VA-PROJEKT

Swedish Environmental Protection Agency

COST EFFECTIVE METHODS

Final Edition

2003-05-12

1701378000

COST EFFECTIVE METHODS

1. Background

In order to improve the situation in the Baltic, existing installations for municipal and industrial wastewater treatment must be improved or new ones be built in places with high pollution. A number of “Hot Spots” have been identified. As the costs are high it is necessary to develop cost effective methods.

A cost effective method should reduce the pollution as much as possible with the lowest possible investment and operation cost.

Depending on the location, the type of receiving water etc., the emphasis can be placed on removal of organic material (BOD, COD) or removal of nutrients as nitrogen and/or phosphorus. In general, it costs less to remove suspended solids or organic material than e.g. phosphorus or nitrogen, but it is possible to find cost effective combinations where both organic material and nutrients can be removed. It is important to remember that the primary objective for collection of sewage and sewage treatment is to maintain a good sanitary standard and avoid water-borne diseases. A simplification of the treatment processes that leads to an inferior sanitary standard can therefore not be allowed.

During the planning of cost effective treatment methods it is advantageous to have access to specific operation costs for removal of suspended solid, organic material, Phosphorous and Nitrogen in treatment plants of different size.

The sanitary sewers are sometimes in bad condition and need to be improved or rebuilt. The slope may be too low or the material may be corroded, which leads to accumulation of sediments in the tubes or leakage of groundwater into the system. It is therefore of interest to discuss different cost effective methods to bring the system back in service.

2. Treatment requirements

2.1 Directives and recommendations

The treatment requirements in the countries which are contracting parties in HELCOM are stated in Recommendation 9/2 and 16/9.

The Commission recommends to the Governments of the Contracting Parties to the Helsinki Convention that:

a) urban (municipal) wastewater deriving from households (domestic wastewater) or industrial enterprises should be collected and treated before being discharged into water bodies; by-passes may only be used in emergency cases;

b) domestic sewage or wastewater of similar type which is collected in a central sewerage system and treated in wastewater treatment plants, loaded with **more than 10 000 person equivalents,** should be treated as soon as possible and not later than 1998 by biological methods or other methods giving equivalent results, so that the treatment should result in (calculated as yearly average values with nitrification inhibitor, and calculated for total amount of influent sewage)

(i) at least **90% reduction of BOD5**; and

(ii) at most a **concentration of BOD5** in the effluent of the treatment plant **of 15 mg/l;**

c) treatment of domestic sewage or wastewater of similar type at plants serving more than 10 000 person equivalents should result as soon as possible and not later than 1998 in effluent yearly average values of **total phosphorus below 1.5 mg P/l;**

d) as a start, each Contracting Party should start research and evaluation projects as soon as possible with the purpose to give a basis for further recommendations for nitrogen removal within three years. The project should, inter alia, include studies of process technology and cost for **nitrogen removal** to reach the targets:

(i) 12 mg total nitrogen/l in the effluent water or 50% reduction of total incoming nitrogen;

(ii) 8 mg total nitrogen/l in the effluent water or 75 % reduction of total incoming nitrogen;

The results of the research and evaluation projects should be reported at annual seminars held within the auspices of the Helsinki Commission;

e) the values stated in b) and c) need not be applied plantwise if a similar reduction in the total discharge of BOD5 and phosphorus as yearly average discharge values in domestic sewage or wastewater of similar type which is collected in central sewerage systems can be documented.

The Commission recommends to the Governments of the Contracting Parties to the Helsinki Convention that:

a) municipal sewage treatment plants, located in areas sensitive to nitrogen, should be equipped with nitrogen removal according to the following stipulations, where values for concentration or for the percentage of reduction are applied:

Size of treatment plant	**Concentration tot-N, mg/l 1) (yearly average)**	**Minimum 2) percentage reduction**	**Year (end of)**	**Countries in transition**
10 001-50 000 pe	15	70-80	1998	2020
50 001-100 000 pe	15	70-80	1998	2020 4)
> 100 000 pe	10 3)	70-80	1998	2010

1) tot-N means the sum of total Kjeldahl nitrogen (organic N + NH4), nitrate (NO3)-nitrogen and nitrite (NO2)-nitrogen

2) reduction in relation to the load of the influent

3) alternatively the daily average must not exceed 20 mg/l N. This requirement refers to a water temperature of 12 ^{o}C or more during the operation of the biological reactor of the waste water treatment plant. As a substitute for the condition concerning the temperature, it is possible to apply a limited time of operation, which takes into account the regional climatic conditions (This note has been changed by the EU directive 98/15/EC).

4) most urgent plants should be equipped with nitrogen removal by 2010. Those plants should be specified to the Commission not later than in 1997.

EU has adopted Directives concerning pollution control. The structure and purpose of EU Directives differ sometimes from HELCOM. The Urban Waste Water Treatment Directive 91/271/EEC contains limit values which are similarly formulated as HELCOM requirements in this sector.

Many of the countries within the Helcom area have national standards equivalent to or more stringent than the Helcom standards.

2.2. Relation between requirements and treatment alternatives

The present wastewater treatment technique makes it possible to reduce the pollution of urban wastewaters and industrial wastewaters very efficiently. If very good treatment results are required, the cost can however be very high. The normal way to obtain a good result is to use a low load and/or include several treatment steps in series, e.g. a final filtration. If a lower reduction of the pollution parameters can be tolerated a substantial reduction of the investment and operation costs can be obtained.

The possibility to choose a cost effective solution can be limited if the requirements in the HELCOM recommendations and the EU directives must be followed strictly.

In many cases the cost for a far-reaching treatment may be prohibitive and the construction has to be postponed for many years until a financing can be arranged. From an environmental standpoint it can be advantageous to start with a simpler installation and extend it later when the economic situation permits the extension. The cost for improving the reduction with 5 % is much higher in the region 90 – 95 % than in lower treatment efficiency regions.

2.3. Relation between wastewater characteristics and treatment methods

The wastewater characteristics e.g. the fraction of organic matter (BOD and COD), phosphorous and nitrogen in suspended form is a base for the decision about treatment methods.

Data from Norway, Sweden and Finland show that the wastewater can be characterised as having

- a high fraction of organic matter in suspended form (COD 60-80 % and BOD 60-80 %)
- a considerable fraction of phosphorus in suspended form (40-70 %)
- a high fraction of nitrogen in suspended form (20-40 %)
- BOD/COD ratio of about 0.4
- BOD_f/COD_f ratio of about 0.4

With these wastewater characteristics, much can be gained economically by enhancing particle separation in primary treatment. By replacing some of the metal cation used in chemical precipitation by a polymeric cation, excess sludge production can be reduced without reduction of the phosphate removal efficiency, since the soluble phosphate concentration is very low in many cases which can lead to reduced oxidation rates in biological treatment.

Even for plants with strict requirements for nitrogen and phosphorus removal, a large fraction of organic matter in particulate form can influence the selection of the treatment process.

2.4. Selection of treatment methods for minimization of the environmental impact

A comparison of different technologies should also include an assessment of the impact on the receiving water bodies.

A way to analyse the plant configuration is to apply the OCP value for the plant. OCP means Oxygen Consumption Potential and has been presented by Professor H. Ødegaard, Norwegian Technical university, Trondheim.

Oxygen consumption in a receiving water is often caused by both primary oxygen consumption (bacterial oxidation of BOD and ammonia) and secondary oxygen consumption (bacterial degradation of algae, the growth of which is promoted by phosphorous and nitrogen).

The calculation of OCP is based on the following ratios:

- 1 kg BOD results in maximum 1 kg primary oxygen consumption
- 1 kg Tot N results in maximum 4 kg primary oxygen consumption
- 1 kg Tot-P results in maximum 100 kg secondary oxygen consumption
- 1 kg Tot-N results in maximum 14 kg secondary oxygen consumption

By using the OCP value it is possible to express the amounts of BOD, nitrogen and phosphorous in one common unit and OCP can be an appropriate way to assess the plant efficiency.

In some cases, however, the situation is such that you want to favour the removal of a special component in the wastewater. This situation may lead to a choice of a special treatment process.

3. Description of different alternatives for cost effective treatment

3.1. Mechanical treatment

The purpose of mechanical treatment is to remove suspended matter from the wastewater. It includes screening, sedimentation, flotation and filtration. Screening and sedimentation alone is not sufficient as a single treatment method and must be combined with other processes to yield an acceptable result. There may be different reasons for including a primary treatment step. In most cases it is included to lower the organic loading on the subsequent biological step. The BOD-removal is only about 30 % but even so the primary treatment is cost efficient. The treatment step efficiency can be enhanced by e.g. addition of flocculation agents. See 3.3 Mechanical-chemical treatment.

Assessment of cost effectiveness, mechanical treatment

Economy and results	Rating	Remarks
Investment	Low	
Operation, energy	Low	
Operation, chemicals	Low	
Operation, manpower	Low	
Expect. Efficiency, SS	Medium	60-70 %
Expect. Efficiency, BOD	Low	About 30 %
Expect. Efficiency, Tot-N	Low	About 10 %
Expect. Efficiency, Tot-P	Low	About 10 %
Result		Results not acceptable as a single process step but sedimentation is cost efficient if the sedimentation step is followed by a biological step.

3.2. Chemical treatment

Chemical treatment is a common name for wastewater treatment processes where chemical precipitation and flocculation agents are used.

The purpose of chemical precipitation is to convert dissolved substances to insoluble particles, which can be flocculated and separated from the liquid. The purpose of chemical flocculation is to remove pollutants, which are present in a suspended or colloidal form.

Chemical precipitation is a very common method for removal of phosphates in wastewater. At the same time particulate material is flocculated, which results in a removal of BOD, COD and Tot-P.

Chemical precipitation is seldom used as a separate process but is combined with mechanical or biological treatment as pre-precipitation, simultaneous precipitation or post precipitation.

Assessment of cost effectiveness, chemical treatment

Economy and results	Rating	Remarks
Investment	Medium	
Operation, energy	Low	
Operation, chemicals	High	Precipitation chemicals
Operation, manpower	Medium	
Expect. Efficiency, SS	High	About 90 %
Expect. Efficiency, BOD	Good	70- 80 %
Expect. Efficiency, Tot-N	Low	About 15 %
Expect. Efficiency, Tot-P	High	About 90 %
Result		Good SS- and Tot-P-removal

3.3. Mechanical-chemical treatment (Direct precipitation)

A combination of mechanical and chemical treatment gives better treatment results than mechanical treatment alone. The results can be compared with a high load biological treatment with chemical precipitation and is a very cost effective method. An installation for direct precipitation can later on be extended to a biological treatment plant with nitrogen removal.

Assessment of cost effectiveness, direct precipitation

Economy and results	Rating	Remarks
Investment	Medium	
Operation, energy	Low	
Operation, chemicals	High	
Operation, manpower	Medium	
Exp. Efficiency, SS	High	90 %
Exp. Efficiency, BOD	Good	70-80 %
Exp. Efficiency, Tot-N	Low	About 15 %
Exp. Efficiency, Tot-P	High	About 90 %
Result		Good results for SS, Tot-P and BOD

3.4. Biological treatment with microorganisms in suspended form (activated sludge type)

The active microorganisms – mainly bacteria - are present in form of small bacterial flocks (activated sludge) suspended in the water. During the biological treatment organic material is partly oxidized to carbon dioxide and water and partly converted to bacterial cell substance that must be removed from the process as excess sludge. Intensive types of biological treatment installations are working with high concentrations of active microorganisms. The concentration of the mixed liquor suspended solids (MLSS) varies in activated sludge and SBR installations between 2000 mg/l and 5000 mg/l. It is often interesting to express the bacteria concentration as mixed liquor volatile suspended solids (MLVSS). In a plain biological treatment the MLVSS is about 80 % of the MLSS but with preprecipitation or simultaneous precipitation the MLVSS is only about 60 % of the MLSS.

3.4.1. Oxidation ponds and precipitation ponds

The simplest form of biological treatment is treatment in oxidation ponds without aeration. Oxidation ponds have been widely used in warm climates but there are also much experience from cold climates. (Northern USA). The active microorganisms are bacteria and green algae. The algae produce oxygen by photosynthesis in daytime but consume oxygen for respiration during the dark hours. The natural aeration is about 4 g O_2/m^2,d and the BOD-load must be limited to about 4 g BOD/m^3,d. It is recommended to arrange two ponds in series with a total area of 15 m^2/p. The area of the first pond should be 9 m^2/p. During spring, summer and autumn the BOD-reduction and even P-reduction is good, but in winter time the BOD-reduction is low and the P-reduction is low or even negative due to the release of phosphates from the bottom sediments.

Assessment of cost effectiveness, oxidation pond

Economy and results	Rating	Remarks
Investment	Low	
Operation, energy	Very low	
Operation, chemicals	Very low	
Operation, manpower	Low	
Exp. Efficiency, SS	Medium	65-90 %
Exp. Efficiency, BOD	High	About 90 %
Exp. Efficiency, Tot-N	High	70-80 %
Exp. Efficiency, Tot-P	Medium	50-70 %
Result		Not quite acceptable

3.4.2. Precipitation ponds

Oxidation ponds can hardly be recommended as a single treatment step because of the low phosphorous removal in wintertime. It is possible, however, to combine pond treatment with chemical precipitation in order to remove dissolved phosphates and suspended algae containing organic material and phosphorous leaving the pond in spring and summer. The system is called precipitation ponds (or fellingsdams after the Swedish word fällningsdammar) and has been tested in Finland, Norway and Sweden with good results.The chemical is added between the first and the second pond. The necessary total area is about 5 m2/p, which is lower than for the conventional ponds. Sludge accumulates in the pond and must be removed at certain intervals.

Assessment of cost effectiveness, precipitation pond

Economy and results	Rating	Remarks
Investment	Low	
Operation, energy	Low	
Operation, chemicals	High	
Operation, manpower	Low	
Exp. Efficiency, SS	Medium	70-80%
Exp. Efficiency, BOD	High	70-90 %
Exp. Efficiency, Tot-N	Low	25-40 %
Exp. Efficiency, Tot-P	High	0.5-0.8 mg/l (85-95%)
Result		Acceptable

3.4.3. Aerated lagoons

The organic loading can be increased substantially if the ponds are aerated e.g. by means of mechanical aerators. With a temperature of 15-25 ^oC, a BOD load of about 70-130 gBOD/m^3d can be applied. The treatment time is about 5 days.

As the aerated lagoons are not dependent of algae and photosynthesis, they can be deeper, often more than 3 meters. The ponds should be preceded by a screen and a sand trap and if possible with a primary sedimentation to avoid formation of a sediment layer at the bottom of the pond. A secondary sedimentation is necessary. In some cases the sedimentation can be arranged in the last part of the pond in a so called "stilling zone".

Mechanical turbine aerators are often used but create an aerosol and in the northern climate with cold winters there is a risk for build up of ice on the aerators. Aerated lagoons are therefore not recommended for municipal wastewater, but can be used for warm industrial waters. Phosphorous removal is low (about 30 %). If higher removal is necessary a post precipitation must be added. Aerated lagoons can also be combined with infiltration or sand beds if nitrogen removal is required. This combination has been used for leachate water from landfills.

Assessment of cost effectiveness, aerated lagoons

Economy and results	Rating	Remarks
Investment	Medium	
Operation, energy	High	Operation costs similar to activated sludge
Operation, chemicals	Low	(High if post-precipitation is added)
Operation, manpower	Low	
Exp. Efficiency, SS	Medium	70-80 %
Exp. Efficiency, BOD	High	80-90 %
Exp. Efficiency, Tot-N	Low	10-20 %
Exp. Efficiency, Tot-P	Low	10-20 %
Result		Not acceptable without post-precipitation

3.4.4. Conventional activated sludge

A conventional activated sludge installation consists usually of bar screens, sand trap (grit chamber), primary sedimentation, aeration basin with aeration system, secondary sedimentation and sludge thickening, sludge dewatering and sludge stabilization. In order to maintain a high concentration of active microorganisms in the system, sludge is recirculated from the sedimentation tank to the aeration basin. A normal concentration of bacterial sludge (MLSS) is 1.5 – 4.0 kg/m^3. A normal volumetric loading is 0.6 – 1.5 kg BOD/m^3d and a normal sludge load is 0.3 – 0.6 kg BOD/kg SS,d. There is a relationship between BOD-loading and treatment efficiency. If the loading is increased, the efficiency is reduced. The stability of the operation is best at high efficiencies and activated sludge installations should therefore be operated at efficiencies over 85 %. Activated sludge units are normally used in combination with chemical precipitation in order to obtain a high Phosphorus removal.

Assessment of cost effectiveness, conventional activated sludge

Economy and results	**Rating**	**Remarks**
Investment	High	
Operation, energy	High	
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	High	
Exp. Efficiency, SS	High	90 %
Exp. Efficiency, BOD	High	90 %
Exp. Efficiency, Tot-N	Low	About 20 %
Exp. Efficiency, Tot-P	Low	20-30 %
Result		Very good BOD-removal. If chemical precipitation is included, very good P-removal.

3.4.5. SBR-reactors

An SBR-reactor (Sequencing Batch Reactor) is basically an activated sludge installation. A complete installation for municipal wastewater consists of a sedimentation tank with continuous flow and the reactor, which is a circular or rectangular tank, where wastewater is treated batch-wise. When the treatment cycle starts, the reactor tank is only filled to 75-80 % of the volume. During the first part of the cycle settled wastewater is introduced and aeration starts. After the aeration, where the biological degradation of organic substance takes place, there is a sedimentation period and during the final period in the cycle, about 20-25 % of the wastewater volume is removed by decantation.

Assessment of cost effectiveness, SBR-reactors

Economy and results	**Rating**	**Remarks**
Investment	High	
Operation, energy	High	
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	High	
Exp. Efficiency, SS	High	90 %
Exp. Efficiency, BOD	High	90 %
Exp. Efficiency, Tot-N	Low	About 20 %
Exp. Efficiency, Tot-P	Low	20-30 %
Result		Very good BOD-removal. If chemical precipitation is included, very good P-removal.

3.4.6. Extended aeration, Oxidation ditches

Extended aeration belongs to the activated sludge "family" and is characterised by a low organic loading (BOD load) and a long treatment time (often more than 12 hours). The BOD-loading is comparatively low, about 200 g BOD/m^3,d or expressed as sludge load, 0.07 kg BOD/kg SS,d.

Extended aeration requires a screen and a sand trap but is normally operated without primary sedimentation. The MLSS is kept high, if possible about 4000g/m^3 or higher. Due to low loading and long aeration time the activated sludge is mineralised in the treatment process and needs normally no separate anaerobic digestion or aerobic sludge stabilization of the excess sludge. This makes the installation cost lower but no biogas can be produced.

Oxidation ditches are a common type of extended aeration. The construction can be simpler than an extended aeration unit with rectangular basins. Oxidation ditches are suitable for BOD-removal combined with Nitrogen removal due to circulation of water and arrangement of the aerators in few points, which results in oxic and anoxic zones.

Assessment of cost effectiveness, extended aeration

Economy and results	Rating	Remarks
Investment	Medium	
Operation, energy	High	
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	Low	
Exp. Efficiency, SS	High	About 90 %
Exp. Efficiency, BOD	High	About 90 %
Exp. Efficiency, Tot-N	Low	20-40 %
Exp. Efficiency, Tot-P	Low	20-30 %
Result		Good result BOD, good result P if chemical precipitation is included. Sludge is stabilized during the process.

3.5. Biological treatment with microorganisms in form of a biofilm

The active microorganisms – mainly bacteria- are present in form of a bacterial film on a supporting material, stone or corrugated plastic sheet. The typical installations are trickling filters and biorotors. Even in infiltration and sand bed installations, fixed-film bacteria are responsible for the biological degradation of organic material in the wastewater.

In an activated sludge process the suspended microorganisms are recirculated to the process as a so-called return sludge but in a biofilm process the bacteria are fixed to the surface and the water is recirculated. Normally, a trickling filter or biorotor is preceded by a primary sedimentation.

3.5.1 Infiltration and sand beds

For very small installations infiltration or sand beds can be used. Before the treatment, the wastewater must undergo a preliminary treatment such as sedimentation or oxidation in an aerated lagoon.

If the permeability of the soil is sufficient, the pre-treated wastewater can be infiltrated directly. If the soil is not suitable for infiltration, a sand bed with a depth of about 80 cm with a top and bottom layer of gravel is placed in an excavation in the soil and the wastewater is distributed over the top layer and collected in the bottom layer.

With a combination of preliminary oxidation and soil bed, nitrogen removal can be obtained by oxidation of ammonia to nitrate in the aerated lagoon and denitrification in the sand layer.

Assessment of cost effectiveness, infiltration/sand bed

Economy and results	Rating	Remarks
Investment	Low	
Operation, energy	Very low	
Operation, chemicals	Very low	
Operation, manpower	Low	
Exp. Efficiency, SS	Medium	
Exp. Efficiency, BOD	High	90-99 %
Exp. Efficiency, Tot-N	Low	20-40 %
Exp. Efficiency, Tot-P	Low	25-50 %
Result		BOD-removal acceptable. N-removal possible if carbon source is added.

3.5.2 Trickling filters

Trickling filters are not used for filtration like e.g. sand filters for removal of suspended solids. A trickling filter is a bioreactor where the bacteria and other active microorganisms are growing on a supporting material with a high surface to volume ratio.

The plastic media trickling filters are common. The supporting material consists of corrugated plastic sheets glued together to a honeycomb like structure (plastic packing). It has a specific surface of 100 – 140 m^2/m^3. The stone media trickling filters consist of crushed rock with a diameter of 50-100 mm and a specific surface of 50-70 m^2/m^3. The stone filters are not so common in new installations. In some countries the access of crystalline bedrock (granite or gneiss) is limited and limestone cannot be used, as it will be dissolved by the carbon dioxide produced during the biological oxidation of organic material.

The stone filters are mostly circular but the plastic media trickling filters are often built in form of a tower with a height of 5 – 7 meters.

There is a relationship between BOD-loading and treatment efficiency. If the loading is increased, the efficiency is reduced. Trickling filters are more tolerant to changes in BOD-load than activated sludge installations and can be operated at relatively high loads and lower efficiencies. A normal load at 10°C is about 16 g BOD/m^{2}d and if nitrification is necessary, the load must be reduced to 3-5 g BOD/m^{2}d.

Assessment of cost effectiveness, trickling filter

Economy and results	**Rating**	**Remarks**
Investment	High	
Operation, energy	Medium	No aeration but recirculation pumping
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	Medium	
Exp. Efficiency, SS	Medium	70-80 %
Exp. Efficiency, BOD	High	80-90 %
Exp. Efficiency, Tot-N	Low	10-20 %
Exp. Efficiency, TotP	Low	20-30 %
Result		BOD-removal acceptable

3.5.3. Biorotors (RBC)

Biorotors or Rotating Biological Contactors utilize the same supporting material as the plastic media trickling filters. A biorotor is constructed of bundles of plastic packing attached radially to a shaft, forming a cylinder of media. The shaft is placed over a tank so that the cylinder (generally consisting of four discs on the same shaft) is submerged approximately 40 %. The tank has four compartments and the water passes from disc one to disc four. The contactor surfaces are spaced so that wastewater can enter the voids in the packing during the submergence. When the four discs are rotated and leave the water in the tank, the liquid trickles out of the voids between the surfaces and is replaced by air and oxygen diffuses into the bacterial film growing on the supporting plastic surface. Alternating exposure to organics in the wastewater and oxygen in the air during rotation is like the dosing of a trickling filter with a rotating distributor. The rotation velocity is 1.5 – 3 rpm. The BOD-loading is about the same as for a trickling filter calculated on the total volume of the plastic packing. As the water enters compartment one, the load is high on disc1 and must no exceed 100 g BOD/m^{2}d. Very often discs 1 and 2 are operated in parallel followed by discs 3 and 4 in series.

Assessment of cost effectiveness, biorotor

Economy and results	Rating	Remarks
Investment	High	
Operation, energy	Low	No aeration, no recirculation pumping
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	Medium	
Exp. Efficiency, SS	Medium	70-80 %
Exp. Efficiency, BOD	High	80-90 %
Exp. Efficiency, Tot-N	Low	10-20 %
Exp. Efficiency, Tot-P	Low	20-30 %
Result		BOD-removal acceptable, nitrification possible

3.6 Biological treatment for nitrogen removal

The treatment plant consists of an activated sludge installation with nitrification and denitrification steps. Generally predenitrification is used and the denitrification step is placed before the aeration step where the main BOD-oxidation and the nitrification take place.

Assessment of cost effectiveness, biological nitrogen removal

Economy and results	Rating	Remarks
Investment	High	
Operation, energy	High	Oxygen needed for oxidation of organic substance and oxidation of NH_4.
Operation, chemicals	Low	High if chemical precipitation is included
Operation, manpower	High	
Exp. Efficiency, SS	High	About 90 %
Exp. Efficiency, BOD	High	About 90%
Exp. Efficiency, Tot-N	High	About 75 %
Exp. Efficiency, Tot-P	Low	About 20 %
Result		Very good BOD-removal and good removal of Ammonia if the sludge age is sufficient

3.7 Biological treatment for phosphorus removal

The treatment plant consists of an activated sludge installation with an anaerobic step placed before the aeration step. In the anaerobic step, phosphorus is released and in the aeration step, phosphorus is taken up by the bacteria.

Assessment of cost effectiveness, biological phosphorus removal

Economy and results	**Rating**	**Remarks**
Investment	High	
Operation, energy	High	
Operation, chemicals	Low	Without chemical precipitation
Operation, manpower	High	
Exp. Efficiency, SS	High	About 90 %
Exp. Efficiency, BOD	High	About 90 %
Exp. Efficiency, Tot-N	Low	About 20%
Exp. Efficiency, Tot-P	Medium	60-90 %
Result		Good BOD-removal. Tot-P-removal lower than with chemical precipitation

3.8. Expected efficiencies for different treatment alternatives

Treatment	**SS %**	**BOD %**	**Tot-N %**	**Tot-P %**	**Bacteria %**
Grit removal	10	-	-	-	
Sedimentation	60-70	about 30	about 10	about 10	
Chemical precipitation, direct precipitation	about 90	70-80	about 15	about 90	
Biological treatment, oxidation ponds	65-90	about 90	70-80	50-70	>99
Biological treatment, precipitation ponds	70-80	70-90	25-40	0.5-0.8 mg/l (85-95%)	>99
Biological treatment, Aerated lagoons	70-80	80-90	10-20	10-20	
Biological treatment, extended aeration (oxidation ditches)	about 90	about 90	20-40	20-30	
Biological treatment, activated sludge (conventional and SBR)	90	90	about 20	20-30	
Biological treatment activated sludge with chemical preprecipitation or simultaneous precip.	90	90	about 20	85	
Biological treatment activated sludge with biol. nitrogen removal	about 90	about 90	about 75	about 20	

Treatment	SS %	BOD %	Tot-N %	Tot-P %	Bacteria %
Biological treatment with biol. nitrification H.Ø.	90	95	20	35	
Biological treatment with biol. phosphorous removal	about 90	about 90	about 20	60-90	
Biological treatment with biol. nitrogen and phosphorous removal	about 90	about 90	about 75	60-90	
Biological treatment with chemical precipitation and biol. nitrogen removal	90	90	70-80	>90	
Advanced treatment with activated sludge, chemical precipitation, biol. nitrogen removal and filtration	>95	>95	75-80	>95	
Biological treatment, Aerated lagoon + sand bed		90-99	20-40	25-50	
Biological treatment, trickling filters	70-80	80-90	10-20	20-30	
Biological treatment, biorotors (RBS)	70-80	80-90	10-20	20-30	

A detailed table can be found in Annex 4.

4 Sludge treatment

Sludge treatment includes

- thickening
- stabilization (anaerobic digestion, aerobic stabilization, chemical treatment)
- dewatering
- final disposal (utilization on farmland, composting, disposal on garbage dumps or drying and incineration)

Sludge treatment is a very expensive part of the total wastewater treatment costs, especially if the costs for the final disposal are included.

Data regarding sludge production and treatment and diposal costs are shown in Annex 8.

5 Investment costs

It has not been possible to make detailed cost calculations for each case as the conditions vary from place to place. In the literature, it is emphasised that the construction costs for similar installations can vary with a factor 2. It has not been possible to obtain relevant cost information from the Baltic countries and the calculations are therefore based on Swedish figures and expressed in Swedish crowns. In the tables the conversion ratio between Euro and Swedish crowns are given to facilitate a comparison.

The time allocated for the study has also been limited. A number of different sources have therefore been used for the calculation of investment costs. The major source of information is feasibility studies written by VAI VA-Projekt AB and discussions with other engineers at VA-Projekt who have developed standard data for different parts of treatment plants. Data have also been taken from articles and from conference papers.

Detailed cost data for treatment plants of different size were also published in a report from Naturvårdsverket written in 1979.The figures have been converted to the cost situation today, but the relations between e.g. the cost of mechanical equipment and construction cost for basins are the same. (See Annex 3). We have tried to calculate the cost situation in 2002 related to the costs in 1979. This results in a factor 3.0.

Different price indexes have also been consulted. The SCB Factor price index for single family houses and apartment houses gives a factor of 3.1 and the consumer price index gives a factor of 3.03 for the period 1979 – 2002. Cost data in the period 1990 – 2002 have been recalculated with different indexes, e.g. SCB Byggindex. More details for the conversion of cost data can be found in Appendix 3.

Costs for precipitation ponds have been estimated to 25-30 % of the construction costs for comparable compact plants.

No cost for the necessary land area has been included in the calculation, because this cost can vary considerably.

The results of the calculations are presented in Annex 5 and the Summary table. The specific capital costs expressed as cost/pe are always higher for a small installation than for a large installation.

6 Operation costs

A number of different sources have been used for the calculation of operation costs. Data have been taken from articles and from conference papers. Another source of information is feasibility studies written by VAI VA-Projekt AB and discussions with other engineers at VA-Projekt.

A detailed cost study was made by Balmér and Mattsson and published as VA-Forsk report 1993-15. We have tried to recalculate the data with different indexes, e.g. SCB Byggindex and Konsumentprisindex. The costs for precipitation chemicals has increased more than the other types of operation costs.

Details about the cost data used in this study can be found in Appendix 3.

Costs for precipitation ponds can according to literature be estimated to 40% of the operation costs for comparable compact plants.

No costs for final sludge handling have been included in the calculations because of the great variations in technique and final disposal.

Some modern cost figures for sludge stabilization and sludge treatment are given in the VA-Forsk report 2000:2, “Användningsmöjligheter för avloppsslam”. See Annex 8.

The results of the operation cost calculations are presented in Annex 6 and 7 and the Summary table. The specific operation costs and yearly costs expressed as cost/pe are always higher for a small installation than for a large installation.

7 Specific costs

7.1. Calculation of specific costs

VAV has published formulas for calculation of extra costs for industrial wastewater connected to municipal wastewater treatment plants. Formulas and diagrams were presented in the VAV publication P26, “Industriavlopp”, published in 1974. Specific costs for the removal of SS, BOD and Tot-P can be calculated with the help of the formulas or the diagrams. As the price level has changed dramatically from 1974 to 2002, diagrams and certain constants have to be recalculated.

7.2. Charges for industrial wastes in Sweden

Industries with higher concentrations of SS, BOD and Tot-P than in ordinary sewage can be charged for the extra kilograms of polluting material Some Swedish cities have calculated tariffs for the industrial wastewater expressed as specific costs for SS, BOD, COD, Tot-P and Tot-N. Such tariffs are interesting for comparison in this connection.

As examples of industrial surcharges the tariffs of Stockholm Vatten and Käppalaverket are presented. The industries pay the basic cost for the volume of wastewater and an extra cost for such polluting material that can be treated at the municipal WWTP. Wastewater that is corroding or toxic is not allowed and is therefore not included in the tariff.

Stockholm Vatten

Suspended solids	SEK/kg	1.77
BOD7	SEK/kg	2.87
Tot-P	SEK/kg	45.12
Tot-N	SEK/kg	26.27

Käppalaverket

Suspended solids	SEK/kg	(included in the other costs)
COD	SEK/kg	2.50
Tot-P	SEK/kg	50-60
Tot-N	SEK/kg	35

The costs in SEK/kg are based on the real costs for treatment in Stockholm and Käppala. The costs in Stockholm have not been adjusted lately and are probably too low.

8. Description of cost effective methods for repair and change of sewers

8.1 Replacement or renovation, Dig or No Dig Methods

Swedish experiences are that mostly traditional replacement of pipes in built-up areas amounts to more than three times the amount for replacement in unbuilt areas as the costs for restoration of the dug up areas is much more expensive than the material cost for the pipe. Therefore renovation of the existing sewers with no-dig methods are often an economically interesting alternative.

Comparison between Dig and No-Dig methods.

No-Dig Methods
- Less traffic disturbances due to the construction work.
- Construction problems due to difficult ground conditions e.g. high water-table, silt, sand, clay or low foundation depth, are avoided.

Dig Methods
- Appropriate for settling sensitive ground, and when there is severe depressions in the existing pipe
- Combining the relining of sewers and water pipes at the same time decreases the cost for the latter to scarcely more than the materials cost.

8.2 Experiences from Sweden

In Sweden ~90% of the pipes are made of concrete and ~10% made of brick material. 1992 7663 m pipes were renovated. The most common causes of renovations were: Fractures, joint displacement, untight joints, age and settling.

The most common methods of renovation were: continuous pipe as PE-lining, in situ repair with flexible linings, Joint injection. Other methods were short pipe installation, and pipe bursting.

8.3 Choice of method for rehabilitation

The choice of method for rehabilitation must be selected on basis of detailed information of the section to be rehabilitated and the desired operative performance. It is crucial to have a knowledge of the pipes present condition, present and future loadings and infrastructural limitations to the rehabilitation work. Is a decrease of dimension, which is the result of many methods, acceptable? (VAV P66, 1989)

Description of the condition of the network

Capacity

If the line suffers from an insufficient capacity it should be cleared whether this is caused from:

- Groundwater penetration
- Occurance of depressions, sediments, blockages , joint displacement
- Occurance of collapsed segments of the pipe
- Low capacity due to insufficient dimension

If possible stormwater should be disconnected from the wastewater system.

Self Cleaning

Self cleaning is assessed from operation experiences, inclination and disturbances.

Tightness

Tightness could be described by the infiltration of groundwater alternatively as a function of precipitation.

Strength/Resistance

Description of existing cracks and deformation. If the resistance of the material is known this is described.

Methods for investigation

Some methods for investigation of the condition are:

- CCTV *Closed Circuit Television*-investigation for documentation of the sewage status, finding of obstacles and registration of laterals localisation.
- Measurement of pH and temperature for control of the corrosivity of the wastewater
- Flow measurement

Preparations

In order to facilitate entry of linings and to promote bond between renovation materials and existing sewer a cleaning of the sewer is normally needed. The measures contains cutting of roots penetrating the pipes, flushing to get rid of sediments and debris. In order to maximize bond between grout and the existing sewer walls it is necessary to remove bacteriological slimes, roots, soft encrustations and grease.

Flows may, depending on choice of method, have to be diverted in order to ensure a successful rehabilitation.

8.4 Joint injection

Joint injection is suitable to increase the tightness of a pipeline to prevent leakages. The method is normally used when joints are not tight, but can also in some extent be used for mending smaller fissures and fractures. Tightening material is injected in the joints and is instantly hardened in contact with water.

A remote controlled robot can be used for joint injection. Normally, existing manholes can be used for accessing the pipe with the necessary tools. The method can be carried out without need of flow diversion.

Joint injection does not increase the strength of the pipeline. The method is not recommended for preventing existing root problems or if joint displacements are expected. It is necessary to inject all non tight joints in a sewer, otherwise leakages will occur as the groundwater level rises.

8.5 Continuous pipe as PE-lining

Rehabilitation with long pipelines is normally executed with continuously welded PE-lines. This is the most frequent method for rehabilitation of sewers in Sweden.

Pits are needed for insertion of the continuously welded pipelines. The pits are often located at connection points, direction changes and at deformations. The size of the pit required depends of the lining depth and the dimension of the pipe. The pipeline is installed by pressure and/or pulling. During the working phase the pipe is blocked and flow diversion is necessary.

This method can only be used if an decreased dimension is acceptable. Sometimes joint injection is needed between the new and the old pipeline.

8.6 Short Line Installation

Rehabilitation with short pipes can be executed from existing manholes and that is an advantage compared with relining with long PE-Lines. The short pipes are normally 0,5 m and the material is PE, PVC or GAP.

Existing manholes can often be used for the insertion of the short pipes. An iron bar lever can be used to thrust the short pipes into the old pipeline from the manhole. During the working phase the pipe is blocked and diversion is necessary.

It is important to have good joints made for a successful short pipe relining. The short pipes are either welded together or joined with rubber rings. The joint needs to be cleaned from sand and other particles. If external sleeves are used the risk of getting stuck in the pipeline is higher.

This method can only be used if an decreased dimension is acceptable. Sometimes joint injection is needed between the new and the old pipeline. Big directional changes can cause problems due to the joints of the short pipes.

8.7 In Situ Rehabilitation/Cured in place pipes

The method involves the insertion of a flexible lining into the sewer, utilising an inversion process, with in situ curing. The lining consists of a polyester needle felt bag, impregnated with thermosetting polyester or epoxy resin and is inserted into the pipe by water pressure. By heating of the water used for inserting the lining the hardener, textile and the old pipeline are bound together. There can be a small gap between the textile stocking and the old pipeline. If this occurs sealing is required at connections to other pipes and manholes. Depending on the size, up to 300 m may be installed in a single insertion.

Cured in place pipes will normally be executed from manholes with remote controlled robot equipment.

The method permits rehabilitation of pipes with large directional changes, although wrinkling of the textile may occur. During the working phase the pipe is blocked and diversion is necessary.

8.8 Pipe Bursting

This method is used when the old pipeline should be replaced by a new pipeline with almost the same diameter as the old pipe. A new pipe-line is pulled by a bursting unit into the old pipeline. Normally the material for the new inserted pipeline is long continuously welded PE or short PE lines. Installation can be executed from manholes or pits and pits for connection of other pipelines is normally needed.

There are two different methods of pipebursting. Pneumatic pipebursting exerts a hammering force to brake brittle pipes and move the mole forward in the pipe with additional help from a vinch.

In hydraulic pipebursting an hydraulic expander is used to break out the existing pipe both brittle and ductile pipes can be bursted. The method entails alternately expanding and contracting the head and jacking the pipes and burster forward. A winch line is attached to the nose of the expander its purpose is mainly to provide directional stability. The expander unit is also smaller than the pneumatic unit which permits operation from existing man-holes or only small excavation is needed. For this reason short-pipes are often used.

8.9 Other methods

For pipes with big dimensions >1200 a method of assembling flexible half pipe elements inside the pipe can be used. The elements are made of fibreglass armed PE. A mortar is injected between the new and the old pipe and a new strong unit is formed. The pipe elements are put in place by personel inside the pipe. The rehabilitation can be executed from existing manholes with little demands for space above ground.

8.10 Summary

From different aspects the suitability of the methods are graded:

3 very suitable
2 suitable
1 possibly suitable
- unsuitable

Table 1 Grading of suitability for different methods. (from VAV P66, 1989)

Aspect	Joint Injection	Continuous Pipe	Short Pipe	Pipe Bursting	Cured in place pipes
Preserved capacity	3	1	1	3	3
Increased capacity	-	-	-	3	1
Self Cleaning	2	2	2	2	3
Tightness	2	3	3	3	3
Strength	-	3	2	3	2
Resistance	-	2	2	2	2

8.11 Cost Estimates

The cost for the different methods can be divided into

- Design and engineering costs
- Materials costs
- Equipment costs
- Construction costs
- Restoration costs

The design and engineering costs are practically the same for different methods.

Materials costs are depending upon whether the existing pipe should be mended or be procured with a new inner coating or if it should be replaced with a new pipe.

Some specific costs estimates from three pilot projects in Kaunas 1997 are presented below. The dimensions, length and the problems faced are not the same but it gives a hint on the amounts.

Table 2 Costs from pilot projects in Kaunas in USD

Pilot project	**Work**	**Amount**	**Unit cost**	**Total**	% of total
Slip lining in a water pipe (400 mm) to a new diameter of (200)	PEH 250*22.7	60 m	110	6600	31
	Excavation	2	4500	9000	43
	Grouting	60 m	10	600	3
	Design, engineering, unforeseen			4900	23
	Total			**21100**	100
Pipe bursting of a water pipe in bad condition in 2 sections: 120 m 80 mm cast iron pipe and 80 m 100 mm cast iron pipe	Pipe Bursting	200 m	50	10000	26
	PEH 125*11,4	200 m	30	6000	16
	Excavation	3	4500	13500	35
	Design, engineering, unforeseen			8900	23
	Total			**38400**	100
Pipe bursting of a waster water pipe 250 mm made of ceramics with cast iron sections	Pipe Bursting	250 m	130	32500	32
	PEH 315*28,6	250 m	130	32500	32
	Excavation	3	4500	13500	13
	Design, engineering, unforeseen			23600	23
	Total			**102 100**	100

9. Summary and discussion

The results of the calculations of **Investment costs** are presented in Annex 5 and the Summary table. The specific capital costs expressed as cost/pe are always higher for a small installation than for a large installation.

The results of the calculations of **Operation costs** are presented in Annex 7 and the Summary table, Annex 9. The specific operation costs and yearly costs expressed as cost/pe is always higher for a small installation than for a large installation.

Examples of **Specific costs** are presented in Chapter 7.

It is possible to get reasonably good treatment results even with systems, which are not so costly. See Chapter 3.8 and Annex 4.

For small communities it may be interesting to build precipitation ponds to get a good BOD-reduction as well as a good phosphorus removal.

For larger communities it may be interesting to build installations for direct precipitation, as they can give reasonably good BOD-reductions and phosphorus removals. It is also possible to start wit a direct precipitation and later extend the treatment plant with biological treatment and nitrogen removal.

REFERENCES

General

Rennerfelt, J. (2000). Kommunal och industriell avloppsteknik. Biokemisk teknologi, Kompendium, KTH.

Rennerfelt, J. (1974). External treatment. In The SSVL environmental care project, Technical summary. Stockholm 1974.

Statens forurensningstillsyn (1978). Retningslinjer for dimensionering av avløpsrenseanlegg. Oslo 1978.

Hahn, R. and Särner, E. (1983). Water resources development and management in arid and semi-arid regions. Lund institute of technology.

HELCOM, www.helcom.fi/recommendations/reclist.html

Treatment plants

Balmér, P. (1999). Resursförbrukning och driftkostnader vid nitrogenrening i nordiska reningsverk. Nitrogenfjerning og biologisk fosforfjerning. Oslo 1999.

Johansen, O.J. (1999). Processløsninger og driftsstrategier for nitrogenfjerning ved Bekkelaget renseanlegg, Oslo. Nitrogenfjerning og biologisk fosforfjerning. Oslo 1999.

Ødegaard, H. (1985). Kostnadsminimering vid rensning av avløpsvann. NTNF Prosjektrapport 27/85.

Ødegaard, H. (1999). The influence of wastewater characteristics on choice of wastewater treatment method. Nitrogenfjerning og biologisk fosforfjerning. Oslo 1999.

Hultgren, J. (1999). Possibilities with large waste water treatment plants in rock.

Ødegaard, H. (1995). Environmental impact and cost efficiency in municipal wastewater treatment. Trondheim 1995.

Oxidation ponds

Janson, L. och Pajuste, E. (1964). Undersökningar av biodammanläggningar i södra och mellersta Sverige. Kungl Väg- och Vattenbyggnadsstyrelsen, Vatten- och avloppsbyrån, Stockholm .

Towne, W.W., Bartsch, A.F. and Davis, W.H. (1957). Raw sewage stabilization ponds in the Dakotas. Sew. Ind. Wastes, Vol. 29, No 4, p.377 – 396

Precipitation ponds

Ødegaard, H., Balmér, P. and Hanæus, J. (1987). Chemical precipitation in highly loaded stabilization ponds in cold climates: Scandinavian experiences. Wat. Sci. Tech. Vol 19, No. 12, pp. 71-77, 1987.

Hanæus, J. och Holmgren, S. (1982). Erfarenheter av fällningsdammar. Länsstyrelsen Östersund.

Balmér, P. and Vik, B. (1978). Domestic wastewater treatment with oxidation ponds in combination with chemical precipitation. Prog. Wat. Tech. Vol.10, Nos 5/6, pp. 867-880.

Hanæus, J. (1991). Wastewater treatment by chemical precipitation in ponds. Doctoral thesis, Luleå University of Technology, Luleå.

Chemical precipitation

Kemira Kemi AB. (1990). Handbook on water treatment. Helsingborg 1990.

Sewers

VAV (1989). Renovering av avloppsledningar. Riktlinjer för val, dimensionering och utförande. VAV P66.

Water Research Centre (1994). Sewerage Rehabilitation Manual. Water Research Centre 1994.

VAI VA-Projekt and Baltic Consulting Group in association with PlanCenter Ltd and Miestprojektas (1997). Leakage Control, Networks Rehabilitation, Strategy and Engineering support.

Paul Hayward (2001). On-Line Replacement Systems. No-Dig International Vol 12, No. 5, 2001.

Cost calculations

Balmér, P. och Mattsson, B. (1993). Kostnader för drift av avloppsreningsverk. VAV VA-Forsk 1993-15.

Andersson, C., Rydberg, A. Och Alsheden, L. (1993). Sewage treatment costs for minor urban areas. K-Konsult, Stockholm 1993.

Andersson, C. (1992). Teknisk och ekonomisk värdering vid val av reningssystem för kommunal avloppsvattenrening. Svenskt-Polskt seminarium.

Emanuelsson, M. och Andersson, Ch. (1992). Beräkning av kostnaden för kvävereduktion. K-Konsult VA-Projekt AB, Lund 1992.

VAV (1974). Industriavlopp. Normalavtal och taxa för anslutning av industri till kommunal avloppsanläggning. VAV P26.

SCB. Byggindex (1990-2002). Statistiska Centralbyrån.

Andersson, C. och Bornö, C. (1979). Kostnader för avloppsrening. Fördelning av kostnader mellan ingående komponenter i kommunala avloppsreningsverk. Naturvårdsverket, Rapport SNV PM 1237.

Andersson, C. och Bornö, C. (1979). Sammanfattning av PM 1237. Rapport SNV

Nordiska ministerrådet (1982). Driftkostnader för avloppsreningsverk. Nordiska ministerrådet. VA-gruppen 1982:2.

Kjellén, B.J. och Andersson, A-C. (2002). Energihandbok för avloppsreningsverk. VA-Forsk rapport 2002:2.

Tideström, H., Starberg, K., Ohlsson, T., Camper, P-A. och Ek, P. (2000). Användningsmöjligheter för avloppsslam. VA-Forsk 2000:2.

VA-PROJEKT

Uppdrag /Assignment	Upprättad av /Issued by	Datum./Date	Sida /Page
Cost effective methods	Jan Rennerfelt	02-05-02	1(1)
Beställare /Client	Kontrollerad av /Checked by	Ändr./Rev	Ändr.bet./Rev
Naturvårdsverket	J Hultgren	02-11-08	C
Uppdragsnummer /Reference No	Godkänd av /Approved by	Status-ersätter /Replace	
1701378000	J Rennerfelt	Final	

ANNEX 1. BASIC DATA FOR COST CALCULATIONS

Type of treatment plant	**Person equivalents**
Oxidation pond	500 pe
Precipitation pond	1000 pe, 2000 pe
Aerated lagoon with biological sand bed	1000 pe
Direct precipitation	25 000 pe, 125 000 pe,
Extended aeration	10 000 pe
Activated sludge	25 000 pe, 125 000 pe
Activated sludge with N-reduction	25 000 pe, 125 000 pe
Activated sludge with P-reduction	25 000 pe, 125 000 pe
Trickling filter	25 000 pe, 125 000 pe
Activated sludge with N- and P-reduction and filtration	25 000 pe, 125 000 pe

Summary from ”Energihandbok för avloppsreningsverk” (Energy handbook for wastewater treatment plants)

The consumption of electricity in Swedish wastewater treatment plants is about 100 kWh/year, unit. The total consumption of electricity is about 0,6 TWh/year in this sector. The municipal water plants in Sweden use about 0,7 TWh/year electricity .The total consumption of electricity is about 145 TWh/year in Sweden. Water and wastewater plants are therefore responsible for about 1 % the total consumption of electricity in Sweden. The demand for electricity is also increasing in this sector and in the country as a whole.

This energy handbook is based on the German handbook "Energie in Kläranlagen" and presented data are based on a large number of municipal wastewater treatment plants in Nordrhein- Westfalen, in Germany.

The specific consumption of electricity is about ca 90 kWh/year, unit for small and medium sized wastewater treatment plants in Sweden. It means about twice the consumption of electricity in German plants. These are normally larger than the plants in Sweden, but still it seems there is a substantial potential for more efficient utilisation of electricity in Swedish wastewater plants. This is especially true when taken into account that about 35% energy savings have been identified from profitable measures in German plants. The specific consumption can then be reduced to about 30 kWh/year, unit.

The handbook covers different process parts and various possibilities for energy savings, both electricity and heat. A model is also presented how to make an energy audit for a wastewater plant.

Most of the wastewater plants in Sweden were constructed during the 1960-, 70- and 80-ties. A large amount of equipment is therefore old and has to be exchanged. Then measures can be made simultaneously to reduce utilisation of energy. The operating costs for old equipment can be three times higher than for modem and well-adapted equipment.

The consumption of electricity at wastewater plants with sludge digestion is generally of the same order as the heating demand. Practically most plants can cover their heating demand by firing bio-gas, which is produced within the plant. The energy demand to be supplied from outside is therefore much larger on the electricity side. The specific electricity consumption is generally higher for wastewater plants with a nitrogen purification process than for plants without such process.

At wastewater plants many small electric motors can be found. However they have only a small share of the total consumption of electricity for motor operation. To realise concrete energy savings, efforts should therefore be directed to analyse the operation of large electric motors. For example the 20 largest motors are responsible for about 75% of the total consumption of electricity in a wastewater plant.

The biological purification process is responsible for 50- 80% of the total consumption of electricity. Therefore special attention should be directed to study the biological purification process when an energy audit is made.

The production of biogas is the heart of the matter when heating is concerned. Heat savings are only of interest when fuels or heat are supplied from outside at a cost. Increasing the amount of solid substances in the sludge can reduce the heat demand. It can also be reduced by heat insulation of the digestion chamber and by reducing ventilation losses in the plant.

ANNEX 3. INDEX FACTORS FOR COST CALCULATIONS

Index factors

Consumer price index,
Factor 2002/1992 = 1,17

Wages
Factor 2002/1992 = 1,22

Construction costs
Factor 2001/1979 = 3.03
Factor 2002/1979 = 3.11

Factor for precipitation chemicals

Chemical	***Concentration mol/kg***	***1980 SEK/kg***	***1993 SEK/kg***	***2002 SEK/kg***
AVR	3.2	450	1000	1400
JKL	2.1	370	700 (PIX 110)	950 (PIX 110)
PIX 111	2.5		900	1400
PAX 21	2.7		1400	1650
PAX XL60	2.7			1700

Factor for precipitation chemicals 2002/1992 = 1,4
Factor for precipitation chemicals 2002/1980 = 3.1 (AVR) and 2.6 (JKL)
Consumption of chemicals 30-60 mol/pe,year

Costs for civil works (sedimentation basins etc.) and buildings

The relation between costs 2002/1979 has been estimated by VA-PROJEKT to 3.0.
Factor price index 2001/1979, small houses factor 3.14
Factor price index 2001/1979, apartment houses 3.10

Relations between costs for civil works, mechanical equipment etc

Year and reference	Civil works and HVAC %	Mechanical %	Electrical and automation (PLC) %	Engineering and administr %
2002 VA-Projekt BR	40	30	15	15
2002 VA-Projekt CN	40	20-40	10-20	15

1979 SNV Mech.step 5000 pe	41	35	8	18
1979 SNV Mech.step 25000 pe	45	35	6	16
1979 SNV Mech.step 125000 pe	44	40	3	14
1979 SNV Biol.step 5000 pe	53	22	10	15
1979 SNV Biol.step 25000 pe	53	23	10	14
1979 SNV Biol.step 125000 pe	48	31	9	12
1979 SNV Chem.step 5000 pe	44	25	13	18
1979 SNV Chem.step 25000 pe	49	25	10	16
1979 SNV Chem.step 125000 pe	50	26	9	14

Expected efficiencies for different treatment alternatives

Treatment	SS %	BOD %	Tot-N %	Tot-P %	Bacteria %
Grit removal	10	-	-	-	
Sedimentation	60-70	about 30	about 10	about 10	
Sedimentation C.A.	75	30	10	10	
Sedimentation H.Ø	50	30	5	15	
Chemical precipitation, direct precipitation	80-90	60-80	about 15	about 90	
Direct precipitation, Norwegian results	90-92	76-79 (COD)	-	91-95	
Direct precipitation, H.Ø.	90	75	10	90	
Direct precipitation, C.A.	90	70	15	90	
Biological treatment, oxidation ponds	65-90*	about 90* 74-98**	70-80*	50-70*	>99* >99**
Biological treatment, precipitation ponds	70-80	70-90 50-75	25-40 30-80	0.5-0.8 mg/l (85-95%) 90%	>99
Biological treatment, Aerated lagoons	70-80	80-90	10-20	10-20	
Biological treatment, extended aeration (oxidation ditches)	about 90	about 90	20-40	20-30	
Biological treatment, activated sludge (conventional and SBR)	about 90	about 90	about 20	20-30	
Biological treatment, activated sludge with primary sed. C.A.	90	90	20	20	
Biological treatment, activated sludge without primary sed. H.Ø.	90	90	10	30	
Biological treatment activated sludge with chemical preprecipitation	>90	>90	about 20	>90	

Treatment	**SS %**	**BOD %**	**Tot-N %**	**Tot-P %**	**Bacteria %**
Biological treatment activated sludge with chemical preprecipitation or simultaneous precip. C.A.	90	90	20	85	
Biological treatment activated sludge with chemical preprecipitation or simultaneous precip. H.Ø.	90	90	10	85	
Biological treatment activated sludge with biol. nitrogen removal	about 90	about 90	about 75	about 20	
Biological treatment with biol. nitrification H.Ø.	90	95	20	35	
Biological treatment with biol. phosphorous removal	about 90	about 90	about 20	60-90	
Biological treatment with biol. nitrogen and phosphorous removal	about 90	about 90	about 75	60-90	
Biological treatment with chemical precipitation and biol. nitrogen removal	>90	>90	75-80	>90	
Advanced biological treatment with chemical precipitation and biol. nitrogen removal H.Ø	90	95	70	90	
Advanced treatment with activated sludge, chemical precipitation, biol. nitrogen removal and filtration	>95	>95	75-80	>95	
Biological treatment, Infiltration/sand bed CA.		90-99	20-40	25-50	
Biological treatment, trickling filters	70-80	80-90	10-20	20-30	
Biological treatment, biorotors (RBS)	70-80	80-90	10-20	20-30	

*Swedish values **Values from N. and S. Dakota. (Spring to fall)

Investment costs in SEK/pe. adapted from Andersson (1992) and SNV 1237.
An Index factor of 3.0 has been used to convert the relative cost for treatment plants given by Andersson to the cost level in 2002. 1 Euro = 9.12 SEK. 1 SEK = 0.1096 Euro.

Treatment systems	**25 000 pe**			**125 000 pe**		
	total cost	excl. sludge treatm.	sludge treatm	total cost	excl. sludge treatm.	sludge treatm
Mechanical treatment	1140	480	660	630	300	330
Biological treatment (activated sludge) incl. mech. treatm.	2190	1380	810	1200	810	390
Biological treatment (trickling filter) incl mech. treatment	2115	1305	810	1170	780	390
Direct precipitation	1590	780	810	870	480	390
Biol. treatment + preprecipitation	2370	1470	900	1290	840	450
Biol. treatment + preprecipitation + filter	2700	1800	900	1500	1050	450
Biological treatment + nitrogen reduction	3090	2280	810	1740	1350	390
Biol. treatm. + N and P-reduction + filtration	3510	2610	900	1980	1530	450

Operation costs in SEK/pe. adapted from Andersson (1992)
An Index factor of 3.0 has been used to convert the relative cost for treatment plants given by Andersson to the cost level in 2002. 1 SEK = 0.1096 Euro.
The operation costs calculated in this way are probably **too low.** Figures from Annex 7 have been used in the final calculations.

Treatment systems	**25 000 pe**			**125 000 pe**		
	total cost	excl. sludge treatm.	sludge treatm	total cost	excl. sludge treatm.	sludge treatm
Mechanical treatment	66	18	48	36	12	24
Biological treatment (AS) incl. mech. treatm.	129	75	54	84	54	30
Direct precipitation	120	66	54	78	48	30
Biol. treatment + preprecipitation	174	111	63	123	87	36
Biol. treatment + preprecipitation + filter	192	129	63	135	99	36
Biological treatment + nitrogen reduction	156	102	54	102	72	30
Biol. treatm. + N and P-reduction + filtration	219	156	63	153	117	36

Operation costs in SEK/pe and year have been adapted from Balmér (1993). The Index factors used to convert the costs from the price level in 1992 to 2002 are shown in the tables.

Year	index factor	10 000 pe	20 000 pe	50 000 pe	100 000 pe
1992	1.00	220	170	125	110
2002	1.17	(257)	(199)	(146)	(129)

Note. The factor 1.17 underestimates the cost for chemicals. A correction has therefore been made below.

Operation costs excl. chemicals

Year	index factor	10 000 pe	20 000 pe	50 000 pe	100 000 pe
1992	1.00	192	148	110	97
2002	1.17	225	173	129	114

Chemical cost in SEK/pe and year adapted from Balmér (1993)

Year	index factor	10 000 pe	20 000 pe	50 000 pe	100 000 pe
1992	1.00	28	22	15	13
2002	1.4	39	31	21	18

Operation costs incl. chemicals in SEK/pe and year

Year	index factor	10 000 pe	20 000 pe	50 000 pe	100 000 pe
2002	1.17 and 1.4	264	204	150	132

1 SEK = 0.1096 Euro.

Sludge production

Standard calculation of sludge production - mechanical, biological and chemical treatment

SludgeType	**g/p,d**		
Primary sludge	55		
Biological sludge	35		
Chemical sludge	25		
Total	115	Organic part 67 g/pd	(58 %)

Standard calculation of sludge production – mechanical and biological treatment

SludgeType	**g/p,d**		
Primary sludge	55		
Biological sludge	35		
Total	90	Organic part 67 g/pd	(74 %)

Table 1. Sludge production, kg/d.

Plant size, pe	**Mech + bio**		**Mech + bio +chem**	
	total	**organic**	**total**	**organic**
10 000	900	670	1 150	670
20 000	1 800	1 340	2 300	1 340
100 000	9 000	6 700	11 500	6 700

Digestion is only economically feasible for plants over 20 000 pe.

Sludge treatment and disposal cost (Disposal on farmland)

From Tideström et al. (2000).

Plant size	**cost type**	**20 000 pe**	**100 000 pe**
Investment cost for digestion	SEK	6 000 000	20 000 000
Operation cost for digestion	SEK/year	200 000	500 000
Investment and operation costs for digestion	SEK/ton DS	1000	600
Capital costs excl. digestion	SEK/ton DS	70	70
Storage costs	SEK/ton DS	230	230
Operation costs excl. digestion excl digestion	SEK/ton DS	90	90
Other operation costs. QA and administration	SEK/ton DS	130	130
Transports (30 km)	SEK/ton DS	160	160

1 SEK = 0.1096 Euro.

SUMMARY TABLE

Annex 9

Treatment	Connection pe	Investment cost 1000 SEK	Investment cost SEK/pe	Capital cost SEK/pe,year	Operation cost SEK/pe,year	Yearly cost SEK/pe,year	Cost SEK/m3
Oxidation pond	500	1645	3290	287	44	331	2.31
Precipitation pond	1000	1466	1466	151	77	228	1.59
Precipitation pond	2000	2565	1283	132	58	190	1.33
Aerated lagoon + biol.sand bed	1000	5335	5335	465	37	502	3.50
Direct precipitation	25 000	39 750	1590	164	174	338	2.36
Direct precipitation	125 000	108 750	870	90	116	206	1.44
Extended aeration	10 000	26 400	2640	271	220	491	3.36
Activated sludge	25 000	54 750	2190	217	190	407	2.85
Activated sludge	125 000	150 000	1200	124	132	256	1.79
Activated sludge N-red	25 000	77 250	3090	318	158	476	3.33
Activated sludge N-red	125 000	217 500	1740	179	100	279	1.95

Treatment	Connection pe	Investment cost 1000 SEK	Investment cost SEK/pe	Capital cost SEK/pe,year	Operation cost SEK/pe,year	Yearly cost SEK/pe,year	Cost SEK/m3
Activated sludge P-red	25 000	59 250	2370	244	190	434	3.03
Activated sludge P-red	125 000	161 250	1290	133	132	265	1.85
Trickling filter	25 000	52 875	2115	218	180	398	2.78
Trickling filter	125 000	146 250	1170	121	122	243	1.70
Activated sludge N-red, P-red, filter	25 000	78 750	3510	362	198	560	3.92
Activated sludge N-red, P-red, filter	125 000	247 500	1980	204	140	344	2.41