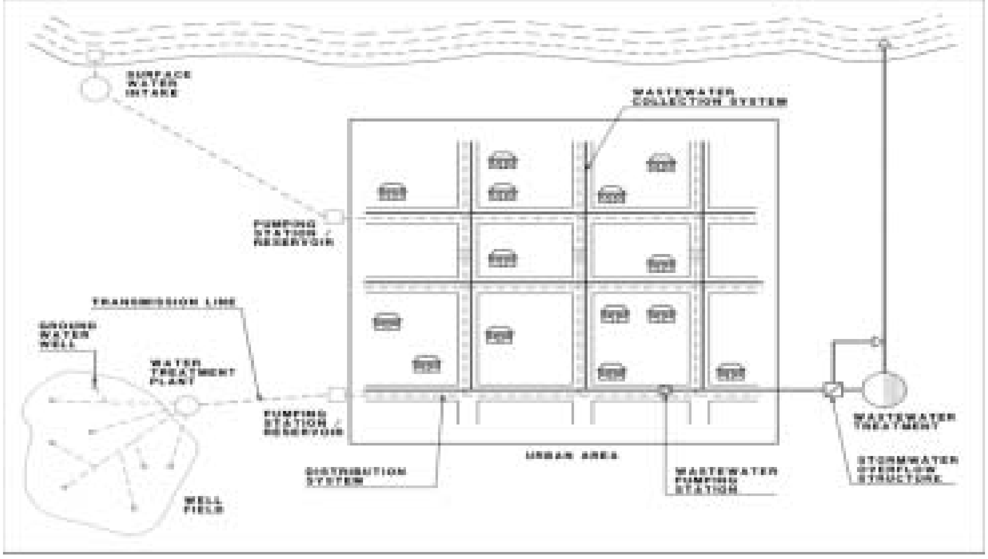
Appendix 2: Documentation of Expenditure Functions - Water Supply

1 Water Supply

The presentation is structured along technical components, starting at the raw water intake moving through the distribution network, via sewage collectors to the wastewater treatment plant as illustrated in the figure below.

Figure 1 Schematic illustration of the basis for expenditure functions



Source: Consultant's estimate

There are two types of expenditure function:

- Investment expenditure functions
- O&M expenditure functions

These expenditure functions are described in sections 1.1 and1.2, respectively.

1.1 Investment Expenditure Functions

Water supply consists of into two components:

- water abstraction/intake, transmission and treatment
- water distribution

1.1.1 Water Intake, Transmission and Treatment (ITT)

The following options are available:

Table 1 Water supply technologies for central supply systems

	Municipality size (number of inhabitants)		
Technology	30-300	300 - 5,000	> 5,000
Groundwater			
No treatment	X	X	X
Normal treatment	X	X	X
Surface water			
No treatment			X
Normal treatment			X
Advanced treatment			X

For all technologies there is the further option of including the 2-lift or not. The lift actually relates to the distribution, but it is included in the ITT expenditure functions for convenience.

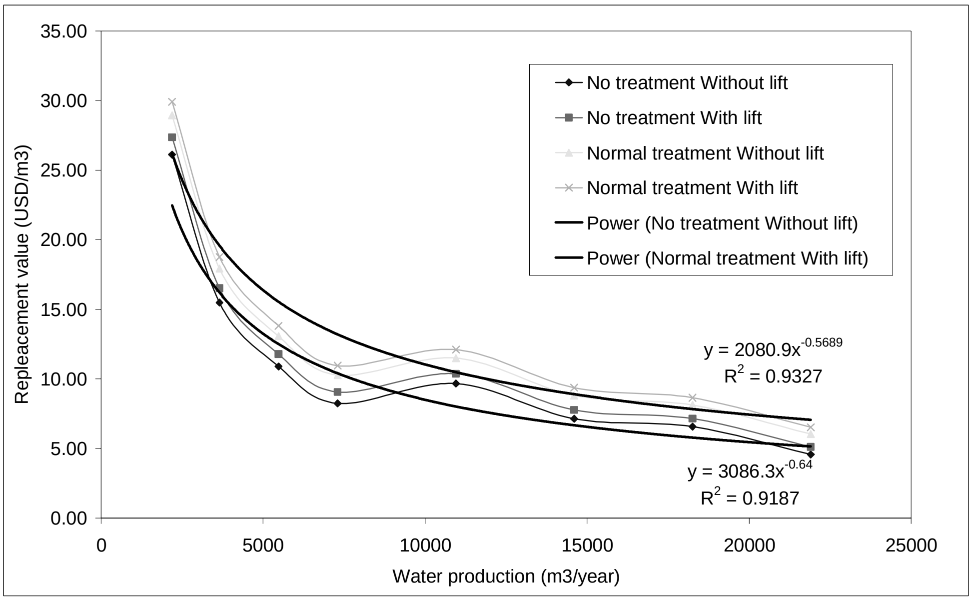
For towns below 30 inhabitants, hand pumps are the only technology available.

All expenditure functions have the following format:

Cost = A * Production ^{B}, where A and B are parameters estimated based on the cost item assessment.

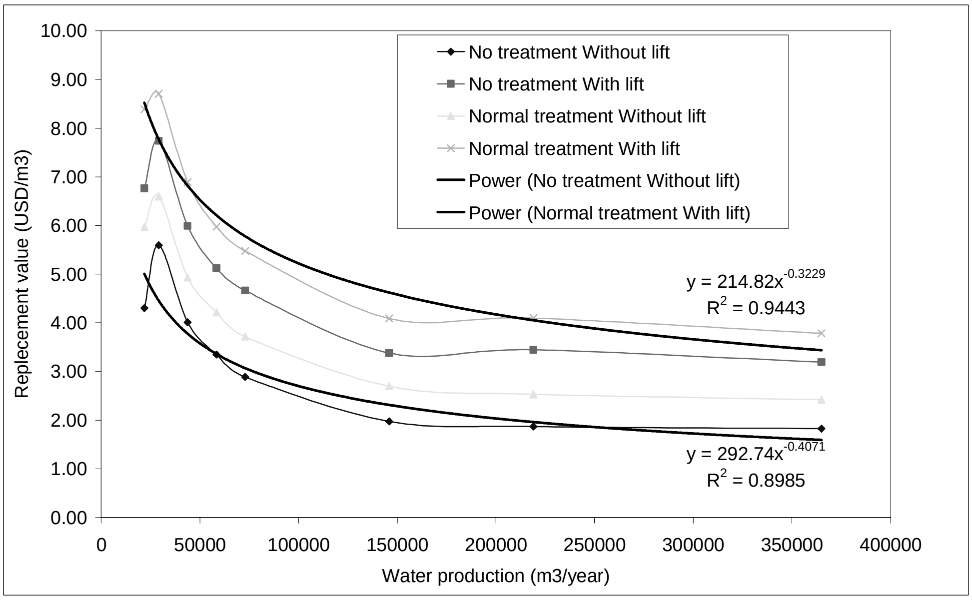
All the expenditure functions are illustrated in the following. The expenditure functions are given as the investment cost per m^3 of the capacity for annual water production. In the figures, "power" refers to the smoothed expenditure functions.

Figure 2 Replacement value/investment expenditure functions for groundwater supply in towns from 30 to 300 inhabitants



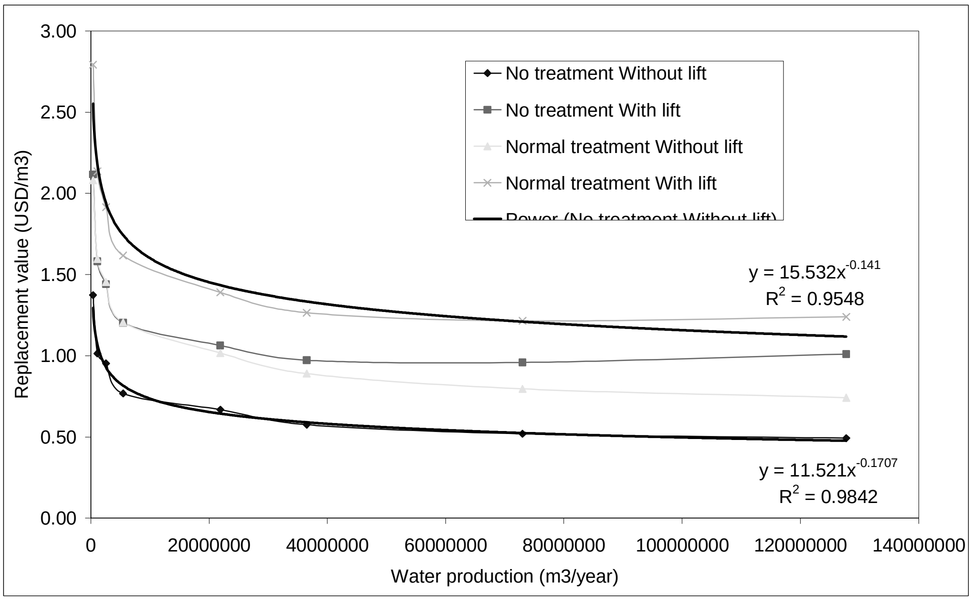
Source: Consultant's estimate

Figure 3 Replacement value/investment expenditure functions for groundwater supply in towns from 300 to 5,000 inhabitants



Source: Consultant's estimate

Figure 4 Replacement value/investment expenditure functions for groundwater supply in towns from 5,000 to 1,750,000 inhabitants



Source: Consultant's estimate

The details regarding the assumptions on the development of the expenditure functions are given in the Appendix 1. The expenditure functions have been developed for a standard town set-up for towns ranging from 30 to 1,750,000 inhabitants. It is assumed that the average daily consumption per capita is 200 litres. The expenditure functions are then estimated on the annual production volume. Thus, when applied for at given town with a consumption exceeding 200 lcd, it is assumed that the cost of the ITT system is linked to the actual production level and not to the town size. The investment cost of the ITT system is, therefore, the same for a town of 50,000 inhabitants and a consumption of 200 lcd and a town with 25,500 inhabitants and a consumption of 400 lcd. Considering that the network is estimated separately, this is a reasonable assumption.

Table 2 Cost item shares of different technologies

Town size	Source	Technology	Equipment	Materials	Labour	Design	Land	Cont.
Below 30		Hand pumps	35	23	28	4	0	10
30-300	Ground-water	No treatment, no lift	48	20	10	10	2	10
		No treatment + lift	48	20	10	10	2	10
		Normal treatment, no lift	48	20	10	10	2	10
		Normal treatment + lift	48	20	10	10	2	10
300-5,000	Ground-water	No treatment, no lift	48	20	10	10	2	10
		No treatment + lift	48	20	10	10	2	10
		Normal treatment, no lift	48	20	10	10	2	10
		Normal treatment + lift	48	20	10	10	2	10
> 5,000	Ground-water	No treatment no lift	48	20	10	10	2	10
		No treatment + lift	48	20	10	10	2	10
		Normal treatment, no lift	48	20	10	10	2	10
		Normal treatment + lift	48	20	10	10	2	10
	Surface water	No treatment no lift	48	20	10	10	2	10
		No treatment + lift	48	20	10	10	2	10
		Normal treatment, no lift	48	20	10	10	2	10
		Normal treatment + lift	48	20	10	10	2	10
		Advanced treatment, no lift	53	15	10	10	2	10
		Advanced treatment + lift	53	15	10	10	2	10

Cost shares of pumping stations

Pumping and booster stations are investments which are included in the ITT functions, although they are part of the water supply systems that relate to the network. This is partly because the key cost driving variable is the total amount of water to be distributed, and partly because the network functions relate to the pipes only.

Most of the energy use relates to pumping and as there may be significant differences in the average energy efficiency, there is a potential gain by changing the pumps and other electric equipment.

FEASIBLE enables easy estimation of the consequences of energy efficiency improvement. The user indicates that all electric equipment should be changed, and the model estimates the investment costs related to such an improvement and estimates the energy saving potential in terms of reduced O&M costs.

Table 3 Expenditure functions for pumping stations etc. Shares of total investment costs for alternative ITT technologies

Pumping stations in % of total	Municipality size		
Technology	30-300	300-5,000	> 5,000
Groundwater			
No treatment, no lift	12	16	8
No treatment, lift	15	18	12
Normal treatment, no lift	12	18	14
Normal treatment, lift	15	17	14
Surface water			
Normal treatment, no lift			6
Normal treatment, lift			7
Advanced treatment, no lift			5
Advanced treatment, lift			6

Source: Consultant's estimates

Technical correction factors

The approach with generic expenditure functions implies the use a number of standard assumptions. By introducing of the technical correction factors, the user has the option to include site specific information, if it is available. A limited number of technical correction factors are included. It is assumed that they change the total investment/replacement value by the same percentages independently of the size of the plant. Below, the values of the technical correction factors related to ITT are given.

The following special physical conditions will cause higher unit expenditure of construction. The factors are recommendations for use where no local data allows a more detailed assessment[1]:

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 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 pumping during the construction period:

   Factor = 1.1

1.1.2 Water Distribution

Water distribution comprises the distribution network and the service connections. Service connections are usually private.

The investment costs of the main distribution network are estimated based on the length of pipes of various diameters.

There are 8 groups of diameters and two expenditure functions with diameter as the input variable.

The length of each diameter size is either a user input, or it is estimated by FEASIBLE. The default values on the distribution are based on our expert judgement.

Function to estimate the length of network
Pipe density (population/km of pipes) = 72*(Total Population)^0.14

Total length of distribution network = Total population / pipe density

This is used as the default value in cases where the user does not have data on the length of the network. If the user has data on the length of the network, the next step in the cost estimation is to determine the length of pipes of different diameters.

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[1] Note that the selection and application of these specific parameters and their values are the sole responsibility of the user. The default values are provided for guidance and are only relevant under "normal" circumstances.

Length of different pipe diameters

The distribution of the total length on various pipe diameters is done using the following table that shows the distribution as a function of the town size.

The model looks up and uses the distribution valid for the closest town size.

Table 4 Distribution of pipe diameters on town size

	Pipe diameters in mm							
Town size	0-50	51-100	101-150	151-200	201-300	301-500	501-700	>700
30	100%	0%	0%	0%	0%	0%	0%	0%
50	92%	7%	0%	0%	0%	0%	0%	0%
75	90%	10%	0%	0%	0%	0%	0%	0%
100	80%	20%	0%	0%	0%	0%	0%	0%
150	70%	30%	0%	0%	0%	0%	0%	0%
200	60%	40%	0%	0%	0%	0%	0%	0%
250	50%	50%	0%	0%	0%	0%	0%	0%
300	30%	70%	0%	0%	0%	0%	0%	0%
300	30%	70%	0%	0%	0%	0%	0%	0%
400	30%	70%	0%	0%	0%	0%	0%	0%
600	30%	70%	0%	0%	0%	0%	0%	0%
800	20%	70%	10%	0%	0%	0%	0%	0%
1,000	20%	60%	20%	0%	0%	0%	0%	0%
2,000	15%	50%	30%	5%	0%	0%	0%	0%
3,000	10%	40%	35%	15%	0%	0%	0%	0%
5,000	10%	30%	40%	15%	5%	0%	0%	0%
5,000	10%	30%	42%	15%	2%	0%	0%	0%
15,000	10%	35%	35%	15%	5%	0%	0%	0%
35,000	10%	25%	32%	23%	8%	2%	0%	0%
75,000	8%	22%	28%	25%	10%	5%	2%	0%
300,000	3%	15%	22%	20%	20%	13%	6%	1%
500,000	3%	5%	20%	22%	20%	20%	6%	4%
1,000,000	2%	8%	20%	25%	15%	12%	10%	8%
1,750,000	1%	5%	30%	15%	15%	12%	12%	10%

Source: Consultant's estimate

FEASIBLE will look up the distribution in the following way. If a town has 57,800 inhabitants, the model will make a linear interpolation between the distribution valid for 35,000 inhabitants and for 75,000 inhabitants.

The resulting distribution will be as shown below.

	Pipe diameters in mm							
Town size	0-50	51-100	101-150	151-200	201-300	301-500	501-700	>700
57,800	9%	23%	30%	24%	9%	4%	1%	0%

Having established in this distribution on diameter size, the length of each size is calculated as the percentage times the total length. Now, the cost of the network can be calculated.

For the largest sizes of diameters, above 700 mm, the default value is 900 mm. This category applies only to the largest towns with a population above 300,000 inhabitants and only to towns with more than a million inhabitants, it becomes important. For the towns of this size, data on the length and average diameter of the pipes will probable known.

Expenditure functions for network

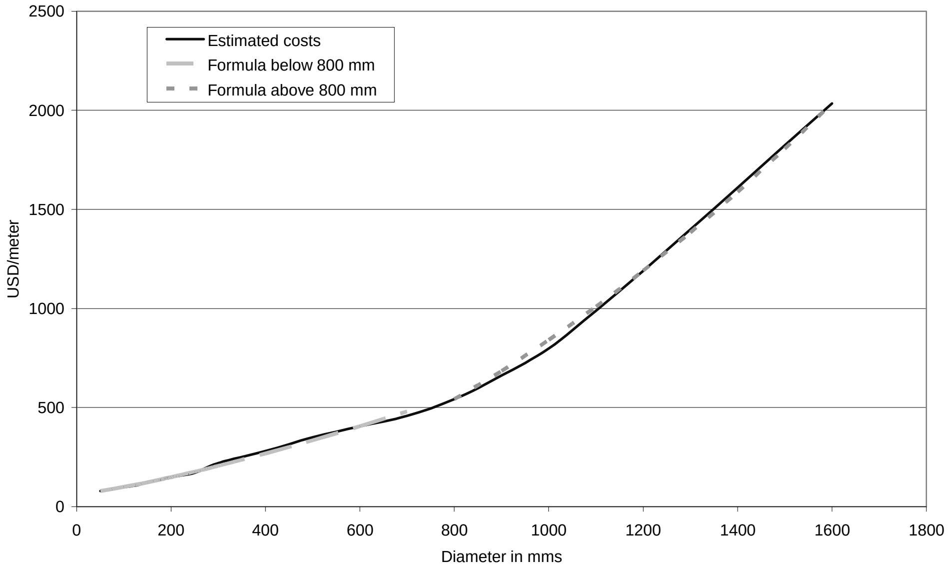
There are two expenditure functions to be applied in relation to investment/replacement value; one for diameters below 800 mm and one for diameters above 800 mm.

Price = 0.088433 * dia^1.29 + 65.8 for diameter range 0 - 800 mm

Price = 0.0040115 * dia^1.785 + 68.1 for diameter range 800 - 1600 mm

The graph below illustrates both of the two expenditure functions defined above as well as the cost assumptions that form the foundation for the expenditure functions. In Appendix 1, the assumptions behind the expenditure functions are given in more details.

Figure 5 Replacement costs for distribution pipes as function of pipe diameter



Source: Consultant's estimate

Applying the 8 different size categories means that the cost of each diameter size is determined by entering the average diameter in each group into the relevant expenditure functions. Thus, in principle, the calculation of each size of pipes takes place by multiplying the length of the pipe of that specific diameter by a unit cost per meter.

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

Table 5 Default values for pipe costs and distribution of cost shares

Average diameters	Total cost per meter	Material	Civil works	Rein-statement	Adm. and design	Contin-gency	Total
mm	USD	%	%	%	%	%	%
25	71	11	25	25	26	13	100
76	89	16	22	23	25	13	100
125	111	22	19	21	25	13	100
175	135	27	17	20	24	13	100
250	175	33	14	17	22	13	100
400	267	43	11	14	20	13	100
600	405	51	9	10	16	13	100
900	821	60	9	6	11	13	100

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 necessary amount of re-investment to keep the system at the current value..

The re-investment value 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. The lifetime of 2nd quality pipes is estimated at only 25 years, but the price is approximately 50% of the price of the highest quality.

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

Table 6 Annual reinvestment as a percentage of total replacement value

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

Source: Consultant's estimate

Taking an example of a 125 mm pipe, the annual re-investment per meter of 1st quality pipes will be USD 2.2, while that of the 2nd quality pipe will be USD 4.0. In case of a significantly lower price level for civil works etc., the difference will lessen. If, for example, all other cost elements have local prices at half the international level, the annual re-investment of one meter of 125 mm pipe would amount to USD 2.2 instead.

Renovation and service extension

Renovation of water supply networks is estimated based the user's input 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 existing network or a new network in a previously non-serviced area.

In case an existing network is to be extended, FEASIBLE estimates the need for a new network by increasing the length of all diameter sizes proportionally to the number of inhabitants connected. If, for example, there is an increase in the number of inhabitants connected to the central water supply by 10%, it is assumed that a 10% increase in the total length of existing pipes of all diameters is needed. This default may be overwritten by the user, if he/she has information about the needed length of new pipes in various diameters.

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

Service connections

By service connections is meant the part of the network which is placed on the property of the consumer. This part of the system is, therefore, usually not part the responsibility of the water company. Accordingly, the associated expenditure is private and is not directly included, however, the user can modify the length of each diameter to reflect service connections.

1.2 O&M Expenditure Functions

1.2.1 Water Intake, Transmission and Treatment

The O&M expenditure functions are divided into:

- electricity consumption
- all other O&M costs

As to electricity consumption, the user may specify data on total electricity consumption and average energy efficiency. FEASIBLE has the following default values that will be used if no specific input is given.

Table 7 Default values for unit electricity consumption kWh/m3 assuming 40% efficiency of pumps

kWh/m^3	Without second lift	With second lift
Groundwater 30-300 inhabitants	0.21	0.35
Groundwater 300-5,000 inhabitants	0.24	0.40
Groundwater > 5,000 inhabitants	0.30	0.50
Surface water > 50,000 inhabitants	0.20	0.40

Source: Consultant's estimate

The cost of operation related to energy is calculated in the following way:

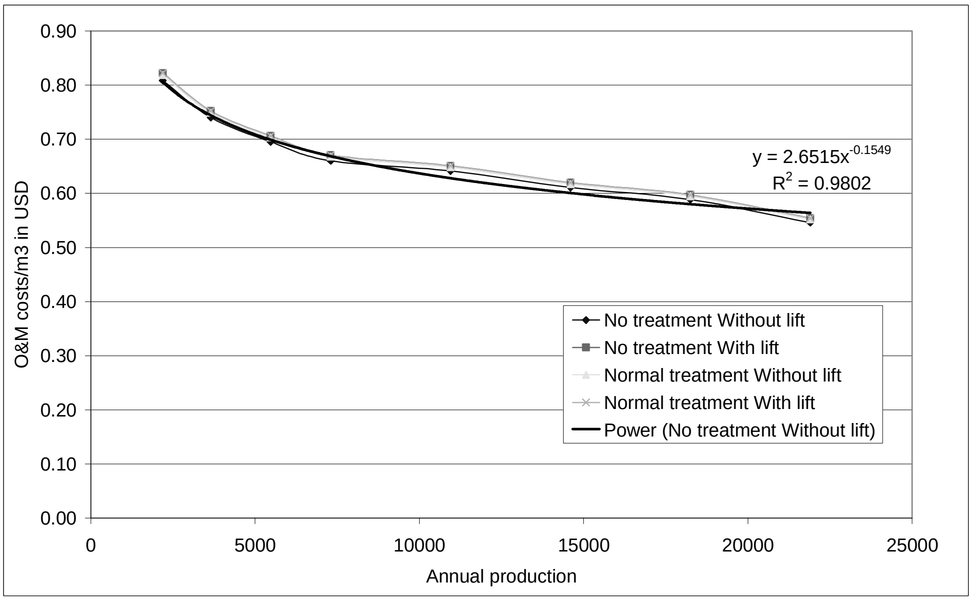
Total electricity is either user input or based on the defaults given above.

Total electricity cost = Total electricity consumption * local electricity price

The function describing volume discount on the prices is a function which has been generally used to estimate expenditure functions. It reflects the fact that the price of the inputs decreases with the amount purchased.

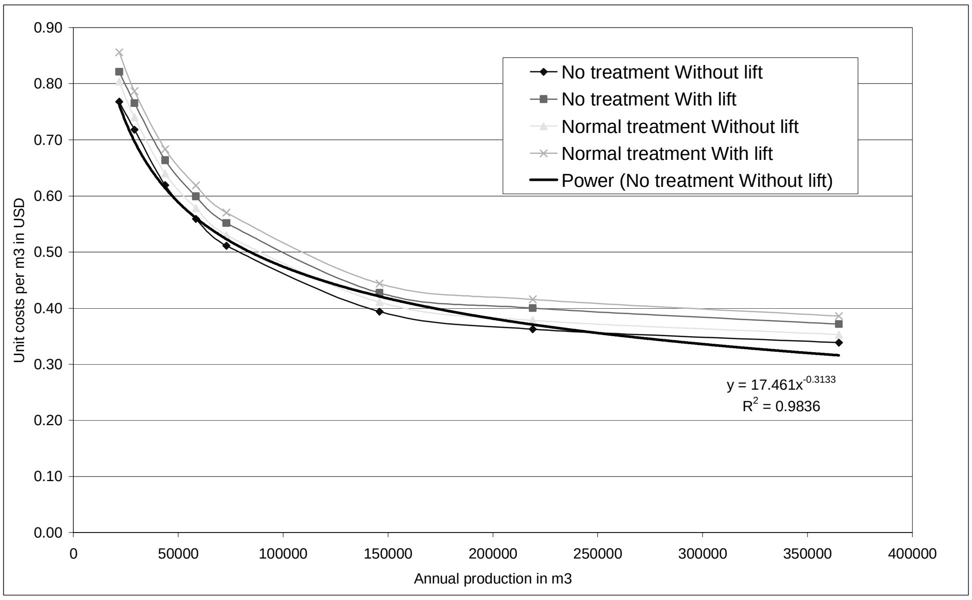
The other O&M costs are included in one expenditure function for each technology.

Figure 6 O&M costs for groundwater supply for towns with 30 to 300 inhabitants



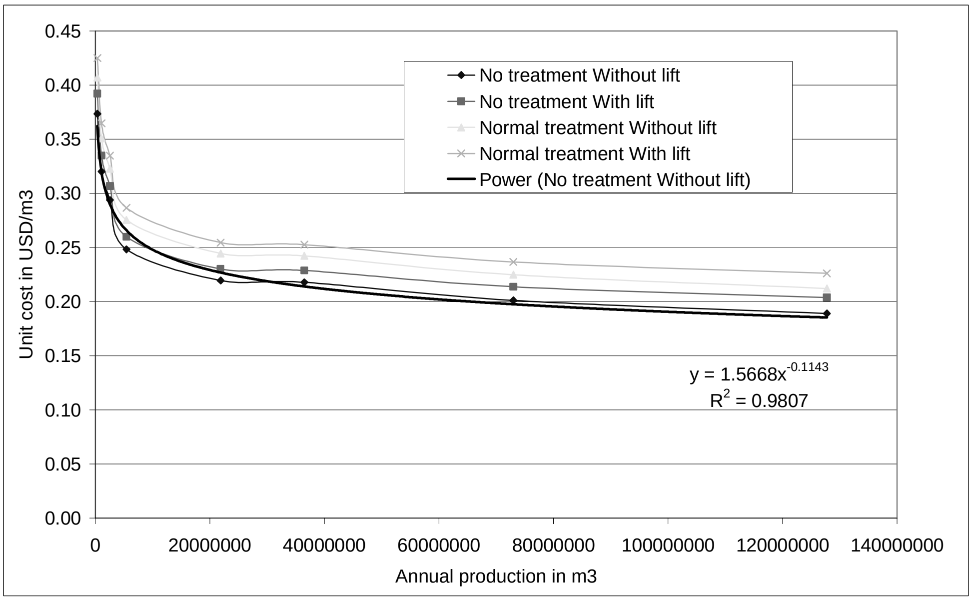
Source: Consultant's estimate

Figure 7 O&M costs for groundwater supply for towns with 300 to 5000 inhabitants



Source: Consultant's estimate

Figure 8 *O&M costs for groundwater supply for towns with more than 5000 inhabitants*



Source: Consultant's estimate

1.2.2 Water Network

The O&M of the network comprises mainly the cost of pumping, which is treated as part of the electricity consumption, described above

The remaining part is estimated at 3% of the replacement value of the network.