Appendix 3: Documentation of Expenditure Functions - Wastewater

1 Wastewater

The wastewater infrastructure comprises the following elements:

- Septic tanks;
- Small treatment plants;
- Collection network;
- Pumping stations; and
- Wastewater treatment plants.

Below, the investment and O&M expenditure functions of each type of infrastructure are described.

The investment expenditure function is actually a replacement value functions which is used to estimate three types of expenditure need. the annual re-investment expenditure, the renovation need and the investment expenditure in case of service extensions requiring new infrastructure.

1.1 Septic Tank

Septic tanks are usually used for treatment of sanitary wastewater from individual households. In principle, septic tanks provide primary treatment with settling of solid phase and cold anaerobic digestion of settled solids. Effluent overflows to the recipient. Sludge must be removed regularly, e.g. once or twice a year, and transported for final treatment in a wastewater treatment plant or otherwise stabilised.

1.1.1 Investment Function

The replacement value function comprises the following parameters (international price level, 2002):.

Construction:
EUR/p.e. = -98 * log(p.e.) + 835[1]

[1] Connection to existing sewer pipes is assumed, i.e. excl. connection to house installations and discharge facilities.

It can be assumed that civil works amount to about 90% of the construction costs. The remaining 10% is equipment.

The lifetime of the septic tank is assumed to be 25 years. Thus, the annual need for re-investment is 4%.

1.1.2 O&M Expenditure function

The operation of the septic tank includes emptying the tank, transport and final treatment/disposal of the sludge. FEASIBLE offers the following options:

- No collection and disposal of the sludge
- Collection, transport and disposal at a wastewater treatment plan
- Collection, transport and disposal at a municipal landfill

It is assumed that the amount of sludge collected in the tank is 0.5 m^3 per person (PE). The amount of BOD is assumed to be 20-25% of the standard PE value, i.e. 15 BOD per day.

The collection and transport costs are assumed to the same as those of collection of municipal solid waste. The type of truck used will differ, but it is assessed to cost approximately the same. The resulting costs are assumed to be:

- Collection cost: about 200 EUR/tonne.

- Cost of transport of sludge from the septic tank: 0.34 EUR per tonne/km.

Disposal at wastewater treatment plant implies that the amount of wastewater is added to amount collected in the network.

1.2 Small Treatment Plants

There are three options as to small treatment plant technology:

- Reed bed treatment;
- Biological sand filters; or
- Stabilisation ponds.

1.2.1 Reed Bed Treatment Plants

Reed bed plants consist of a primary sedimentation tank (septic tank) followed a shallow soil filter planted with reed. Sanitary wastewater flows through the plant and undergoes treatment by means of settling, biological decomposition, filtration and adsorption to humus and clay.

The treated wastewater flows to the recipient. Septic sludge must be removed frequently and transported for final treatment at a wastewater treatment plant or otherwise stabilised.

Expenditure functions, less than 2,000 p.e.
The replacement value function is shown below assuming an international year 2002 price level:

EUR/p.e. = -1390 * log(p.e.) + 6,300

It can be assumed that civil works amounts to about 80% of the construction costs.

The O&M cost function is shown below assuming the same price level as the replacement value:

EUR/year = 13.5 * p.e. + 6,750

1.2.2 Biological Sand Filters

Biological sand filters consist of a primary sedimentation tank (septic tank) followed a ventilated sand filter. Sanitary wastewater flows through the plant and undergoes treatment by means of settling, biological decomposition and filtration.

The treated wastewater flows to the recipient. Septic sludge must be removed frequently and transported for final treatment at a wastewater treatment plant or otherwise stabilised.

Expenditure functions, less than 2,000 p.e.
The replacement value function is shown below assuming an international year 2002 price level:

EUR/p.e. = -5697 * log(p.e.) + 3,520

It can be assumed that civil works amount to about 80% of the construction costs.

The O&M cost function is shown below assuming the same price level as the replacement value:

EUR/year = 13.5 * p.e. + 6,750

1.2.3 Stabilisation Ponds

A simple pond system consists of a screen, a grit, a grease chamber and stabilisation ponds. Stabilisation ponds are shallow earthen basins with a long detention time. Biological treatment takes place by means micro organisms. The solids and dead micro organisms settle on the bottom, and the treated wastewater overflows to the recipient.

Settled sludge is removed regularly e.g. once a year and utilised as fertilizer or disposed of to a landfill after dewatering.

Stabilisation ponds are suitable for hot climates, only.

Expenditure functions, less than 2,000 p.e.
The replacement value function is shown below assuming an international year 2002 price level. It is further assumed that the average temperature in ponds are 18°C.

EUR/p.e. = -257 * log(p.e.) + 1,120

It can be assumed that civil works amount to about 80% of the construction costs.

The O&M cost function is shown below assuming the same price level as the replacement value:

EUR/year = 13.5 * p.e. + 6,750

1.3 Wastewater Collection

This component includes the works in relation to a single pipe wastewater collection system from the property lines to the wastewater treatment plant, i.e.

- Network collection system
- Service connections
- Main/trunk/interceptor sewers

Similar to the case of the water distribution network, cost estimations for the collection network are based on three cases:

- No information about the length of the network,
- Information available about the total length of network, but no data on pipe diameters
- Full data on both length and diameters.

The cost estimation is based on the costs of four diameters groups. In case no data on the length of pipe in each group is available, FEASIBLE calculates a default length which the user can modify.

The function for estimation of total pipe length is:

If population < 50,000 then L2 = Pop * (-0.05833 * Pop + 4.92)

If 50,001 < population < 500,000 then L2 = Pop * (-0.00278 * Pop + 2.14)

If population > 500,001 then L2 = 0.75 * Pop

Based on either the result of applying these default functions or the length of the network inserted directly, the distribution on pipe diameters takes place based on the following default values.

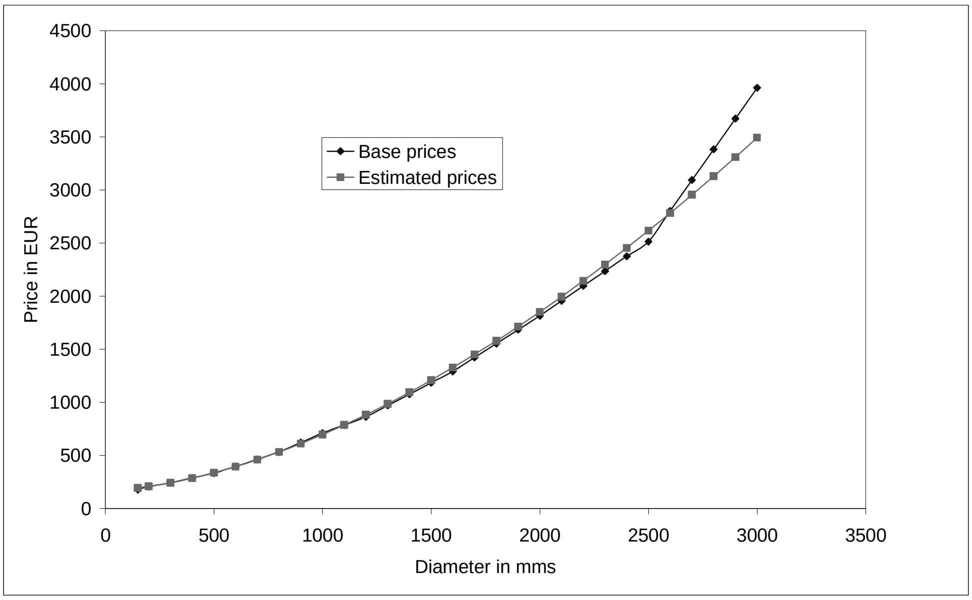
Table 1 Default distribution on pipe diameter for collection networks

Length of network	Distribution of length on diameter groups (%) ≤ 500 mm	501 - 1000	1001-1500	> 1500	Total (%)
≤ 5,000	100	0	0	0	100
5,001 - 50,000	85	11	4	0	100
50,001 - 500,000	83	10	5	2	100
> 500,000	81	9	6	4	100

Source: Consultant's estimate

The expenditure functions are illustrated below. The graph includes both the point cost estimates and the fitted curve which has been used to derive the costs used here.

Figure 1 Unit costs for wastewater pipes of different diameter, EUR per m



Source: Consultant's estimate

By applying the 4 different size categories, the cost of each diameter group is determined by the average diameter in each group entered into the attached expenditure functions. In principle, the calculation of each size of pipes, thus, takes place by multiplying the length of the pipe of that specific diameter by a unit cost per meter.

The price correction is done using the general principle of cost shares and price indicators. The cost shares differ among pipe sizes, the larger the pipe diameter, the larger the share of the costs of the pipe itself compared to the civil works, reinstatement of the road surface etc.

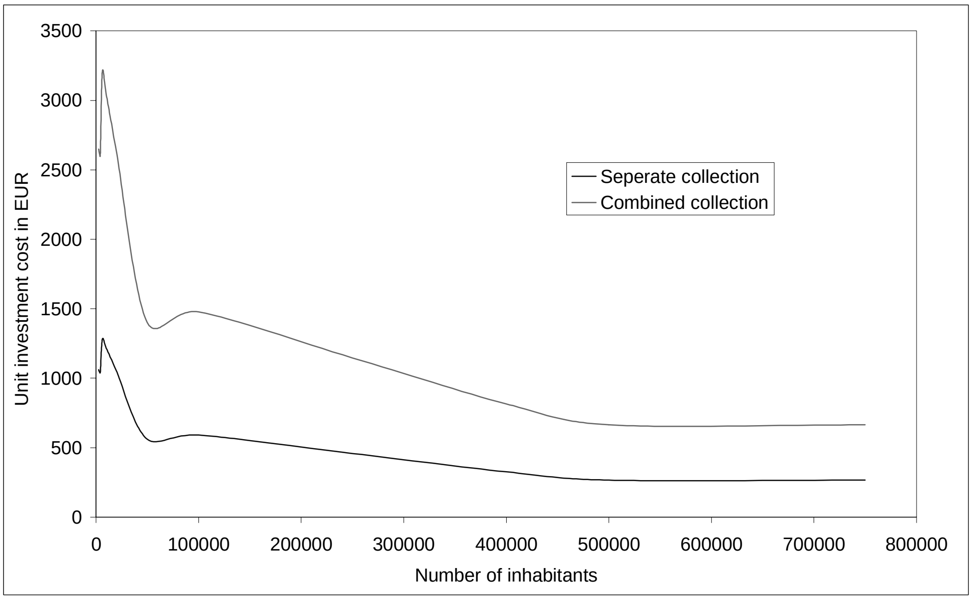
Table 2 Default values for pipe costs and distribution of cost shares

Average diameter mm	Total cost per meter EUR	Material %	Civil works %	Re-instatement %	Adm. and design %	Contin-gency %	Total %
250	222	16.34	20.83	32.52	17.30	13.00	100
750	494	28.76	21.10	25.13	12.01	13.00	100
1,250	934	37.88	21.37	19.41	8.34	13.00	100
2,000	1852	47.22	21.77	13.18	4.82	13.00	100

Note: Reinstatement: Reinstatement of road surface
Source: Consultant's estimate

Replacement value and re-investment
The expenditure functions described above give the cost of establishing a new network with the given length of each diameter size. This value, which we call the replacement value of the network, is first of all used to estimate the amount of necessary re-investment of keeping the system at the current value. As described in the general section on reinvestment (see appendix 1).

Figure 2 Replacement value function for wastewater collection networks



Source: Consultant's estimate

The total replacement value function illustrated above is a result of combining the assumptions on the function concerning total pipe length based on connected population, with the default distribution on pipe diameters as a function of population size and, finally, the unit price of pipes of different diameters. It reflects the unit replacement value of the collection system as a function of population.

The values shown are in EUR per capita. Figure 2 shows the unit replacement value of a collection network in case of either a separate or a combined system.

The investment expenditure of a single pipe separate system excludes storm water run-off, i.e. it is designed for separate sanitary wastewater only. FEASIBLE allows estimation of the cost in case of storm water and wastewater being collected in the same pipeline located in the street, i.e. a combined sewerage system (CSS). The expenditure is suggested to be 2.5 times that of a separate system.

The re-investment is calculated as the annual depreciation of the network, and it is assumed to be a constant annual amount derived from the lifetime of the network. FEASIBLE allows two different pipe qualities with different prices and lifetimes. The expenditure functions above are based on the price of 1 quality of pipes.

The lifetime of 1st quality water supply pipes is estimated at 50 years, while that of 2nd quality pipes is estimated at only 25 years. However, the price of the latter is approximately half the price of the highest quality pipes.

Thus, annual re-investment as a percentage of the total replacement value is given below.

Table 3 Annual reinvestment as a percentage of the total replacement value

Pipe quality	Annual re-investment in % of total replacement value
1st quality	2%
2nd quality	4%

Source: Consultant's estimate

Taking as an example a 250 mm pipe, the annual re-investment per meter of the 1st quality will be around USD 4, while for the 2nd quality, it will be USD 8. In case of a significantly lower price level for civil works etc., the difference will become smaller.

Renovation and service extension
Renovation of wastewater collection networks is estimated based on input by the user on percentage renovation. The replacement value is simply multiplied by this percentage.

Service extensions can take two forms. It can either be an extension of an existing network. In such case, FEAISBLE estimates the need for new network by increasing the length of all diameter sizes proportionally to the number of connected inhabitants. If, for example, there is an increase in the number of connected inhabitants to a central sewer network by 10%, it is assumed that an additional 10% of all existing diameters are needed. This default may be overwritten by the user, if information is available about the needed length of new pipes of various diameters.

In the case of a new town with no existing network, the user has the same options as described above for existing networks. If no information is available, FEASIBLE will use the defaults to estimate the total length and distribution on pipe sizes. If the total length is known, only the defaults on distribution is needed, and the user may also have all necessary input data for detailed specification.

Service connections
By service connections is meant the part of the network which is placed on the consumers' property. This part of the system is, therefore, usually not the responsibility of the wastewater company and the associated expenditure is private.

1.3.2 Operational Expenditure

The operational expenditure covers:

- Staff, building, materials and vehicles for cleaning and inspection of the sewer network

The operational expenditure for wastewater services will be estimated using a percentage of the investment expenditure. This covers all operational expenditure except electricity, which will be specified separately, section on pumping stations.

For cleaning and inspection, the consultant recommends 1% of the value of a new system.

1.3.3 Network Expenditure, Adjustment to Local Conditions

In order to adapt the generic expenditure functions to local conditions, a number of correction factors are recommended[2].

In the following, special physical conditions will cause higher unit expenditure of construction are listed along with factors by which the expenditure of the collection system should be multiplied. It is recommended to use the factors where no local data allows a more detailed assessment:

1) The service areas have soft ground, which implies that either the ground must be excavated and filled with sand, or the pipes must be piloted:

   Factor= 1.2

[2] The selection and application of these factors is the sole responsibility of the user. The user should consider whether these default factors are appropriate in the specific context. It is assumed that, prior to these corrections, a general correction to the local price level has been made.

2) The service areas have rocky ground, which implies difficult excavation conditions or a need for blasting:

   Factor = 1.2

3) The service areas have a high groundwater table, which implies a need for pumping during the construction period:

   Factor = 1.1

4) The service areas will need only spot wise road surface reinstatement when collection pipes are constructed or replaced:

   Factor = 0.8

1.4 Pumping Stations

1.4.1 Investment Expenditure Function

The expenditure related to pumping is estimated in the following way. The user should specify the number of pumping stations and the total installed capacity. Based on the installed capacity, the total replacement value of the pumping stations is estimated.

FEASIBLE enables an estimate of only upgrading the pumping stations to achieve a higher efficiency. That is only to replace pumps etc., but not the buildings.

The two functions are:

1 New installation or total replacement value:

$Unit\ expenditure_{pst}$ = 2 * (16,570 * Installed cap (in kW) $^{0.559}$)

$Total\ expenditure_{pst}$ = $Unit\ expenditure_{pst}$ * number of pumping stations

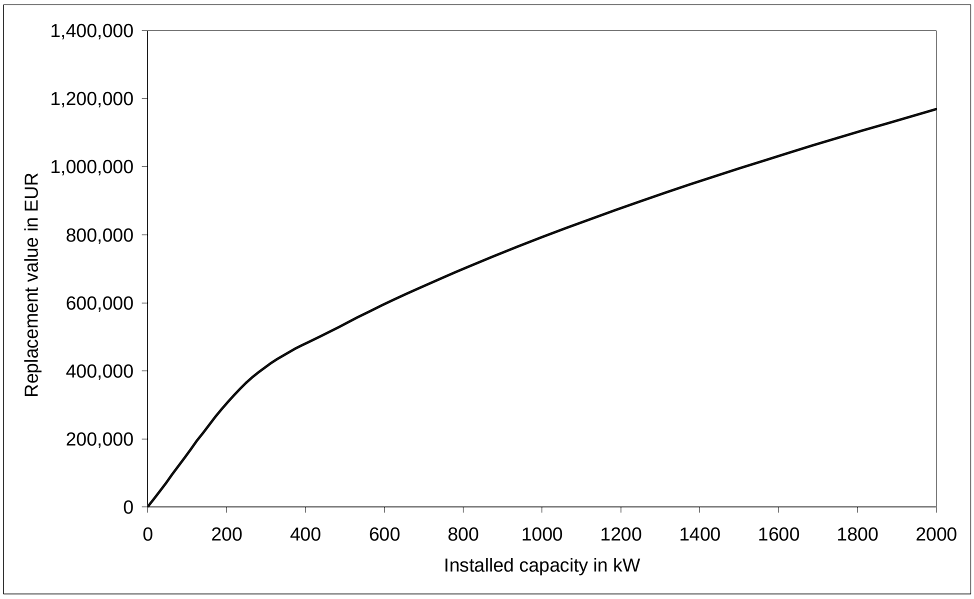
2 Upgrading:

$Unit\ expenditure_{pst}$ = (16,570 * Installed cap (in kW) $^{0.559}$)

$Total\ expenditure_{pst}$ = $Unit\ expenditure_{pst}$ * number of pumping stations

The unit function for upgrading of pumping stations is shown below.

Figure 3 Expenditure function for upgrading of pumping stations



Source: Consultant's estimate

1.4.2 O&M Expenditure Function

The O&M costs comprise electricity consumption, maintenance in terms of small repairs and some manpower for inspection and maintenance.

The electricity consumption constitutes the largest part of the O&M costs, and it is calculated based on the following data:

- Total electricity consumption for pumping of wastewater in kwh
- Total amount of wastewater collected in m^3;
- Number of pumping stations; and
- Energy efficiency in both base and target years.

Energy consumption per pumping stations = total electricity / number of PS

Energy consumption per m^3 collected = total electricity / amount of wastewater

If there is no information about the electricity consumption for pumping, but only a total for collection and treatment of wastewater, the default value is 40% of the total used for pumping. If there is no information about electricity per m^3, the default value is 0.5 kWh/m^3. In that case, the total electricity consumption for pumping is given as 0.5 kWh/m^3 * total amount of wastewater collected in m^3.

For the base year, expenditure for electricity consumption is simply the total electricity consumption for pumping multiplied by the national electricity price.

For the target year, the consumption depends on whether an upgrading takes place. If the pumping stations are upgraded, the electricity cost is calculated in the following way:

Electricity in target year (kWh/m^3) = kWh/m^3 in base year * (1 + renovation % * ((efficiency base year/efficiency target year) - 1))

In addition to the electricity consumption, the maintenance expenditure is 1% of the replacement value of the pumping stations, and the operational costs are assumed to be 0.5% of the replacement value.

The distribution on cost elements is as shown in the below table.

Table 4 Distribution of O&M costs on cost elements (%)

	Material	Labour	Other
Maintenance expenditure	25	50	25
Operational expenditure	15	60	25

Source: Consultant's estimate

1.5 Wastewater Treatment

This component includes the wastewater treatment plant and the outfall pipeline, if applicable.

Expenditure functions for wastewater treatment were developed as part of a project for DEPA[3]. Data was collected for 24 newly constructed treatment plants, systematised and compared with the costing model presented in section 7. Overall, the ratio between model price and actual price was 0.96. The model underestimated the expenditure (ratio 0.89) for plants below 10,000 p.e., while the ratio for larger plants was close to 1[4]

The operational expenditure of wastewater treatment presented is based on the experience of the consultant with advanced treatment plants, during the last 10 years.

The following combinations of wastewater treatment plants are considered:

M	Mechanical	Category 1
MC	Mechanical-Chemical	Category 2
MB	Mechanical-Biological	Category 2
MBC	Mechanical-Biological-Chemical	Category 3
MBN	Mechanical-Biological-Nitrification	Category 3

[3] DEPA: Calculation system for investment costs for wastewater treatment (in Danish), COWI and Lønholt&Jans I-S, 1990.

[4] For the two plants larger than 100,000 p.e. the model overestimated the cost with 24%, however, the low number of plants did not permit any generalisation or correction.

MBCN	Mechanical-Biological-Chemical-Nitrification	Category 4
MBNP	Mechanical-Biological-Nitrification-Organic P	Category 4
MBND	Mechanical-Biological-Nitrification-Denitrification	Category 4
MBCND	Mechanical-Biological-Chemical-Nitrification-Denitrification	Category 5
MBNDP	Mechanical-Biological-Nitrification-Denitrification-Organic P	Category 5

The investment expenditure of wastewater treatment plants is divided into categories 1 to 5 as shown above.

The influent water quality assumed is illustrated in the table below

Table 5 Influent quality in mg/L (yearly average)

BOD	N	NH_4 - N	P	SS
250	50	30	8	300

Source: Consultant's estimates.

The categories are assumed to provide the effluent quality illustrated.

Table 6 Effluent quality by type of treatment (in mg/L - yearly average)

Treatment	Expenditure category	Effluent quality in mg/L				
		BOD	N	NH_4 - N	P	SS
M	1	175	45	35	7	25
MC	2	100	40	35	2	25
MB	2	25	35	30	6	25
MBC	3	15	35	30	1	25
MBN	3	15	35	2	6	25
MBNC	4	15	35	2	1	25
MBND	4	15	8	2	6	25
MBNDC	5	15	8	2	1	25
MBNDP	5	15	8	2	1	25

Source: Consultant's estimates.
Note: The assessment of effluent quality is based on frequent 24-hour sampling proportional to flow (say, at least 12 samples taken at regular intervals over one year).

Organic pollution is the primary parameter for establishing the expenditure functions for the capital expenditure of new wastewater treatment plants.

The following assumptions have been made:

- The pollution parameter used in the expenditure functions is PE. The number of PE is defined at the total load of BOD (including industry) divided by 60 g/day.

- The function assumes a wastewater flow of 200 l/PE/day.
- $BOD_{inlet}/N_{inlet} = 4.5$
- Peak $flow_{rain}$/Peak $flow_{dry\ weather}$ is equal to 2
- The design temperature of inlet water is 7 ^{o}C[5]
- "Medium quality" design. Very fancy and very cheap solutions have not been assumed.

The expenditure functions are shown in Table 7.

New connections are estimated as the number of people assuming one P.E per person, while the effect of industries has to be assessed as part of the pre-model analysis.

Table 7 Investment expenditure functions for wastewater treatment plants

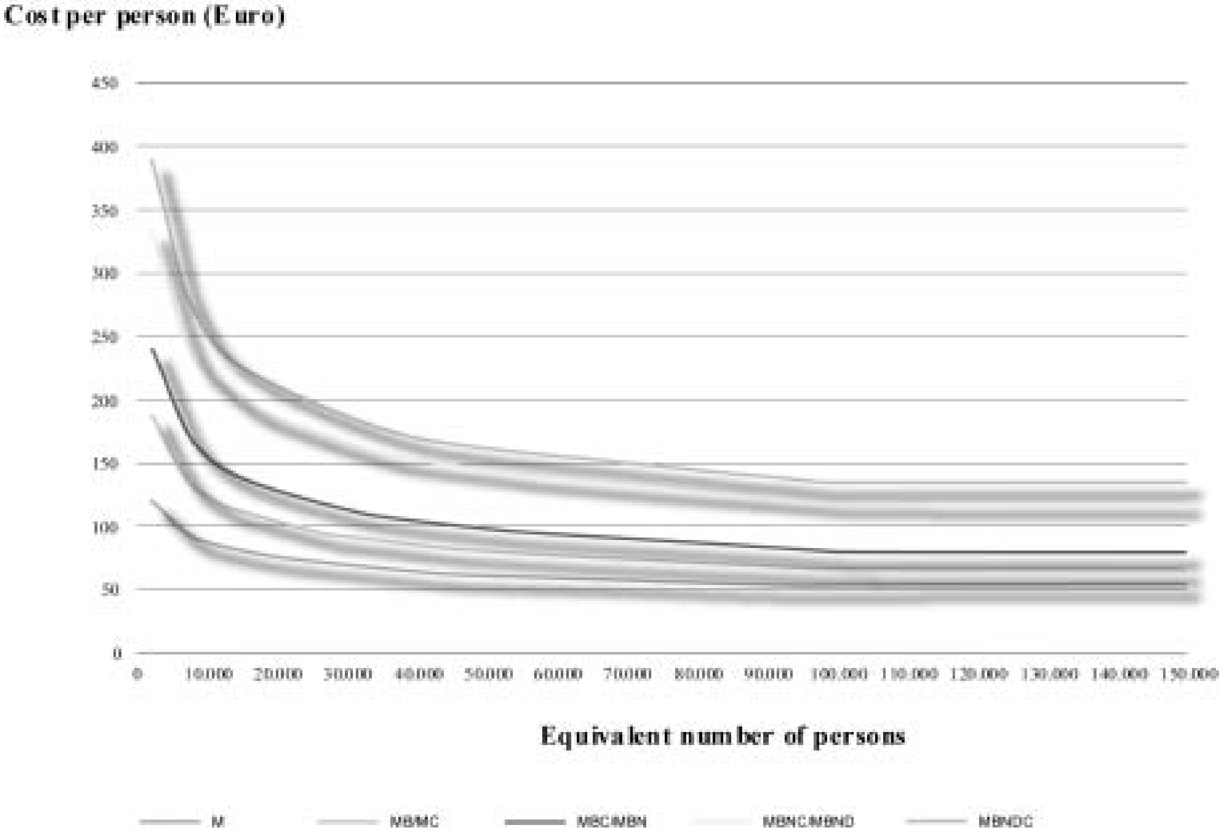
	Load in P.E.			
Technology	<400	400-2,000	2,000-100,000	>100,000
M	188.1	=10^(-0.2745*log(PE)+3.8605)/7.44	=10^(-0.2073*log(PE)+3.6385)/7.44	53.8
MC	403.2	=10^(-0.4735*log(PE)+4.7093)/7.44	=10^(-0.2632*log(PE)+4.0149)/7.44	67.2
MB				
MBC	483.9	=10^(-0.4307*log(PE)+4.6769)/7.44	=10^(-0.2808*log(PE)+4.1823)/7.44	80.6
MBN				
MBNC	779.6	=10^(-0.5229*log(PE)+5.1240)/7.44	=10^(-0.2612*log(PE)+4.2600)/7.44	121.0
MBND, MBNP				
MBNDC, MBNDP	873.7	=10^(-0.5015*log(PE)+5.1178)/7.44	=10^(-0.2722*log(PE)+4.3608)/7.44	134.4

Source: Consultant's estimates.
Note: The expenditure is given in EUR/p.e., price level 1990. In FEASIBLE, the figures have been corrected to reflect the 1999 price level.

The expenditure functions are illustrated in Figure 4.

[5] We acknowledge the fact that inlet temperatures in many towns in the CIS are substantially higher, maybe 12 ^{o}C, which reduces the capital costs significantly. However, we believe that inlet temperatures will fall to European levels as energy prices go up and energy efficiency concerns lead to less waste of hot water.

Figure 4 Investment expenditure functions for wastewater treatment.



Source: Consultant's estimate

1.5.1 Renovation and Re-Investment

Renovation

When no data exists which permits the user to asses the renovation need as a percentage of the investment expenditure of a new system, it will be assumed that the renovation expenditure is equal to the investment expenditure of a new system.

Re-investment

Re-investment is determined using the user's estimate of the current value of the plant. If the value is estimated to be 50%, then the annual re-investment will be 4 % in the first year of the planning period. It will increase over time and reach 8% after about 12 years and then it will remain at that level unless the plant is renovated or replaced. See Appendix 1 for more details.

1.5.2 Operational Expenditure

The operational expenditure for wastewater services is estimated using a percentage of the investment expenditure. This covers all operational expenditure except electricity, which will be specified separately.

Electricity consumption:

Category 1:	15 kWh/year/PE
Category 2:	25 kWh/year/PE
Categories 3-5:	40 kWh/year/PE

These values are for an efficiency of 40%. The model allows for efficiency improvements. By investing in replacement of electric equipment, it is possible to increase efficiency. The user enters the new efficiency level (the same efficiency as used for renovated pumping stations). It is assumed that the electrical equipment comprise of the total replacement value of the treatment plant.

Other operational expenditure: 3% of the total investment expenditure for wastewater treatment.

1.5.3 Plant Expenditure, Adjustment to Local Conditions

In order to adapt the generic expenditure functions to local conditions, a number of correction factors are recommended[6]

A number of special physical conditions which will cause higher unit expenditure of construction are listed below along with factors by which the expenditure of the collection system should be multiplied, when relevant. It is recommended to use the factors where no local data allows a more detailed assessment:

1) The site has soft ground with a high groundwater table, which implies that either the ground must be excavated and filled with sand or the constructions must be piloted:

   Factor = 1.3

2) The site has rocky ground, which implies difficult excavation conditions or a need for blasting:

   Factor = 1.3

3) The plant receives storm water from a combined system, with a magnitude of 3-4 times max wastewater flow.

   Factor = 1.2

4) The plant is designed for a wastewater flow different from 200 l/PE/day.

[6] Selection and application of these factors is the sole responsibility of the user. The user should consider whether these default factors are appropriate in the specific context. It is assumed that prior to these corrections, a general correction to the local price level has been made.

Factor=1+(Actual flow-200)/200*0.3 (For plants >M)

This factor is only valid in the range 0.85 to 1.3. For flows lower than 100 l/PE/day, a factor of 0.85 should be used. For flows higher than 400 l/PE/day, special considerations have to be made. Most likely, employing other measures to reduce the wastewater flow will be preferable, i.e. water demand management or sewer rehabilitation.

Factor=1+(Actual flow-200)/200*0.5 (For plants =M)

This factor is only valid in the range 0.75 to 1.5. For flows lower than 100 l/PE/day, a factor of 0.75 should be used. For flows higher than 400 l/PE/day special considerations have to be made. Most likely it will be preferable to employ other measures reducing the wastewater flow i.e. water demand management or sewer rehabilitation

5) Final sludge disposal.

The following amounts of sludge will normally be produced:

Table 8 Assumptions as to sludge production

Plant type	Stabilised dry solids (kg/PE/year)	Dewatered 25% (m3/PE/year)
M	13	0.05
MC	23	0.09
MB, MBN, MBND, MBNP, MBNDP	20	0.08
MBC, MBNC, MBNDC	30	0.12

Source: Consultant's estimates.

These calculated amounts must be added to the amount of solid waste to be deposited in the city, and the solid waste expenditure functions from investment in the facilities must be used.

6) Temperature of inlet water. If the temperature is higher than 7 ^{o}C, it will be possible to save substantial costs due to a smaller required size of basins. However, great care should be exhibited prior to reducing capital expenditure for this reason. Will inlet temperatures remain higher in the future? or will they be affected by changes in consumption patterns for hot water or other changes?

1.6 Cost Element Shares

The weight factors for correction of investment expenditure to reflect the local price level are given in Table 9. These weight factors are equal to the structure of the total investment expenditure. For each type of water infrastructure, the table shows how the total investment is distributed on various expenditure elements. The shares for each type sum to 100% (each row).

Table 9 Weight factors for price correction of investment expenditure (% of investment expenditure)

	Equipment[7]	Civil works		Other expenditure		
		Materials	Labour	Engineering & administ.	Contin-gency	Land
WATER						
Network	48 %	12 %	20 %	10 %	10 %	0.1 %
Groundwater	48 %	20 %	10 %	10 %	10 %	0.2 %
Basic surface water	48 %	20 %	10 %	10 %	10 %	0.2 %
Advanced surface water	55 %	15 %	10 %	10 %	10 %	0.2 %
WASTEWATER						
Collection	40 %	10 %	25 %	10 %	15 %	0.1%
Treatment	36 %	34 %	10 %	10 %	10 %	0.2%

Source: Consultant's estimates.

The total operational expenditure is adjusted to the local price level by using a similar set of weights. For the water supply sector, these weighs are equal to the structure of the total operational expenditure on a number of expenditure items..

For wastewater, operational expenditure is the sum of energy expenditure that is calculated directly using unit energy consumption and local energy price and the remaining operational expenditure in the international price level estimated based on the expenditure function. Therefore, the weight factors shown below do not include a value for energy in the case of wastewater.

[7] Mechanical, electrical and pipe supply

Table 10 Weight factors for price correction of operation expenditure (in international price level)

	Energy	Materials	Salary	Others	Total
WATER					
Groundwater and network	20 %	15 %	50 %	15 %	100 %
Basic surface water and network	15 %	20 %	50 %	15 %	100 %
Advanced surface water and network	15 %	20 %	50 %	15 %	100 %
WASTEWATER					
Collection		28 %	56 %	16 %	100 %
Treatment		40 %	40 %	20 %	100 %

Source: Consultant's estimates.