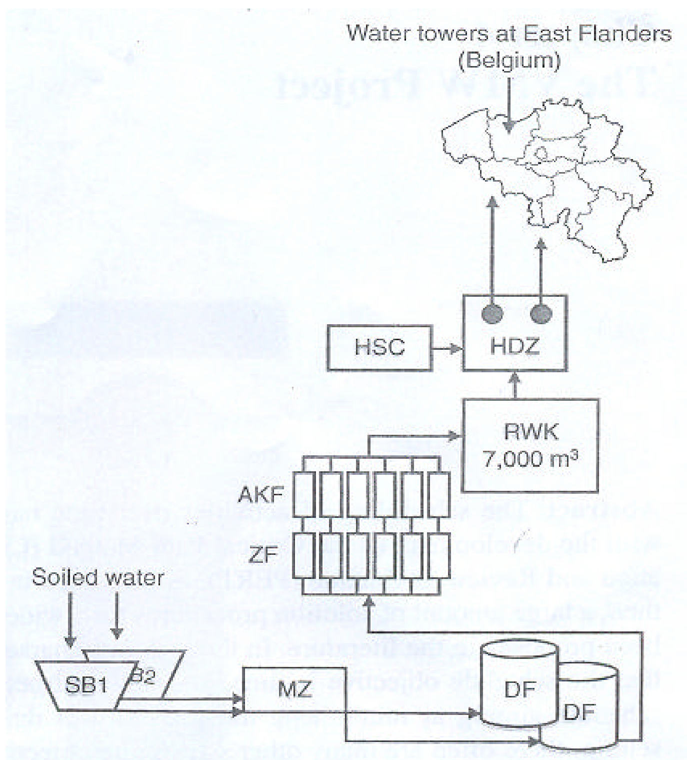
The VMW Project

1. Introduction

The Vlaamse Maatschappij voor Watervoorziening (VMW) is a Flemish water distribution company, which covers approximately 50% of Flanders, locatedin the northern region of Belgium. The VMW services 2.5 million customers with a pipeline network of 27,000 km and a yearly production of 140 billion liters of water[1].

Fig. 1. Graphical scheme of the production process at the WPC of Kluizen



This center produces and delivers water by transforming surface water into drinkable water and by distributing it towards its customers. Therefore, surface water is taken from the area (with a total surface of $\pm 120\ \mathrm{km}^2$) around the WPC and is stored in two open water reservoirs (spaarbekkens, SB 1 and SB 2) with a total capacity of 11,000,000 m^3. From this point on, a number of different steps are performed in order to purge the water and make it drinkable. Figure 1 displays the different steps of this production process without going into details.

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[1] Estimates based on data from the year 2003.

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The filtering of the surface water consists of a number of filtering steps. These are, in order of appearance, the micro sieving (microzeef, MZ), the decantation filtering (actief koolfilter, AKF). Chemical products are added at various points during this process $\left(\text{e.g. } H_2SO_4, AlCl_3, NaOH, NaOCl\right)$. At the end of this water treatment process, the pure water is stored in a reservoir with treated water (reinwaterkelder, RWK) which forms a buffer between the treatment and the pumping phases. During the pumping phases, a number of pumps which are located in a high pressure room (hogedrukzaal, HDZ) disperse the water to the different regions in East Flanders. This HDZ is fed with energy coming from the high voltage cabin (hoogspanningscabine, HSC).

The storage capacity of the RWK amounts to 7.000 m^3 while the daily demand of pure water equals 30,000 m^3 or more (at peak moments, it amounts to 40,000 m^3/day). For this reason, an extension of the storage capacity of pure water is needed (referred to as subproject 1 in the remainder of this chapter). Moreover, forecasts made at the late 1990s of the daily demand indicated an increase to 59,000 m^3/day in 2005 and 65,000 m^3/day in 2013. Since the existing production center (as depicted in Fig. 1) then worked at almost 100% capacity, an extension was needed. This observation has led to the idea of building a new production center with a much higher capacity (referred to as subproject 2). Section 2 describes these two subprojects in more detail.

2. Description of the Project

This section briefly describes the two subprojects of the project at the WPC Kluizen, i.e. subproject 1, "An extension of the storage capacity of treated water" and subproject 2, "An increase of the production capacity to 70,000 m^3/day. The first subproject, as described in Sect.2.1, consists of an increase of the storage capacity by building two extra reservoirs for treated water RWK) which serve as buffers for pure water between the treatment and the pumping phases. In doing so, the WPC will be able to meet the daily demand of the customer much easier. However, it does not lead to the desired increase in the production capacity. In a second subproject, which is described in Sect. 2.2, the construction of the new production center must guarantee the desired production capacity of 70,000 m^3/day.

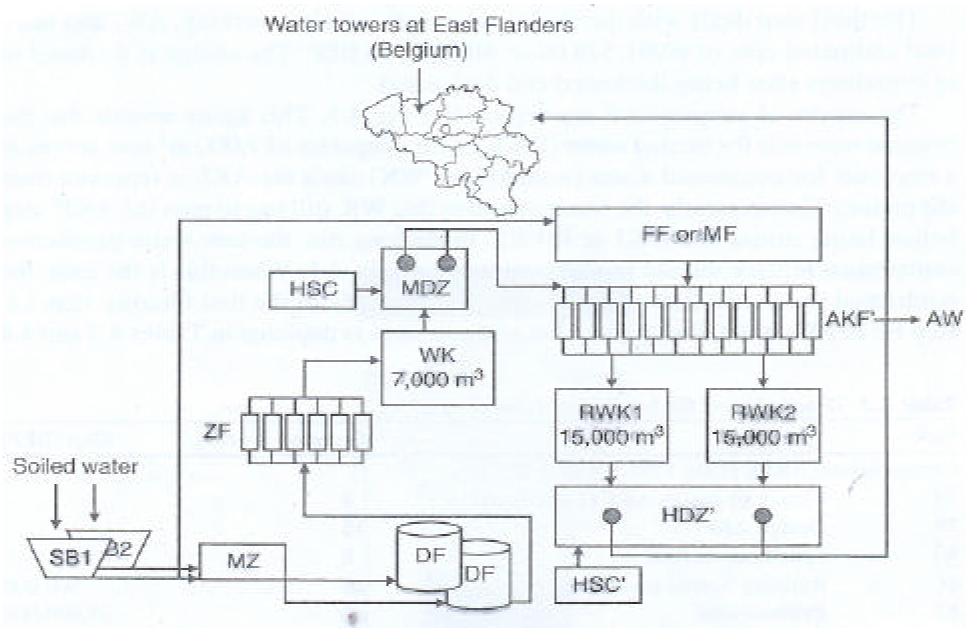
2.1. Subproject 1: Extension of the Storage Capacity of Treated Water

This first subproject consists of two steps, i.e. the building of the two reservoirs for treated water (RWK) at the production plant itself and the additional activities outside the production plant.

Table 1 Description of the first step of subproject 1

Task	Task name	Duration (weeks)	Cost (BEF)
New RWK1 and RWK2 and HDZ (266,900,000 BEF)			
	Architecture		
1	Obtain building license	1	
2	Find contractor (available)	1	
3	Obtain environmental license	7	
4	Execution of work	130	196,900,000
	Equipment		
5	Design (available)	1	
6	Specification	8	
7	Public tender	16	
	Equipment		
8	Fabrication	50	
9	Execution of work	40	70,000,000
HSC (10,000,000 BEF)			
10	Negotiations with power distribution company	4	3,000,000
	Additional work on cables		
11	Design	10	
12	Specification	8	
13	Request offer	8	
	Realisation		
14	Fabrication	40	
15	Execution of work	12	7,000,000
16	Coming into operation	52	
Updating existing HDZ to MDZ (10,000,000 BEF)			
17	Design	10	
18	Specification	10	
19	Request offer	10	
	Realisation		
20	Fabrication	45	
21	Execution of work	26	10,000,000
22	Coming into operation	15	
Constructing pipes between installations (15,000,000 BEF)			
23	Design	26	
24	Specification	26	
25	Realisation	26	
26	Coming into operation	10	15,000,000

Fig. 2. Graphical scheme of the production process at the WPC of Kluizen and the new storage extensions (RWK1, RWK2, HDZ′ and HSC′)

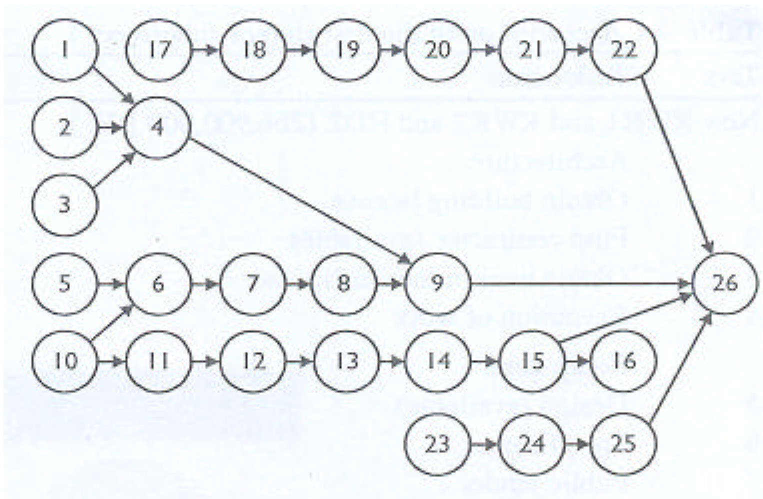


Activities at the Production Plant Itself

In order to increase the storage capacity of pure water, two new reservoirs for treated water (denoted by RWK1 and RWK2 in Fig. 2) have to be built, each with a capacity of 15,000 m^3. Pumps in a new high pressure room (HSZ') will assure the circulation of the pure water towards the customer, while the energy supply has to come from a new high voltage cabine (HSC'). The existing pumps located at the HDZ will be modified (in fact, they will be replaced by pumps with middle pressure capacity (middendrukzaal, MDZ)) in order to assure the flow of water towards the new reservoirs. Constructing pipes between these installations will complete this first step of subproject 1. Figure 2 gives a graphical representation of this first extension. Due to the new reservoirs for treated water RWK1 and RWK2, it will be much easier to satisfy peak moments in demand. The newly established installation will still not be able to produce much more than 30,000 m^3/day.

A list of the detailed activities of these steps is depicted in Table 1 of the appendix. Each activity has an ID number and a task name. The duration and the cost of each activity are also given in this table. Figure 3 gives a network representation of the different tasks of this subproject. Note that the precedence relations between the activities are of the finish-start type (FS) with a time-lag of zero, less it is indicated otherwise in the appendix. The total estimated cost of this step amounts to € 7,483,905.51 or 301,900,000 BEF (BEF is the old currency used in Belgium at the time of the project baseline schedule construction with € 1 = 40.3399 BEF).

Fig. 3. Network representations of the work completed at the production plant WPC Kluizen



Activities Outside the Production Plant

The activities outside the production plant mainly focus on an optimal supply of the pure water to the customer. Therefore, a new pipeline has to be constructed from the WPC Kluizen to its customers (towns in the northern region of Flanders such as Eeklo and Waarschoot). Moreover, at some regions, WPC Kluizen is obliged to deliver a certain amount of water to another water distribution company TMVW (Tussengemeentelijke Maatschappij Voor Watervoorziening) while at other regions (e.g. Zelzate) the delivery is vice versa (WPC Kluizen receives an amount of water). The main steps of this subproject can be summarized as follows[2]:

- The construction of a new pipeline between Kluizen and Eaklo.
- The delivery of water to the TMVW (i.e. building a measuring station and fitting it in the existing communication system).
- The construction of a pumping station (in order to increase the pressure of the water) at Zelzate.
- The construction of a pumping station (in order to increase the pressure of the water) that supplies a water tower in Eaklo.
- The construction of a pumping station (in order to increase the pressure of the water) in Waarschoot.

As before, a list of the detailed activities of these steps is depicted in Table 2 of the appendix. Figure 4 gives a network representation of the different tasks of the second step of subproject 1. It has a total estimated cost of € 5,032,238.55 or 203,000,000 BEF.

[2] Eaklo, Kluizen, Waarschoot and Zelzate are small villages or towns in the Eastern part of Flanders.

2.2. Subproject 2: Increase of the Production Capacity

The construction of the new production center with a desired production capacity of 70,000 m^3/day is a capital-intensive project with a total estimated cost equal to ± € 13,150,751.49 or 530,500,000 BEF. It mainly consists of three steps, i.e. building the carbon filters (actief koolfilters, AKF), establishing an alternative system for the decatation filtering and the treatment of waste.

Table 2 Description of the second step of subproject 1

Task	Task Name	Duration (weeks)	Cost (BEF)
Pipes from Kluizen to Eeklo (170,000,000 BEF)			
27	First draft design	26	
28	Find permission and contractor	70	170,000,000
29	Construct pipeline	52	
30	Coming into operation	4	
Water supply to TMVW (1,500,000 BEF)			
31	Design	4	
32	Find permission	26	
33	Connection electricity	26	
	Equipment		
34	Specification equipment	12	
35	Delivery equipment	26	1,000,000
36	Execution	10	
37	Fitting in communication system	2	500,000
38	Coming into operation	2	
Constructing pumps at Zelzate (2,500,000 BEF)			
39	Design for connection electricity	4	
40	Connection electricity	10	400,000
41	Design	1	
42	Specification	8	
43	Request offer	8	1,500,000
44	Delivery	30	
45	Execution	15	600,000
46	Coming into operation	4	
Constructing pumps and building water tower at Eeklo (24,000,000 BEF)			

47	First draft design	8	
48	Design	15	
49	File building license	5	
50	Request building license	26	
51	Specification	10	
52	Public tender	18	
53	File environmental license	5	
54	Notification VLAREM	1	
55	Realisation	75	16,000,000
56	Design	4	
57	Specification	10	
58	Request offer	8	
	Execution		
59	Fabrication	30	
60	Equipment	20	8,000,000
61	Coming into operation	8	
Constructing pumps at Waarschoot (5,000,000 BEF)			
62	First draft design	8	
63	Design	15	
64	File constructing license	5	
65	Request constructing license	26	
66	Specification	10	
67	Public tender	18	
68	File environmental license	5	
69	Notification VLAREM	1	
70	Realisation	52	
71	Design	4	
72	Specification	10	
73	Request offer	8	
	Execution		
74	Fabrication	30	
75	Equipment	10	5,000,000
76	Coming into operation	4	

Fig. 4. Network representation of the work completed outside the production plant WPC Kluizen

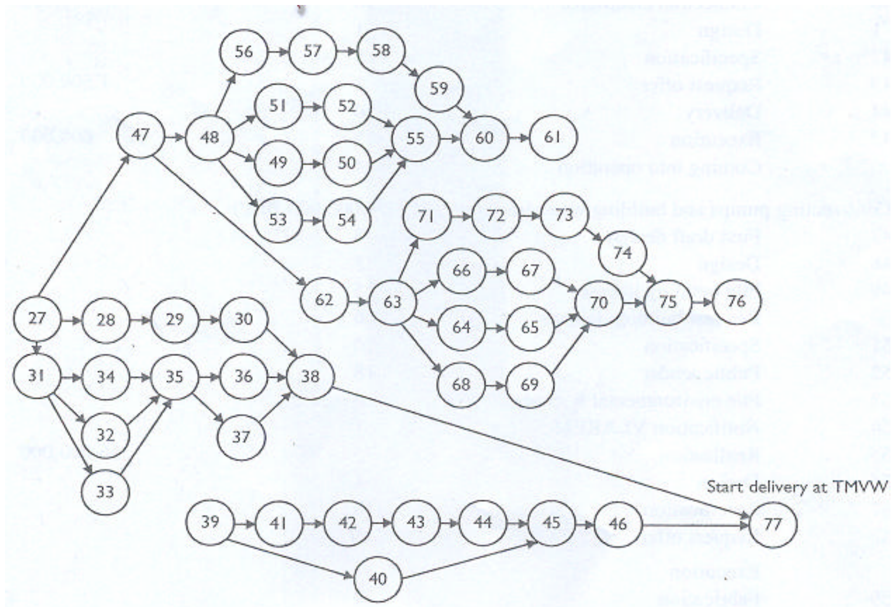


Fig. 5. Graphical scheme of subproject 2: Increase in capacity

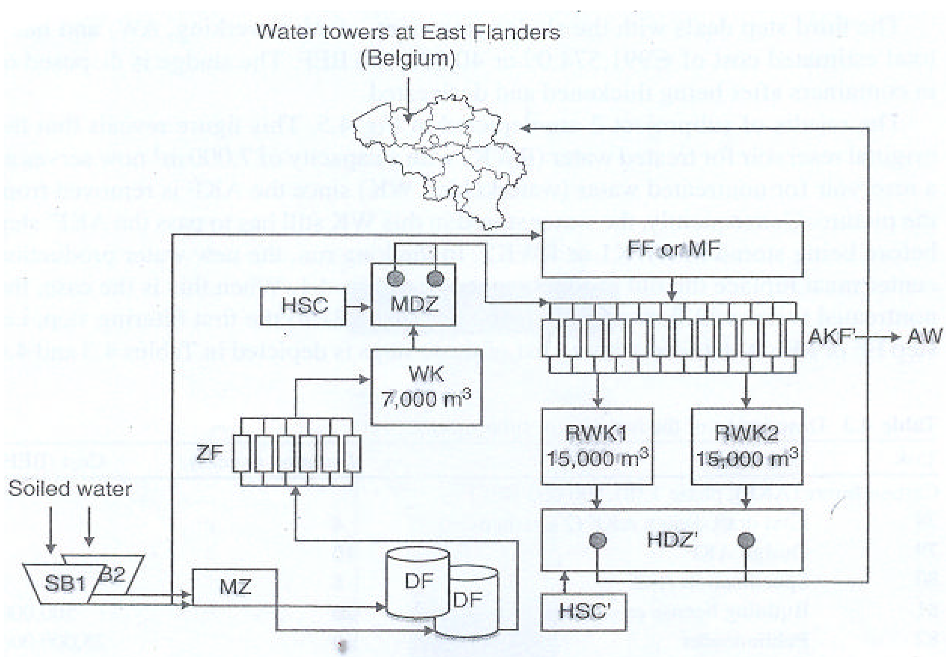


Table 3. Description of the first step of Subproject 2

Task	Task name	Duration (weeks)	Cost (BEF)
Carbon filters (AKF), phase 1 (85,500,000 BEF)			
78	First draft design AKF (2 alternatives)	4	
79	Design AKF	10	
80	Specification AKF	8	
81	Building license procedure	26	500,000
82	Public tender	10	25,000,000
83	Execution building reservoir for AKF	52	
84	Design carbon filter	10	
85	Determine number of filters	0	
86	Specification	6	
87	Request offer	8	
	Equipment AKF		
88	Fabrication materials	26	
89	Execution of work	26	20,000,000
90	Request offer	8	
	Carbon filters		
91	Construction filters	40	
92	Delivery filters	2	35,000,000
93	Delivery carbon	2	5,000,000
94	Coming into operation AKF	8	
Carbon filters (AKF), phase 2 (100,000,000 BEF)			
95	Determine number of carbon filters	0	
96	Specification	4	
97	Request offer	10	
	Equipment AKF		
98	Fabrication materials	26	
99	Execution of work	26	10,000,000
100	Request offer	10	
	Carbon filters		
101	Construction filters	40	
102	Delivery filters	2	90,000,000
103	Coming into operation AKF	4	

In a first step, 12 new carbon filters (denoted by AKF in Fig. 5) will be built in two phases. In a first phase, three carbon filters will be built, while in a second phase the remaining nine carbon filters will be installed.

In a second step, an alternative technique for the rather old-fashioned decantation filtering step (see Fig. 1) has to be selected. The two alternatives are:

- Membrane processes (membraanfilter, MF) employ a semi-permeable (selective) membrane and a driving force (pressure, concentration, etc.) across the membrane to separate target constituents from a feed liquid. Water passes through the membrane, forming a treated water stream (permeate) and leaving behind the other constituents in a concentrate. Different types of membrane processes can remove dissolved and colloidal constituents in the size range of 0.0001-1µm. The commercially available membrane processes include micro-filtration, ultra-filtration, reverse osmosis, membrane electrolysis and diffusion dialysis. The technologies operate differently, and each is best suited for specific applications. They are all useful for separation of molecular mixtures.
- Air flotation techniques (flotatiefilter, FF) are used to remove insoluble contaminants from a solvent. The removal is based on the adhesion of dissolved air at the contaminants, after which it will come to the surface of the liquid.

The total cost of this step amounts to € 7,560,752.50 or 305,000,000 BEF for the first alternative and € 5,577,604.31 or 225,000,000 BEF for the second alternative. This chapter only considers the first alternative. Similar results with respect to the proposed schedules of Sect. 3 have been obtained in the case of the second alternative.

The third step deals with the sludge treatment (afvalverwerking, AW) and has a total estimated cost of € 991,574.09 or 40,000,000 BEF. The sludge is disposed of in containers after being thickened and desiccated.

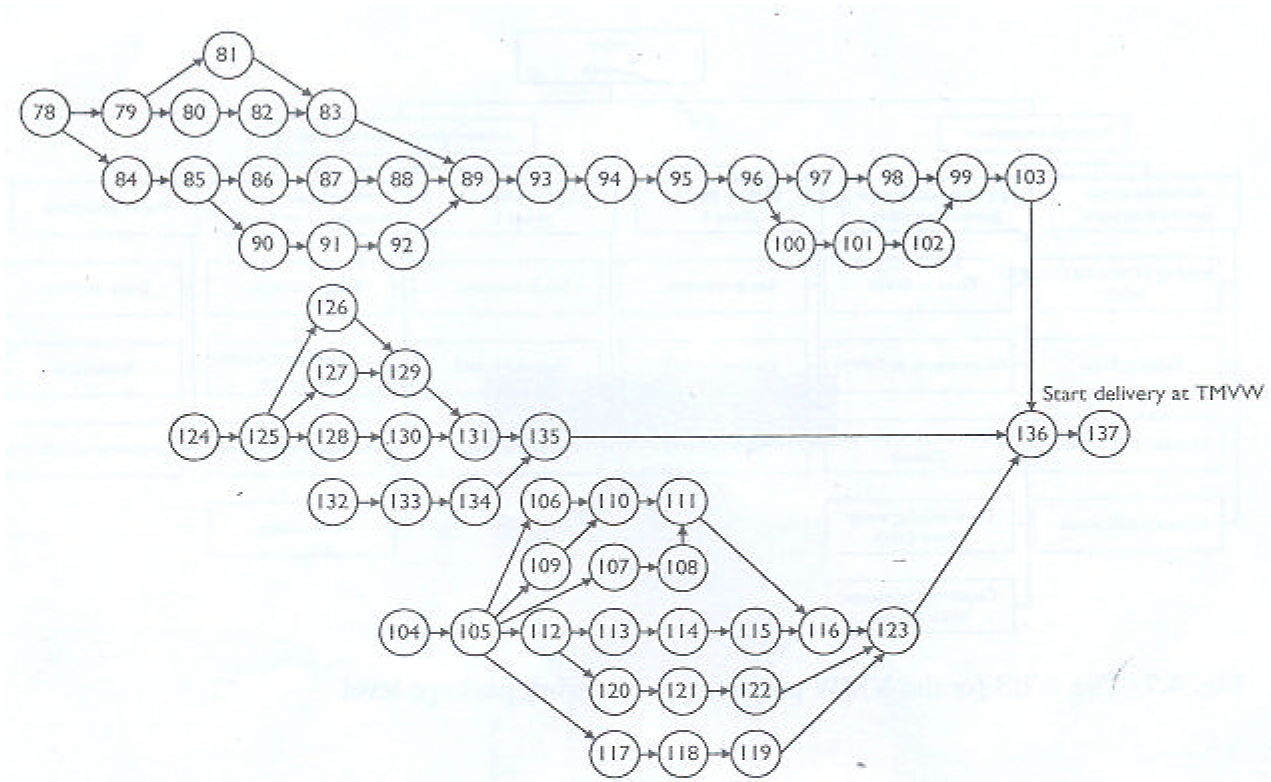
The results of subproject 2 are depicted in Fig. 5. This figure reveals that the original reservoir for treated water (RWK) with a capacity of 7,000 m^3 now serves as a reservoir for nontreated water (waterkelder, WK) since the AKF is removed from the picture. Consequently, the water stored in this WK still has to pass the AKF′ step before being stored in RWK1 or RWK2. In the long run, the new water production center must replace the old production center of Fig. 1. When this is the case, the nontreated water will flow directly from SB1 and SB2 to the first filtering step, i.e. step FF or MF. A detailed activity list of these steps is depicted in Tables 3 and 4 of the appendix. Figure 6 gives a network representation of the different tasks of this project.

Table 4. Description of the second step of subproject 2

Task	Task name	Duration (weeks)		Cost (BEF)	
Water treatment (membrane or air flotation) (305,000,000 BEF for alternative 1 and 225,000,000 BEF for alternative 2)					
		Alt. 1	Alt. 2	Alt. 1	Alt. 2
104	First draft design flotation filtering	0.2	26		
105	First draft design and specification of architecture	20	52		
106	Public tender	14	18		
107	Preparation building license	10	26		
108	Request building license	26	26		
109	Preparation environmental license	10	26		
110	Request environmental license	26	26		
111	Realization architecture for flotation or membrane technique	156	104	200,000,000	40,000,000
112	Design for flotation/membrane technique	20	26		
113	Specification	10	10		
114	Request offer	8	10		
	Equipment for flotation/membrane technique				
115	Fabrication	52	52		
116	Execution of work	52	52	70,000,000	150,000,000
	Connection installations				
117	Design	26	26		
118	Specification	26	26		
119	Realisation	26	26	20,000,000	20,000,000
	Automation				

120	Design	20	26		
121	Request offer automation	12	26		
122	Realization equipment	40	52	15,000,000	15,000,000
123	Coming into operation (flotation or membrane technique)	12	12		
Waste treatment (40,000,000 BEF)					
124	First draft design	15			
125	Design	40			
126	Specification	15			
127	Obtain environmental and building license	26			
128	Design and specification	16			
129	Realisation architecture	52	20,000,000		
	Realisation				
130	Fabrication	40			
131	Execution of work	26	20,000,000		
	Connect installations				
132	Design	26			
133	Specification	26			
134	Realisation	26			
135	Coming into operation (installation)	10			
136	Coming into operation (extra production)	52			

Fig. 6. Network representation of the three steps to increase the production capacity



3. Analysis of the Project

3.1. Features of the Project

The project under study is the subject of a widely discussed topic in the project scheduling literature. It involves the scheduling of project activities in order to maximize the *net present value (npv)* of the project in the absence of resource constraints. The observation finds its motivation by the following statement by Herroelen et al. (1997):

> When the financial aspects of project management are taken into consideration, there is a decided preference for the maximization of the net present value of the project as the more appropriate objective, and this preference increases with the project duration.

Since the project is a very capital-intensive project (total estimated cost exceeds the value of €25,000,000.00) with a total project duration of approximately 7 years, the maximization of the net present value seems the appropriate objective function. This problem is classified in the project scheduling literature as the max-*npv* problem and can be formulated as follows:

$$\text{Minimize} \quad \sum_{i=1}^{137} c_i \, e^{-a\,(s_i + d_i)} \tag{1}$$

subject to

$$s_i + l_{ij} \leq s_j \qquad \forall\, (i,\, j) \in A \tag{2}$$

$$s_0 = 0 \tag{3}$$

$$s_{137} \leq 362 \tag{4}$$

$$s_i \in int^{+} \qquad \forall\, i \in N \tag{5}$$

where the variables d_i, c_i and s_i denote the duration, the cost at the completion of the activity and the start time, respectively, of an activity i.

Assignment

Please find the schedule, which will maximize the net present value.