Guidance for decision-making on sewage sludge management

Recommended proceedings for Waste Water Treatment Plant Operators

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LIST OF ABBREVIATIONS

AOX	adsorbable organic halogen compounds
ATH	N-Allylthiourea solution
BAT	Best Available Technique
BOD	biochemical oxygen demand
°C	degree centigrade
cec	cation exchange capacity
cfu	colony-forming unit
COD	chemical oxygen demand
d	day
DS	dry solids
DWA	German Association for Water, Wastewater and Waste
EC	European Commission
E.coli	Escherichia coli (bacterium)
EU	European Union
EUR	Euro (European Currency)
g	gram
h	hour
kg	kilogram
l	litre
m	meter
m^2	square meter
m^3	cubic meter
meq	milliequivalents
mg	milligram
MJ	megajoule
MPN	most probable number
N	nitrogen
oDS	dry organic substance
O_2	molecular formula for the diatomic gas oxygen
P	phosphorus
PAH	polycyclic aromatic hydro-carbon
PCB	polychlorinated biphenyl
p.e.	population equivalent
pH	chemical term, the negative log of the activity of the hydrogen ion in an aqueous solution
QMS	quality management system
TTC	triphenyl-tetrazoliumchloride
WWTP	waste water treatment plant

INTRODUCTION

Purpose of the document

This guidance was produced to emphasize the importance of a proper preparation of decisions concerning an economical and environmentally safe management of sludge from municipal waste water treatment and is geared to assist in making appropriate planning and disposal choices.

To facilitate the best possible solution, it is essential that relevant issues are known early in the process and certain procedures in the decision-making be followed. It is therefore an objective of this document to raise awareness for the various aspects that should be considered in conjunction with efforts to achieve an optimized sewage sludge disposal and maximise the utilization of this secondary resource within an economically sound framework. More and more actors from the waste water sector and an increasing share of the society have an interest in this and support in any form is highly sought.

Each operator of a waste water treatment plant (WWTP) is in the situation to make regularly important decisions about investments in technical installations and about the routes used for the disposal of the generated sludge. Basis for these decisions must be the specific characteristics of the disposal object, long-term management objectives, protection needs and the economy. In that context, a wide range of different aspects needs to be thoroughly considered. They pertain among others the availability of technical options and general access to them, own capacities to manage the sludge and secure an adequate quality for different uses, the efficiency of desired investments and prospects to get cooperative solutions realized. All this influences decision-making and leads to individually varying solutions. Planning sludge disposal requires a holistic approach in which the specific local circumstances, infrastructure and economic settings have to be given due consideration. It should not set ambitions too high at the outset but follow a clear vision to handle the residues of waste water treatment eventually in a way that is the best for the people and the environment.

In the meantime municipal sewage sludge disposal is facing a vast variety of options. Not every place has the means and conditions to apply or to benefit from all of them. However, the disposal concept of WWTPs must comprise more than the determination of the sludge's final destination. To the many aspects that must likewise be considered belong

- the technology that already exists at the WWTP,
- the technologies it could possibly integrate to enhance the sludge storage and treatment process but also
- external alternatives that may exist for that.

The above must also be viewed with regard to

- the expected evolution of sludge amounts and quality parameter,
- different logistical challenges,
- price developments,
- testing requirements, and
- documentation requirements.

Assessing the various disposal options with all advantages and disadvantages they can have on own operations might be particularly difficult for operators of smaller WWTPs. Cooperate approaches may improve the situation for them, however.

A decision on a certain procedure adequate to the individual situation can only be made, when all necessary steps of treatment up to the very last residues and their way of disposal as well as the conditions associated to that are duly considered and integrated. Through this can be determined, among others, of which consistency the sludge has to be and what dry solid (DS) content must be attained in each case with pre-treatment. The selection of a dewatering technique and upstream conditioning should take into consideration results which were obtained with sufficiently large tests in facilities of comparable nature. In addition to the empirical knowledge and experimental research account should also be made on unfavourable operating situations (such as load variations) in the evaluation.

Along with a number of benefits of sludge, there are several problems which must be carefully managed to protect public safety and the integrity of the environment. The most serious of these are harmful constituents contained in the sludge: heavy metals, toxic organics (e.g. halogenated compounds, nonylphenoles and linear alkylbenzene sulphonates), and worrisome organisms/pathogens. For example 332 organic compounds with known or suspected toxic effects have been detected in German sewage sludge, 42 of them regularly, mostly within the range of g/kg to mg/kg dry matter.

Specific pollution control measures, management practices and careful monitoring, including analytical measurements, are required to mitigate these risks. A more secured access and use of the different disposal options will be possible when the sludge gets stabilised and the concentrations of harmful components reduced. How quick such an advanced management can be realized depends largely on the capacities to make good planning and investment decisions.

Good knowledge on the technological options is essential in this respect. Complementing this decision-making aid a ***"Technical guide on treatment and recycling techniques for sludge from municipal waste water treatment"*** has therefore been prepared. It is made available together with this document and the parallel use of both materials as a package in planning processes is highly recommended.

Usage of this guidance

With the information delivered by this guidance, WWTP operators are given a possibility to assess potential management options for the sludge quantities produced in their plants with regard to the practical feasibility and economic advantages certain solutions may have to offer. They will likewise find tips and helpful details to qualify their processes, understand given limits but also the potentials and challenges for an optimized sludge utilization in their place. This kind of assessment can be done regardless of the fact whether a mere theoretical case, a desired management solution or the proposal from a third party is concerned. To let other practitioners and additional opinions of sector experts become part of the exercise is not against the idea of this guidance but possible and wanted. The main goal is not to deliver a strict and final concept; it rather is the provision of an orientation and effective procedure to come to logic, well substantiated decisions about how to approach and plan sludge management.

Starting point for deliberations on the management and further improvement of sludge processing are the running treatment process and amounts of liquid sludge it generates. Critical steps that must be implemented before a utilization/disposal of the sludge becomes possible and how the spectrum of disposal options can be influenced are highlighted. With the help of economic indices and benchmark values all this can be taken further into an analysis of the economic efficiency of different disposal solutions.

The below flowchart illustrates a systematic approach that WWTPs should be following in the drawing up of an appropriate sludge disposal concept. It can also be read as a decision tree displaying the relevant questions at each stage in the decision process, short explanations of the next following steps and the outcome that is to be produced in each activity. Accompanying links to further explanations and relevant chapters in the document are also provided. The flow chart forms the core element of this document from which the main guidance for proper decision-making will be derived and to which readers should always revert for just this purpose.

NOTE:

earthification	highlights a reference technology respectively term that is explained in more detail in the accompanying ***"Technical guide on treatment and recycling techniques for sludge from municipal waste water treatment"***;
↗	marks an active link to another document or document section, or makes reference to a source which to consult is highly recommended to the reader;
↗R	symbolises that the reader should also see the 'cost quotation' notice in the references section at the end of the document in order to get the right idea on how these figures were derived.

Some characteristic cost figures and price ranges are given for orientation purposes. These were highlighted in the text of the respective document sections by applying a light blue writing colour.

The authors recommend that if the complete picture about a certain issue in this guidance is sought, appropriate terms should be selected to screen the document with the search function. Sludge dewatering for example is of relevance for the entire process of handling the sludge up to its final disposal and has therefore various implications, e.g. for storage, transport, costs, etc.. To get the complete overview on that, searching for the term 'dewatering' in this document would be helpful and lead readers at once throughout all aspects where dewatering has a meaning.

RECOMMENDED LOGIC TO PLAN A SEWAGE SLUDGE UTILISATION AND DISPOSAL PROCESS

Legend*:	* Please note that this flowchart contains also active links (in blue and underlined) to the explanatory sections following later in this guidance
Steps	'D' marks a Documentation stage, 'E' marks an Examination stage, 'A' marks the conclusion of a specific stage of Actions
	Characterizes a data collection and/or documentation step
	Characterizes an examination and/or verification procedure
?	Characterizes a critical decision point respectively question to be answered
A	Characterizes a decision-based Action
A_I	Characterizes an intermediate Action that must be undertaken until an alternative option is available or a better solution found

Step		Activity		Output	Links
D1		Generation of data files on the sludge generation at the WWTP, e.g. by measuring and recording	⇨	Baseline data on e.g. - produced amount, - DS content, etc.	↗ Base data ↗ Control ↗ Documentation
↗ E1		Conducting plausibility check of the data	⇨	Data verification by means of reference values (e.g. per capita generation, water consumption rates, other operational records, etc.)	
	?	*Were base data found to be plausible?*	If not →	**A_I** Error source must be searched and the data corrected	
A1	**A**	Determining and preparing set of data needed as baseline for disposal decision	⇨	Baseline data on sludge available	↗ Base data
A2	**A**	Familiarization with sludge disposal requirements and framework	⇨	Assessment of disposal situation vis-á-vis critical criteria such as - sludge qualities, - stabilisation levels, - storage capacities, etc.	↗ Legal Requirements ↗ Quality ↗ Reactivity ↗ Control ↗ Storage capacity

Step		Task / Question			Result / Action	Links
↗ E2		Examining biological reactivity of the sludge	⇨		Stability parameters, e.g. odour, BOD, ignition loss, gas-generating potential	↗ Reactivity ↗ Control
	?	*Is a stabilised sludge available or the stabilisation done at the WWTP?*	If not →	A_I	Sludge must be given away for stabilisation and further disposal to third parties unless own stabilisation capacities are created	↗ Stabilisation capacities
		↓				
↗ E3		Examining the content of potentially harmful substances	⇨		Lab results on harmful matter content	↗ Control ↗ Harmful substances
	?	*Is the sludge found to be within the critical limits?*	If not →	A_I	Measures for intensive pollutant control must be initiated (e.g. further stabili-sation or treatment steps)	↗ Control ↗ Critical limits
		↓				
↗ E4		Examine storage capacities				↗ Storage capacity
	?	*Are the available capacities for intermediate storage found to be sufficient?*	If not →	A_I	Sludge volume exceeding handling capacities at the WWTP must be given to most reasonable disposal routes available unless own storage capacities are created	
		↓				
↗ E5		Examine current costs for the available disposal pathways	⇨		Overview on the costs vis-à-vis the limits set by budget	↗ Disposal costs
	?	*Are current costs too high or conditions for preferred disposal routes unfavourable?*	If not →	A	Preferred disposal routes can be used	↗ Economic assessment ↗ Disposal contracts
		↓				
↗ E6		Examine possibilities for joint solutions or creation of synergies	⇨		Knowing about other WWTPs preparedness for co-operation	↗ Economic assessment
	?	*Can joint solutions or synergies be used?*	If not →	A_I	Most reasonable disposal routes at hand must be used	↗ Cost assessment ↗ Disposal contracts
		↓				
A3	A	Determining and preparing set of joint baseline data	⇨		Joint baseline data on the sludge of all partners available	↗ Base data
		↓				

↗ E7		Examine viability of internal treatment options				↗ Economic assessment
	?	*Did an investment into own installations show to make sense?*	If not →	A_I	Sludge must be given away for disposal to third parties unless own treatment capacities are created	↗ Space availability ↗ Disposal contracts
↓		↓				
A4	A	Set up and operate own treatment installations				
		↓				
A5	A	Forward treated sludge and/or treatment residues to further utilisation or final disposal				↗ Final outlets ↗ Disposal contracts
		↓				
D2		Documentation of disposal	⇨		Records and certificates on the amounts and qualities forwarded to different disposal routes, the residues disposed of and associated costs	↗ Control ↗ Documentation

The decision flow is basically determined from the analysis of information (collected and documented data/operation records) and certain examination exercises which consequently lead to a new action and eventually a specific way of managing things.

In the following some explanations will be provided which shall help comprehending the specific cascade structure of the decision flow in sludge disposal planning. Delivered with them are additional information and arguments which substantiate the meaning of the different sludge disposal aspects (concerns) and need to have them considered as milestones in the decision-making process.

Decision-making means to deal with various of these concerns and to eventually attain the right balance between them and the best possible compromise for a specific situation. Each aspect and concern requires certain questions to be asked and examined more thoroughly. First therefore is to look closer at the most relevant examinations that must be undertaken to come to appropriate sludge disposal decisions. Particular reference is made here to those steps that always precede an important decision point in the process (marked with 'E' in the above flowchart).

SUPPORTING EXPLANATIONS

Reference in the flowchart	Aspects to consider
E1	For disposal decisions which usually result in multiannual disposal contracts and have considerable financial consequences, reliable data are essential. It is good practice to carry out on-going mass balances on water, waste water and waste water solids handling at a WWTP. Such exercises should be devised to suit the particular characteristics and requirements of a given operation. Where certain materials (e.g. solvents, metals, specific toxic organic and inorganic substances) have the potential to adversely affect the waste water treatment operations and subsequent sludge management, then these should also be tracked using mass balance techniques. Continually monitoring suspended solids situation is a very practical help here. A typical solids balance derives from the following equation:

(Suspended Solids in Inflow) + (New Solids Made) = (Change in Mixed Liquor Suspended Solids) + (Solids in Surplus Sludge) + (Suspended Solids in Final Effluent)

One objective of such a balance is to determine the 'New Solids Made'. This is the amount of new biomass (mainly bacterial cells) that is created each day. This information is needed in order to establish a record of the sludge age as a very important plant monitoring and sludge management parameter. The 'New Solids Made' can be calculated also by difference when the other values are measured.

Other process control parameters in WWTPs with activated sludge process would typically include

- biochemical oxygen demand (BOD) or chemical oxygen demand (COD),
- mixed liquor suspended solids,
- feed to mass ratio,
- mean cell residence time (sludge age),
- dissolved oxygen,
- nutrient requirements,
- cone settleability,
- sludge volume index,
- surplus sludge production,
- pH-value,
- mixing considerations,
- microscopic examination of sludge,
- upflow velocity (clarifier).

Within this of particular importance with regard to the generation and subsequent management of sludge are:

Mixed liquor suspended solids (in mg/l)	The parameter is logged on a daily basis. It is essential for the calculation of the 'Feed to Mass' loading and determination of sludge age. The 'Mixed Liquor Volatile Suspended Solids' give an alternative parameter. It refers to the 'volatile' or organic fraction of the mixed liquor suspended solids and is typically about 80 % of its value.

Sludge age (in days)	The sludge age may be defined as the mass of mixed liquor suspended solids in the plant at any time divided by the mass of new solids made each day. The latter can be determined using the given solids balance formula. The higher the 'Feed to Mass' loading the shorter the sludge age and vice versa. This is because new biomass is produced at a fast rate when feed supply is high and at a slower rate as feed supply is reduced. For this reason the sludge age can be thought of as a measure of the rate of turnover of solids in the WWTP – hence 'Mean Cell Residence Time' is used as the alternative name for sludge age. Sludge age is typically about 20–30 days in activated sludge plants operating at high (>95 %) BOD removal efficiencies. A long sludge age is required for certain specific objectives, nitrification being the most usual. However, solids-liquid separation problems can result if the sludge age is excessively long.
Dissolved oxygen (in mg/l)	There should be a permanently installed dissolved oxygen monitoring system which should be regularly calibrated. The dissolved oxygen should be maintained above 1 mg/l in all parts of the aeration basin. For systems using surface aerators this usually requires a concentration of about 1.5 mg/l measured at the liquid surface. Where nitrification is required the dissolved oxygen needs to be 2 mg/l or higher in all parts of the basin.
Cone settleability (in ml/l)	A daily record of the volume of sludge settling in an Imhoff cone (or, if not available, a standard 1 litre graduated cylinder) should be kept. This provides an indication of sludge settleability trends and is an 'early warning system' for impending solids-liquid separation problems. However, there is no universal optimum cone settleability value, the important thing is stability.
Surplus sludge production (in kg/day)	A record should be kept of the quantity of surplus sludge solids removed from the plant each day. If the sludge is dewatered prior to off-site disposal the tonnage of dewatered material should be logged, together with its solids content.
Upflow velocity (in m/h)	For effective solids-liquid separation in a settling tank (clarifier) it is necessary that the rate of rise of the liquid (the upflow velocity) should be significantly less than the solids natural settling velocity. If this is not the case there will be carryover of solids with the final effluent discharge. Upflow velocity is calculated by dividing the total flow through the tank (m^3/h) by the surface area of the tank (m^2). The desirable upflow velocity depends on the nature of the particles to be removed. To satisfactorily settle activated sludge solids the upflow velocity in a final clarifier should be typically 0.5 to 1 m/h, whereas trickling filter solids, which are more dense and settle faster, can be successfully settled in a clarifier having a liquid upflow velocity of up to 2 m/h.
Microscopic examination of sludge	Regular examination of samples of mixed liquor should be carried out using a microscope. Magnification power of x100 to x200 is adequate. The principal aspects to be noted are: - bacterial floc size and shape, - presence of filamentous bacteria, - presence of protozoans (flagellates, ciliates), - presence of rotifers. There are many other species which may be observed but the above will provide a sufficiently reliable indication of the overall condition of the sludge.

The plausibility of base data about a WWTP's sludge generation can be checked on the basis of reference values which are contained in the WWTP's planning and approval documents as far as the overall capacity and number of connected inhabitants are concerned. Information from the municipal registers can be useful for secondary control. Water consumption records and benchmark values, available from the literature or from WWTPs operating under similar conditions represent quasi indicators which can be used where recording is at its beginning or no sufficient details are available for a planning exercise.

Tab.1: Overview on main operations parameter's relevance for sludge disposal and use options

Method of Treatment and Disposal													
		Stabilisation											
Parameter	Sedimentation	aerobic	anaerobic	chemical	thermal	Thickening	Dewatering	Drying	Transportation	Landfilling	Composting	Agriculture	Incineration
Temperature		x	x				x	x			x		x
Density						x		x	x				
Rheological prop.							x	x	x	x		x	x
Settleability	x					x	x						
Solids concentr.	x	x	x	x	x	x	x	x	x	x	x	x	x
Volatile solids		x	x	x	x				x	x	x	x	x
Digestability			x										
pH		x	x	x			x				x	x	
Volatile acids			x										
Fats and oils		x	x									x	
Heavy metals			x							x	x	x	x
Nutrients		x	x								x	x	
Particle size	x					x	x						
CST						x	x						
Spec. resistance						x	x						
Compressibility							x						
Centrifugability							x						
Calorific value													x
Leachability										x			
Microbiol. prop.		x	x								x	x	

Source: ISWA/EEA, 1997

E2 Stabilised sludge with reduced concentrations of harmful components offer a high security as far as different usable disposal options and a secured access to them are concerned. Only a few disposal routes are open for unstabilised sludge. It is therefore important for each operator to know the biological reactivity of the sludge produced by their WWTP and the effectiveness of any stabilisation processes employed on site.

E3 All disposal routes require compliance with specific requirements or maximum allowable values or ceiling concentrations (*see* ↗ **Harmful substances**, ↗ **Critical limits**). For WWTPs which are at the beginning of the disposal chain hygiene and safety requirements (stabilisation result, quality for application on land) are especially important. Adherence to legal provisions (*see* ↗ **Legal Requirements**) must be ensured. Buffer (storage basins) to handle peaks of harmful matter concentrations and treatment inefficiencies are essential.

E4	An adequate interim storage capacity increases disposal safety, in that it ensures a certain flexibility to avail of the different outlets that are available for sludge to varying degrees and at different times. This is particularly true for those cases where ceiling concentrations cannot be met. The storage capacity for raw sludge should be split so as to use it also as a buffer for the filtrate in case of a discontinuously performed **drainage** or as a seasonal buffer before **earthification**. To temporarily lend storage space for dewatered sludge can be an option, too.

E5 A disposal concept can only be completed when all options, their implications on the running operation and the financial impacts are known. For this an assessment of the general disposal framework and evaluation of the different disposal options available must be undertaken. In the following will be summarized the issues WWTP operators must be looking at in their decisions:

Quality	A material utilization of sludge is only possible where the critical limits (prescribed maximum allowable pollutant concentrations for the specific applications as per the respective laws) can be reliably kept. Orientation for other utilizations should be obtained from the specifications of the users.
Water/solid ratio	This ratio can be adjusted in accordance with the targeted disposal route(s) with either static or mechanical drainage, and with additional drying if necessary.
Storage	Access to storage capacities is in any case recommended, either on site or by lending storage space; most suitable are basins, stack rooms, swap body container, bunker and tower silos.
Conditioning	Conditioning should be performed where further treatment steps will follow, especially dewatering; available options comprise lime, polymers or anorganic agents such as iron salt, optimizing the use of these agents is highly recommended to minimize operating expenses.
Transpor-tation	The advantages of nearby disposal options are the greater, the more transportation-related prices (fuel prices, permits, road toll) increase. Often the use of swap body containers is promoted for WWTPs without storage capacities but this is rather expensive from the logistic and investment point of view. Semi-truck trailer are the cheaper option. Elevated silo tower under which these trucks can pass for loading are likewise an alternative. They should have at least a capacity of 75 tons. Whenever possible, the transportation by railway or ship should be considered.
Outlets	Principally, more than one disposal option should be considered in the disposal concept so as to have security for the disposal of all sludge generated and to be more independent from incidents and temporary problems that quite often happen in this sector.
Procurement	For service arrangements or to procure equipment and construction works, the procurement rules must be observed (for example within the EU the current threshold at which tendering for services and equipment becomes mandatory is 207,000 EUR according to the late Commission Regulation (EU) No 1336/2013 – in non EU-countries other stipulations may be in effect at the national and regional level). It is recommended to have a pre-qualification before tendering or to let a call for expressions of interest

	precede the tender invitation and bidding.

Essential criteria in examining actual market conditions and the offers made for a specific technological option or service field should be

- the technology and/or contract's running time,
- competitive pricing,
- reliability of the contractor, and in this context also
- the general framework which may have changed over time.

These examinations should be repeated before the disposal contracts phase out or within a reasonable time span of a few years respectively.

E6 More economical disposal prices can be achieved by bringing together the sludge amounts from several WWTPs or by accumulating larger units. The existence of stipulations concerning sludge mixtures must be observed when such considerations are made.

E7 For each operation to have its merits vis-á-vis other alternatives and to be economically carried out, a critical quantity or throughput has to be reached. There exists no broad-brush figure how much this must be in a certain area and only a comparison of the specific options available can deliver such an assessment.

In any case, appropriate economies of scale must also be produced in order to make a specific disposal option efficient. In the case of **solar drying installations**, an annual quantity of 500 tons dried sludge output (>80 % DS) is said to give the lower margin for economic operations, i.e. the point from where such an investment would begin to make sense. As a general rule of thumb most **incinerators** should be able to handle a sludge input rate of around 3 tons DS per hour. Anything below a hourly throughput rate of 0.2 tons DS would most likely be too expensive for this kind technology.

Beside this aspect of critical mass the light has to be shed also on the qualitative aspects and requirements of disposal operations and, in particular, on those associated with the sludge's final use/destination. An orientation when certain options for treatment and utilization make sense from that point of view is given with the examples below:

- **Dewatering**:
  - whenever transportation is necessary and/or an utilization very close to the place of sludge generation is not possible;
  - when subsequent drying will be undertaken and the available sludge underwent appropriate conditioning.
- **Drying**:
  - for sludge which has the potential to be used as a fuel, which is particularly valid for sludge with a sufficient organic content (>46 % dry organic sub-stance (oDS)) and reaching a calorific value after drying of about 9 MJ/kg;
  - when sufficient dewatering is undertaken beforehand and excess heat or cheap energy (solar energy, energy from combined heat and power generation, self-supplied energy) can be used for drying and drying results above 80 % DS content can be achieved with it;
  - where there is no other drying scheme in place and regional circles can be

	closed when dried sludge is available for utilization; - dried sludge is sought to substitute primary fuel and possibly also mineral resources.

Associated aspects	Further explanations	
↗ **Base data**	Aside from that clear objectives and a general vision for the sludge disposal should be existing, the following are the information which should be made available as a basis for the development of the disposal concept and corresponding decisions: - the number of connected citizens and of connected industries and total number of connected population equivalents; - the generated sludge amounts (annual quantity of produced wet sludge as kept in operating records); - data on the type and quality of the sludge (*see also* **↗ Quality**), i.e. solid matter/DS content, ignition loss (both obtained thru analyses), the expected DS content after the different treatment stages at the WWTP. Part of the acquisition of base data should be a quantitative prognosis on sludge developments (considering population growth respectively foreseeable changes of connection rate or WWTP capacity) and with regard to critical financial benchmarks, e.g. - possible range of disposal fees (as contained in service offers/indicative price offers of external provider firms and known from own records or neighbouring communities) on a DS content basis; - operating expenses (as contained in indicative price offers of equipment providers or known from operators of similar technologies – particularly important are the energy costs, rental prices for equipment/storage capacities, auxiliary materials, maintenance and personnel); - approximate investment need for construction, technical installations and other (infrastructure) equipment such as for power supply, control instruments; - operating life expectancy; - limits of borrowing (concerning the amount and runtime of loan for investment financing) and the expected interest rate.	
↗ **Quality**	Amount of sludge:	The sludge quantity for which utilization needs to be secured or which must be disposed of affects the economic and technical feasibility of the disposal options. Two principal ways to look at sludge quantity are the volume of the wet sludge, which takes into account both the sludge water and solids content, and the mass of the dry sludge solids. Because the water content of sludge is high and very variable, the DS mass is generally used to characterize sludge quantities. Data on minimum and maximum sludge quantities are important for developing an understanding of the daily operating requirements. Maximum daily sludge quantities will govern equipment and storage facility sizing and daily operating schedules.
	Sludge solids content:	The solids content of sludge depends on the type of sludge and on whether and how it has been further treated prior to disposal. It affects sludge transportation costs, leachate formation, and the

	efficiency of utilization/disposal operations. Treatment processes such as conditioning, thickening/dewatering, **composting**, and drying can lower sludge water content and thus raise the solids share. The efficiency of these treatment processes, however, can vary substantially from time to time, producing sludges with substantially lower solids content than the process was designed to produce. The options that will subsequently be used for the utilization/disposal of the sludge must therefore show a certain flexibility to handle varying sludge qualities.
Harmful substances content:	Although sewage sludge conceivably could exhibit the characteristics of ignitability, corrosivity, or reactivity, most concerns about sewage sludge have focused on its toxicity since sewage sludge is the sink of unwanted and thus potentially dangerous substances contained in the waste water. The spectrum of harmful constituents of sludge is manifold. It includes heavy metals, toxic organics and harmful organisms above all. Restricting factor for the further use of the sludge is their presence and concentration. Sludge quality first and foremost must be therefore assessed over the criteria of harmful matter content (*see* **↗ Harmful substances**).
Sludge phosphorus content:	Since phosphorus is needed as a fertilizer in agriculture, a requirement for getting a sustainable waste water treatment and sludge management process is to avail of the possibility to recover the phosphorus. Most of the phosphorus used in agriculture originates from mining of phosphate ores, which thus is a limited resource. **Phosphorus recovery** through spreading of the sludge on agricultural land was found not to be very efficient and comes in combination with the risk of contaminating the soil and water resources with harmful substances. Phosphorus recovery from the waste water or the sludge is developed as a means to overcome the two disadvantages. It moreover reduces the sludge amount to be handled and thereby the transport cost.
Sludge nitrogen content:	Nitrogen in sludge is a source of potential groundwater pollution. The potential for ground-water pollution is significantly affected by the quantity and type of nitrogen. Nitrogen may be present in sludge as organic nitrogen, ammonia, nitrate, and nitrite. Generally, nitrate is the principal species of concern because it is the most soluble form of nitrogen, and therefore is relatively mobile in most soil types. Nitrification and treatment methods providing anaerobic conditions inhibit nitrogen movement and allow microbial destruction of pathogens.
Sludge organic content:	It is an important determinant of potential odour problems during handling, storage and surface disposal. Sludge organic content is most often expressed as the per cent of total solids that are volatile solids. A number of treatment options can be used to reduce sludge volatile solids content and thus the potential for odour development. These include **anaerobic digestion**, **aerobic digestion**, and composting. Anaerobic digestion as the most common method of **sludge stabilisation** generally biodegrades about 50 % of the

	volatile solids in a sludge.
pH of a sludge:	It affects its suitability for use on land and surface disposal. Low pH sludges (less than approximately pH 6.5) promote leaching of most heavy metals. High pH sludges (> pH 11) destroy many bacteria and, in conjunction with soils of neutral or high pH, can temporarily inhibit movement of most heavy metals through soils. Also, biological activity is reduced in high pH sludges, leading to a reduction in the decomposition of organic material.

↗ Legal Requirements

The treatment and disposal of sewage sludge must be executed within a given legal framework. This framework usually concerns more than the permitted disposal routes and requirements to be met, it often also relates to other aspects such as operating permits, occupational safety and health protection, documentation and reporting obligations, soil, water and emission protection. While establishing their disposal concept WWTP operators have to be aware of current legislation and may only act in full compliance with it (*see the national laws and regulations governing e.g. the management of waste water, waste and the protection of groundwater, soil and the environment for relevant details*).

↗ Reactivity

Raw sewage sludge due to its composition, especially the organic content and high presence of water, is a biologically highly reactive material. Indicators for the biological reactivity are the BOD, ignition loss and gas-generating potential, all which can be reduced by applying biological stabilisation processes.

The degree of stabilisation of sewage sludge is a function of the sludge age. It usually takes more than 45 days before sludge can be considered as fully stabilised.

25 days old sludge can be considered as semi-stabilised, i.e. there will still be gas developments after dewatering. Also exposure for 28–30 days in an anaerobic digester at 32 °C does not give a sludge that is completely stabilised.

Testing the sludge on the aforementioned indicators is necessary to know about the biological reactivity and present state of stabilisation (*see* **↗ Stabilisation capacities**). A certain indication of the degree of stabilisation is the odour during intermediate storage in silos or stack rooms. A largely aerobically stabilised sludge, unlike semi-stabilised sludge, is largely odourless even after prolonged storage time and at high ambient temperatures. Quick testing can be done with the Triphenyl-tetrazoliumchloride (TTC)-test (*see* **↗ Stabilisation capacities**) and more precisely with a test on oxygen depletion. To avoid a false measurement caused from the reaction with ammonium, N-Allylthiourea solution (ATH) must be added during the oxygen depletion analysis. The measurement itself is performed at a temperature of 20 °C.

A plant's stabilisation performance, as a rule of thumb, is indicated for a standard DS content of about 4 g/l through an O_2 uptake at the following scale

- 0.2 to 0.3 mg/(l•min) for plant's achieving a partial stabilisation,
- 0.1 to 0.15 mg/(l•min) for plants achieving sufficient stabilisation results.

↗ Stabilisation capacities

It is recommended that each WWTP operator, depending on the chosen procedure for sludge stabilisation, undertakes to periodically analyse the following parameters in order to determine the degree of achieved sludge stabilisation and detect changes in the effectiveness of the method applied by them:

- Loss on ignition; where a value <50 % indicates a well stabilised
  50–65 % a partially stabilised and
  >65 % a non-stabilised sludge.
- Oxygen depletion: where <0.06 kg O_2/(kg oDS•d) indicate a well stabilised sludge.

Oxygen depletion is calculated as the O_2 uptake from 1 kg organic solid matter per day by using the following formula:

$$\text{Oxygen depletion } [\text{g } O_2/(\text{kg oDS} \bullet \text{d})] = \frac{O_2 \text{ uptake mg}/(\text{l} \bullet \text{min}) \text{ x } 60\text{min x } 24}{\text{oDS } [\text{g/l}]}$$

Also a test on the toxic effects of water constituents with TTC and formazan as indicator dye should be performed to see the result of the stabilisation. Enzymes, which decrease in number and effectiveness with increasing degree of stabilisation, reduce TTC to a red formazan dye. The quicker this colour change happens in this test the higher is the need for the sludge to undergo further stabilisation.

↗ Harmful substances

The nature of the sewage sludge depends on the waste water treatment process and on the source of the waste water (industrial discharges, but also problematical substances from households). In general it contains both toxic and non-toxic organic wastes. Of the two, non-toxic compounds comprising all materials of plant and animal/human origin, including proteins, amino acids, sugar and fats are most prevalent. Toxic organic compound comprises Polynuclear aromatic hydrocarbons (PAHs), alkyl phenols, polychlorinated biphenyls (PCBs) organochlorine pesticides, monocyclic aromatics, chlorobenzenes, aromatic and alkyl amines, polychlorinated dioxins, phenols, drugs, hormones and others. In addition to these organic pollutants sewage sludge also contains traces of many heavy metals like arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. These metals are persistent, i.e. they do not break down in the environment and therefore build up over time. The heavy metals introduced by the application of sludge to land therefore become permanent additions to the total quantity in the soil. Some of these substances can be phytotoxic and some toxic to humans and/or animals, so it is necessary to control the concentrations in the soil of potentially toxic elements and their rate of application to the soil. Sewage sludge also contains modern inorganic substances like nanoparticles. Furthermore, pathogenic bacteria, viruses & protozoa along with other parasitic helminthes which can give rise to potential hazards to the health of humans, animals and plants are found in sewage sludge. Some common pathogens in sludge include the bacteria *Escherichia coli (E.coli)* and *Salmonell*a, the virus Hepatitis A, and parasitic worms. Apart from those components of concern sewage sludge also contains useful concentrations of nitrogen, phosphorus, organic matter, and trace nutrients. Each component of the sludge has its own environmental impact, which must be taken into account when choosing a disposal route.

↗ Critical limits

The most likely sources of problems with sludge are the presence of heavy metals, particularly mercury and cadmium, toxic and persistent organic compounds, and the potential for infection by disease-causing organisms. Lab analyses must help in detecting these unwanted threats and to keep monitoring and control over them and the critical limits set for (*see* **↗ Control**).

Thermal treatment of sludge supposedly is the safest method to have most of the contaminants destroyed effectively, inorganic pollutants (heavy metals) however remain also in the combustion residues. Hence thermal utilisation of sludge should become a disposal option, with due care being taken that the necessary installations are planned or reconditioned appropriately. This means that sufficient mechanisms for emission control must be in place and safe disposal of the residues will be ensured. Many countries have legislative acts in place that contain the necessary provisions for this. For the territory of the EU these are for example the Directives ↗ 2010/75/EU and ↗ 1999/31/EC.

Utilisation on land on the other hand requires similar mechanisms of quality assurance and control. While for most of the metals it can be assured that in small concentrations they are held in the soil, there come additional risks from organic pollutants, pathogens and parasites here. Also heavy metal loading of the soils must be avoided, since once the metals are in the soil there is no practicable way to reverse the process. Corresponding provisions are to be fixed by an appropriate legislation.

An orientation for that gives the EU with the Directive ↗ 86/278/EEC as well as the national acts pertaining to soil and water protection and the use of sludge in agriculture that EU member states and other countries have enforced. Most of these regulations list ceiling concentrations and also quantity limits up to which sludge can be applied to land (*see the national laws and regulations governing e.g. the management of sewage sludge, fertiliser use or application of other matter to land and those made for the protection of the environment, air, soil and groundwater resources for relevant details*).

An exemplary overview of the provisions imposed on critical limits in different regions of the world give the following tables.

Tab.2: Some international standards for maximum concentrations of pathogens in sewage sludge

	Salmonella	Other pathogens
Denmark	No occurrence	Faecal streptococci: < 100 g
France	8 MPN/10 g DS	Enterovirus: 3 MPN/10 g of DS Helminths eggs: 3/10 g of DS
Finland (539/2006)	Not detected in 25 g	Escherichia coli < 1000 cfu
Italy	1000 MPN/g DS	
Luxembourg		Enterobacteria: 100 g no eggs of worm likely to be contagious
Poland	Sludge cannot be used in agriculture if it contains salmonella	
Bulgaria	not detected in 20 g	Escherihia coli, Clostridium perfringens < 1g titer Helminths eggs 1/1000 g DS

Source: Sede and Andersen, 2002; Alabaster and LeBlanc, 2008

Tab.3: Maximum permissible concentrations of potentially toxic elements in sludge-treated soils (mg kg^{-1} dry soil)

	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Directive 86/278 /EEC	1-3	100-150	50-140	1-1,5	30-75	50-300	150-300
Austria							
- Lower Austria	1,5	100	60	1	50	100	200
- Upper Austria	1	100	100	1	60	100	300/150
- Burgenland	2	100	100	1,5	60	100	300
- Vorarlberg	2	100	100	1	60	100	300
- Steiermark	2	100	100	1	60	100	300
- Carinthia							
if 5<pH<5,5	0,5	50	40	0,2	30	50	100
if 5,5<pH<6,5	1	75	50	0,5	50	70	150
if pH>6,5	1,5	100	100	1	70	100	200
Belgium							
Flanders	0,9	46	49	1,3	18	56	170
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							
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
Luxembourg	1-3	100-200	50-140	1-1,5	30-75	50-300	150-300
Estonia	3	100	50	1,5	50	100	300
Hungary	1	75	75	0,5	40	100	200
Latvia	0,5-0,9	40-90	15-70	0,1-0,5	15-70	20-40	50-100
Lithuania	1,5	80	80	1	60	80	260
Malta							
pH 5<6	0,5	30	20	0,1	15	70	60
pH 6-7	1	60	50	0,5	50	70	150
pH >7	1,5	100	100	1	70	100	200
Netherland	0,8	10	36	0,3	30	35	140
Portugal							
Soil pH<5,5	1	50	50	1	30	50	150
5,5<soil<7	3	200	100	1,5	75	300	300
Soil pH>7	4	300	200	2	110	450	450
Poland							
Light soil	1	50	25	0,8	20	40	80
Medium soil	2	75	50	1,2	35	60	120
Heavy soil	3	100	75	1,5	50	80	180
Romania	3	100	100	1	50	50	300
Slovakia	1	60	50	0,5	50	70	150
Slovenia	1	100	60	0,8	50	85	200
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	3	400	135	1	75	300	20
USA	20	1450	775	9	230	190	1500

Source: Sede and Andersen, 2002

↗ Control

In order to be able to enforce environmental and safety stipulations for sewage sludge and secure that the sludge meets the standards of the disposal route eventually used, a system of internal and external control mechanisms must be established. Beside national and regional control authorities, laboratories are a critical part in such a system. Also effective daily operations at WWTPs are unthinkable without laboratory support.

Monitoring the material flows and selectively control the WWTP's processes and technical components necessitates that various parameters including nitrogen and ammonia concentration, pH-value and DS content are frequently analyzed and monitored. WWTP operators for that reason should be obliged to run their own laboratory facilities (for the purpose of daily operations management and internal control) and to let the sludge they treat for further utilisation undergo tests from independent laboratories with a relevant certification and/or accreditation (external control). Laboratory procedures must in any case comply with approved methods and meet monitoring requirements. Analyses and all reporting should be supported by a Quality Management System (OMS). Of all QMS regimes, the ISO 9000 family of standards is probably the most widely implemented worldwide.

Test procedures and requirements at the best should be fixed as national standards. Some generally recognized procedures for sludge foresee that every six months at the latest should be tested the

- content on heavy metals (e.g. lead, cadmium, zinc, mercury);
- total level of pollution with organic halogen compounds (AOX);
- total nitrogen and ammonia nitrogen;
- nutrients potassium and phosphate as well as magnesium.

The presence of dioxins and PCB's should at least be tested in biannual cycles.

Sludge utilization on land demands for a particularly tight monitoring and appropriate mechanisms for quality assurance. The following is an overview of analytical methods and techniques used to analyse the parameters of sewage sludge and sludge-derived products.

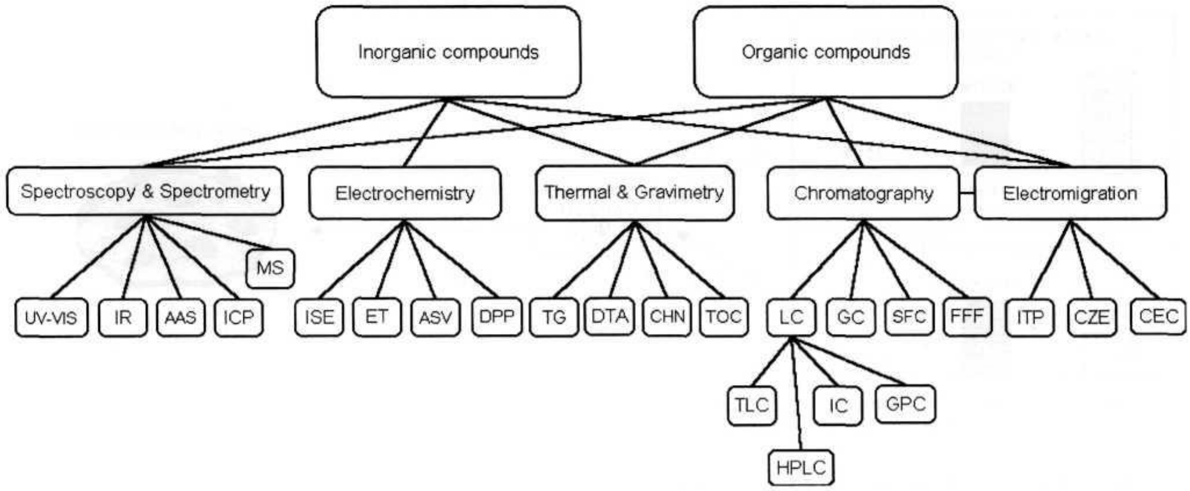


Figure 1: Overview of analytical methods used in sludge analysis

with the following meaning of the abbreviations shown: AAS - Atomic Absorption Spectrometry, ICP - Induced Coupled Plasma, MS - Mass Spectrometry, ISE - Ion Selective Electrode, ET - Electrotitration, ASV - Anodic Stripping Voltamperometry, DPP - Derivative Pulse Polarography, TG - Thermogravimetry, DTA - Differential Thermal Analysis, CHN - Elemental Analysis, TOC - Total Organic Carbon, LC - Liquid Chromatography, TLC - Thin Layer Chromatography, HPLC - High Performance Liquid Chromatography, GPC - Gel Permeation Chromatography, GC - Gas Chromatography, SFC - Supercritical Fluid Chromatography, FFF - Field Flow Fractionation, ITP - Isotachophoresis, CZE - Capillary Zone Electrophoresis, CEC - Capillary Electrochromatography

Graphic source: Kosobucki, A. Chmarzyński, B. Buszewski: Sewage Sludge Composting. in Polish Journal of Environmental Studies Vol. 9, No. 4, 2000

Monitoring water and soil quality must accompany every sludge application program on land. Soil analyses and records on all sludge applications on land are required so that excess amounts will not be added to any site. Corresponding provisions are to be fixed by an appropriate legislation.

An exemplary overview of the provisions imposed on quantity limits up to which sludge can be applied to land in different regions of the world gives the following table (*see also the national laws and regulations governing e.g. the management of sewage sludge, fertiliser use or application of other matter to land and those made for the protection of the environment, air, soil and groundwater resources for relevant details*).

Tab.4: Quantitative limits for sewage sludge applications on agricultural land in European countries

	Allowed limit dry sludge matter per hectare
Austria, Upper Austria	10 t during three years
Czech Republic	5 t in the course of three successive years amount may be increased to up to 10 t in the course of five successive years provided that sludge contains less than half the limit value of each hazardous substance monitored
Denmark	7 t per year
Belgium, Flanders	2 t per two-year period
Germany	5 t over a three-year period
Italy	5 t per year (15 t over the course of three consecutive years) 50% less if used on soils with pH<6 and CEC<15 meq/100g 50% maximum increase if used on soils where soil pH>7.5
Luxembourg	3 t
Poland	2 t
Portugal	6 t per year
Slovakia	15 t over the course of five consecutive years
Slovenia	3 t per year

Source: EU, 2009

↗ Pollutant reduction

Measures for the reduction of sludge pollutants at the WWTP comprise a wider spectrum. In places where such is not performed yet, it can include the establishment of nitrification steps and precipitation of phosphorus, or the integration of biological stabilisation processes. In the other cases, process optimisations (using cascade arrangements or multiple cycles) are an appropriate method to improve pollutant reduction and attain more stable sludge compositions (*see the **"Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment"** for relevant details*).

↗ Storage capacity

WWTPs are advised to secure access to or maintain a separate storage space for sludge to make themselves less affected by uncertainties regarding its disposal. A storage capacity equivalent to one year is considered to be optimal; in the minimum it should be space to store the generated sludge volume for 3–6 months. This buffer allows the WWTP operator to keep calm over problems in the processing and marketing of the sludge and act more flexible as regards the use of the different utilisation pathways and conversion capacities available. Sludge failing to conform to the specifications of its user or a drop out of a user may require new ways of disposal or at least a time to negotiate and conclude new utilisation contracts.

Incinerators and **co-combustion** facilities cannot be regarded as being continuous and stable consumers of sludge either as these plants must undergo revisions and are not saved from changes in the supply and prices of their other fuel products requiring them to adapt their operations. In all these cases, storage capacities are needed. Storage capacities are also required when the feeding of certain processes comes to a standstill, such as could be in the winter season in places where the earthification or composting of sludge is undertaken.

	Storing sludge has some difficulties mainly due to problems arising from the formation of gas and odours and from leaching. WWTPs produce sludge permanently whereas storing this waste over longer periods of time requires higher technical efforts. The gas formation in the sludge enriches the air with toxic components and may lead to a danger of methane explosions. In closed storage units this risk must be reduced in that air is permanently extracted and an atmosphere with low oxygen content created. For open air storage roofing must be recommended to reduce re-dilution and odour dispersion. Most common storage options are basins, stack rooms, swap bodies, bunker and tower silos. Tower silos under which trucks can pass for loading should have a storage capacity of at least 75 tons, at larger plants they should be good enough to hold the quantity for about three and more days.
↗ Space availability	Space availability in general can be a very limiting factor when it comes to sludge management. As is outlined in several sections of this document storage (*see* **↗ Storage capacity**) and transportation aspects (*see* **↗ Cost assessment**) have a great meaning in sludge handling and for the economics of this process and both are strongly linked to space. To implement a sludge treatment and set up the necessary facilities for that has its own space requirements. Certain options must be ceased in planning when the appropriate land area and/or the space needed to carry out specific operations is not available and cannot be acquired by reasonable means. Treatment/disposal options with a particularly high space demand are solar drying techniques, aerobic stabilisation processes such as open (windrow) composting and drying beds as well as earthification. WWTPs planning to apply solar drying need to have sufficient land resources for setting up the drying halls. As a rule of thumb a floor space of 1.2–1.5 m² will be needed per each ton of drained sludge input to the drying process. A significant reduction of this space demand is possible where surplus heat from other sources can additionally be introduced to the drying halls to support the evaporation process. Sludge earthification is a disposal option applied for WWTPs in the size of 1,000–30,000 population equivalents (p.e.). WWTP capacities from the technical standpoint do not pose a limit to make us of this technique, but space availability usually does in this case. There are also places where this sludge disposal technique has been adopted for WWTPs with 90,000 p.e..
↗ Final outlets	A comprehensive description of the conversion technologies and outlets principally available for sludge provides the accompanying ***"Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment"***. As far as the use of a specific option for sludge disposal respectively utilization is concerned, the following aspects shall also be considered in planning the pre-treatment:

All disposal options:	- Usually there is a prescribed bandwidth for the minimum and maximum DS content, WWTPs preparing sludge for a certain utilization must stay with their output safely within the bandwidth specified for each application. Also other specifications such as given on harmful matter content and other physical properties must be met.

	Thermal use of sludge:	- Conditioning may not be required. Since it is helping in the dewatering which usually precedes a thermal utilization attention should be paid on that dewatering in this case is facilitated by the use of poly-electrolytes and perhaps slack as conditioners. Other conditioners may increase the ash content. Ash from the **monovalent incineration** of sludge is more and more of interest for the recovery of phosphorus (*for further details see* ***"Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment"***).
	Use on land:	- Lime is preferred as a sludge conditioning agent. - WWTPs preparing sludge for use on land must stay with their output safely within the bandwidth of the allowed substance concentrations specified for each application (*see* ↗ **Critical limits**). - The relevant lab certificates and permits must be obtained (*see* ↗ **Control** *and the national laws and regulations governing e.g. the management of sewage sludge, fertilizer use or application of other matter to land and those made for the protection of the environment, air, soil and groundwater resources for relevant details*).

↗ Cost assessment

The amount of sludge for which the disposal must eventually be undertaken depends largely on the DS content, or in other words, the result of drainage. Needed capacities and expenses for storage, transportation and final treatment are directly resulting from this. A basic rule is: the less water is contained in the sludge the more cost-effective will be the disposal operations. It has to be noted though that many disposal options require a certain degree of dewatering. Incinerating units often demand drained sludge which can be pumped with thick matter pumps (20–35 % DS) whilst others want a dried sludge that can be blown in from pneumatic feeding systems (>90 % DS).

Transport distance is another critical cost driver in sludge disposal. Generally better rates can be negotiated with service providers when sufficient capacities for storage are at hand, guaranteeing them a stable supply stream but at the same time flexibility if certain type of problems put a halt or temporarily hamper delivery acceptance. The delivery of sludge to power plants usually follows the principle "just-in-time" to avoid problems with odours. In reality this practice may not hold as a consequence of the changing availability of the boilers for sludge amounts. Significant demands on additional space derive from integrating storage operations but also the use of **mobile dewatering** at the WWTP. Costs therefore must be viewed in dependence from applied operation modes and employed techniques, resulting in specific relations some of which are listed hereunder:

Dewatering: (for further details see **Technical guide on the treatment and recycling techniques for sludge**	- Thickening and dewatering reduce the water content and thus the total amount of sludge, reduced quantities mean less costs for the transportation and further treatment and disposal operations. - Flocculating agents (usually polymers or inorganic substances) are expensive. Efforts should focus on achieving the lowest possible consumption of these agents so as to minimize operating expenses. Investing in studies leading to an optimization in this field can pay off quickly for WWTPs. - To avail of mobile dewatering services is generally more expensive

from municipal waste water treatment)	per unit. Mobile dewatering does require investments into storage capacities for the filtrate, space for the mobile drainage unit to be parked and to manoeuvre, to place container bodies and a roofed yard in winter season. - Using mobile dewatering without that storage capacities are available entails the need of a larger number of swap body containers and a sophisticated logistic for their exchange to avoid dead time. - The power connection of the WWTP must be sufficient for a mobile dewatering otherwise appropriate power generators must be hired or installed, both leading to substantial costs. **Centrifuges** have a particularly high power demand at start-up. - Access roads must be appropriately dimensioned or upgraded. Indicative cost range to dewater a sludge from approx. 5 % to about 25 % DS is 50–100 EUR/t DS ↗R; annual maintenance costs for dewatering equipment make up 2–3 % of the initial investment. The costs for flocculating agents amount to approx. 40 EUR per ton DS (8 g polymer/kg DS) ↗R. (↗R *see in the references section under* **↗ Cost quotation**)
Transportation:	- Better prices are usually negotiable where storage capacities are available and flexible loading times can be offered. - Loading with wheel loaders is more costly than using elevated storage silos under which transport carriers can pass. - Closed storage requires precautionary measures to mitigate dangerous gas concentrations and air filtration. - Open-air storage requires investment into roofing to reduce re-dilution of the sludge by rainfall and odour dispersion. - DS content shrinks further during storage which may impact on acceptability of the material for further utilization options and thus the price of disposal. - Using semi-truck trailers is generally more reasonable than transports which are done with container boxes.
Thermal use of sludge: (for further details see **Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment**)	A sludge which is compatible with storage and feeding mechanisms is critically important for power stations, the quality must allow emission limits to be safely kept when mixed to their other fuel. In case of the preparation of sludge for thermal utilisation, following factors are further influencing the price demand of the service providers and should therefore carefully be taken into consideration in the assessment of potential costs: - Dry sludge is advantageous from a technical point of view (ensuring a high energetic efficiency of the co-combustion process) and disposal prices would therefore have to be lower for a dried sludge of the same composition than for wet sludge. Outlets for wet sludge in the thermal industry can perhaps better be found where the payment for the disposal service is the main interest. - The risk of gas development, especially for explosive methane (as price driver) is higher for raw sludge. This sludge has a higher organic content though rendering it interesting as an energy carrier. Stabilised (digested) sludge in contrast has a lower calorific value but is safer in its handling. - A higher chlorine to sulphur ratio of the sludge increases wear and

	a higher ash content abrasion. Higher moisture content causes caking in the boiler. The consequences for maintenance are considered by plant operators in their prices.

Costs should be based on a uniform per ton DS content calculation, costs that incur from aggregates, lab analyses, for transportation and weighing fees must be accounted as well.

↗ Economic assessment

Cost-efficiency is always a major consideration when deciding where sludge is going to be used and which technology to employ for that. Especially for the investments which concern the integration of pre-processing and disposal installations in the WWTP it is important to know about the advantages/benefits and additional burdens/disbenefits arising from such steps. Each intervention has economic implications which must be comprehensively assessed as a basis for proper decision-making. In the following this shall be exemplified on two potential areas where with focus on certain disposal options an intervention at the WWTP itself can be interesting (*see also* **↗ Cost assessment** *and* **↗ Disposal costs** *for other issues of importance for the economic evaluation*).

Dewatering: (for further details see **Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment**)	*Integration of stationary installations:* Due to continuous operation, the nitrogen degradation potential of the plant can be taken into consideration so as to spare an additional storage for the filtrate. Generally, a smaller storage capacity will be needed for liquid sludge and the effectiveness of drainage can be better controlled and permanently optimized. Flow management capabilities and flexibility as regards disposal will increase and own dewatering expertise is going to be won. On the other hand a substantial investment is to be made and capital as well as personnel bound by this. The precise overall costs can hardly be determined in advance since a number of potential problems and operation standstills cannot be predicted very well. *Use of mobile dewatering:* There is no need for investment and specially trained personnel and the annual costs are quite reliably to calculate. As it might be possible to rent the required equipment also without personnel, times not requiring all capacities of own staff can then be used to undertake the dewatering independently. More space and significantly higher storage capacities are needed on the other hand. Larger amounts of sludge must first accumulate in order to make dewatering efficient. It is unlikely that the best drainage result will ever be attained in this way since there is limited opportunity to develop a profound experience and no optimisations can be undertaken in the long-term.
Thermal use of sludge: (for further details see **Technical guide on the treatment and recycling techniques**	The incineration option is a long-term commitment which is cost-effective for large volume waste water treatment systems or as a regional solution (with the option to use the sludge generated by other WWTPs in the area) mainly. Incineration plants are technical sophisticated and cost intensive, and they must be managed with a high level of expertise and attention to maintenance. However, they are a safe way of disposal as they destroy most of the harmful constituents of sludge reliably, moreover they can have energetically

for sludge from municipal waste water treatment)	advantages. While evaluating this option, economies of scale and in particular ash disposal and emission control must be duly considered. Public acceptance is particularly important. How much the construction and operation of an incinerator or the upgrade of an existing installation cost depends on the site, how much sludge must be handled with it, and what other technically feasible options exist. Process capacity (size of the installation), organic and water content of the feedstock material, applied drying mode, energy costs and the price regime for the disposal of the ashes are the main cost determinants for the thermal treatment. Likewise cost drivers are the emission abatement and control needs specified in the respective national regulations on incineration. The two options are either a higher investment in cleaning devices or very tightened specifications that are made on sludge quality and which entail higher treatment expenses.
Composting of sludge:	The costs of sludge composting are strongly influenced from the employed rotting technique (passive or intensive methods) and transportation expenses. Costs for quality control applied on input material and compost product with the help of lab analyses, for administration along the whole disposal chain and to advise sludge producers and compost users on good practice and safe handling make up quite a significant portion of the financial need.

↗ Disposal costs

Aside from the payment (fees) claimed by sludge users and final depositories for the service of safely disposing of waste components and residues that might otherwise be problematic, following boundary conditions are also influencing the overall disposal costs for WWTPs:

- Loading technology (Is direct loading from silos possible or must wheel loaders be used?);
- Loading arrangement (Can loading at the WWTP be flexibly scheduled?);
- Transport technology (Can semi-truck trailer or must containers be used?);
- Transportation distances (How far from the loading point are the places of utilization?).

More cost aspects in relation to the use of specific disposal routes and technical arrangements are summarized hereunder together with indicative price ranges (*see also* **↗ Cost assessment** *for other issues of importance*).

Transpor-tation:	Transportation costs vary in dependence from the transportation distance, and the means and time needed for transportation. Internationally common cost range: 3–30 EUR net price per ton sludge. ↗R

Thermal use of sludge: (**mono-valent incineration with energy recovery - Specifications of the incinerating facility must be considered**)	*Drained sludge:* For auto-thermal incineration in monovalent sewage sludge incineration plants, the drainage of raw sludge up to 25 % DS content is generally sufficient. With the appropriate equipment at hand this can be achieved by mechanical dewatering and may not require thermal drying. Monovalent sludge incineration opens up the possibility of phosphor recovery from the ash. In recent years, the stationary fluidized bed has become a preferred technology for monovalent incineration. Such installations are usually erected at WWTP sites and have the advantage for the operator that waste water treatment and sludge disposal can take place independently at the site and transport costs are reduced to a minimum. Waste heat and energy recovered in the process can be used in the plant to support any operations and reduce the external energy demand. Internationally common cost range exclusive of transportation: drained sludge (>25 % DS) 180–550 EUR per ton DS. ↗R
Thermal use of sludge: (**co-combustion with energy recovery - Specifications of the incinerating facility must be considered**) (for further details see **Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment**)	Specifications of the incinerating facility have to be known and must be guiding the pre-treatment. A sludge stabilisation is not needed. Temporary halts of sludge deliveries to the combustion facility due to plant revisions or operating problems must be taken into account. Storage capacities are useful and arrangements with backup providers (at least 2 alternative installations) should be sought; longer-lasting disposal contracts are to be preferred but put a limit on the negotiation of prices (price adjustment clause be possibly incorporated). *Drained sludge:* Sludge consistency should allow pumping, i.e. max 35 % DS. The conditioning should follow the user specifications (especially as the selection of flocculant is concerned). For transportation semi-truck trailer or swap-body container are suitable, a wheel loader might be needed. Internationally common cost range including transportation: drained sludge (25 % DS) 40–80 EUR per ton original sludge ↗R 120–320 EUR per ton DS ↗R *Dried sludge:* Sludge consistency should allow blowing of sludge (about 90 % DS) but drying is cost-intensive. Solar drying has cost advantages. The transportation is usually performed in silo trucks, elevated silo tower or pneumatic systems for loading are an advantage. Silo trucks are however an expensive solution, specifications must be strictly kept. Internationally common cost range including transportation: dried sludge (90 % DS) 30–90 EUR per ton original sludge ↗R 40–100 EUR per ton DS ↗R
Incineration: (**in combination with other waste**)	Less stringent requirements as regards sludge quality and consistency, i.e. highly contaminated sludge, can also be accepted where incinerators do have adequate emission control and cleaning devices. Usually this is the case in dedicated incineration facilities for mixed waste, like municipal waste incinerators.

(for further details see **Technical guide on the treatment and recycling techniques for sludge from municipal waste water treatment**)	A stabilisation of the sludge is normally not needed here but can be demanded from the operator of the incineration facility. An incineration of fresh sludge can be done in an appropriate mixture with other waste materials showing sufficient calorific value, otherwise a pre-drying might be requested. Transportation is best done with semi-truck trailer or swap-body container. Wheel loader might be needed. Internationally common cost range including transportation: 40–100 EUR per ton original sludge ↗R 150–350 EUR per ton DS ↗R
Application on land: (**landscaping, re-cultivation - Ceiling con-centrations and permitting procedures must be observed!**) (see national laws and regulations governing these)	*Drained sludge:* The dewatering of the sludge should exceed the margin of 25 % DS if possible. Composting might help to stabilise the sludge and especially to bring it in a stable hygienic state. A quality assurance to secure a high quality standard is necessary. The use of the stabilised sludge within the region should be preferred. Suitable for transportation are semi-truck trailer or swap-body container, temporary changes of viscosity in case of transportation over longer distances must be considered. Wheel loader might be needed. The application of the sludge is little dependent from season and state of vegetation. Thorough documentation and trustworthiness of the user are important. Internationally common cost range including transportation: drained sludge (>25 % DS) 30–70 EUR per ton original sludge↗R 100–280 EUR per ton DS ↗R
Application on land: (**agriculture - Ceiling con-centrations and permitting procedures must be observed!**) (see national laws and regulations governing these)	*Wet thickened sludge:* The costs for transportation and to dispense are high but expenses for dewatering are spared. An agricultural use is only cost-efficient when used nearby to the place of sludge generation. The more a thickening has been undertaken, the more cost-effective will be the utilization. Delivery to and spreading on the land preferably with tanker; immediate incorporation into the soil is recommended. Stabilisation/ hygienisation is necessary to avoid nuisance from odours and to reduce risks form pathogens (further restrictions may apply for non-stabilised sludge). Due to harmful substances content, continual lab analyses are necessary (*see* **↗ Control**). Documentation is important! Internationally common cost range including transportation: wet thickened sludge (4 % DS) 5–45 EUR net price per m³ original sludge 200–320 EUR per ton DS ↗R *Drained sludge:* Only stabilised sludge has to be used, sludge conditioned with lime is one preferable option. A quality assurance to secure a high quality standard is needed. This involves tight analyses and control (*see* **↗ Control**). Application should take place within the region. The disposal costs can be reasonable especially where storage buffer can be used. Wheel loader might be needed. Delivery with semi-truck trailer or in swap-body container and spreading on the field with spreader. Thorough documentation and trustworthiness of the user are important. Internationally common cost range including transportation: drained sludge (25 % DS) 30–45 EUR per ton original sludge ↗R 100–180 EUR per ton DS ↗R

↗ Disposal contracts

A contractual basis must be obtained for services received in conjunction with the utilization of sludge and the disposal of excess amounts and treatment residues. To procure such services and conclude contracts on disposal prices bidding procedures are normally required. Procurement rules applying and the avoidance of barriers to competition must be especially observed in this context.

As part of the tender procedure the WWTP or contracting party should demand for a set of information, unless they are available as part of an operating certificate/license or permission. The WWTP/contracting party, through submission of these information, should obtain proof on the service provider's reliability and actual capacity to handle the sludge in an appropriate and legal manner, and in accordance with the schedule laid down in the disposal concept. It may have quite disastrous financial and operational consequences, if at the end the service supplier respectively user of the sludge cannot deliver adequate services and the WWTP cannot dispose of the sludge as planned but is forced on short notice to switch to other disposal options at incalculable costs. Failures and violations in the proper handling of sludge ultimately create a negative image and fall back to its original producer even when he has passed the sludge for further treatment/disposal or use per contract to a third party. Part of the critical information that should be available about the service provider respectively recipient of the sludge in a verifiable format are:

- Certification on good conduct and ethical compliance;
- Proof of official registration and professional qualification/permission;
- Description and proof (if any) on quality assurance system/measures in place;
- Description and proof (if any) on capacity to deal with hazards and residues;
- Technical and personnel capacities (staffing, equipment);
- Financial standing and references;
- Approach and technologies to be used (especially as regards mass and quality detection, loading, transportation, dispersion, residuals handling);
- Place of intended use, proof on sufficiency of spatial conditions;
- Listing of subcontractors and their parts in the service.

Disposal contracts should be concluded for reasonable time spans whereby the contractual periods should be longer in case of thermal utilization and can be shorter for disposal on land. Developments which have a foreseeable impact on the market (certain deadlines or changes in legislation, changes in available capacities due to installations build-up or closure) should be taken into account. International experience shows that contracts with a minimum lifetime of 3–5 years are a quite common standard.

↗ Documentation

The utilization/disposal of sludge should be well documented so as to be able to comply with reporting obligations, create the records and documentary basis for any possible certification procedures and cases of dispute, and as a simple but effective means for an operations monitoring and to support future planning and investment decisions. Permitting procedures, for example when plans are made to provide sludge for the utilization on land, make a proper documentation generally necessary. Recording the quantity and quality of the sludge generated at WWTPs is particularly important for disposal planning. Well documented treatment operations, outputs and costs (including disposal prices) give the information needed for optimizing plant processes and operational results. Quality control (in certified laboratories) and reporting allows a sludge management plan to be successfully implemented and to secure a continuous beneficial use of sludge. Where sludge from municipal waste water treatment is to be used in agriculture, the sludge from each WWTP has to be analysed according to the regulations in certified and/or nationally accredited laboratories (*see* ↗ **Control**). Also the existence of a nutrient management plan for the area in question should be ensured, including a detailed analysis of soils, according to the prescribed standards. If the limit values in the regulations are exceeded in any way, the intention of having the sludge used for applications on land should be ceased (*see* ↗ **Critical limits**). Analyses and all reporting should be supported by a Quality Management System (QMS). Of all QMS regimes, the ISO 9000 family of standards is probably the most widely implemented worldwide. Recording all sludge disposal routes would have to be part of it. Log books are to be used to record every shipment of sludge. In this log book will be noted the shipment date, volume removed off site, sludge transporter, destination of the sludge and the site to which sludge was applied or where it was deposited. Whenever sludge has been delivered to a farm this is to be confirmed by signed receipts. Competent authorities check sludge amounts shipped to farms on an annual basis, together with the review of the nutrient management plan and any other relevant monitoring data. Log books shall work as the basis for them, requiring sludge producers to keep them for current and previous years *(check for any national provisions that may exist on that or compare with the practices in other countries such as the member states of the EU where such obligation exists, among others prescribed by Article 10 of the Directive ↗ 86/278/EEC)*. Sufficient conditions for the long-term record keeping of data, information and reports must thus be ensured. For quality assurance, independent control mechanisms will be employed leading to further documentary requirements.

REFERENCES

This guidance integrates and has been drawn up based on information and practical experiences from many sources. Principal orientation for their compilation and the structure of this document has been obtained from the work report of the DWA working group AK-13.4 titled "DWA-Arbeitsbericht, Arbeitsgruppe AK-13.4; Leitfaden zur Klärschlammentsorgung" and other materials this expert body has produced.
The German Association for Water, Wastewater and Waste (DWA) has been formed as a politically and economically independent organization. The DWA functions as a forum in which experts exchange their experience and new ideas on water, waste water and waste issues and make them available to other stakeholders and policy bodies. The organization also promotes the worldwide transfer of this knowledge and those of experts between companies, institutions and associations. The large pool of information available on different issues of water and waste water management is also the result of the technical work performed by numerous specialized bodies and groups which have formed within the DWA. *↗ www.dwa.de*

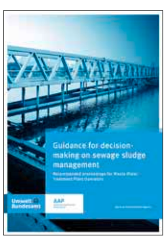
Likewise an important international body and centre of competence in the field of waste water and sewage sludge management standards is the International Organization for Standardization (ISO) with its specialized Technical Committee ISO/TC 275 Sludge recovery, recycling, treatment and disposal. The ISO/TC 275 at the moment has 28 participating and observing countries. Information about the work of ISO/TC 275 can be found ↗ here, to check the affiliation of your country and relevant national bodies joining the committee go to *↗ www.iso.org* .

Other online sources that could be of interest for those involved in the operation, management and monitoring of waste water and sludge processing to check whether good practice is followed and where there might still be room for improvement are:

- **Best Practice Guide** from Ireland which can be viewed and downloaded at www.envirocentre.ie/includes/documents/BPGWastewater.pdf .
- **Online information platform** "Good Practices in Sludge Management" accessible at http://www.purebalticsea.eu/index.php/gpsm:good_practices .

Further specific references in the document context

↗ Cost quotation : Prices and costs depend on various factors and often have a site specific component. This document can only deliver a rough orientation on this issue and therefore works with price ranges. These ranges have been derived from quotations in numerous sources and were carefully analysed in how far they fit to the purposes and circumstances this document is intended to address. Above mentioned DWA work report and other DWA materials make up a part of the sources reviewed. Sources for further cost data include publications from e.g. Thomé-Kozmiensky (2010, 2001), IKrW (2005), Wizgall (2004); Hunziker (2003), Breuer/Geering (2002), Hahn (2002), Ermel (2002), Brunner (2001), Sintic/Drees (2001) and information given directly by WWTP operators and equipment providers.



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