Fifth International Conference on Construction in the 21st Century (CITC-V)
"Collaboration and Integration in Engineering, Management and Technology"
May 20-22, 2009, Istanbul, Turkey

Economic Evaluation of Paste Thickener Construction in Optimal Management of Industrial-Complex Water Cycle

Seyed Hossein H. Nourzad
Department of Civil Engineering, IUST, Iran
shhn80@gmail.com

Mohammad Kashef
Department of Civil Engineering, METU, Turkey
m_kashef@mail.iust.ac.ir

Mohammad Hadi Afshar
Department of Civil Engineering, IUST, Iran
mhafshar@iust.ac.ir

Abstract

Using close water cycle in industrial complexes has a high level of importance from different aspects. Supplying water from scarce fresh water resources (river and groundwater) has irrecoverable effects on environment as well as extraction of that and transiting it to the plant is not economical. Versus traditional methods for reproducing of return water such as tailing dams, these days the state of the art methods is used such as paste thickeners (PT) – costly facilities that thicken the tailings by taking its water for reusing in the plant. In this research optimal usage of variable-capacity PT in close water cycle of a copper complex have been evaluated economically, using Net Present Value concept with the combination of Tabu search – one of the most powerful meta-heuristic methods. Results show 50% reduction in operation expanses by using variable-capacity PT instead of conventional methods.

Keywords

Economic evaluation, Paste thickener, Optimal management

1. Introduction

At this step after defining the project, which is mostly defined in respond to social need, the project components should be determined and the feasibility study should be done. During the feasibility study technical, economical and environmental dimensions of the project are evaluated.

Most major projects have environmental effects and risks that have to be evaluated initially and HSE (Health, Safety and Environment) requirements have to be considered. General governmental projects have other objectives other than economical ones. Their economical evaluations, especially when the project is related to national assets, are quite different because the effect of loosing these assets should be considered too.

In this paper, the economical evaluation of using paste thickeners with variable capacity, in a copper complex, has been studied.

For solving this problem, after preparing a simulation model of the complex water cycle, first optimum solutions are found by means of a meta-heuristic method called Tabu search to minimize the operation expenses. Next, considering the 5-year construction era and a 20-year operation era and using the "Net Present Value" concept, all the economic aspects of the project such as total expense for one unit of water supply for the plant are calculated.

2. Optimization Method

Optimization methods are divided into two groups: Mathematical and meta-heuristic. One of the meta-heuristic methods is Tabu search.

Tabu search is stabilized on neighborhood search but with avoiding being trapped in local optimums. The main idea of this method is in visiting regions that have not been searched recently. Therefore the method begins with an initial solution which is produced randomly and if a better solution, which isn't a Tabu solution found, the search process moves to it. This process is continued until the termination criterion is satisfied. According to the above, the main factors and concepts of this approach are as below (Consoli and Dowman, 2006; Cunha and Ribeiro, 2004; Glover, et al., 2005; Glover, 2004; Glover, 1998; Glover, 1994; Hertz, Alian et al., 1992):

2.1 Initial Solution

As in other heuristic methods, at the beginning of each problem, one initial solution is chosen randomly so that the search is started from that point. One advantage of TS (Tabu search) is that it decreases the effect of the initial solution by intensification and diversification because theoretically, in large nonlinear problems, different initial solutions cause various local optimums.

2.2 Movement

Movement means transfer from the current solution to the next best point in the neighborhood which isn't forbidden. The important point is that sometimes although the new solution is worse than the current global optimum and the current solution, still movement will be done (uphill climbing) with hope that local optimums are avoided and the whole space can be visited so that desirable solutions are found.

2.3 Tabu List

Best solutions of recent iterations are saved in a Tabu list. The policy is to apply restriction to returning to visited areas and avoiding cycles and getting trapped in local optimums. Small lists let special areas to be searched more carefully (intensification) and larger lists let the process search wider spaces (diversification). Either all decision variables of solutions or one or more of the solution properties can be saved in the Tabu list.

2.4 Aspiration Criteria

Sometimes according to the aspiration criteria, if an optimum is found in the neighborhood, although it has common properties with the solutions existing in the Tabu list, its prohibition is ignored and it is chosen for continuing the process.

2.5 Termination Criteria

For stopping the approach from searching, different criteria can be applied such as maximum number of iterations; number of iterations done with no improves or finding a solution with a smaller objective function than the users defined value.

3. Economic Evaluation Method

Defining a project is usually because of a social necessity. Public projects, in which the government is responsible, mostly have political or civil goals. After the project is defined, technical, economical and environmental evaluation of the project is required. In other words all the necessities of the project including designing and construction technologies, human resources, materials and equipment and other issues regarding HSE must be provided simultaneously, whereas, the project must meet the economic indicators. The topic discussed in this chapter is the economic evaluation of the project. The following steps in the sequence indicated must be followed.

First a variety of choices for performing the project must be listed. Then the planning vision has to be defined. In projects such as the project studied in this article, from the beginning of the construction stage until the end of the operation is considered as the vision of planning. In the next step the descent cash flow profile for each project in the duration of planning vision is provided. Then the figures considering the concepts of NPV and an appropriate descent rate are made similar. Then by employing one of the economic indicators such as NPV, NFV, B/C or IRR the desirability of the project is determined. The above indicators are divided into two groups: direct and indirect. The direct indicators such as NPV and NFV will directly calculate the profit while the indirect ones for instance IRR and B/C will calculate the profit rate.

One of the most important means of economic comparison of projects is NPV which however nowadays is not the only basis for deciding in huge projects, but still is the root for other methods. In this method first the net value of the expenses and income of the project are calculated by applying an appropriate descent rate (Capital cost or minimum attractive rate of return). The difference of these two is the NPV or the profit which if positive indicates that the project is economic. An important issue is that the NPV is responsive to the distribution of the expenses and income during the planning vision since as these figures are close to present there will be less descent and vice versa. Other than the indicators above, others such as “Payback Period” and “Maximum Cash Outlay” are considered in economic planning.

Finally we note that the above method is applicable for certainty situations and if there is risk or uncertainty in the project other methods should be used. In this article we have considered certainty situation.

4. Copper-Complex Water Cycle

4.1 Description

The case study of this research is optimization and economic evaluation of the closed water system of a copper complex with paste thickener facilities.

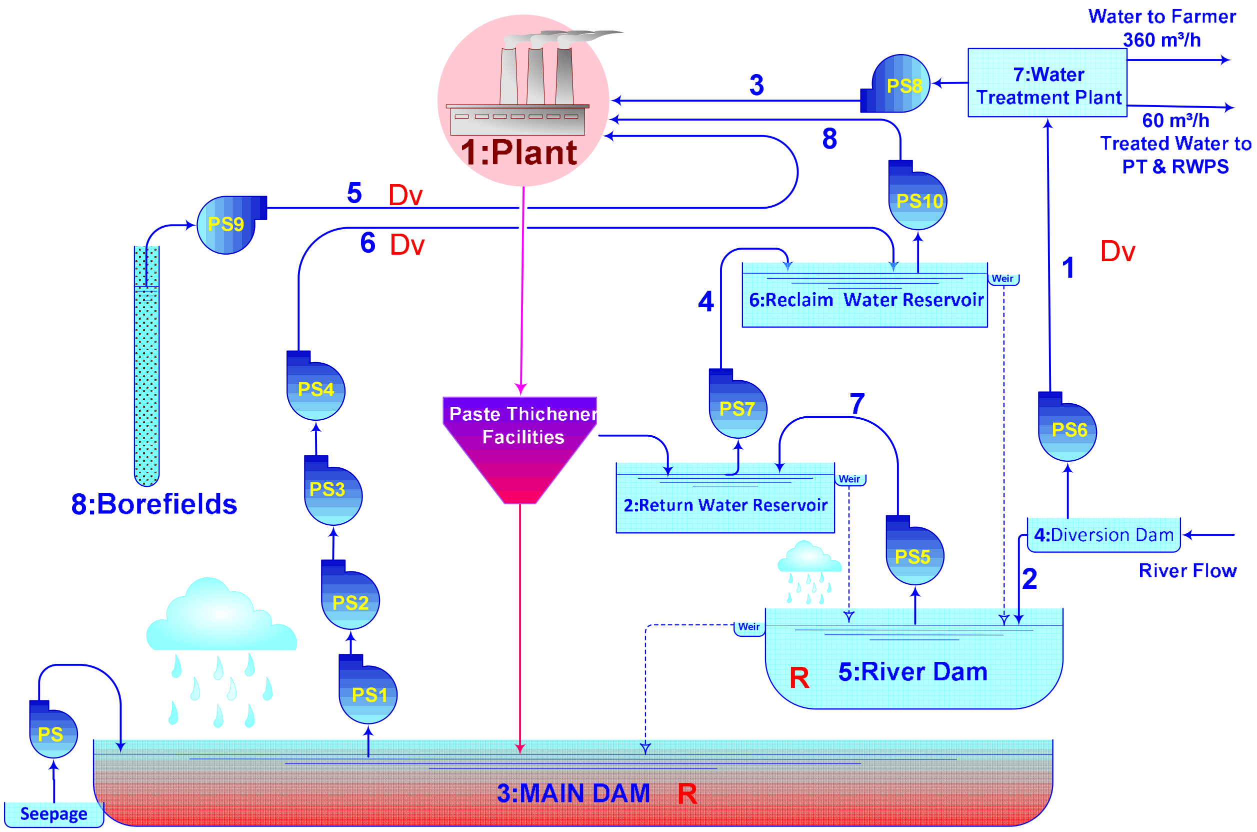

Figure 1: The Copper Complex Water Cycle

Water is used in two ways in industry; open cycles which water goes back to the river after being used and closed cycles which water returns to the loop again. In closed loops, by using water repeatedly it remains in the cycle. The small amount of off take in closed looped industrial water systems is for amending the facilities of industrial producing process and also replacing water in water cycles (Minerals Council of Australia, 2006; Aleyasin,2006).

The vital component in copper production process is water. After milling the mineral rock, it is solved with water and some chemical solutions are added so that the copper stands on top of the solution as foam that is collected with large spoons and goes for the purring process. The remaining solution is called tailing and contains more than 60% water and about 40% unsolved solid matters.

Water sources for this complex are seasonal river water and underground sources. According to the little availability of water, using an open cycle isn't possible and the shortcoming should be ensured from surface water and ultimately underground water in case of necessity.

Components needed for forming a closed water cycle in this project are: pipe lines, pump stations, tailing dams, diversion dam, water reservoirs and treatment plants as shown in Figure 1.

Paste thickeners are the most important part of the process. Tailings can be transported directly to the dam. In this case, the released water is stored behind the dam and is delivered to a reservoir near the complex via a flouting pump station and several stations midways. The other way is using paste thickeners which are combinable with the former system. These expensively installed foundations will decrease the time and operation costs and will obtain a considerable amount of water from the tailings.

Paste thickeners separate solid from liquid (water and deposits). Separation is based on two Newton and Stocks theories. Tailings enter the paste thickeners; solid particles settle at the bottom and are moved out of the reservoir with or without pumps. The remaining water is released from the top to a waterway.

According to Figure 1, the complex water can be supplied in four ways: seasonal river, wells, returned water from the tailing dam and finally return water from paste thickeners and water dam.

4.2 Configuration of Optimization Problem

As explained in the previous chapters, the Tabu search method has been applied in order to calculate the optimized result. Therefore first it is required to formulate the objective function and the problem constraints.

4.2.1 Objective Function

The object in this problem is to minimize the expense for one year operation of the complex. The expenses include the cost for the power supply for pumping the water in the water cycle, the cost of buying underground and river water and the cost of using paste thickener utilities.

In order to calculate the operation expenses, first, according to the TS optimization method, decision variables are created. Then plant simulator model will calculate the flow for the different communication lines from solving the equations set and by knowing the pipe flow and hydraulic head of pumping station the consumed power for the water cycle is calculated.

$$\text{Objective Function: Minimize } \sum (\text{Energy}_\text{i} \times CPUE + GWater \times CPUG + RWater \times CPUR$$

$$Energy = \frac{\gamma . Q_i . Head_i}{\eta} . T$$

$Energy_i$: Consumed energy in i$^{\text{th}}$ pump station (J)

$CPUE$: Cost per unit of energy (Rials/J)

T : Duration (s)

Q_i : Discharge of the i$^{\text{th}}$ pump station (m^3/s)

$Head_i$: Head (m)

η : Pump efficiency

$GWater$: Groundwater consumed (m^3)

$CPUG$: Cost per unit of groundwater (Rials/m^3)

$RWater$: River water consumed (m^3)

$CPUG$: Cost per unit of river water (Rials/m^3)

4.2.2 Constraints

Typically constraints of this problem are two types; one is water demand for each node that should be supplied; second type is related to pumps and pump stations. For the second type, constraint is derived from ability of pump stations to supply the needed head for pumping the water between the nodes.

$$\left(\sum_{n=1}^{N_{PS}} Head_n \right)_j \geq \left(Head_s + Head_f \right)_j$$

$$\left(\sum Q_{in} \right)_i \geq Demand_i$$

$Head_n$: Produced head by n^{th} pump station

$(Head_s + Head_f)$: Needed head for flow in j^{th} connection

$\left(\sum Q_{in}\right)_i$: Total discharge to i^{th} node

$Demand_i$: Water demand in i^{th} node that should be supplied

4.3 Numerical Example

After configuring the optimization problem, by establishing an appropriate association between the plant simulator and the TS optimization model, the problem is solved for a one year operation period. Table 1 shows the achieved results.

Table 1: Optimal Rule for One-year Operation of Water Cycle without Paste Thickener

	Variable		1	2	3	4	5	6	7	8	9	10	11	12
Decision Variable	water from diversion dam to treatment plant	m^3/hr	1,252	675	665	652	671	1,247	1,389	1,800	1,800	1,800	1,800	0
	water from tailings dam to water tank	m^3/hr	789	580	1,042	902	569	97	156	38	202	974	485	0
	water from wells to water tank	m^3/hr	3,500	3,490	3,500	3,500	3,500	3,500	3,482	2,285	2,231	1,949	2,952	0
State Variable	Release from diversion dam to water dam	m^3/hr	105	139	8	18	31	12	144	2	1,378	1,378	1,378	1,378
	water from treatment plant to plant	m^3/hr	866	832	255	245	232	251	827	969	1,380	1,380	1,380	1,380
	water from return water tank to reclaim water tank	m^3/hr	684	680	775	1,413	266	1,280	676	1,492	1,298	1,487	1,397	1,483
	water from water dam to return water tank	m^3/hr	684	680	775	1,413	266	1,280	676	1,492	1,298	1,487	1,397	1,483
	water from reclaim water tank to plant	m^3/hr	4,184	4,180	4,265	4,913	3,766	4,780	4,176	4,974	3,582	3,718	3,346	4,435
	tailings dam storage	$milionm^3$	5.00	6.37	8.02	9.18	11.13	12.14	13.65	14.80	16.68	18.64	20.85	23.55
	water dam storage	$milionm^3$	5.00	4.59	4.20	3.64	2.64	2.47	1.55	1.17	0.10	0.18	0.11	0.12

As the result shows, in the complex operation without using the paste thickener, more water should enter the pumping cycle, therefore even though the cost of operating a paste thickener is zero, but pumping a large amount of water from the tailings dam causes increase in the cost of pumping water, also the amount of underground water procured in this situation is much more than the amount of water used in the water cycle using paste thickener. Furthermore in this condition, more storage capacity is needed for the tailings dam.

Table 2: Optimal Rule for One-year Operation of Water Cycle with Paste Thickener

	Variable		1	2	3	4	5	6	7	8	9	10	11	12
Decision Variable	water from diversion dam to treatment plant	m^3/hr	1,379	659	678	652	662	1,333	1,389	1,800	1,800	1,800	1,800	0
	water from tailings dam to water tank	m^3/hr	132	0	460	23	0	0	0	0	0	0	336	0
	water from wells to water tank	m^3/hr	231	808	1,007	1,251	1,043	0	1,423	578	1,431	1,411	889	0
State Variable	Release from diversion dam to water dam	m^3/hr	105	139	8	18	31	12	144	2	1,378	1,378	1,378	1,378
	water from treatment plant to plant	m^3/hr	502	959	239	258	232	242	913	969	1,380	1,380	1,380	1,380
	water from return water tank to reclaim water tank	m^3/hr	3,487	4,478	4,053	4,475	3,394	4,315	4,187	3,709	3,042	2,489	2,909	3,695
	water from water dam to return water tank	m^3/hr	1	25	1,390	59	1,399	1,378	16	1,379	1,391	11	2	1,492
	water from reclaim water tank to plant	m^3/hr	4,898	4,709	4,861	5,482	4,646	5,358	4,187	5,131	3,620	3,920	4,320	4,584
	tailings dam storage	*milionm*^{3}	5.00	5.36	6.17	7.34	7.90	9.09	10.26	10.92	12.62	14.61	15.61	16.61
	water dam storage	*milionm*^{3}	5.00	5.34	5.33	4.35	4.31	3.32	2.34	2.37	1.38	1.39	2.39	3.40

4.4 Optimized Solution Economic Evaluation Results

After deciding on one-year operating in either situation, evaluating the planning vision economically is needed. First, considering the results (Table 1 and 2), the quantities and expenses of operation must be calculated. Therefore the amount of water pumped in the cycle, groundwater and river water consumed in a one year period are calculated. (Table 3)

Table 3: Estimation of 5-year Construction plus 20-year Operation of Water Cycle

Variable					Months of the Year											
			Description	*Unit*	1	2	3	4	5	6	7	8	9	10	11	12
One-Year Operation	Quantities	Without PT	**Pumping**	1000 Mwat	8,997	7,582	9,918	10,118	6,862	6,329	5,930	5,928	6,232	10,105	8,208	2,916
			Groundwater	Mm^3/mon	252	252	252	252	252	252	251	165	161	141	213	0
			River	Mm^3/mon	82	44	44	43	44	81	91	117	117	117	117	0
		With PT	**Pumping**	Mwat	5,317	5,824	7,150	6,232	5,426	6,067	6,260	6,240	5,959	5,053	5,991	4,825
			Groundwater	Mm^3/mon	15	53	66	82	68	0	93	38	93	92	58	0
			River	Mm^3/mon	80	38	40	38	39	77	80	104	104	104	104	0
	Costs	Without PT	**Pumping**	10E9 Rls	8,097	6,824	8,926	9,106	6,176	5,696	5,337	5,335	5,609	9,095	7,387	2,624
			Groundwater	10E9 Rls	10,080	10,080	10,080	10,080	10,080	10,080	10,040	6,600	6,440	5,640	8,520	0
			River	10E9 Rls	2,460	1,320	1,320	1,290	1,320	2,430	2,730	3,510	3,510	3,510	3,510	0
		With PT	**Pumping**	10E9 Rls	4,785	5,242	6,435	5,609	4,883	5,460	5,634	5,616	5,363	4,548	5,392	4,343
			Groundwater	10E9 Rls	600	2,120	2,640	3,280	2,720	0	3,720	1,520	3,720	3,680	2,320	0
			River	10E9 Rls	2,400	1,140	1,200	1,140	1,170	2,310	2,400	3,120	3,120	3,120	3,120	0
	Benefits		**Tailings Disposal**	10E9 Rls	2,844	2,844	2,844	2,844	2,844	2,844	2,844	2,844	2,844	2,844	2,844	2,844
			Plant Water	10E9 Rls	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555	1,555
			Farmers Water	10E9 Rls	26	26	26	26	26	26	26	26	26	26	26	26

The cost of each of these quantities during the operation years is estimated considering the value of currency and finally the cost of operation in each year during the twenty years of operation is calculated.

For calculating the expenses of the construction period; the costs of accumulation including pipe lines, reservoirs, pump stations, tailings dam and also fabrication and installation of paste thickener equipments are dispensed equally throughout the 5 year construction period.

The project has three income sources. One from selling water to the copper plant, second from selling the water to downstream farmers and finally from storage of the tailings that enter the project from the plant. In order to estimate the income of the project each of the above are estimated within the operation period.

Finally by calculating the expenses and incomes of the project, the descent cash flow during the planning vision is shown (Figure 2).

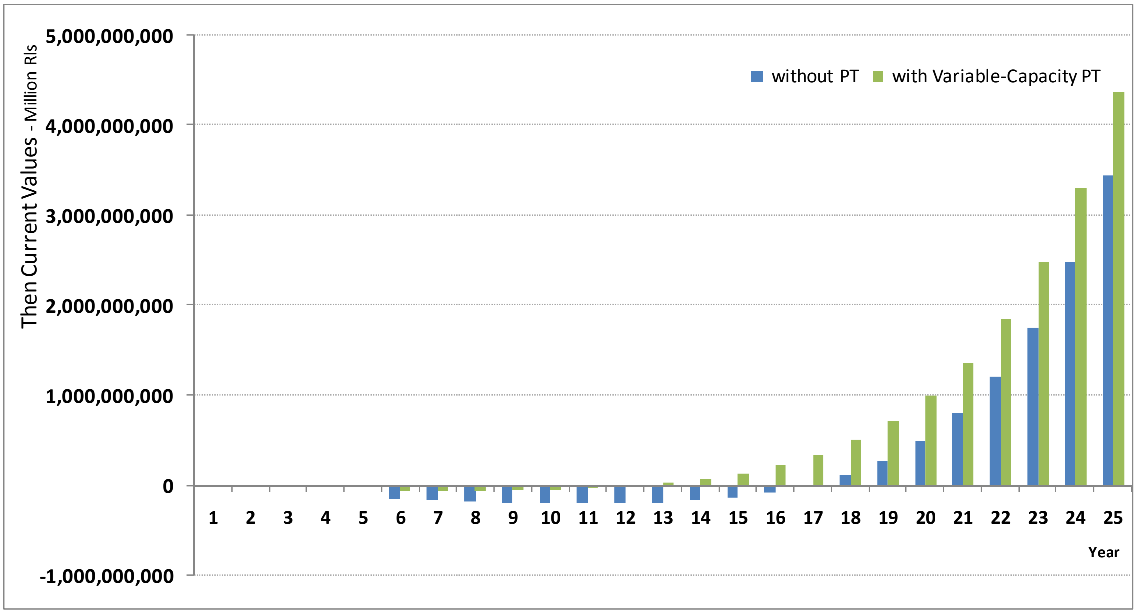

Figure 2: Descent Cash Flow in two Different Conditions

Now considering the cash flow and the concept of Net Present Value (NPV) and by employing an appropriate descent rate, the incomes and expenses can be coincided and obtaining the NPV for both conditions from their difference is possible (Table 4).

Table 4: Economic Evaluation with NPV Concept

Project	Unit	Cost Present Value	Benefit Present Value	Net Present Value
without PT	Million Rls	1,969,361,644	2,064,597,883	95,236,239
with Variable-Capacity PT	Million Rls	1,095,962,807	2,064,597,883	968,635,076

As shown in Table 4, the cost present value, while applying paste thickeners, has a significant decrease although the benefit present value in both conditions is identical. Therefore the net present value or the profit in this condition increases which shows the economic justification of employing paste thickeners.

5. Conclusions

1. According to Table 1 and 2, in the plant operation, without using paste thickeners the operation expense is constantly more; in addition, in this condition underground water consumed is multiplies in comparison to applying paste thickeners. Therefore the necessity of installing paste thickeners is strongly perceived for both decreasing the operation costs and reducing the consumption of ground water.

2. The results in Table 4 prove the economic justification of applying paste thickeners in the closed water cycle of the copper complex since in this condition the NPV is approximately

equal to the cost present value. In other words the benefit to cost (B/C) is almost 2. Whereas while not applying paste thickener this amount is roughly 1 (meaning NPV almost 0).

Therefore the followings are the advantages of applying a closed water cycle in conjunction with installing paste thickener:

- A significant increase in NPV,
- A considerable decrease in underground water consumption,
- Decrease in the amount of pumped water from the tailings dam, which causes a decrease in the necessary capacity for the pipe lines and pump stations route,
- Increase in recycling speed of water for reuse,
- Increase in water supply system certainty.

6. References

Aleyasin, A. (2006). “Water Crisis”. Iran consultant engineer community publisher, Tehran, Iran.

Consoli, S., and Dowman, K. (2006). “Combinatorial optimization and metaheuristics”. Brunel University, School of Information Systems, Computing and Mathematics.

Cunha, M.C., and Ribeiro, L. (2004). “Tabu search algorithms for water network optimization”. *European Journal of Operational Research*, 157, pp. 746–758.

Glover, F., Kelly, J., and Laguna, M. (2005). “New advances and applications of combining simulation and optimization”. Graduate School of Business, University of Colorado, U.S.A.

Glover, F. (2004). “Tabu search and adaptive memory programming, advances, applications and challenges”. Graduate School of Business, University of Colorado, U.S.A.

Glover, Fred. (1998). “Tabu search - Wellsprings and challenges”. *European Journal of Operational Research*, 106, pp. 221-225.

Glover, Fred. (1994). “ Tabu search: Part I & II” in *ORSA Journal on Computing*.

Hertz, Alian, Taillard, E., and Werra, D. (1992). “A Tutorial on Tabu Search”. Centre de Recherche sur les Transports.

Minerals Council of Australia. (2006). “Strategic water management in the minerals industry”. Ministerial Council on Mineral and Petroleum Resources and Minerals Council of Australia.