Chapter 4
Results and discussions

As a result of substances and their impact list on the inventory, relevant data had been collected in WWTP and other available literatures. The inventory of resource used and emissions had been calculated per functional unit, 1 m^3 of the treated wastewater with satisfied quality to meet the standard for discharged effluent of the IEAT. The outcome had been evaluated by means of the EPS method in the life cycle impact assessment, which was focused on environmental loads such as emissions and natural resource depletion.

4.1 Life cycle inventory

Due to the life cycle of the WWTP, involved of raw material acquisition through the manufacture of components or materials such as chemicals, media filter and maintenance spare parts. Moreover, this processing of data did not be used any LCA software or their databases. Recently the formal LCA studies have been widely received more attention in the education field, on the other hand, a few formal LCA studies are evaluated in Thailand, due to the lack of sufficient databases relevant to domestic condition (Lohsomboon, P. 2002). Some data required for this study were not accessible, therefore the assumptions for the up-stream processes were provided as follow:

- Electricity production in Thailand (Ongmongkolkul, A., Nielsen, P.H. and Nazhad, M.N. 2001) was used in this study referred to the chemical production of NaOH and HCl.
- Filtration material such as sand filter, anthracite filter and activated carbon and other chemicals with the exception of NaOH and HCl, were considered to be raw material extractions.
- The amount of fuel consumption and emissions released during transportation were calculated for chemical and waste disposal only.

- Recovery of gold resin was confidential, and at the request of the waste management company was excluded in this inventory.
- Ion exchange resin is composed of DVB 8% and polypropylene 92%, therefore the polypropylene production was estimated in this study.
- Specific lubricant oil, used as maintenance material in WWTP, was derived from Petrol production data (White, P., Fanke, M. and Hindle, P., 1995).
- Municipal solid waste (MSW) landfill controls only leachate as effluent standard which had been not employed any gas control system to prevent unwanted movement of landfill gas into the atmosphere.
- Filter-cake sludge from WWTP disposed at the hazardous landfill is stabilized and solidified before disposal in secured landfill. Their leachate and gas is controlled, however, there is still the possibility of contamination to the soil.

LCI results were calculated by using computer modeled spreadsheets, such as Microsoft excel program, to combine and compile the input and output data of each unit process. These inventories had been collected all concerned data since July, 2002 to June, 2003. The inventory display a detail of raw materials and environmental releases, which are provided in Appendix D. Some essential parts of WWTP inventory were selected to perform analysis as shown in Table 4.1.

With consideration to the allocated system for this study as defined in section 2.2.2, co-products allocation in which the process, used by two or more products, must be allocated (Wenzel, H., Hauschild, M. and Alting, L., 1998). When possible, allocation should be based on actual inventory data from the process, rather than the basis of secondary data such as weight or value (Graedel, T.E., 1998).

The gold recovery system (T3) was focused to co-products arising when gold resin from the gold recovery process was recovered by another process, as presented in the following Fig. 4.1. In this case, the allocation was based on a weight by-product. Therefore, the total of the inventory table was divided between treated gold wastewater and gold resin allocation step (Curran, M.A., 1996). The relative contribution for treated gold wastewater could be calculated by which made value approximately to 1. Therefore, there was not any change to the effects on the environmental impacts in the inventory table.

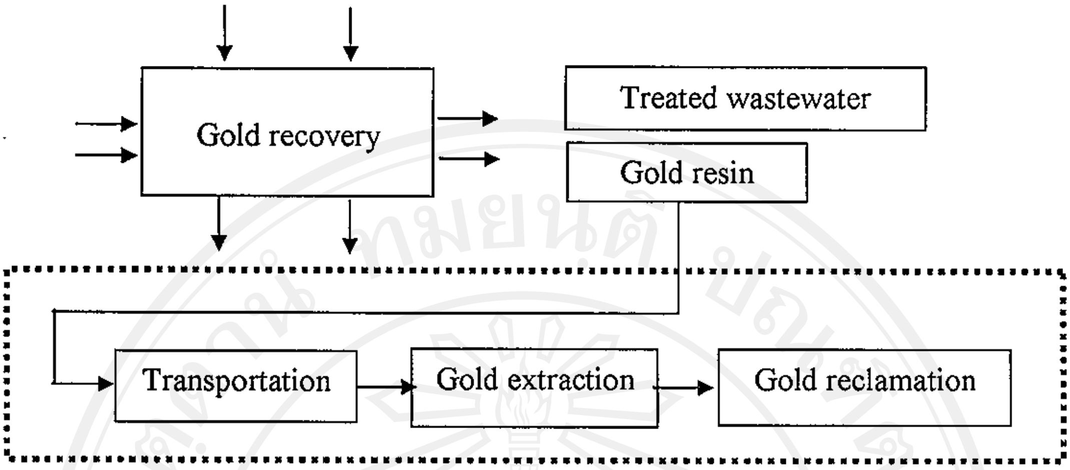

Figure 4.1 Diagram of Gold recovery process for considering allocated approach

Table 4.1 Selected exchanges per functional unit (1 m^3 of treated wastewater)

Selected exchanges per functional unit (1 m^3)

Inputs

Resource		
Energy and fossil:		
Energy	17.07	MJ
Fuel oil	0.20	kg
Lignite	0.89	kg
Natural gas	0.55	kg
Raw material:		
Copper	2.10	g
Calcium chloride	0.24	kg
Ferrous sulfate	59.87	g
Hydrochloric acid	0.59	kg
Sodium hydroxide	0.75	kg
Resin	5.41	g
Water	23.49	kg

Outputs

Product:		
Treated wastewater	1.00	m^3
Emission to air:		
CO	3.08	g
CO_2	1.24	kg
Dust (coarse)	0.60	g
Methane	6.19	g
N_2O	0.11	g
NO_x	19.72	g
NMVOC	0.17	g
SO_2	6.23	g
SO_x	0.34	g
Emission to water:		
Chloride	0.02	g
COD	0.01	g
Copper	0.29	g
Nickel	1.07	g
SS	0.01	g
TOC	0.02	g
Emission to soil:		
Aluminum	0.37	g
Arsenic	0.08	g
Calcium	51.62	g
Copper	30.66	g
Iron	66.47	g
Lead	3.60	g
Magnesium	8.79	g
Manganese	0.43	g
Nickel	78.54	g
Tin	4.79	g

Solid waste generation:

Plastic packaging	4.45	g
Paper waste	0.09	g

4.1.1 Resource used

In this study, the resource used is a summation of energy use and raw material. Total energy includes processed energy, transportation energy and energy of material resources (Curran, M.A., 1996).

- Processed energy is the energy used to acquire and produce the materials and fuels for wastewater treatment systems.
- Transportation energy is the energy used to transport chemical and waste disposal. The most frequently used mode of transportation is by truck.
- Energy of material resources, is the energy content of fuel resources that are used as raw materials such as energy content of diesel, fuel oil and natural gas that are utilized as raw materials for HCl and NaOH production.

4.1.2 Atmosphere emission

The LCI result of releases to the air implies that the substances list such as CO, CO_2, SO_2 and N_2O, have been effected on the environment. These emissions have been associated with the combustion of fuel for material production process and transportation.

4.1.3 Wastewater discharge

The LCI result of wastewater discharge include substances are classified as pollutants and the quantity of pollutants in wastewater effluent. Some of the most wastewater pollution are heavy metals, i.e.-Ni, Cu, Pb and inorganic substances to water.

4.1.4 Solid waste

Solid wastes are generated by solid outputs from the WWTP that are disposed to landfills both of MSW and hazardous waste. A volume of materials occupying the landfill was extracted to organic substances and to the soil. The combustible component in MSW could be estimated by the amount of gas produced in the landfill, i.e., CH_4, CO_2, NH_3.

Note that in this case, co-products arising in the gold recovery process are allocated by by-product weight based on actual inventory data from the process. Therefore, the total of the inventory table is divided between treated gold wastewater and the gold resin allocation step. The relative contribution for treated gold wastewater can be calculated by dividing the weight value for treated gold wastewater with the weight value of both products, which can be approximately to be 1. There is no change to the existing inventory table.

4.2 Life cycle impact assessment

The LCA steps of impact assessment are dealt to the reduction of complex inventory data to impact-related figures. In this study, the methodology for valuing life cycle assessment of WWTP is called the EPS system. This system is combined characterization and valuation into single values, which are derived by WTP. Impact categories are identified from five safeguarded subjects included biodiversity, human health, ecological health, resource, and aesthetics. Their indices are combined characterization and weighting factors for emission and resource depletion. When LCI results are reported for environmental release, it can be contributed to 4 categories; energy and resource used, emission to air, emission to water and emission to soil. The appropriate quantity of resource used and emissions released from inventory are multiplied by weighting indices to arrive at ELU, which can then be added together to arrive at an overall ELU for the life cycle of WWTP. The environmental impact categories of highest importance are received more attention than categories of least concern and reduction of ELU is studied to improve WWTP (David T. Allen and David R. Shonnard, 2002).

Due to a valuation step is implied in each ELU calculation, the indices for resource depletions can be considered as the weighting indices. Indices for emissions are obtained from combined characterization and weighting factors. The list of weighting indices and impact indices can be found from the table of combined characterization and weighting factors for emissions and resource depletion (weighting indices) as list below (Steen, B. 1999 and Steen, B., 2001).

- weighting indices for fossil resource depletion
- weighting indices for depletion of ore and other inorganic material
- weighting indices for land use
- emission of organic substances to air
- emission of freons and similar substances to air
- emission of inorganic substances to air
- emission of radionuclides to air
- emission of substance groups to air
- emission of inorganic substances to water
- emission of organic substances to water
- emission of substance groups to water
- emission of organic substances to soil

Table 4.2 shows the selected environmental weighting factors from the EPS system. Calculate the ELUs of T4 was due to air emissions from one kilogram of HCl production. From inventory list, air emissions of HCl production based on one cubic meter of treated wastewater are 0.015 g of carbon dioxide, 0.003 g of carbon monoxide, 0.0025 g of dust, 0.0003 g of methane, 0.0005 g of nitrogen dioxide, 0.0007 g of non methane VOC and 0.025 g of sulfur dioxide, respectively.

Table 4.2 Selected environmental indices from the EPS system, in ELUs per kilogram. (Steen, B., 2001)

Energy		Emission to air	
Crude oil	0.51	CO_2	0.11
Lignite	0.05	CO	0.33
Natural gas	1.10	Dust (coarse)	36.00
		Methane	2.72
		N_2O	38.30
		Non methane VOC	2.14
		SO_2	3.27

Solution : Total ELUs due to air emissions are
(0.015 g CO_2 x 0.11 ELU/kg of CO_2 + 0.003 g CO x 0.33 ELU/kg of CO + 0.0025 g of dust x 36.00 ELU/kg of dust + 0.0003 g of CH_4 x 2.72 ELU/kg of CH_4 + 0.0005 g of N_2O x 38.30 ELU/kg of N_2O + 0.0007 g of non methane VOC x 2.14 ELU/kg of non methane VOC + 0.025 g of SO_2 x 3.27 ELU/kg of SO_2)/1000 g/kg = 0.0002 ELU.

The environmental impacts are valued to ELU based on 1 m^3 of treated wastewater from the summation of each treatment processes, which are summarized in the following Table 4.3.

- Rinse water recycled process (T1)
- Heavy metal treatment process (T2)
- Gold recovery process (T3)
- Batch treatment and neutralization process (T4)

Table 4.3 Environmental impacts of each treatment processes in the WWTP

Environmental impacts	ELU/m^3			
	T1-Rinse water recycle	T2-Heavy metal precipitation	T3-Gold recovery	T4-Batch treatment and neutralization
Energy	1.55E-01	9.51E-02	3.00E-02	4.81E-01
Raw material	1.34E-01	1.12E+00	2.04E+03	2.52E+00
Total Resource used	2.89E-01	1.21E+00	2.04E+03	3.00E+00
Emission to air	1.21E-02	3.60E-02	6.56E-03	2.23E-01
Emission to water	3.15E-02	2.78E-02	3.90E-06	1.84E-01
Emission to Soil	0.00E+00	1.93E-01	0.00E+00	3.71E-01
Total	3.32E-01	1.47E+00	2.04E+03	3.78E+00
Grand total	**2.04E+03**			

Remarks : The result of total resource used is a summation of energy use and raw material.

From this calculation, it was found the total ELUs value for the whole life cycle of wastewater treatment plant is 2,040 ELU/ m^3 of treated wastewater. It can be shown as the first 2 major processes impacting on the environment are the gold recovery process (T3) and the batch treatment and neutralization process (T4). The graphic overview of environmental impacts is presented in the following Fig. 4.2. The assessment result by the EPS method can be suggested that the highest contributor to each treatment process is resource used. The energy used and raw material are the major environmental impacts categories caused by T1, while their impacts of T2, T3 and T4 are originated from raw material categories.

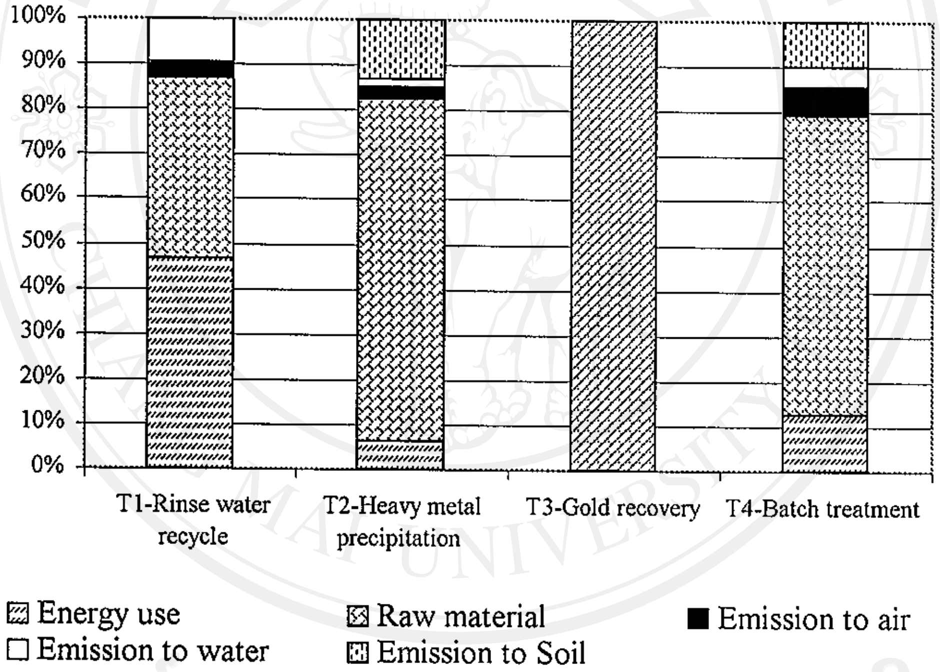

Figure 4.2 Contribution of the environmental impacts on WWTP.

4.2.1 Resource used

As a result of total ELUs, it was found that the resource usage calculation is the main source of the environmental burden for each treatment process. According to the inventory, the use of gold in the gold recovery process (T3) is of greater concern due to the precious metals assigned with high indices as a result of depleting of ores and other inorganic materials. However, the input of gold is less than nickel and copper. Moreover, the indices for resource depletion are the same as the weighting indices for the depletion of gold is quite high comparing with other ore and inorganic mineral as a consequent of environmental impact value of gold recovery process is the highest contribution of the environmental impacts on WWTP.

With consideration to the energy resource use, the percentage of ELUs due to energy can be presented in the following Fig. 4.3. Among energy use, batch treatment and the neutralization process (T4) are the most significant contributors to total ELUs, which can be accounted for 64% of total energy consumption. Almost all energy consumption is come from fuel oil, lignite and natural gas that are generated electricity used in production.

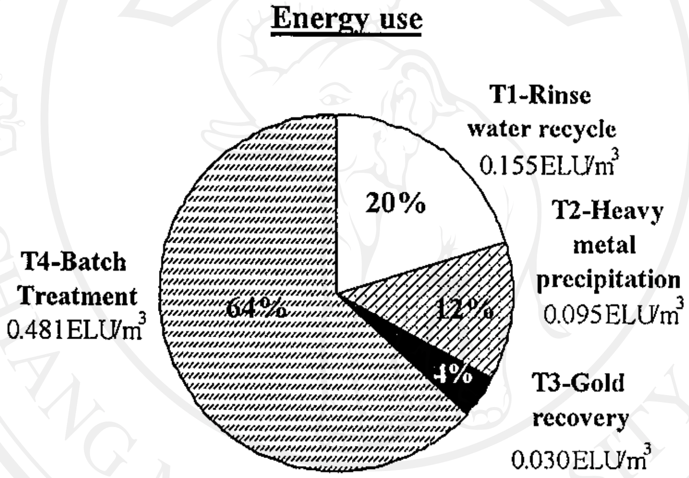

Figure 4.3 Environmental impact of energy use for the life cycle of WWTP

In another view of energy used for each treatment process, energy consumption in rinse water recycled process (T1) is shown as the highest environmental burden accounted for 47% of total ELUs of T1. While batch treatment and neutralization process (T4) is approximated to 13% of total ELUs of T4 as represented in Fig 4.2. This is due to electricity consumption in T1 used for high-pressure pump operates in RO system as shown in Fig. 4.4, which is calculated from WWTP inventory list.

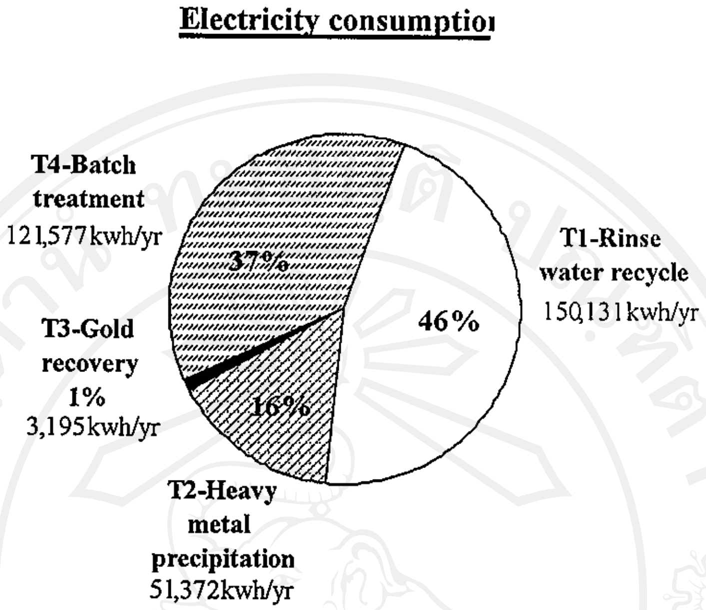

Figure 4.4 Electricity consumption of WWTP

4.2.2 Emission to air

Fig. 4.5 is used to be represented that the highest emission to air contribution to ELUs is generated from batch treatment and neutralization process (T4); approximately 81% of the total. Due to gas generation, i.e. CH_4, CO_2 and NH_3 from waste disposal at landfill, waste volume of this system is higher than other treatment processes. The second largest contribution is heavy metal treatment process (T2); approximately 13% of the total.

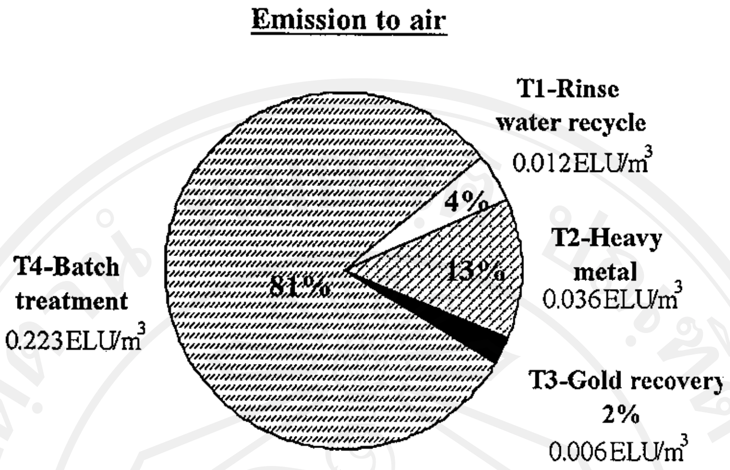

Figure 4.5 Environmental impact of emission to air for the life cycle of WWTP

4.2.3 Emission to water

The result of emission to water is shown in Fig. 4.6. The highest contribution to ELUs is batch treatment and neutralization process (T4); approximately 76% of the total. It is forced to be heavy metal in the emission of effluent. The second largest contribution is come from the rinse water recycled process (T1) approximately 13% of the total. The concentrated water, or rejected water from the RO system, is contaminated some heavy metals from the rinse water-cleaning process of electronic products production. However, the list of weighting indices of water emissions may be added to the ELU for inorganic substances, in the water. The ELU for substances of metal to water input are not available.

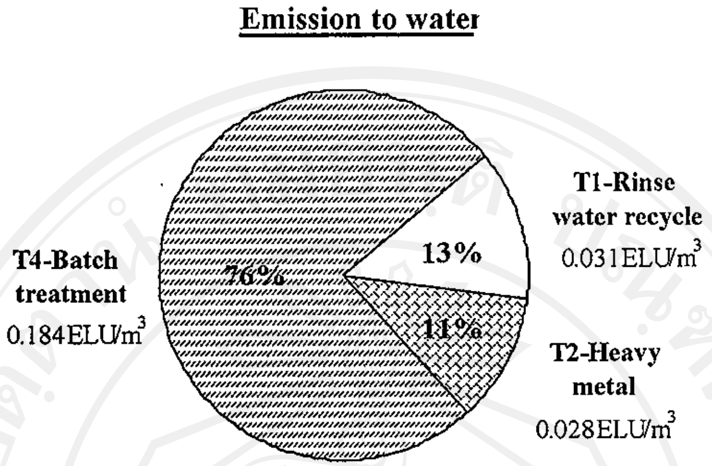

Figure 4.6 Environmental impact of emission to water for the life cycle of WWTP.

4.2.4 Emission to soil

Fig. 4.7 shows that the highest contribution to emission to soil is batch treatment and neutralization process (T4); approximately 66% of the total. The second largest contribution is the heavy metal treatment process (T2); approximately 34%. This contribution is due to heavy metal emissions from filter-cake sludge components disposed to the soil during landfill operations. Solid waste generation is calculated in the inventory table, but lack the weighting indices for emission of organic substances to soil. Refer to the identification of significant environmental aspects and their indicators, it is noted that an index is missing in one of the methods, it sometimes means that the index is zero and sometimes that is not considered. As a alternative is to try to find a similar substance, it turns out to be significant contribution to the overall impact (Steen, B., 2001).

Therefore, the MSW can be calculated to gas emission. Almost all weighting indices are applied for pesticide emissions within the soil; otherwise, emission of metals to soil is provided for Cd and Hg. The assumption of other metals is estimated to Cd because trace inorganic contaminants, i.e. Ni, Cu and Pb is also considered a probable carcinogen as Cd (Sawyer, C.N., Mccarty P.L. and Parkin, G.F., 1994).

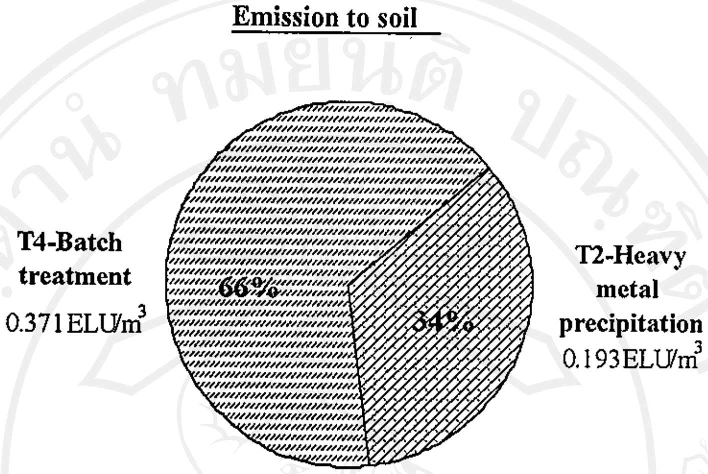

Figure 4.7 Environmental impact of emission to soil for the life cycle of WWTP.

4.3 Sensitivity analysis for environmental impact potential at WWTP

The last phase of LCA is the life cycle interpretation, which is a systematic technique to evaluate the results of the inventory analysis and impact assessment for improvement. A key step to interpreting the results of the LCA is the evaluation of the completeness, sensitivity and consistency of data (USEPA, 2001). In the EPS system, sensitivity analysis is recommended to be used as estimation of identified uncertainty for individual input data (Steen, B., 1999).

As a result of the LCI and LCIA, the highest contribution to WWTP was resource used especially, on the gold recovery process (T3) and batch treatment and neutralization process (T4). T3 and T4 were reviewed for their information from the previous study to identify the data elements that contributed the most environmental burden or high ELU; otherwise, known as significant issues. The identification of the significant issues for T3 and T4 were listed; gold inlet of wastewater (T3), gold resin usage (T3), electricity consumption (T4), chemical transportation (T4), waste transportation (T4), sludge generation (T4) and NaOH production (T4).

Before drawing a conclusion of the selected environmental impacts to improve WWTP, the evaluation could be increased substantially by carrying out a sensitivity analysis. For more details of the sensitivity analysis in this case, refer to Appendix F. Fig. 4.8 and 4.9 illustrates the environmental impacts of T3 and T4 coming from the life cycle of the WWTP at 10%, 50% and 100% adverse change in the individual raw material.

From Fig. 4.8, it can be seen that the gold inlet wastewater is a significant subject for T3, which is most sensitive to the total environmental impact. Gold resin usage does not be sensitive to the changes.

The results are obtained as shown in Fig. 4.9, the selected environmental impacts of chemical transportation, sludge generation and NaOH production are sensitive and significant issues for T4. There are varied significantly with their changes. The most significant subject for T4 is shown as sludge generation. When the degree of sludge generation is added by 50%, the differential is approximately changed to 33%. Comparison of the electricity consumption, when the degree of resource used is added to 100%, the selected impact is changed only by 16%. It is the same as waste transportation, with little significant change.

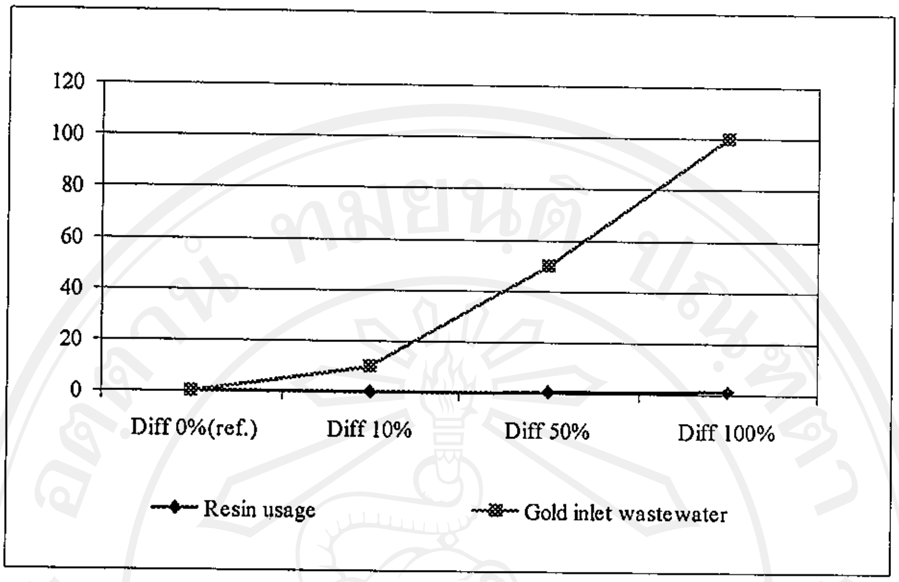

Figure 4.8 Comparison of T3 significant issues Vs differential percentage of changes from sensitivity analysis.

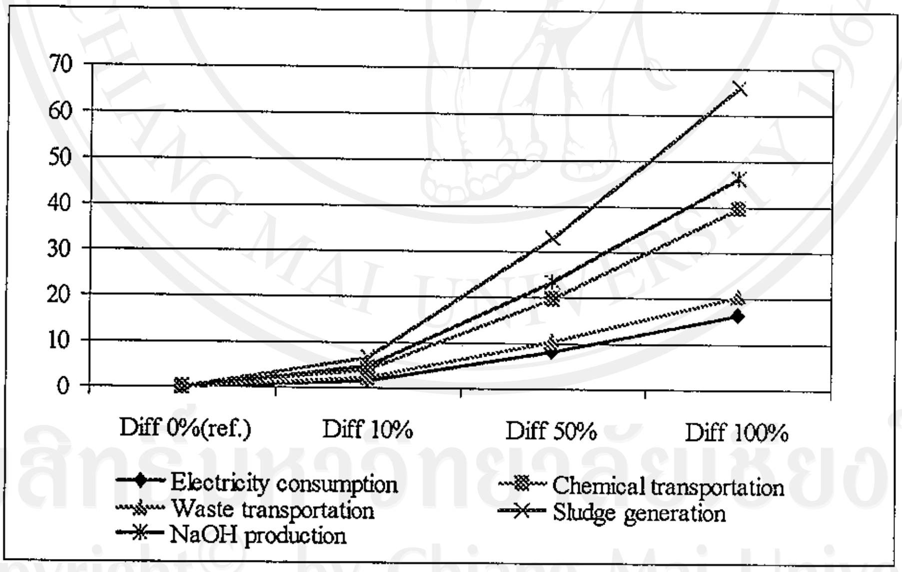

Figure 4.9 Comparison of T4 significant issues Vs differential percentage of changes from sensitivity analysis.

The result of the sensitivity analysis can be confirmed and concluded the highest contribution to each treatment process is raw material consumption, especially, on the gold recovery process (T3) and batch treatment and neutralization process (T4). It can be shown that the main factors effected with ELU are listed below, which will be modified from the environmental perspective as listed;

- Gold inlet of wastewater (T3)
- Chemical transportation (T4)
- Sludge generation (T4)
- NaOH production (T4)

4.4 Modifications

With reference to propose of this study, the reduction of ELU had been applied by waste minimization concepts to maximize the environmental benefit of WWTP as described in Section 2.3. Based on waste minimization, techniques were considered to 2 terms: source reduction and recycling and recovery.

The source reduction term can be assisted by reducing and eliminate the hazardous waste at the source. The source controlling method can be separated into 3 methods: input material changes, technological changes and good operating practices. The other term, recycling and recovery, is an effective method for reuse and reclamation that will be considered for modifying T3 and T4 in the next section below. Integration of waste minimization will be implemented to the actual WWTP and monitored for all changes for comparison with the existing data.

4.4.1 Modification of gold recovery process (T3)

With reference to the results obtained coming from LCIA, the greatest contributor to the environmental impact potential was focused in gold inlet of wastewater. By observing the gold recovery process, it was recorded that the trend of gold inlet varies and directly effects the percentage of gold recovery. Even though the scope of this study was limited to WWTP, the main problem was come from the source of discharge, or the production line. Thus, the team endeavored to solve this problem in both parts; gold reduction at the source and the consideration of processes and equipment modification. There was included the improvement of wastewater treatment operations and housekeeping practices on T3.

Therefore, this study was focused on WWTP. The modification was the need to reduce material consumption and increase efficiency during their operations.

The opportunities for waste minimization of WWTP, first objective was focused on gold wastewater inlet to T3 for reducing and controlling. The second objective was to be developing and modifying the existing gold recovery process to establish high efficiency.

These recommendations were further improvement through a discussion with the Facility team and process engineers in reducing the gold wastewater inlet. The actions list was initiated to implement waste minimization to T3. It was started with checking the existing data from last year and monitoring closely gold analysis data for inlet and outlet samples by grab sampling each shift change (2 times/day). This data was examined and assessed by mass balance daily.

In this step, the existing process had been modified to install more water meters for calculating gold rinse volume per day and the percentage of gold recovery. The result of gold mass balance was critical and could not be disclosed here, but it was found that gold metal in wastewater was lost at WWTP. Thus, the working team was planning to clean the piping and all concerned equipment before modifying the existing gold recovery process. The details of implementation of waste minimization are as follows;

a) Cleaning of the piping system and T3 storage tank

The result of pipe cleaning had shown some slime forming within the pipe. When considering the piping system, not only is the piping slope 1:100, suitable for wastewater drainage, but the piping material is using UPVC pipe. Thus, the gold rinse wastewater was apt to generate slime. Samples of this slime was sent to laboratory and checked for gold contamination. The analysis was found some gold metal was part of the slime's composition. T3 storage tank cleaning had found some sedimentation and little slime, but without gold concentration from its analysis.

b) Modifying the extra gold recovery process in to the production line.

To ensure protection from gold loss, this company decided to install an additional gold recovery process into their production line as the first stage. The other existing recovery system in WWTP is the second stage. The new system is used an ion exchange resin and provided a micron filter and chemical additives for preventive maintenance and the protection damage of gold resin.

4.4.2 Modification of batch treatment process (T4)

This study was shown the batch treatment and neutralization process (T4), which will be modified chemical transportation, sludge generation and NaOH production. All 3 parts are of concern to the main existing problem of WWTP, i.e.- high sludge generation in the clarifier tank effected to low quality of the effluent. When considering a waste minimization method, the source reduction technique can be solved this problem. Moreover, the recycling technique is interested in utilizing recycled sludge.

With reference to wastewater treatment operations, it could be seen that their wastewater analysis result for each unit processes were standard. However the final neutralization process, always had a level of nickel in the wastewater that exceeds the standards. These problems were referred to 3 traditional approaches as described below in the situation list;

a) To reduce or eliminate nickel contamination at the source.
b) Treat the wastewater to meet the standard.
c) Combination of a) and b)

For the first option, there are three primary possible resources of nickel-laden solution contaminating the wastewater: spills from the store of raw material, spills from the operation in the production line and discharges of spent nickel solution that goes into the wastewater flow (The United States-Asia Environmental Partnership, 2002). All of these improvement identifications could be reduced the nickel contamination of the wastewater, but it was out of the study's scope. The latter option was to be developed and improved efficiency of wastewater treatment so that spills will be minimized and discharges will be reduced and contained, was recommended.

Concerning WWTP process and operation, the existing batch treatment and neutralization process (T4) is treated by the chemical precipitation method as described in section 2.2. The main problem was found in this system was an unsuitable chemical used for coagulation but it could be solved with a jar test. The standard jar test is used to determine the proper coagulant dosage to the wastewater entering the treatment plant effected to water quality and the cost of operation and production. The detail of the jar test operation method is shown in Appendix G.

The purpose of this test, is to find the best chemical dosage to remove heavy metals, whose main components are nickel and copper, to lower than standard limitations. A wide range of treatment chemicals, is available for precipitating dissolved metals out of the wastewater. Some of these chemical is produced less sludge when compared to other chemicals of comparable removal efficiency. Therefore, the selection of a treatment chemical for these applications is important for reasons of efficiency and sludge volume production (Hazardous Waste Reduction Program, 1989).

The jar test condition was sampling wastewater from raw wastewater at the plant, then chemical substances were prepared from the existing sample used and trial various coagulants i.e., lime, ferrous chloride, sodium carbonate and ferric chloride. The optimum coagulant for treating wastewater both of T2 and T4 was ferric chloride, but in T2 operation more heavy metal precipitant was added to help reduce sludge generation, a high volume of coagulant consumption and maintain effluent quality.

The next jar test for ferric chloride was started to find the optimum coagulant and flocculation dosage in T4. The total number of jar tests was 8 samples. Coagulant dosing of these jar tests were varied at 50, 100 and 150 ppm at pH 11.0-11.5. The dosing of polymer were varied at 5, 10 and 15 ppm, as shown in table 4.4. However, the best jar test results were found only 2 (shown in table 4.5). Not only their effluent analysis results were lower than standard limit but also generating sludge volume were decreased. The best condition for T4 was sample No.5, which was added with $FeCl_3$ 100 ppm and polymer 10 ppm.

The jar testing results at this time, were carefully measured samples and simulate treatment plant reality. This was provided important and reliable information directly applicable to plant operation. Modification of the coagulant was obtained, and then implemented to the real WWTP. The change of coagulant was effected to chemical transportation, sludge generation and NaOH production. These significantly impact to T4, and was reduced and compared with the results before modification.

Table 4.4 The varied chemical dosage to each jar test

Sample No.	$FeCl_3$ 46% (ppm)	Polymer (ppm)
1	50	5
2	100	5
3	150	5
4	50	10
5	100	10
6	150	10
7	150	15
8	100	15

Table 4.5 The jar test results for T4 of WWTP

Sample No.	$FeCl_3$ 46% (ppm)	Polymer (ppm)	Effluent analysis result (ppm)		Sludge condition
			Ni	Cu	
5	100	10	0.16	0.05	++++
6	150	10	0.08	0.06	++++

After analyzing the significant of impact emission and processes, it was important to find the solution to reduce these impacts via a waste minimization approach. When identifying and evaluating waste minimization options for operating this WWTP, the emphasis was placed first on the simple, low or no cost material handling and process changes such as improved operations and house keeping practices.

All these alternatives had been considered. The more expensive equipment modifications and waste recovery options had been evaluated. Implementation was depended on the company's requirements and the priority of their problems. In this study, some of the alternatives were implemented to the WWTP as listed below, but some suggestion options were shown in Chapter 5 for further improvement.

1) T1-Rinse water recycle

   - Set up a routine maintenance plan for operating the multimedia filter tanks and RO system, emphasizing pre-treatment and RO membrane cleaning.

   - Recycled RO piping was a sterilized piping system with Hydrogen peroxide added to protect against any bacteria growing which contaminated the products.

2) T2-Heavy metal precipitation

   - Changed the existing coagulant to FeCl3 and heavy metal precipitant.

   - Adjusted the optimum chemical dosage by jar test.

   - Set up a routine plan to jar test for the optimum chemical dosage.

   - Adjusted the relay of the pH controller which will send a signal to the chemical dosing pump and control the alkaline solution with continuous feeding.

   - Separated all wastewater containing nickel into this system. Allowing no drum containing high concentrations of waste to protect against a shock load to the treatment system.

   - Set up routine maintenance i.e., clean and calibrate all chemical dosing pumps, calibrate pH probe and check valves and wastewater feeding pumps.

   - Taking off the sludge cake from the filter press at least 3 times per day.

3) T3-Gold recovery

   - Installed a gold recovery system in the production line.

   - Cleaned all drainage pipes and storage tanks.

   - Added slime control agents into the drainage pipes by metering pumps.

   - Set up a plan for checking the deterioration of the gold ion exchange resin and the filter cartridge replacement.

4) T4-Batch treatment and neutralization

   - Changed the existing coagulant to FeCl3.

- Adjusted the optimum chemical dosage by jar test.
- Set up a routine plan to jar test for the optimum chemical dosage.
- Adjusted the relay of the pH controller which will send a signal to the chemical dosing pump and control the alkaline solution with continuous feeding.
- Set up routine maintenance i.e., clean and calibrate all chemical dosing pumps, calibrate pH probe and check valves and wastewater feeding pumps.
- Taking off the sludge cake from the filter press at least 3 times per day.

The results of these modifications are presented as an overview of environmental impacts in Table 4.5. The total ELUs value for a modified whole life cycle of wastewater treatment plant is around 19.78 ELUs/ m^3 of treated wastewater. It is found that the most important process produced more environmental impact, is the gold recovery process (T3). The second environmental impact contribution is the batch treatment and neutralization process (T4), identical to the first evaluation.

Table 4.6 Environmental impacts of each treatment processes in the modified WWTP

Environmental impacts	ELU/m3			
	T1-Rinse water recycle	T2-Heavy metal precipitation	T3-Gold recovery	T4-Batch treatment and neutralization
Energy	1.28E-01	5.97E-02	7.16E-03	2.53E-01
Raw material	1.14E-01	1.15E+00	1.46E+01	1.90E+00
Total Resource used	2.42E-01	1.21E+00	1.46E+01	2.15E+00
Emission to air	9.25E-03	1.65E-02	3.50E-03	1.21E-01
Emission to water	1.99E-02	1.51E-02	2.17E-06	1.60E-01
Emission to Soil	0.00E+00	4.48E-01	0.00E+00	7.63E-01
Total	2.71E-01	1.69E+00	1.46E+01	3.19E+00
Grand total	**1.98E+01**			

The graphic in the Fig. 4.10, shows the results of the contribution of the environmental impacts on modified WWTP. This result is compared to the percentage of ELU for each treatment process. The results of the highest ELU is resource usage. All ELU calculation for modified WWTP is illustrated in the following Fig. 4.11 and Fig. 4.12. These figures are identified the environmental impact of energy and raw material use for the life cycle of WWTP. Fig. 4.13, 4.14 and 4.15 show the potential of modification results for emissions to air, water and soil for the life cycle of WWTP, respectively.

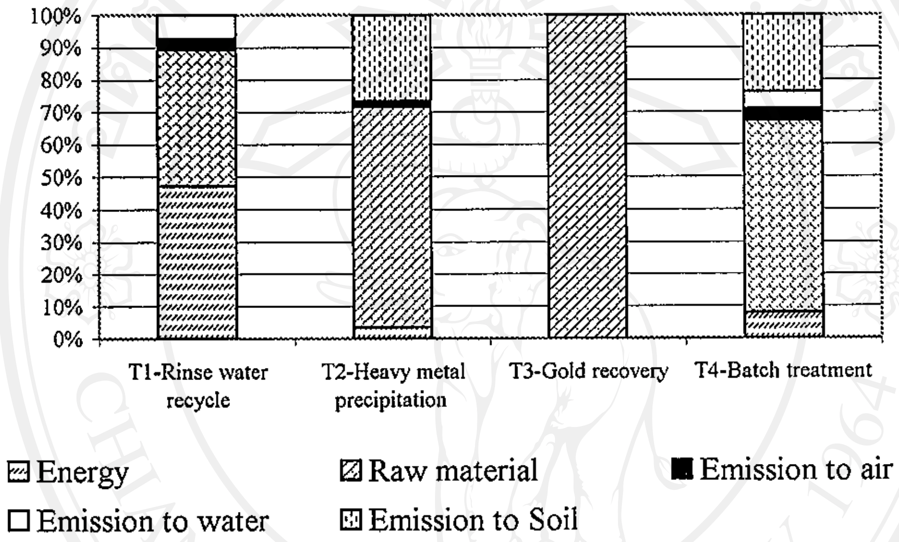

Figure 4.10 Contribution of the environmental impacts on modified WWTP

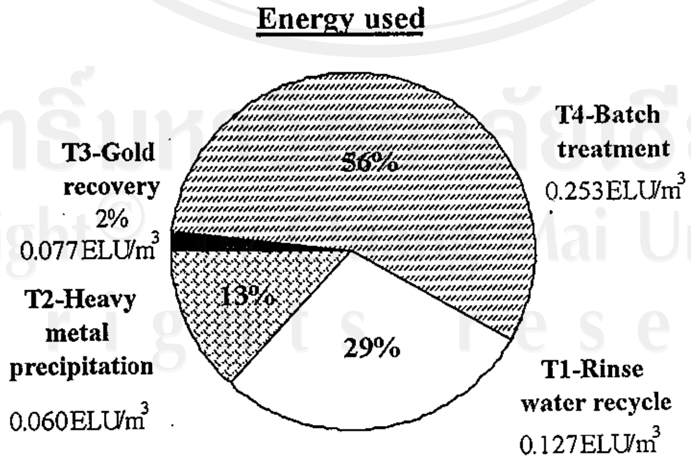

Figure 4.11 Environmental impact of energy use for the life cycle of modified WWTP

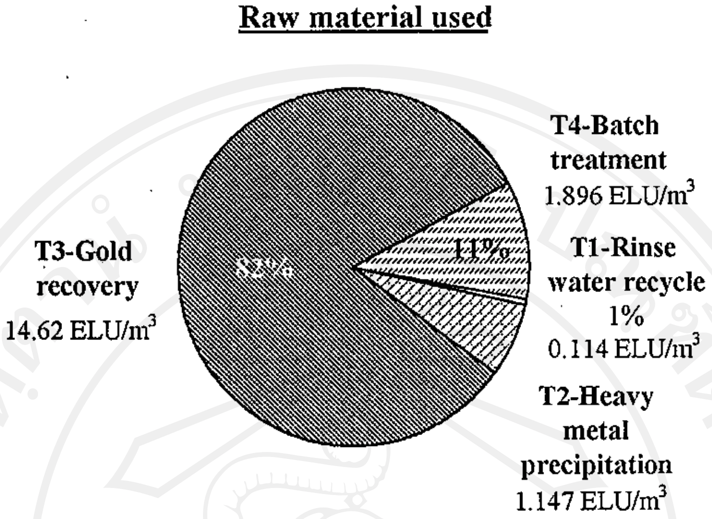

Figure 4.12 Environmental impact of raw material use for the life cycle of modified WWTP

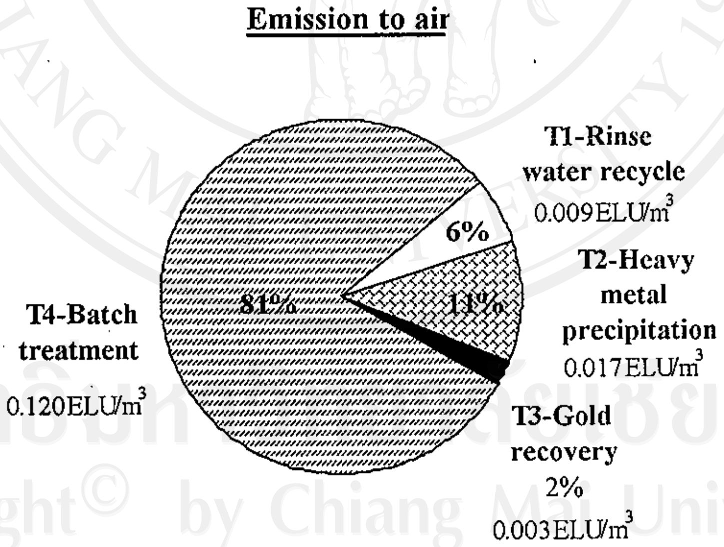

Figure 4.13 Environmental impact of emission to air for the life cycle of modified WWTP

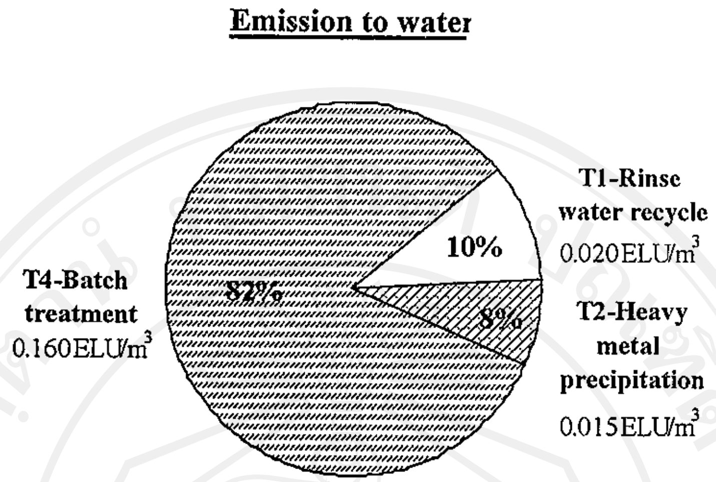

Figure 4.14 Environmental impact of emission to water for the life cycle of modified WWTP

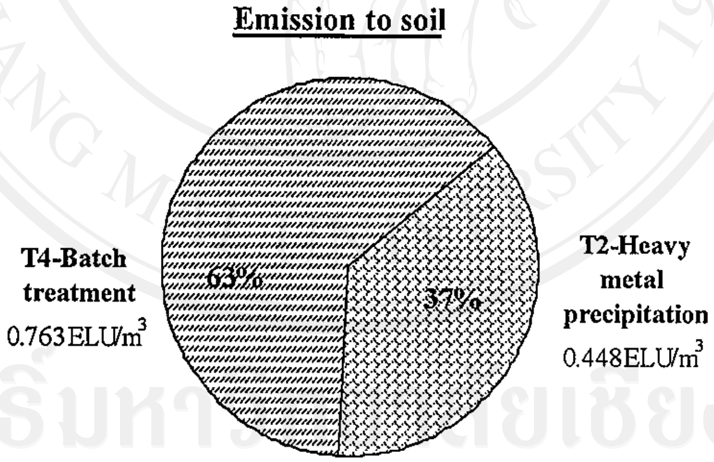

Figure 4.15 Environmental impact of emission to soil for the life cycle of modified WWTP

4.5 Comparison assessment

The impact comparison between the ELU of WWTP and modified WWTP is obtained and shown in Table 4.7 that was calculated from the data in Table 4.2 and 4.5. The impacts are reduced from the first evaluation, specifically, gold recovery (T3), except for heavy metal precipitation (T2).

After the modification on gold recovery (T3), they showed that raw material highly contributed to most environmental impact potentials. The ELU reduction of rinse water recycle (T1) and batch treatment and neutralization (T4) is about 18% and 15% for overall systems, respectively. The ELU of emission to soil of heavy metal precipitation (T2) and batch treatment and neutralization (T4) is increased, which is effected to the value of total ELUs of T2.

Table 4.7 The comparison between the ELU of WWTP and modified WWTP

Environmental Index	Percent reduction				
	T1-Rinse water recycle	T2-Heavy metal precipitation	T3-Gold recovery	T4-Batch treatment and neutralization	Total ELU/m3 ww
Energy	17.57	37.19	76.16	47.48	41.24
Raw material	14.90	-2.60	99.28	24.67	99.13
Total Resource used	16.33	0.52	99.28	28.33	99.11
Emission to air	23.87	54.08	46.62	45.99	46.08
Emission to water	36.96	45.81	44.38	13.04	19.87
Emission to Soil	0.00	-131.83	0.00	-105.56	-114.56
Grand Total	18.56	-14.72	99.28	15.47	99.03

4.5.1 Result of comparison assessment on rinse water recycle process (T1)

Fig. 4.16 shows the schematic diagram of total ELU of T1 modifications as compared to the original system. All their environmental indices are lower than the first evaluation, especially emissions to water. Therefore, it can be concluded that the efficiency of the rinse water recovery is increased.

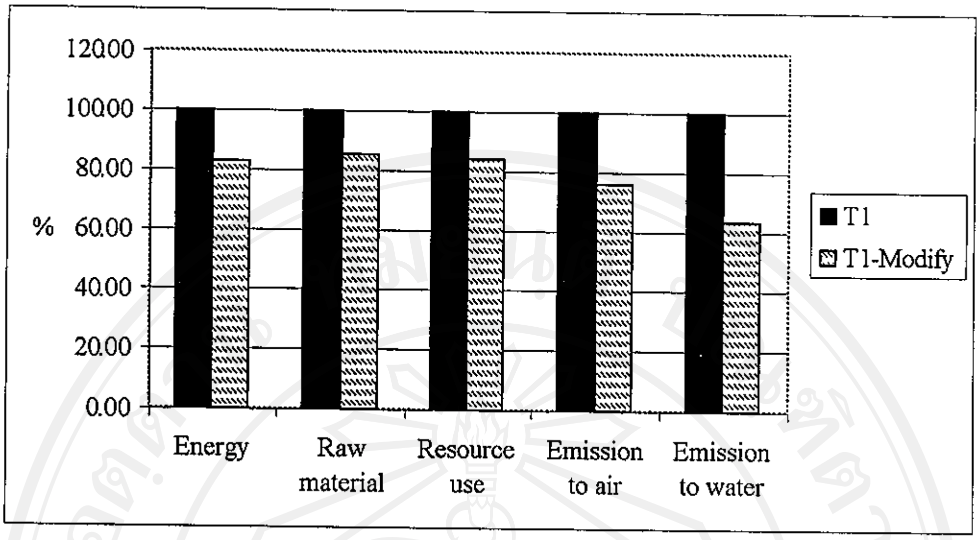

Figure 4.16 Schematic diagram of total ELU of T1 modifications as compared to the original system

4.5.2 Result of comparison assessment on heavy metal treatment process (T2)

From Fig. 4.17 is illustrated the schematic diagram of total ELU of T2 modification as compared to the original system. It is shown that the ELU of raw material consumption and emission to soil is increased. The changes of the chemical dosage are directly effected the raw material consumption. The high volume of collecting the sludge of T2 is increased due to the change of routine maintenance of dry cake removal, approximately increasing the volume to 2-3 times.

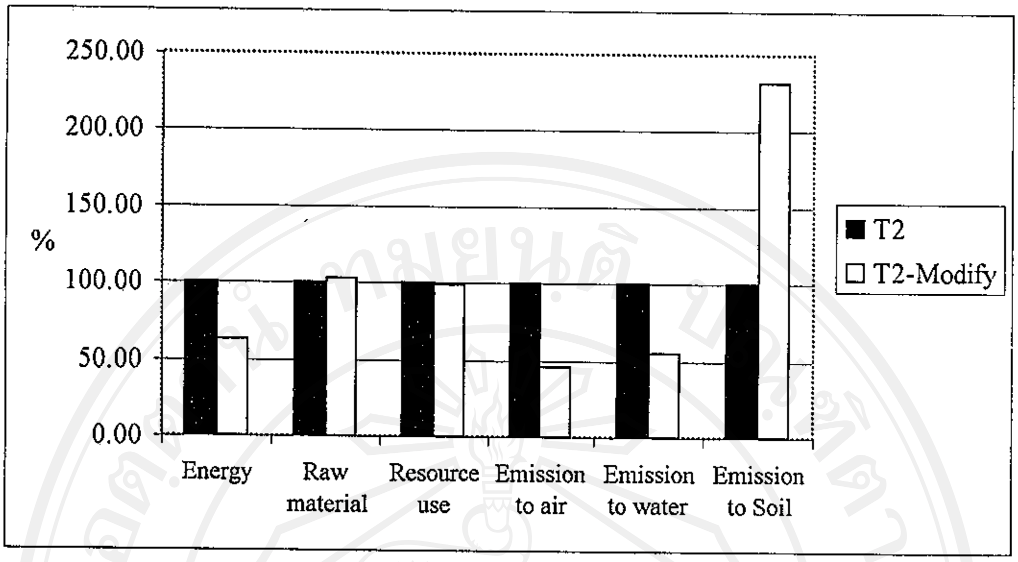

Figure 4.17 The schematic diagram of total ELU of T2 modifications as compared to the original system

4.5.3 Result of comparison assessment on gold recovery (T3)

This modification is focused on inlet gold wastewater coming to WWTP; therefore, the comparison of the environmental impact potential of the first evaluation and the modifications is obtained around 99% reduction of ELU as illustrated in Table 4.7. The gold recovery percentage is amazingly higher. However, gold lost and maintenance requirements are also lowered. It is found that the percentage of gold recovery from after modifications is approximated 98%. This value ias increased from the existing data by 77.38%. All of these figures are calculated from inlet and outlet data of gold concentration in wastewater; excluding gold reclamation.

The graphic overview of the total ELUs of T3 modifications as compared to the original system are presented in the following Fig. 4.18. The total ELUs for each environmental indices is lower than the first evaluation. Thus, these modifications on the gold recovery system (T3) has been increased its efficiency and reduced potential environmental impacts.

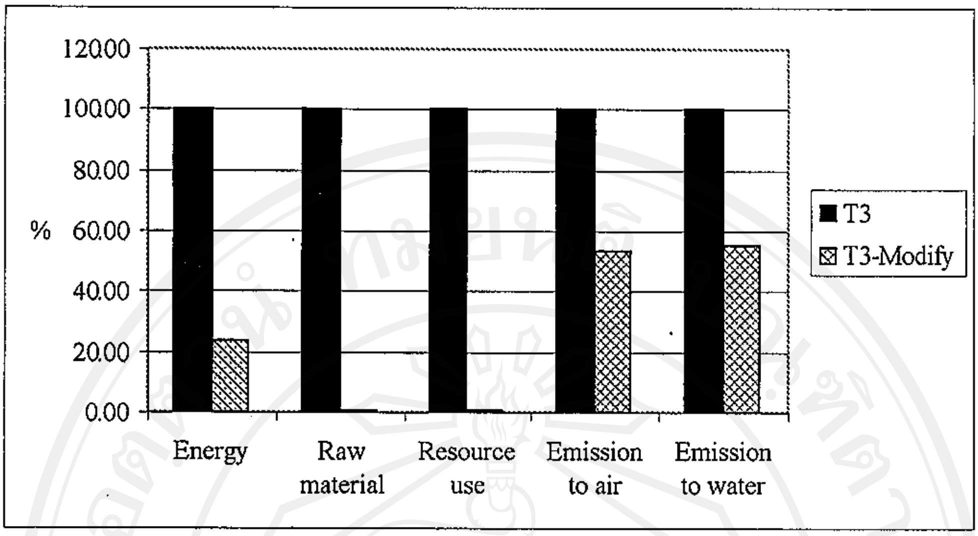

Figure 4.18 The schematic diagram of total ELU of T3 modifications in comparison to the original system

Considering to effect of these result, the environmental impacts of each treatment processes in the WWTP is calculated by exclusion of gold data as shown in Table 4.8. The Table 4.9 illustrates in the modification result of the environmental impacts of each treatment processes at the modified WWTP which is excluded gold data.

Table 4.8 Environmental impacts of each treatment processes in the WWTP, excluded gold data.

Environmental impact	ELU/m3 ww			
	T1-Rinse water recycle	T2-Heavy metal precipitation	T3-Gold recovery	T4-Batch treatment and neutralization
Energy	1.55E-01	9.51E-02	3.00E-02	4.81E-01
Raw material	1.34E-01	1.12E+00	2.32E-01	2.52E+00
Emission to air	1.21E-02	3.60E-02	6.56E-03	2.23E-01
Emission to water	3.15E-02	2.78E-02	3.90E-06	1.84E-01
Emission to Soil	0.00E+00	1.93E-01	0.00E+00	3.71E-01
Total	**3.32E-01**	**1.47E+00**	**2.69E-01**	**3.78E+00**

Table 4.9 Environmental impacts of each treatment processes in the modified WWTP, excluded gold data.

Environmental Index	ELU/m3 ww			
	T1-Rinse water recycle	**T2-Heavy metal precipitation**	**T3-Gold recovery**	**T4-Batch treatment and neutralization**
Energy	1.28E-01	5.97E-02	7.16E-03	2.53E-01
Raw material	1.14E-01	1.15E+00	8.98E-02	1.90E+00
Emission to air	9.25E-03	1.65E-02	3.50E-03	1.21E-01
Emission to water	1.99E-02	1.51E-02	2.17E-06	1.60E-01
Emission to Soil	0.00E+00	4.48E-01	0.00E+00	7.63E-01
Total	**2.71E-01**	**1.69E+00**	**1.00E-01**	**3.19E+00**

When compare ELU value from Table 4.3 and Table 4.8, the total ELUs value for the whole life cycle of WWTP in Table 4.3 is 2,040 ELU/m^3 of treated wastewater but total value for Table 4.8 is reduced to 5.851 ELU/m^3. The first 2 major processes impacting on the environment are changed from gold recovery process (T3) and the batch treatment and neutralization process (T4) to the batch treatment and neutralization process (T4) and heavy metal treatment process (T2), when gold data are excluded from the calculation. But the highest contributor to each treatment process in Table 4.8 is still be resource used.

When compare ELU value from Table 4.6 and Table 4.9, the total ELUs value for the modification of whole life cycle of wastewater treatment plant in Table 4.6 is approximated 19.8 ELU/m^3 of treated wastewater but total value for Table 4.9 is reduced to 5.25 ELU/m^3. The ELU reduction for whole system is changed from 99% to 10.25%, as first figure is included gold data but the latter is excluded gold data in the assessment.

4.5.4 Result of comparison assessment on batch treatment and neutralization (T4)

From Fig. 4.19, the schematic diagram of total ELU of T4 modifications in comparison to the original system illustrated the total ELUs of all environmental indices are reduced from the first, except the emission to soil. The high volume of collecting sludge of T4 is increased due to the change of routine maintenance of dry cake removal was increased to 2 times approximately. Otherwise the sludge on the clarifier is still be full which is effected to effluent quality, especially nickel.

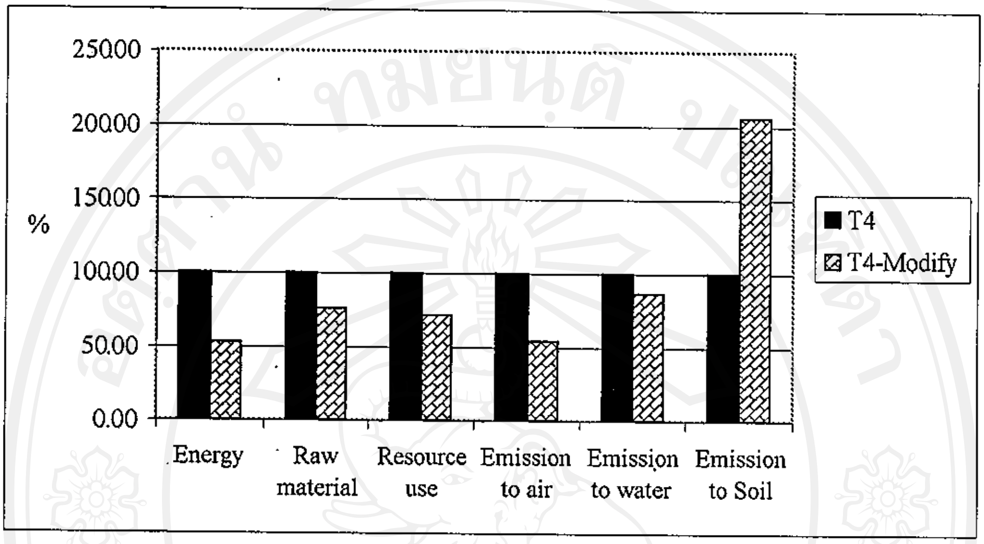

Figure 4.19 The schematic diagram of total ELU of T4 modifications in comparison to the original system

These problems are caused by a low capacity of press volume and can not be gained enough support for generating sludge volume. The existing filter press have poor efficiency for this operation due to high volumes of wastewater and chemical consumption. The existing filter press is designed to be operated for 7 cycles/day; however the actual filter press can be operated only for 2 cycles/day. An extreme measure is due to limited man power and their capacity. Therefore, liquid sludge may still be filling in the precipitation tank. A filter press with an expanded capacity should be considered to remedy this problem.

The following log scale graphs are shown the comparison of before and after modification, which result in Fig. 4.20 is calculated ELU from exact data of WWTP. The other Fig. 4.21 is concentrated on sludge generation that calculated ELU from the result of Jar test examination in laboratory scale, excluded the collected sludge in sedimentation tank. It is found that these modification can be reduced sludge volume to 25%, measured from In-hoof cone. From calculation, cake dryness is assumed to 20%.

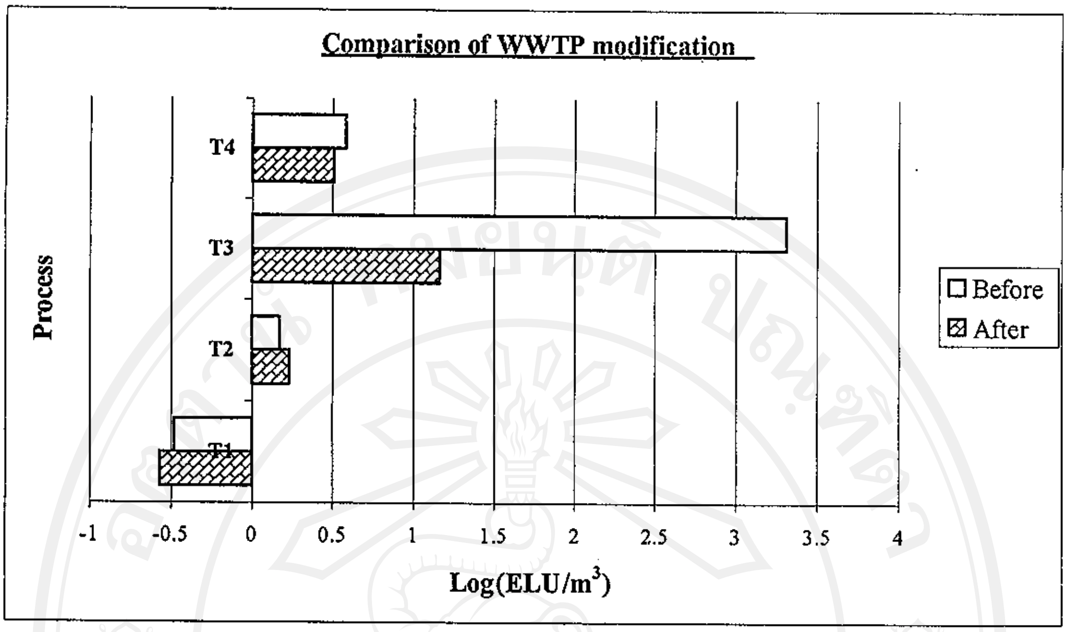

Figure 4.20 The log scale graph of total ELU of WWTP modifications in comparison to the original system.

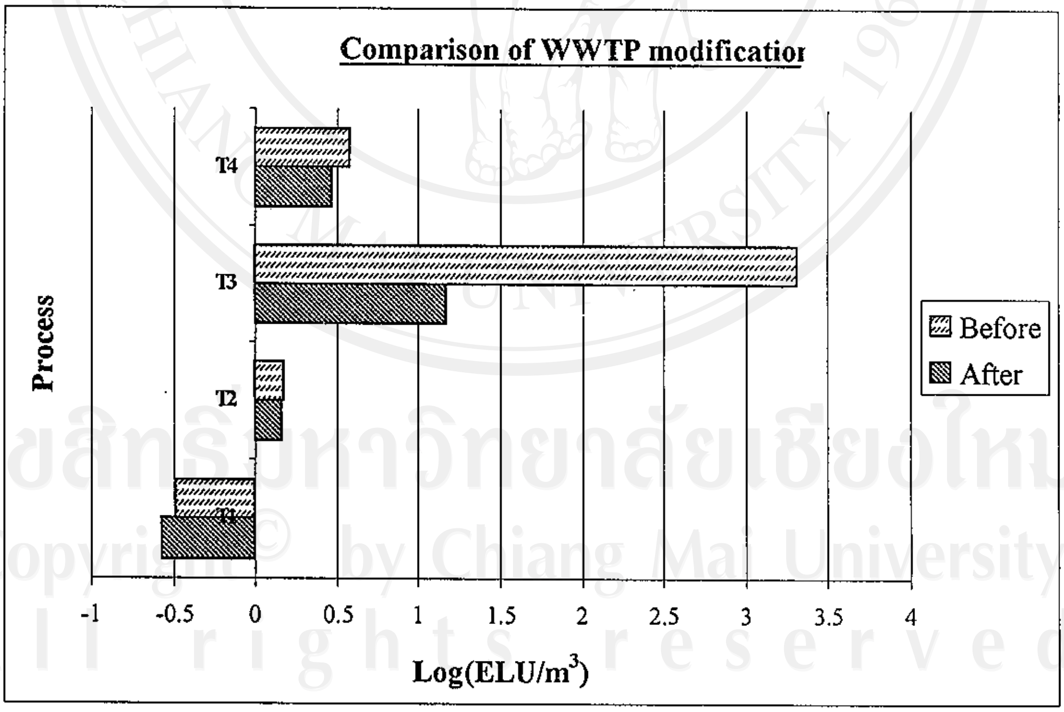

Figure 4.21 The log scale graph of total ELU of WWTP modifications in comparison to the calculation on Jar test result.