard analysis critical control point (HACCP) approach for existing and new hazards (Howard and Schmoll, 2006; Aertgeerts and Angelakis, 2003; Fewtrell and Bartram, 2001). This multiple barrier approach is based on seven principles: (1) hazard analysis, (2) identification of critical control points, (3) threshold value establishment at critical points, (4) monitoring requirements for critical points, (5) corrective action and contingency plans, (6) record keeping procedures, and (7) validation of HACCP plans. Adapted to groundwater protection this approach would include the set up of a reliable monitoring system to detect possible contamination early, and a shut down procedure or switch to other water supplies, if threshold limits are infringed (WHO, 2004; Howard, 2003; Barry et al., 1998).

2.2 Wastewater treatment

If wastewater is not treated, but discharged into the environment, it contaminates surface and groundwater incurring environmental and economic costs like:

- costs caused by increase in disease and mortality and indirect loss of income
- higher treatment costs for the production of safe drinking water or increased costs at household level for buying bottled water
- loss of income from fisheries
- loss of income from tourism, as a polluted environment deters tourists
- loss of biodiversity in rivers and the sea

A good management of wastewater is therefore of manifold benefit for the population and the environment.

2.2.1 Wastewater constituents

Wastewater can be derived from a number of **sources** (domestic, industrial and - depending on the drainage system - stormwater) and contains a range of contaminants at different levels in relation to the source. Domestic wastewater can be differentiated into 'greywater' (wash water from bath and kitchen), 'yellow water' (urine) or 'black water' (urine and faeces). These three sources exhibit very different characteristics (Table 2). Through separate collection and treatment of these streams the different characteristics can be used most efficiently. This concept constitutes the basis of Ecological Sanitation (Ecosan) (Peasey, 2000; Winblad and Simpson-Hébert, 2004). Greywater constitutes the highest volume of domestic wastewater but contains only a limited amount of contaminants (mainly surfactants, boron, P, fats) and can be easily treated to be reused in irrigation or toilet flushing (Kramer et al., 2007). Human urine contains the highest levels of nutrients and can become a valuable fertiliser (Larsen et al., 2001), while faeces contain high levels of organic material and minerals (Ca, Mg, Fe) that can be treated to generate biogas and soil conditioner. The latter also contain the highest levels of pathogens and should be handled accordingly (WHO, 2006).

Industrial wastewater that contains high levels of heavy metals and/or organic pollutants should be treated at the industrial site and not mixed with domestic wastewater, as it will require special treatment and would impair the treatment effectiveness of conventional wastewater treatment plants (Chan et al., 2009; Üstün et al., 2007, Chang et al., 2002).

Table 2: Typical characteristics of domestic wastewater components (after Geigy, Scientific tables, 1981 in Fittschen and Hahn, 1998)

	yearly load (kg/cap/a)	greywater (bath/kitchen)	black water (flush toilet)	urine (urine separation)	faeces (dry toilet)
volume (L/cap/a)		25 000 – 100 000	6 000 – 25 000	500	50
nitrogen	4-5	3 %	97 %	87 %	10 %
phosphor	0.75	10 %	90 %	50 %	40 %
potassium	1.8	34 %	66 %	54 %	12 %
COD	30	41 %	59 %	12 %	47 %

Health risks stemming from wastewater are related to microorganisms that can lead to disease by ingestion or contact. **Pathogens** of concern are classified as virus, bacteria, protozoa and helminth (Table 3):

- Viruses are the smallest pathogens and include highly contagious enteroviruses (polio, echo, coxsackie), hepatitis A and E, and a range of viruses causing diarrhoea and gastroenteritis (Toze, 1997). Due to their small size, they are able to pass filtration devices and can be detected in drinking water, even after disinfection (Vivier et al., 2004, Meng and Gerba, 1996). Their removal rates are significantly correlated to temperature with a faster die-off at high temperature (John and Rose, 2005) and with turbidity reduction, as they are partially attached to solids (Characklis et al., 2005).
- Bacteria are the most common and numerous pathogens including harmless and pathogenic coliforms, salmonella, shigella, and enterococci. They cause classical waterborne diseases like typhoid, dysentery, cholera and other gastrointestinal illnesses (Asano et al., 2007; Toze, 1999). Those attached to particulate matter (10-70%) (Boutilier et al., 2009; Characklis et al., 2005) could be removed via settlement or filtration. If removal of salmonella can be achieved, the removal of the majority of other bacterial pathogens will be completed (Pescod, 1992).
- Protozoan pathogens are single-celled eukaryotic parasites, which survive as cysts outside their host, the most common being *Giardia lamblia* and *Cryptosporidium parvum* (Cohn et al, 1999; Toze, 1997; Rose et al., 1996). They can be inactivated via UV-radiation (Linden et al., 2002; Craik et al., 2000), but are fairly resistant to chlorination (Finch and Belosevic, 2002; Clancy et al, 2001; Craik et al., 2000).
- Helminths are common intestinal parasites including nematode, tape worms, hook worms, round worms and whip worms (Blumenthal et al., 2000; Toze, 1997). They produce eggs (ova) that can survive for months in water or soil.

Table 3: Occurrence and survival of pathogens (after Crittenden et al., 2005; Feachem et al., 1983)

	size [μm]	**common conc. in domestic sewage [number/100mL]**	**infectious dose N_{50}**	**usual survival time [days]**		
				in sewage	in faeces / sludge	on crops
viruses	0.01 – 0.3	10^2 - 10^4	1 - 10	<50	<20	<15
bacteria	0.2 - 10	10^7 - 10^{10}				
faecal coli.		10^5 – 10^8	10^6 - 10^{10}	<30	<50	<15
salmonella		10^2 – 10^4		<30	<30	<30
shigella		10^0 – 10^3	10 - 20	<10	<10	<5
protozoa	10-50, cysts: 4 - 6	10^0 – 10^5	1 - 20	<15	<15	<2
helminths	mm-cm, eggs: 35 - 70	10^0 – 10^3	1-10	months	months	<30

coli. : coliform bacteria, conc.: concentration

Wastewater also contains a range of harmless microorganisms that are used as **indicator** organisms for faecal contamination as they are ubiquitous and easy to detect, the most prominent being *Escherichia coli* (*E. coli.*). The spores of the anaerobic bacterium *Clostridium perfringens* and enterococci are exclusively faecal, show an extended survival time compared to *E. coli.* and other pathogens and have similar removal characteristics to viruses and helminth eggs (Personné et al., 1998; Pescod, 1992; McFeters et al., 1974). Therefore, monitoring for them should be implemented more often.

Wastewater contains a range of **inorganic and organic constituents** that should be reduced before discharge into the environment or further reuse. Attention should be paid to nutrients, salinity levels, heavy metals, organic matter content as well as trace organics like endocrine disrupting compounds (EDCs) and pharmaceutically active compounds (PhACs) (Bolong et al., 2009; Kasprzyk-Hordern et al., 2009; Toze, 2006). The latter two are of special concern, when reaching sensitive aquatic habitats (Kolpin et al., 2004). The concentration of these constituents depends on the type of toilet (dry, separation or flush) and on the volume of water that is being used in bath and kitchen to dilute the sewage (Table 2).

Surrogate parameters are commonly used to assess the quality of water, as they are easy to measure. The total organic carbon content (TOC) is commonly not measured, but reported indirectly as chemical oxygen demand (COD ≈ TOC/4) or biological oxygen demand (BOD ≈ COD/2). COD describes the amount of oxygen needed to oxidise all possible constituents via strong chemical oxidisers (and includes BOD). BOD_5 is a measure of respiratory needs of microorganisms over 5 days at 20 °C. Total suspended solids (TSS) are another measure of turbidity. As a number of other constituents are associated with solids, the removal of TSS is seen as an indicator for removal of attached contaminants (mainly pathogens, heavy metals and organic contaminants) (Boutilier et al., 2009; Makepeace et al., 1995).

Nitrogen can occur in a number of forms (nitrate NO_3^-, nitrite NO_2^-, ammonium NH_4^+ or ammoniac NH_3, nitrogen gas N_2) and is reported as total-N, organic-N or Kjeldahl-N (organic-N plus ammonium). It can be converted from one form to another through natural processes - many performed by microbes (like nitrification, denitrification, mineralisation). Phosphorus occurs in the form of phosphate (PO_4^{3-}). Elevated concentrations of both nutrients lead to eutrophication of aquatic systems (Smith et al., 1999).

2.2.2 Techniques and removal efficiencies

Apart from dry toilets (pit latrines, dehydrating toilets and composting toilets), where yellow water and faeces are treated separately, wastewater treatment systems are generally divided into primary, secondary, tertiary and advanced treatment techniques and disinfection.

- The **primary** treatment step is mechanical, where settable and floating solids are removed using screens, settling ponds, septic tanks, Imhoff tanks or clarification basins. It results in reduction in BOD, TSS, TOC and some metals associated with TSS (Asano et al., 2007). BOD reduction can be 25 – 50 % in the effluent and even more in hot climates (Mara, 1997). It generates large amounts of pathogenic sludge that have to be treated (Krekeler, 2008).
- The **secondary** treatment step is biological, where organic carbon is eliminated by bacteria in wastewater stabilisation ponds, baffled reactors, anaerobic filters, constructed wetlands, filter tanks, sequencing batch reactors, membrane bioreactor, activated sludge tanks, trickling filters or rotating biological contractors. Aerobic carbon break down is generally more effective than anoxic respiration, but anaerobic processes work quite well in hot climates, require no extra aeration, and generate methane, which should be captured for energy generation. BOD removal rates vary between 60-90% (Krekeler, 2008). Sludge generation is higher for aerobic systems than anaerobic systems. Secondary treatment also involves the oxidation of ammonium to nitrate (nitrification) and subsequent reduction to nitrogen gas (denitrification). The former process requires aerobic conditions, so additional oxygen is commonly supplied through aeration, while the latter process requires anaerobic conditions and the presence of sufficient organic carbon. A combination of aerobic and anaerobic steps therefore results in the highest nitrogen removal rates. Nutrients can also be removed when plants are able to extract them from the effluent (Kivaisi, 2001; Pescod, 1992). Phosphate can also be removed with chemical precipitation. A typical wastewater stabilisation pond series consists of three stages: anaerobic ponds (50-70% BOD removal), facultative ponds (mostly aerobic with microalgae growth for further BOD removal), maturation ponds (aerobic with algae or macrophytes for nutrient and pathogen removal, and biomass harvesting) (Pescod, 1992).
- The **tertiary** treatment step removes residual suspended solids via mechanical filtration (micro-, depth, or surface filtration) and is commonly used to optimise the disinfection process, as particles can shield pathogens from disinfection with chlorine and UV light. Infiltration of effluent through a soil passage (soil aquifer treatment, SAT) either for later

recovery or for artificial recharge is also used for polishing water quality (Moreno et al., 2008; Idelovitch et al., 2003; Bouwer, 2002). It removes large amounts of pathogens, suspended solids, organic matter and heavy metals (Pescod, 1992).

- The **advanced** treatment step removes residual colloidal and dissolved solids, including salts and trace organics, using a number of different techniques (nanofiltration, reverse osmosis, advanced oxidation, ion exchange, activated carbon adsorption and is applied when water reuse guidelines set specific quality restrictions. Advanced techniques like activated carbon or reverse osmosis have to be applied for enhanced removal efficiency of EDCs and PhACs.
- The **disinfection** step inactivates pathogens and can be achieved with chlorine, ozone, or UV radiation (Table 4). The most common technique is chlorine, as ozone is very cost intensive, but it may lead to disinfection by-product formation (Bougeard et al., 2010; Richardson et al., 2000; Krasner et al., 1989).

Table 4: Main advantages and disadvantages of common disinfection systems (after Tchobanoglous and Burton, 1991)

type	pathogen removal (log units)	advantages	disadvantages
chlorine compounds	virus: 1 – 3 bacteria: 2 – 6 protozoa cysts: 0 – 1.5	- established and effective technology - chlorine residual can be monitored and maintained - relatively cost effective	- hazardous chemical requiring safety measures - residual toxicity of treated effluent requires dechlorination - oxidises also organic and inorganic compounds - formation of DBPs - TDS in treated effluent is increased
chlorine dioxide	helminth eggs: 0 - <1	- effective disinfectant - biocidal properties not affected by pH - provides residuals	- unstable, must be produced on site - oxidises also organic and inorganic compounds - formation of DBPs - decomposes in sunlight - high operating costs
ozone	viruses: 3 - 6 bacteria: 2 – 6 protozoan cysts: 1 – 2 helminth eggs: 0 - 2	- effective disinfectant - more effective than chlorine with respect to viruses, spores, cysts - biocidal properties not affected by pH - little ground space required	- no residual effect - less effective at low dosages - oxidises a variety of organic and inorganic compounds - safety concerns (corrosive and toxic) - energy intensive - relatively expensive (extensive maintenance required)
UV radiation	viruses: 1 - >3 bacteria: 2 – >4 protozoan cysts: >3 helminth eggs: 0	- effective disinfectant - no residual toxicity - more effective than chlorine in activating viruses, spores - improved safety compared to chemical agents - little ground space required	- no residual effect - hydraulic design of UV systems is critical - energy intensive and relatively expensive

DBPs: disinfection by-products

Removal efficiencies of a typical wastewater reclamation facility for different constituents are summarised in Table 5. It can be seen that primary treatment removes inorganic and some organic suspended solids and attached heavy metals like mercury and cadmium. Phosphate is also found attached to solids (Pitt et al., 1999) and is hence removed partially. Biological ponds with water hyacinths as secondary treatment (Reddy and Sutton, 1984) remove most of the organic carbon and suspended solids as well as ammonium and some heavy metals, but do not reduce mineral contents. Lime precipitation and filtration as tertiary treatment removes most of the remaining heavy metals and phosphate. Finally, advanced treatment reduces the concentration of dissolved minerals and nickel. Boron is a critical parameter for plant health when used in agricultural irrigation but overall boron removal is very poor. Households should be advised to reduce their boron output by using detergents without borate bleaches.

Table 5: Removal of wastewater constituents in a water reclamation facility near San Diego, USA. Primary treatment: rotary drum screen and disk screens; secondary treatment: biological treatment ponds with water hyacinths, tertiary treatment: lime precipitation and depth filtration, advanced treatment: reverse osmosis, air stripping and carbon adsorption (after Asano et al., 2007)

	raw sewage	primary effluent	secondary effluent	tertiary effluent	advanced effluent	overall
	mg/L	% removed				
COD	185	19	74	5		98
TSS	219	40	55	4		>99
TOC	91	21	64	8	7	>99
TDS	1452	9	10	6	72	97
NH_4-N	22	5	52	1	39	96
NO_3-N	0.1	0	0	0	0	0
PO_4	6.1	16	28	54	0	98
Ca	74.4	3	7	0	88	99
Mg	38.5	1	0	82	13	96
Na	198	3	0	0	91	94
Cl	240	3	0	0	90	94
SO_4	312	9	0	0	91	>99
B	0.35	0	0	13	3	17
Cd	0.0006	17	0	67	0	83
Cu	0.063	0	33	52	0	83
Pb	0.008	0	0	93	0	91
Hg	0.0003	33	33	0	0	67
Ni	0.007	0	33	11	45	89
Zn	0.081	6	64	27	0	97

In general, inactivation/**removal rates of pathogens** can be influenced by the amount of particulate matter, oxygen, salinity, UV-light and temperature, the latter being the most important (John and Rose, 2005; Yates et al., 1990; Jansons et al., 1989). In primary treatment only settlement of particulate associated pathogens and some helminth eggs and protozoa cysts occur. Secondary treatment log removal rates vary widely between <0.1 (= 1,25 % removal) and 2 (= 99 % removal) for all pathogens due to the complex interplay of microorganisms, solids and water chemistry (John and Rose, 2005). Overall, the lowest removal rates are reported for viruses and the highest for bacteria. Tertiary treatment techniques show increasing log removal rates from depth filtration (0 – 4) over microfiltration (0 - 6) to reverse osmosis (4 - 7) with basically complete removal (Asano et al., 2007; Crook 1992). Their numbers are also reduced by die-off over time (Table 3) and hence wastewater stabilisation ponds with detention times of >21 days have been found to be fairly effective in removing pathogens (Table 6) and are recommended where conventional treatment plants are too expensive or difficult to operate (Al Salem, 2006; Blumenthal et al., 2000, Shuval, 1990). Percolation through soil or slow sand filtration has also been found to remove significant portions of pathogens (Bouwer, 2002; Schijven and Hassanizadeh, 2000; Bitton and Harvey, 1992).

Table 6: Relative removal efficiencies (%) of sewage treatment operations (after Shuval, 1990)

treatment operation	BOD_5	COD	TSS	bacteria	helminth eggs
fine screening	5 – 10	5 – 10	2 - 20	0	
chlorination raw, settled sewage	15 - 30	-	-	90 - 95	
sedimentation	25 - 40	20 – 35	40 - 70	50 – 90[a]	medium
chemical precipitation	50 - 85	40 – 70	70 - 90	40 - 80	
trickling filtration after sedimentation	50 - 95	50 – 80	50 - 92	80 - 95	good
activated sludge treatment after sedimentation	55 - 95	50 – 80	55 - 95	99[b]	good
stabilisation ponds	90 - 95	70 - 80	85 - 95	>99.9[c]	excellent

a: depending on residence time, 3 – 6 hours minimum; b: can decrease to 60% for poorly aerated systems; c: for series of three or more ponds with total residence time of 15 – 20 days or more

The **choice** for the appropriate technique depends on a range of factors; the wastewater volume and inflow quality and the required treated effluent outflow quality being the most important (Table 7). If water is generally scarce, dry sanitation should be considered. Separation of streams into grey-, yellow and black water decreases treatment costs and increases reuse options, but increases infrastructure costs. The installation of only greywater reuse systems at household level is another choice to consider (McIlwaine and Redwood, 2010; Redwood, 2008), which would reduce the volume and increase concentrations of nutrients and organic matter of the residual sewage to be treated. Extensive systems like constructed wetlands, wastewater stabilisation ponds etc. are recommended for small volumes and if space is not an issue. Their implementation in karst regions requires special care to avoid subsidence problems and overflow, but they are the most suitable treatment system for effluent reuse in agriculture (Shuval et al., 1986). Anaerobic systems are efficient for organic matter removal and have low energy consumption, but are sensitive to changes in inflow volume. As a general rule, as a treatment process becomes more complex (intensive systems), the amount of ground space needed will be reduced, whereas total costs and sludge production will increase. A detailed evaluation of different treatment techniques based on health risk, economic efficiency, environmental effects, operational requirements, plant technology, irrigation technology and type of reuse can be found in DWA (2008).

Table 7: Advantages and disadvantages of different types of wastewater treatment systems

type	advantages/applicability	possible risks and constraints
separate streams	- efficient reuse of all streams - retains nutrients for irrigation reuse - water saving technology - low costs	- odours and flies possible - perceived less hygienically - different treatment and collection systems - risk of groundwater pollution
combined streams	- one treatment and collection system	- contamination of large amounts of lightly polluted greywater - one toilet flush pollutes 3-9 L freshwater
decentralised systems	- low investments costs - low operational costs - for low density communities - low costs for sewer system - possible to operate with less skilled personal	- treatment efficiency variable - risk of groundwater pollution
centralised systems	- more effective control of quality standards and operational procedures - higher quality of effluent possible	- high investment costs - large sewer system - high operational costs - needs skilled personal
extensive systems	- for low loads - high nutrient removal rates - biomass harvesting for energy production - low sludge production - high pathogen removal rates	- space intensive - evaporation high - fly breeding possible - no electricity needed
intensive systems	- can achieve high removal efficiency	- high sludge production - high operational costs - electricity required continuously
aerobic system	- for high and variable loads - higher removal efficiency for nutrients and organic matter	- high sludge production - high energy consumption
anaerobic system	- low sludge production - high treatment efficiency for organic matter in hot climate - low energy consumption - methane can be used for energy production - retains nutrients for irrigation reuse - for concentrated sewage	- restricted to low-solid wastewater - sensitive to variable loads - limited removal of N and P - possible odour nuisance
soil aquifer treatment	- high solid removal rates - high pathogen removal rates - high public acceptance - seasonal storage possible	- not suitable in fractured/karst rock - potential for clogging and algae growth if not maintained properly

Operational issues like the personal requirements, cost of operation and maintenance including sludge processing costs, the availability of space and electricity, as well as climate, groundwater table fluctuations and soil conditions for pond systems should be considered when planning wastewater treatment systems. If only small volumes have to be treated or distances between individual residential buildings in a village are large, decentralised systems should be used. Centralised systems require an extensive sewerage/reuse pipe system increasing the chance of potential leaks and usually require pumping stations. Their costs are high due to high operational and maintenance cost as well as their need for skilled manpower. Centralised systems are only viable and efficient, if skilled personal and financial resources are available to operate and maintain the plant. Otherwise diffuse pollution from many decentralised systems is preferable to one large point source contamination from a non-working WWTP. Simple solutions that can be upgraded and maintained by local personal are more appropriate and cost-effective than high-end technology that does not work (Choukr-Allah, 2010). An overview about costs of common treatment options are given in Table 8.

Table 8: Economic considerations for different wastewater treatment systems (after WHO, 2006)

system	land requirements (m^2/inhabitant)	construction costs (€/inhabitant)	O & M costs (€/inhabitant/a)
conventional primary treatment	0.02 – 0.04	9 – 15	0.4 – 0.8
facultative pond	2.0 – 4.0	11 – 23	0.6 – 1.2
anaerobic pond + facultative pond	1.2 – 3.0	9 – 23	0.6 – 1.2
anaerobic pond + facultative pond + maturation pond	3.0 – 5.0	15 – 30	0.8 – 1.5
facultative aerated lagoon	0.25 – 0.5	15 – 27	1.5 – 2.7
constructed wetlands	3.0 – 5.0	15 – 23	0.8 – 1.2
rapid infiltration	1.0 – 6.0	9 – 23	0.4 – 1.2
overland flow	2.0 – 3.5	12 – 23	0.6 – 1.2
conventional activated sludge	0.12 – 0.25	31 – 50	3.0 – 6.1
activated sludge + extended aeration	0.12 – 0.25	27 – 38	3.0 – 6.1
conventional activated sludge + tertiary filtration	0.15 – 0.30	38 – 58	4.6 – 7.7
trickling filter	0.12 – 0.3	38 – 46	3.0 – 4.6

It is beneficial to consider effluent reuse at the same time as wastewater collection, treatment and disposal are planed, so the sewage treatment system can be designed to meet the effluent quality requirements (Pescod, 1992) (Fig. 7). **If reuse for irrigation is considered, anaerobic treatment might be preferred as it retains more nutrients and sludge volumes are lower**. If high mineral concentrations exist, these might have to be reduced using advanced treatment to meet irrigation water standards. **If effluent is to be discharged into streams, aerobic treatment with high removal rates of organic matter and nutrients is required**. The selection of the right location should also consider possible reuse options, as large distances to reuse schemes and high pumping lifts should be avoided. Agricultural reuse sites should mainly be selected based on the soil characteristics (permeability etc). The wastewater treatment plant should be shielded from any rainwater or inundations (topography) entering the plant. In karst areas, reuse options must consider the risk of contamination for nearby drinking water sources, such as springs and wells, and WWTPs should have a minimum distance to streams, wells or sinkholes, in case spills of raw sewage or half-treated effluent occur or wastewater is bypassed during times of peak flow. WWTPs should frequently be monitoring the effluent water quality and should be fitted with standby power supplies and large enough storage capacities for wastewater in case of peak flows (Pescod, 1992).

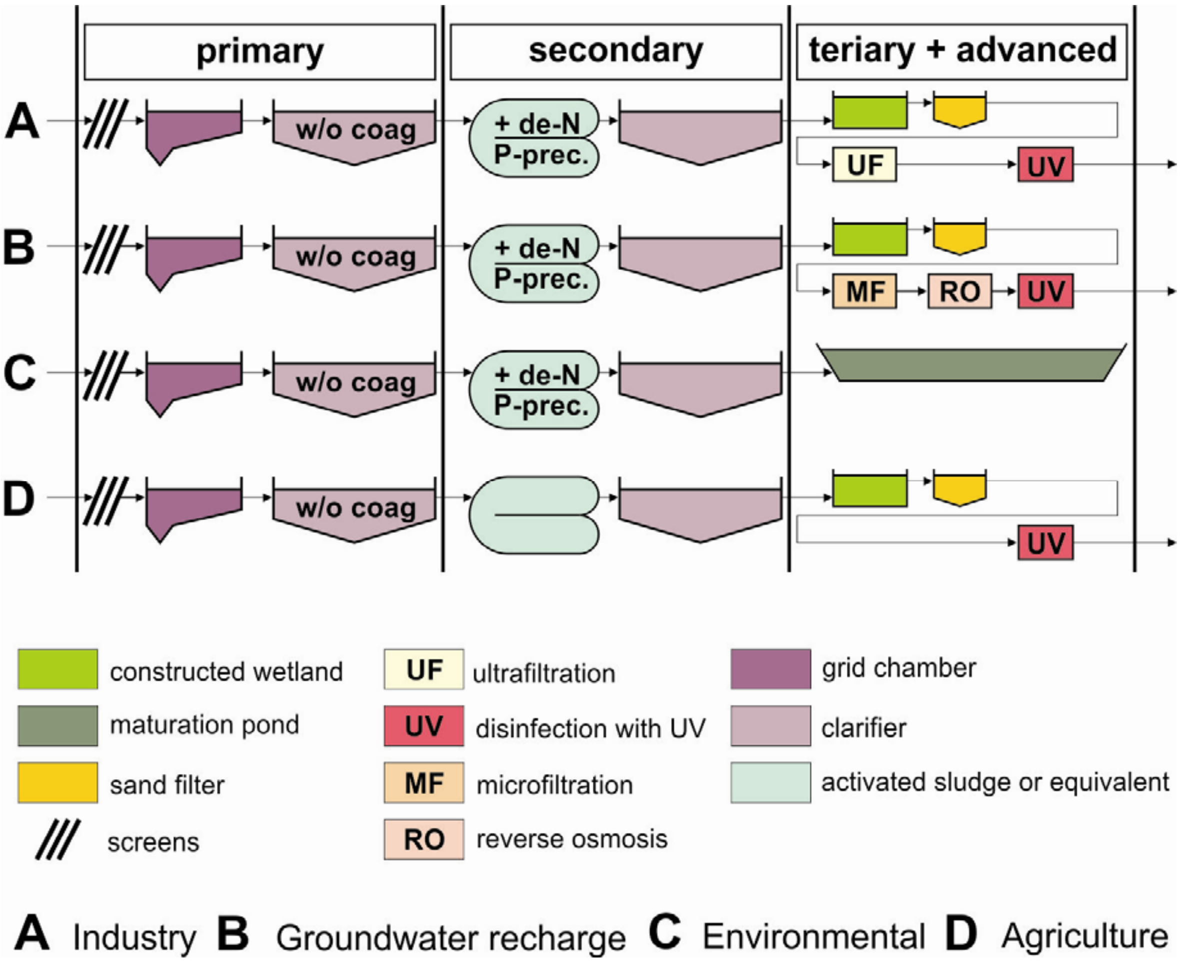

Fig. 7: Example for possible treatment trains depending on reuse (after AQUAREC, 2006)

Overall, affordability, operability, reliability, suitability and environmental soundness have to be considered for selecting a sustainable wastewater treatment system (Kramer et al., 2007). To select the right treatment systems the following factors have to be assessed:

- wastewater quality and volume based on the current and projected population size
- final wastewater destination and required quality (reuse scheme or discharge scenario)
- sludge production and disposal management
- costs of construction, operation and maintenance including the availability of electricity, spare parts and operator skills
- charges to be set and the willingness and ability of the population to pay them and their acceptance/demand for reused water
- land availability, topography, geology, climate and distance to residential and reuse areas
- management structure including public and private obligations

2.2.3 Sewer systems

Sewer systems are the infrastructure conveying sewage from buildings to the WWTP, including drains, manholes, pumping stations, sewer overflows etc. and need to be considered when selecting a site for the WWTP. Some regions have combined sewer systems, where stormwater and sewage are mixed, resulting in much higher and more variable volumes to be treated at the WWTP. The advantages are a regular flushing of the sewer system and the included treatment of stormwater, which is of importance in highly urbanised regions (Gasperi et al., 2008). The conventional sewer system is based on gravity and hence a gradient allowing a velocity of 0.5 – 1 m/s once a day for self cleaning is required (Amador Water Agency, 2009). If gradients are lower pressured pipes or pumping stations have to be installed. **Gradients that are too steep and allow velocities to be higher than 3 - 8 m/s on average will lead to fast wear down of the pipe material** (Table 9). In case of high gradients, it is critical to choose the appropriate curvature in the sewage network in order to avoid additional wear down and blockages (DWU, 2010: chapters 3.8 and 3.9).

Table 9: Allowable wastewater main slope (after DWU, 2010)

size of pipe (inch)	size of pipe (mm)	minimum slope (%)	maximum slope (%)
6*	152	0.50	12.35
8	203	0.33	8.40
10	254	0.25	6.23
12	305	0.20	4.88
15	381	0.15	3.62
18	457	0.11	2.83
21	533	0.09	2.30
24	610	0.08	1.93
27	686	0.06	1.65
30	762	0.055	1.43
33	838	0.05	1.26
36	914	0.045	1.12
39	991	0.04	1.01
>39	> 991	**	**

* pipes smaller than 6 inch are not allowed for wastewater mains (pipes smaller than 4 inches are not allowed in general); ** for pipe diameters greater then 39 inches, the slope is determined by Manning's Formula (Manning's roughness coefficient of 0.013) to maintain a velocity greater then 0.61 m/s and less then 3.04 m/s when flowing full

The set up of primary and secondary pipes can be conventional (requiring a larger diameters and a high number of man holes) (DWU, 2010) or can be simplified (a low technical solution more adjusted to the specific set up with lower gradient, smaller pipe diameter and laid in yards or under sidewalks resulting overall in much lower costs) (Mara, 1999; Mara, 1996; Bakalian et al., 1994). A completely different sewer system is vacuum sewerage (Little, 2004; Read and Geoffrey, 2004), where only limited amounts of water are needed for flushing. It significantly reduces the volumes of sewage to be treated, but breaks down when leaks occur and cannot operate without electricity (Table 10).

Table 10: Comparison of advantages and disadvantages of sewer systems (after Kramer et al., 2007)

type	advantages	disadvantages
free water level sewerage	- no energy consumption	- exfiltration and infiltration possible - maximum gradient
pressurised sewerage	- small diameter pipes - narrow trenching, shallow excavations	- technically complex - high energy consumption - exfiltration possible
vacuum sewerage	- small diameter pipes - narrow trenching, shallow excavations - no exfiltration	- technically most complex - high energy consumption
simplified sewerage (low-cost, low-tech)	- minimum pipe length - minimum gradient - small diameter pipes - less inspection manholes - less trenching and excavations	- exfiltration possible - more blockages
settled sewerage	- possible option where septic tanks exist - minimum gradient - small diameter pipes	- requires septic tanks to be emptied and cleaned on a regular basis

Common materials are vitrified clay, cement, reinforced concrete, cast iron, ductile iron, steel, PVC and HDPE pipes, depending on the composition and quality of the sewage, size of the pipe, pressure on the pipe and its location in the overall system. The installation of sewer pipes should accommodate the fact, that plastic pipes are destroyed by prolonged UV radiation (due to elusion of plasticiser). As all pipes can be destroyed through mechanical stress, **pipes should be placed into trenches with a minimum depth of 1.2 m, filled with fine material in order not to cause any leaks** (DWU, 2010). This might be problematic in karstic regions, where soil covers are thin or absent. Leaks should also be prevented by using bell and spigot joints with flexible seals. **Wastewater pipes should ideally be separated from water pipes by about 2.5 - 3 m to avoid any cross contamination. Where wastewater pipes cross water supply lines, wastewater pipes should be housed in a clay liner.** Manholes should be placed, where changes in size, material, grade, pipe alignment or intersections occur or at least every 150 – 250 m. **If sewers have to be built in groundwater protection zone II, leakage has to be rules out** (Eiswirth et al., 1995; Härig and Mull, 1992). **If the contamination risk is very high, double-walled pipe systems or vacuum systems and leak monitoring systems are required. In case of high contamination risk semi-double-walled or single-walled pipe systems with a limited numbers of joints combined with adequate monitoring is sufficient** (ATV-DVWK, 1995). **In karst regions, construction materials should not be hazardous to water and connections should be secure. Water tightness tests and inspections should be carried out at regular intervals** (ATV-DVWK, 1995).

2.2.4 *Effluent discharge*

If effluents are not reused, they are discharged into the environment either directly into the sea or into streams. As these are sensitive aquatic ecosystems, standards and limits are set for the discharge. Two different approaches can be found, firstly emission threshold values based on best technology and practical means (example Table 15) setting a minimum requirement, and secondly environmental quality standards based on ecotoxicological indicators and an immission assessment. The latter aims at the protection of human health, water quality, and ecosystems and both are often combined (Ragas et al., 2004). Nutrient levels should be as low as possible to avoid eutrophication. Immission assessment evaluates effluent discharge volumes in relation to stream flow, so sufficient dilution can be guarantied (Kasprzyk-Hordern et al., 2009). Effluent standards might hence be described as effluent concentration (mg/L), effluent mass loads (kg/a) or treatment efficiency (removal efficiency in % of influent quality) (Jacobsen and Warn, 1999). Effluent standards should also specify sampling methods, monitoring and reporting needs as well as non-compliance measures. Sampling frequency and sampling method for effluent discharges from selected European countries are shown in Table 11. Samples can be collected either flow-weighted, time-weighted or just as a grab sample. Detailed information about water and wastewater sampling is provided by EPA SA (2007a).

Table 11: Sampling frequency per year and method for effluent discharge in EU countries (Jacobsen et al., 1999)

	size of wastewater treatment plant in thousands					method
	<2	2-10	10-50	50 - 100	>100	
EU Directive	4	12	12	24	24	24h sample
Austria	12	26	104	260	260	24h flow proportional
Switzerland	52	52-104	104	162	162	24h flow proportional
Germany	differing between federal states but higher than EU Directive					grab
Spain	as EU directive					
France		4-12	6-104	6-104	52-365	24h flow proportional
Italy	12					grab
UK	4-12	12	26	26	52	grab

In **Germany**, the wastewater ordinance (Abwasserverordnung, BGBl., 2004) sets the emission threshold values that have to be fulfilled (depending on the origin of the wastewater) as well as the timing and procedure for analysis. In general, the threshold values are dependent on the size of the treatment plant and standards increase with increase in volume treated based on technological and practical means (grey values in Table 13). A range of different threshold values including a range of more specific parameters (e.g. TSS, heavy metals, AOX, TOC, hydrocarbons, surfactants, pesticides, PAHs, PCDD/Fs etc.) are set for industrial wastewaters generated during the production of dairy, food oils, beverages, fish, meat, animal feed, coal briquettes, ceramics, paper, leather, textiles, plastics, solvents, paints, resins, steel, etc..

For environmental quality standards, the impairment of water quality of receiving streams through effluent discharges should be as minimal as possible. Estimations of surface water flow volume compared to effluent discharge are undertaken to estimate the water quality downstream of the WWTP (e.g. Lüsse and Angerbauer, 2002). Water quality of streams is evaluated according to a range of parameters (selected parameters in Table 12). The WFD only allows an upgrade in water quality not deterioration and the overall aim is to reach class II for all waters (LAWA, 1998). Hence, discharge permits can be denied if the impact on the receiving water quality is too high and WFD requirements would not be met (LfU, 2008).

Table 12: Physical-chemical water quality classification of selected parameters for streams (after LAWA, 1998)

class	tot. P	NO_3-N	NH_4-N	tot. N	AOX	Pb [A,S]	Cd [A]	Cr [S]	Cu [S]	Ni [S]	Hg [A]	Zn [S]
	mg/L*					mg/kg**						
I	≤ 0.05	≤ 1.0	≤ 0.04	≤ 1.0	„0“	≤ 25	≤ 0.3	≤ 80	≤ 20	≤ 30	≤ 0.2	≤ 100
I-II	≤ 0.08	≤ 1.5	≤ 0.10	≤ 1.5	≤ 0.01	≤ 50	≤ 0.6	≤ 90	≤ 40	≤ 40	≤ 0.4	≤ 150
II	≤ 0.15	≤ 2.5	≤ 0.30	≤ 3.0	≤ 0.025	≤ 100	≤ 1.2	≤ 100	≤ 60	≤ 50	≤ 0.8	≤ 200
II-III	≤ 0.30	≤ 5.0	≤ 0.60	≤ 6.0	≤ 0.05	≤ 200	≤ 2.4	≤ 200	≤ 120	≤ 100	≤ 1.6	≤ 400
III	≤ 0.60	≤ 10	≤ 1.20	≤ 12	≤ 0.1	≤ 400	≤ 4.8	≤ 400	≤ 240	≤ 200	≤ 3.2	≤ 800
III-IV	≤ 1.20	≤ 20	≤ 2.40	≤ 24	≤ 0.2	≤ 800	≤ 9.6	≤ 800	≤ 480	≤ 400	≤ 6.4	≤ 1600
IV	> 1.20	> 20	> 2.40	> 24	> 0.2	> 800	> 9.6	> 800	> 480	> 400	> 6.4	> 1600

A: aquatic ecosystem, S: suspended solids and sediments, *: compared to 90th percentile; **: compared to 50th percentile. Class I: pristine, natural background level; I-II: very low anthropogenic impact; II: low impact, II-III: significant impact; III: elevated impact; III-IV: high impact; IV: very high impact

The maximum loads stated in the wastewater ordinance are therefore adjusted by the states to take into account the vulnerability and conditions of the receiving water (Table 13). Discharge quality has to be higher for discharge into pristine waters (class I), in groundwater protection zones, where important ecosystems are impacted, or where waters are used for fishery, swimming or river bank filtration and additional threshold values for heavy metals and AOX can be devised (LfU, 2008). Required levels are evaluated based on the water quality class, the puffer capacity of the stream, the mean flow velocity during mean dry weather flow and the mixing ratio between stream and effluent volume.

In karst aquifers effluent discharge readily infiltrates into the aquifer through the riverbed and could cause contamination with nutrients and pathogens (Personné et al., 1998). Hence, **discharge into streams might not be permitted and discharge into dry river beds or sinkholes is forbidden**. Effluent standards have to fulfil at least the requirement level 3. Additional treatment (e.g. membrane filtration, UV disinfection) for pathogen removal is required. Effluent quality could also be improved through horizontal or vertical filtration through soils or special infiltration beds with plant cover (reeds). A hydraulic conductivity of K_f = 10^{-3} – 10^{-4} m/s, a minimum thickness of 0.5 m, a horizontal/vertical flow area of 2.5/1.5 m²/inhabitant and a sealing with PE-foil are required (DWA, 2005). In karst areas mixed sewer systems should be avoided. Only heavily polluted stormwater should be treated in wastewater treatment plants. Wherever possible, lightly polluted stormwater should be pretreated with decentralised infiltration units before infiltration to the groundwater. They have to fulfil a minimum soil thickness of 0.2 m, a depth to water table of at least 1 m and should be overgrown. Detailed regulations about the design of these infiltration units are given in DWA- M 153 and M 178 (DWA, 2007; 2005).

Table 13: Quality requirements (mg/L) of municipal effluent from treatment plants in Germany for mean annual discharge in 2h mixed effluent samples (after LfU, 2008)

required level	inhabitants (in thousands)	<1	1 - 5	5 – 10	10 – 100	>100
	loads (kg/day BOD)	< 60	60 – 300	300 – 600	600 – 6000	>6000
1	COD	150 (135)	110 (95)	90 (75)	90	75
	BOD_5	40 (35)	25 (20)	20 (15)	20	15
	NH_4-N	-	-	10	10	10
	total N	D	D	D	18	13
	total P	D	D	D	2	1
2	COD	120	110 (95)	90 (75)	90	75
	BOD_5	30	25 (20)	20 (15)	20	15
	NH_4-N	nitr	nitr	10	10	10
	total N	D	D	18	18	13
	total P	D	D	2	1.5	1
	TSS	-	-	-	20	20
3 (+karst)	COD	110	90	75	75	75
	BOD_5	25	20	15	15	15
	NH_4-N	nitr	nitr	5	5	5
	total N	D	deni, D	18	18	13
	total P	2	2	1.5	1	0.5
	TSS	-	-	20	15	15

D: monitoring according to declaration of discharger; nitr: nitrification step required; deni: denitrification step required; values in brackets: limits for filtered sample from wastewater stabilisation ponds; grey shaded values indicate values after BGBl., 2004.

As the **European** WFD is mainly concerned with the natural state of waters, it does not set emission standards for effluent discharge. The EU Directive 91/271/EEC (1991) sets standards for COD, BOD, TSS, total N and total P and similar values have been adopted in many European member states (Table 14).

Table 14: Effluent standards for discharge into surface freshwater in selected European countries (after Jacobsen and Warn, 1999)

country	inhabitants In thousand	COD mg/L	BOD_5 mg/L	TSS mg/L	Total N mg/L	Total P mg/L	Type of treatment or remark
EU	>2	125	25	35			secondary
	10 – 100	125	25	35	15	2	tertiary
	>100	125	25	35	10	1	tertiary
Austria	0.05 - 0.5	90					secondary
	0.5 – 5	75	20			2	tertiary
	5 – 50	75	20			1	tertiary
	>50	75	15			1	tertiary
	>10	75	15			0,5	tertiary
Switzerland	0.2 – 2		20	20			secondary
	2 – 10		20	20		0,8	tertiary
	>10		15	15		0,8	tertiary
France	>2	125	25	35			
	10 – 100	125	25	35	15	2	
	>100	125	25	35	10	1	
Italy		160	40	80	10	0,5	lakes <10 km from shore
		160	40	80		10	
Netherlands	1.8 – 18	125	20	30	15	2	tertiary
	18 – 90	125	20	30	10	2	tertiary
	>90	125	20	30	10	1	tertiary
Slovakia	<0.05		60	50			
	0.05 - 0.5		50	40			
	0.5 – 5	140	40	35			
	5 – 25	120	35	30		5	
	25 – 100	100	30	25		3	
	>100	90	20	20		1,5	

In the **United States** the Water Pollution Control Act/Clean Water Act regulates discharge of pollutants into surface waters. Any point discharge into navigable waters is prohibited unless a permit is obtained from the EPA. Water quality criteria for non-priority pollutants are regulated in the “Gold book” (US EPA, 1986), while priority pollutants (currently 126 organic and inorganic pollutants) have been added and updated a number or times. The environmental immission limits differentiate between acute and chronic criteria for freshwater, saltwater and drinking water and are based on toxicological evaluations of each chemical for aquatic life and human health. Nutrient criteria for rivers and streams, for example, differentiate between ecoregions across the country with different values according to the natural background of the system. The EPA has set wastewater emission standards for municipal WWTPs and a number of specific industries under Title 40 Code of Federal Regulation (CFR). These standards are based on the performance of current treatment techniques and not upon risk to receiving waters (Table 15). The high levels for e.g. nickel, acetone or phenol indicate that they are not sufficiently removed with conventional technology, but would need to be treated with advanced treatment (compare Table 5).

Table 15: Effluent limitations attainable by the application of the best practicable control technology currently available (BPT limitations) after CFR Title 40 §437.42 for multiple waste streams (e-CFR, 2011)

regulated parameter (mg/L)	maximum daily concentration	maximum monthly avg. concentration
BOD_5	163	53.0
oil and grease	127	38.0
pH	6-9	6-9
TSS	74.1	30.6
antimony	0.249	0.206
arsenic	0.162	0.104
cadmium	0.0172	0.0102
chromium	0.746	0.323
cobalt	0.192	0.124
copper	0.500	0.242
lead	0.350	0.160
mercury	0.00234	0.000739
nickel	**3.95**	**1.45**
silver	0.120	0.0351
tin	0.409	0.120
titanium	0.0947	0.0618
vanadium	0.218	0.0662
zinc	0.497	0.420
acetone	**30.2**	**7.97**
acetophenone	0.114	0.0562
bis(2-ethylhexyl) phthalate	0.215	0.101
2-butanone	4.81	1.85
butylbenzyl phthalate	0.188	0.0887
carbazole	0.598	0.276
o -cresol	1.92	0.561
p -cresol	0.698	0.205
n-decane	0.948	0.437
fluoranthene	0.0537	0.0268
n-octadecane	0.589	0.302
phenol	**3.65**	**1.08**
pyridine	0.370	0.182
2,4,6-trichlorophenol	0.155	0.106

As a **general** rule: the larger the treatment plant and the more sensitive the environment receiving the discharge, the higher the effluent quality should be. Typical discharge standards adopted worldwide are presented in Table 16.

Table 16: Typical discharge standards in mg/L (after Veenstra et al., 1997)

discharge to	BOD	TSS	Kjeldahl-N	total N	total P
low quality surface water	50	50			
high quality surface water	20	20	10		1
sensitive surface water	10	10	5	10	0.1

2.2.5 Site selection for wastewater facilities

The selection and design process for wastewater facilities has to cover all relevant geological and hydrogeological aspects, which may impede the functionality of wastewater treatment or cause water resources contamination (Table 17). Those are:

Table 17: Aspects to be covered during the geoscientific investigation for site selection of wastewater treatment plants (WWTPs)

issue	means/source of information	subject of investigation
geology, tectonics, karst features	DEM, geological mapping, mapping of existing tectonic faults, direction/dip of faults, mapping of karst features/degree of karstification	rock type, dip direction/angle: - suitability of underground as a geological barrier (→ reuse areas) - landslide risk - rockfall risk - karst collapse structures - risk of vertical/horizontal movements causing rupture of WW conveyor lines or damages to WWTP structures (sites on active faults bear an elevated risk of damage)
hydrogeology	tracer tests, hydrological model, water balance, DEM, geological structure contour maps (top/base of geol. units), maps of GW vulnerability and GW hazards, delineation of GW protection zones	- GW flow direction, flow velocity in saturated zone (travel time/path; → GW vulnerability, pollution risk) - thickness of unsaturated zone, travel time through unsaturated zone (→ GW vulnerability, pollution risk) - infiltration, GW recharge (→ GW vulnerability, pollution risk) - GW vulnerability - GW hazard inventory/map (wastewater and other hazards) - assessment of pollution risks - GW protection needs (→ delineation of protection zones)
hydrology	DEM, meteorological stations, surface water runoff stations, hydrological model (flow accumulation)	- risk of flooding
earthquake probability	analysis of previous earthquake events (location, depth, strength/effect), DEM	- likelihood to affect the facilities (sites near zones with high probability of earthquakes bear an elevated risk of damage)
stability of geological underground	geotechnical study (e.g. using cone penetration tests/CPT), DEM	- unstable underground (e.g. landslide material or alluvium) may need special foundation

DEM: digital elevation model, GW: groundwater, WW: wastewater

Most of the above-mentioned investigations are also required for the Environmental Impact Assessments which have to be prepared for wastewater facilities.

In karst aquifers tracer tests provide useful insight into the connection and travel time between locations. In this respect, it is recommended to conduct tracer tests between intended effluent discharge or wastewater reuse areas and water sources used for drinking purposes in order to determine whether these facilities may have a potentially negative impact on the water resources. For these investigations it should be borne in mind that amount of flow and flow paths are highly variable in karst systems, especially those of Lebanon (Margane, 2011).

Annex 1 lists all relevant criteria for site selection of wastewater facilities and their relevance from the perspective of water resources protection.

The term georisk encompasses natural disasters like earthquakes, landslides, flooding or volcanic eruptions. Due to its geographic position along a major fault line between the African and the Asian tectonic plates (Yammouneh fault) and the subduction zone of the African plate under the European plate in the vicinity, Lebanon has seen a number of earthquakes and subsequent landslides in the past (Elnashai and El-Khoury, 2004). In the twentieth century alone 13 earthquakes with a magnitude ≥ 4 have been recorded. Karst terrains are also prone to collapse and subsidence hazard resulting from dissolution and subsequent rock failure (Waltham et al., 2005).

Planning for WWTP locations and sewer lines has to consider the risk of earthquakes, landslides and rock collapse or subsidence, as the destruction of a WWTP or parts thereof and the subsequent spilling of raw sewage into the environment can have detrimental effects on the surface, drinking and groundwater quality (Memon et al., 2002). Construction of the WWTP should therefore comply with earthquake safe building guidelines (Shibata, 2006; European Committee for Standardisation, 2004) and engineering methods for karst terrain (Waltham et al., 2005). Earthquake safe building guidelines require structural integrity and residual load bearing capacity to prevent collapse. The structures should be simple, regular and with a low centre of gravity to transmit the seismic forces evenly. Materials should behave plastic rather than brittle with special attention given to connections between structural elements and minor parts that are important for the integrity of the structure (e.g. anchor bolts) (Shibata, 2006). Ground conditions are to be investigated before construction (avoid slope instability, ground rupture, liquefaction) and the stiffness of the foundations should transmit energy as uniformly as possible (European Committee for Standardisation, 2004). The energy generated by sloshing movements of liquids in tanks has to be considered during construction of tanks.

Apart from cracks and breaks, failure of sewer systems is due to liquefaction of the ground during an earthquake. It occurs primarily in areas with high groundwater level, clayey soils or where the backfill material was only loosely compacted (Tanaka et al., 2008). Compaction of the backfill soil by more than 90% and installation of a flexible coupling between sewer lines and manholes have been found to significantly reduce floating of manholes and damage between the manholes and the sewer lines (Shimizu et al., 2007). **Sewer systems in earthquake prone regions should be constructed using long ductile iron pipes with socket joints** (Schiemann and Kahnt, 2010; Hilka and Glücklich, 2005). Vacuum sewerage is problematic as even small cracks corroborate the system.

Construction in sinkhole terrain needs a proper investigation of the underground. After mapping of visible karst features, invisible features should be investigated with geophysical methods like electrical resistivity surveys or ground penetrating radar. Soil probing and drilling should follow. Foundations need to be based on sound bedrock or the load should be spread with rafts etc. (Waltham et al., 2005). Examples for pile construction in pinnacled rock complexes are shown in Fig. 8.

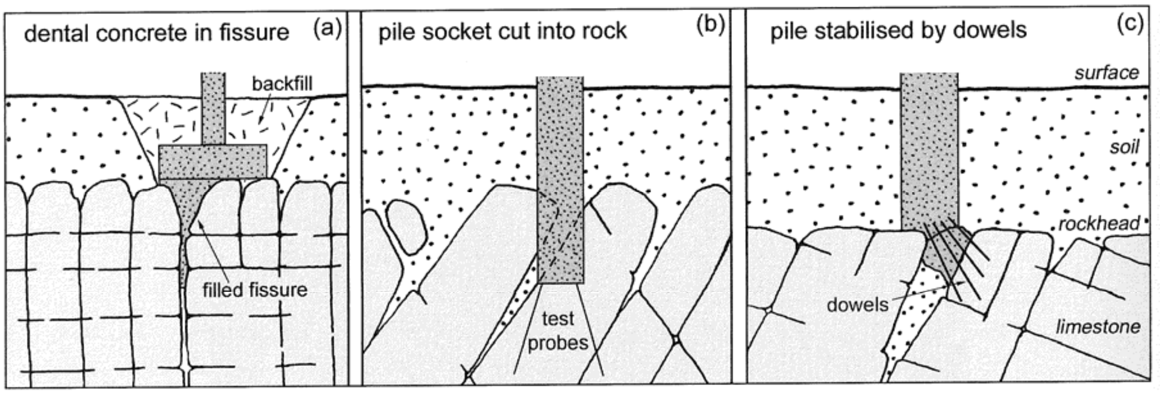

Fig. 8: Pile integrity in karst achieved by treatment of rockhead fissures (a) dental concrete filling in a wide fissure, (b) pile socket cut into rock and probed beneath, (c) pile stabilised by dowels through concrete fill (after Sowers, 1986)

To assess the likelihood of the occurrence of georisks the BGR developed a risk assessment method for a number of hazards (earthquakes, landslides, floods) which has been applied in Indonesia and Central America (Balzer et al., 2010) and could be modified to suit Lebanon. Predictions about earthquake occurrence and peak acceleration and displacement of the ground under average soil conditions in Lebanon have been investigated already and might be used as an initial basis (Elnashai and El-Khoury, 2004). An earthquake damage estimation for sewer systems mainly needs information about the distribution of seismic activity, geological and soil conditions, unit restoration costs, spatial occurrence and an indicator for liquefaction (backfilling material and compaction, pipe depth, soil, groundwater level) (Tanaka et al., 2008).

Countermeasure plans should be established (based on the importance of a WWTP facility and the distance to emergency shelters, hospitals etc.) and could include bypass pipes, extension joints, earthquake proof reinforcement, temporary inflow pipes, temporary sedimentation and chlorination tanks, a stand-by facility, portable pumps and a communication pipe to another treatment plant (Tanaka et al., 2008). In general, the building of back-up systems with different designs should be considered to prevent failure of all systems.

2.3 Wastewater reuse

Many countries of the world are facing an increasing scarcity of freshwater due to a growing demand of water resulting from high population growths and increase in living standards, as well as a decrease in water resources availability due to climate change and pollution (Al Salem, 1996; Miller, 2005). While demands can be reduced through water conservation measures and increasing water efficiency (e.g. low-water technology in households, agriculture and industry, water loss reduction programmes), most water resources are already exploited, sometimes even overexploited, and unconventional water resources have thus to be considered. These include reuse of wastewater and stormwater. Many areas produce wastewater in volumes equalling the demand in freshwater (e.g. Turkey in 2008: water abstraction 11.6 km^3; wastewater discharge 8.7 km^3 (TurkStat, 2010)) and dispose of them into waterways and adjacent coastal areas leading to degradation of these ecosystems and pollution of freshwater sources. It is therefore of manifold benefit to recycle these streams of water.

While water treatment is capable of rendering wastewater to superior quality suitable for potable use (Hammer, 2008; Qin et al., 2005; Cheremisinoff, 2002), there is great potential to use recycled water for non-potable uses, which constitutes the biggest portion of demand (agriculture consumes about 70 % of water worldwide). These reuse options include irrigation (agriculture, landscaping, home gardens), industrial reuse (e.g. cooling), domestic reuse (e.g. toilet flushing), environmental flows to stabilise ecosystems and groundwater recharge to increase freshwater supplies (Table 18). Non-potable options are less costly as they mostly involve less treatment (Asano et al., 2007). Reuse in agriculture has the added benefit of reusing the nutrients existing in wastewater and hence reducing the demand on commercial fertiliser. The sewage from one person in a year is sufficient to fertilise about 200 m^3.

As wastewater effluent is produced continuously but water demands for irrigation vary seasonally, a storage system or a combination with other reuse schemes should be planned. Storage needs to be dimensioned to be able to accommodate about 30 % of the annual effluent (Fig. 9). The need for storage is often considered a disadvantage of wastewater reuse as it increases the cost compared to effluent discharge into the environment. It should be considered though, that conventional water sources (rain, surface water) are not available either during the months of highest demand and would also require storage resulting in similar costs. If above ground storage is used, bacterial re-growth and algae growth has to be considered (DWA, 2008). Limitation on nutrient and pathogen levels might have to be adjusted. Underground storage or closed storage tanks limit algae growth and evaporation losses.

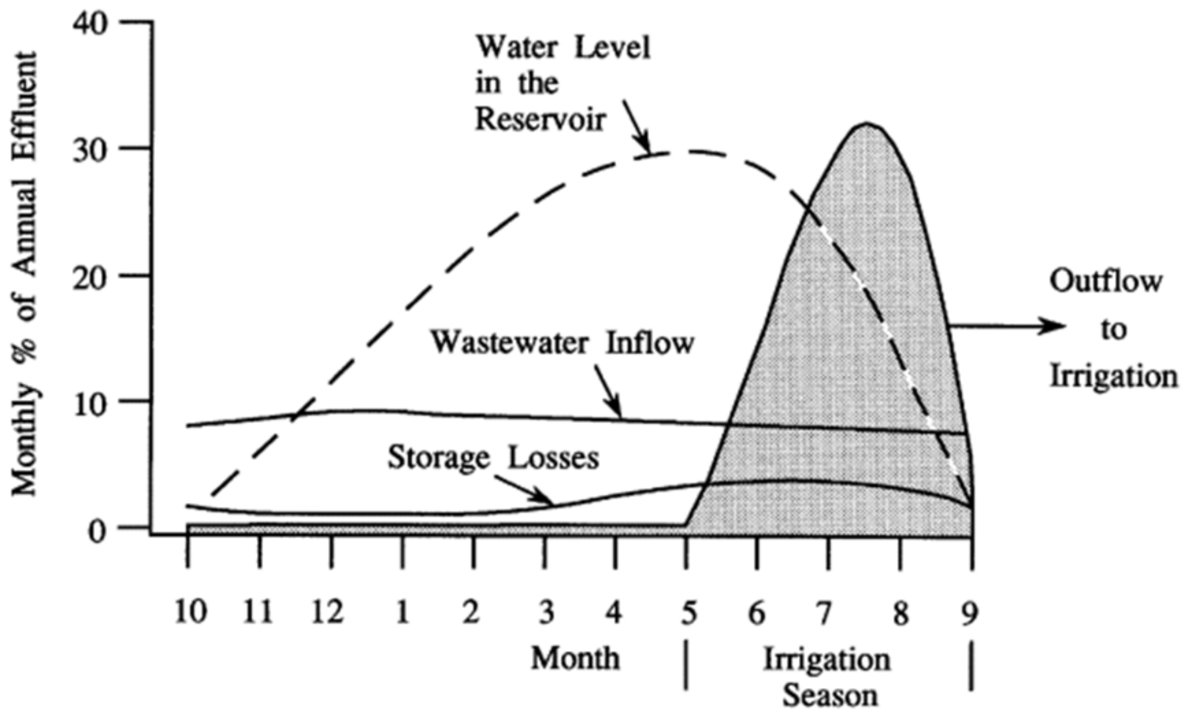

Fig. 9: Seasonal storage of wastewater effluent for irrigational purposes under typical climatic conditions in Israel (from G. Shelef, www.biu.ac.il/Besa/waterarticle3.html)

Soil aquifer treatment (SAT) is a method for treating water (removal of TSS, nutrients, TOC, heavy metals and trace elements) and for aquifer recharge (Idelovitch et al., 2003; Bouwer, 2002; Pescod, 1992). As a rule of thumb, travel times of 30 - 50 days result in sufficient pathogen die-off (Pescod 1992). **Due to commonly high flow velocities SAT is therefore mostly not applicable in karst areas**. Filter beds with a combination of vertical and horizontal flow systems could be engineered to achieve long retention times though. In general, artificial aquifer recharge in karst regions is possible with very high quality water, but recharged water is subject to the same high flow velocities as naturally recharged groundwater. Hence recharged water cannot be recovered at the place of recharge and retention times before discharge further downstream are short.

While reuse has a number of advantages, it is not without potential **risks** mainly related to health and the environment, especially when low-quality water is used (Jiménez and Garduño, 2001). Potential constrains could also be economic feasibility and cultural non-acceptance of reuse, requiring the appropriate choice of treatment and reuse option (Table 18).

Table 18: Advantages and possible risks or constraints for different reuse options

reuse option	advantages	possible risks and constraints
irrigation	- highest demand for water - nutrients recycling - fertiliser use reduced - well established	- surplus nutrients might reach groundwater - storage systems needed - clogging of irrigation systems - high hygiene requirements - soil salinisation - crop damage
industrial	- cost-saving - recycling of wastewater constituents	- corrosion or fouling - aerosol transmission - additional treatment needed
environmental	- habitat creation / conservation	- additional treatment needed
aquifer recharge	- Natural biodegradation and filtration - high removal rates with SAT - limited treatment requirements	- groundwater contamination - interactions of reclaimed water and groundwater - specific hydrogeological requirements

The decision for the most feasible **reuse application** or combination of applications requires a regional survey of supply of wastewater and (seasonally varying) demand for reuse water to match the source and reuse option. Before the reuse option is included in the design of a wastewater facility, it must be ensured that treated wastewater will in fact be reused by the local farmers. The legal requirements and guidelines for reuse, health standards, and groundwater protection should be compiled. After a review of the geographical, geological and hydrogeological conditions and the marketability of possible crops (including their salinity tolerance), the economic evaluation should be undertaken of treatment, storage and distribution costs compared to a scenario without reuse (including environmental and fertiliser costs) (Kramer et al., 2007). Considerations should also be given to the cultural acceptance and potential consumer confidence in food products based on treated wastewater, as reuse projects often fail, when stakeholders are not consulted, informed and educated. Apart from hygiene education, local socio-cultural conditions and attitudes towards wastewater reuse and environmental protection have to be taken into account, before deciding on the most appropriate reuse option.

Other options of enhancing water resources like desalination or water conveyance from further away commonly will be less cost effective, especially if environmental costs were to be included (Table 19) (Al Salem and Abouzaid, 2006).

Table 19: Estimated cost of options for enhancing water resources (after Al Salem and Abouzaid, 2006)

option for enhancing water resources	costs in US $\$/m^3$
reducing end-user demand (recirculation, low-water use technology and leakage repair)	0.05 - 0.50
treatment of wastewater for irrigation	0.3 – 0.6
desalination of brackish water	0.45 – 0.70
desalination of sea water	0.5 – 1.0
water conveyance by pipelines	0.1 – 15*
transporting the water by marine vessels	0.5 – 15*
transporting giant floating bags by sea without including the costs of terminals, inland transport, or purification	0.15 – 0.35*

* The price of the water itself is not included. The cost depends mainly on the distance.

Health concerns exist as common secondary treatment techniques are not very effective at removing pathogens, so caution has to be taken to avoid the spread of diseases and wastewater treatment processes should focus more on removing pathogens (chapter 2.2.2). Main pathways of agricultural reuse are through direct contact with reclaimed wastewater by farm workers or unplanned access by the public, indirect infections through consumption of contaminated food, spread of contaminated aerosols during irrigation and contamination of downstream freshwater sources through infiltration/runoff into surface or groundwater (Blumenthal, 2002; Blumenthal et al., 2000). Nevertheless, most of these health risks can be managed with low cost measures like appropriate occupational health measures (e.g. protective clothing), crop restrictions (e.g. not for crops eaten raw), signage of plots irrigated with reclaimed water, colour-coded dual plumbing systems and restrictions on irrigation method or timing (Asano et al., 2007; WHO, 2006). The irrigation method with greatest health concern for consumers is spray/sprinkler irrigation, if contaminated crops are eaten uncooked and unwashed. The risk can be reduced through the restriction to crops that are not eaten raw, and through a high level of hygiene at the consumer end. Inhabitants living in the range of sprinkler aerosols could also be affected if the concentration of pathogens is too high and wind conditions are favourable, but results are inconclusive (Petterson and Ashbolt, 2003; Pescod, 1992). Furrow irrigation entails the highest contact with reuse water for farm workers; drip irrigation the lowest (Blumenthal et al., 2000).

For maximum protection a multi barrier approach is suggested (Kramer et al., 2007):

- wastewater treatment: reduce pathogen concentrations
- crop restrictions: only for processed, cooked or fodder crops
- irrigation method: drip/trickle irrigation instead of sprinkler or furrow irrigation (also advisable to avoid salt related leaf damage and salt accumulation in the root zone, see Table 20)
- scheduling of irrigation: restrictions how long before the harvest reuse water can be applied
- location restrictions: buffer strip to dwellings and to surface water and groundwater infiltration features
- human exposure control: protective clothes, hygiene, washing of harvested produce before sale, cooking of crops, clear signage of reclaimed water, immunisation

The use of treated wastewater is certainly safer than the use of raw wastewater, which can be found in a number of countries including Lebanon. It is therefore of utmost importance that the above protection measures are monitored and controlled and clear instructions are given to the users. For disease control it could also be an option to vaccinate farm workers and supply them with prophylactic treatments (Blumenthal et al., 2000).

Table 20: Evaluation of common irrigation methods in relation to the use of treated wastewater (after Rhoades et al., 1992; Doneen and Westcot, 1984)

parameters of evaluation	furrow irrigation	border irrigation	sprinkler irrigation	drip irrigation
foliar wetting and consequent leaf damage resulting in reduced yield	no leaf damage	some bottom leaves	severe leaf damage	no leaf damage
salt accumulation in the root zone with repeated applications	salt accumulation in the ridge	not likely	not likely	salt wedge between drip points
ability to maintain high soil water potential	stress between irrigations	stress between irrigations	stress between irrigations	high soil water potential
suitability to handle brackish wastewater without significant yield loss	fair to medium	fair to medium	poor to fair	excellent to good
exposure of farm worker to health hazards	high	medium to high	very high	low
applicability	slightly sloped areas; row crops	only flat areas; deep rooted crops and orchards	undulating; all crops	any slope; only row crops
water efficiency	50 - 65 %	45 - 60%	60 - 70 %	75 – 85 %

Environmental risks to soil, plants, groundwater and ecosystems can occur and are mostly related to salinity levels, specific toxicity effects of plants and nutrient pollution.

As seen above (Table 5), **salinity** levels in wastewater can be high and are not reduced without advanced treatment options. On the contrary, salinity is increased through evaporation from treatment ponds and basins, especially in hot climates. Salinity levels are also increased through flood and furrow irrigations where large amounts of water evaporate and salt accumulation occurs on the ridges, where the plants are located. If groundwater tables are high secondary salinisation can occur through capillary rise of groundwater and sufficient drainage and leaching is needed. High levels of salinity affect the water availability to crops through osmotic pressure. Crops show varying sensitivity to salinity though and more salt tolerant crops (Table 21) could be grown (Pescod, 1992). To limit salinity increase in the groundwater, irrigation should be scheduled right to match plant needs as closely as possible to avoid extensive leaching and irrigation inefficiency. Drip irrigation is most suitable to prevent salinity problems, has the highest water efficiency and the lowest contamination potential, but high capital costs (Table 20). Simplified but detailed methods for calculating irrigation and fertigation requirements under drip irrigations have been compiled for different crops for the Jordan Valley (GTZ, 2006b). The water requirements are based on evapotranspiration losses incorporating on crop stages, ground coverage, irrigation efficiency and leaching requirements. Scheduling for irrigation is calculated from the net irrigation depth, growth irrigation depth, precipitation, irrigation frequency and irrigation duration. Nutrient management compares the target yield and crop requirement with nutrients in reclaimed wastewater, manure and soil. The sufficiency concept takes into consideration the availability of nutrients in the soil depending on soil structure and crop growth stage (GTZ, 2006b).

Table 21: Salt and boron tolerance of plants as experienced in the Jordan Valley (after GTZ, 2006a)

EC (dS/m)	< 1.7	citrus, carrots, strawberry, onion
	1.7 – 3.0	olive, pepper, cucumber, cauliflower, lettuce, watermelon, cabbage, grapes
	>3.0	asparagus, date palms, barley, wheat, tomato, squash, eggplant, sweet corn, potato, alfalfa, rocket, parsley
B (mg/L)	0.5 – 0.75	lemon
	0.75 - 1	wheat, strawberry
	1 - 2	pepper, carrot, potato, cucumber, lettuce
	4 - 6	alfalfa, parsley, tomato
	6 - 15	asparagus, celery

EC: electrical conductivity in deciSiemens per metre at 25°C, 1 dS/m = 1000 μS/cm

Apart from total salinity the relation of sodium to calcium plus magnesium concentrations (expressed as the sodium adsorption ratio SAR) is an important indicator for irrigation water quality as high sodium concentrations cause dispersion and swelling of clay minerals. This leads to a reduction of soil permeability and infiltration rates, and the formation of hard clay crusts (Rhoades et al., 1992). Some plants, for example fruit trees, are also very sensitive to elevated levels in sodium, chloride or boron. Boron originates from bleach in detergents and has low removal rates. While nutrients are essential for high yields of crops, an excess of nitrogen can result in yield loss and disease due to luxuriant growth (Morishita, 1988). Grassy and leafy crops are generally better in nutrient uptake. Guidelines at what concentration these parameters could limit the application as irrigation water depending on the sensitivity of the plants are presented in Table 22. Elevated levels of suspended solids will mainly affect the irrigation system through clogging and should be especially low for drip and micro-irrigation systems. If spray irrigation is used, particles deposited on leafs might lower yields due to reduced photosynthesis capacity (GTZ, 2006a).

Table 22: Guidelines for interpretation of water quality for irrigation (after Ayers and Westcot, 1985)

potential irrigation problem	**unit**	**degree of restriction on use**		
		none	slight to moderate	severe
EC	dS/m	< 0.7	0.7 - 3.0	> 3.0
TDS	mg/L	< 450	450 - 2000	> 2000
SAR = 0 - 3 and EC	dS/m	> 0.7	0.7 - 0.2	< 0.2
= 3 - 6 and EC	dS/m	> 1.2	1.2 - 0.3	< 0.3
= 6 - 12 and EC	dS/m	> 1.9	1.9 - 0.5	< 0.5
= 12 - 20 and EC	dS/m	> 2.9	2.9 - 1.3	< 1.3
= 20 - 40 and EC	dS/m	> 5.0	5.0 - 2.9	< 2.9
Na Surface irrigation	SAR	< 3	3 - 9	> 9
Na Sprinkler irrigation	meq/l	< 3	> 3	
Cl Surface irrigation	meq/l	< 4	4 - 10	> 10
Cl Sprinkler irrigation	meq/l	< 3	> 3	
boron (B)	mg/L	< 0.7	0.7 - 3.0	> 3.0
nitrogen (NO_3-N)	mg/L	< 5	5 - 30	> 30

EC: electrical conductivity in deciSiemens per metre at 25°C, 1 dS/m = 1000 µS/cm; SAR: sodium adsorption ratio, meq/L: milliequivalent per litre

Increased concentrations of **heavy metals** can also lead to toxicity in plants (Table 23) and can be transferred through the plant to the consumer, when bioaccumulation is high, e.g. for cadmium (Pescod, 1992). Problems related to heavy metals and organic contaminants can be lowered by reducing turbidity, as these contaminants are largely attached to solids (McBride, 1994).

Table 23: Recommend maximum concentration of trace elements for crop production not exceeding a water application rate of 10 000 m³/ha/a for long term use (after Rowe and Abdel-Magid, 1995; Pescod, 1992)

mg/L	long-term use	short term use	Remarks
Al	5.0	20	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
B	0.75	2.0	Essential to plant growth at a few tenths mg/L; toxic to many sensitive plants (e.g. citrus) at 1 mg/L, most grasses can tolerate 2-10 mg/L
Be	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Cd	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/L in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	0.10	1.0	Not generally recognised as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu	0.20	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solutions.
F	1.0	15	Inactivated by neutral and alkaline soils.
Fe	5.0	20	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	2.5	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/L). Acts similarly to boron.
Mn	0.20	10	Toxic to a number of crops at a few-tenths to a few mg/L, but usually only in acid soils.
Mo	0.01	0.05	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	0.20	2.0	Toxic to a number of plants at 0.5 mg/L to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Pb	5.0	10	Can inhibit plant cell growth at very high concentrations.
Se	0.02	0.02	Toxic to plants at concentrations as low as 0.025 mg/L and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. As essential element to animals but in very low concentrations..
V	0.10	1.0	Toxic to many plants at relatively low concentrations.
Zn	2.0	10	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

During irrigation portions of the water will percolate down to the **groundwater** or run off overland into surface waters and can reach drinking water supplies. During the percolation through the soil, attenuation processes generally lower concentrations of nutrients, heavy metals and organic trace contaminants (Katz et al., 2010; 2009). As karst areas are particularly prone to direct infiltration and have only limited capacity to attenuate contaminants, special emphasise should be given to buffer strips (min. 30 m) around sinkholes and along streams. Livestock should also not be allowed in these zones (Currens, 2002). The risk of groundwater contamination can be lowered by choosing fields with appropriate soil thickness and soil properties, by restricting application of reclaimed water in groundwater protection zones and close to streams and by increasing the water quality of reuse water. **The consequences of effluent reuse on groundwater quality are often not considered, but should be of special focus in karst regions**.

Wastewater reuse requires regular monitoring of reclaimed water quality and also the installation of groundwater monitoring wells to observe any changes to groundwater quality early (EPA SA, 2007a, b). Sampling frequency have to be often enough to allow a statistical interpretation of the data. Clear operational rules on how to sample, how to interpret the results and how to assess compliance with quality standards have to be in place (Kramer et al., 2007). Sampling can be either based on total outflow or on the size of the WWTP and a higher sampling frequency is commonly required for larger WWTPs with higher volume output. Common parameters should be sampled more regular than expensive and less common parameters (Table 24).

Table 24: Sampling frequency of reclaimed wastewater for reuse in agriculture (modified after Salgot and Huertas, 2006)

	permanently - weekly	**1-2 per month**	**monthly – once a year**	**once per 1 - 5 years**
microbiological analysis	*E. coli.*, Salmonella, bacteriophage		Helminths eggs, Taenia	Legionella, Giardia, Cryptosporidium
physico-chemical, inorganic	ph, EC, turbidity, TSS, COD, BOD, DO, AOX, total N, NH_4, residual Cl_2	SAR, UV 254, DOC, NO_3, SO_4, Cl, total P	B	
heavy metals			As, Cd, Cr, Cu, Hg, Ni, Pb, Zn	Al, Ba, Be, Co, Fe, Li, Mn, Mo, Se, Sn, Th, V
organic pollutants			surfactants, hydrocarbons	aldehyde, phenols, diuron, 2,4-D, EDTA, benzene, benzo(a)pyrene, PAHs
micropollutants				PhAC, EDC, DBP

UV 254: analysis for concentration of humic acids

Overall, the aim of wastewater **reuse guidelines** is to protect the population from health risk and the environment from degradation and pollution. Most of the worldwide available guidelines are based on either the US EPA guidelines (US EPA, 2004; see 2.3.3) or the WHO guidelines (WHO, 1989; see 2.3.1). These guidelines are suitable for developed countries with anyway high wastewater treatment standards, but should be adjusted in developing countries and account for the end use (Choukr-Allah, 2010). The guideline should include assessment of the irrigation method, exposure scenario and hygiene measures (Blumenthal and Peasey, 2002). Too stringent regulations cannot be enforced and are eventually ignored (Choukr-Allah, 2010). This concept has been accounted for in the newer WHO guidelines (WHO, 2006).

2.3.1 International

Worldwide total reuse of untreated wastewater is highest in China, Mexico and India, while treated wastewater reuse is highest in the USA, Saudi Arabia and Egypt. Kuwait, Israel and Singapore have the highest percentage of treated wastewater reuse compared to total extraction. Large areas in Chile, Mexico and Cyprus are irrigated with treated wastewater (Jiménez and Asano, 2008).

In 2006, the World Health Organisation (WHO), the United Nations Environment Programme (UNEP) and the Food and Agriculture Organisation (FAO) updated the older guidelines (Mara and Cairncross, 1989) and presented quality standards for reuse of wastewater, faeces and greywater in agriculture and aquaculture based using a unit combining mortality and morbidity called disability-adjusted life years (DALY). Best practice guidelines for reuse management including crop restriction, irrigation techniques, good personal hygiene and produce handling are essential to this concept of reuse (WHO, 2006). The new health-based guidelines of a DALY loss of $\leq 10^{-6}$ per person per year (this is achieved by a 6 - 7 log unit reduction of pathogens) can hence be achieved by a combination of measures (log unit reduction in brackets), e.g. treatment level (0.5 - 7), die-off between irrigation and consumption (1 - 2), drip irrigation (2 - 4), subsurface irrigation (6), washing of produce (1), produce disinfection (2), produce peeling (2), produce cooking (6 - 7). A target of ≤1 helminth eggs/L is applicable to irrigation of all crops apart from high growing crops (fruit trees, olive trees, date palms etc.). In addition, maximum tolerable soil concentrations based on human health protection for various chemicals are given (Table 25). Monitoring should be conducted at the point of use or the point of effluent discharge. Urban/rural WWTP should take samples for *E. coli.* every two weeks/four weeks and for helminth eggs every months/1-2 months, respectively. Testing of produce for human consumption should include testing for *E. coli.*, thermotolerant coliforms, helminth eggs and heavy metals (WHO, 2006).

Table 25: Maximum tolerable soil concentration of selected inorganic and organic compounds based on human health protection (WHO, 2006)

inorganic compounds	soil (mg/kg)	organic compounds	soil (mg/kg)
Ag	3	2,4-D	0.25
As	8	2,4,5-T	3.82
B	1.7	aldrin	0.48
Ba	302	chlordane	3
Be	0.2	dieldrin	0.17
Cd	4	lindane	12
F	635	DDT	1.54
Hg	7	PAHs	16
Mo	0.6	PCDs	0.89
Ni	107	PCDDs	0.00012
Pb	84	benzene	0.14
Sb	36	chlorobenzene	211
Se	6	toluene	12
Tl	0.3	phthalate	13 733
V	47	pyrene	41
		styrene	0.68
		toxaphene	0.0013

The WHO guidelines ensure health safety via a comprehensive risk assessment of all process steps from wastewater production through to produce consumption (Stockholm framework), but no environmental assessment is included. Validation at the beginning of a new system and verification/monitoring afterwards has to be performed to prevent hazards. While this system allows for more flexibility, each reuse project has to be assessed individually, which is of limited practicality for controlling compliance.

The older guidelines set more specific values and have been adopted in similar form by a number of countries worldwide. The helminth egg guideline of ≤1 egg/L for unrestricted irrigation was later revised to ≤0.1 egg/L and higher quality standards for flood irrigation and children were added (Table 26). The microbiological guidelines can be met through the use of wastewater stabilisation ponds (WSP), wastewater storage and treatment reservoirs (WSTR) or through conventional treatment processes (Blumenthal and Peasey, 2002).

Table 26: Revised 1989 WHO guidelines for wastewater reuse in agriculture. Grey shaded fields are revised or added compared to original guidelines (after Blumenthal and Peasey, 2002)

	reuse condition	exposed group	irrigation method	helminth eggs/L	faecal coli./100 ml
A	**unrestricted**: crops eaten uncooked, sports fields, public parks	workers, consumers, public	any	≤ 0.1	$\leq 10^3$
B	**restricted**: cereal crops, industrial crops, fodder crops, pasture and trees	B1 workers >15 years	spray / sprinkler	≤ 1	$\leq 10^5$
		B2 workers >15 years	flood /furrow	≤ 1	$\leq 10^3$
		B3 workers including children, nearby communities	any	≤ 0.1	$\leq 10^3$
C	localised irrigation of crops in category B if exposure of workers and the public does not occur	None	trickle, drip or bubbler	not applicable	not applicable

For groundwater or environmental protection purposes no specific guidelines are given, as local differences make a general guideline challenging. Recommended water quality guidelines for maximum crop production and soil protection are given though (Table 22). The WHO guidelines name a number of control measures to reduce environmental impacts (Table 27).

Table 27: Recommended control measures for various problems (after WHO, 2006)

problem	control measure
nitrogen excess	- dilute with freshwater - limit the quantity of water applied - remove excess nitrogen through treatment
organic matter	- allow time between irrigation for soil to biodegrade it - enhance removal through treatment
salinity	- avoid use of water with 500 – 2000 mg/L TDS depending on soil type and drainage - reduce upstream salt use and discharge into wastewater - increase soil washing, improve ground drainage, apply soil amenders - dilute water
chlorides	- use water <100 mg/L in sprinklers - use water <350 mg/L for flood irrigation - irrigate at night
toxic organic compounds	- pretreat or separate industrial wastewater - promote cleaner production in industries - educate society to use less toxic compounds and dispose of them safely
heavy metals	- pretreat or separate industrial wastewater - use only in soils with pH >6.5
TSS	- remove solids with treatment - plough soils when clogged - do not use drip irrigation that can get clogged

Before the revised WHO guidelines from 2006, the UNEP set guidelines for municipal wastewater reuse in the Mediterranean region and specified microbiological and chemical health risks (UNEP, 2005). They consider four categories of reuse: I: urban and residential uses, II: unrestricted irrigation and industrial reuse, III: restricted agricultural irrigation, and IV: irrigation with drip or subsurface irrigation (Table 28).

Table 28: Recommended guidelines for water reuse in the Mediterranean region (after UNEP, 2005)

	helminth eggs/L[a]	faecal coli./100mL[b]	TSS (mg/L)	recommended treatment
I	≤0.1	≤200	≤10	secondary + filtration + disinfection
II	≤0.1	$\leq 10^{-3}$	≤20, ≤150[c]	secondary + filtration + disinfection or secondary + storage/maturation ponds/ infiltration
III	≤1	$\leq 10^{-5}$	≤35, ≤150[c]	secondary + few days storage or oxidation pond system
IV	none	none	as required by irrigation technology	minimum primary treatment

a: does not require routine monitoring, b: should be monitored weekly, at least monthly, c: when treating with stabilisation ponds

2.3.2 Europe

The urban wastewater treatment directive (91/271/EEC) does not specify wastewater reuse guidelines, but encourages wastewater reuse where "appropriate" under the requirement of minimising adverse effect on the environment, without further specifying how appropriateness is assessed. The WFD also promotes water reuse and efficiency, if the good environmental status of water bodies (surface water, groundwater and coastal waters) is not affected. The Groundwater Daughter Directive (GWD) requires authorisation and monitoring for artificial groundwater recharge, but does not prohibit recharge with treated wastewater.

Direct reuse or treated wastewater is mainly practiced in southern Europe (mainly Spain, Italy, Cyprus and Malta), where water deficits are more pronounced, but only about 2.4 % of total treated effluent is reused in Europe (MED-EUWI, 2007). A compilation of existing European reuse guidelines and new proposed limits based on risk assessment for different reuse option was undertaken by AQUAREC (Table 29) (Salgot and Huertas, 2006) Climate change predictions for Europe forecast a shift of precipitation from the main vegetation period in summer towards winter, resulting (together with an increase in temperature) in a water deficit during summer and an increase in water demand for irrigation (Kundzewicz et al., 2007). Indirect reuse of treated wastewater, though, is a well established practice throughout Europe (e.g. London, Berlin, Barcelona), where treated effluent discharged to streams is extracted further downstream mainly for potable use (MED-EUWI, 2007).

Table 29: Overview of the compiled chemical limits for reclaimed water reuse from existing guidelines and proposed chemical limits depending on the specific uses (mg/L) (after Salgot and Huertas, 2006)

parameter	1: private, urban and irrigation	2: environmental and aquaculture	3: indirect aquifer recharge	4: industrial cooling
parameters of very high analytical frequency (daily - weekly)				
pH	6-9.5	6-9.5	7-9	7-8.5
BOD	10-20	10-20		
COD (or TOC)	100	70-100	70-100	70
DO	>0.5	>3	>8	>3
AOX			25	
UV absorbance ($cm^{-1}*10^3$)	30-70	30-70	10	
EC (µS/cm)	3000	3000	1400	
TSS	10-20	10-20		10-20
residual Cl_2	0.2-1	0.05		0.05
total Kjeldahl-N	15-25	10-20		10-20
NH_4-N	2-20	1.4	0.2-20**	1.5
parameters of high analytical frequency (monthly)				
SAR ($mmol/L^{0.5}$)	5	5		
Na	150	150-200		200
nitrate			25	
chloride	250	250-400	100	400
sulphate	500	500	100	
total P	2-5	0.2-1		0.2
parameters of medium analytical frequency (monthly - once a year)				
As	0.1-0.02	0.1-0.02	0.005	
B	0.4	0.4	0.2**	
Cd	0.005	0.005	0.003	
Cr (total)	0.01-0.1	0.01-0.1	0.025	
Cr (III)	0.1	0.1		
Cr (IV)	0.005	0.005		
Hg	0.001-0.002	0.001-0.002	0.0005	
Pb	0.1	0.1	0.005	
F	1.5-2	1.5-2		
surfactant	0.5-1	0.5-1		
mineral oil	0.05	0.05		

Table 29 (cont.)

parameter	1: private, urban and irrigation	2: environmental and aquaculture	3: indirect aquifer recharge	4: industrial cooling
parameters of low analytical frequency (once a year - once per 5 years)				
Al	1-5	1-5		
Ba	10	10		
Be	0.1	0.1		
Co	0.05	0.05		
Cu	0.2-1	0.2-1		
Fe	2	2		
Li	2.5	2.5		
Mn	0.2	0.2		
Mo	0.01	0.01		
Ni	0.2	0.2	0.01	
Se	0.01-0.02	0.01-0.02		
Sn	3	3		
Th	0.001	0.001		
V	0.1	0.1		
Zn	0.5-2	0.5-2		
CN (total)	0.05-0.1	0.05-0.1		
pesticides	0.05	0.05		
pentachlorophenol	0.003	0.003		
EDTA etc.	0.0001	0.0001	0.0001	
tetra/trichloromethylene	0.01	0.01		
NDMA	0.0001*		0.0001*	
THM	0.03	0.03		
aldehyde	0.5	0.5		
aromatic organic solvents	0.01	0.01		
benzene	0.001	0.001		
benzo(a)pyrene	0.00001	0.00001		
phenol (total)	0.1	0.1		
EDC	0.0001*	0.0001*	0.0001*	
PhAC	0.0001*	0.0001*	0.0001*	

* proposed value, ** option not to desalinate, depending on the aquifer, EDTA: ethylenediaminetetraacetic acid, NDMA: nitrosodimethylamine, THM: trihalomethane

A number of countries have released national or regional guidelines (Table 30), but clearer institutional arrangements and the establishments of codes of best practice are needed (Angeliakis and Durham, 2008; Bixio et al., 2006; Angelakis et al., 1999). Existing standards are either based on the low risk level WHO guidelines (1989) (e.g. France, Spain) or on the minimum risk level California Title 22 standards (1978) (e.g. Cyprus, Italy).

Table 30: Existing country/regional water reuse criteria within the European Union (after AQUAREC, 2006)

country/region	type of criteria	comment
Belgium: Flemish regional authority	Aquafin proposal to the regional government (2003)	based on Australian EPA guidelines
Cyprus	Provisional standards, 1997	quality criteria for irrigation stricter than WHO 1989 standards but less than CA Title 22 (TC <50/100 mL in 80 % of the cases on the a monthly basis and <100/100 mL always)
France	Art 24 décret 94/469 (1994); Circulaire DGS/SD1.D./91/n°51	both refer to water reuse for agricultural purposes. Essentially WHO 1989 standards with the addition of restrictions for irrigation techniques and set back distances to residential areas and roadways
Italy	Decree of Environmental Ministry 185/2003	three water reuse categories: agriculture, non-potable urban and industrial. Possible to set stricter regional norms
Sicily, Emilia Romagna, Puglia	Regional guidelines	microbiological standards similar to CA Title 22 for Puglia and Emilia Romagna and to WHO 1989 standards in Sicily
Spain	Royal Decree 1620/2007	for 14 possible applications similar to CA Title 22 regulations, but different standards, draft legislation issued in 1985
Andalucía, Balearic Islands and Catalonia	Regional Health Authorities	irrigation standards based on WHO 1989 standard

TC: total coliforms, CA: Californian

Germany

In the past, Germany did not experience significant water stress and agricultural reuse is not practiced widely, as enough freshwater resources are available and no specific reuse guidelines are available. One example for wastewater reuse for agricultural irrigation of fodder and fuel crops can be found in Braunschweig, where the local wastewater treatment plant irrigates 3000 ha of adjacent fields and also infiltrates significant volumes of treated effluent for groundwater recharge since 1975 (Eggers, 2008). Sludge has also been applied to the fields. So far, no negative impacts on the groundwater quality, but an increase in soil fertility and in water quality of receiving streams have been found. Indirect water reuse through bank filtration and artificial recharge has been practiced for decades along the Rhine and Ruhr valley and in Berlin (Jekel and Gruenheid, 2008; Drews and Gerdes, 2002; Haberer, 1994; Kötter, 1985). Germany recycles significant amounts for industrial applications, e.g. food and beverage industry (Rosenwinkel et al., 2008).

Cyprus

In Cyprus 100 % of treated wastewater is recycled (MED-EUWI, 2007). Domestic water is used for urban and agricultural irrigation (trees and fodder). Regulations are somewhere between the WHO and the Title 22 standards and a code of practice has been issued (Table 31).

Table 31: Provisional quality criteria for irrigation with reclaimed water in Cyprus (1989) (after UNEP, 2005)

irrigation of		BOD_5 (mg/L)[1]	TSS (mg/L)[1]	FC (MPN/100 mL)[1]	helminth eggs/L	treatment
all crops (*)	A	10	10	5/15	Nil	Secondary, tertiary and disinfection
vegetables eaten cooked (**), Amenity areas of public unlimited public access	A	10/15	10/15	50/100	Nil	Secondary, tertiary and disinfection
crops for human consumption. Amenity areas of limited public access	A	20/30	30/45	200/1000	Nil	Secondary, storage >1 week and disinfection or tertiary and disinfection Stabilisation-maturation ponds total retention time >30 days or secondary and storage >30 days
	B	-	-	200/1000	Nil	
fodder crops	A	20/30	30/45	1000/5000	Nil	Secondary and storage >1 week or tertiary and disinfection Stabilisation-maturation ponds total retention time >30 days or secondary and storage >30 days
	B	-	-			
industrial crops	A	50/70	-	3000/10000	-	Secondary and disinfection Stabilisation-maturation ponds total retention time >30 days or secondary and storage >30 days
	B	-	-	3000/10000	-	

A: Mechanised methods of treatment; B: stabilisation ponds. 1: first values must not be exceeded in 80 % of samples per month, minimum number of samples 5 / second value is maximum value allowed, * Irrigation of leaved vegetables, bulbs and corms eaten uncooked is not allowed, ** Potatoes, beetroots, colocasia. Note: The irrigation of vegetables is not allowed. The irrigation of ornamental plants for trade purposes is not allowed. No substances accumulating in the edible parts of crops and proved to be toxic to humans or animals are allowed in effluent.

France

The French guidelines (based on the WHO guidelines) allow reuse of treated wastewater, if the environment, the aquifer and the public are not at risk and set additional requirements concerning irrigation management, timing and distance to residential areas/leisure areas (Table 32). Permits are needed, reuse water quality has to be monitored and the scheme operated by trained operators (Lazarova et al., 2000). The administrative effort and strict local controls hinder a widespread reuse. However, reuse for irrigation has been practiced around large cities and, especially in the south of the country, irrigation in agriculture and on golf courses, and use for environmental flows are common. Indirect potable use along the Seine River is also practiced.

Table 32: Water reuse recommendations in France (1991) (after UNEP, 2005)

	criteria	irrigation type	vegetation	treatment
A	none	on-surface or subsurface trickle irrigation	cereals, industrial crops, fodder, fruit trees, forest and green areas with restricted access	-
B	≤ 1 helminth egg/L	surface or furrow irrigation; spray irrigation if aerosol propagation limited: setback distances from residential areas >100 m, hedges, etc.	fruit trees, cereals and fodder, nurseries and food crops eaten cooked; sport fields if irrigation is stopped several weeks before access	stabilisation ponds >10 days retention time or equivalent
C	≤ 1 helminth egg/L ≤ 10^3 FC/100 mL	irrigation methods with limited contact with crops: low pressure sprinklers, surface irrigation, furrows; setback distances from residential areas > 100 m	fruit trees, pasture, food crops eaten raw, etc.; sport fields, golf courses, green areas with open access	stabilisation ponds >10 days retention time or equivalent

Note that the new French draft regulations (November 2000) are based on the following criteria: (a) Secondary treatment (EU Directive, 1991): SS < 35 mg/L and total COD < 125 mg/L, for lagoon effluents: SS < 150 mg/L, dissolved COD < 125 mg/L, *E. coli.* < 1000/100 mL, and no *Salmonella* and *Taenia* eggs, (b) Setback distances (from roads, houses) ≥ 50 m, (c) Spray irrigation during off-hours. Low range sprinklers are recommended, (d) Sub-surface irrigation was not taken into account.

Italy

As water resources are scarce, especially in the South, water reuse in Italy is practiced for irrigation of orchards, vineyards and vegetables (Barbagallo et al., 2001). Uncontrolled practice has been going on for decades (Angelakis and Bontoux, 2001), but in 2003, Italy promulgated extremely strict water reuse standards addressing 54 parameters, partially based on drinking water standards (Table 34). In metropolitan areas separate supply networks for reclaimed water are envisaged or already established (Angelakis and Bontoux, 2001). Some regional microbiological standards have been established based on the older Italian guidelines (Table 33).

Table 33: Microbiological standards for irrigation with reclaimed water in Italy (1977) after UNEP, 2005)

<table>
<tr><th>region</th><th>irrigation</th><th>TC/100 mL[a]</th><th>physico-chemical</th></tr>
<tr><td rowspan="2">national standards</td><td>unrestricted (b)</td><td>2</td><td rowspan="2">SAR ≤15</td></tr>
<tr><td>restricted (c)</td><td>20</td></tr>
<tr><td rowspan="2">Emilia Romagna</td><td>unrestricted</td><td>2</td><td rowspan="2">-</td></tr>
<tr><td>restricted</td><td>20</td></tr>
<tr><td rowspan="2">Puglia:</td><td>unrestricted</td><td>2</td><td rowspan="2">15 mg/L BOD_5; 40 mg/L COD; 10 mg/L TSS; 0.2 mg/L residual Cl_2; pH 6.5-8.5</td></tr>
<tr><td>restricted</td><td>20</td></tr>
<tr><td rowspan="2">Sicily:</td><td>restricted</td><td>3000</td><td rowspan="2">40 mg/L BOD_5; 160 mg/L COD; 30 mg/L TSS; pH: 6.5 - 8.5</td></tr>
<tr><td>irrigation is prohibited for crops that are in direct contact with the reclaimed water</td><td>1000 FC/100 mL, 1 helminth egg/L, ND salmonella</td></tr>
</table>

a: mean value of 7 consecutive sampling days, b: unrestricted irrigation: crops that can be eaten raw, c: restricted irrigation: pasture

Table 34: Quality requirements for wastewater irrigation in Italy after Decree of Environmental Ministry 185/2003 (after Juanicó and Salgot, 2008)

parameter	standard	parameter	standard
SAR	10	CN (mg/L)	0.05
TSS (mg/L)	10	H_2S (mg/L)	0.5
BOD_5 (mg/L)	20	SO_3 (mg/L)	0.5
COD (mg/L)	100	SO_4 (mg/L)	500
total P (mg/L)	2	Cl_2 residual (mg/L)	0.2
total N (mg/L)	15	Cl (mg/L)	250
NH_4 (mg/L)	2	F (mg/L)	1.5
EC (μS/cm)	3000	oil and fats (mg/L)	10
Al (mg/L)	1	mineral oils (mg/L)	0.05
As (mg/L)	0.02	total phenols (mg/L)	0.1
Ba (mg/L)	10	pentachlorophenol (mg/L)	0.003
B (mg/L)	1	total aldehydes (mg/L)	0.5
Cd (mg/L)	0.005	tetra-/trichloroethylene (mg/L)	0.01
Co (mg/L)	0.05	chlorinated solvents (mg/L)	0.04
Cr (total) (mg/L)	0.1	total THM (mg/L)	0.03
Cr (VI) (mg/L)	0.005	aromatic solvents (mg/L)	0.001
Cu (mg/L)	1	benzene (mg/L)	0.01
Fe (mg/L)	2	benzo(a)pyrene (μg/L)	0.01
Hg (mg/L)	0.001	organic N solvents (mg/L)	0.01
Mn (mg/L)	0.2	surfactants (mg/L)	0.5
Ni (mg/L)	0.2	chlorinated biocides (μg/L)	0.1
Pb (mg/L)	0.1	phosphorated pesticides (μg/L)	0.01
Se (mg/L)	0.01	other pesticides (mg/L)	0.05
Sn (mg/L)	3	*E. coli.* (cfu/100 mL) (80 % samples)	10
Tl (mg/L)	0.001	*E. coli.* (cfu/100 mL) (CW)	50
V (mg/L)	0.1	*E. coli.* (cfu/100 mL) (WSP)	100
Zn (mg/L)	0.5	salmonellae (cfu/100 mL)	nil

CW: constructed wetlands, WSP: wastewater stabilisation ponds

Spain

Spain reuses the highest amount of water in Europe (347 Mio m³/a) and the main applications are irrigation of vineyards, orchards and golf courses, groundwater recharge to stop coastal seawater intrusions and river flow augmentation (Teijón et al., 2009; MED-EUWI, 2007; Sala et al., 2002). Especially along the Mediterranean coast and on the Canary and Balearic Islands, where water is scarce, many reuse schemes have developed. Regulations are managed by the regional authorities and three different regional guidelines are currently operative (Balearic Islands, Catalonia and Andalusia) (Table 35 for Andalusia). The national guideline has finally been approved in Dec 2007 and also place emphasis on hazard control (Esteban and de Miguel, 2008). The quality criteria (Table 36) are to be considered minimum requirements and regional authorities can demand stricter values.

Table 35: Quality guidelines for water reuse in Andalusia (after UNEP, 2005)

type of application	**FC /100 mL**	**helminth eggs /L**
irrigation of sport fields and parks with public access	<200	<1
vegetables to be consumed raw	<1000	<1
production of biomass intended for human consumption and refrigeration in open circuits	<1000	None
recreational lakes	<2000	<1
refrigeration in semi-closed circuits	<10000	None
industrial crops, cereals, dry fodder seeds, forests and conserved or cooked vegetables	None	<1
irrigation of green areas with no public access, production of biomass not intended for human consumption and recreational lakes with access prohibited	None	None

Table 36: Draft of wastewater quality standards proposed by CEDEX in 1999 (Spain) (after UNEP, 2005)

	use of the reclaimed wastewater	Quality Criteria				
		helminth eggs/L	*E. coli.* (cfu/100 mL)	TSS (mg/L)	Turbidity (NTU)	other criteria
1	residential uses: garden irrigation, toilet flushing, home air conditioning systems, car washing (not for human consumption)	<0.1	0	<10	<2	
2	urban uses and facilities: irrigation, street cleaning, fire-fighting, decorative fountains (not for industrial cooling or food industry)	<1	<200	<20	<5	
3	greenhouse crops irrigation	<1	<200	<20	<5	Legionella p. 0 cfu/100 ml
4	irrigation of raw consumed food crops. Fruit trees sprinkler irrigated	<1	<200	<20	<5	
5	irrigation of pasture for milking or meat animals	<1	<1000	<35		Taenia saginata and solemn <1 egg/L
6	irrigation of crops for canning industry and crops not raw-consumed. Irrigation of fruit trees except by sprinkling	<1	<1000	<35		
7	irrigation of industrial crops, nurseries, fodder, cereals and oleaginous seeds	<1	<10000	<35		
8	irrigation of forested areas, landscape areas and restricted access areas. Forestry	<1		<35		
9	industrial cooling, except for the food industry		<10000	<35		Legionella p. 0 cfu/100 ml
10	impoundments, water bodies and streams for recreational use in which the public's contact with the water is permitted (except bathing)	<1	<200	<35		must be odour free
11	impoundments, water bodies and streams for recreational use in which the public's contact with the water is not permitted			<35		must be odour free
12	aquaculture (plant or animal biomass), (not for filtering shellfish)	<1	<1000	<35		
13	aquifer recharge by localised percolation through the soil (minimal thickness 1.5 m)	<1	<1000	<35		total N <50 mg/L
14	aquifer recharge by direct injection	<0.1	0	<10	<2	total N <50 mg/L

cfu: colony forming unit

Turkey

Turkey has regulations for wastewater reuse in agriculture according to the Water Pollution Control Regulations since 1991 based on WHO standards (Table 37) and for heavy metals (Table 38). The five effluent classes are related to sodium and salinity hazard (Tanik et al., 2005). Permits for reuse have to be obtained. A revision of microbiological standards and boron limits are advised (Kramer et al., 2007).

Table 37: Effluent quality criteria for irrigation (after Kramer et al., 2007)

	effluent class I	effluent class II	effluent class III	effluent class IV	effluent class V
salinity and sodium hazard	very low	low	medium	usable with care	cannot be used
TSS (mg/L)	20	30	45	60	>100
BOD_5 (mg/L)	0-25	25-50	50-100	100-200	>200
NH_4 (mg/L)	0-5	5-10	10-30	30-50	>50
NO_3 (mg/L)	0-5	5-10	10-30	30-50	>50
FC /100mL.	0-2	2-20	$20-10^2$	10^2-10^3	$>10^3$
pH	6.5-8.5	6.5-8.5	6.5-8.5	6-9	<6 or >9
EC (µS/cm)	0-250	250-750	750-2000	2000-3000	>3000
TDS (mg/L)	0-175	175-525	525-1400	1400-2100	>2100
Na (%)	<20	20-40	40-60	60-80	>80
SAR	<10	10-18	18-26	<26	
$NaCO_3$ (mg/L)	<66	66-133	133-625	625-710	
Cl (mg/L)	0-142	142-249	249-426	426-710	>710
SO_4 (mg/L	0-192	192-336	336-575	575-960	>960
B (mg/L)	0-0.5	0.5-1.12	1.12-2.0	>2.0	

Table 38: Maximum Concentrations of Toxic Elements in Effluents for Irrigation (after Kramer et al., 2007)

elements	max. concentration (mg/l)	elements	max. concentration (mg/l)
aluminium (Al)	5.0	lead (Pb)	5.0
arsenic (As)	0.1	lithium (Li)	2.5
beryllium (Be)	0.1	manganese (Mn)	0.2
cadmium (Cd)	0.01	molybdenum (Mo)	0.01
chromium (Cr)	0.1	nickel (Ni)	0.2
cobalt (Co)	0.05	selenium (Se)	0.02
copper (Cu)	0.2	vanadium (V)	0.1
fluorine (F)	1.0	zinc (Zn)	2.0
iron (Fe)	5.0		

2.3.3 USA

The use of reclaimed water dates back to the 1960s in California (for urban and agricultural irrigation due to water scarcity) and in Florida (to control discharge into sensitive wetlands). Texas and Arizona also use reclaimed water on a larger scale for irrigation. Many examples for aquifer recharge exist and industrial reuse is also increasing. Generally guidelines are fairly strict requiring coagulation/flocculation, sedimentation, filtration and disinfection, sometimes leading to problems with disinfection by-products (Bougeard, et al., 2010; McQuarrie and Carlson, 2003). The US EPA has issued guidelines on water reuse (Table 39, US EPA, 2004), but the states have developed their own guidelines, the most prominent being the Californian Title 22 guidelines (2000) (Table 40). These guidelines are not based on the risk approach like the WHO guidelines, but are much stricter requiring no detectable faecal coliforms for unrestricted irrigation and are therefore not realistic for developing countries (Kramer et al., 2007). In Texas salinity is a major problem and crop selection, irrigation technique and water quality recommendations similar to Table 22 and Table 23 are given (Fipps, 1996).

Table 39: Suggested guidelines for water reuse (after US EPA, 2004)

type of reuse	BOD_5 (mg/L)	TSS (mg/L)	Turbidity (NTU)	FC /100 mL	Cl_2 residual (mg/L)	setback distances (m)	treatment required
urban reuse	≤10		≤2	nil	1	15 to A	secondary + filtration + disinfection
restricted access area irrigation	≤30	≤30		≤200	1	90 to A 30 to B	secondary + disinfection
unrestricted agricultural reuse	≤10		≤2	nil	1	15 to A	secondary + filtration + disinfection
restricted agricultural reuse	≤30	≤30		≤200	1	90 to A 30 to B	secondary + disinfection
environmental reuse	≤30	≤30		≤200			secondary + disinfection (min), (+ dechlorination)
groundwater recharge	site specific						minimum: primary for spreading, secondary for injection
indirect potable reuse*	drinking water standards					site-specific	secondary + filtration + disinfection + advanced

A: potable water supply wells, B: areas accessible to the public (if spray irrigation), Note: Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contractors, and may include stabilisation pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do not exceed 30 mg/l. Some stabilisation pond systems may be able to meet this coliform limit without disinfection. *Monitoring should include inorganic and organic compounds or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards.

Table 40: California water recycling criteria: treatment and quality requirements for non-potable uses of reclaimed water (State of California Title 22 Water Recycling Criteria (2000) (after UNEP, 2005)

type of use	TC/100 mL[a]	treatment required
irrigation of fodder, fiber and seed crops, orchards[b] and vineyards[b], processed food crops, non food bearing trees, ornamental nursery stock[c], and sod farms[c]; flushing sanitary sewers	none required	secondary
irrigation of pasture for milking animals, landscape areas[d], ornamental nursery stock and sod farms where public access is not restricted; landscape impoundments; industrial or commercial cooling water where no mist is created; nonstructural fire fighting; industrial boiler feed; soil compaction; dust control; cleaning roads, sidewalks, and outdoor areas	≤23 ≤240*	secondary + disinfection
irrigation of food crops[b]; restricted recreational impoundments; fish hatcheries	≤2.2 ≤23*	secondary + disinfection
irrigation of food crops[e] and open access landscape areas[f]; toilet and urinal flushing; industrial process water; decorative fountains; commercial laundries and car washes; snow-making; structural fire fighting; industrial or commercial cooling where mist is created	≤2.2 ≤23* 240 (max)	secondary + coagulation[g] + filtration[h] + disinfection
non-restricted recreational impoundments	≤2.2 ≤23* 240 (max)	secondary + coagulation + clarification[i] + filtration[h] + disinfection

a: Based on running 7-day median; b: No contact between reclaimed water and edible portion of crop, c: No irrigation for at least 14 days prior to harvesting, sale, or allowing public access, d: Cemeteries, freeway landscaping, restricted access golf courses, and other controlled access areas, e: Contact between reclaimed water and edible portion of crop; includes edible root crops, f: Parks, playgrounds, schoolyards, residential landscaping, unrestricted access golf courses, and other uncontrolled access irrigation areas, g: Not required if the turbidity of the influent to the filters is continuously measured, does not exceed 5 NTU for more than 15 minutes and never exceeds 10 NTU, and there is capability to automatically activate chemical addition or divert the wastewater if the filter influent turbidity exceeds 5 NTU for more than 15 minutes, h: The turbidity after filtration through filter media cannot exceed 2 nephelometric turbidity units (NTU) within any 24-hour period, 5 NTU more than 5% of the time within a 24-hour period, and 10 NTU at any time. The turbidity after filtration through a membrane process cannot exceed 0.2 NTU more than 5% of the time within any 24-hour period and 0.5 NTU at any time, i: Not required if reclaimed water is monitored for enteric viruses, Giardia, and Cryptosporidium. *in more than one sample in any 30-day period, TC: total coliforms

2.3.4 Australia

Australia is a water scarce country, which was affected by a long drought, so reuse of reclaimed water has increased (up to 20 % of total effluent in South Australia in 2006) (Radcliffe, 2007). It is mainly used for agricultural irrigation (example Bolivar, SA), urban non-potable uses (example Mawson Lakes, SA) and industrial reuse (example Kwinana, WA) often using aquifer storage and recovery (Anderson et al., 2008; Radcliffe, 2004; Dillon, 2001). New national guidelines for general reuse including sewage and greywater were released in 2006 and expanded in 2009 to include stormwater reuse, managed aquifer recharge and recycled water for potable use (NRMMC, EPHC, AHMC, 2006; NRMMC, EPHC, NHMRC, 2009), replacing the previous Australian national water guidelines (ARMCANZ/ANZECC, 2000). States are expected to adjust their regional guidelines to the new national standard which is based on a HACCP approach to risk management and also set the tolerable risk as 10^{-6} DALY per person per year like the WHO standards (2006). Indicative log removal rates of pathogens with different treatment techniques (Table 41) and risk reduction through preventive measures are given (Table 42). The risk management framework based on human and environmental risks is completed with monitoring and a management plan. After a system analysis (assessment of water system, preventive measures, operational procedures and process control, verification of quality performance, incident and emergency management) and supporting requirements (employee awareness, community involvement, research and development, documentation and reporting), a review of the total management framework completes the elements of the framework.

Table 41: Indicative log removals of enteric pathogens and indicator organisms (NRMMC, EPHC, AHMC, 2006)

treatment	*E. coli.*	bacterial pathogens (including Campylobacter)	viruses (including adenoviruses, rotaviruses enteroviruses)	phage	*Giardia*	*Cryptosporidium*	*Clostridium perfringens*	helminths
primary treatment	0–0.5	0–0.5	0–0.1	N/A	0.5–1	0–0.5	0–0.5	0–2
secondary treatment	1–3	1–3	0.5–2	0.5–2.5	0.5–1.5	0.5–1	0.5–1	0–2
dual media filtration with coagulation	0–1	0–1	0.5–3	1–4	1–3	1.5–2.5	0–1	2–3
membrane filtration	3.5–>6	3.5–>6	2.5–>6	3–>6	>6	>6	>6	>6
reverse osmosis	>6	>6	>6	>6	>6	>6	>6	>6
lagoon storage	1–5	1–5	1–4	1–4	3–4	1–3.5	N/A	1.5–>3
chlorination	2–6	2–6	1–3	0–2.5	0.5–1.5	0–0.5	1–2	0–1
ozonation	2–6	2–6	3–6	2–6	N/A	N/A	0–0.5	N/A
UV light	2–>4	2–>4	>1*	3–6	>3	>3	N/A	N/A
wetlands - surface flow	1.5–2.5	1	N/A	1.5–2	0.5–1.5	0.5–1	1.5	0–2
wetlands – subsurface flow	0.5–3	1–3	N/A	1.5–2	1.5–2	0.5–1	1–3	N/A

N/A = not available; UV = ultraviolet; >1.0, * adenovirus >3.0 enterovirus, hepatitis A Note: Reductions depend on specific features of the process, including detention times, pore size, filter depths, disinfectant

Table 42: Exposure reductions provided by on-site preventive measures (NRMMC, EPHC, AHMC, 2006)

control measure	reduction
cooking or processing of produce (e.g. cereal, wine grapes)	5 - 6 log
removal of skins from produce before consumption	2 log
drip irrigation of crops	2 log
drip irrigation of crops with limited to no ground contact (e.g. tomatoes, capsicums)	3 log
drip irrigation of raised crops with no ground contact (e.g. apples, apricots, grapes)	5 log
subsurface irrigation of above ground crops	4 log
withholding periods — produce (decay rate)	0.5 log/day*
withholding periods for irrigation of parks/sports grounds (1 – 4 hours)	1 log
spray drift control (micro-sprinklers, anemometer systems, inward-throwing sprinklers, etc)	1 log
drip irrigation of plants/shrubs	4 log
subsurface irrigation of plants/shrubs or grassed areas	5 - 6 log
no public access during irrigation	2 log
no public access during irrigation and limited contact after (non-grassed areas) (e.g. food crop irrigation)	3 log
buffer zones (25 – 30 m)	1 log

* based on virus inactivation. Enteric bacteria are probably inactivated at a similar rate. Protozoa will be inactivated if withholding periods involve desiccation.

Currently most states have issued their own reuse guidelines and best management practices for irrigation. The South Australia EPA advises to use wastewater irrigation management plans to minimise the risk of polluting surface and groundwater resources based on a site specific risk assessment (Table 43). They provide guidelines for different reuse options including biological, inorganic parameters and heavy metals (Table 44 and Table 45). Guidelines for the protection of aquatic ecosystems are up to 100 times more stringent than guidelines for irrigation (Table 45) showing the assumed attenuation capacity of soils. If soils are thin or direct infiltration along preferential flowpaths occurs like in karst areas, this attenuation capacity of the soil is limited and hence reuse water guidelines should be adjusted. Monitoring of runoff samples, surface water samples and groundwater samples is prescribed twice per irrigation period for at least nitrate and TDS. Soils should be tested at least every three years for EC, pH, total P and total N if treated domestic wastewater is used (EPA SA, 1999). If hazards to groundwater are suspected soils should be sampled in a 75 x 75 m grid for soil texture, soil depth, depth to groundwater, infiltration rates and water holding capacity (EPA SA, 2009a).

Table 43: Site limitations in relation to wastewater irrigation (EPA SA, 2009a)

feature	limitations			risks
	slight	moderate	severe	
slope				
flood irrigation	<1 %	1−3 %	>3 %	excess run-off and erosion
sprinkler	<6 %	6−12 %	>12 %	
trickle, drip	<10 %	10−20 %	>20 %	
flooding	none–rare	occasional	frequent	erosion, waterlogging, increased recharge
distance to watercourses	>200 m	100−200 m	50−100 m	contamination by runoff
landform	convex slopes and plains	concave slopes, foot slopes	drainage plains, incised channels	erosion and seasonal waterlogging
surface rock	nil	0 - 5 %	>5 %	shallow soil, increased runoff
hc (mm/hr)				
topsoil	20 - 80	5 - 20	<5	excess runoff
subsoil to 1 m	20 - 80	1 - 20	<1	waterlogging, poor filter
depth to water table (m)	>3	0.5 - 3	<0.5	wetness, risk of groundwater contamination
depth to bedrock (m)	>1	0.5 - 1	<0.5	restricts root growth, increased waterlogging, small soil-water storage
water-holding cap. (mm/m)	>200	<200		little availability to hold water between irrigation
EC (dS/m)	<2	2 - 8	>8	restricts plant growth
P sorption cap. (mg P/kg)	>1000	200 - 1000	<200	leaching to groundwater
pH (in $CaCl_2$)	4 - 9	3 - 4	>9	reduced plant growth
CEC (cmol(+)/kg)*	>15	<15		limited ability to hold nutrients

cap: capacity, hc: hydraulic conductivity, * average 0-40 cm

Table 44: Classification of reclaimed water for use in South Australia (EPA SA, 1999)

	E. coli. /100 mL	BOD (mg/L)	TSS (mg/L)	typical treatment
A	<10	<20	<2 NTU	secondary + tertiary + disinfection
B	<100	<20	<30	secondary + disinfection
C	<1000	<20	<30	primary sedimentation + lagooning or secondary
D	<10 000			primary sedimentation + lagooning or secondary

A: primary contact recreation, residential non-potable, municipal use with public access/adjoining premises, B: secondary contact recreation, unrestricted crop irrigation, municipal use with restricted access, irrigation of pasture and fodder for grazing animals, wash down and stock water, fire fighting, C: passive recreation, municipal use with restricted access, rRestricted crop irrigation, irrigation of pasture and fodder for grazing animals, D: restricted crop irrigation, irrigation for turf production, silviculture, non food chain aquaculture; specific removal of viruses, protozoa and helminths may be required for class A – C, helminths need to be considered for pasture and fodder in class D

Table 45: Inorganic criteria for irrigation water quality compared to the guideline for the protection of aquatic ecosystem (EPA SA, 1999)

parameter	guideline value for irrigation water quality (mg/L)	guideline value for the protection of aquatic ecosystem (mg/L)
pH	4.5 - 9	6.5 - 9
salinity		<1000
ammonia		0.02 – 0.03
Al	5	0.1
As	0.1	0.05
Be	0.1	0.004
Cd	0.01	0.0002 – 0.02*
Cr	1	0.01
Co	0.05	
Cu	0.2	0.002 – 0.005*
F	1	
Fe	1	1
Pb	0.2	0.001 – 0.005*
Li	2.5	
Mn	2	
Hg	0.002	0.0001
Mo	0.01	
Ni	0.2	0.015 – 0.15*
Se	0.02	0.005
U	0.01	
V	0.1	
Zn	2	0.005 – 0.050*

* depending on hardness

2.3.5 Mexico

Mexico reuses large amounts of wastewater (about 85 % of total effluent) for agricultural irrigation either treated (35 %) or untreated (65 %). Large scale irrigation examples are the Mezquital Valley (max. 90 000 ha), the Ciudad Juarez (26 000 ha) (Jiménez, 2008a) Direct and indirect reuse is practiced in the Tula Valley, where wastewater from unlined canals infiltrated into the groundwater (Jiménez, 2008b). Due to increases in disease, standards were introduced in 1991 and revised a number of times before the latest revision in 1996 (Table 46). The regulations also define suitable irrigation methods. The guidelines are simple, cost effective and easily enforced and monitored. Further revisions were recommended though, which could be met with cost effective wastewater stabilisation ponds or wastewater storage and treatment reservoirs (Table 46). Crop restrictions, irrigation technique restriction and human exposure control should also be considered to be included in revised guidelines (Peasey et al., 2000).

Table 46: Proposed changes to Mexican Standard NOM-001-ECOL-1996 (after Peasey et al., 2000)

irrigation	Mexican Standards		proposed standards for Mexico		WHO guidelines (1989)	
	FC/100ml*	ova/litre	FC/100ml	ova/litre	FC/100ml	ova/litre
restricted	≤10^3	≤5	≤10^3-10^4	≤0.1-1.0	no limit	≤1
unrestricted	≤10^3	≤1	≤10^3	≤0.1-1.0	≤10^3	≤1

* monthly mean, daily mean 2000 FC/100 mL. Unrestricted irrigation for all crops, restricted irrigation excludes salad crops and vegetables that are eaten raw

2.3.6 Middle East and North Africa (MENA) region

Water reuse has been practiced for centuries, but mainly with untreated wastewater (Bahri, 2008a). Due to the increasing water scarcity, many countries in the MENA region are now recycling wastewater with Jordan and Syria leading the way (Table 47).

Table 47: Wastewater production, treatment and reuse in selected MENA countries (after FAO, 2009; FAO wastewater database, 2004)

country	produced (Mio m³/a)	treated (% produced)	reused (% produced)	reused (% treated)	total water use (Mio m³/a)
Bahrain	45	100	18	18	357 (2003)
Egypt	10012	7	2	29	68300 (2000)
Jordan	82	88	79	90	941 (2005)
Kuwait	119	87	44	50	913 (2002)
Libya	546	20	7	36	4326 (2000)
Oman	78	13	11	88	1321 (2003)
Saudi Arabia	730	75	17	22	23670 (2006)
Syria	825	67	67	100	16700 (2003)
Tunisia	240	70	14	20	2850 (2001)
UAE	881	22	21	96	3998 (2005)

The Arab countries can be divided in three categories regarding the standards of wastewater treatment and reuse regulations (Choukr-Allah, 2010):

1) advanced treatment of wastewater and effluent reuse for unrestricted irrigation (Bahrain, Oman, Saudi Arabia, Qatar, Kuwait, UAE)
2) moderate regulations for wastewater disposal not meeting international standards, but no disposal of raw sewage; regulations for restricted irrigation (Egypt, Iraq, Jordan, Morocco, Syria, Tunisia)
3) disposal of raw sewage without treatment, no environmental or health control considerations; reuse of raw sewage (Palestine, Yemen, Lebanon)

A basic comparison of guideline values is given in Table 48.

Table 48: Wastewater reuse guidelines for some selected countries (modified after Choukr-Allah, 2010)

	E. coli./ 100 mL	helminth eggs/L	BOD_5, COD, NO_x, TSS, EC	crops eaten uncooked allowed	code of practice
WHO	1000	< 1	no	yes	yes
Oman	200	< 1	yes	yes	
Saudi Arabia	2.2	< 1	yes	no	yes
Kuwait	20	< 1	yes	no	yes
Egypt	decrees, but no specific standards				
Jordan	100	< 1	yes	no	yes
Morocco	1000	absence	yes	yes	no
Syria	1000	< 1	yes	no	yes
Tunisia	-	< 1	yes	no	yes
Palestine	1000	< 1	yes	no	yes
Lebanon	draft guidelines				
Yemen	proposed standards after Jordanian Standards JS 893/1995				

Egypt

Only limited amounts of wastewater are treated. Indirect and direct reuse of sewage and reuse of drainage water are practised on a large scale though, as canals flow into the Nile, which is used to extract irrigation water. Treated effluent and sewage sludge are also used in agriculture (Bahri, 2008a). As yet there are no specific regulations dealing with water reuse, but water pollution from effluents is regulated by a number of decrees, e.g. for the protection of the Nile River requiring secondary treatment prior to discharge to the Nile and irrigation channels with BOD <50 mg/L and FC <5000/100 mL. Reuse of water for irrigation of timber trees and green belts is allowed, but irrigation of vegetables and crops is generally not allowed unless treated to standards for agricultural drainage water (Bahri, 2008a), but enforcement is low. A range of examples for reuse exist and comprehensive guidelines for restricted agricultural reuse are under preparation (Bahri, 2008b).

Israel

Israel has practiced reuse of wastewater for decades and about 75 % of all sewage is reused, mainly for irrigation and groundwater recharge (Angelakis et al., 1999). It must be approved by the authorities and meet high water quality criteria similar to the Title 22 standards (Table 49). Guidelines have been updated and new criteria of salinity, boron, heavy metals and nutrients were added distinguishing between irrigational reuse and environmental discharge (Tal, 2006) (Table 50). The largest water reclamation scheme in Israel is the Dan Region Project using aquifer recharge and recovery via soil aquifer treatment resulting in a very high quality suitable for unrestricted irrigation (Idelovitch et al., 2003; Kanarek and Michail, 1996). Where reclaimed water still contains nutrients, these are often not accounted for by the farmer leading to problems of overfertilisation (Juanicó, 2008).

Table 49: Criteria for the reuse of wastewater effluent for irrigation in Israel (after Angelakis et al., 1999)

parameter	I	II	III	IV
BOD_5 total (mg/l)	15	35	45*	60*
BOD_5 dissolved (mg/l)	10	20	-	-
TSS (mg/l)	15	30	40*	50*
DO (mg/l)	0.5	0.5	0.5	0.5
coliforms (/100 ml)	12 (80%); 2.2 (50%)	250	-	-
residual Cl_2(mg/l)	0.5	0.15		-
sand Filtration or equivalent	required	-		-
chlorination (minimum contact time, min)	120	60		-
set back from residential areas (m)	-	-	250	300
set back from paved road (m)	-	-	25	30

I: Unrestricted crops, including vegetables eaten uncooked (raw), parks and lawns, II: Deciduous fruits (Irrigation must stop 2 weeks before fruit picking; no fruit should be picked from the ground), conserved vegetables, cooked and peeled vegetables, green belts, football Fields and golf courses, III: Green fodder, olives, peanuts, citrus, bananas, almonds, nuts, etc., IV: Cotton, sugar beet, cereals, dry fodder seeds, forest irrigation, etc.; * Different standards will be set for stabilisation ponds with retention time of at least 15 days.

Table 50: Public health regulations on effluent standards and sewage treatment (Israeli Ministry for Environmental Protection, 2010)

parameter	unrestricted irrigation*	rivers	parameter	unrestricted irrigation*	rivers
EC (dS/m)	1.4		Al (mg/L)	5	
BOD (mg/L)	10	10	As (mg/L)	0.1	0.1
TSS (mg/L)	10	10	B (mg/L)	0.4	
COD (mg/L)	100	70	Be (mg/L)	0.1	
NH_4 (mg/L)	10	1.5	Cd (mg/L)	0.01	0.005
total N (mg/L)	25	10	Co (mg/L)	0.05	
total P (mg/L)	5	1	Cr (mg/L)	0.1	0.05
Cl (mg/L)	250	400	Cu (mg/L)	0.2	0.02
F (mg/L)	2		Fe (mg/L)	2	
Na (mg/L)	150	200	Hg (mg/L)	0.002	0.0005
FC (/100 mL)	10	200	Li (mg/L)	2.5	
DO (mg/L)	<0.5	<3	Mn (mg/L)	0.2	
pH	6.5-8.5	7.0-8.5	Mo (mg/L)	0.01	
residual Cl_2 (mg/L)	1	0.05	Ni (mg/L)	0.2	0.05
anionic detergent (mg/L)	2	0.5	Pb (mg/L)	0.1	0.008
total oil (mg/L)		1	Se (mg/L)	0.02	
SAR $(mmol/L)^{0.5}$	5		V (mg/L)	0.1	
CN (mg/L)	0.1	0.005	Zn (mg/L)	2	0.2

Jordan

Jordan faces serious water scarcity and has made great improvements in sewage collection and treatment coverage. All wastewater from the As-Samra WWTP near Amman (large wastewater stabilisation pond systems, 180 ha) is mixed with freshwater (salinity levels are too high for direct irrigation due to the evaporation from the ponds) and used for unrestricted irrigation in the Jordan Valley. Indirect reuse occurs, when treated effluent is discharged into wadis and later withdrawn for irrigation. Reclaimed water is also used for aquifer recharge near Aqaba (Bahri, 2008b). Wastewater reuse is included in the National Water Strategy since 1998 and is encouraged by the government demanding reuse options to be investigated for all new wastewater treatment projects. Guidelines for various reuse options were issued in 1995 (JS 893/1995). Revised more stringent standards were enacted in 2003 8JS 893/2002), prohibiting the irrigation of vegetables eaten raw or recharging aquifers for potable use. The use of sprinklers and irrigation two weeks before harvest are also forbidden. Further revisions in 2006 (Table 51 and Table 52) specify conditions for reclaimed domestic wastewater quality standards when discharged to wadis/streams or used for irrigation and are less strict for BOD, COD and *E. coli.* than previous guidelines, but include advice on irrigation practices and human exposure control (Kramer et al., 2007). Greywater reuse is being tested in various pilot projects (McIlwaine and Redwood, 2010). Apart from desalination, the new Water Strategy envisions all treated wastewater to be used for irrigation as well as greywater reuse and rainwater harvesting at domestic scale (MWI, 2009). Groundwater and surface water protection are also of high priority and unsustainable groundwater abstractions are supposed to be phased out.

Table 51: Current Jordanian standards for wastewater reuse in irrigation and discharge to wadis/streams JS 893/2006 (after JISM, 2006))

parameter	cooked vegetables, parks, playgrounds and sides of roads within city limits	fruit trees, sides of roads outside city limits, and landscape	field crops, industrial crops and forest trees	discharge to wadis or streams
BOD (mg/L)	30	200	300	60
COD (mg/L)	100	500	500	150 (300 WSP)
DO (mg/L)	>2	-	-	>1
TSS (mg/L)	50	200	300	60 (120 WSP)
pH	6-9	6-9	6-9	6-9
turbidity (NTU)	10	-	-	-
NO_3 (mg/L)	30	45	70	80 (100 WSP)
total N (mg/L)	45	70	100	70 (100 WSP)
E. coli./100 mL	<100	<1000	unlimited	1000*
helminth eggs/L	≤1	≤1	≤1	≤1
FOG (mg/L)	8	8	8	8

FOG: fat, oil and grease; *In WWTP applying WSP (wastewater stabilisation ponds) *E. coli.* levels (1000 CFU) can be exceeded if the wadi or stream water will be stored in a reservoir used for Irrigation.

Research found that farmers apply to much fertiliser (P, K) and nutrients included in reclaimed water are often not accounted for (Meerbach and Böning-Zilkens, 2006). Irrigation practices are often not adjusted to the growing stage of the plants and the water holding capacity of the soil resulting in application of too much or too little water. The former can lead to excessive percolation with loss of nutrients and groundwater contamination and the latter to salt accumulation and yield losses (Meerbach and Böning-Zilkens, 2006).

Table 52: Further guidelines for reuse in irrigation and discharge to wadis/streams (JS 893/2006) (after JISM, 2006)

parameter (mg/L)	irrigation	discharge to wadis/streams	parameter (mg/L)	irrigation	discharge to wadis/streams
TDS	1500	1500	As	0.1	0.05
total PO_4	30	15	Be	0.1	0.1
Cl	400	350	Cd	0.01	0.01
SO_4	500	300	Co	0.05	0.05
HCO_3	400	400	Cr (total)	0.1	0.02
Na	230	200	Cu	0.2	0.2
Mg	100	60	Hg	0.002	0.002
Ca	230	200	Li	2.5 (0.075 citrus)	2.5
SAR	9	6	Mn	0.2	0.2
CN	0.1	0.1	Mo	0.01	0.01
phenol	<0.002	<0.002	Ni	0.2	0.2
MBAS	100	25	Pb	0.2	0.2
Al	%	2	Se	0.05	0.05
B	1	1	V	0.1	0.1
F	2	1.5	Zn	5	5
Fe	5	5	residual Cl_2		≤1

MBAS: methylene blue active substances = anionic surfactants, detergents

Morocco

Morocco has a low connection to the sewer network and an even lower level of functional treatment plants, and consequently sewage is largely disposed of into rivers/the sea or reused without adequate treatment, but reuse of treated wastewater is on the rise (Aomar and Abdelmajid, 2002). Regulations for irrigation are in place since 2002 based on the WHO 1989 guidelines (Table 53). In inland towns effluents are used for irrigation of crops, golf courses and urban greens. Low-cost wastewater treatment systems have been used for a number of pilot reuse projects for example in Ouarzatate, Rabat Ben, Sergao, Marrakech and Drarga (Bahri, 2008b, Soudi et al., 2000). Compared to saline groundwater, treated wastewater lowers the negative impacts of salinity on crops. Control measures like crop handling and drip irrigation were found to determine the final quality of the produce (El Hamouri et al., 1996).

Table 53: Quality standards for all water used for irrigation including wastewater effluent (after Aomar and Abdelmajid, 2002)

parameters	limit value	parameter	limit value
FC /100 mL	5000*	As (mg/L)	0.1
salmonella in 5L	Absence	Be (mg/L)	0.1
cholera vibrio in 450 mL	Absence	Cd (mg/L)	0.01
pathogen	Absence	Co (mg/L)	0.05
parasite eggs/cysts	Absence	Cr (mg/L)	0.1
ancylostoma larva	Absence	Cu (mg/L)	0.2
cercariae of Schistomosa haematobium	Absence	Hg (mg/L)	0.001
phenol (mg/L)	3	Li (mg/L)	2.5
CN (mg/L)	1	Mn (mg/L)	0.2
Al (mg/L)	5	Mo (mg/L)	0.01
F (mg/L)	1	Ni (mg/L)	0.2
Fe (mg/L)	5	Pb (mg/L)	5
* 1000 cfu/100 ml for crops consumed raw		Se (mg/L)	0,02
		V (mg/L)	0.1
		Zn (mg/L)	2

Palestine

In Palestine the wastewater is largely discharged into the environment without treatment and has seeped into the groundwater. Excessive withdrawal from the coastal aquifers has also resulted in seawater intrusions and groundwater salinisation. Wastewater reuse is therefore included in the national water sector strategic plan for reuse in irrigation and groundwater recharge. Greywater reuse at household level is also tested (McIlwaine and Redwood, 2010). Draft standards differentiate between numerous different reuse options and set standards for physical parameters, pathogens, nutrients, and inorganic compounds, but are not enforced as yet. Best management practiced require a stop of irrigation two weeks before harvest, no sprinkler irrigation, closed pipes for transport over permeable soils, no irrigation of vegetables and allow no dilution with fresh water to meet quality standards (Kramer et al., 2007). The main hindrance for wastewater reuse is therefore the low quality of the effluent produced by current treatment plants (Bahri, 2008b).

Syria

Agriculture has a water demand of >90 % of total water demand in Syria, hence potential for reuse is high. All new WWTPs have provisions for reuse. The use of untreated sewage for irrigation has lead to a deterioration of surface and groundwater as well as soil quality. Generally, water reuse is encouraged and it has been included in water resource planning, but there are currently no guidelines or regulations, only frameworks and specifications for reuse in agriculture, discharge to water bodies and industrial reuse exist. Reuse is restricted to fodder and industrial crops and fruit trees (Bahri, 2008b). Pilot projects with wastewater treatment in constructed wetlands and reed beds, and later reuse of water and sludge in agriculture at Haran-Al-Awamied have been established by the GTZ and have achieved high efficiency in pathogen removal and low running costs (Mohamed et al., 2009).

Tunisia

A gradual approach with the extension of wastewater treatment and pilot scale irrigation operations started in the 1960s (Choukr-Allah, 2010). Since the early eighties a water reuse policy is in place in Tunisia and reuse is well established. This is possible through a high rate of connection to sewer and treatment systems and the prohibition of discharge of untreated industrial wastewater to the sewer system (Bahri, 2008b). Main reuse is agricultural irrigation, landscape irrigation and groundwater recharge. Large scale irrigation of fruit and olive trees has been practiced around Tunis and recharge of aquifers has been successful in reducing seawater intrusions (Bahri, 2008b). The Decree 89-1047 regulates the use of treated effluent for agricultural reuse (Table 54). Restrictions for irrigation of vegetables eaten raw, heavily used pastures and the use of raw sewage are in place as well as codes of practice for irrigation and human exposure control measures (Kramer et al., 2007). Reuse is encouraged through a subsidised water price and awareness raising and is made possible through good regulations and institutional coordination (Neubert, 2002).

Table 54: Tunisian standards for reclaimed water reused in agriculture (JORT Decree No 89-1047, 1989) (after UNEP, 2005)

parameters	max. conc.	parameters	max. conc. (mg/L)
pH	6.5 - 8.5	As	0.1
EC(µS/cm)	7000	Cd	0.01
COD (mg/L)	90*	Co	0.1
BOD_5 (mg/L)	30*	Cr	0.1
helminth eggs /L	< 1	Cu	0.5
TSS (mg/L)	30*	Hg	0.001
Cl (mg/L)	2000	Fe	5
F (mg/L)	3	Mn	0.5
B (mg/L)	3	Ni	0.2
halogenated hydrocarbons (mg/L)	0.001	Pb	1
* 24-hr composite sample; except special authorisation		Se	0.05
for wastewater stabilisation ponds		Zn	5

Note: Monitoring of physical-chemical parameters once a month, trace elements once every six months, and helminth eggs once every two weeks. Secondary treated effluents allowed for all types of crops except vegetables, whether eaten raw or cooked. Site restrictions related to harvesting, animal grazing, reclaimed water application methods, etc.

2.3.7 Conclusions

Reclaimed wastewater is a valuable source of water that could alleviate stresses on water supplies. It can be used for agricultural irrigation, urban irrigation, industrial reuse or groundwater recharge. One of the main problems is the fact, that wastewater occurs primarily in urban areas away from agricultural areas, which consume about 70 – 80 % of the total demand and hence have the greatest potential for wastewater reuse. Consequently, central WWTPs near urban areas have restricted reuse potential and decentralised WWTPs in rural areas have high reuse potential.

Apart from quantity, quality of effluents determines the possibility and type of reuse. Treatment levels should be based on environmental and public health impacts depending on reuse choice. Reclaimed water contains valuable nutrients that are best utilised in agricultural irrigation and quality standards can often be met by extensive systems in rural areas. For groundwater recharge (either for enhancing the drinking water supply or to prevent salt water intrusions in coastal areas) tertiary treatment is needed to remove nutrients and heavy metals to avoid contamination. For industrial reuses, prevention of corrosion and scaling in systems might require additional treatment. Reuse on greens with public access or storage in publicly accessible impoundments requires additional pathogen removal. Urban reuse options of reclaimed water like irrigation of greens, toiled flushing, fire fighting, cooling or even potable reuse generally require a higher level of treatment. As large urban WWTPs should be equipped with sophisticated treatment technology some of these options might be feasible.

For agricultural reuse, health risks can largely be eliminated with appropriate irrigation management and human exposure control measures. Unless consumer acceptance is too low and produce is not marketable, health related issues should not be a constraint for reuse and it has been practiced successfully worldwide.

In contrast, environmental impacts to water resources are of concern, especially in mature karst areas found over large areas in Lebanon. **Treatment standards need to be high, as infiltration to the groundwater is highly likely. A special reuse class for karst areas with more stringent limits for pathogens and nutrients is recommended. Areas, where wastewater reuse can safely be applied have to be selected based on hydrogeological criteria addressing the protection needs of downstream drinking water resources.** Restrictions for areas unsuitable for wastewater irrigation (e.g. due to slope, soil thickness or proximity to water courses or infiltration features) have to be in place and enforced. Irrigation management has to be followed more strictly than in other areas and requires additional education of farmers.

2.4 Sludge management

Depending on the treatment system different **amounts of sludge** are generated (Table 55). During primary treatment large and medium solids, plastics, toilet paper, grease etc. is settled, skimmed or screened from the sewage. The resulting primary sludge is comparatively high in solids, easily dewatered, and depending on the garbage content, it is either landfilled or combined with the secondary sludge for further treatment. During secondary treatment fine solids, organic material, and detritus of microorganisms settle, and iron and manganese hydroxides precipitate. The resulting secondary sludge is low in solid content. If activated sludge systems are used, part of the secondary sludge is fed back into the secondary treatment to sustain the bacterial population. Tertiary filtration and adsorbers require regular backwashing and produce smaller amounts of tertiary sludge, which is commonly settled and the supernatant recycled into the treatment system. While membrane techniques (reverse osmosis, ultrafiltration) have high energy consumption and high maintenance costs, they produce very high quality water and only limited volumes of sludge as no microorganisms are added during treatment (ATV-DVWK, 2001). Due to the high amounts of sludge generated with common secondary treatment methods about half of the operating costs are associated with sludge treatment (Pescod, 1992). Various measures can be used to decrease the amount of sludge either during wastewater or during sludge treatment (Pérez-Elvira et al., 2006).

Table 55: Sludge production in different wastewater treatment processes (Tchobanoglous and Burton, 1991)

process	range (mean) (kg/m^3)	% total solids
primary Settling	0.108 – 0.168 (0.150)	4 - 10
advanced Primary Treatment	0.185 – 0.315*	0.4 - 10.8
activated Sludge	0.072 – 0.096 (0.084)	0.5 - 1.5
trickling Filter	0.060 – 0.096 (0.072)	1 - 3
anaerobic treatment	0.006 – 0.020 (0.010)	1 – 8
wastewater stabilisation ponds	0.021 - 0.036 m^3/capita/a [1]	11 - 23

*depending on the amount of chemical coagulant added, 1: Nelson et al., 2004

Raw sludge is high in water content, high in oxygen demand and contains high concentrations of valuable organic matter and nutrients, but also pathogens (*E. coli.* 10^5/g, enterovirus 10^2-10^4/g, *Giardia* 10^2-10^3/g, helminths 10^2-10^3/g (Carrington, 2001)), heavy metals and organic pollutants that are attached to the solids. Raw sludge should not be allowed to enter waterways, but has to be treated. A number of **treatment techniques** are available to dewater the sludge and render it safe for reuse (Binnie et al., 2002; Cheremisinoff, 2002, Pescod, 1992).

Dewatering can be achieved with:

- primary consolidation: stirred tanks or centrifugation reduce water content by up to 50%
- mechanical dewatering: conversion to sludge ‘cake’ with filter plate press, filter belt press, centrifuge or vacuum filtration resulting in solid contents of up to 25 %
- thickening: using polymers as coagulants/flocculants resulting in a solid content of the settled flocs of 5 - 10 %
- lagoons, reed beds or drying beds: storage in lagoons results in solid contents about 10%, drying beds are effective in hot, dry climates; percolation of sludge water into the groundwater has to be prevented with appropriate linings

The dewatered sludge can be further treated for decomposition/mineralisation of organic matter and inertisation of pathogens with (Milieu Ltd./WRc/RPA, 2010; Carrington, 2001; Langenkamp et al., 2001):

- mesophilic anaerobic digestion: digestion tank is maintained at 32 - 38 °C for 12 or at 22 – 28 °C for 20 days under anaerobic conditions followed by a secondary stage with 14 days retention time. Bacteria break down organic matter content resulting in the release of methane gas, which should be used to generate the required temperature in the digester and electricity. The resulting biosolids are generally safe for reuse in agriculture.
- thermophilic aerobic digestion: minimum 55 °C for at least 4 h, thereafter mean retention time 7 day
- incineration: after drying the sludge is burned at 650 – 760 °C , whereby the organic content is destroyed and only mineral ash is left. As it is often not economical for smaller treatment plants to have a sludge incinerator, the sludge is commonly transported to existing incineration plants (either waste incinerator or coal power plants)
- thermal drying: sludge is converted at 80 °C for 10 minutes into granular form with about 90 % solid content and the pathogens are destroyed due to the heat. The resulting pellets are used in agriculture or as soil amendments.
- pasteurisation/disinfection: the liquid sludge is heated to about 70 °C for at least 30 mins (or minimum 4 h at 55 °C) to destroy pathogens before further digestion in anaerobic tanks. The resulting biosolids are safer to use and can be applied more widely.
- lime stabilisation: lime is added to the liquid sludge until the pH is above 12 for at least 2 h at 55 °C to reduce the number of pathogens. The liquid sludge can be used directly or be further dewatered and digested.
- composting (windrows or aerated piles): within the body of the pile temperature rise due to the biochemical reactions, a minimum of 4 h at 55 °C and 5 days at 40°C should be maintained and piles turned at least three times.

The advantages and disadvantage of these treatment measures are compiled in Table 56.

Table 56: Advantages and drawbacks of sludge stabilisation processes (after Jiménez, 2007; Kramer et al., 2007)

treatment method	advantages	disadvantages
anaerobic digestion	- methane generation - sludge easy to dewater and very stable	- very low quality supernatant - costly - helminth egg removal ~70 %
incineration	- energy production - volume reduction high	- high temperature are hard to achieve if sludge contains high water contents - loss of nutrients
thermal drying	- pathogen and helminth ova removal very high	- high energy needs
lime stabilisation	- low cost and easy to operate - good as an emergent stabilisation method - good pathogen control (6-8 log of coliforms, 5-7 log of Salmonella, >98% helminth eggs)	- sludge production higher than compared to other treatments - bad odours from ammonia - helminth ova removal 0.5-2 logs
composting	- low cost and easy to operate - good reduction of volatile suspended solids (20-30%) - sludge well accepted in agriculture - good pathogen inactivation (5-7 log of faecal coliforms, >95% helminth eggs) - low nutrient loss - less bioavailability of metals	- demands a bulking material - much ground space required - risk of odour problems
drying/reed beds	- low cost and easy to operate - particular suitable in hot climates	- much ground space needed

Pathogen die-off is dependent on the temperature and time of storage (Fig. 10). At temperatures above 80 °C, all pathogens die off in a matter of minutes, while at temperature below 45 °C pathogens can survive up to one years (Jiménez, 2007; Peasey, 2000). If untreated sludge is spread in drying beds or applied to the soil, the pathogen survival depends on (Carrington, 2001):

- type of pathogen: spore forming bacteria, eggs and cysts are more resistant
- environmental factors:
    - UV-light: all pathogens are sensitive to sunlight
    - Temperature: longer survival at low temperatures
    - moisture content: desiccation kills many pathogens
    - pH: survival low at pH <4 or >10)
- quality of waste:
    - pathogen starting levels: higher concentrations result in longer survival (logarithmic removal rates) and depend on health status of population
    - organic content: replication of pathogens, but also growths of indigenous microorganisms under suitable conditions that outcompete pathogens
    - toxic substances: high concentrations of contaminants might lead to lower replication rates

- application rate: thick sludge layers prevent sunlight penetration, heat dissipation and evaporation

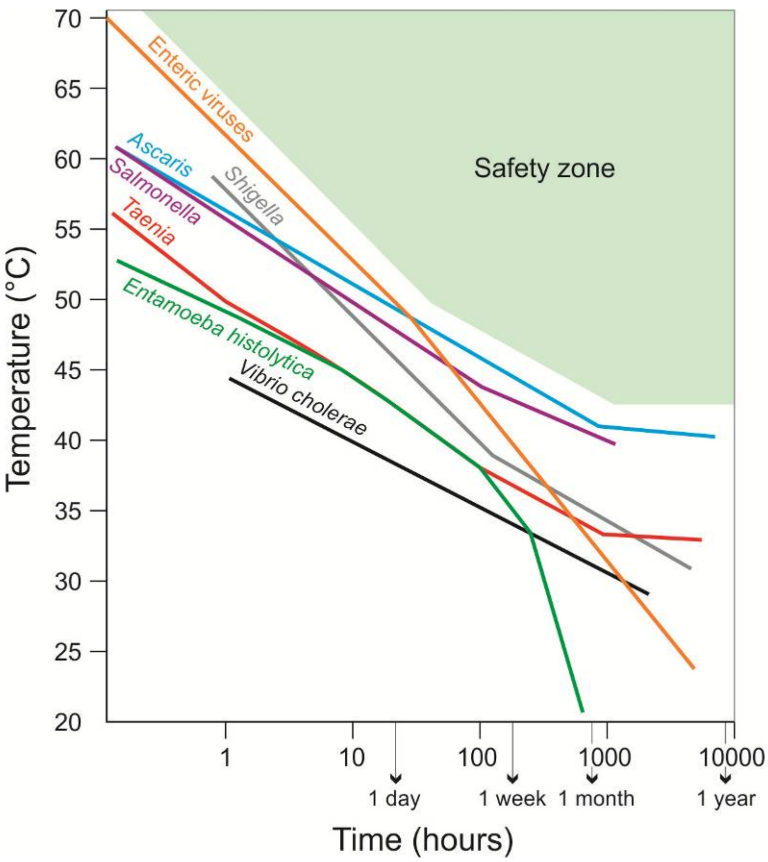

Fig. 10: Time-temperature dependence of pathogen die-off in sludge (after Langenkamp et al., 2001)

The final treated sludge – also called biosolids - can be disposed of in landfills (depending on the regulations and landfills have to be properly designed in karstic areas to avoid leachate reaching the groundwater), incinerated (see above) or reused as:

- soil amendment increasing water and nutrient holding capacity and improving soil structure
- fertiliser containing slowly releasing nutrients and trace elements
- incorporation into construction material

The organic matter content in compost and biosolids increases the cation exchange capacity of the soil, which increases the binding of for example phosphate and trace elements and lowers the impact of pesticides and other pollutants, hence increasing yield and health of crops (Meerbach and Böning-Zilkens, 2006). Sewage sludge is a valuable fertiliser as it contains high concentration of phosphate, potassium, nitrogen and micronutrients like Fe, Mn, Se, Cu, Zn etc. (Table 59). Wastewater sludge can also be mixed with clays or sludge ash to form bricks or added to cement with comparable compressive strength to normal bricks or cement and will remove heavy metals from the biosphere (de Quervain, 2001; Tay and Show, 1992). **This might be a valuable reuse option in karstic areas, where sludge application is limited.**

While the application of sewage sludge onto agricultural areas is a valuable resource for organic matter, nutrients and trace elements, it might also contain elevated amounts of pathogens (depending on the sludge treatment process), **heavy metals and organic contaminants** (depending on the source of the wastewater). Depending mainly on the soil properties (pH, CEC, EC, organic content etc.), these elements accumulate in the soil and are partially available for accumulation in crops. Metals from solid sludge are more bioavailable than from the original soil but less bioavailable than from liquid sludge (Pescod, 1992). The accumulation in plants is highest for essential elements like Cd, Ni, Cu and Zn, while Hg, Cr and Pb bioaccumulate less (Stöven and Schnug, 2009; McNab et al., 1997; Pescod, 1992). Metal concentration also differs from plant to plant; from one part of the plant to the other and is influenced by sludge treatment (Wen et al., 2002a,b; Kumar et al., 1995; Smith, 1994; Bruemmer et al., 1986). Sludge application to pasture should take into account that grazing animals are likely to ingest toxic elements and these will eventually be transferred to humans (Table 57). If the soil pH is low or the soil is very sandy, heavy metals are prone to leach out of the soil and contaminate the groundwater (Wong et al., 2007; Wang et al., 2005, Qureshi et al., 2004, Alloway, 1990). Heavy metals are also more bioavailable and phytotoxicity increases in acidic soils. Organic contaminants commonly have low water solubility and will hence be mainly transported with solids. Their uptake by plants is rather limited (Mattina et al., 2003; O'Connor, 1996), but they bioaccumulate in animals, when these ingest soil particles or sludge particles attached to plants (Chaney et al., 1996).

Table 57: Risk and factors of contaminants to enter the food chain via different transfer pathways (after SEDE and Arthur Andersen, 2002)

contaminants	**pathogens**	**heavy metals**	**organic contam.**
main factors / **pathway**	treatment method; application method	pH and CEC of soil, type of metal	solubility and degradability of compound
sludge – (plant surface) - human	limited with hygiene measures and good application practice		
soil – human	low with hygiene measures		
soil –plant	no	high for Cd, Cu, Ni Zn, low for Cr, Pb ; less accumulation in grains/fruit	low uptake by plants
soil – (plant) – animal	possible	no accumulation in meat	main pathway
soil – surface water (attached to suspended solids in runoff)	possible	significant	possible
soil – groundwater	Possible, mainly with particulates	low at high pH, possible with particulates	low in dissolved form; possible with particulates

In order to prevent groundwater, soil and crop contamination, it is necessary to control the concentrations of toxic elements in the sludge and monitor the existing concentration in the soil as well as the rate and timing of sludge application (Pescod, 1992). Sludge application to acidic soils is generally more restricted than for alkaline soils. Control measures to prevent pathogen transfer into the food chain are for example a three week grazing prohibition on pastures after sludge application, a stop of application three weeks before harvest of forage, or a stop of application ten month before harvest of vegetables or fruit from trees. The injection of sewage sludge rather than spreading on the surface also reduces pathogen transfer to humans (Carrington, 2001). Organic contaminants are degradable through biological or chemical reactions and hence will be removed over time from the soil (Yong and Mulligan, 2004; Alexander, 1999). In contrast, heavy metals cannot be degraded and will accumulate in the soil, be transferred to plants, animals, humans or to surface and groundwater over time. This is also true for persistent organic pollutants (POPs) like PCDD/Fs, PAHs, PCBs, HCB. **It is therefore vital to reduce the input of heavy metals and persistent organic pollutants to the sewer system.** Contamination of surface and groundwaters can be managed by controlling erosion (no application on steep slopes or bare soils without incorporation into the soil), setback distances from waterways, and prohibition of application on saturated soils or areas with high groundwater levels (Langenkamp et al., 2001). Borders around sites towards residential areas of 30 m and of 100 m around wells, sinkholes and surface waters are appropriate (Eash et al., 1998). Karst areas require special evaluation and in groundwater protection areas sludge applications are often not allowed. Similar to the application of fertilisers, the application of biosolids should be based on the needs of the crops and overfertilisation must be avoided. Sludge application in agriculture is not an alternative to waste disposal. A factor affecting the acceptance among the population is odour control. Vehicles transferring sludge to the field should use routes outside of residential areas to minimise inconvenience to the public (Eash et al., 1998). Discharge points of the sludge should be as near to the ground as possible and liquid biosolids should be incorporated into the soil quickly (Pescod, 1992).

The **upper limit** for soil pollutant accumulation could be based on daily human intake limits (via plants, animals, soil, airborne particles, surface water, groundwater) and site specific evaluation is recommended (Chang et al., 2002). For example threshold values for organic pollutants in respect to the contamination pathway soil – plant /- animal and soil – water are presented in Table 58. Permissible concentrations of cadmium in soils based on the transfer of soil Cd into the human food chain were determined to be 2.0 and 2.5 mg/kg for pH ranges of 5.0 – 5.5 and 5.5 – 6.0, respectively (Smith, 1994). Other models recommend Cd 4, Hg 7, Ni 107, Pb 84 mg/kg in the soil as permissible concentration (Chang et al., 2002). Regulations could also be based on the ecotoxicological impacts of contaminants on the soil microflora, which determine soil fertility and nutrient cycling. However, this approach is difficult to assess as positive and negative impacts of sewage sludge application are possible (Stöven and Schnug, 2009; Obbard, 2001). Another approach is to prevent any accumulation of contaminants in the soil based on input (fertiliser) and output (harvest) calculations (chapter 2.4.2).

Table 58: German threshold values for persistent organic pollutants for soil – plant /animal and soil – water pathway (after Langenkamp et al., 2001)

	soil - plant/ - animal (mg/kg soil)	soil – water (mg/kg soil)	soil – water (g/L soilwater)
HCB, HCH	0.05	0.02	
DDT	0.1		0.1
PCB (6)	0.05 (each)	0.1	
PAH (16)	10	5	0.2 (without naphthalene)
BaP	1	0.2	
PCDD/Fs	40 ng TEq/kg soil		

HCB: Hexachlorobenzene, HCH: Hexachlorocyclohexane, DDT: dichlorodiphenyltrichloroethane, PCB (6): Chlorinated biphenyle (sum of 6 congeners PCB 28, 52, 101, 138,153, 180), PAH (16): polychlorinated aromatic hydrocarbons (Sum of acenapthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1, 2, 3-c,d)pyrene.), BaP: Benzo(a)pyrene, PCCD/F: Polychlorinated dibenzo-p-dioxins and –furans

When judging the impact of sludge application on heavy metal accumulation in soils, it should be compared to other fertilisers, which would be applied instead. While organic contaminant loads are high in sewage sludge (Langenkamp et al., 2001) compared to other fertilisers, heavy metals concentrations (especially Cd and Cr) can be much higher in conventional phosphate fertilisers (Table 59). Studies have also shown that the organic matter in the sewage sludge increased yields of crops compared to common mineral fertilisers (Meerbach and Böning-Zilkens, 2006; Xie et al., 2001).

Table 59: Mean concentration of nutrients and heavy metals in organic and mineral fertilisers (after UBA, 2002; Bannick et al., 2001)

material	**P_2O_5**	**N**	**K_2O**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
	g/kg dry weight			mg/kg dry weight						
sewage sludge	48.7	34.9	5.0	1.3	41	302	**0.9**	28	**60**	826
biological waste compost	8.2	14.3	10.1	0.5	25.6	49.6	**0.16**	15.9	52.7	195
liquid manure (cattle)	23	50	65.9	0.3	7.3	44.5	0.06	5.9	7.7	270
liquid manure (pigs)	57.7	105	69.4	0.4	9.4	**309**	0.02	10.3	6.2	**858**
solid manure (cattle)	19.1	25.3	32.3	0.29	12.9	39	0.03	5.2	30	190
solid manure (pigs)	49.6	34.8	36.6	0.33	10.3	**450**	0.04	9.5	5.1	**1068**
poultry dung	36.0	55	30.0	0.25	4.4	52.6	0.02	8.1	7.2	336
superphosphate	**180**			**10.8**	114	17.2		**28.8**	18.5	236
triplesuperphosphate	**450**			**26.8**	**288**	27.3	0.04	**36.3**	12	489
converter lime				<0.4	**1406**	7.7	<0.02	8.9	19	9.5

2.4.1 Europe

In Europe sewage sludge generation is about 24 - 35 kg/capita/a and agricultural reuse varies from 30 to 70 % (Langenkamp et al., 2001). The European sewage sludge directive 86/278/EEC (EC, 1986) regulates the use of sewage sludge in agriculture and seeks to promote sewage sludge application while protecting the environment. A review of the directive is underway since 2000 and an assessment has been published in Milieu Ltd./WRc/RPA (2010) and will include values for organic contaminants as well (Table 62). It is also discussed to include pathogen limits for example *E. coli.* <1000 cfu/g DW and *Clostridium perfringens* <3000 cfu/g DW (Carrington, 2001). Currently untreated sludge is only allowed if it is injected or incorporated into the soil.

To minimise health hazards from treated sludge **the use of sludge is prohibited:**

- on grassland or forage crops less than three weeks before grazing or harvesting
- **on fruit and vegetable crops** during the growing season, with the exception of fruit trees
- on ground intended for the cultivation of fruit and vegetable crops which are in direct contact with the soil and normally eaten raw, ten months before harvesting

Further rules for the **protection of the environment** are:

- application of sewage sludge is not permitted if sludge or soil exceed maximum limits defined by the guidelines (for example Table 60 and Table 61)
- if soil pH is <6 the increased mobility and availability of metals to crops have to be taken into account and a reduction of the permissible limits might be necessary
- nutrient requirements of plants need to be taken into account
- the quality of soil, surface and groundwater should not be impaired
- sludge and soils have to be sampled and analysed regularly (for dry matter, organic matter, N, P, Cd, Cr, Cu, Hg, Ni, Pb, Zn) and records must be kept

The maximum limits for heavy metals in soils treated with sewage sludge (Table 60) and the sewage sludge itself (Table 61), as well as for organic contaminants in sewage sludge (Table 62) for selected European states show that most countries have adopted even lower values than the EU threshold limits. A comparison of the EU to USA regulations (Table 60) shows that in the USA permissible values are much higher by a factor of up to ten. Many countries also distinguish between acidic and neutral soils or between sandy and clayey soils with lower limits in acidic and sandy soils. The UK has added maximum limits for Mo (3 mg/kg DW), Se (2 mg/kg DW), As (2 mg/kg DW) and F (200 mg/kg DW) in a code of practice (DoE, 1989). In addition, maximum permissible limits for average annual rate over a 10-year period are set even if soil concentrations are below the max. permissible limits (Table 60, last row).

Table 60: Maximum permissible concentrations of heavy metals in sludge-treated soils (mg/kg dry soil) in selected European Countries and the USA and max permissible load (last row)(after Milieu Ltd./WRc/RPA, 2010; SEDE and Andersen, 2002)

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Directive 86/278/EEC	*1-3*	*100-150(4)*	*50-140*	*1-1.5*	*30-75*	*50-300*	*150-300*
Belgium, Flanders	0.9	46	49	1.3	18	56	170
Belgium, Walloon	2	100	50	1	50	100	200
Bulgaria							
pH=6-7.4	2	200	100	1	60	80	250
pH>7.4	3	200	140	1	75	100	300
Cyprus	1-3	100-150	50-140	1-1.5	30-75	50-300	150-300
Denmark	0.5	30	40	0.5	15	40	100
Finland	0.5	200	100	0.2	60	60	150
France	2	150	100	1	50	100	300
Germany (6)	1.5	100	60	1	50	100	200
Germany (7)							
clay	1.5	100	60	1	70	100	200
loam/silt	1	60	40	0.5	50	70	150
sand	0.4	30	20	0.1	15	40	60
Greece	3	-	140	1.5	75	300	300
Ireland	1	-	50	1	30	50	150
Italy	1.5	-	100	1	75	100	300
Netherland	0.8	10	36	0.3	30	35	140
Poland							
sand	1	50	25	0.8	20	40	80
loam/silt	2	75	50	1.2	35	60	120
clay	3	100	75	1.5	50	80	180
Spain							
soil ph<7	1	100	50	1	30	50	150
soil ph>7	3	150	210	1.5	112	300	450
Sweden	0.4	60	40	0.3	30	40	100
UK(1)	3	400 (5)	135	1	75	300 (3)	20
USA (2)	*20*	*1450*	*775*	*9*	*230*	*190*	*1500*
Directive 86/278/EEC (max. limits to be added to soil kg/ha/a)	*0.15*	*-*	*12*	*0.1*	*3*	*15*	*30*

(1) for soil of pH ≥5.0, except Cu and Ni are for pH range 6.0 – 7.0; above pH 7.0 Zn = 300 mg kg-1 DW; (2) Approximate values calculated from the cumulative pollutant loading rates from Title 40 CFR, Part 503 (e-CFR, 2011); (3) Reduction to 200 mg kg-1 proposed as a precautionary measure; (4) proposed but not adopted (1990); (5) provisional value (DoE, 1989). (6) Regulatory limits as presented in the German 1992 Sewage Sludge Ordinance, (7) proposed new German limits (BMU, 2010b)

Table 61: Maximum level of heavy metals (mg/kg DW) in sewage sludge used for agricultural purposes (after Milieu Ltd./WRc/RPA, 2010; SEDE and Andersen, 2002)

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Directive 86/278/EEC	*20-40*	*-*	*1000-1750*	*16-25*	*300-400*	*750-1200*	*2500-4000*
Belgium (Flanders)	6	250	375	5	100	300	900
Belgium (Walloon)	10	500	600	10	100	500	2000
Bulgaria	30	500	1600	16	350	800	3000
Cyprus	20-40	-	1000-1750	16-25	300-400	750-1200	2500-4000
Denmark	0.8	100	1000	0.8	30	120	4000
Finland	3	300	600	2	100	150	1500
France	20	1000	1000	10	200	800	3000
Germany (1)	10	900	800	8	200	900	2500
Germany (2)	2.5	100	700	1.6	80	120	1500
Greece	20-40	500	1000-1750	16-25	300-400	750-1200	2500-4000
Ireland	20		1000	16	300	750	2500
Italy	20		1000	10	300	750	2500
Netherlands	1.25	75	75	0.75	30	100	300
Poland	10	500	800	5	100	500	2500
Spain	20	1000	1000	16	300	750	2500
Spain	40	1750	1750	25	400	1200	4000
Sweden	2	100	600	2.5	50	100	800
United Kingdom				PTE regulated through limits in soil			
USA (3)	*85*		*4300*	*57*	*420*	*840*	*7500*

(1) regulatory limits as presented in the German 1992 Sewage Sludge Ordinance; (2) proposed new limits (BMU, 2010b), (3) additional limits for As 75, Mo 75 and Se 100 mg/kg DW (Title 40 CFR, part 503.13, e-CFR, 2011)

Table 62: Standards for maximum concentrations and properties (grey shaded rows) of persistent organic contaminants in sewage sludge for selected European countries (mg/kg DW except PCDD/F: ng TEq/kg DW) (after Milieu Ltd./WRc/RPA, 2010; SEDE and Andersen, 2002)

	AOX	DEHP	LAS	NP/NPE	PAH	PCB	PCDD/F
water solubility		low	high	high	low	low	low
persistence		medium	medium	medium	high	high	high
bioaccumulation		high	high	high	high	high	high
aquatic ecotoxicity		medium – high	high	high	high	high	high
human toxicity (acute)		low	medium	medium	high	medium	high
Directive 86/278/EEC	-	-	-	-	-	-	-
EC (2000)[a]	500	100	2600	50	6[b]	0.8[c]	100
Denmark (2002)		50	1300	10	3[b]		
France	Fluoranthene: 4 Benzo(b)fluoranthene: 2.5 Benzo(a)pyrene: 1.5					0.8[c]	
Germany (BMU 2002)	500					0.2[d]	100
Germany (BMU 2010b)[e]	400					0.1[d]	30
Sweden				50	3b	0.4[c]	

AOX: Absorbable organic halides, DEHP: Bis(2-ethylhexyl) phthalate, LAS: Linear Alkylbenzene Sulfonate, NP/NPE: Nonylphenol/Nonylphenol ethoxylate, PAH: Polycyclic aromatic hydrocarbon, PCB: Polychlorinated biphenyls, PCDD/Fs: polychlorinated dibenzodioxins/-furans; a: proposed but withdrawn, b: sum of 9 congeners: acenapthene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-c,d)pyrene , c: sum of 7 congeners: PCB 28, 52, 101, 118, 138, 153, 180 d: per congener, e Proposed new limits in Germany (BMU, 2010b)

2.4.2 Germany

In Germany, wastewater sludge management is regulated by the sewage sludge ordinance (Klärschlammverordnung, AbfKlärV, 1992, last amended in November 2010, further amendment under revision expected to introduce new limits for more organic contaminants (BMU, 2010a, 2010b)). It allows sewage sludge application on agriculturally or horticulturally used soils, if certain conditions are fulfilled. Those conditions are:

- application of sewage sludge on areas used for growing fruit or vegetable as well as permanent grassland and forests soils is banned since 1992
- application of sewage sludge is banned in groundwater protection zones I and II, within 10 m of water bodies and in areas protected by the Federal Nature Conservation Act
- special application restrictions apply for animal fodder crops, where sewage sludge can only be applied prior to sowing; has to be worked into the soil

Regular analyses of sewage sludge (every 2-6 months) on the content of Cd, Cr, Cu, Hg, Ni, Pb, Zn, sum of organic halogen compounds (AOX), total and ammonia nitrogen, phosphate, K, Mg, as well as dried residue, organic substance, basifying substance and pH have to be performed. In addition, analyses of polychlorinated biphenols (PCBs) and polychlorinated dibenzodioxins and – furans (PCDD/Fs) have to be performed at least every 2 years. Less restrictive analyses and obligations apply for sludge from small scale treatment plants (<1000 inhabitants) treating only domestic wastewater. Analyses of soils (every 10 years) on the same parameters have to be performed and have to be below the guidelines values (Table 63) to allow further sewage sludge application. Restrictions on the quantity of applied sewage sludge are 5 t/ha within 3 years. If the sewage sludge tested with specified methods does not exceed any of the limits (Table 63), it will be certified. Operators of wastewater treatment plants are obliged to register volumes and properties of sewage sludge as well as recipient details and receiving soil analyses and to submit these to the responsible authorities every year. Farmers are also responsible to document quantity and quality of applied sewage sludge.

In 2006, about 30 % of all sewage sludge was used as fertiliser. As sewage sludge cannot be landfilled, if it contains more than 5 % organic material, the remaining sewage sludge is incinerated for energy generation in coal power plants or special sewage sludge incineration plants (Hermann and Goldau, 2004).

Table 63: Permissible limits for sewage sludge and soils (Sewage sludge ordinance, 1992), proposed new limits (BMU, 2010b) and common values from German sewage sludge 1987 (Crößmann, 1987; Alberti et al., 1987) and 2006 (BMU, 2010a)

in dry matter	limits sewage sludge	limits Soil	proposed new limits for sewage sludge[1]	values German sewage sludge (1987)	common values in German sewage sludge (2006[2])
Cd (mg/kg)	10 (5)	1.5 (1)	3	2.9	1.0
Cr (mg/kg)	900	100	120	82	37
Cu (mg/kg)	800	60	850	458	300
Hg (mg/kg)	8	1	2	2.2	0.6
Ni (mg/kg)	200	50	100	31	25
Pb (mg/kg)	900	100	150	140	37
Zn (mg/kg)	2500 (2000)	200 (150)	1800	1524	714
PCB (µg/kg) congeners no 28, 52, 101, 138, 153, 180	200 (sum)	2	100 (each)	<1, <1-300, 24-500, 45-65, 50-170, <1-53	154 (sum) (1996)
PCDD/F (ng TEq/kg)	100	1000	30		17 (1996)
Benzo(a)pyrene (mg/kg)		10	1	0.5-0.6	
AOX (mg/kg)	500		400	<0.1-0.5	196 (1996)

() values apply for light soils, i.e. soils with clay content < 5% or pH 5-6; 1: BMU, 2010b; 2: BMU, 2010a

The German Federal Soil Protection Act (‘Bundesbodenschutzgesetz’, BGBl., 1998) is based on the precautionary principle and requires the prevention of long-term accumulation of contaminants in the soil. In 1999 about 3 Mio t of mineral fertiliser, 29 Mio t manure, 1.4 Mio t sewage sludge and 2.8 Mio t compost/organic wastes were used on 17 Mio ha of agricultural land, resulting in the deposition of large amounts of heavy metals and organic pollutants. Accordingly new recommended permissible heavy metals and organic pollutant concentrations were calculated based on the input and output of pollutants to and from the soil. For organic fertilisers the input is based on the mineral content and a residual 8 % of organic matter is assumed and normalised to a load of 50 kg P_2O_5/ha/a. The output is based on the uptake by grains, which show comparatively low heavy metal uptake rates. Uncertainties due to variation of limits in the analytic methods were also incorporated to give maximum limits. It also accounts for the susceptibility of soils by giving different values for clayey, silty and sandy soils and reduced values for Cd, Ni and Zn if soil pH is <6.

If these new recommendations were to be followed, old regulations would have to be adjusted as follows (Bannick et al., 2001):

- sewage sludge: As fertilisation with sewage sludge leads to an accumulation of heavy metals in the soil under the current laws, a revision of permissible limits to lower recommended values (Table 64) and additional analysis for organic parameters and pathogens should be enforced. This will result in a higher incineration rate of sewage sludge. Before incineration a phosphorus recovery with coagulation and crystallisation methods might be undertaken to prevent this valuable nutrient from being wasted (Pinnekamp et al., 2007).

- liquid and solid manure: As liquid manure shows similar concentrations of heavy metals than sewage sludge (Table 59), the same standards should be applied. Liquid manure also contains elevated concentrations of pharmaceutically active compounds and endocrine disrupting compounds, which should be analysed and regulated. Currently no restrictions regarding heavy metal or organic pollutant loads exist for manure.
- mineral fertilisers: Some mineral fertilisers contain elevated concentrations of cadmium or chromium. The same limits as for sewage sludge should be applied.
- compost: Compost application does not lead to an accumulation of pollutants in the soil and can be continued at current practices.

Table 64: New recommended guideline values based on the protection values for soils in comparison to current standards (after UBA, 2002; Bannick et al., 2001)

	soil type	Cd	Cr	Cu	Hg	Ni	Pb	Zn
protection values for soils in aqua region extract (after **soil protection act**. 1998) (mg/kg DW)	clay	1.5	100	60	1	70	100	200
	silt	1	60	40	0.5	50	70	150
	sand	0.4	30	20	0.1	15	40	60
current permissible limits (mg/kg DW)								
biological waste ordinance		1.5	100	100	1	50	150	400
sewage sludge ordinance		10	900	800	8	200	900	2500
EU-ecological agriculture ordinance		0.7	70	70	0.4	25	45	200
new recommended limits for fertilisers (mg/kg DW)								
compost, organic waste	clay	1.6	107	70.0	1.08	75.9	107	260
	silt	1.1	64.4	48.8	0.56	54.6	75.7	207
	sand	0.46	32.5	27.5	0.12	17.4	43.7	111
sewage sludge	clay	1.3	75.0	80.0	0.84	58.7	78.7	427
	silt	0.92	46.2	65.6	0.48	44.3	57.1	391
	sand	0.49	24.6	51.2	0.20	19.1	35.5	326
liquid manure, cattle	clay	1.2	73.4	60.6	0.78	54.3	75.2	277
	silt	0.82	44.6	46.2	0.42	39.9	53.6	241
	sand	0.38	23.0	31.8	0.12	14.7	32.0	177
liquid manure, pigs	clay	1.3	75.6	86.7	0.86	60.2	80.0	479
	silt	0.96	46.8	72.3	0.50	45.8	58.4	443
	sand	0.53	25.2	57.9	0.21	20.6	36.8	378
poultry dung	clay	1.5	89.2	79.4	0.96	67.0	92.0	382
	silt	1.0	54.4	62.0	0.53	49.6	65.9	339
	sand	0.50	28.3	44.6	0.18	19.1	39.8	261
solid manure, cattle	clay	1.4	88.2	66.6	0.92	64.1	89.6	285
	silt	0.95	53.4	49.2	0.48	46.7	63.5	241
	sand	0.43	27.3	31.8	0.14	16.3	37.4	163
solid manure, pigs	clay	1.5	90.0	89.6	0.99	69.3	93.9	462
	silt	1.1	55.3	72.2	0.56	51.9	67.8	418
	sand	0.56	29.2	54.8	0.21	21.4	41.7	340

2.4.3 Switzerland

In 2003, the Swiss government decided to fade out biosolids application until Oct 2006. During 2003 – 2006 biosolids were not allowed to be applied on vegetable and fodder crop fields. They had to fulfil stricter levels of contaminants (Table 65) and maximum application rate was 5 t/ha. **Since Oct 2006 biosolids application is not permitted anywhere in Switzerland** (with the exemption of sewage sludge from small treatment plants in rural areas), **but have to be incinerated to fulfil the requirements for a precautionary principle of soil and health protection. The main reasons for this prohibition were the levels of mercury and endocrine disrupting compounds in sewage sludge.**

Table 65: Limit values and recommended values for sewage sludge (applicable between 2003 to 2006), organic and mineral fertiliser (mg/kg DW) (after ChemRRV, Schweizerischer Bundesrat, 2003)

	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Zn	AOX*	PAH*	PCDD/Fs* (ng TEq/kg)
sewage sludge	5	60	500	600	5	20	80	500	2000	500		
organic fertiliser	1			100	1		30	120	400		4	20
mineral fertiliser	50**		2000									

* recommended value, ** g/t P

2.4.4 USA

In the USA about 50 % of all biosolids are applied to agricultural land. Biosolids application is regulated under Title 40 Code of Federal Regulation (CFR) Part 503 and soils and biosolids have to meet certain quality standards based on acceptable environmental change (Table 60 and Table 61) (US EPA, 1993). A risk assessment was used to find the most stringent values as final limits by evaluating toxic exposure data, oral reference dose and human cancer potency values to calculate the allowable dose of each pollutant via 14 different exposure pathways. Two important pathways were through contaminated surface and groundwater (McFarland et al., 2010). Biosolids are classified according to their pathogen level and site and crop harvesting restrictions apply. Class B biosolids (with detectable pathogens) have to fulfil buffer requirements, access restrictions for the public and crop harvesting restrictions, while Class A (no detectable pathogens and low metal concentrations) can be applied without crop restrictions. Site suitability investigates the soil characteristics, slope, vegetation, crop need and distance to surface and groundwater (Table 66). Application to flooded, frozen or snow covered ground are restricted. Application of biosolids has to match the nutrient requirements of the crops and 5 – 15 t/ha is set as the agronomic rate (US EPA, 1994). As many soils are already rich in nitrogen due to historic application of manure and fertiliser, leaching of nitrate to the groundwater is of concern and sites underlain by potable groundwater with bedrock at shallow depths should be avoided (McFarland et al., 2010).

Erosion control measures include slope restrictions, buffer zones/filter strips (minimum 10 m to surface water), berms, dikes, silt fences, diversions, siltation basins and terraces. Some states have increased buffer distance to surface waters, sinkholes, wells etc. to 100 m.

Table 66: Degree of limitations for biosolids application to agricultural land (after McFarland et al., 2001)

soil factors	slight	moderate	severe
slope (%)	<6	6 -12	>12
depth to seasonal groundwater (m)	>1.2	0.6-1.2	<0.6
depth to bedrock (m)	>1.2	0.6-1.2	<0.6
permeability of the most restricting layer above 1 m (cm/hr)	0.24-0.8	0.08-0.24	<0.08 or >2.4
available water capacity (cm/meter)	> 2.4	1.2-2.4	<1.2

Monitoring, record keeping and reporting are important parts of the regulations and apply also to biosolids that are landfilled or incinerated. The operator has also to verify that groundwater quality is not compromised and installation of monitoring wells is common practice. Revisions of the regulations are likely to include limits for PCDD/Fs and a range of other organic contaminants. Management measures also include community friendly practices to control odours, traffic, noise and dust inconveniences.

2.4.5 Australia

Regulations for biosolids application vary from state to state and are based on the protection of the environmental and public health. In **South Australia** guidelines differentiate between larger wastewater treatment plants (>1000 inhabitants) receiving domestic and industrial wastewater, and smaller treatment plants and septic tanks receiving only domestic wastewater (EPA SA, 1997). Sites with shallow groundwater table, close to surface waters (<100 m), high nutrient levels or sloping ground (>5 %) have to use preventive measures to prevent surface and groundwater contamination. Application is not allowed on waterlogged soils, rocky grounds, on field for human or animal food production, soils with pH <5.5. Biosolids are classed based on their stabilisation grade (pathogen levels A or B) and contamination grade (level of heavy metals A, B or C, Table 67) to three intended reuse (unrestricted urban use (A + A), landscaping (A + B), approved use (B + C)). Any biosolids application from larger WWTPs has to be approved of by EPA and is subject to the levels of heavy metals in biosolids and soils for each site (Table 67). Records of biosolids and soil analysis have to be undertaken. An application limit based on max annual heavy metal loads results in a max application rate of about 5 – 10 t/ha. For agricultural use buffer distances to watercourses (100 m), access roads (5 m), public roads/property boundary (50 m) and to adjoining properties (100 m) have to be fulfilled. Biosolids from small WWTP (<1000 inhabitants) and septic tanks are not required to analyse soil or biosolids samples and are only bound by management restrictions and should monitor any impact to the environment. The amended draft guidelines (EPA SA, 2009b) recommend slightly different heavy metal limits and have added chlordane and dieldrin limits, but no more limits for As, Hg, Ni and Pb (Table 67). In addition, specifications for a minimum depth to groundwater in relation to the clay content of the soil have been developed, ranging between 8 m minimum depth for clay contents <5% and 1.5 m minimum depth to groundwater for >35 % clay content. Further operational health and safety and best management practices are included. Biosolids have to be tested by combining five samples from every 500 t.(total 2500t) for pH, moisture, Cr, Cr, Cu, Zn, dieldrin, chlordane, total N, ammonia, TKN, NO_3, NO_2, total P, salmonella, helminth eggs, total virus content and *E. coli.* (EPA SA, 2009b). Lagoon sludges have to be tested every 500 m³. Soils have to be analysed for pH, CEC, clay content, organic matter content, As, Cd, Cr, Cu, Hg, Fe, Ni, Pb, Zn every 40 ha.

Table 67: Maximum permissible concentration of contaminants (after EPA SA, 2009b; EPA SA, 1997)

EPA SA, 1997	**As**	**Cd**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
soils for food production (mg/kg DW)	*20*	*3*	*200*	*1*	*60*	*200*	*250*
limits of application to soils (kg/ha/a)	*0.7*	*0.15*	*12*	*0.1*	*3*	*15*	*30*
biosolids grade A (mg/kg DW)	20	3	200	1	60	200	250
biosolids grade B (mg/kg DW)	20	11	750	9	145	300	1400
biosolids grade C (mg/kg DW)	>20	>11	>750	>9	>145	>300	>1400

EPA SA, 2009b	**Cd**	**Cr (VI)**	**Cu**	**Zn**	**chlordane**	**dieldrin**
biosolids grade A (mg/kg DW)	1	1	100	200	0.02	0.02
biosolids grade B (mg/kg DW)	11	1	750	1400	0.2	0.2
biosolids grade C (mg/kg DW)	20	1	2500	2500	0.5	0.5

National guidelines for sewerage systems including effluent management, reclaimed water reuse and biosolids management were issued in 2004 (NWQMS, 2004) and have been adopted with minor variations by **Western Australia**. These guidelines also use classes based on a pathogen (P1-P4) and contaminant grading (C1-C3) systems regulating the allowable uses (Table 69). Apart from heavy metals, these guidelines include more organic contaminants (Table 68) and are also more specific on management practices and control measures like maximum nutrient loadings (Table 70), buffer distances (Table 71), slope limitations (Table 72) and withholding periods after biosolids application (Table 73) (Biosolids Working Group, 2002). Application of biosolids is prohibited on soils with pH <5, in public drinking water source areas, water reserves and proclaimed catchment areas, environmental protected areas (RAMSAR wetlands, national parks, conservation reserves), areas subject to waterlogging within the 1 in 20 year flood line and areas with public health concern. The biosolids application rate per hectare that can be applied directly to land is limited by the lowest of the nitrogen, the phosphorus or the contaminant rate. The quality of the soil has to be assessed before biosolids application and accurate record on the quantity and quality of biosolids have to be kept.

Table 68: Biosolids contaminant and pathogen acceptance concentration thresholds and max allowable soil contamination concentration after biosolids application (mg/kg DW) (after Biosolids Working Group, 2002)

contaminant	grade C1	grade C2*	maximum allowable soil contaminant concentration
As	20	60	20
Cd	3	20	1
Cr (total)	100	500	100
Cu	100	2500	100
Hg	1	15	1
Ni	60	270	60
Pb	150	420	150
Se	3	50	5
Zn	200	2500	200
DDT/DDD/DDE (total)	0.5	1	0.5
other organochlorine pesticides	0.02	0.5	0.02
PCBs	0.3	0.5	0.3

pathogen grading requirements	grade P1	grade P2	grade P3	grade P4
salmonella /50g DW	<1	<10		
thermotolerant coliforms /g DW	<100	<1000	<2 Mio	>2 Mio

Grade C3: untested or greater than C2 limit values

Table 69: End uses of biosolids according to classifications (after Biosolids Working Group, 2002)

biosolids classification	min pathogen grade	min contaminant grade
unrestricted (public sale)	P1	C1
urban landscaping, horticulture, agricultural land application (root crops)	P2	C2
agricultural land application (no root crops), forestry, mine-site rehabilitation	P3	C2
landfill, thermal processing	P4	C3

Table 70: Soil vulnerability categories and maximum nutrient loadings (after Biosolids Working Group, 2002)

vuln. category	soil description	maximum P loading (kg/ha/yr)	maximum N loading (kg/ha/yr)
A	coarse sandy soils/gravels draining to surface waters with moderate/high eutrophication risk	10	140
B	coarse sandy soils/gravels draining to waters with low eutrophication risk	20	180
C	loams/clay soils (phosphorus retention Index > 10) draining to waters with moderate/high eutrophication risk	50	300
D	loams/clay soils (phosphorus retention Index > 10) draining to waters with low eutrophication risk	120	480

Table 71: Minimum buffer distances for direct land application of biosolids (after Biosolids Working Group, 2002)

	buffer distance (metres)
boundary of wetland vegetation around estuaries and lakes	400
conservation wetlands (i.e. RAMSAR or ANCA)	200
drinking water supply bores	100
agricultural, stock and domestic water supply bores	50
high water mark for agricultural dams reservoirs	100
permanent creeks, streams rivers and other wetlands	100
banks of intermittent flow water courses	50
farm driveways, access roads and fence lines	5
animal enclosures	50
occupied dwellings on property where biosolids are applied	100
occupied dwellings on other properties	500

Table 72: Recommended slope limitations for direct land application of biosolids (after Biosolids Working Group, 2002)

slope (%)	comment
0 - 3	ideal, no concern for runoff or erosion
3 - 6	acceptable, slight risk of erosion
6 - 12	acceptable if soil conservation practices are used to minimise erosion levels (e.g. contour banking)
12 - 15	no application of biosolids unless the site is maintained in grass vegetation with at least 80% ground cover
>15	unacceptable

Table 73: Withholding periods after biosolids application (after Biosolids Working Group, 2002)

use	withholding period
human food crops	30 days for all crops, 12 months for vegetables eaten raw and close to the surface (e.g. lettuce); 18 month for vegetables eaten raw and below the soil surface (e.g. carrots)
animal feed and fibre crops	30 days
animal withholding periods	30 days for grazing; 45 days for lactating or new born animals; no poultry or pigs allowed
turf	1 year

2.4.6 Israel

The Israeli water regulations (use and disposal of sludge) 5764-2004 regulate the use and disposal of sewage sludge to prevent pollution of water resources (Ministry of the Environment, 2004). It requires WWTPs to stabilise and treat wastewater sludge. Stabilised sludge classified as Class A (FC <1000 cfu/g DW, salmonella < 3 cfu in 4g DW, enteric virus <1 cfu in 4 g DW, helminth eggs <1 in 4 g DW) or Class B (FC <2 Mio cfu/g DW) is allowed to be used as fertiliser or soil improvement if heavy metal limits are not exceeded (Table 74). The total applied quantity of nitrogen in a year should not exceed 50 kg/dunam (= 0.1 ha) in biosolids and irrigation water concentrations have to be <15 mg/L. For health concerns biosolids are not allowed for private gardens, pot plants, public parks, nurseries, agricultural crops designed for human consumption. For groundwater protection biosolids shall not be used in protected areas, in less than 50 m distance to water courses, in less than 100 m distance to potable water resources, where groundwater levels are less than 20 m below ground or where the slope exceeds 12 %. Records regarding biosolids applications have to be kept and clearly visible warning signs have to be erected where Class B biosolids are used. Rules for the transport and storage of biosolids are also included. Currently large amounts of untreated sludge (>59 000 t DW/a) are disposed of in the Mediterranean Sea. This practice is scheduled to stop in 2020 and older WWTP should be modernised and new WWTP build by then. It is expected that about 40% will be incinerated, 30% be reused as class A and 30% be reused as class B.

Table 74: Maximum permissible limits for heavy metals in treated sludge and as load to agricultural fields (after Ministry of the Environment, 2004)

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
treated sludge (mg/kg DW)	20	400	600	5	90	200	2500
load (g/dunam/a)	30	600	900	7.5	135	300	3750

2.4.7 MENA region

Some countries have established guidelines for sludge management, including maximum permissible limits for heavy metals and pathogens in biosolids, maximum concentrations in soil and maximum application rates (Table 75) that have to be fulfilled for biosolids application to be permitted.

Table 75: Standard for maximum concentrations in biosolids, soils treated with biosolids and application rates for Oman (WHO, 2006b), Turkey (http://web.deu.edu.tr/atiksu/toprak/ani4152.html) and Jordan (JS 1145/1996, after GITEC, 2004)

max. permissible limits for	country	Cd	Cr	Cu	Hg	Ni	Pb	Zn
biosolids (mg/kg DW)	Oman	20	1000	1000	20	300	1000	3000
	Turkey	20	1200	1200	25	200	1200	3000
	Jordan	85	3000	4300	57	420	840	7500
soils (mg/kg DW)	Oman	3	400	150	1	75	30	300
	Turkey	3	100	100	2	50	100	300
	Jordan	39	3000	1500	17	420	300	2800
application rates (kg/ha/a)	Oman	0.15	10	10	0.1	3	15	15
	Turkey	0.033	2	2	0.042	0.33	2	5
	Jordan	1.9	150	75	0.85	21	15	140

In **Oman** (145/193, 1993), restrictions include a 3 week withholding period before grazing and a 6 months withholding period before the harvest of fruits or vegetables in contact with soil and to be eaten raw. No application should apply on soils with pH <7 (WHO, 2006b).

In **Turkey**, sludge can be either landfilled (water content max. 65 %), incinerated (fixed organic chlorine content <1 % or halogenated organics <0.005 %) or used for agricultural purposes if it originated from domestic wastewater treatment plants and are epidemically safe. Heavy metal and agronomic parameters have to be tested every 6 months. Soils have to be analysed for pH and heavy metals before and during application (http://web.deu.edu.tr/atiksu/toprak/ani4152.html).

In **Jordan** (JS 1145/1996), sludge application is only permitted from April – July at a max. application of 12 t/ha/a if they comply with heavy metal levels according to Table 75 and pathogens level 2 (faecal bacteria 103 MPN/g, Salmonella <0.75/g, helminth eggs <0.25/g, intestinal viruses <0.25/g). It is not permitted three months before harvest, for fertilising vegetables, greens, or land situated between residential areas and has to be approved by official authorities. Sludge samples have to be tested for agronomic parameters, heavy metals and pathogens every month. Organic pollutants have to be tested every 6 months. Soils have to be tested for agronomic parameters, heavy metals and organic pollutants before the first application (GITEC, 2004).

3 Current situation in Lebanon

3.1 Country profile

Lebanon is a country of 10,452 km² at the eastern coast of the Mediterranean Sea with about 4.5 Mio inhabitants and a current population growth rate of 1.5 – 2.2 % (values are estimations as the last census was undertaken in 1932, El-Fadel et al., 2000). The country was stricken with civil unrest between 1975 and 1990 and subject to bombing during the war with Israel in 2006. Both events damaged large sections of the existing civil infrastructure.

Geographically, Lebanon can be divided into four zones running parallel to the coast (Fig. 12):

- a flat, narrow coastal strip of 0 - 3 km width where large proportions of the population are living
- Mount Lebanon mountain with a mean elevation of 2200 m and the highest peak of about 3000 m receiving the highest amounts of rainfall and snow
- Bekaa Valley with an average elevation of 900 m and a width of 7 – 20 km with fertile land that is used heavily for irrigated agriculture
- Anti-Lebanon mountain range with elevations of up to 2800 m constituting the border to Syria

About 300 - 360 thousand ha of the country are arable land and between 67 and 100 thousand ha are currently under irrigation. The main crops are fruit and olive trees (45 %), cereals, vegetables and vines. About 12 % of the population works in agriculture and the contribution of this sector to the GDP is about 6 - 12 % (CDR, 2009; EMWater, 2004). About 25 - 30 % of the agricultural land is commercially farmed by only 1.6 % of the farmers with farm sizes greater than 10 ha, while more than half of the farmers cultivate only 9 % of the arable land with traditional techniques and farm sizes smaller than 0.5 ha (LEDO, 2001).

Climatically, Lebanon enjoys a Mediterranean climate with mild wet winters and long, dry summers. The four different geographical zones show large differences in climate. While the coastal zone has an average annual temperature of 19 – 22 °C and mean precipitation of 600 - 900 mm/a, the Mount Lebanon region has an annual mean temperature of about 15 °C at an elevation of 1000 m and 9 °C at 2000 m and precipitation can reach up to 1500 - 2000 mm, at elevation exceeding 2000 m mostly occurring as snow. The Bekaa Valley and the Anti-Lebanon Mountains sit in the rain shadow of Mount Lebanon and have hot summer and cold winters and receives only between 250 – 800 and 500 - 900 mm, respectively. Annual evaporation is estimated to be around 1300 mm. From the 150 meteorological stations before the civil war, only 48 have been reconstructed after the civil war (JICA, 2003), but most meteorological data are classified as confidential, and available climatic data are hence limited. Nowadays around 35 stations are still operational (personal communication National Meteorological Service). Meaningful snow cover observations and snow water equivalent measurements have not been undertaken so far. Climate change prognosis forecast a general increase in temperature resulting in an increase in evapotranspiration and a reduction in rainfall and especially in snow fall for the region (up to -80 % by 2100), leading to a general decrease in available water resources (Evans, 2009). However, these simulations are still preliminary and are hampered by the lack of significant input data from the entire region (especially Lebanon and Syria).

Hydologically, about 40 streams are present in Lebanon, but only about 13 - 17 are flowing the whole year round, while all others are seasonal. Most of these rivers are shorter than 60 km and originate from karst springs on the western slopes of the Mt Lebanon range and flow towards the Mediterranean Sea. The Litani River is the longest river in Lebanon (170 km) and drains the Bekaa Valley towards the south, entering the Mediterranean Sea north of Tyre. The Orontes drains the Bekaa Valley crossing the border in the north into Syria, while the Hasbani River, a tributary to the Jordan River, crosses the southern border. Due to the steep slopes and quick transfer in the karst system, rainfall is relatively quickly transferred to the Sea and shows large variations in flow throughout the year. From 75 stations before the civil war, 32 gauging stations have been reconstructed (JICA, 2003), but flow profiles are not even and are not cleaned regularly, so that runoff measurements are not correct. Moreover, many gauging stations are located at places where flow is highly turbulent. Mean flow velocity can therefore not be obtained through the currently conducted propeller measurements. Better profiles, more suitable locations and more modern technologies are therefore required to obtain reasonable figures of streamflow. Previous records show the highest flow rate in spring and the lowest in autumn, unless they are fed by deeper aquifers like the El Assi, which results in a later and lower peak (Fig. 11). The values in Fig. 11 should be used with caution as they are most likely no long-term means, but represent short-term measurements or estimations. For example, the values for the Ibrahim River (total runoff around 320 Mio m^3) seem unrealistically high as it should be about half of the El Assi River (total runoff around 655 Mio m^3) and the Nahr El Kalb (total runoff around 115 Mio m^3) is commonly dry in autumn (JICA, 2003). Total average annual runoff has been estimated to be around 3000 Mio m^3 (JICA, 2003). Water quality is impacted primarily by wastewater, fertiliser and pesticides (LEDO, 2001).

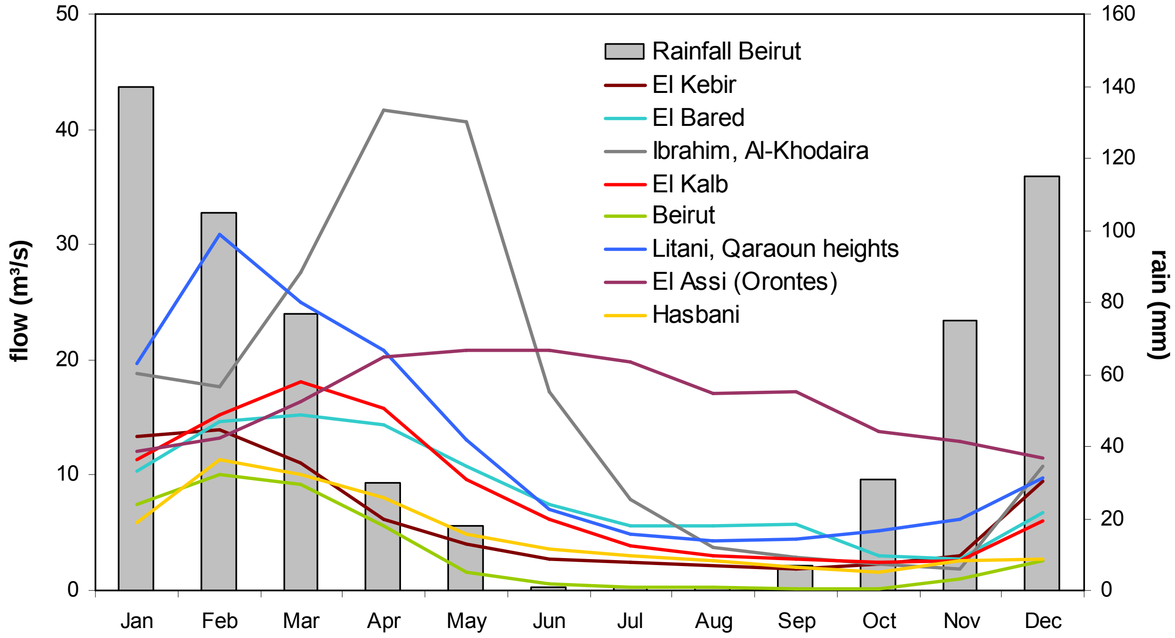

Fig. 11: Estimated flow rates of selected rivers (after El-Fadel et al., 2000)

Geologically, the major part of the country is built up of a thick sedimentary sequence from Jurassic to recent. Lebanon is dominated by fractured karstic limestone of Cretaceous and Jurassic age. The lower Cretaceous consists mainly of sandstone alternating with marlstone, shale and conglomerates. Regionally, basalts can be found between Jurassic and Cretaceous sediments and Tertiary basalt outcrops in North Lebanon. The Bekaa Valley and the coastal strip are covered with Tertiary and Quaternary sediments (Fig. 12). Tectonically the area belongs to the Arabian plate and a major transform margin runs from north to south through the country with the main faults being the Yammouneh and Serghaya faults. The two mountain ranges are anticlines and the Bekaa Valley is formed by a syncline or graben. Influence from the collisional margin between the Arabian and the Eurasian plate results in a number of strike-slip and dip-slip faults. Due to this, Lebanon has experienced a number of earthquakes during the recent past. The basic geology has been mapped in the 1940s; however, detailed maps of karst features do not exist.

Hydrogeologically, the major aquifers are the Cretaceous and Jurassic limestones. Smaller aquifers are found along the coast and an aquifer of regional importance is also present in the Bekaa Valley. The basalts and the Cretaceous sandstones function as aquitards. Snow cover on the mountain ranges is the major source of groundwater recharge and hence, recharge could be reduced significantly due to climate change, if predictions are correct. Rainfall infiltrates quickly into the fissured limestones and reappears at springs, for example the Jeita spring. Submarine discharge in the Mediterranean Sea has also been observed, but not quantified yet. Due to the karstic nature of the main aquifers, the extent of the catchment areas and the flow paths are only vaguely known. Though no accurate groundwater recharge values are available, it is estimated to be around 600 Mio m³/a (Khair et al., 1994). The most comprehensive studies date back to the 1970s (LEDO, 2001). The karstic nature also means that the aquifers have high storage capacities, but storage times are relatively short and large amounts of water are lost to the sea (transmissivity about 0.01 - 0.1 m²/s) (UNDP, 1970).

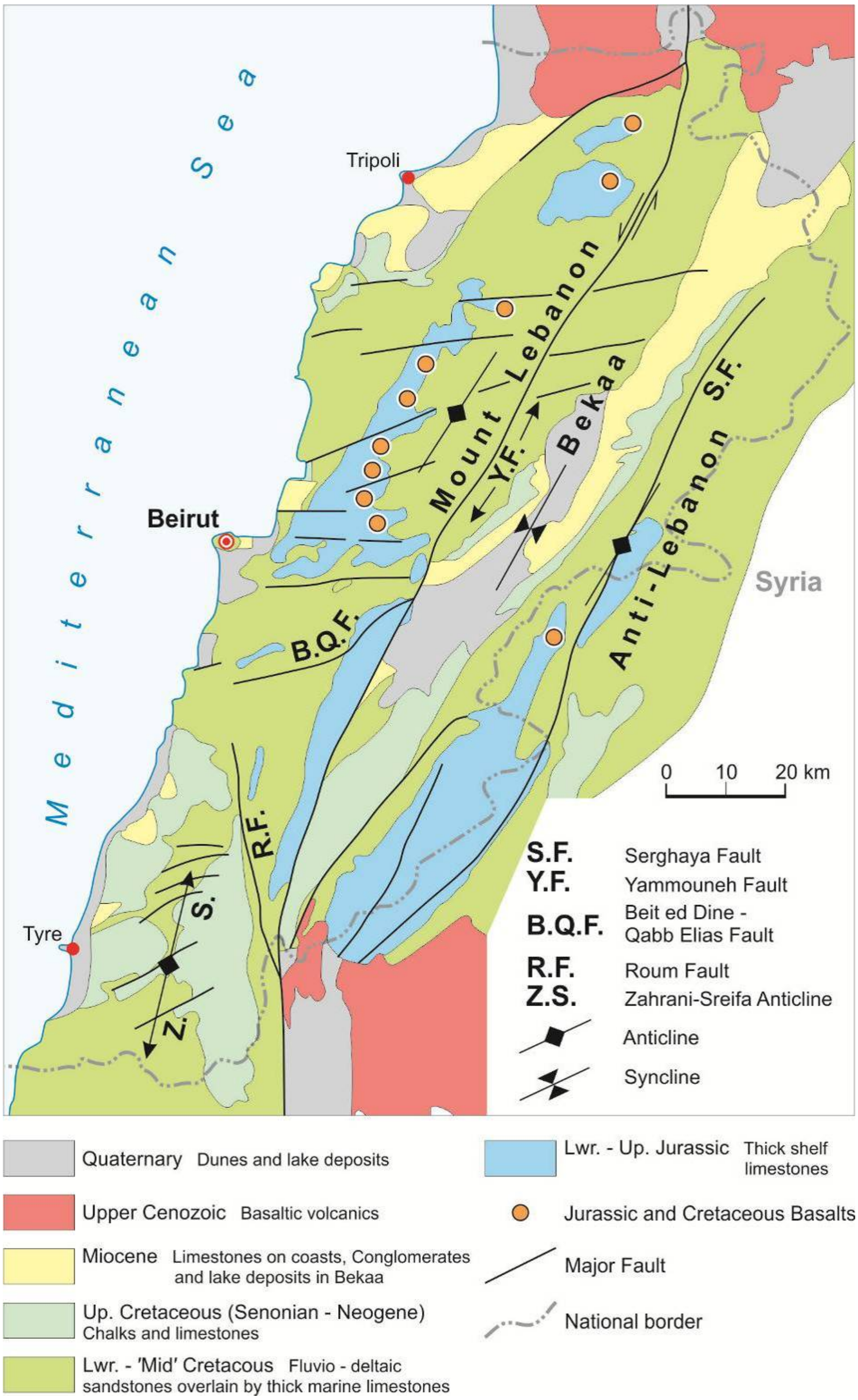

Fig. 12: Overview of geological and structural features of Lebanon (after C. D. Walley geology-ddc.aub. edu.lb-projects-geology-geology-of-lebanon.html)

3.2 Water resources

There is a considerable lack of all data relevant for a water balance and it will not be possible to establish a comprehensive assessment of water resources availability for Lebanon until realistic data for all components have been acquired. All current estimations are based on old and incomplete data. For no catchment, a water balance has yet been established based on an actual and complete dataset.

Compared to neighbouring countries like Syria or Jordan, Lebanon receives much higher precipitation. But as this rainfall is mainly occurring in winter and flows quickly to the sea, only limited proportions of it can be used. Lebanon does not receive surface flow from neighbouring countries. Precipitation is estimated at ~8600 Mio m^3. About half of this is lost due to evaporation (~4300 Mio m^3). After the subtraction of surface flow to neighbouring countries (~670 Mio m^3) and groundwater discharge to the sea or neighbouring countries (~1030 Mio m^3), the net potential water resources are ~2600 Mio m^3, of which about 2000 Mio m^3 are exploitable (EMWater, 2004; El Fadel et al., 2000). As no accurate long-term data are available, the water budget is highly questionable (Kronfol and Kaskas, 2007; Khair et al., 1994). Observations since the 1950s show a decrease in precipitation and river flows (Khair et al., 1994) and this trend may continue if climate change predictions for the region are correct.

Agricultural **demand** is the highest with about 70 % of the total demand and is estimated to increase as more area is going to be irrigated. Domestic and industrial demands are expected to increase due to population growth and increase in living standard and after 2010 water demand may exceed the total exploitable water resources (Fig. 13). Values about actual water use are sparse, as metering systems in households and industrial premises are not common, illegal connections to the water network exist and large volumes are extracted from licensed (about 10000) and unlicensed (estimations are about 50000) groundwater wells that are not metered either. The high number of illegal wells was mainly drilled during the civil war when municipal water networks were damaged and supplies were insufficient (Khair et al., 1994). A sustainable water management is therefore urgently needed.

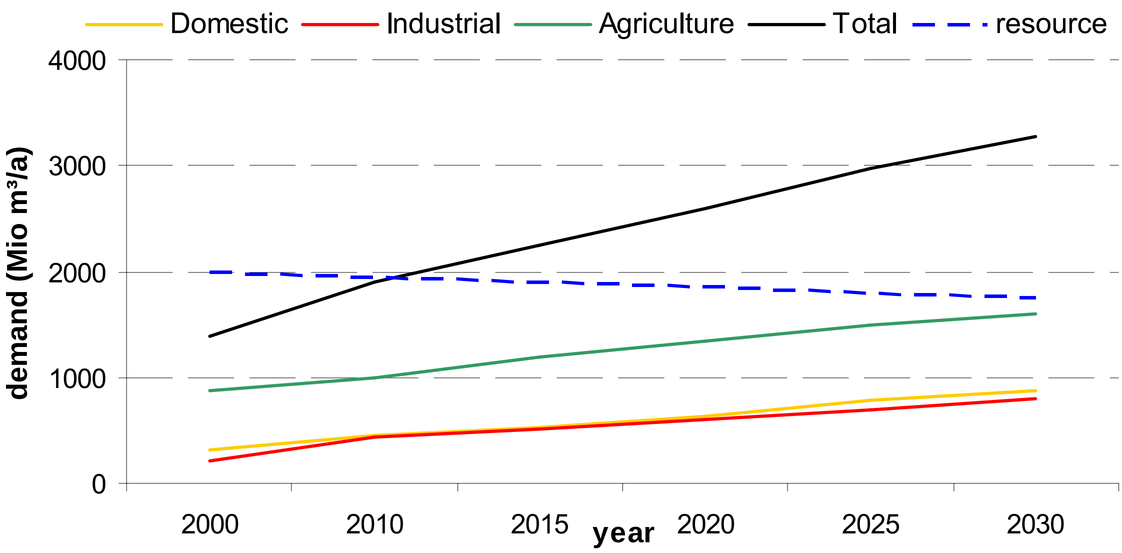

Fig. 13: Estimated water demand and exploitable water resources by sector (Mio m³/a) (after El-Fadel et al., 2000)

Industry and agriculture obtain about 70 and 50 % of its water needs from groundwater, respectively (EMWater, 2004). While large parts of the country (76 - 85 %) are connected to the public water supply, the supply is not continuous (for example in Beirut only 10 % receive water continuously) and about 50 % is lost in the system through leaks (Lictevout, 2010). Many of the water treatment plants are not functioning correctly or are using insufficient treatment technologies, about 80 % of the chlorination units are out of service and the water quality deteriorates during transport in the network (Kronfol and Kaskas, 2007). Hence, due to a lack in consumer confidence, large proportions of the population buy their water from water tanks, bottled water or use private wells, resulting in an increase in annual expenses of about 0.6 % per household (LEDO, 2001). Irrigation practices are mostly not water efficient with old water networks, unlined canals and flood irrigation. A large decrease in water demand could hence be achieved by rehabilitation of the water supply network in urban and rural areas.

Due to the rainfall in winter and the water demand in summer, water **storage** is a major issue in Lebanon. Seepage into the fissured underground restricts dam building in most parts of the country. So far only one large dam on the Litani River (Quaroun lake) with a max capacity of 220 Mio m³ and a medium sized dam (Chabrouh dam, Kesrouan region) with 8 Mio m³ have been built. The construction of more dams is one of the main objectives of the Ministry of Energy and Water. However, it will not be easy to locate appropriate sites. A large number of smaller ponds, lakes and dams for domestic and irrigation purposes have been constructed with capacities between 5000 and 60000 m³ and a total storage volume of 5.5 Mio m³ (El-Fadel et al., 2000).

Apart from quantity related problems, the **quality** of water resources is severely impacted by discharge of raw sewage and industrial wastewater, uncontrolled solid waste disposal, leakage from gas stations, the use of fertiliser and pesticides and salt water intrusions along the coast, due to excessive groundwater withdrawals. Accordingly, surface and groundwater show increased concentrations of pathogens, heavy metals, hydrocarbons, nitrate, pesticides, and salt (Kronfol and Kaskas, 2007; LEDO, 2001; El-Fadel et al., 2000). The annual costs related to increased mortality and morbidity due to pathogen induced diseases is estimated to be more than 7 Mio US$ (LEDO, 2001). Water quality data are also sparse and continuous monitoring is not undertaken (LEDO, 2001). The protection of surface or groundwater resources is currently not part of land use planning practice. Land use zoning is only related to housing density and does not take into consideration environmental or soil stability aspects.

Groundwater vulnerability mapping on a national scale with DRASTIC showed that large portions of the country are highly vulnerable due to the karstic nature of most aquifers (Metni et al., 2004). As this method does not evaluate enhanced surface flow and infiltration through sinkholes, but assumes diffuse percolation into the soil, it does not delineate relative vulnerability in karst terrains. It would be essential to map the complexity of karstic features to allow a more detailed vulnerability mapping. Sinkholes of >400 depth and very fast groundwater flow velocities of up to 2 km/h have been recorded in Lebanon (Margane, 2011; Metni et al., 2004).

3.3 Wastewater treatment and reuse

Currently, wastewater is largely (92 %) discharged to surface streams, the Mediterranean Sea, boreholes or percolates into the groundwater through cesspools and septic tanks (LEDO, 2001). Therefore, domestic wastewater of about 250 Mio m³/a with a BOD load of ~100000 t/a and industrial wastewater 43 Mio m³/a with a BOD load of ~5000 t/a and high loads of heavy metals (e.g. 40 t/a of Cr from tanneries, 2 t/a of Ni and Pb from one fertiliser company (EMWater, 2004) pollute the environment (Table 76). The beaches along the coast have lost their recreational potential due to faecal contamination (EMWater, 2004).

Table 76: Summary of the main pollutants discharged into the sea and their main contributors based on the Baseline Budget of pollutant release from 2003 (after Environtech, 2005)

pollutant	total estimated quantity (kg/a)	industry/sector	contribution
BOD_5	154 330 000	agriculture	69 %
COD	3 183 000	paper	60 %
total Kjeldahl-N	24 720 000	agriculture	71 %
oil and grease	51 040	tanning	76 %
ammonia	38 310	tanning	78 %
PAH	110	urban wastewater	100 %
total P	1 593 000	urban wastewater /agriculture	50 /41 %
fluorides	672 000	fertilisers	100 %
cyanides	225	aluminium	100 %

While a number of new WWTPs are under construction or in planning (Table 77), currently only three larger plants are functional: (1) the Ghadir WWTP south of Beirut; (2) the WWTP in Saida, both only with primary treatment not meeting the environmental limits for discharge to the sea, and (3) the WWTP in Baalbek with secondary treatment. A few other larger WWTP are completed (e.g. in Tripoli), but the networks are not completed, so that they are running at a pilot scale. A number of small decentralised wastewater treatment systems have been implemented by international aid organisations (mainly US AID), for example in Hammana, Jabbouleh, Baalbek region and Bchetfine (EMWater, 2004) and could treat about 16 000 m³/day (MEDAWARE, 2004a). Due to a number of reasons, only about 20 % of these plants are still running properly (M. Scheu (GIZ), personal communication). Community participation in these projects was high and resulted in a high willingness to pay for the service (Choukr-Allah, 2010).

To fulfil the plan to connect 80 % of population to treatment plants, the Ministry of Energy and Water (MoEW) favoured a central concept for wastewater treatment with about 20 large WWTPs and extended pipelines (the maintenance of the network would be vital, as sewer lines would run alongside rivers and leakages are a hazard to water resources), while the Council for Development and Reconstruction (CDR) favoured a decentralised solution with about 60 medium WWTPs (UNEP, 2006; EMWater, 2004). Smaller and more distant communities will not be served, and will require local solutions. Also many larger systems will not be able to serve all areas of the villages. The installation of small-scale WWTPs, greywater reuse combined with dry toilets or septic tanks should be investigated for such areas.

Table 77: Inventory of status of WWTPS in Lebanon (after GTZ, 2009, personal communication)

location	size of WWTP (population equi. in thousands)	design flow (thousand m³/day)	Components: primary treatment	Components: biological treatment	Components: sludge stabilisation	wastewater treatment process	effluent reuse envisaged?	Method of sludge treatment	financing agency	date of commissioning	status of WWTP
Beirut & Mount Lebanon											
Al Ghadir	850	138	X	-	-	Pre	NO	raw	KfW	1997	**operational**
Jbeil	48	9	X	X	X	Biofil	NO		AFD	2010	collector pending
Qartaba	8.75	1	X	X	X		NO		IGDC		preparation
Jiyeh	45	5.95	X	X	X	Biofil	NO		FP	2009	collector pending
Bourj Hammoud / Dora	1.664	325	X	X	X		NO		EIB	2011	design
Keserwan/ Tabarja	505	70	X	X	X		NO		EIB	2012	tender
Hrajel	37	6	*Details pending*						IGDC	2012	design
Khenchara	20	2.5	X	X	-		NO		Abu Dhabi	2010	
Barouk	12	1.9	X	X	-		NO		Arab Fund	2012	
Aamatour	5	0.9	X	X	-	EA with TF	NO		USAID	2008	completed
Hammana	6.25	1.125	X	X	-	EA	NO		USAID	2008	completed
Bater	5	0.9	X	X	-	EA	NO		USAID	2008	completed
Bekaa											
Baalbek	89	12.5	X	X	X	EA	YES		WB	2009	**operational**
Zahle	120	18	X	X	X	AS	YES	thickening, drying	IGDC	2010	construction
Jib Jinnine	77	10.5	X	X	X		YES		IDB	2009	construction
Saghbin	4.1	0.53	X	X	X		YES		IDB	2009	construction
Majdal/ Anjar	275	44.5	X	X	X		YES		IGDC	2012	preparation
Laboueh	53	7	X	X	X		YES		Iranian Fund	2009	construction
Rachaya	6	0.6	X	X	-	TF	-		YMCA		completed
Aitanit	35.7	5	X	X	X	TF	YES	AnSS, DB	USAID	2006	construction
Fourzol	7.4	1	X	X	X	TF	YES	AnSS, DB	USAID	2009	construction
Chmistar	13.2	1.8	X	X	X	TF	YES	AnSS, DB	USAID		preparation
Ablah	14.63	2	X	X	X	TF	YES	AnSS, DB	USAID		preparation

Table 77 (continued)

location	**size of WWTP (population equi. in thousands)**	**design flow (thousand m³/day)**	**components**			**wastewater treatment process**	**effluent reuse envisaged?**	**method of sludge treatment**	**financing agency**	**date of commissioning**	**status of WWTP**
			primary treatment	biological treatment	sludge stabilisation						
					North Lebanon						
Tripoli	792	135	X	X	X	EA	NO	incineration	EC / EIB	2009	completed
Batroun	25	4.1	X	X	X	EA	NO		FP	2010	construction
Chekka	16.7	1.75	X	X	X	EA	NO		FP	2010	collector
Michmich	42	6.8	X	X	X		NO		IGDC	2012	preparation
Koura	68	11	X	X	X		NO		Arab Fund / AFD	2011	design
Abdeh	185	30	X	X	X	AS	NO		Arab Fund	2012	preparation
Bcharreh / Hasroun	22	3.56	X	X	X		?		Arab Fund	2012	preparation
					South Lebanon						
Saida	390	70.2	X	-	-		-	raw	JBIC	2006	**operational**
Sour	200	45	X	X	X		NO		EIB	2011	tender
Nabatiye	100	9.8	X	X	X	EA	NO		FP	2007	collector pending
Hebbaryeh	6.5	0.92	X	X	-	UASB	NO		USAID	2007	completed

Pre: Pretreatment only; Biofil: biofiltration; TF: trickling filter, EA: exteneded aeration; UASB: upflow anaerobic sludge blanket; AnSS: anaerobic sludge stabilisation; DB: drying beds; AFD: French Development Agency; IGDC: Italian Government for Development and Cooperation; FP: French Protocol; EIB: European Investment bank, IDB: Islamic Development Bank, WB: World Bank; JBIC: Japan Bank for International Cooperation

A reasonably large amount of urban households is connected to a **wastewater network**, but as these do not lead to WWTPs, the sewage is only collected and discharged into the environment at fewer points. This has transformed the problem of diffuse contamination into high-level point source contamination, resulting in a greater hazard (Metni et al., 2004). This situation arose from the fact, that different institutions were responsible for sewer networks (municipalities), the construction of WWTP and operation during initial period (CDR) and the subsequent operation (Water Establishments). A clarification concerning these responsibilities has still not been achieved. About 40 - 67 % of all households, with higher percentages in rural areas (up to 75 %), are not connected to any sewer network and use either septic tanks or more often cesspools (Lictevout, 2010; EMWater, 2004). Sewer networks that need pumping stations are prone to sewer overflow as electricity is not always available (about 50 % of the time).

Due to the lack of treated wastewater, only a limited extent of wastewater reuse is practiced in Lebanon so far. Jabboule WWTP is treating about 90 m³/day and Hasbaya WWTP about 240 m³/day and parts thereof are used for irrigation (MEDAWARE, 2004b). Reuse of untreated sewage in agriculture and indirect (potable and irrigational) reuse of sewage is practised in Lebanon as water is withdrawn from streams that have received sewage upstream. The use of untreated sewage is not as common as in other MENA countries, but in the Bekaa region some sewers are deliberately blocked to divert sewage to the fields (Choukr-Allah, 2010). Crop restrictions are not respected and human exposure control is low (Choukr-Allah, 2010). Highest potential for wastewater reuse is for agricultural purposes as this sector accrues the highest demand. In the Bekaa Valley, where porous aquifers are available groundwater recharge should be investigated and along the coast industrial reuse might be feasible. A limited number of greywater reuse projects have successfully been implemented, for example a greywater reuse scheme with trickle filters including 30 households in West Bekaa were installed by MECTAT (Middle East Center for the Transfer of Appropriate Technology) and funded by IDRC (Canada) achieving a net benefit of about 300 US$ per family per year (Choukr-Allah, 2010, EMWater, 2004).

3.4 Legislation

Lebanon is signatory to a number of **international** conventions and declarations for the protection of water resources and the environment. These include the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention, signed 1976), The Genoa Declaration on the Second Decade of the Mediterranean Action Plan (signed 1985), Convention on Biological Diversity (CBD, ratified 1994), the Convention on Wetlands of International Importance (RAMSAR, signed 1999) and the Stockholm Convention on Persistent Organic Pollutants (signed 2001). The Barcelona Convention and the Genoa Declaration prescribe the treatment of wastewater from settlements with more than 100000 inhabitants before discharge into the Sea.

Lebanon has also promulgated a number of **national** laws and decrees for the protection of the environment and water resources. The Ministry of Environment has drafted an Environmental Framework Law, a Framework for Protected Areas and a Decree for Environmental Impact Assessment (EIA), but an efficient environmental legislative framework is still missing (EMWater, 2004). The following regulations are in place, but are mostly not enforced:

- Protection of surface water and groundwater resources (Order No. 144 of 1925)
- Protection of catchment areas (Order no 320/26 of 1926)
- Protection zones for water sources and recharge areas (Decree No. 10276 of 1962)
- Restriction on the depth of unlicensed boreholes (Decree No. 14438 of 1970) and the Preservation and protection of boreholes (Decree No. 680 of 1998)

- Standards for drinking water (Table 78, Law 444 of 2002) exist only for biological and inorganic parameters, but not for heavy metals or organic contaminants
- Environmental limit values for wastewater discharge into the environment (Table 79, MoE decision 8/1 of 2001) are existing (EMWater, 2004).
- Direct discharge of sewage to irrigation or drainage channels, watercourses, bottomless pits/wells or the sea is hence prohibited (Order 320 of 1926; Decree 2775 of 1928; Decree 8735 of 1974), small on-site WWTPs or septic tanks have to be installed in areas unconnected to the sewer system (Decree 7975 of 1931; Decree 2761 of 1933; Decree 8735 of 1974) and pretreatment of industrial wastewater before discharge is required (Decree No. 2761 of 1933) (UNEP, 2006).
- The drilling of public groundwater bores is only allowed with a license (Law No. 320 of 1926) and a bore log (Decree No.14438 in 1970) has to be prepared, while private bores up to 150m depth require only notice. Decree 14438 also addressed the permissible quantity of groundwater and surface water that could be extracted (Kronfol and Kaskas, 2007)
- Standards for the minimization of pollution to air, water and soil (MoE Decree No. 52/1, 1996) set minimum levels for urban wastewater, treated domestic wastewater and were updated by the national standards for environmental quality (NSEQ) in 2001 (MoE Decision 8/1) replacing pollutant loads with upper limits concentrations for wastewater discharges (Envirotech, 2005).
- The irrigation with treated wastewater is currently prohibited (Decree 8735 of 1974) and hence no standards for water reuse are established (EMWater, 2004), but as reuse is envisaged for the future, draft wastewater reuse guidelines have already been prepared (Table 80).
- Since 1998, 110 pesticides are banned (Decision 94/1, dated 20/5/98), however, no fines or legal action against offenders were set and the disposal of existing stock was not regulated (LEDO, 2001)
- The Ministry of Energy and Water recently implemented the concept of greywater reuse in its Ten Year Water Plan (2000-09) (Choukr-Allah, 2010).
- The new ten-year plan (2010-2019) from the Ministry of Energy and Water has been prepared, and is awaiting approval from the government. It envisages groundwater recharge of 200 Mio m³/a and the construction of more dams for storage.

The above mentioned regulations (Decree No. 10276 of 1962) for water resources protection do not contain any details concerning the methods for delineation of water resources protection zones, land use restrictions or how to implement water resources protection zones. No water resources protection zones have yet been implemented in Lebanon.

The environmental programme of the Ministry of Environment (2010-2012) wants to protect the environment through sustainable development, preventive measures, the polluter pays principle, stimulating environmental friendly projects and introducing environmental friendly concepts in all policies (BankMed, 2010). The enforcement of existing laws, implementing decrees on environmental impact assessment, activation of environmental monitoring and adaptation to climate change are all part of the programme. Monitoring of water quantity and quality (including snow), waste management and a revision of guidelines on water pollutants are also addressed (BankMed, 2010).

Table 78: Drinking water standards (EMWater, 2004)

parameter	standard value	parameter	standard value
total coli. (MPN/100 mL)	0	NO_3 (mg/L)	5 (max 50)
faecal streptococcus (MPN/100 mL)	0	Cl (mg/L)	25 (max 200)
faecal coli. (MPN/100 mL)	0	SO_4 (mg/L)	25 (max 250)
sulphate reducing bacteria (MPN/200 mL)	1	Na (mg/L)	20 (max 150)
thermotolerant coli. (MPN/100 mL)	0	K (mg/L)	10 (max 12)
salmonella (MPN/5 L)	0	Mg (mg/L)	30 (max 50)
pathogenic staphylococci (MPN/100 mL)	0	Ca (mg/L)	100
bacteriophages (MPN/50 mL)	0	total Al (mg/L)	0.05 (max 0.2)
enteroviruses (MPN/10 L)	0	dry residues (mg/L)	1500
temperature (°C)	12 (max. 25)	EC (µS/cm)	400
pH	6.5 - 8.5 (max. 9)		

Table 79: Environmental limit values for discharge of sewage into the sea, surface waters and sewers (after EMWater, 2004)

parameter (mg/L)	discharge into			parameter (mg/L)	discharge into		
	sea	surface waters	sewer		sea	surface waters	sewer
pH	6-9	6-9	6-9	Ag	0.1	0.1	0.1
temperature (°C)	35	30	35	Al	10	10	10
BOD_5	**25**	**25**	**125**	As	0.1	0.1	0.1
COD	125	125	500	Ba	2	2	2
total P	10	10	10	Cd	0.2	0.2	0.2
total N	**30**	**30**	**60**	Co	0.5	0.5	1
TSS	60	60	600	total Cr	2	2	2
AOX	5	5	5	Cr(VI)	0.5	0.2	0.2
detergents	3	3		Cu	1.5	0.5	1
***E. coli.* (MPN/100 mL)**	**2000**	**2000**		Fe	5	5	5
Salmonellae (MPN/L)	nil	nil	nil	Hg	0.05	0.05	0.05
hydrocarbons	20	20	20	Mn	1	1	1
phenol index	0.3	0.3	5	Ni	0.5	0.5	2
oil + grease	30	30	50	Pb	0.5	0.5	1
TOC	75	75	750	Sb	0.3	0.3	0.3
NH_4	10	10		Sn	2	2	2
active Cl_2	1	1		Zn	5	5	10
cyanides	0.1	0.1	1	SO_4	1000	1000	1000
F	25	25	15	sulphide	1	1	1
NO_3	90	90		PO_4	5	5	

The draft wastewater reuse guidelines (prepared by the FAO) are based on a multiple barrier approach including wastewater treatment, crop restrictions, irrigation management and human exposure control. The programme CROPWAT is suggested for water management. Nutrient management to avoid excessive nitrogen application, which could lead to poor-quality produce and leaching of nitrate into groundwater supplies, might require the blending of reclaimed water with freshwater and the establishment of a nutrient balance. Soils with low water holding capacity should be irrigated with smaller amounts of water but more often. When using sprinkler irrigation, buffer zones of about 300 m to water bodies and publicly accessible areas are proposed. Sampling frequency of treated wastewater for BOD, TSS, total P, total N, pH, temperature, TDS, NO_3, PO_4, *E. coli.*, FC and helminths eggs should be once per months for smaller WWTPs (2000 - 50000 PE) and twice per months for larger WWTP (>50000 person equivalents (PE)). Na, Ca, Mg, K, SO_4, Cl and B are recommended to be measured twice per year and heavy metals once a year (FAO, 2010a). It is also stressed that WWTPs need to be operated by skilled personnel and sampling takes place according to a set protocol.

Table 80: Draft Lebanese guideline for wastewater reuse (FAO, 2010a)

class	**I**	**II**	**III**
restrictions	produce eaten cooked; irrigation of greens with public access	fruit trees, irrigation of greens and with limited public access; impoundments with no public water contact	cereals, oil plants, fibre and seed crops, canned crops, industrial crops, fruit trees (no sprinkler irrigation); nurseries, greens and wooden areas without public access
proposed treatment	secondary + filtration + disinfection	secondary + storage or maturation ponds or infiltration percolation	secondary + storage /oxidation ponds
BOD_5 (mg/L)	25	100	100
COD (mg/L)	125	250	250
TSS (mg/L)	60 (200 WSP)	200	200
pH	6 - 9	6 - 9	6 - 9
residual Cl_2 (mg/L)	0.5 - 2	0.5	0.5
NO_3-N (mg/L)	30	30	30
FC (/100ml)	<200	<1000	none required
Helminth eggs (/1 L)	<1	<1	<1

Note: Irrigation of vegetables eaten raw is <u>not</u> allowed

There are also no approved standards for sludge disposal or management, but draft guidelines have been proposed by the FAO. In addition to limits for heavy metals shown in Table 81, guidelines for pathogens of FC <1000 MPN/g DW, salmonella <0.75 MPN/g DW, and helminth eggs <0.2 viable number/g DW are proposed. To fulfil the pathogen standards storage of 8 months is recommended. Storage space for compliant sludge for 8 months and disposal sites for non-compliant sludge has to be identified. Drying beds have to be properly isolated from the underlying groundwater. Draft management guidelines prohibit biosolids application on lands for fruits or crops eaten raw, on lands with a slope >5 %, on areas with depths to the groundwater level <1.5 m and soils with higher heavy metal contents than specified in the guidelines (Table 81). Application rates should be calculated based on nitrogen needs of crops and consider heavy metal content in soils and biosolids. Withholding periods of 2 months before grazing and 30 days before unrestricted access to farmland as well as 8 months storage after biosolids production are suggested (personal communication, R. Nemer). Applied biosolids should be incorporated into the soil with mechanical methods and not with manual traditional methods. Good hygiene practices during and after contact with biosolids are needed for health protection. Storage of biosolids should not be close to drains, irrigation channels or water resources. Buffer zones of 10 m to wells, springs, surface waters, spring and flood prone areas are required after FAO, but buffer zones of 150 and 750 m to water supply wells and surface water supply intakes, respectively, are envisaged by the MoEW (personal communication, R. Nemer). Frequency of analysis for pH, dry matter, organic matter, total N, NH_4-N, P_2O_5, K_2O, MgO, heavy metals and pathogens is dependent on size of the WWTP and range between once a year and once a month for WWTP designed for < 5000 and >100000 PE, respectively (FAO, 2010b).

Table 81: Proposed limits for heavy metal concentrations in biosolids and soils (mg/kg DW) (FAO, 2010b)

class	use	(As)	Cd	Cr	Cu	Hg	Ni	Pb	(Se)	Zn
A	unrestricted: B + public sites and greens	20	5	250	375	4	125	150	8	700
B	restricted I: C + agriculture	20	20	500	1500	15	270	300	50	2500
C	restricted II: D + forest, reclamation land	30	32	600	1500	19	300	400	90	2800
D	not suitable for use: landfills, soils at WWTP	>30	>32	>600	>1500	>19	>300	>400	>90	>2800
soil	agricultural		1	100	100	1	60	100		200
soil	non-agricultural		5	250	375	4	125	150		700

Note: Biosolids application to vegetables eaten raw is not allowed.

A National Wastewater Management Plan (NWMP) was initially prepared in 1982, but has not been implemented until recently (UNEP, 2006). In 1995, the National Emergency Rehabilitation Programme (NERP) was launched and comprised two major programmes: (1) the Coastal Pollution Control Programme (CPCP) was set up to fulfil the requirements of the Barcelona Convention and (2) the Water Resources Protection Programme (WRPP) included the rehabilitation of water treatment plants and water sources (springs and wells) and distribution networks (EMWater, 2004). A National Water Master Plan for freshwater management was proposed in 2003 using a number of estimations (JICA, 2003), but was not accepted by the Ministry of Energy and Water. Therefore, it is still lacking, mainly due to a lack of data and a lack of policy (Kronfol and Kaskas, 2007). There is urgent need for a comprehensive Water Code to address water and wastewater management. Reviewing of existing legislation and new regulations for wastewater reuse and sludge management are needed. Without enforcement of existing (and new) laws though, no policy will be successful.

3.5 Institutional framework

A range of national bodies are responsible for the water and wastewater sector:

- Ministry of Energy and Water (MoEW): oversees hydraulic projects (building dams), the exploitation and protection of water resources, and supervises the regional Water Establishments and the Litani River Authority. It is also responsible for the development of the National Water Master Plan, but is not able to fulfil all these functions due to lack of staff and data. The structure within the Ministry has increased in complexity since the current minister has introduced twelve personal advisors.
  - Regional Water Establishments (RWE): since 2000 (law 221/2000) the previous 21 Water Authorities were reorganised into 4 Water Establishments, which are responsible for the water supply and wastewater treatment in an integrated water management.
  - Litani River Authority (LRA): management of water resources (surface and groundwater); mainly gauging of rivers; preliminary studies for dam construction
- Council for Development and Reconstruction (CDR): implementation of priority reconstruction and development projects in basic infrastructure, social and productive sectors with external financial aid. Most large-scale wastewater projects are planned and implemented solely by CDR. The concept for the wastewater sector of CDR is different from the one supported by MoEW.
- Ministry of the Environment (MoE): establishment and enforcement of environmental standards; influence on land use planning; control of pollution from various anthropogenic activities; protection of biodiversity; mainly restricted to monitoring
- Ministry of Agriculture (MoA): development of irrigation projects; reforestation projects; management of natural resources; supervision of the Green Plan
  - Green Plan (GP): execution of land rehabilitation and land development projects
- Ministry of Public Works (MoPW): planning of land use and infrastructure projects, but implementation mainly undertaken by the CDR
- Ministry of Public Health (MoPH): ensuring water safety; epidemiological surveillance
- Municipalities (under the Ministry of the Interior): responsible for building and maintenance of infrastructure and provision of basic services like water and sewer networks. Many municipalities have started to construct sewer networks with the main aim to transfer wastewater to some point outside the village without considering treatment possibilities and possible negative impacts on downstream water resources. In most cases this must be seen as counter-productive because new wastewater projects will most likely follow different concepts so that these investments were mostly in vain.

Although the new organisation of water authorities into RWEs in 2000 allows for an integrated water resource management, the new regulatory and structural decrees were only issued in 2005, and the transition of responsibilities is still not fully completed and has slowed down progress (CDR, 2009). Basically all institutions have only limited numbers of qualified staff and lack current and verified data (El-Fadel et al., 2000). There is insufficient coordination between the different institutions and a lack of country-wide planning resulting, for example, in the building of sewer networks without prior knowledge of WWTP locations or the construction of WWTPs without the related collector lines. The responsibility for operation and maintenance of wastewater schemes remains unclear. Due to the lack of capacities at the Water Establishments, most wastewater projects implemented through foreign donor funds by CDR foresee a certain period during which operation and maintenance is done by contractors paid out of these funds. According to current regulations, the wastewater network will have to be operated and maintained by the municipalities. However, the municipalities neither have the necessary know-how and staff nor the financial means to do so. A consequence might be that pumping stations would most likely not be operated due to the high costs. This would in most cases have severe negative environmental consequences. **It is therefore strongly recommended to transfer responsibility for operation and maintenance of the sewer networks to the Water Establishments.**

There is insufficient funding for a proper maintenance and operation of water and wastewater services as the tariffs do not cover the costs, which is enhanced by the limited collection of fees from consumers. The current water supply tariff system (no metering) does not encourage water savings.

4 Proposed Best Management Practices

As has been outlined above, there are numerous problems facing water and wastewater management in Lebanon. A holistic approach to water and sanitation including protection of resource should be adapted to mitigate direct and indirect impacts on human and ecosystem health (UNEP/WHO/HABITAT/WSSCC, 2004). For a national water master plan reliable long term monitoring of meteorological, hydrological and groundwater characteristics is vital (El-Fadel et al., 2000). In addition, determination of water demand and current use is needed. The regular faecal contamination of drinking water resources due to non-existing wastewater treatment requires urgent action to safeguard public health, groundwater resources and the environment. The karstic nature of most of Lebanon's aquifers makes them especially vulnerable to contamination and hazards should be reduced even more. Wastewater master plans should be prepared for all surface water catchments with special consideration of surface water and groundwater protection needs in these catchments (Margane, 2011).

4.1 Groundwater protection

Groundwater protection is the first step for a sustainable resource management. The concept encompasses a staged zoning around drinking water sources (wells and springs) with increasing land use restrictions closer to the source. The innermost protection zone (zone I) is commonly 10 - 50 m around the source itself. Commonly the source is surrounded by a locked fence and is allowed to be entered only by staff of the Water Establishment. In karst areas the inner protection zone (zone II) encompasses areas of high and very high vulnerability (e.g. areas around sinkholes and streams, along structural faults, slopes with runoff into streams or sinkholes, areas with thin soils) and the outer protection zone (zone III) should comprise the entire catchment area in karst regions. Therefore, groundwater protection in karst areas requires vulnerability mapping for the delineation of the protection zones and most likely tracer tests for the delineation of the catchment area. The quality of available data is essential for a reliable vulnerability map and special attention should be given to a detailed mapping of karstic features.

Legislation has to outline the specifications for the protection zones, the delineation method and land use restrictions for each zone, as well as measures and penalties for non-compliance. A coherent system of regulations and clearly defined responsibilities between institutions is essential for a successful implementation. The population has to be educated about the installation of protection zone and the associated land use restrictions and the zones have to be clearly marked. Compromises have to be found for existing land uses that would not comply with the new regulations. Recommended land use restrictions are:

zone I

- no activities apart from necessary work related to the water supply
- no wastewater facilities in this zone including
- no sewage collectors crossing this zone

As a considerable share of the drinking water supplies originates from karst springs of touristic value and hence cannot be fenced off completely, special care has to be taken to collect all liquid and solid wastes and transport them out of the zone safely. No vehicles apart from electric ones should be allowed, meaning parking lots should be at least 50 m downstream from the spring. No handling of hazardous material and any material/dust from construction work should not be allowed to enter the water resource. The extreme vulnerability of caves might require restrictions concerning visitor numbers and visitors must be accompanied by a guide to enforce water resource protection.

zone II

- no sewage collectors, cesspool or septic tanks. If sewers have to cross this zone they have to be double walled or surrounded by an impermeable layer
- no wastewater treatment plants
- no industrial land use, landfills or dumping of wastes
- no quarries or mines
- agricultural activities using fertilisers allowed but application of pesticides not allowed; irrigation water should comply with environmental limits for discharge to streams
- no application of sewage sludge
- no livestock
- no new developments or building constructions should not be allowed; all existing residential buildings have to be connected to a wastewater treatment plant
- no new construction of roads

zone III

- most activities are permitted, but general care should be taken not to contaminate the groundwater resource; operation of industrial and commercial sites should follow environmentally sound practices
- no underground storage tanks of hazardous substance, but if necessary only with impermeable liner and double walls; above ground storage tanks with double walls and equipped with leak detectors and drainage system
- no discharge of untreated wastewater into the environment, especially industrial wastewater has to be treated
- no infiltration of strongly contaminated stormwater e.g. from petrol stations, high traffic roads or industrial premises; these stormwaters should be collected and infiltrated via filtration systems or treated through constructed wetlands (see EPA SA, 2007c; McCann and Smoot, 1999 for stormwater best management practices in karst areas)

- landfills have to be constructed with liners and drainage systems to avoid percolation of hazardous leachate into the groundwater
- sewage collectors should be surrounded by soils of low permeability and have to be checked regularly for leakages
- environmental impact assessments for industrial facilities
- erosion control through natural vegetative cover

Land use planning in Lebanon currently is pretty archaic and needs to integrate the need for water resources protection into existing land use plans. Currently, land use plans comprise mainly regulations concerning the size of residential buildings. What is urgently needed is on the one hand an integration of water, environmental, and forest protection areas and on the other hand areas designated for industrial and commercial areas, quarries, landfill sites and sites for other potentially hazardous activities.

A risk assessment for existing hazards to water resources and the environment must be undertaken with the possible consequence of site closures and cleanup operations. This requires a hazard map and a systematic risk assessment. New potentially hazardous sites should only be allowed if it can be proven that they will not have any negative effects on water resources or the environment. These decisions should be taken by a Licensing Committee, comprising representatives of all related ministries and governmental institutions, such as is the case in Jordan since many years. Monitoring wells should be installed (especially in zone II) to check if the restrictions are enough to comply with drinking water quality standards Monitoring should be conducted at regular intervals and additionally during rainfall events, when most of the pollutants are transported (Watson et al., 1997). **The control of compliance of land use restrictions and their enforcement will be a major challenge in Lebanon**.

4.2 Wastewater treatment

Wastewater treatment should provide effluent of appropriate quality for human health and the protection of the environment depending on the further use (see Fig. 7). In karst regions, quality requirements for discharge into the environment are higher than in other regions due to the extremely high vulnerability of groundwater resources. The first assessment for the most suitable wastewater treatment system should consider the separation of streams, as treatment of each stream can be adjusted to the specific contamination resulting in much higher effluent quality. Industrial wastewater should be separated from domestic wastewater, especially if reuse is considered.

A **feasibility study** with holistic view of the entire wastewater system (from collection to sludge disposal) should be undertaken for selecting the most appropriate system (see also Table 7). A wastewater master plan needs to provide information about current and future volumes and quality of wastewater in a catchment. The source and the final destination of the treated effluent are the main criteria, but cost, operation, topography etc have to be considered as well. Cost-effective extensive treatment systems should be considered, if space is not an issue, as they efficiently remove pathogens and create less sludge than intensive systems. In any case, primary and secondary treatment is necessary to comply with minimum effluent standards. If the effluent is discharged into the karst environment further pathogen (Table 6 and Table 41) and nutrient removal is likely to be required. The effluent quality should be monitored in regular intervals to evaluate compliance with applicable guidelines and further treatment should be added when needed. This might also include soil aquifer treatment in constructed infiltration beds and could be combined with artificial recharge. In this case, monitoring wells are needed to judge water quality before it enters the aquifer to avoid transfer of contaminants.

Among other things (Annex 1), **the site selection for a WWTP and collector lines has to consider georisks (e.g. landslides, ground collapse, earthquakes), topography and hydrogeological criteria especially in karst regions. No WWTP or sewer network should be built in groundwater protection zone I or II. The construction of sewer networks in protection zones II needs to be done in such a way that leakages and subsequent infiltration into the groundwater can be excluded, i.e. sewer networks will have to be placed into beds of clay or other low permeable material.** In addition, connectivity between the effluent discharge point and the downstream drinking water sources should be checked using with tracer tests. Leakages and blockages in sewer lines and the WWTP should be regularly monitored for and removed as soon as possible. Therefore, **sewer lines have to be accessible for maintenance and repair over the entire length during all times.** Topographically low positions near rivers are generally used for gravity sewer systems, and are preferable where continuous electricity for pumps is an issue, but also pose the highest risk to water resources. The WWTP should preferably be located close to the wastewater source and the reuse location as well, in order to minimise network costs and leakage potential. In reality this will be difficult to combine, as agricultural areas suitable for wastewater reuse are located at mid to high elevations (1200 – 1800 m). Here, transfer through the unsaturated zone (near-vertical movement) takes much longer (by a factor of ten or more) than transfer in the saturated zone. On its way through the unsaturated zone groundwater passes soil and layers of lower permeability, so that the attenuation effect can play an important role, especially if the unsaturated zone attains a high thickness. However, most WWTPs will serve populated areas situated lower in the catchment. High pumping costs would therefore be accrued for reuse in the higher regions. Transfer and reuse at the coast would be less costly.

Contingency plans for possible disruption of the wastewater treatment have to be in place addressing all foreseeable emergencies. As parts of the treatment plant could not be functioning due to routine maintenance, technical failure, missing spare parts or damage (either from georisks or human violence), parallel treatment systems are advisable. Storage for untreated sewage and independent power supply are minimum standards to avoid overflow of raw sewage into the environment. Even better is an additional treatment line that can be used during high loads. The main issue here is the availability of land. During the land acquisition for new WWTPs and additional space for future extensions should be incorporated. Additional space is required for storage of treated sludge for 8 months, before it can be used safely for land application, and disposal sites for sludge not suitable for land application have to be identified. Drying beds, storage areas and disposal sites have to be constructed with liner and drainage underneath to prevent any leaching of sludge water into the underlying groundwater. Maintenance has to be carried out regularly to avoid any unnecessary malfunctioning and requires skilled personnel.

Current environmental effluent standards might need to be revised in order to add a category for discharge into sensitive waters (i.e. karst areas) with more stringent values (see Table 16) based on resource protection rather than best technological means, but if existing laws were enforced, this would already be a major step in the right direction.

4.3 Wastewater reuse

The evaluation of wastewater reuse **options** (Table 18) has to consider primarily supply and demand and additional costs compared to discharge and other water sources (Table 19). While agricultural reuse schemes commonly assess **risks** to health and to soil and crops, consequences for surface and groundwater are often ignored. Due to overland flow and percolation, irrigation water will also reach water resources. In areas with thick soils, attenuation of contaminants limits possible pollution, but especially in karst areas, where preferential flowpaths are common, pollution risks have to be assessed and good management practices have to be in place.

Recommendations for reuse in **karst areas** are:

- In case of reuse in irrigation and aquifer recharge, treated wastewater reuse standards should be similar as for discharge into the environment, because karst aquifers are highly vulnerable and contamination can reach drinking water supplies fast. Less stringent water quality standards should only be used for irrigation where sufficiently thick soils or extensive layers of low hydraulic conductivity are verifiably present to prevent percolation to the groundwater. High water quality also allows for irrigation of sensitive crops like fruit trees that are common in Lebanon. **Since effluent quality should be high regardless of discharge or reuse, no additional treatment costs are incurred for reuse**.
- Reclaimed water of lesser quality could be reused for toilet flushing and possibly some industrial reuse. This way it will be re-entering the treatment process and not be released into the environment.

- If aquifer recharge is performed with low quality water, the infiltration system has to be designed appropriately to add additional treatment to the water before it reaches the groundwater.
- Irrigational and recharge reuse should not be permitted in groundwater protection zones I and II, e.g buffer strips around sinkholes and along streams should be respected (minimum 50 m).
- If artificial recharge is undertaken, this area should be assigned the status of groundwater protection zone I and be fenced off to avoid any unwanted dumping of solid or liquid wastes.
- To avoid excess runoff and erosion slope angle should be larger than 3, 12 or 20% for flood irrigation, sprinkler irrigation or drip irrigation, respectively (Table 43).
- Soils need to have a minimum thickness, as well as minimum quality to be able to retain water and nutrients long enough for plant uptake and to limit leaching to the groundwater (Table 43).
- Added nutrients in the reuse water and additional fertiliser should match the demand of the crops, e.g. at the start of the growing season less nutrients should be applied, to avoid leaching of nitrate into the groundwater. Overfertilisation is a common problem in reuse schemes.
- Irrigation management should adjust applied volumes of water to the crops need and the water holding capacity of the soil to prevent excessive leaching into the groundwater.
- Heavy metals are of limited problematic in karst regions as the high pH in soils generally reduces their mobility.

General recommendations are:

- Health protection measures for farm workers should include protective clothes, good hygiene practices, and possibly immunisations (for example polio, diphtheria, tetanus).
- Health protection measures for consumers should include washing of produce, withholdings times before harvest, and crop restrictions to produce that is not peeled or cooked (Table 42).
- Health protection measures for adjacent population should include the use of drip or trickle irrigation, buffer strips near dwellings and clear signage of reclaimed water (Table 42).
- Irrigation management should prevent salt accumulation in the root zone and capillary rise of groundwater.
- Crop selection should be adjusted to salinity, lithium and boron levels of the reclaimed water (Table 21).
- Elevated levels of heavy metals should not be applied to crops for human consumption to avoid bioaccumulation.
- Elevated nitrate levels can lead to yield loss and should only be used on grassy and leafy crops or water has to be blended with freshwater.

A national policy for wastewater reuse should include guidelines for water quality and management measures as outlined above and has to formulate how and by whom these guidelines will be enforced. However, regulations must be realistic and achievable in the national context. It is advisable to increase measures and water quality standards step by step, so they can actually be met. If guidelines are too strict and cannot be enforced, they will most likely be ignored completely (Pescod, 1992). As the use of treated wastewater is certainly safer than the use of untreated wastewater as is practiced in the Bekaa Valley, any improvement on water quality and water resource protection measures is a step in the right direction. **It is extremely important that the above protection measures are monitored and controlled and clear instructions are given to the users.**

4.4 Sludge management

Sludge will be produced during wastewater treatment with amounts depending on the treatment system (Table 55) (estimation for Lebanon record a sludge production of >300 t/day or >1.3 Mio m³/day of raw sludge (LEDO, 2001)) and has to be dewatered and treated further (chapter 2.4) resulting in significant costs and further risk to water resources, that have to be incorporated in the planning. Environmental impact assessment has to specifically include sludge treatment. **Sludge should not be released into the environment without treatment.**

The common options for sludge handling are landfilling, incineration (thermal reuse), reuse in construction material or land application. The high organic content in the sludge will result in methane production during **landfilling**, which should be extracted and used for energy generation to avoid the release of potent greenhouse gases. Groundwater has to be protected from landfill leachate. For **incineration**, the water content of sludge has to be reduced significantly. It is probably not viable for each treatment plant to install a separate incineration facility, so sludge has to be transported safely to a central facility. Groundwater protection measures have to be applied to the incineration facility and storage of dewatered sludge should be handled accordingly. **The reuse of sludge in construction materials is the safest option with regards to groundwater protection as contaminants are immobilised in the cement matrix.** This reuse option should be considered in karst areas. If **land application** is envisaged, any plastics, sanitary items etc should be disposed of separately during primary treatment and should not be included into biosolids. While pathogens can be largely eliminated through treatment (see Fig. 10), biosolids have accumulated all contaminants attached to particulates (like heavy metals and persistent organic contaminants) that are not significantly decreased during treatment. **Therefore, sludge application in karst areas is prohibited in many European countries**.

Recommended measures for the reduction of groundwater contamination during land application of biosolids are:

- Prevent the input of inorganic and organic contaminants at the source through source separation and awareness raising in the population.
- No application of biosolids in groundwater protection zone I and II.
- No application on steep slopes (> 12 %) to reduce erosion and overland runoff (Table 72). Such conditions prevail in many parts of the Mount Lebanon mountain range and would result in a downstream transfer of the contaminant load due to erosion.
- No application on bare soils without vegetation without incorporation into the soil.
- No application on water logged soils or where the groundwater level is high (< 0.5 m below ground).
- No biosolids applications on soils with pH <5.5 – 6.
- No application during the rainy season, when strong precipitation events increase overland runoff.
- Setback distances to water courses and sinkholes (minimum 50 m) (Table 71).
- Withholding times between biosolids application and grazing of animals and harvest of crops (Table 73).
- Release of nutrients is slower than from treated wastewater, but added nutrients in the biosolids should match the demand of the crops and the nutrient holding capacity of the soils to avoid leaching of nutrients into the groundwater (Table 70).
- Concentrations of nutrients, heavy metals and organic contaminants in the biosolids and the soil have to be monitored regularly and application rates have to be adjusted to avoid pollutant accumulation in the soil and leaching to groundwater.
- Soils need to have a minimum thickness, as well as minimum quality to be able to retain contaminants and nutrients in order to limit leaching into the groundwater. Application rates have to be adjusted to the cation exchange capacity and soil structure and should not exceed certain maximum limits (about 5 t/ha/a).

If biosolids application is prohibited as outlined above, probably manure and mineral fertiliser application should be restricted too, as they also contain high amounts of heavy metals and organic contaminants, e.g. pharmaceuticals (Table 59). Regulations have to specify standards for biosolids quality, upper limits for application in relation to soil quality, management measures and standards about record keeping, monitoring and reporting. It is important to monitor and limit sludge application, so it is not used as a waste disposal option and leads to water resources contamination.

4.5 Education and public acceptance

There is clear need for educating the population in general and potential polluters in particular about changes in regulations and their purpose, as each citizen has to take part in environmental protection. The four topics (groundwater protection, wastewater treatment, wastewater reuse and sludge management) addressed in this report will all require awareness raising campaigns to be successfully implemented. These campaigns can be in form of regular newspaper articles, regular TV spots, public seminars, billboard advertisements, leaflets, TV documentaries and stipulation of the foundation of civil organisations that promote environmental awareness from citizen to citizen. For example the Association of the friends of Ibrahim Abd El Al, Greenline, Mubadarat or T.E.R.R.E. Liban are already working towards a more sustainable way of living, some with a focus on water issues. Special courses or workshops should be given to planners, decision makers, farmers and major polluting industrial companies. Environmental education should be made mandatory in the curriculum at schools for all levels, as the education of children will propagate this knowledge to the older generation as well as to the coming generation. It will be important to find well-known sponsors, public figures and celebrities with positive connotations for the campaigns to increase the acceptance of the message.

(1) groundwater protection

The local population should be educated about where their water comes from and the importance of groundwater for their daily lives. Education should encompass problems of quantity as well as quality. They need to understand how **vulnerable** groundwater resources in karst areas are and that groundwater protection zones are important to keep water resources clean. People must be made aware that by discharging pollutants into the environment through dumping of waste, spilling of or leaking hydrocarbons and discharging wastewater into the underground or into rivers does not remove pollution but rather is the source of contamination in the water they drink. **Pertaining to the necessary enforcement of land use restrictions, acceptance of water resources protection measures will be a true challenge because people will have to accept that they simply cannot do on their land what they want to do in the interest of all.** It is extremely important that the land use restrictions and protection measures are monitored and controlled and clear instructions are given to the population. Personnel for the enforcement of the new regulations need to be trained and anti-corruption measures have to be employed.

In addition, **water conservation** measures should be implemented. These measures should include more efficient irrigation methods, as well as water saving devices in the households (water saving toilet flushing, shower heads, water saving washing machines etc). Especially farmers and construction companies should be informed about water saving technologies. Incentives for water saving should be created by changing the tariff system from a flat rate to a metered system. To reduce social inequity a minimum volume should be supplied at a low price, while additional water needs should be charged at a higher rate.

(2) wastewater treatment

First of all, the population has to be educated about **what should not be disposed of into the sewer system.** It should be made clear that solid wastes and hazardous materials like paint, varnish, organic solvents, mineral oil, batteries, pharmaceuticals etc. should not go down the drain. This also means that safe ways of disposal have to be provided for these compounds so the problem is not merely transferred to illegal dumping of wastes. The management and recycling of waste is also a very important issue with regards to groundwater protection. Collection points for hazardous wastes not belonging into the normal domestic waste should be installed in each municipality. Guidelines for waste management, site selection for landfills and waste incinerators need to be established and education campaigns regarding waste handling should be added in a next step. Shortcomings in this sector have been identified but are lacking implementation (BankMed, 2010; Envirotech, 2005).

If reuse for agricultural irrigation is envisaged, boron and lithium concentrations are of concern, as they show low removal rates in wastewater treatment systems and especially citrus trees are sensitive to these compounds. **Boron** originates mainly from detergents, bleaches and whitening toothpaste. To limit its entry into the sewer system, detergent producers should be advised to shift their production to more biodegradable and environmental friendly compounds. Apart from batteries, **lithium** originates from pharmaceuticals against depression, bipolar disorder etc. If pharmaceuticals are a major issue in the catchment, urine separation toilets should be considered. The population should be aware that old or unused medicines do not belong into the toilet.

If these campaigns are successful and prevent the input of inorganic and organic contaminants, the good quality of domestic wastewater should allow for a high quality of treated wastewater and sludge without advanced treatment techniques and hence allow for a widespread reuse at limited costs.

Standard operation procedures (SOPs) must be established and there must be a reporting system that makes it obligatory to follow them in order to make sure that wastewater treatment plants are operated in the right way.

Another important point is the competence of the WWTP operators. Staffs need to be qualified and adequately paid to guarantee that plant operation, maintenance and quality control are executed correctly. Staffs need to be trained on sampling procedure, record keeping and general monitoring.

(3) wastewater reuse

There is a common lack of knowledge how wastewater treatment is working and the quality that can be achieved. Public perception of treated wastewater is influenced by cultural and social factors and varies from country to country (EMWater, 2004). Many reuse schemes have failed due to overestimation of demand as expectation of higher acceptance in the population for reuse water was assumed. Since wastewater reuse may involve pumping costs, those costs may have to be covered by the farmers. Otherwise it must be clear who else would cover these costs in the future. Therefore, all involved stakeholders (municipalities, Water Establishments, CDR) and potential users have to be consulted as early as possible during the project planning and the selection of the appropriate technology should be based on the demand, user’s preference and their economic potential. They have to be educated and advised about the control measures for safe usage. Consumers have to be informed about the safety of the produce and a public authority should regularly control its safety.

Methods and tools for awareness raising programmes for wastewater reuse have been developed and should be used (UNEP/WHO/HABITAT/WSSCC, 2004; Wegelin-Schuringa, 2001; UNICEF, 1999). Participatory approaches should involve stakeholders during the assessment phase, the design phase and the implementation phase in order to promote changes in attitude and advocate the benefits of reuse (Kramer et al., 2010). **Positive examples from other people will have the strongest impact on behavioural changes** (UNICEF, 1999). It is therefore often successful to start with a small-scale project with local involvement and then upscale to regional projects.

Greywater, especially if it is from one's household, does not have the ‘yuck’ factor and reuse of greywater is accepted much more widely (Po et al., 2003). Household and neighbourhood scale greywater treatment systems are available and their installation should be promoted especially in areas that will not be served by centralised systems (McIlwaine and Redwood, 2010; Morel and Diener, 2006).

Many **farmers** lack basic agricultural training and environmental awareness and need to be trained, so reuse is done in the intended way. Information about the existence and purpose of groundwater protection zones, as well as health and environmental protection measures - as recommended above (chapter 4.3) - has to be disseminated. The boundary of groundwater protection zones I and II have to be visibly marked by signposts, which state what is not allowed in these protection zones and who has to be notified in case of violations thereof. Concerning treated wastewater reuse, an analysis of soil thickness and quality should be undertaken to advise which areas could be irrigated with treated wastewater and where reuse could not be applied. Health protection measures have to be explained to farmers, consumers and the adjacent population, as human behavioural patterns are the main factor for disease transmission (WHO, 2006). All channels, pipes and outlets of reclaimed water have to be clearly marked. **Crop selection and irrigation management is an important part of successful reuse implementation.** Nutrient requirements have to be assessed to prevent overfertilisation (GTZ, 2006b). It requires the knowledge of nutrient levels in reclaimed water and soil as well as nutrient needs of specific crops. As salinity levels of treated wastewater are commonly higher than ground- or surface water, farmers have also be educated how to prevent salinisation problems and salinity related yield losses.

(4) biosolids management

Similarly to wastewater reuse, biosolids application requires detailed instructions to the user and education of the consumer. The evaluation of areas suitable to biosolids application should be undertaken by a trained person. Management measures as outlined above (chapter 4.4) have to be explained to the farmers and examples of good practice should be established. The calculation of fertiliser need also applies to biosolids application. Samples of soil and sludge quality have to be taken and good record keeping practice has to be introduced to the farmer and distributor of biosolids. Undesirable odours and nuisances related to biosolids application should be minimised to increase public acceptance.

4.6 Economic considerations

Financial aspects often constrain the selection of the treatment method. Costs for wastewater treatment and reuse vary widely depending on the costs for land, especially if expropriation is required, topography, the size of the treatment plant and sewer network, the volume of wastewater to be treated, the treatment method, the type of sludge management and the reuse options applied (see also Table 8). Apart from the overall costs for construction of a sewer network and treatment plant, the costs for no action and negative effects on the population and the environment have to be considered. **Establishing wastewater treatment facilities sooner rather than later is commonly less costly than doing nothing.** These costs comprise increased costs for drinking water treatment due to contamination, increased costs for finding and connecting new water sources when the previously used source becomes polluted (Table 19), increased health costs and costs for income loss for the population, costs related to loss in agricultural productivity, costs related to loss in economic development opportunities (tourism), costs for negative impacts on the environment, and added benefits from wastewater reuse should be considered (Table 82). Around 50 - 60 % of fertiliser costs can be saved through the use of reclaimed water (GTZ, 2006b).

Table 82: Economic benefits of irrigation with wastewater in Morocco (after Soudi et al., 2000)

crops	net benefit from recycled water (€/ha)*	net benefit from fertilising benefits (€/ha)**	total benefits (€/ha)
wheat	75	149	224
grain maize	159	361	514
fodder maize	157	357	514
zucchini	68	155	222
pumpkin	61	122	183
tomato	155	354	510
potato	94	214	308

* calculated on the basis of a 0.02 €/m³ cheaper price compared to other water supply and an irrigation rate of 1000 m³/ha, ** assuming wastewater concentrations of N = 40 kg/ha, P = 11 kg/ha and K = 28 kg/ha

Economic analysis and financial planning are important factors, and financial viability will decide about the long-term fate of projects. Foreign donors commonly sponsor the construction, but do not supply funds for long-term operation and maintenance. Hence tariffs have to cover these costs in the long run (Table 83). **Extensive systems have commonly reduced construction costs (20 – 30 %) and reduced operational costs (40 – 50 %) due to lower electricity consumption (Table 84) and lower sludge production** (Kramer et al., 2007). **Sludge treatment often amounts to about 50 % of operational costs** (Pescod,

1992) and has to be included in financial feasibility studies. **Sewer construction regularly accounts to about 50 % of the total construction costs**.

Table 83: Construction and annual operation and maintenance costs (€/PE) of some wastewater treatment systems (after Abbassi and Al Baz, 2008)

costs for	type	number of PE						
		100	200	500	1000	2000	5000	10000
construction	sewer system	6300	5350	4300	3650	3120		2130
	primary settling	1975	1065	800	650	520	390	320
	activated sludge	1690	1390	1100	925	765	600	505
	biofilters	1625	1345	1050	885	730	575	480
	oxidation ponds	1600	1050	610	400	265	150	100
operation and maintenance	sewer system	21.0	18.5	15.0	13.5	12.0	9.8	8.5
	primary settling	80.5	68.8	56.0	47.8	41.0	34.0	28.3
	activated sludge	140	118	95.0	80.3	68.0	54.0	46.0
	biofilters	156	122	88.5	69.8	54.8	39.5	31.8
	oxidation ponds	36.8	27.0	19.0	14.0	10.5	7.5	1.0

Table 84: Comparison of the energy consumption of the different sections of the water cycle in the municipalities belonging to the Costa Brava Water Agency (after Sala and Serra, 2004)

type and source of water	range in energy consumption (kWh/m^3)
drinking water supply [a]	
surface water	0.0002 – 1.74
groundwater	0.37 – 1.32
desalination	4.94 – 5.41
biological wastewater treatment	
activated sludge	0.43 – 1.09
extended aeration	0.49 – 1.01
waste stabilisation ponds	0.05
reclamation treatment for pathogen removal [b]	
pulsed bed filters plus UV disinfection	0.18
direct filtration plus UV disinfection	0.50 – 1.21
Title 22 with UV disinfection	0.20 – 0.63

a: transportation to main storage tanks included; b: consumption of the distribution of reclaimed water not included owing to its high variability depending on the user location; Title 22: treatment requirements outlined by the Californian Title 22 guidelines (see Table 40)

Costs for monitoring needs and costs for staff to control compliance with management measures have also be added to the running costs of a project.

4.7 Monitoring and control requirements

Monitoring, control and enforcement of regulations are necessary to ensure good groundwater quality. After implementation each of the four topics addressed requires monitoring and regulations should outline the frequency and sampling techniques necessary. Environmental rangers similar to Jordan are probably needed to control and enforce new regulations. In Jordan, the rangers are part of the national police force operating in coordination with the Ministry of Environment. They have the right to detain persons, who are in violation of the environmental law or the water law, and are responsible for the implementation of the regulations related to water resources protection, such as protection zones.

Monitoring needs with regards to **groundwater protection areas and land use restrictions** are:

- In and upstream of groundwater protection zones observation wells with multi-parameter probes for continuous monitoring of water level, EC, turbidity, pH should be installed.
- Samples for pathogens, heavy metals and hydrocarbons should be taken regularly and additionally after heavy rainfall events.

Control needs with regards to groundwater protection areas and land use restrictions require checking if:

- fences and locks around groundwater protection zone I are not damaged
- signposts indicating the boundaries of groundwater protection zones are still existing and recognisable
- observation bores are working correctly and data are extracted and reported regularly
- no illegal dumping of liquid or solid wastes occurs
- no hazardous material is stored or handled in protection zone I and II
- pesticide is not used, only designated fertilisers are used and no livestock is held in protection zone II
- no new constructions or extensions of existing constructions have been done in protection zone II
- reclaimed water is only used in designated areas and not anywhere else
- all hazardous waste tanks are double walled and equipped with leak detectors
- no discharge of untreated wastewater happens
- other land use restrictions are complied with
- no vegetative cover is destroyed (which would change the groundwater vulnerability in which the boundaries of protection zones are based on)
- environmental impact assessments for all legally allowed new facilities are undertaken

Monitoring needs with regards to **wastewater treatment** are:

- Effluent quality complies with effluent standards according to further use or disposal.
- Sewer networks are inspected for blockages and leakages.

Control needs with regards to wastewater treatment require checking if:

- no spillage of untreated sewage occurs
- all parts of the treatment system are working properly
- all equipment including emergency equipment is functional

The **parameter list and frequency** depends on whether reuse is intended (health impact through exposure, impact on crops grown), the potential impact on water resources and discharge into river courses or the sea. Samples of the treated wastewater effluent should be taken and analysed for the following parameters at the below mentioned intervals for the below mentioned purposes (Table 85):

Table 85: Recommended sampling frequencies of WWTPs effluent

parameter	reuse	impact on water resources*	discharge into river courses	discharge into the sea
EC, pH, temperature, in-/outflow	continuously	weekly	continuously	continuously
BOD_5, COD, TSS, total N, total P, TOC	every 10,000 m³	weekly	every 10,000 m³	every 0.1 Mio m³
NO_3, PO_4	every 50,000 m³	monthly	every 50,000 m³	every 0.5 Mio m³
E. coli., FC, helminth eggs	every 10,000 m³	weekly	every 10,000 m³	every 0.1 Mio m³
thermotolerant coli., cryptosporidium, Giardia	every 0.5 Mio m³	monthly	every 50,000 m³	every 5 Mio m³
Na, Ca, Mg, K; Cl, SO_4, B, Li	every 50,000 m³	monthly	every 50,000 m³	every 0.5 Mio m³
Cd, Cr, Cu, Hg, Ni, Pb, Zn	every 50,000 m³	monthly	every 50,000 m³	every 0.5 Mio m³
Al, As, Be, Co, Fe, Mn, Mo, Se, V	every 0.5 Mio m³	quarterly	every 0.1 Mio m³	every 5 Mio m³
AOX, phenols, FOG	every 1 Mio m³	monthly	every 50,000 m³	every 10 Mio m³

* water sampling at drinking water sources (springs/wells)

It has to be emphasised that laboratories in Lebanon are currently not able to deal with such large numbers of samples and with many of these parameters at the required level of accuracy, so that laboratory capacities must be developed in order to carry out adequate sampling programs.

Monitoring needs with regards to **reuse of treated wastewater** are:

- Water quality lies within the guideline limits for the specific use.
- Sampling frequencies of treated wastewater should principally depend on the potential impact and not on the size of the treatment facility. In this sense, it is recommended to analyse indicator parameters, such as BOD_5, total N and *E. coli.* every 10,000 m³. For new WWTPs a higher sampling frequency is recommended over the first two years.
- If aquifer recharge is practiced, water quality below the infiltration field has to fulfil guidelines for groundwater protection and requires continuous sampling.
- Fertiliser needs have to be adjusted to nutrients added through reclaimed wastewater depending on crop needs.
- For large-scale irrigation, groundwater monitoring wells should be installed and monitoring for nitrate, salinity and pesticides undertaken.

- Crops intended for human consumption have to be controlled for their safety.

Control needs with regards to reuse of treated wastewater require checking if:

- reclaimed water is not used in unsuitable areas or groundwater protection zones I and II
- health protection measures are observed
- irrigation practices comply with management guidelines
- crop restrictions are respected

Monitoring needs with regards to **sludge management** are:

- Biosolids quality complies with guideline values.
- Soil quality complies with guideline values.
- Fertiliser needs have to be adjusted to nutrients added through biosolids depending on crop needs.

Control needs with regards to sludge management require checking if:

- sludge is not released into the environment without treatment
- drying beds, storage and disposal sites for sludge at the WWTPs do not allow leaching of sludge water into the groundwater
- final biosolids are stored at individual farms, so groundwater pollution does not occur
- records of applied biosolids volumes and quality are kept
- biosolids application is not practiced in unsuitable areas, buffer strips or groundwater protection zones I and II
- biosolids application rates do not exceed maximum limits
- biosolids application is not practiced during the rainy season
- withholding periods between biosolids application and harvest or grazing are respected

Samples of wastewater sludge should be taken and analysed for the following parameters at the below mentioned intervals for the below mentioned purposes (Table 86):

Table 86: Recommended sampling frequency of WWTPs sludge

parameter	land application of treated biosolids	disposal in landfills
amount	continuously	landfills for sludge should not be constructed in karstic areas
EC, pH	every 50 t	
BOD_5, COD, TSS, total N, total P, TOC	every 50 t	
NO_3, PO_4	every 50 t	
E. Coli, FC, helminth eggs	every 50 t	
thermotolerant coli., cryptosporidium, Giardia	every 500 t	
Na, Ca, Mg, K; Cl, SO4, B, Li	every 50 t	
Cd, Cr, Cu, Hg, Ni, Pb, Zn	every 50 t	
Al, As, Be, Co, Fe, Mn, Mo, Se, V	every 500 t	
AOX, phenols, FOG	every 2500 t	
PCB, PCDD/Fs	every 5000 t	

5 Conclusions

To avoid groundwater contamination and pollution of drinking water resources, groundwater protection zones should be implemented, especially in karst areas of Lebanon. These should comprise three zones of increasing land use restriction with decreasing distance to the water supply source (well or spring) (chapter 4.1). These should be based on vulnerability mapping with special attention to infiltration conditions.

5.1 Criteria for the selection of wastewater treatment facilities

Generally a number of selection criteria need to be considered in the site selection and design of wastewater facilities. They have to encompass all components of the facilities, namely the collector lines, the treatment plant and the discharge facility. A comprehensive wastewater management plan needs to address the following issues:

- volumes and quality of wastewater sources (including future increase)
- required quality of effluent
- wastewater management in those areas which cannot be serviced by the planned wastewater facilities
- sludge management and
- wastewater reuse

The special conditions in the Mount Lebanon mountain range are highly problematic with respect to water resources protection. Problems, which might cause damages to the WWTP or the sewer network and subsequent leakages of untreated wastewater into the underground, arise especially from elevated risks associated with (see also chapter 2.2.5):

- topography (the high gradients require appropriate solutions for the sewer network: material, spacing of manholes, pressure breaks, etc.)
- events of extremely high rainfall (might cause overflow of sewers and bypassing of WWTP if capacity of both is not high enough)
- landslide and rockfall formation
- karst collapse structures
- soil stability
- tectonic movements and earthquakes
- open karst, i.e. direct infiltration
- high degree of karstification, i.e. rapid infiltration and fast flow in unsaturated and saturated zone
- flooding (interruption of treatment process)

A matrix of criteria (Annex 1) is suggested to be used for site selection and design of wastewater facilities in Lebanon. The matrix is divided into:

- general criteria
- geological and hydrogeological criteria and
- cost related criteria

5.2 Criteria for wastewater reuse

Wastewater reuse should only be allowed in areas where there will be no negative impact on the quality of downstream water resources. This means that reuse should primarily take place only on sufficiently thick geological units of low permeability, which act as a hydrogeological barrier. This applies to most parts of the Bekaa Valley and smaller areas along the coast, where Tertiary and Quaternary sediments are present (Fig. 12). In karst areas, it applies to areas where the J5 (Bhannes Formation; basalt, limestone, marl, claystone) or the C1/C2a (Chouf Sandstone Formation/Abieh Formation; sandstone, claystone, lignite, basalt/limestone, marl) outcrop. Only where those layers crop out over sufficiently large areas, wastewater reuse will be an option. In the Mount Lebanon mountain range this is mostly the case at elevation between 1000 and 1800 m. **Wastewater reuse on outcrops of the J6 (Bikfaya Formation) and J4 (Keserwan Formation) units should be ruled out,** because of the very high vulnerability of the underlying groundwater to pollution as a consequence of the high karstification. Vulnerability maps are urgently needed to delineated suitable wastewater reuse areas.

Apart from those hydrogeological aspects, health aspect related to the impact on human beings resulting from exposure to the reuse water and resulting from the crops grown using reuse water have to be considered. Human exposure of farmers can be controlled by good hygiene practices, clear signage of reclaimed water taps and low contact irrigation methods. Human exposure of consumers can be controlled by crop restrictions (e.g. no irrigation of vegetables eaten raw or no selling of fruits in contact with the ground), washing or processing of produce and stoppage of irrigation with reclaimed water before harvest.

Maximum allowable limits of the related **standard for reuse of treated wastewater in agriculture should be based on water resources protection needs (potential impact on water resources) and not on general crop restrictions and health protection alone.** It is recommended to only allow class I wastewater reuse in karst areas if all other protection measures (e.g. location in groundwater protection zone I+II, thin soils, steep slope, close to streams or infiltration features, etc) are fulfilled. Class II + III should only be allowed in areas with thick soils, for example in the Bekaa Valley.

The reuse of treated wastewater requires continuous monitoring of effluent quality, groundwater quality, soil quality and quality of food products grown with reuse water (chapter 4.7).

5.3 Criteria for sludge management

There are several options for the use of residual sludge resulting from wastewater treatment processes:

- treatment and use as fertiliser for agricultural cultivation
- disposal on designated waste disposal site
- integration in construction material
- incineration in power plants or solid waste incinerators

The selection of the best management option for each individual WWTP has to be based on the following facts:

- potential negative impact on downstream water resources (EIA required)
- local acceptance by population and farmers
- costs

If sludge is going to be used in agriculture, it may require special treatment for unwanted components contained in the sludge, such as pathogens, heavy metals, hydrocarbons, etc. before its use is possible safely. It must be stressed that the chemical composition of the sludge will be different from location to location, depending on the input, and will also change over time. Therefore monitoring of sludge quality is very important (chapter 4.7).

As outlined for wastewater reuse in chapter 5.2, also sludge application should only be allowed in areas where there will be no negative impact on the quality of downstream water resources. Therefore the same criteria as mentioned above for reuse of treated wastewater apply for the application of sludge. Application of sludge on outcrops of the J6 and J4 units should be ruled out, because of the very high vulnerability of the underlying groundwater to pollution.

Local acceptance by population and farmers of sludge application should be created through public awareness programs.

In case of disposal, designated facilities must be established. They should be located in areas where no potentially negative impact on water resources could occur. It must be ensured that sludge is actually transported to these designated facilities and not dumped anywhere else. This requires an appropriate reporting and supervision system. If sludge is to be stored on the premises of the WWTP, these areas need to be constructed properly with a foundation of clay liner and drainage channels to collect seepage water. Land acquisition should consider future extensions and areas needed for sludge storage.

Maximum allowable limits of the related **standard for reuse of sludge in agriculture should be based on water resources protection needs (potential impact on water resources) and not on general land use and health protection alone**. It is recommended to use only three classes:

- class A: application allowed if all other protection measures (e.g. location in groundwater protection zone I+II, thin soils, steep slope, close to streams or infiltration features, application during dry season etc) are fulfilled
- class B: application allowed in areas with thick soils or impermeable layers, for example in the Bekaa Valley
- class C + D: application not allowed

The recommended maximum application rate is 5 t/ha/a. Soil samples have to be taken prior to the first application and thereafter every 25 t/ha applied to test if accumulation of heavy metals is still within the acceptable limits.

5.4 Monitoring of treated wastewater effluent, sludge quality, the effects of wastewater reuse and sludge application and the impact of wastewater facilities on water resources

The operation of wastewater facilities, the reuse of treated wastewater, the application of sludge and the impact on water resources need to be monitored and controlled. All related activities should be laid down in a **monitoring concept**, which should be prepared for each facility, comprising the locations where monitoring is needed, specific parameter lists, time intervals for monitoring and analysis, responsibilities, laboratories, staff and budget. Quality assurance measures will be needed to provide that analysis results are correct.

Overall, the two main concerns are the lack of data to base any water resource and wastewater management plans on and the enforcement of guidelines. Firstly, long-term monitoring of climate, water flow and groundwater recharge as well as detailed mapping of geological and hydrogeological features is required. Secondly, while a number of laws and regulations already exist, the staffs for their enforcement are lacking. Capacity building of environmental rangers, agricultural staff and WWTP operators as well as raising of environmental awareness in the population will be needed.

Recommended reading:

Reference	Main topic
Schmoll et al., 2006	groundwater protection
Watson et al., 1997	karst protection
Aoki et al., 2006	sustainable urban water management
Jagannathan et al., 2009	water management in Arab countries
MEDAWARE, 2003, 2004,2005	sustainable urban water management and reuse
EPA SA, 2007c	stormwater best management practices
McCann and Smoot, 1999	stormwater best management practices
Al Baz et al., 2008	wastewater management
UNEP/WHO/HABITAT/WSSCC, 2004	wastewater management
Kayombo et al., 2005	waste stabilisation pond design manual
McIlwaine and Redwood, 2010	greywater reuse, Middle East countries
Morel and Diener, 2006	greywater reuse
AQUAREC, 2006	wastewater reuse
UNEP, 2005	wastewater reuse
WHO, 2006	guidelines for reuse
Kramer et al., 2007	wastewater treatment and reuse
GTZ, 2006b	irrigation management with reuse water, Jordan
UNICEF, 1999	communication and education
EPA SA, 2007a	water and wastewater sampling
EPA SA, 2007b	groundwater sampling

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ANNEX 1: Criteria for Site Selection and Design of Wastewater Facilities in Lebanon

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source
General Criteria						
number of inhabitants to be serviced (capacity)	xxx	xxx	xxx		financial feasibility	municipalities
WW facilities used for domestic, industrial, commercial WW	x	x	xxx	xx	integration of industrial and commercial WW will require special treatment	decision/agreement needed which to include
planned extension of residential /industrial / commercial areas (landuse plan)	xx	xx	xx		WW planning must be coordinated with landuse planning authorities	municipalities / Landuse Planning Dept.
population growth rate	xx	x	xx			municipalities / Landuse Planning Dept.
planning horizon	x	x	xx			
material to be used (by law / regulation; appropriate ?)	xx	xx	xx		material must be appropriate to support geological/tectonic stresses, temperature, pressure, etc.	determine appropriate material for each condition
existing network (location / diameters / material / design)	xxx	x	xx		previous concepts must fit with new concepts	compile location/condition/diameter/material of existing network
character of WW (composition, including seasonal variability)		xx	xxx		amount of sludge; reuse potential of sludge (limited if industrial WW is treated and treatment method does not ensure complete removal of all hazardous substances)	chemical analyses
topography (which (parts of) villages can be connected / combined ? Where have primary / secondary collector lines to be laid down ? pumping required ? when / where ? Can collector lines follow roads / existing infrastructure ?)	xxxx	xxx	xxx	xx	pumping costs should be minimized / avoided	establish detailed DEM, determine optimal trace lines of primary/secondary conveyors; discuss with municipalities (land ownership)
land ownership (need for expropriation ?)	xx	xx		xx		cadastre map (not up-to-date)

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source
local acceptance	x	xx		xx	must be discussed with involved mayors of municipalities	local awareness campaigns
existing (nature / groundwater /surface water / forestry / wildlife) protection / conservation zones	xxxx	xxxx	xxxx			compile info from all related agencies
existing infrastructure (roads; access / accessibility)	xxx	xx	xx			compile related info
availability & amount of energy to be needed	xxxx	xxx	xxxx		effluent discharge by gravity or pumping required for reuse ?	compile/assess related info
Geological and Hydrogeological Criteria						
geology (rock type, underground as a barrier, dip direction/angle)	xx	xx			if natural geological barrier is existing, it should be used	geological mapping
stability of geological underground	xxx	xxx	xxx		unstable underground (e.g. landslide material or alluvium, may need special foundatation	geotechnical study (e.g. Using cone penetration tests/CPT)
landslide / rockfall probability / likely effect	xxx	xxx	xxx		damages by landslides or rockfalls must be avoidded	geological mapping
tectonics (existing faults, direction)	xxxx	xxxx	xxxx		sites on active faults bear an elevated risk of damage	geological mapping
earthquake probability (likelihood to affect the site)	xxxx	xxxx	xxxx		sites near zones with high probability of earthquakes bear an elevated risk of damage	analysis of previous earthquake events (location, depth, strength/effect)
groundwater flow direction / flow velocities	xx	xxx		xxx	high GW flow velocities (even if only seasonal) bear a high pollution risk	tracer tests
thickness of unsaturated zone / flow velocity in unsaturated zone	xxx	xxx	xxx	xxxx	leakage loss from network; reuse possibility	tracer tests
infiltration / GW recharge	xx	xx	xx	xxx	unhindered infiltration into the underground (aquifer) at high GW recharge rates bear a high risk of pollution	water balance/hydrological modelling

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source
karst features (degree of karstification)		xxx		xxxx	high karstification near WW facilities bear a high pollution risk; flow paths in karst system are often not sufficiently known	geological mapping
risk of downstream water resources to become polluted		xxxx		xxxx		
distance / travel time to water source (used for drinking purposes)	xxx	xxx	xxx	xxx	the higher the travel time the lower the pollution risk	tracer tests
risk of flooding	xxx	xxx	xxx	x	WWTP and collector lines must be protected against flooding	DEM, hydrological model
Cost related Criteria						
method of treatment (primary / secondary / tertiary)			xxx	xxx	can existing regulations / guidelines for effluent (reuse) quality be maintained at all times ?	
reliability of treatment			xxx	xxx		
storage capacity (bypass in case of overload ?)		xx	xx	xx	must be large enough to guarantee that bypassing untreated WW will not be necessary	
possibility / need for treated WW reuse		xx	xxx	xxx	discharge location must be high enough to use as little energy as possible for reuse	
sludge management / reuse of (treated) sludge for agriculture		xx	xx	xx	can existing regulations / guidelines for quality of (organic) fertilizer be maintained at all times ?	analysis of sludge content; determine sites for sludge application; determine treatment of sludge and related feasibility
costs for primary collector lines						
costs for secondary collector lines						
costs for household connections						
costs for WWTP construction						
costs for effluent discharge pipeline / canal						

Criteria	Collector Lines	WWTP Location	WWTP Design	discharge Location	Remarks	Tasks / source
overall costs for construction (available funds)					including equipment, laboratory and staff for continuous monitoring of treated WW quality	
annual costs for maintenance and operation (available budget)					including continuous monitoring of treated WW quality and sludge mgmt.	

xxxx - killing arguments, xxx - very important arguments, xx - important arguments, x - less important arguments