APPLICATION OF LIFE CYCLE COST ANALYSIS METHOD ON WASTEWATER TREATMENT PLANTS IN EGYPT

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ABSTRACT

Several wastewater treatment plants technologies have been set up in the Egyptian villages; however, the most efficient and economical technology hasn't been determined. This research aims to focus on reaching the best system concerning the achievement of purpose of the establishment which is wastewater treatment and at the same time the least cost in terms of construction, operation, maintenance, and energy through the life time of the plant. The most cost efficient plant was determined according to the life cycle cost analysis (LCCA) method which depends on the life time of the plant to calculate its total cost.The data had been added of (Initial-Replacement-Resale-Power-O&M) costs, number of years from base date and discount factor for each amount for Centralized and decentralized Wastewater Treatment Plants (WWTPs) which had been collected for each plant, and the present value had been calculated for each amount of money and the life cycle cost, (LCC), for each plant. After calculating LCC for each plant, a comparison between them was done for choosing the least.The economic evaluations werestudied in June 2016.

Keywords: Centralized WWTP, Decentralized WWTP, LCC, LCCA method.

1 INTRODUCTION

The Nile Delta suffers from a big problem which is the people's sewage of liquid wastes and its unhealthy treatment which caused the underground water level to rise. It was also the cause of the seepage of water to streams and canals and eventually comes back to the drinking water and agricultural crops. This, in turn, resulted in a large number of the population catching the liver and kidney diseases.Seventy percent of Egypt's population which represents about 60 millions capita are far away from wastewater service. Introducing wastewater service to 60 million costs huge amounts of money and the country is unable to afford. These sums don't include expropriation congestion in the Egyptian countryside.

The lowest cost plant of these plants has been determined by calculating the present value for each amount of money, then the LCC for each plant can choose the least of them. After finding the best systems, these systems have been recommended to be used for serving other rural areas that have no treatments.

2 LITERATURE REVIEW

2.1 Aerobic Treatment

Aerobic treatment requires the presence of oxygen for organisms to reduce the organic load of the waste into carbon dioxide and water. **[1]**

2.1.1 Activated Sludge System

Activated sludge system is the most widely used wastewater treatment plant in Egypt**.**It is called active sludge because of the existence of organisms that doing biodegradation the organic material. In this system, a number of organisms are returned to the tank.

The system consists of several chambers with a high concentration of micro-organisms that remove the nutrients from the wastewater to increase the efficiency of wastewater treatment. In order to maintain the activity of these organisms and to obtain high efficiency, it is necessary to maintain a continuous supply of oxygen to the tank.

Activated sludge consists of a large percentage of the bacteria that are suspended and mixed with the wastewater in the aeration tank, where these bacteria feed on organic matter and convert it to water,CO_2 and energy**. [1]**

2.1.2 Sequencing Batch Reactors

The sequencing batch reactor (SBR) is considered a fill-and-draw activated sludge system. The processes of equalization, aeration, and clarification are all achieved in the same tank, unlike a conventional activated sludge system, in which the same processes are accomplished in separate tanks. Wastewater is added to the tank, treated to remove undesirable components, and then discharged. SBR systems consist of five common steps carried out in sequence: (1) fill, (2) react (aeration), (3) settle (sedimentation/clarification), (4) draw (the effluent is decanted), and (5) idle. Sludge wasting usually occurs during the settling phase**. [2]**

2.1.3 Oxidation Ditches

The oxidation ditch is an extremely effective variation of the activated sludge process. It consists of an oval channel with continuous oxygen supply devices to ensure ventilation such as brush rotors or disc aerators.The solids are kept suspended in the effluents within this ditch. Primary treatment containsscreensand grit chambers. Secondary treatment requires a secondary deposition basin formost applications. Tertiary filters may be required after clarification and disinfection. Re-aeration may be necessary prior to final discharge. **[2]**

2.2 Natural Treatment

Waste Stabilization Ponds (WSP) and Constructed Wetlands (CW) are natural methods of wastewater treatment and are considered effective alternatives to sewage treatment It is advantageous that they treat wastewater in natural ways and that it is a sustainable system in nature in the future, unlike other methods that need complex methods of operation and need high maintenance costs. **[3]**

2.2.1 Waste Stabilization Ponds

Waste Stabilization Ponds (WSPs) are large, shallow ponds. Natural processes are used in waste treatment, including algae and bacteria. It is used for wastewater treatment in temperate and tropical climates. It is one of the best methods of cost, ease of operation and suitable for domestic and industrial water treatment.Natural stabilization ponds are very effective in eliminating fecal coliform bacteria and the only condition to ensure their operation is the sun and require simple labor for daily supervision.**[3]**

2.3 Centralized and Decentralized wastewater treatment plants

Centralized wastewater treatment plants are in most countries the typical facilities found in urban agglomerations. House drainage is connected to an underground sewage network connected to larger pipelines that are ultimately connected to the treatment plants. These systems are expensive to construct (drilling-installation), which represents 70-90% of the capital costs.

Decentralized systems prefer decentralized systems for liquid waste treatment in the case of low population densities such as rural areas**. [4]**

In rural areas of developing countries, people are disposing of wastewater on-site due to the lack of access of government activities to provide sanitation services to small communities. These methods of treatment of wastewater allow the filtration of wastewater into the soil and thus the pollution of groundwater, which is a serious damage to human health and the environment. The implementation of decentralized wastewater treatment plants reduces these impacts and, according to this technology, it is possible to reuse this water. **[5]**

2.4 Life-cycle cost analysis (LCCA)

2.4.1 Discounting Future Amounts to Present Value

Project-related costs occurring at different points in time must be discounted to their present value as of the base date before they can be combined into an LCC estimate for that project. The discount rate used to discount future cash flows to present value is based on the investor's time-value of money. In the private sector, the investor's discount rate is generally determined by the investor's minimum acceptable rate of return (MARR) for investments of equivalent risk and duration. Since different investors have different investment opportunities, the appropriate discount rate can vary significantly from investor to investor.

However, the discount rate to be used for energy- and water conservation investments in federal buildings and facilities is established each year by DOE.**[6]**

2.4.2 Interest, Discounting, and Present Value

When a cash amount is invested at a given interest rate, the future value of that cash amount at any point in time can be calculated using the mathematics of compound interest. Suppose that an initial sum of Po dollars is invested for t years at a rate of interest, i, compounded annually. In one year, the yield would beiP_0, which, added to the principal, PD, would give us, **[6]**

$$P_1 = P_0 + iP_0 = P_0(1+i) \quad (1)$$

After t years, the future compound amount would be,

$$P_t = P_0(1+i)^t \quad (2)$$

Conversely, if we know the interest rate and the value of an interest-earning amount at the end of the first year, we can compute the initial investment amount using,

$$P_0 = \frac{P_1}{(1+i)^t} \quad (3)$$

If we know the interest rate and the value of an interest-earning amount at the end of t years, we can compute the initial investment amount using,

$$P_0 = \frac{P_t}{(1+i)^t} \qquad (4)$$

The discount rate is a special type of interest rate which makes the investor indifferent between cash amounts received at different points in time. That is, the investor would just as soon have one amount received earlier as the other amount received later. The mathematics of discounting is identical to the mathematics of compound interest. The discount rate, d, is used like the interest rate, i, shown in equations 2.2and 2.3 to find the present value, PV, of a cash amount received or paid at a future point in time. Thus we can find the present value of a future amount received at the end of year t, F,, using

$$PV = \frac{F_t}{(1+d)^t} \qquad (5)$$

2.4.3 Discounting formulas and discount factors

Table (1) summarizes the discounting operations most frequently used in the LCC analysis.**[6]**

Table 1. Present-Value Formulas and Discount Factors for Life-Cycle Cost Analysis

PV formula for one-time amounts The Single Present Value (SPV) factor is used to calculate the present value, PV, of a future cash amount occurring at the end of year t, F_t given a discount rate, d. $PV = F_t * \frac{1}{(1+d)^t}$	$PV = F_t * SPV_{(t,d)}$  The SPV factor for d=3% and t = 15 years is 0.642.
PV formula for annually recurring uniform amounts The uniformPresent Value (UPV) factor is used to calculate the present value, PV, of a series of equal cash amounts, A_o, that recur annually over a period of n years, given d. $PV = A_o * \sum_{t=1}^{t=n} \frac{1}{(1+d)^t}$	$PV = A_o * UPV_{(n,d)}$  The UPV factor for d=3% and n = 15 years is 11.94.

2.4.4 LCC Formula for Building-Related Projects

The general LCC formula shown in eq. 7, requires that all costs be identified by year and amount.This general formula, while it is straightforward from a theoretical standpoint, but requires extensive calculations, especially when the study period is more than few years long and for annually recurring amounts, for which future costs must first be calculated to include changes in prices. **[6].**
A simplified LCC formula for computing the LCC of energy and water conservation projects in buildings can be stated as follows:

LCC = I + Repl. — Res. + E + W + OM&R (7)

LCC = Total LCC in present-value of a given alternative،
I = Present-value investment costs،
Repl. = Present-value capital replacement costs،

Res. = Present-value residual value (resale, scrap and salvage values) less disposal costs
E = Present-value energy costs،
W = Present-value water costs, and
OM&R= Present-value non-fuel operating, maintenance, and repair costs.**[6]**

3 DATA COLLECTION

Average economic data has been collected for several of plants which are used in Egypt for the selected systems.

3.1 Centralized systems:

Table 2. Average economic data for Centralized systems

Systems / Cost $	CO	SBR	OX
Construction cost /m^3	111	611	166
Cost of operation and consumables/m^3	0.017	0.022	0.0056
Power cost/m^3	0.0033	0.0056	0.0028
Specific surface area (m^2/m^3)	0.11	0.056	0.11

Table (2) shows average economic data for CO – SBR – OX systems**. [7]**

The selected (CO) WWTPs systems are represented by [Benisuef (Tansi bane malo) - Damietta (faraskor - kafersaad) – Fayoum (Zaueakerdasa - Alagmeen) - Gharbiya (Nvea - Alsanta) – Dakahliya (Balqas – Almanzla – Bdawe – Dkerns - kafer met fatek – Salmone - Shaha)]
The selected (SBR) WWTPs systems are represented by [Alexandria (Dams - Korshed and Zweda - Mobark)]

The selected (OX) WWTPs systems are represented by [Damietta (Alrahmna - Kaferelbatekh - Kaferelseman) – Fayoum (Qton - Atsa)]

Notes:

- Cost of the land = 16,666$/Acre
- Initial Investment = construction cost + cost of the land
- After 20 years we need to replace the mechanical works. It is 60% of construction cost at the initial date.
- Buildings are 40% of construction cost at the initial date.
- After the end of the project, Resale value is 70% for buildings**. [7]**

Table 3. Average economic data for Centralized systems (flow is 10000 m^3/day)

Systems / Cost $	CO	SBR	OX
Initial Investment	1,190,500	1,746,055	6,150,777
Replacement	666,666	1,000,000	3,333,333
Resale value	311,111	466,666	1,711,111
O&M	60,833	20,277	81,111
Power	12,166	10,166	20,277

Table (3) shows average economic data for CO – SBR – OX systems if flow is 10000 m^3/day.

3.2 Decentralized systems:

Table 4. Average economic data for Decentralized systems

Systems / Cost $	AS	WSP
Construction cost /m^3	77.8	133.3
Cost of operation and consumables/m^3	0.00167	0.00056
Power cost/m^3	0.001	0.00083
Specific surface area (m^2/m^3)	0.11	0.83

Table (4) shows average economic data for AS – WSP systems. **[7]**

The selected (AS) WWTPs systems are represented by [Boraig - Smella]. The selected (WSP) WWTPs systems are represented by [Moufty - Om sen-Koleaa - Komdabaa]

Table 5. Average economic data for Decentralized systems (flow is 2000 m^3/day)

Systems / Cost $	AS	WSP
Initial Investment	171,444	385,722
Replacement	93,333	0
Resale value	43,555	186,666
O&M	1,215	405
Power	822	600

Table (5) shows average economic data for AS - WSP systems if flow is 2000 m^3/day.**[7]**

4 PRESENT VALUE CALCULATIONS FOR EACH PLANT

Data for costs and values of discount factors have been addto this table, then we calculate the present values for each cost and LCC for each plant that are showed in the following parts,

4.1 Centralized WWTPs

Table 6.Present Value calculations CO.AS plant
Project Title: Conventional Activated Sludge plant

Investment-related amounts(1)	**Amount on BD (2)**	**Discount factor (3)**	**Present value (4)=(2)*(3)**	**PV TOTALS (5)=Summation of (4) by type**
Initial Investment	1,190,500	1	1,190,500	Initial Investment +1,190,500
Replacement	666,666	0.149	99,333	Capital replacement + 99,333
Resale value	311,111	0.022	6,844	Resale value -6,844
				TOTAL INV.-RELATED 1,289,833

				COSTS
Operation-related amounts	**Amount on base data**	**Discount factor**	**Present value (4)=(2)*(3)**	
O&M	60,833	9.8	596,163	Annual O&M 596,163 Power 119,233 TOTAL OPERATION _ REL. COSTS 715,396
Power	12,166	9.8	119,233	
TOTAL PV LIFE-CYCLE COSTS = 2,005,229				

Table 6 shows present value Calculations forCO.AS plant and we get that the present value of initial investment costis1,190,500$,replacement cost is99,333 $,resale value cost is -6,844$,O&Mcostis596,163$andpower cost is 119,233$.
Total investment related costs= 1,289,833$, Total Operation Related Costs= 715,396 $and Total PV life cycle cost = 2,005,229 $.

Table 7. Present Value calculations for OX plant
Project Title: Oxidation Ditch plant

Investment - related amounts (1)	**Amount on BD (2)**	**Discount factor (3)**	**Present value (4)= (2)* (3)**	**PV TOTALS (5)=Summation of (4) by type**
Initial Investment	1,746,055	1	1,746,055	Initial Investment +1,746,055 Capital replacement + 149,000 Resale value -10,266 TOTAL INV.-RELATED COSTS 1,895,054
Replacement	1,000,000	0.149	149,000	
Resale value	466,666	0.022	10,266	
Operation-related amounts	**Amount on base data**	**Discount factor**	**Present value (4)= (2)* (3)**	
O&M	20,277	9.8	198,722	Annual O&M198,722 Power 99,633 TOTAL OPERATION _ REL. COSTS 298,355
Power	10,166	9.8	99,633	
TOTAL PV LIFE-CYCLE COSTS = 2,193,409				

Table 7 shows Present Value Calculations for OX plant and we get that The Present Value of Initial investment cost is 1,746,055 $**,** Replacement cost is 149,000 $, Resale value cost is -10,266 $, O&M Cost is 198,722$and Power cost is 99,633$. Total investment related costs = 1,895,054$, Total Operation Related Costs = 298,355 $ and Total PV life cycle cost = 2,193,409$.

Table 8. Present Value calculations for SBR plant
Project Title: Sequence Batch Reactor plant

Investment-related amounts(1)	**Amount on BD (2)**	**Discount factor(3)**	**Present value (4)=(2)*(3)**	**PV TOTALS (5)=Summation of (4) by type**
Initial Investment	6,150,777	1	6,150,000	Initial Investment +6,150,000 Capital replacement + 496,666 Resale value -37,644 TOTAL INV.-RELATEDCOSTS 6,647,443
Replacement	3,333,333	0.149	496,666	
Resale value	1,711,111	0.022	37,644	
Operation-related amounts	**Amount on base data**	**Discount factor**	**Present value (4)= (2)* (3)**	
O&M	81,111	9.8	794,888	Annual O&M794,888 Power 198,722 TOTAL OPERATION _ REL. COSTS 993,610
Power	20,277	9.8	198,722	
TOTAL PV LIFE-CYCLE COSTS = 7,641,053				

Table 8 shows Present Value Calculations for SBR plant and we get that The Present Value of Initial investment cost is 6,150,000 $**,** Replacement cost is 496,666$, Resale value cost is -37,644 $, O&M Cost is 794,888 $ and Power cost is 198,722$$.Total investment related costs = 6,647,443 $, Total Operation Related Costs = 993,610 $and Total PV life cycle cost = 7,641,053 $

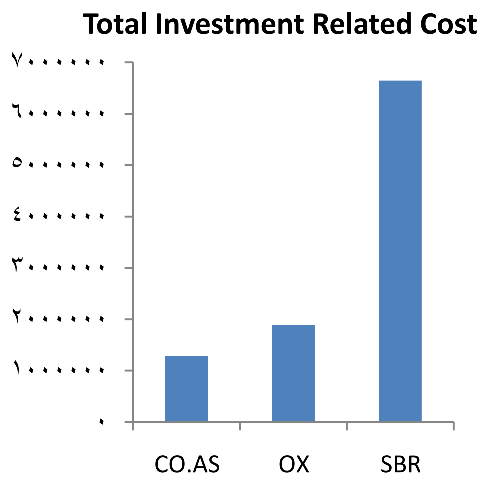

Figure 1.TotalInvestmentRelatedCosts for (CO.AS), (OX) and (SBR), $

Figure 1shows that the least value of Total Investment related costs is(CO.AS) plant (1,289,833$followed by) (OX) plant (1,895,054$) and (SBR) plant(6,647,443$).Total Investment related costs for SBR plant is 500% more than OX & CO.AS costs.The values of Total Investment related costs for CO.AS and OX plants are so close.

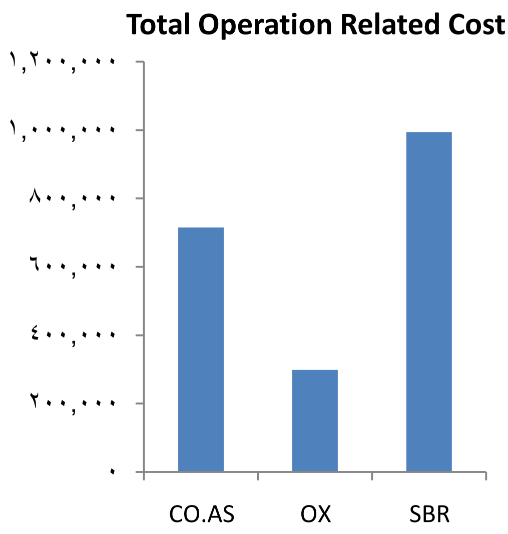

Figure 2.TotalOperationRelatedCostfor (CO.AS), (OX) and (SBR), $

Figure 2 shows that the least value of the Total operation related costis (OX) plant (298,355,$), followed by (CO.AS) plant (715,396,$) , and (SBR) plant= 993,610$. The total operation costs for OX plant is 900%. less than AS & SBR costs.

4.2 Decentralized WWTPs

Table 9. Present Value calculations for AS plant
Project Title: Activated Sludge plant

Investment - related amounts(1)	**Amount on BD (2)**	**Discount factor (3)**	**Present value (4)=(2)*(3)**	**PV TOTALS (5)=Summation of (4) by type**
Initial investment	171,444	1	171,444	Initial Investment +171,444
Replacement	93,333	0.149	13,906	Capital replacement + 13,906
Resale value	43,555	0.022	958	Resale value -958 TOTAL INV.-RELATEDCOSTS 185,350
Operation-related amounts	**Amount on base data**	**Discount factor**	**Present value (4)=(2)*(3)**	
O&M	1,216	9.8	11,923	Annual O&M11,923
Power	822	9.8	8,057	Power 8,057 TOTAL OPERATION _ REL. COSTS 19,980

Table 9 shows Present Value Calculations for AS plant and we get that The Present Value of Initial investment cost is 171,444$**,** Replacement cost is 13,906$, Resale value cost is -958$, O&M Cost is 11,923$and Power cost is 8,057$. Total investment related costs = 185,350$, Total Operation Related Costs = 19,980$and Total PV life cycle cost = 205,330$

Table 10. Present Value calculations for WSP plant
Project Title :Waste Stabilization Pond plant

Investment - related amounts(1)	**Amount on BD (2)**	**Discount factor (3)**	**Present value (4)=(2)*(3)**	**PV TOTALS (5)=Summation of (4) by type**
Initial investment	385,722	1	385,722	Initial Investment +385,722
Replacement	0	0	0	Capital replacement + 0
Resale Value	186,666	0.022	4,106	Resale value -4,106 TOTAL INV.-RELATEDCOSTS 385,722
Operation-related amounts	**Amount on base data**	**Discount factor**	**Present value (4)=(2)*(3)**	
O&M	405	9.8	3,974	Annual O&M 3,974
Power	600	9.8	5,880	Power 5,880 TOTAL OPERATION _ REL. COSTS 9,854
TOTAL PV LIFE-CYCLE COSTS = 395,576				

Table 10 shows Present Value Calculations for WSP plant and we get that The Present Value of Initial investment cost is 385,722$**,** Replacement cost is 0 $, Resale value cost is -4,106$, O&M Cost is 3,974$and Power cost is 5,880$.Total investment related costs = 385,722$, Total Operation Related Costs = 9,854$and Total PV life cycle cost = 395,576 $

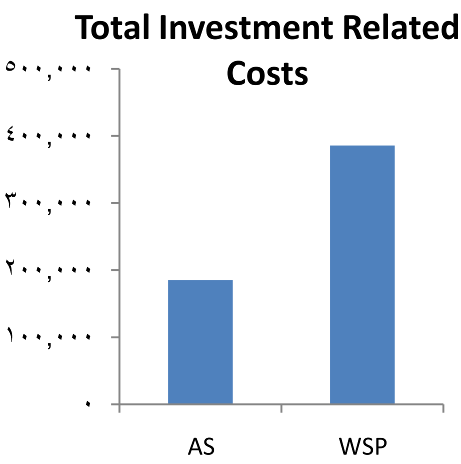

Figure 3. Total Investment related costs for (AS) and (WSP), $

Figure 3 shows that Total Investment related costs for (AS) plant =185,350$is less than (WSP) plant=385,722$.

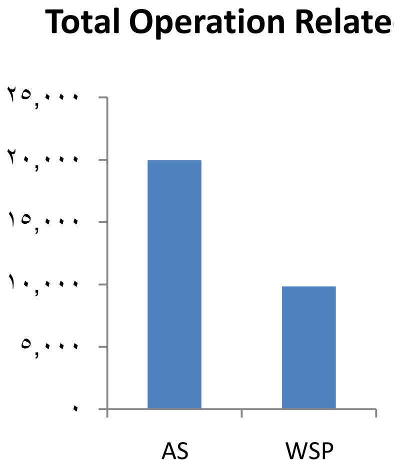

Figure 4.Total Operation Related Cost for (AS) and (WSP), $

Figure 4 shows that the Total operation related cost for (WSP) plant=9854$ is less than (AS) plant = 19980$

5 COMPARISON BETWEEN SYSTEMS FROM LCC

After calculating LCC for each plant, we compare between them for choosing the least.

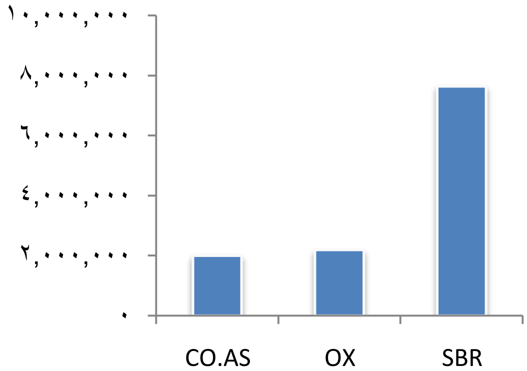

Figure 5. Total PV Life-Cycle Costs for (CO.AS), (OX) and (SBR) plants, $

Figure 5 shows that the least value of LCC of systems is CO.AS =2,005,229$, followed by OX = 2,193,409 $, and SBR=7,641,053$.The value of LCC for SBR plant is 600% higher than OX plant because of its high cost of construction. The value of LCC for AS plant is higher than OX plant value due to the increase in the cost of O&M costs for AS plant than OX plant.

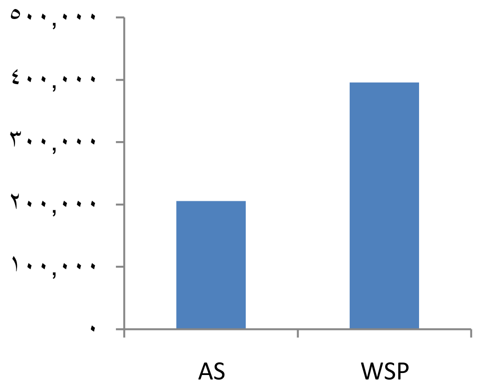

Figure 6. Total PV Life-Cycle Costs for (AS) and (WSP) plants, $

Figure 6 shows that the LCC of AS plant =205,330$is less than WSP = 395,576$.

CONCLUSIONS

According to the previous results, the following can be concluded, by applying LCCAmethod, the best system which is concerning with the achievement of wastewater treatment and at the same time the least cost throughout its existence time, went to Oxidation Ditch for centralized WWTPs and went to Activated Sludge for decentralized WWTPs. On the other hand, Sequence Batch Reactor plant cost is very high, about 500% higher than the cost of Oxidation Ditch plant,so it must be excluded.

ABBREVIATIONS

AS	:Activated Sludge
BD	:Base Date (Initial Date)
CO	:Conventional Activated Sludge
LCC	:Life Cycle Cost
LCCA	:Life Cycle Cost Analysis
O&M	:Operation and Maintenance
OMC	:Operation and Maintenance Cost
OX	:Oxidation Ditch
P/C	:Planning/Construction
PV	:Present Value
SBR	:Sequence Batch Reactor
SD	:Service Date
WWTP	:Wastewater Treatment Plant
WSP	:Waste Stabilization Ponds

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