

**Bangpoo Industrial Estate,
Samut Prakarn,
Thailand;**

An investigation of environmental pollutants

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EXECUTIVE SUMMARY

The Bangpoo Industrial Estate is located in the Samut Prakan Province of Thailand. This industrial estate is managed by the Industrial Estate Authority of Thailand (IEAT) and has been in operation since the early 1980's, being one of the first industrial estates in Thailand.

The industrial estate consists of a large number of small to medium sized companies involved in a wide range of activities primarily involving chemical and electrical products. A wide range of chemicals are used at facilities within the estate, including many organic compounds as well as many heavy metals and their compounds.

The estate includes an IEAT managed central wastewater treatment plant (WWTP), which receives a complex mixture of wastes from many different sources. Treated effluent from the WWTP is discharged via an underground conduit to a location on Sukhumvit Road within a residential / commercial district, from where it is carried in an uncovered channel. In addition, two main canals flow through the estate, and receive wastewaters directly from a number of facilities. Effluent carried in these canals is ultimately discharged to the Gulf of Thailand.

Greenpeace visited the Bangpoo Industrial Estate in June 2001 and again in May 2003. On both occasions a number of environment samples were collected from within and near to the industrial estate; Samples of sediment were collected from the two canals running through the industrial estate as well as from the main wastewater treatment plant and its discharge canal on Sukhumvit Road.

Analysis of these samples has demonstrated widespread contamination in and around the Bangpoo Industrial Estate with a range of toxic and persistent heavy metals and many organic pollutants, indicative of inadequate waste management practices employed on this estate. Many of the pollutants identified exhibit a range of toxic effects on terrestrial and aquatic organisms. It is noteworthy that a large proportion of the organic compounds isolated during this study could not be identified. The nature and potential environmental impacts of these unidentifiable compounds cannot be known or predicted.

Significant contamination was found in the sediments of both canals, including high concentrations of many toxic and persistent heavy metals, indicating significant inputs of these to both canals.

The northwestern canal was found to be seriously contaminated with copper, lead, nickel and zinc, containing concentrations of these metals at many times typical background levels; 100 times for copper, 100 times for lead, 50 times for nickel and 125 times for zinc. These metals cannot be broken down to less toxic substances in the environment.

The southeastern canal contained lower, but still very high concentrations of many heavy metals. Concentrations increased progressively downstream along the course of this canal, most notably for copper, nickel and zinc. The highest concentrations of copper, nickel and zinc found in this canal were 28, 17 and 8 times typical background levels, respectively.

A number of organic pollutants were also identified in these canals including two phthalate esters (DEHP and DnBP), nonyl phenol isomers and trace levels of di- and tri-chlorobenzenes.

Nonyl phenols and the phthalates DEHP and DnBP are ubiquitous in the environment. These persistent compounds have many uses, including use as additives in the production of PVC and its products. These compounds have a range of toxic effects including disruption of endocrine systems.

Samples collected from one of the lagoons of the main wastewater treatment plant (WWTP) contained a number of heavy metals at elevated concentrations, principally copper, nickel and zinc. Treated effluent from this WWTP is discharged via an underground conduit to a location on Sukhumvit Road. Samples collected from this location in 2001 and 2003 contained a similar pattern of elevated heavy metal concentrations to that found at the WWTP, though at appreciably lower concentrations than those found in the two canals.

A range of organic compounds were also identified in the samples collected from the WWTP, though some of them only at trace levels. These included 2,4,6-trichlorophenol and the flame retardant (TBEP) in the incoming effluent, as well as di- and tri-chlorinated benzenes and the phthalate DEHP in the sediment samples. One of the uses of 2,4,6-trichlorophenol is in the preparation of the fungicide prochloraz. Chlorophenols have a wide spectrum of toxic effects including teratogenic and carcinogenic actions.

An even wider range of organic compounds was detected in samples collected from the WWTPs discharge canal on Sukhumvit Road in 2003. A number of compounds identified at the WWTP were also found in this discharge canal, including 2,4,6-trichlorophenol, the flame retardant (TBEP) and the phthalate DEHP. Other compounds identified within this canal but not at the WWTP itself include hexachlorobutadiene, chlorinated toluenes and higher chlorinated benzenes. Some of these compounds were found at only trace levels.

Many of these compounds are persistent in the environment and exhibit a range of toxic effects. Most have links to industrial activities being raw materials, products, or wastes compounds generated from such activities.

The occurrence of many organic compounds within both the WWTP and its discharge canal, as well as the elevated heavy metal concentrations in the discharge canal, demonstrates the inability of the WWTP to fully remove and/or degrade a range of chemicals discharged to it.

Those industries which discharge to the WWTP while producing wastestreams containing pollutants that the WWTP is unable to degrade have a responsibility to pre-treat their wastes prior to discharging them to the WWTP. Such pre-treatment is clearly not fully effective.

A number of compounds found within the WWTP discharge canal on Sukhumvit Road have recently been detected in seawater at a number of locations off the coast of Thailand, including nonyl phenol, the phthalates DEHP and DnBP, and 2,4-dichlorophenol. Specifically, DEHP has been identified in seawater off the Samut Prakan coast.

The combining of highly complex wastestreams from different industries typically results in a combined effluent for which techniques to deal with them either do not exist or are unproven in practical application. No simple "off the shelf" solutions are available for dealing with such complex wastestreams. Combined wastewater treatment plants such as that at the Bangpoo Industrial Estate typically address only a limited range of physical, biological and simple chemical variables.

Heavy metals can never be addressed through such processes, other than to scavenge the metals from wastewaters into other media such as sludges. Some organic compounds identified within this study are highly resistant to biodegradation treatments used at these facilities. Furthermore, many of the more volatile organic compounds (VOCs) in wastestreams may be released to the atmosphere before they can be degraded.

As a result, WWTPs often simply concentrate heavy metals and certain persistent organic contaminants in solid residues, which far from providing a solution, is merely the transfer of contamination from one environmental medium to another, creating an additional contaminated wastestream that must be dealt with. Certain organic pollutants identified in this study may also severely hinder the operation of the WWTP. Where batch manufacturing processes are employed, the flow rate and composition of wastewaters can be highly variable, further reducing the efficiency of many treatment regimes.

Some wastestreams discharged to the main WWTP have undergone pre-treatment. Where this is performed using similar technologies to those employed at the main WWTP, the above limitations will also apply to the individual treatment facilities.

A number of regulations are applicable to activities within the estate, including criteria for discharged effluent. While these standards include criteria for a range heavy metals, they set limits for only a very limited number of organic compound groups. Wastewaters that meet these limited legislative requirements are considered acceptable for discharge to surface water, despite the toxic and persistent chemicals that may still be present, including organochlorinated and organophosphorous compounds. This is despite the inclusion of these compounds in the National Chemicals Management Profile for Thailand as specific chemicals creating concern.

The environmental management of industry must incorporate moves towards the elimination of pollution through a range of waste reduction strategies including the phasing out of hazardous substances. The ultimate goal of such measures should be the implementation of truly clean and sustainable technologies.

1 INTRODUCTION

The Bangpoo Industrial Estate is located in the Samut Prakan Province of Thailand. The estate has been in operation since the early 1980s and was one of the first industrial estates in Thailand.

The industrial estate is managed by the Industrial Estate Authority of Thailand (IEAT), a state enterprise under the Ministry of Industry (Homchean 1998). The IEAT has responsibility for the management and planning of the estate, including addressing the control and monitoring of industrial pollution (Homchean 1998).

The estate consists of a large number of small to medium sized companies involved in a wide range of activities primarily based on chemical and electrical products, in such areas as insecticides, herbicides, heavy metals based products, formulation of PVC and other plastics, paints and resins and glues, oil based products, leather and textile products and batteries (Kongtip 2001).

A wide range of chemicals are used within the estate, including flammable, heavy metals and their compounds as well as various insecticides, herbicides and fungicides (Kongtip 2001).

The estate includes a central wastewater treatment plant (WWTP) which receives a complex mixture of wastes from many different sources. This facility is managed by IEAT, who are also responsible for setting quality criteria for wastewaters discharged to the WWTP. A number of facilities within the estate are equipped with pre-treatment systems to ensure meeting these criteria (Homchean 1998).

The WWTP is designed to deal with wastewaters at a rate of 45 000 m³ per day. Treatment of wastewaters is primarily through an aerobic activated sludge system, though neutralization and solid settling facilities are also employed (SDC 2003).

Treated effluent from the WWTP is discharged via an underground conduit to a location on Sukhumvit Road within a residential / commercial district, from where it is carried in an uncovered channel.

Two main canals also flow through the estate, and receive wastewaters directly from a number of facilities. Effluent carried in these canals is ultimately discharged to the Gulf of Thailand.

2 SAMPLING PROGRAM

Greenpeace visited the Bangpoo Industrial Estate in June 2001 and again in May 2003. On both occasions, a number of environment samples were collected from within and near to the estate. On both occasions, samples of sediment were collected from canals running through the industrial estate. Similarly, samples of effluent and sediment were also collected from a nearby location on Sukhumvit Road where treated effluent from the estates main WWTP emerges from an underground conduit within a residential / commercial district.

In May 2003, an additional three samples were collected from the main wastewater treatment plant (WWTP) located in the western part of the estate. A sample of partially treated effluent and two sediment samples were collected from one of the treatment lagoons within the WWTP. The treated effluent that emerges from underground at the location on Sukhumvit Road, as described above, is discharged from this WWTP (BIEA 2003).

2.1 General Sampling Procedures

All samples were immediately sealed and cooled upon collection, and remained so until opened for analysis. The samples were returned to the Greenpeace Research Laboratories in the UK for analysis. Detailed description of sample preparation and analytical procedures are presented in Appendix 1.

2.2 Sample Descriptions

The industrial estate has two main canals running through it, which receive discharges from many industries. On the occasions that the industrial estate was visited, the two canals running through the estate were observed to be flowing at a slow rate. A number of the discharges to the canals have been observed to change substantially in flow from one time to another. These factors mean that the composition of the water in the canals will vary significantly over time.

Sediment samples were collected from locations along each canal in order to establish the degree of contamination of the canals with a range of pollutants, as upon release to a watercourse, many persistent environmental pollutants tend to bind to suspended material before finally accumulating in the bottom sediments (Alloway 1990, ATSDR 2000). The nature and extent of the pollution load carried by the canals provides insight into the nature and extent of pollutants discharged to them over an extended timescale.

The canal sampled in June 2001 was that running northeast to southwest in the northwestern part of the estate. Three sediment samples were collected from this canal. One sample (MI01015) was collected from just upstream of the estate near to unit G61, a second sample (MI01014) was collected in the middle of the estate near to unit 165, and the third sample (MI01013) was collected as the canal leaves the estate, near to unit 17A.

Sample Number	Sample Description	Sample Location
MI01013	Sediment	Northwestern canal, downstream of estate near unit 17A
MI01014	Sediment	Northwestern canal, in the middle of the estate near unit 165
MI01015	Sediment	Northwestern canal, upstream of estate near unit 17A
MI01016	Sediment	Sukhumvit Road; where treated effluent from the estates main WWTP emerges from an underground conduit
MI01017	Effluent	Sukhumvit Road; where treated effluent from the estates main WWTP emerges from an underground conduit, as per MI01016

Table 1. Description of the samples collected from the Bangpoo Industrial Estate, Samut Prakan Province, Thailand, in June 2001.

In June 2001, a sample of treated effluent (MI01017) was collected from a location on Sukhumvit Road, approximately 2 kilometers from the western corner of the industrial estate, where effluent emerges from an underground conduit into an uncovered canal. The effluent at this point has a visibly large flow rate. A sample of sediment (MI01016) was also collected from the open canal at this location. This effluent is discharged by the main waste-water treatment plant (WWTP), located in the western side of the estate, subsequent to treatment (BIEA 2003).

The industrial estate was revisited in May 2003. Three samples were collected from the main WWTP. A sample of partially treated effluent (AT03049) was collected from a pipe discharging into the eastern most treatment lagoon of the WWTP. A sample of sediment (AT03050) was collected from the treatment lagoon at the point where this effluent entered. A second sample of sediment (AT03051) was collected from the same treatment lagoon near to the main effluent input to this lagoon, opposite the point where samples AT03049 & AT03050 were collected. A worker at the WWTP reported that the collected effluent had already undergone partial treatment. It was not possible to obtain a sample of the main input to this treatment lagoon. The main input is believed to be combined untreated effluent many industries.

The location on Sukhumvit Road sampled in June 2001 was revisited in May 2003, and a sample of treated effluent (AT03057) and sediment (AT03058) were collected as per the samples collected in June 2001.

Sample Number	Sample Description	Sample Location
AT03049	Effluent	Waste water treatment plant; collected from an input pipe to the eastern treatment lagoon
AT03050	Sediment	Waste water treatment plant; collected from the eastern treatment lagoon where an input pipe discharges to the lagoon (sample AT03049)
AT03051	Sediment	Waste water treatment plant; collected from the eastern treatment lagoon near to the main input, on the opposite side to sample AT03050
AT03052	Sediment	Southeastern canal running through the estate; in the commercial area just upstream of where the canal leaves the industrial estate
AT03053	Sediment	Southeastern canal running through the estate; near to the downstream end of the estate, near to unit 34F
AT03054	Sediment	Southeastern canal running through the estate; in the middle of the estate, near to unit E25
AT03055	Sediment	Southeastern canal running through the estate; from the northeastern branch of the canal at the upstream end of the estate, near to unit G1
AT03056	Sediment	Southeastern canal running through the estate; from the southwestern branch of the canal at the upstream end of the estate, near to unit G23
AT03057	Effluent	Sukhumvit Road, where treated effluent from the estates main WWTP emerges from an underground conduit
AT03058	Sediment	Sukhumvit Road, where treated effluent from the estates main WWTP emerges from an underground conduit, as per AT03057

Table 2. Description of the samples collected from the Bangpoo Industrial Estate, Samut Prakan Province, Thailand, in May 2003.

In May 2003, five samples of sediment were collected from the canal running northeast to southwest in the southeastern part of the estate, a separate canal to that sampled in June 2001. In the upstream section of the canal, it consists of two separate branches, which

converge within the estate to form one canal. Both branches of the canal were sampled near to where they entered the industrial estate.

One sample of sediment (AT03056) was collected from the southwestern branch near to unit G23; a second sample of sediment (AT03055) was collected from the northeastern branch near to unit G1. Progressing downstream along the canal, one sediment sample (AT03054) was collected after the convergence of the two branches near to unit E25, a further sediment sample (AT03053) was collected further downstream near to unit 34F and a final sediment sample (AT03052) was collected within the commercial area of the estate just prior to the canal leaving the industrial estate.

A summary of the locations sampled in both June 2001 and May 2003 are given in Table 1 and Table 2, respectively. The locations of the samples collected are also presented on a map of the Bangpoo Industrial Estate in Figure 1.

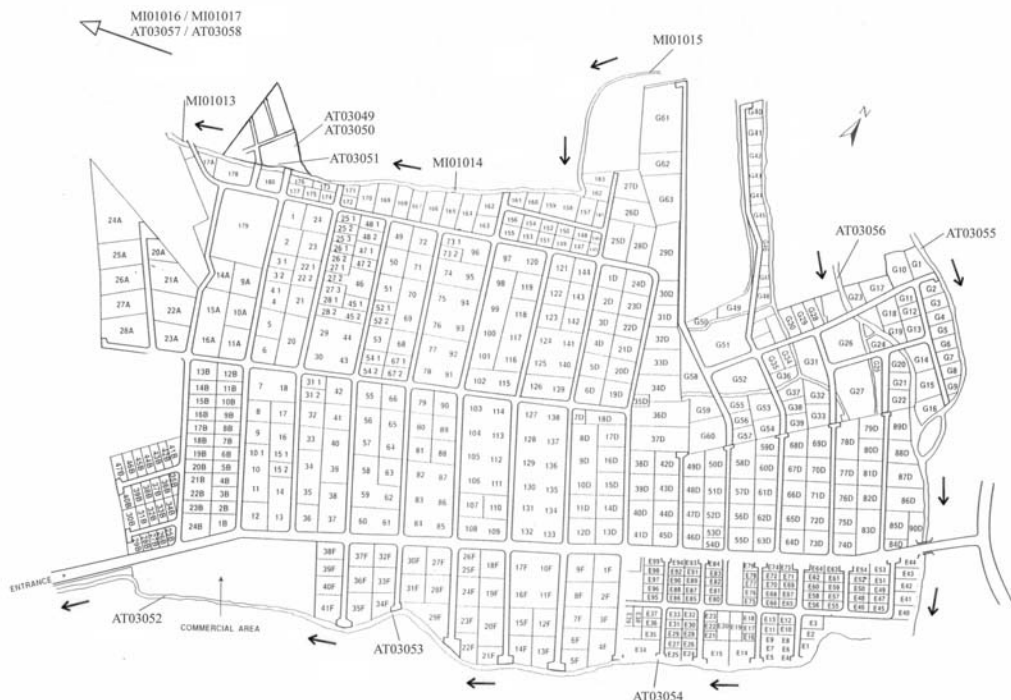


Figure 1. Map of the Bangpoo Industrial Estate showing the location of samples collected. The arrows depict the direction of flow of the canals running through the estate.

3 RESULTS AND DISCUSSION

The results of the organic screen analysis and heavy metals analysis of the samples are presented in Tables 3 and 4, including a breakdown of the groups of organic compounds reliably identified in the samples. Table 3 presents the results from the samples of sediment collected from the two canals running through the estate. Table 4 presents the results from the samples collected from the main WWTP and its discharge canal on Sukhumvit Road.

For a full list of organic compounds both reliably and tentatively identified in the samples, see Appendix 2. For more information on the common sources, environmental behavior and toxicological outlines for key pollutants detected during this study see Appendices 3 and 4.

3.1 Canal Sediments

The data from the samples of sediment from both canals show significant contamination of the canal sediments with a range of toxic and persistent heavy metals and organic pollutants. The nature and extent of contamination along the courses of the two canals indicates significant inputs of environmental pollutants to both canals.

The metals analysed in this study are naturally present in uncontaminated aquatic and terrestrial ecosystems, but typically at low concentrations (ATSDR 2000, Salomons and Forstner 1984).

3.1.1 Northwestern canal

The northwestern canal is contaminated with a range of heavy metals, especially with chromium, copper, lead, nickel, and zinc.

Heavy metal concentrations in the sample collected upstream of the estate (MI01015) were significantly lower than concentrations found in sediment collected within the industrial estate (MI01014). The upstream sample contained only copper at an elevated concentration, at approximately three times the typical uncontaminated background level for river sediments (Salomons and Forstner 1984).

The sediment sample collected in the middle of the estate (MI01014) contained the highest concentrations found in any of the canal sediment samples for nearly all metals. This sample was seriously contaminated with copper, lead, nickel and zinc. The concentrations of these metals were extremely elevated above those found in the upstream sample (MI01015). Furthermore, the concentrations of copper, lead, nickel and zinc found in this sample were elevated above typical uncontaminated background levels by considerable factors; one hundred times for copper, one hundred times for lead, fifty times for nickel and one hundred and twenty-five times for zinc (ATSDR 2000, Salomons and Forstner 1984).

This sample (MI01014) also contained cadmium, chromium, and mercury concentrations at higher concentrations than those found in the upstream sample (MI01015). These metals were present at approximately twice typical background levels (ATSDR 2000, Salomons & Forstner 1984).

The canal sediment collected on the downstream edge of the industrial estate (MI01013) contained lower concentration of all metals compared to those found in the middle of the estate (MI01014). This sample (MI01013) did, however, contain copper, mercury, nickel and zinc at significantly higher concentrations than those found upstream of the estate

Sample number	MI01015	MI01014	MI01013	AT03056	AT03055	AT03054	AT03053	AT03052
Sampling set	2001	2001	2001	2003	2003	2003	2003	2003
Canal	Northwest canal	Northwest canal	Northwest canal	Southeast canal	Southeast canal	Southeast canal	Southeast canal	Southeast canal
Description	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Location	upstream of estate	middle of estate	down-stream of estate	upstream of estate; southwest branch	upstream of estate; northeast branch	middle of estate	middle of estate	down-stream end of estate
Metals	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Arsenic (As)	<40	54	<40	<40	<40	<40	<40	<40
Cadmium (Cd)	<1	2	<1	<1	4	<1	<1	<1
Chromium (Cr)	69	1076	90	120	210	58	130	147
Cobalt (Co)	19	21	15	16	16	11	16	12
Copper (Cu)	35	4781	349	109	53	216	946	1380
Lead (Pb)	41	2965	40	47	73	73	58	76
Manganese (Mn)	1110	1036	762	733	918	870	716	590
Mercury (Hg)	0.28	0.73	0.5	0.3	0.3	<0.2	0.6	0.6
Nickel (Ni)	42	3485	83	94	101	48	707	1130
Zinc (Zn)	298	12498	543	979	242	359	829	790
No. of organic compounds isolated	32	21	41	15	10	12	38	19
No. reliably identified (% of total)	10(31%)	9(43%)	18(44%)	3 (20%)	2 (20%)	6 (50%)	12 (32%)	5 (26%)
Chlorinated compounds								
Dichlorobenzenes	1*	1*	1*	1*		2*	2*	2*
Trichlorobenzenes						1*		1*
Polycyclic aromatic hydrocarbons (PAHs)								
Phenanthrene derivatives							1	
Phthalate esters								
DEHP				1	1	1	1	1
DnBP						1	1	1
Other aromatic hydrocarbons								
Alkyl benzenes	1	2	3				1	
Benzenemethanol						1		
Non-chlorinated phenols								
Nonyl phenols				many isomers				
Alkyl phenols							1	
Oxygenated compounds								
Aliphatic alcohols	1		1					
Aliphatic aldehydes	1							
Aliphatic hydrocarbons								
Linear	5	5	12		1			
Branched	1						2	
Cyclic		1	1					
Others								
Lupane triterpene derivatives							2	
Sulfur, mol. (S8)							1	

Table 3. Organic chemicals and heavy metals identified in samples of sediment collected in June 2001 and May 2003 from the two canals running through the Bangpoo Industrial Estate, Samut Prakan Province, Thailand. Samples are presented from left to right running downstream along each canal. For the organic compounds reliably identified, the number of compounds identified using general GC/MS screening method is presented for each group; * signifies those compounds identified only at trace levels using a selective ion monitoring (SIM) method. Metal concentrations are given in mg/kg dry weight.

Sample number	AT03049	AT03050	AT03051	AT03057	AT03058	MI01017	MI01016
Sampling set	2003	2003	2003	2003	2003	2001	2001
Area	WWTP	WWTP	WWTP	Sukhumvit Rd	Sukhumvit Rd	Sukhumvit Rd	Sukhumvit Rd
Description	Effluent	Sediment	Sediment	Effluent	Sediment	Effluent	Sediment
Location	input pipe to lagoon	by input pipe to lagoon	lagoon near main input	emerges from underground	emerges from underground	emerges from underground	emerges from underground
Metals	$\mu\text{g/l}$	mg/kg	mg/kg	$\mu\text{g/l}$	mg/kg	$\mu\text{g/l}$	mg/kg
Arsenic (As)	<0.4	<40	<40	<0.4	<40	---	<40
Cadmium (Cd)	<10	<1	1	<10	<1	<10	<1
Chromium (Cr)	<20	52	69	39	78	<20	139
Cobalt (Co)	<20	10	11	<20	3	<20	5
Copper (Cu)	96	35	107	53	157	<20	192
Lead (Pb)	53	35	34	34	49	<30	42
Manganese (Mn)	630	703	442	180	154	164	249
Mercury (Hg)	<2	0.3	<0.2	<2	<0.2	<1	0.18
Nickel (Ni)	382	48	195	303	231	397	375
Zinc (Zn)	135	170	414	133	566	27	411
No. of organic compounds isolated	71	19	18	40	43	4	53
No. reliably identified	11 (15%)	9 (47%)	6 (33%)	12 (30%)	22 (51%)	3(75%)	19(36%)
Chlorinated compounds							
Dichlorobenzenes		3*	3*		3*	3*	2*
Trichlorobenzenes and derivatives		1*	1*	2*	2+3*		2*
Tetrachlorobenzenes					3*		1*
Pentachlorobenzene					1		1*
Hexachlorobenzene					1*		1*
Chloromethyl-trichlorobenzene,					1		
Dichlorophenols and derivatives				1+2*			
Trichlorophenols	1*			1*			
Hexachlorobutadiene					1*		
Organophosphates							
2-butoxyethanol phosphate (3:1)	1			1			
Polycyclic aromatic hydrocarbons (PAHs)							
Naphthalene derivatives	6	1					
Phthalate esters							
DEHP		1	1		1		
DMP					1		
Other aromatic hydrocarbons							
Alkyl benzenes	2						1
Benzenemethanol		1	1		1		
Non-chlorinated phenols							
Nonyl phenols				many isomers	many isomers		
Alkyl phenols				1	2		
Phenol, 2-nitro-	1*						
Oxygenated Compounds							
Aliphatic alcohols				1			
Aromatic ketones					1		
Aliphatic hydrocarbons							
Linear		1					8
Branched		1					2
Cyclic							1
Nitrogen-Sulfur compounds							
Benzothiazole derivatives				1			
Carbamodithioic acid derivatives				1			

Table 4. Organic chemicals and heavy metals identified in samples of effluent and sediment associated with the main wastewater treatment plant (WWTP) of the Bangpoo Industrial Estate, Samut Prakan Province, Thailand. For the organic compounds reliably identified, the number of compounds identified using general GC/MS screening method is presented for each group; * signifies those compounds identified only at trace levels using a selective ion monitoring (SIM) method. Metal concentrations are given in mg/kg dry weight for solids and $\mu\text{g/l}$ for aqueous samples

(MI01015). The most elevated metals were copper and zinc, at approximately seven times typical uncontaminated background. The concentrations of mercury and nickel were approximately twice those found upstream of the estate, but were only very slightly elevated above typical uncontaminated background levels (ATSDR 2000, Salomons and Forstner 1984).

3.2 Canal Sediments

The data from the samples of sediment from both canals show significant contamination of the canal sediments with a range of toxic and persistent heavy metals and organic pollutants. The nature and extent of contamination along the courses of the two canals indicates significant inputs of these pollutants to both canals.

The metals analysed in this study are naturally present in uncontaminated aquatic and terrestrial ecosystems, but typically at low concentrations (ATSDR 2000, Salomons and Forstner 1984).

3.2.1 Northwestern canal

The northwestern canal is contaminated with a range of heavy metals, especially with chromium, copper, lead, nickel, and zinc. The metals analysed for in this study are naturally present in uncontaminated aquatic and terrestrial ecosystems, but typically at low concentrations (ATSDR 2000, Salomons and Forstner 1984).

Heavy metal concentrations in the sample collected upstream of the estate (MI01015) were significantly lower than concentrations found in sediment collected within the industrial estate (MI01014). The upstream sample contained only copper at an elevated concentration, at approximately three times typical uncontaminated background levels for river sediments (Salomons and Forstner 1984).

The sediment sample collected in the middle of the estate (MI01014) contained the highest concentrations found in any of the canal sediment samples for nearly all metals. This sample was seriously contaminated with copper, lead, nickel and zinc. The concentrations of these metals were extremely elevated above those found in the upstream sample (MI01015). Furthermore, the concentrations of copper, lead, nickel and zinc found in this sample were elevated above typical uncontaminated background levels by considerable factors; one hundred times for copper, one hundred times for lead, fifty times for nickel and one hundred and twenty-five times for zinc (ATSDR 2000, Salomons and Forstner 1984).

This sample (MI01014) also contained cadmium, chromium, and mercury concentrations at higher than those found in the upstream sample (MI01015). These metals were present at approximately twice typical background levels (ATSDR 2000, Salomons and Forstner 1984).

The canal sediment collected on the downstream edge of the industrial estate (MI01013) contained lower concentration of all metals compared to those found in the middle of the estate (MI01014). This sample (MI01013) did, however, contain copper, mercury, nickel

and zinc at significantly higher concentrations than those found upstream of the estate (MI01015). The most elevated metals were copper and zinc, at approximately seven times typical uncontaminated background. The concentrations of mercury and nickel were approximately twice those found upstream of the estate, but were only very slightly elevated above typical uncontaminated background levels (ATSDR 2000, Salomons and Forstner 1984).

The lower concentrations of heavy metals in the downstream sample (MI01013) compared to those found within the estate indicates only slow movement of these metals along the canal. This may be a result of the slow flow rate along this canal.

The transfer of heavy metals along the canal can, however, already be observed to a degree for copper, zinc and to a lesser extent nickel. These metals tend to be the more mobile in aquatic systems (ATSDR 2000, Bryan & Langston 1992, Mance *et al.* 1984, Mance & Yates, 1984), which may explain their preferential transfer along the canal.

Upon release to a watercourse, many heavy metals including lead and chromium, tend to bind strongly to suspended material in the water body, finally accumulating in the bottom sediments (Alloway 1990, ATSDR 2000). With time, all heavy metals discharged to this canal will pass along its course, primarily bound to sediment particles.

The metals found in high concentrations in the sediments of this canal cannot be destroyed through wastestream treatment as many are persistent in the environment, binding strongly to sediments (ATSDR 2000). These metals exhibit a wide range of toxic effects on terrestrial and aquatic organisms. Detailed information on the environmental behaviour and toxicological properties of these metals is discussed in Appendix 4.

Due to the diversity of industries located within the estate, it is not possible to identify the individual sources of these metals to this canal. Possible industrial sources of these metals are discussed below (ATSDR 2000). Industrial activities utilizing these raw materials, products and processes could release high levels of these metals into the environment.

Chromium and its compounds are used in alloys, tanning agents, textile pigments and preservatives, pesticides, catalysts and corrosion inhibitors. Copper and its compounds are extensively used as alloys and electrical conductors, dyes, pigments, printing inks, catalysts, pesticides, disinfectants and fertilisers. Lead is widely used in alloys, solder and batteries. Lead compounds have been used in paint pigments, PVC stabilisers, in pesticides, varnishes, lubricants, glazes and petrol additives. Nickel and its compounds are used in alloys, batteries, and catalysts and for electroplating. Zinc and its compounds are used as alloys, pesticides, catalysts, PVC stabilisers, fertilisers, paints, pigments and dyes.

In addition to the elevated metal concentrations in the sediments collected from this canal, a number of organic pollutants were identified. In all three samples, the organochlorine compound 1,4-dichlorobenzene was identified at trace levels. A number of alkyl benzenes and aliphatic hydrocarbons were also identified in all three samples, and some oxygenated aliphatic hydrocarbons were identified in samples MI02013 and MI02015.

The organochlorine 1,4-dichlorobenzene (1,4-DCB) is widely used in lavatory deodorant blocks and room deodorants. It is also employed as a moth control agent and as an

insecticide (Bryant 1993, CEC 1986). 1,4-DCB is reported to cause headaches and dizziness, toxic effects in the liver and kidney, to increase rates of cancer among experimental animals and to result in birth defects (Bornatowicz *et al.* 1994).

Alkyl benzenes and aliphatic hydrocarbons found in the environment are primarily a result of their presence in crude oil and petroleum products (Hsieh *et al.* 2000) as well as in sewage (Chaloux *et al.* 1995). Many alkyl benzenes are highly resistant to degradation and can accumulate in sediments (Preston & Raymundo 1993, Hsieh *et al.* 2000).

The oxygenated aliphatic hydrocarbons identified in samples MI02013 and IT02015 may be formed as a result of microbial degradation of petroleum derived aliphatic hydrocarbons (Di Cello *et al.* 1997).

3.2.2 Southeast canal

The data from the sediment samples collected in May 2003 from the canal running northeast to southwest in the southeastern part of the estate demonstrates increasing load with a number of toxic and persistent heavy metals downstream along its course, most notably for copper, nickel and zinc.

The two samples of sediment (AT03055 & AT03056) collected from the two upstream branches of the canal near to where they enter the industrial estate contained lower concentrations of many heavy metals compared to samples collected further downstream. At both these locations, however, the sediment samples did contain elevated concentrations of some heavy metals above what is typically found in uncontaminated river sediments. In both samples, concentrations of copper, lead, nickel, zinc were approximately twice those typically found in uncontaminated sediment, other than for AT03056 which contained zinc at approximately ten times that found in uncontaminated river sediments (ATSDR 2000, Salomons and Forstner 1984).

The sediment sample (AT03055) collected from the northeastern branch of this canal also contained an elevated concentration of cadmium, at 4 mg/kg. Uncontaminated river sediments typically contain less than 1 mg/kg of cadmium. None of the other samples collected from this canal contained cadmium above 1 mg/kg. The source of the cadmium at the upstream location of this canal is not clear but may not be associated with activities within the industrial estate.

Possible sources of cadmium from industrial sources include the use of this metal and its compounds in metal plating, nickel-cadmium batteries, pigments and PVC stabilisers (ATSDR 2000).

The concentrations of chromium, copper, mercury, nickel, and zinc progressively increase downstream along the southeastern canal. The highest concentrations of these metals were found in the sample of sediment collected within the commercial of the estate just prior to the canal leaving the industrial estate (AT03052). The concentrations of copper and nickel in this sample were more than twenty times those found in upstream samples. These concentrations are twenty-eight and seventeen times typical uncontaminated background levels for copper and nickel respectively (ATSDR 2000, Salomons & Forstner 1984). Concentrations of chromium, mercury and zinc in this sample were less elevated, being

approximately three times higher than in upstream samples, though this zinc concentration is approximately eight times uncontaminated background levels (ATSDR 2000, Salomons & Forstner 1984).

The distribution pattern of heavy metals within this canal is similar to that observed for the northwestern canal, with copper and zinc being preferentially transferred along the canal, possibly as a result of their higher mobility. However, all heavy metals discharged to this canal will, over time, pass along its course, as described in Section 3.1.1.

Detailed information on the environmental behaviour and toxicological properties of these metals is discussed in Appendix 4. Potential sources of these metals are discussed above in Section 3.1.1.

A number of organic compounds were also identified along the course of the canal, though some at only trace levels.

Both upstream samples (AT03055 & AT03056) contained a number of organic pollutants. Both samples contained DEHP (bis-(2-ethylhexyl) 1,2-benzenedicarboxylate), a phthalate esters. The sample from the southwestern branch (AT03056) also contained a mixture of nonylphenol isomers and the organochlorine 1,4-dichlorobenzene, the latter at trace level.

These compounds are widely used in many applications and their presence at these two upstream locations suggests that additional sources to those within the industrial estate may be contributing to the presence of these compounds in the southeastern canal.

The source of 1,4-dichlorobenzene may be from its use in lavatory deodorant blocks and room deodorants as described in section 3.1.1.

The phthalate DEHP is a widely used chemical, it is employed as a plasticiser in the production of soft PVC (Cadogan *et al.* 1993, Kemi 1994) and is also used in many other products including inks and dyes, in cosmetics and in perfume oils (ATSDR 2000). Phthalates are persistent in the environment and are the most abundant man-made chemicals in the environment (Jobling *et al.* 1995). DEHP can accumulate in soils and sediments because of its low water solubility and vaporization abilities and it has been found in fresh, marine, and industrial waters (Giam *et al.* 1998, Tan 1995). DEHP produces a spectrum of toxic effect in developing and adult animals and in multiple organ systems including the liver, reproductive tract (testes, ovaries, secondary sex organs), the kidneys, lungs, and the heart (Tickner *et al.* 2001). It has been demonstrated that DEHP is able to bind to the human estrogen receptor, although it showed no significant estrogenic activity (Jobling *et al.* 1995).

Nonyl phenols are used as antioxidants in PVC and polystyrene (Olsson *et al.* 1998). They are ubiquitous in the environment due to the widespread use of nonylphenol ethoxylates (NPEs) as nonionic surfactants. These compounds undergo degradation in waste treatment plants or in the environment generating nonylphenols as metabolites (Ying *et al.* 2002). Nonyl phenols are persistent chemicals of environmental concern due to their aquatic toxic and estrogenic effects (Bokern & Harms 1997, Jobling *et al.* 1996).

Both DEHP and trace levels of 1,4-dichlorobenzene were detected in all sediment samples collected along this canal. In addition to these compounds, the phthalate ester DnBP (di-

n-butyl 1,2-benzenedicarboxylate) was detected in all three sediment samples collected from the canal further downstream (AT03052-AT03054). The absence of DnBP in the two upstream samples (AT03055 & AT03056) suggests input to the canal within the industrial estate. DnBP is a widely used chemical employed for similar uses to those described above for DEHP (Cadogan *et al.* 1993, Kemi 1994, ATSDR 2000).

Two additional chlorinated compounds were detected at trace levels in sediment samples collected from the middle and lower portions of the canal (AT03052-AT03054); 1,2-dichlorobenzene and 1,2,4-trichlorobenzene. These compounds are usually co-produced with 1,4-dichlorobenzene, and may be present as contaminants in products incorporating this chemical (Bryant 1993, CEC 1986). Chlorinated benzenes are among the most persistent organochlorine compounds, being highly resistant to microbial degradation. Di- and tri-chlorobenzenes may be formed as persistent end-products from the biodegradation of other organochlorines (Middeldorp *et al.* 1996).

Two aliphatic alkanes, an alkyl benzene and molecular sulfur (S₈) were also detected in sample AT03053. These may result from their presence in crude oil (Overton 1994). Aliphatic hydrocarbons exhibit only slight acute toxicity by all routes of exposure. The liquid may cause irritation upon contact with skin or eyes. Ingestion of aliphatic hydrocarbons may lead to aspiration of the substance into the lungs, causing pneumonia. Prolonged skin exposure may cause irritation due to the ability of these solvents to remove fats from the skin (Ritchie *et al.* 2001).

3.3 Wastewater treatment plant

The main wastewater treatment plant (WWTP) receives effluent from many industries within the estate, some of which has been partially pre-treated. The samples of effluent entering one of the treatment lagoons (AT03049) contained significant concentrations of copper, nickel, and zinc. The concentrations of these metals were, however, below effluent standards for industrial and industrial estate sources in Thailand (Homchean 1998).

Heavy metal contaminants in wastestreams cannot be destroyed through waste treatment, but can only be moved from one medium into another. This is demonstrated by the presence of elevated concentrations of copper, nickel and zinc found in the two samples of sediment collected from this treatment lagoon (AT03050 & AT03051). The concentrations of these metals in the WWTP lagoon sediment samples were, however, less elevated than those found in the most contaminated sediments collected from both the northwestern (MI01014) and southeastern canals (AT03052).

Effluent sample AT03049 contained a range of organic compounds, some of them are of environmental concern. 2,4,6-trichlorophenol, which was reliably identified in this sample, though at trace levels, is known to be used in the preparation of fungicide prochloraz (Stringer & Johnston 2001). It is also could be formed in aqueous media during chlorination of the well known environmental contaminant bisphenol A (Yamamoto & Yasuhara 2002). Chlorophenols have a wide spectrum of toxic effects including teratogenic and carcinogenic actions (Nagyova & Ginter 1995). 2,4,6-trichlorophenol is reasonably anticipated to be a human carcinogen (DHHS 2002). Moreover, it was found that 2,4,6-trichlorophenol could be converted into products with

increased toxic effects during the photolytic degradation in aqueous media (Svenson & Hynning 1997). Several naphthalene derivatives were also detected in effluent AT03049, however, the origin of them in this sample is unknown. One representative of organophosphorous compounds was detected in this sample; 2-butoxyethanol phosphate (3:1), also known as tris(2-butoxyethyl) phosphate (TBEP). TBEP is a flame retardant and is mainly used in floor polishes, as a solvent in some resins, a viscosity modifier in plastics, and also as a plasticiser in synthetic rubber, plastics and lacquers (WHO 2000). Studies in laboratory animals have shown that the liver is the target organ for TBEP toxicity, however, the long-term toxicity and carcinogenicity of TBEP have not been investigated (WHO 2000).

Two sediment samples AT03050 and AT03051 had very similar patterns of organic compounds identified. Both contained phthalate DEHP and trace levels of dichlorobenzenes and trichlorobenzene which were discussed above in section 3.1.2.

Treated effluent from the main WWTP is discharged via an underground conduit to a location on Sukhumvit Road (BIEA 2003). The sample of effluent collected from this location in 2003 (AT03057) contained copper, nickel and zinc at elevated concentrations. These metals were present at five, ten and eight times typical concentrations in uncontaminated river water, though the concentrations found are below effluent standards for industrial and industrial estate sources in Thailand (Homchean 1998). The effluent sample collected from this location in 2001 (MI01017) contained only nickel at an elevated concentration, approximately twice that found in 2003 (AT03057).

Both samples of sediment collected from this location in 2001 (MI01016) and 2003 (AT03058) contained similarly elevated concentrations of copper, nickel and zinc. The concentrations of these metals in both samples were approximately four to six times typical background levels for river sediments (ATSDR 2000, Salomons and Forstner 1984). Lead was also present in both samples at very slightly elevated concentrations.

The same metals were found in elevated concentrations in the effluent collected at Sukhumvit Road (AT03057) as those in the partially treated effluent entering the WWTP lagoon (AT03049). Furthermore, the sediment at Sukhumvit Road (MI01016 & AT03058) was contaminated with a similar range of metals. These data demonstrate the failure of the processes employed at the WWTP to fully remove heavy metals from the wastestreams they receive.

The persistence and toxicity of the metals found to be contaminating this canal, and their potential sources are discussed above in Section 3.1.1.

A wider range of organic compounds was detected in the effluent (AT03057) and sediment (AT03058) samples from the WWTPs discharge canal on Sukhumvit Road compared to those found in the input effluent (AT03049) and sediments (AT03050 & AT03051) from the WWTP treatment lagoon.

These compounds include hexachlorobutadiene, chlorinated phenols, chlorinated toluenes and chlorinated benzenes. Some of these were found to be present at only trace levels (see Table 4). The phthalate DEHP and the flame retardant TBEP were detected in both locations (before and after treatment). However, it is necessary to mention that it was not possible to collect sample from the main effluent input at the time of the sampling,

therefore effluent sample AT03049 only partially represents the scale of the contaminants entering treatment lagoon. Nevertheless, the presence of organic contaminants in the treated water and associated sediment is clearly an indication of the insufficient treatment of effluents, which leads to continuous pollution of the environment with persistent and toxic substances.

2,4-dichlorophenol is used in the manufacture of industrial and agricultural products such as pesticides, germicides, soil sterilants, seed disinfectants and antiseptics. This compound is a key intermediate in the synthesis of the herbicide (2,4-dichlorophenoxy) acetic acid (2,4-D) (Budavari 1989). 2,4-D is one of the most frequently used herbicides and is an environmental pollutant. Evidence exists that 2,4-D exposure results in an increased risk for certain malignant disorders such as nasal carcinoma and soft tissue sarcoma in humans and animals (Mehmood *et al* 1996). 2,4-DCP was found to be toxic to aquatic life (Ensley *et al* 1994, Kaiser *et al* 1995) and animals (Nagyova & Ginter 1995). It was shown (Muller & Herbarth 1994) that dichlorophenols are very toxic to the single-celled eucaryotic organism *Tetrahymena pyriformis*, which is comparable in sensitiveness and responsiveness to human tissue cells. In this investigation it was found that the toxicity of 2,3-dichlorophenol is 50 times higher than the toxicity of pure phenol. Additionally, 2,4-dichlorophenol is a precursor of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) (Ghorishi & Altwicker 1996). 2,4,6-Trichlorophenol, also found in the effluent sample AT03049, was discussed above.

Hexachlorobutadiene (HCBD) is not found naturally in the environment, it either commercially manufactured or is formed as a by-product of the production of chlorinated hydrocarbons (ATSDR 2000, Lerche *et al.* 2002). Hexachlorobutadiene is nephrotoxic compound and there is a limited evidence for the genotoxicity and carcinogenicity of HCBD in animals (Lerche *et al.* 2002). It has been also reported to be toxic to rat kidney, but neither toxicity data, nor data on the metabolism of HCBD, are available in humans (Lerche *et al.* 2002, Green *et al.* 2003).

Chlorinated benzenes, from di- to hexachlorinated, have been found at trace levels in the sediment sample AT03058 with the exception of the pentachlorobenzene and chlorinated methylbenzenes (toluenes), which have been identified in general screening method since presented at higher levels. Pentachlorobenzene was used in the past as a fungicide and flame retardant, but it is probably a chemical which is no longer used or produced. The pesticide pentachloronitrobenzene contains traces of pentachlorobenzene as impurity (Lerche *et al.* 2002). Target organs of pentachlorobenzene are the liver and the kidney, as is the case for most chlorobenzenes (Lerche *et al.* 2002). Hexachlorobenzene (HCB) was used as fungicide and as chemical intermediate in dye manufacture and the synthesis of other organic chemicals. It is a highly persistent and bioaccumulative compound that has been detected in all environmental media (Stringer & Johnston 2001). HCB is a toxic chemical and is reasonably anticipated to be a human carcinogen (DHHS 2000). Trichlorotoluenes have relatively few industrial applications. 2,3,6-trichlorotoluene is used as intermediate in the production of herbicides (Lin & Krishnamurti 1993).

Carbamodithioic acid, dimethyl-, methyl ester may be a degradation product of thiuram. The main use of thiuram is as an accelerator and vulcanization agent in the rubber industry. It is also used as a fungicide on seeds and as a foliar fungicide on turf, fruit and vegetables. It has been in commercial use since 1925 (RSC 1991).

2-methylthiobenzothiazole (MTBT), which was detected in the effluent sample AT03057, is a product of incomplete methylation of 2-mercaptobenzothiazole (MBT). MBT is a toxic and poorly biodegradable pollutant. It is used in a variety of applications such as biocorrosion inhibitors, anti-fungal drug in medical application, coating agent for metallic surfaces, and predominantly as a vulcalization accelerator in the rubber industry (Fiehn *et al.* 1998). MTBT is frequently found in both the effluent of wastewater treatment plants and surface water (Paxeus 1996).

Many of the chlorinated compounds found in samples AT03057 and AT03058 were also identified in samples collected from the same location in 2001, though again only at trace levels.

4 CONCLUSIONS

This study has demonstrated contamination of many areas of the Bangpoo Industrial Estate with range of organic pollutants as well as many toxic and persistent heavy metals. This widespread contamination is indicative of the generally inadequate process control and waste management practices employed on this estate.

The two canals that flow through the estate are both highly contaminated, principally with high concentrations of many heavy metals, but also with a number of organic pollutants. Wastes carried by both canals are ultimately discharged in to the Gulf of Thailand.

Effluent and sediment samples collected from the WWTP lagoon have shown that a range of persistent and toxic organic chemicals as well as significant quantities of heavy metals have been discharged to this facility.

A similar set of organic compounds to those found in the WWTP were found in samples collected from a canal carrying treated wastewater from this WWTP, though many at only trace levels. This canal contained additional organic pollutants to those identified at the WWTP, which may be a result of their historic discharge from the WWTP via this canal. Elevated concentrations of copper, nickel and zinc were also found. The presence of these pollutants in an open canal within a residential / commercial area on Sukhumvit Road is cause for concern.

The occurrence of many compounds both at the WWTP and within its discharge canal, as well as the elevated heavy metal concentrations in this canal, demonstrates the inability of the WWTP to effectively remove and/or degrade a range of chemicals discharged to it.

The concentrations of the heavy metals in the effluent samples collected from the WWTP discharge canal were below effluent standards for industrial and industrial estate sources in Thailand (Homchean 1998). Elevated heavy metals concentrations in the sediment of this discharge canal, however, demonstrates their accumulation through ongoing discharge, albeit at relatively low levels.

It is noteworthy that a number of compounds found in the sediment of the WWTP discharge canal on Sukhumvit Road have recently been detected in seawater at a number of locations off the coast of Thailand. This includes nonyl phenol and the phthalates DEHP and DnBP, as well as chlorinated phenols including 2,4-dichlorophenol.

Specifically, DEHP has been identified in seawater off the Samut Prakan coast (Boonyatumanond *et al.* 2002).

For all but one sample, less than half the total number of organic compounds isolated from each sample could be identified. The data for the effluent sample entering the WWTP (AT03049) shows that it was only possible to identify 11 of the 71 compounds isolated. The nature and potential environmental impacts of these unidentifiable compounds cannot be known or predicted.

The wastewater treatment plant is intended as a solution to deal with the complex waste streams that are generated by the many industries that discharge their wastestreams to this facility. In practice this is not the case, and furthermore it never can be.

Those industries which produce wastestreams containing pollutants that the Bangpoo Industrial Estate WWTP is unable to degrade have a responsibility to remove these through pre-treatment prior to discharging their wastewaters to the WWTP. Clearly this is not fully achieved. Furthermore, where such pre-treatment is carried out using similar technologies to those employed at the combined WWTP, the limitations described below will also apply to these individual treatment facilities.

The combining of highly complex waste streams from diverse chemical manufacturing processes typically results in a combined effluent for which techniques to deal with them either do not exist or are unproven in practical application (Englande 1994).

Combined wastewater treatment plants typically address only a limited range of physical, biological and simple chemical variables such as pH, conductivity, dissolved and suspended solids, biological and chemical oxygen demand (BOD, COD, nitrogen and phosphorus, along with certain other major ions) (Hadjivassilis *et al.* 1994).

Certain organic compounds, such as many highly chlorinated compounds, are highly resistant to biodegradation (Gruttner *et al.* 1994a). Metal contamination of wastewater can never be addressed through such processes, other than to scavenge the metals from the dissolved to the particulate fraction (Gruttner *et al.* 1994b). As a result, many of the most toxic and persistent components of chemical waste streams may simply pass through the WWTP unmodified. Many of the more volatile organic compounds (VOCs) in wastestreams may be released to the atmosphere before they can be degraded (Haas & Herrmann 1996).

Furthermore, the operation of the WWTP may well be severely hindered by the presence of certain organic contaminants, which can exert toxic effects on the micro-organisms responsible for biological waste treatment. For example, dichlorobenzenes identified in this study may inhibit the degradation of other compounds (Robertson & Alexander 1996), or increase the susceptibility of the bacterial system to toxic shock (Limbert & Betts 1995).

Shock loading with higher concentrations of particular compounds can perturb biodegradation processes in a manner that may be highly complex and difficult to predict (Lu & Tsai 1993, Torslov & Lindgaardjorgensen 1994, Strotmann *et al.* 1995). In addition, systems designed specifically to treat chemical wastes are frequently less

efficient at achieving conventional biological treatment to reduce biological oxygen demand (BOD), suspended solids and related variables.

Some of the less persistent organic compounds identified in this study, such as 2,4-dichlorophenol, can be degraded by microbiological processes. However, few microorganisms are able to degrade chlorinated aromatic compounds (Mohn & Tiedje 1992). To achieve acceptable and reproducible degradation of such compounds, specific process designs are generally required (Fulthorpe & Allen 1995, Gonzalez *et al.* 1996). Complex and expensive equipment, and long treatment residence times are often required to achieve the removal of these compounds to an acceptable standard (Tunay *et al.* 1994), such as the upflow anaerobic sludge blanket plant (Duff *et al.* 1995).

WWTPs are known to concentrate heavy metal and certain persistent organic contamination in solid residues, which far from providing a solution, is merely the transfer of contamination from one environmental medium to another, creating an additional contaminated wastestream that must be dealt with.

The mixing of highly complex wastestreams, some of which may contain chemically active compounds, can also result in the formation of new compounds not present in any of the individual wastestreams (Johnston *et al.* 1996).

Effluent treatment systems for combined wastewaters are frequently subject to stimulation or inhibition as a result of changes in the flow rate and composition of wastewaters discharged to them (Limbert & Betts 1995, Jin & Battacharya 1996). Changes in environmental variables such as process temperature and temperature of the inflowing effluent can have similar effects (Liss & Allen 1992). Activated sludge digestion, as employed at this WWTP, can be particularly sensitive to the changes in flow rate which result from batch production processes (McAllister *et al.* 1993, Rebhun & Galil 1994).

A number of standards are applicable to activities within the estate, including criteria for wastewaters discharged to the WWTP as well as treated effluent discharge standards (Homchean 1998). These standards are set for a range of criteria, including the heavy metals analysed for in this study. These standards, however, set limits for only a very limited number of organic compound groups; Oil and grease, phenols and cresols, and pesticides. No limits are set for organochlorine or organophosphorus compounds (Homchean 1998). Wastewaters that meet these limited legislative requirements are considered acceptable for discharge to surface water, despite the toxic and persistent chemicals that may still be present.

Clearly, many pollutants identified are not fully addressed through these regulations, despite the inclusion of many in the National Chemicals Management Profile for Thailand, which lists heavy metals, organochlorinate and organophosphorous compounds as specific chemicals creating concern. Further, the pollution of inland waterways, and marine pollution with a range of heavy metals and certain organochlorine pesticides is included under priority concerns related to chemical production, import, export and use (SCSIN 1998).

The environmental management of industry must incorporate the move towards the elimination of pollution. This necessitates the adoption of clean production. In such systems, products are designed so that they are necessary, reusable, recyclable and

generate only non-hazardous wastes. Investment needs to be made into measures to eliminate pollution via the phasing out of hazardous substances and the implementation of truly clean and sustainable technologies.

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