Enabling
& Transboundary Cooperation
Integrated Water Resources Management
in the extended DRIN RIVER BASIN

GEF/UNDP/GWP-Med Project "Enabling Transboundary Cooperation and Integrated Water Resources Management in the Extended Drin River Basin

In the framework of the Memorandum of Understanding for the Management of the Extended Transboundary Drin Basin

Pilot activity "Preparation of Wastewater Management Decision Support Tool"

Wastewater management solutions in the Shkodra city

Report

Annex 2: Sludge drying reed beds for Shkodra City

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The Coordinated Action for the implementation of the Memorandum of Understanding for the management of the Drin basin (Drin CORDA) is supported by the GEF Drin Project. Thus, the latter constitutes an institutional project implemented by the United Nations Development Programme (UNDP) and executed by the Global Water Partnership (GWP) through GWP-Mediterranean (GWP-Med), in cooperation with the United Nations Economic Commission for Europe (UNECE). The Drin Core Group (DCG), being the multilateral body responsible for the implementation of the Memorandum of Understanding serves as the Steering Committee of the Project. GWP-Med serves as the Secretariat of the DCG.

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1 Introduction

The municipality of Shkodra is in planning the construction of sewage collectors and a WWTP for Shkodra city. The present Annex is focusing on sludge drying reed beds (SDRB) for mineralization and stabilization of sewage sludge from WWTP. The reed bed technology is an alternative to mechanical dewatering (e.g., belt presses, centrifuges) and should be considered when choosing the most appropriate sludge treatment technology and disposal method.

The proper use and disposal of sludge are among the most important questions wastewater treatment plants have to face today. Almost all operators of WWTPs are challenged by the problem of storage and disposal of biological solids.

Sewage sludge resulting from the wastewater treatment process is regarded as a potentially useful resource if adequately processed. Its treatment process is relevant for Phosphorus reuse. Phosphorous is an irreplaceable natural resource and an essential ingredient of nutrients (mineral fertilizers). Being a pillar of intensive agriculture, the threats of depletion of its natural reserves (phosphate rock) is realistic to occur in the future decades.

Sludge management is highly complex and has a cost ranging from 10 to 60 % of the total operating costs of the wastewater treatment plants (WWTP) depending on the sludge treatment technology.[1] The adequate final destination of treated sludge is a fundamental factor for the success of a sanitation system. Nowadays, sludge management is not limited to treatment and disposal only but also addresses resource recovery and pollutant removal. Nutrient reuse has been neglected in many countries, mainly outside Western Europe. Thus, it is vital to include circular economy principles into the early phase of WWTP design. Another issue is the lack of national strategies for sewage sludge reuse or final disposal, which slows down the implementation of sustainable sludge handling.

Reed bed technology presented in this Annex produces a mineralized product that can be used as a soil amendment in agriculture. Compared to other techniques, sludge drying reed beds' main advantages are lower operational and maintenance costs.

2 General description of sludge drying reed beds

SDRBs enable sludge dewatering, stabilization, mineralization, and hygenization. In the process, at least partly stabilized sludge slurry is spread on an open bed of sand or gravel, after which drying takes place by a combination of evapotranspiration and gravity drainage through the filter layer.[2]

SDRBs are used for more than two decades in different countries; consequently, several technological options are available. They can treat primary and secondary sludge, septage as well as their mixtures.

Sludge is applied sequentially, and between the series of sludge application, a resting period (period without sludge) follows. This procedure is carried out for many years until the bed is filled with stabilized dewatered sludge, and the bed has to be emptied. The beds are dimensioned to be filled up in approximately ten years. The water drained from the sludge percolates through the filter layer of the unsaturated filter bed with prevailing aerobic conditions where treatment processes reduce pollutant concentrations of the drained water. The latter is then pumped back to the wastewater treatment plant for further treatment.

[1] https://www.iwapublishing.com/sites/default/files/ebooks/9781780402130.pdf

[2] https://books.google.si/books?id=drobBQAAQBAJ&pg=PA245&lpg=PA245&dq=Regstrup+reed+beds&source=bl&ots=Ocuwf7ugkc&sig=ACfU3U1CT73BhTqDPz7K5O5WYxCpARWCJg&hl=sl&sa=X&ved=2ahUKEwiS3KzzytDlAhUls4sKHXXADs8Q6AEwAHoECAgQAQ#v=onepage&q=Regstrup%20reed%20beds&f=false

Experience has shown that the quality of the final product concerning pathogen removal and mineralization of hazardous organic compounds after treatment makes it possible to recycle the biosolids to agriculture as an enhanced treated product.[3]

3 Principle of operation

Reed beds are constructed in rectangular concrete basins or soil excavated basins. The bottom of basins is impermeabilized with a waterproof membrane to protect groundwater and to prevent water gains. The drained water from the sludge is collected through perforated pipes, placed on the bottom of beds, and returned to a wastewater treatment plant. On the bed, there is a filter layer with layers of gravel and sand. In the top layer of sand, reeds (*Phragmites Australis*) are planted.

The number of beds and the surface area varies and depends on the amount of sludge to be treated and the local climate. Sludge is distributed homogeneously on the surface of the bed in loading calculated batches. Each feeding period is followed by a resting period. During this time, sludge dewatering and mineralization occurs. Sludge feeding of beds rotates within the system, which is why often several beds are needed. The resting periods' duration depends on the system's treatment capacity, local weather conditions, age of the system, dry matter content, and characteristics of the sludge.

Sludge dewatering occurs mainly due to water percolation through the sludge residue and filter layer, while solids remain on the surface. Residual water content is further reduced by plant evapotranspiration and evaporation from the surface. The final product can be dewatered to up to a maximum of 40% of dry matter content, while the volume of all loaded sludge can be reduced for more than 90% of the initial volume. Examples of implemented reed bed systems are shown in the picture below.

Figure 1: Reed beds in Denmark: Skövde (2003, 1.200 tonnes of dry solids per year; left), Rudkøbing (1992, 250 tonnes of dry solids per year; middle), and Kolding (1998, 2.000 tonnes of dry solids per year; right)[4]

Sludge mineralization due to aeration by plants, cracks in the sludge residue, granular filter layer, and aeration pipes, placed on the beds' bottom. The passive aeration creates aerobic conditions that promote the presence of aerobic microorganisms that accelerates sludge mineralization.

It is expected that a reed beds system can be in operation for more than 30 years. After approximately 8 to 10 years of operation, individual beds are emptied sequentially. Before harvesting the biosolids,

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[3] S. Nielsen. Helsinge sludge reed bed system: reduction of pathogenic microorganisms. Water Science and Technology, 56 (2005), pp. 175-182;
E. Uggetti, I. Ferrer, S. Nielsen, C. Arias, H. Brix, J. Garcia. Characteristics of biosolids from sludge treatment wetlands for agricultural reuse- Ecological Engineering, 40 (2012), pp. 210-216

[4,40] Arias, A., C., 2013. Sludge dewatering and mineralization in reed beds. Design and operation consideration. Pictures borrowed from S. Nielsen.

the bed to be emptied is not loaded for about 4 to 6 months to further stabilize the top layer. Once the bed is emptied, a resting period is recommended to allow the plants' regrowth and the microbial community before a new cycle of loading. The final harvested product from the reed bed system is a dewatered, mineralized, and stabilized sludge. It is an earthy material, which can be reused.

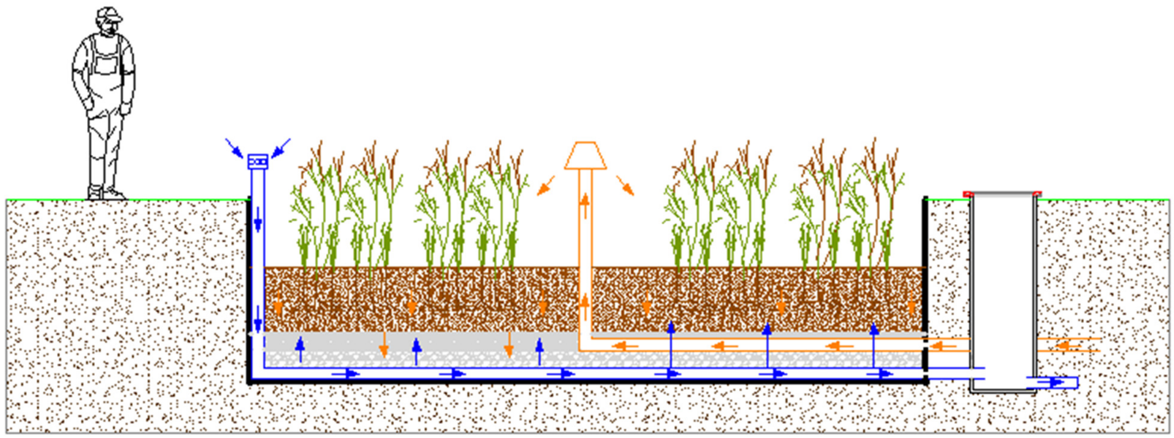

Figure 2: Scheme of SDRB[5]

4 Reed beds for Shkodra city using LIMNOSOLIDS® technology

In the concrete case of central WWTP for Shkodra city, the Annex presents a system of sludge drying reed beds, using LIMNOSOLIDS® technology.

4.1 Short description

Sludge from WWTP will be distributed to sixteen beds following a defined operational plan (sludge quantities, loading, and resting period). Around the beds, there should be at least 3 m wide road for operation and maintenance of SDRB.

The filter layer is installed at the bottom of SDRB, as illustrated in Figure 3. The bottom of the SDRB and filter layer is flat. There can be 45- or 90-degree embankments along with the filter layer. The height from the top of the filter layer to the top of embankments should be at least 1,3 m. The beds' water tightness is ensured by non-permeable foil resistant to mechanical loads, UV light, air, and root growth. EPDM foil, 1,52 mm thick, meets these requirements and is widely used for this purpose. To protect the foil from external influences, geotextile is put above and beneath the foil.

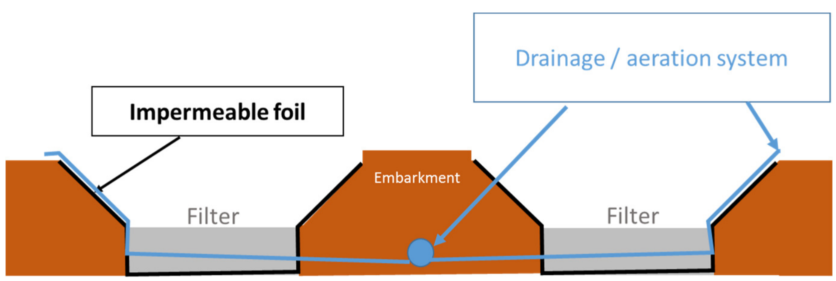

Figure 3: Schematic diagram of the position of filter layer, impermeable foil and drainage/ventilation system[6]

[5] Limnos Ltd. www.limnos.si
[6] Limnos Ltd. 2019.

The filer media (sand filter) is placed on the entire bottom surface of SDRBs and consists of different sand and gravel fractions. Such a structure of the filter layer enables good dewatering ability and ensures favorable conditions for plant growth. Plants must be planted uniformly over the entire filter surface. The plant density must be at least seven plants per m^2.

The drainage waters are collected by drainage pipes placed at the bottom of the bed and pumped back to the WWTP. On one side, drainage pipes are led out of the filter layer and are connected to air and covered with a perforated cap.

4.2 Design parameters

Design parameters relevant for dimensioning of reed beds:

- Design horizon: 30 years
- Design capacity: 115.000 PE
- Primary sludge: 4.025 kg TSS/day
- Secondary sludge: 4.855,19 kg TSS/day
- Mixed sludge: 8.880,19 kg TSS/day or **3.241.269,35 kg TSS/year**
- Flow: 646,52 m^3/d (1,4% TS)
- Sludge characteristics before dosing sludge to reed beds:
  - Anaerobic biological sludge – stabilized
  - Mechanical properties of sludge: fluid sludge
  - Water content: 98-99 %
  - Dry solids content: max 5 %
  - VTS content: 85 – 90 %

4.3 Required area (area of filter layer)

The most important process parameter to affect sludge drying is the loading rate of dry matter. The sludge loading rate is expressed in kg TSS/ m^2/year. It represents the mass of solids dried on one m^2 of bed in one year.[7] The loading rate depends on climate (temperature, precipitation, humidity), and thus optimal local operating conditions need to be determined during the design phase.

The maximum proposed loading rate in Shkodra is 60 kg TSS/m^2 y. Thus, the minimum required area of filter layer (the area used for sludge treatment) for Shkodra city is 5,4 ha. The proposed area does not include embankments and maintenance roads.

Required area of filter layer: 54.000 m^2. Estimated gross area (including embankments, maintenance roads): cc. 76.500 m^2

4.4 Dimensioning

Proposed number of beds: 16.

Dimensioning of reed beds should be adopted to the specific location. Dimensioning should consider method of sludge excavation.

Theoretical dimensions of SDRB are presented in the table below.

Table 1: SDRB dimensions

[7] https://www.un-ihe.org/sites/default/files/fsm_book_lr.pdf

Reed bed	Width [m]	Length [m]	Area [m²]	Height* [m]
RB (1-16)	30	112,5	3.375	1,95

* height of filter layer + height for sludge depositing and freeboard.

4.5 Operation of SDRB

Each bed will be filled with anaerobic biological sludge – stabilized. Available storage for each bed is at least 10 years of sludge loadings. After sludge reaches the maximum level of the bed, the loading must be stopped. Before excavation of sludge, at least 6 months resting period without loading must take place.

The phases of loading are presented in the figure below (Figure 4).

Sludge is usually removed with a small excavator with a shovel on a long arm. Almost all sludge can be excavated, leaving at least 5 cm of sludge at the bottom for quicker plant recovery and the start of a new loading cycle.

Sludge can be used only if it meets the legislation requirements. Sludge analysis must be performed before a decision is made on its final disposal. The produced sludge on SDRB is compost like material that can be easily transported to the wanted location. For distribution on the agricultural fields, a simple manure spreader can be used.

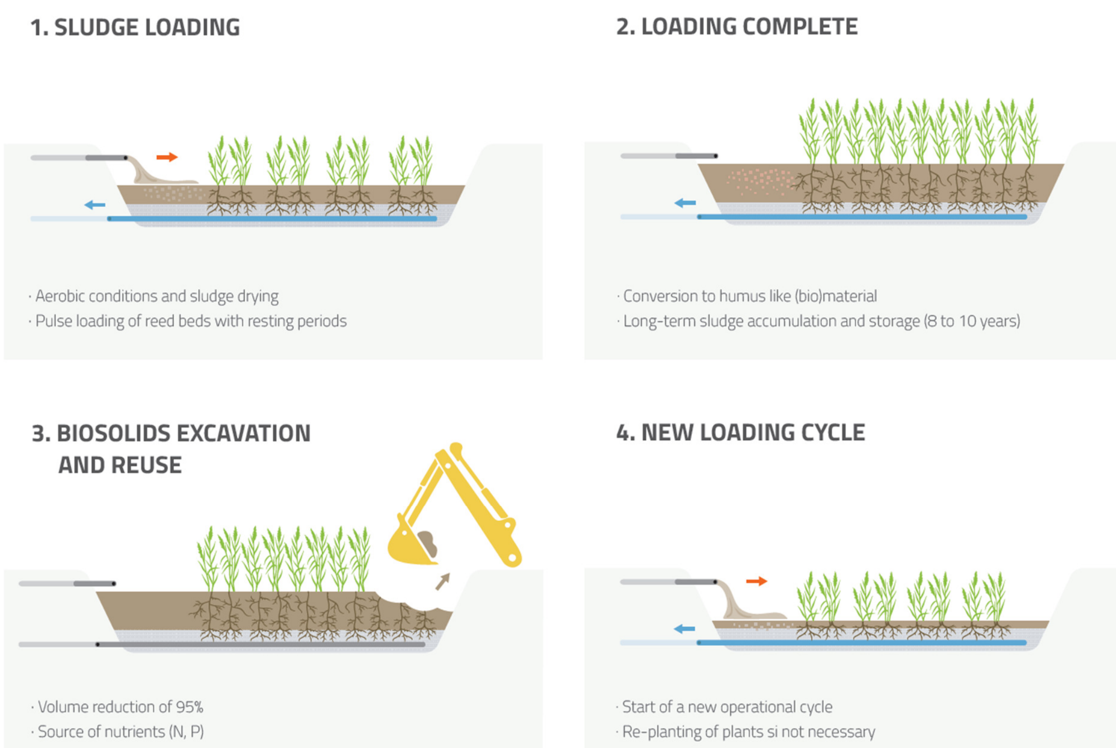

Figure 4: Four phases in operation of sludge drying reed beds[8]

[8] Limnos Ltd. www.limnos.si. 2020.

5 Cost analysis

5.1 Investment costs

Total construction costs for SDRB Shkodra are 4.169.315,0 EUR. The costs do not include project documentation, operation staff training, and dissemination. Land acquisition costs are also not included.

5.2 Operation and maintenance costs

The consultant estimated operation and maintenance cost of SDRB for Shkodra city.

Typical O&M costs of SDRB include regular and periodic maintenance. **Regular maintenance** is a set of measures and actions that have to be carried out regularly throughout the year to maintain the level of effective sludge treatment and technology / technical correctness of SDRB.

Periodic maintenance includes a set of maintenance works necessary due to ongoing technology improvements and predicted lifetime of SDRB parts. Periodic investment works ensure sustainability and increase the effectiveness of the treatment plant.

Regular operation and maintenance works of SDRB consists of:

- Daily check of plants (colour and growth);
- Daily check if the sludge is drying out (no water on the surface);
- Weekly control of the water level in the filter layer;
- Monthly check of external parts of drainage pipes and manholes;
- Cleaning of pipes and manholes as needed;
- Management and operation activities (loading dosing/patterns);
- Service of mechanical equipment (e.g., pumps);
- Monitoring;
- Landscaping;
- Activities related to the final disposal of sludge.

Year after year, SDRB degrade due to age and other factors. Periodic investment maintenance consists of carrying significant repairs to restore the system to optimum operational conditions. Periodic investment operation and maintenance works of SDRB consists of:

- Replacement costs at the end of the warranty;
- Repairs.

Operation and maintenance costs for reed beds for sludge treatment are assessed in the table below.

Table 2: The assessment of operation and maintenance costs for sludge drying reed beds

Descriptions	**Unit**	**Cost [€/y]**
Energy - electricity	159.100	15.900,00
Workforce	1,6	17.300,00
Maintenance		46.804,10
• *Civil works*	*1% of investment*	*32.521,40*
• *Mechanical equipment and installations*	*1,5% of investment*	*12.182,70*
• *Electrical equipment and installations*	*2,0% of investment*	*2.100,00*

Descriptions	Unit	Cost [€/y]
Monitoring		6.900,00
• *Formal*	*1/10*	*500,00*
• *Intern*	*64*	*6.400,00*
Sludge reuse (regular scenario)	6.483 tons/year	97.245
TOTAL:		**184.149,10**

6 Sludge quantities and its use

After an operational cycle of 10 years or more, the biosolids (organic matter recycled from sewage, especially for use in agriculture) is excavated and then disposed (e.g., incinerated) or reused (e.g., as fertilizer on agricultural land). There are two possible scenarios about when and how much of biosolid has to be removed from the SDRB for disposal or reuse. Experience has shown that the final product's quantity depends on wastewater characteristics, climate conditions, chemical, and biological processes in SDRB. The content of mineralization and dry matter has the most significant impact on the final product's quantity. Sludge quantities are not easy to predict due to listed uncertainties. Thus, two scenarios were simulated, regular (normal conditions) and optimal (optimal conditions) scenario. The main characteristics of the scenarios are presented below.

Table 3: Two scenarios for quantity of dewatered, mineralized and stabilized sludge after treatment on SDRB

Scenario	Loading (kg TSS/m2)	Mineralization (%)	Dry solid content (%)	Sludge disposal (t/year)	Year of emptying SDRB
Optimal scenario	60	40	50	3.890	16
Regular scenario	60 kg	40	30	6.48	10

We can achieve a bigger volume reduction under optimal conditions (optimal scenario) than under regular conditions (regular scenario). The predicted sludge quantities and related costs are presented in the table below. For sludge disposal, we used unit price of 60 EUR/t and for biosolids use 15 EUR/ton.

Table 4: Costs for disposal or reuse for different scenarios

Scenario	Optimal scenario		Regular scenario	
	Disposal	Reuse	Disposal	Reuse
Sludge disposal (t/year)	3.890		6.483	
Cost per unit (EUR/t)	60	15	60	15
Cost per year (EUR/year)	233.400	58.350	388.980	97.245

6.1 Quality of the final product after treatment on SDRB

Before the final decision on sludge disposal/biosolids' reuse, regular monitoring and sludge analysis are required. The biosolids should meet the standards for agricultural land disposal, limit values set in The Decision Nr. 127/2015 on Requirements for the use of sludge in agriculture. Reuse in agriculture depends on crop needs and land use and national regulations accepted according to Nitrate Directive 91/676/EEC (e.g., a maximum annual limit of nitrogen per hectare). In case sludge does not meet limit values for biosolids' reuse, it can be excavated and transported to the nearest incineration plant. The excavated material has lower volume compared to mechanical dewatering, and thus, manipulation costs are cheaper.

6.2 Agricultural land requirements for biosolids use

The required area of agricultural land for the application of biosolids is calculated in the table below. The calculation is based on the nitrogen balance but could also be based on the annual load of dry matter per hectare of agricultural land or phosphorus content (mg/kg TP).

Table 5: Nitrogen balance after 10 years of SDRB use

Scenario	**Percentage of nitrogen in biosolids**	**Sludge disposal in 10 years (t)**	**kg of nitrogen**	**1 Scenario: extensive agriculture** *(N* **input per** *ha* **agricultural land: 170 kg N/ha)**	**2 Scenario: intensive agriculture** *(N* **input per** *ha* **agricultural land: 800 kg N/ha)**
				Required agricultural land (ha)	**Required agricultural land (ha)**
Optimal scenario	3%	38.900	1.167.000	6.865	1.459
	5%	38.900	1.945.000	11.442	2.432
Regular scenario	3%	64.830	1.944.900	11.441	2.432
	5%	64.830	3.241.500	19.068	4.052

6.3 Other final disposals

In case of Shkodra Municipality would not be able to use biosolids in agriculture, other potential uses could be considered, such as:

- landfill covering (part of landfill sanitation);
- revitalization of quarries or other degraded areas;
- erosion sanitation;
- greening of highway embankments;
- construction industry (adding it/mixing with construction material);
- fertilizer for floriculture (mixing it with soil);
- fertilizer for industrial plantations (e.g., hemp);
- stabilization with lime and land application;
- fertilizer for green areas and parks;
- fertilizer for recreational areas (e.g., football stadium).

The final disposal use must be aligned with the existing sludge management framework taking into account legislation, strategies and plans, permitting processes, existing infrastructure for sludge management, and land characteristics of the soil to which sludge is applied.

7 Conclusions

SDRB is not a novelty but a proven and efficient technology, and in these terms, comparable to any other conventional techniques. SDRB can fully substitute conventional sludge lines. The great advantage of technology is the ease of operation and low operational costs leading to financial savings. The technology also enables biosolids reuse. Compared to other treatment methods, they have more than 50% lower operational and maintenance costs (smaller quantity, less transport) during a life span of 30 years.

The initial investment costs in SDRB would amount to 4.169.315 EUR, while annual operating costs are estimated at 86.904 EUR per year. The investment is higher than mechanical dewatering, but taking into account the 30-year lifespan, the SDRB is a cheaper option. Table 6 presents investment costs in comparison to different sludge treatment technology. The difference in investment cost for sludge treatment is considerable, but considering smaller operational costs of the reed beds and sludge reuse in agriculture, this is an economically favorable option. Sludge drying reed beds optimize annual operational costs for more than 80 %.

Table 6: Option analysis for sludge treatment for Shkodra city

	Scenario 1: mechanical dewatering	**Scenario 2: reed beds**			
		optimal scenario		**regular scenario**	
Sludge alternatives	disposal	disposal	reuse in agriculture	disposal	reuse in agriculture
CAPEX [€]	1.990.000	4.169.315	4.169.315	4.169.315	4.169.315
OPEX [€/y]	863.473,60	320.304,10	145.254,10	475.854,10	184.141,60
NPV O&M [€/y]	-14.931.214	-5.538.709	**-2.511.739**	-8.229.004	-3.184.312
NPV INVESTMENT [€]	-1.990.000	-4.169.315	**-4.169.315**	-4.169.315	-4.169.315
NPV TOTAL [€]	-16.921.214	-9.708.024	**-6.681.054**	-12.398.319	-7.353.627
Ranking	**5**	**3**	**1**	**4**	**2**

The main advantages of sludge drying reed beds are:

- low and simple maintenance,
- simple mechanical equipment (robust technology),
- low energy consumption,
- no chemicals,
- high reduction of total solids during the mineralization phase,
- landscape attractiveness.