Textile Mill Effluents Study:
Final Phase 1 Report

Identification and Evaluation of Best Available Technologies Economically Achievable (BATEA) for Textile Mill Effluents

Submitted to:

Environmental Protection Branch, Environment Canada

Submitted by:

Marbek Resource Consultants

in association with
Fintex Mechanical & Process Inc.
Hara Associates
and
Crechem Technologies Inc.

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In September 2001, this *Phase 1 Report* was released for stakeholder comment. The feedback received was considered in subsequent stages of this study, and by Environment Canada in the development of a proposed risk management strategy for textile mill effluents.

To provide a complete record, this report has been re-issued with the stakeholder comments included as Appendix E. No other change has been made to the content of the report.

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List of Acronyms

AATCC	American Association of Textile Chemists and Colorists
AP	Alkylphenol
APE	Alkylphenol ethoxylate
BATEA	Best Available Technologies Economically Achievable
BOD	Biological Oxygen Demand
BTU	British Thermal Unit
CATCC	Canadian Association of Textile Colorists and Chemists
CEPA	Canadian Environmental Protection Act
CISTI	Canada Institute for Scientific and Technical Information
COD	Chemical Oxygen Demand
CTT	Centre des Technologies Textiles
EC	Environment Canada
GDP	Gross Domestic Product
ITS	Institute of Textile Science
LAE	Linear Alcohol Ethoxylates
LC50	Median Lethal Concentration
MWWTP	Municipal Wastewater Treatment Plant
NP	Nonylphenol
NPE	Nonylphenol Ethoxylate or Polyethoxylate (as a general class)
NRC	National Research Council
PSL	Priority Substances List
TME	Textile Mill Effluent
TSC	Textile Society of Canada
TSMP	Toxic Substances Management Policy
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency

1. INTRODUCTION

1.1 OBJECTIVES

The overall objective of this project is to analyse best risk management instruments to reduce the environmental impacts of textile mill effluents (TMEs) and releases of nonylphenol and its ethoxylates (NPEs) in the Canadian wet processing textile industry.

Key project tasks include:

- Identify and analyze the best available technologies economically achievable (BATEA)[1] for TME and NPE pollution prevention and pollution control, and determine the effluent quality that can be attained,

- Propose risk management objectives for TMEs and NPEs in wet textile mill processes, and

- Conduct a qualitative and quantitative assessment of risk management instruments and implementation plans based on established technical, environmental and socio-economic criteria.

1.2 SCOPE

The sector addressed in this study is the ***wet processing textile industry,*** which includes textile mills involved in wet processes such as scouring, neutralizing, desizing, mercerizing, carbonizing, fulling, bleaching, dyeing, printing, and other wet finishing activities. The Canadian wet textile processing industry consists of about 145 mills in six categories: knit, woven, stock/yarn, carpet, wool and non-woven. Facilities that conduct only dry processing (carding, spinning, weaving, and knitting), laundering, or manufacture of synthetic fibres through chemical processes, are outside the scope of this study.

The toxic substances addressed include textile mill effluents (TMEs) and nonylphenol and its ethoxylates (NPEs). Waste streams such as air emissions and solid waste are not considered. This study also does not examine the risks posed by TMEs and NPEs. This has been addressed in the Priority Substances List (PSL) assessments of these substances, which have led to the recommendation that these substances be declared toxic under CEPA, 1999.

As noted, the technologies to be considered in this analysis include both pollution prevention and pollution control, with primary focus on pollution prevention. The BATEA considered include technologies/practices presently in use in the textile industry in Canada or abroad, where there is potential for use/increased use in the Canadian textile industry. Technologies include not only processes, but also best practices such as housekeeping, improved scheduling, chemical substitution, etc.

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[1] In this study, the term BATEA is understood to include both technologies and practices for pollution prevention/ control (sometimes referred to as "Best Available *Techniques* Economically Achievable").

About 96% of TMEs in Canada are discharged to municipal wastewater collection systems. A Municipal Wastewater Effluent Strategy is currently in development by Environment Canada. This strategy will address the issue of effluent quality for Canadian municipal wastewater treatment plants (MWWTPs). A management instrument will be designed and discussed with stakeholders. This present study does not consider technical options for municipal systems, but will take account of any management decisions affecting MWWTP discharges.

1.3 WORK PLAN

The objectives identified in Section 1.1 will be accomplished in three distinct Phases.

Phase 1 began with the identification of an inventory of BATEA, and development of an effluent toxicity model. The project team then analysed each BATEA, by modelling impact on effluent quality and estimating costs. Finally, the team will develop proposed risk management objectives based on environmental objectives and the BATEA analysis.

Phase 2 will involve a qualitative assessment of a range of risk management instruments designed to meet the risk management objectives selected in Phase 1. Integral to this evaluation will be the establishment of criteria for inclusion or exclusion of the risk management instruments, leading to a recommendation on the most promising risk management instruments.

Phase 3 of the project will require a quantitative analysis of the most promising risk management instruments identified in Phase 2. This assessment will provide a basis for a recommendation on the best management instrument or instruments for the management of TMEs and release of NPEs in the textile industry.

Table 1.1 provides an overview of the methodology that has been used in Phase 1 of this project. Detailed discussion of methodology for individual task areas is provided in the relevant sections of this report.

Table 1.1 - Phase 1: Identification and Analysis of BATEA

TASK AREA 1: Identify Main Causes of Effluent Toxicity	
Task 1.1	*Identification of major chemical species that cause effluent toxicity:* • A literature search was conducted to identify major chemical species that cause effluent toxicity. The search was conducted through the Canada Institute for Scientific and Technical Information (CISTI) at the National Research Council (NRC) and other databases. See Appendix A for details.
Task 1.2	*Establish a correlation between effluent toxicity and major species in effluents:* • Toxicity and concentration data was collected for the major toxic species present in textile mill effluents, as identified in Task 1.1. • A mathematical expression was developed for effluent toxicity, based on lethal concentration (LC50) and the concentration of the major toxic species present in effluents.

TASK AREA 2: Inventory of BATEA	
Task 2.1	*Identification and review of studies on best available technologies for textile mill effluents:* • A literature search was conducted for studies on best available technologies for reducing textile mill effluents, including both pollution prevention and control. All relevant studies were compiled and a review of technologies was prepared, with emphasis on technologies that have been used and have potential for use by the wet processing textile industry. Equipment suppliers were also contacted for further information, to complement the literature search.
Task 2.2	*Identification of BATEA:* • Based on the results of Task 2.1 and the experience of the project team, a representative list of twelve pollution prevention and control technologies and techniques (BATEA) was selected for more detailed assessment.
Task 2.3	*Benchmark the Canadian wet processing textile industry vis-à-vis the selected BATEA:* • For the BATEA identified in Task 2.2, the Canadian textile industry was benchmarked to determine current application and potential for the technologies identified. Information was sourced from manufacturers, chemical suppliers and textile industry end-users (clients), and complemented by the knowledge of the project team.
TASK AREA 3: Achievable Effluent Quality	
Task 3.1	*Determine achievable effluent quality from each of the selected BATEA:* • Using the toxicity correlation developed in Task 1.2, and technology data collected in Task Area 2, the project team determined the reduction of toxicity and selected pollutants that can be achieved through the application of each BATEA. The team also considered qualitatively the positive and negative impacts of BATEA on other environmental issues.
TASK AREA 4: Cost of BATEA	
Task 4.1	*Determine cost profile of each BATEA in terms of capital and operating costs:* • For each BATEA, a standardized cost profile was prepared addressing initial capital costs and ongoing operating costs, adjusted as appropriate for scale of plant, current technology, and expected replacement.
Task 4.4	*Estimate Payback, Annualized Cost, and Net Present Value* • Payback, annualized cost, and net present value of the costs of implementation were evaluated for the selected BATEA.
TASK AREA 5: Risk management objectives	
Task 5.1	*Recommend risk management objectives for TMEs and for NP/NPEs (in progress):* • Risk management objectives will be developed for TMEs and NP/NPEs for mills discharging directly to the environment and for mills discharging to municipal waste water treatment plants. The objectives will be based on BATEA effluent quality, and on surface water quality as defined by the Canadian Water Quality Guidelines.

1.4 THIS REPORT

This Phase 1 report is the first major deliverable under this project. It presents the results of Task Areas 1 to 4, organized as follows:

Section 2 provides **background information** relevant to this study.

Section 3 presents the **effluent toxicity model.**

Section 4 reviews **best available technologies economically achievable** (BATEA), including summary information on achievable effluent quality and cost for each BATEA.

Section 5 presents the methodology and detailed results concerning **achievable effluent quality.**

Section 6 presents the methodology and detailed results concerning **costs for each BATEA**, including capital and operating costs/savings, payback, and net present value.

Section 7 presents information concerning a number of **additional technologies/practices** that can be used to reduce effluent volume and/or toxicity from the wet processing textile industry.

The report also includes a series of Appendices, providing information on the literature review undertaken as part of this study, plus additional detail on topics addressed in the main body of the report.

2. BACKGROUND

2.1 CANADIAN ENVIRONMENTAL PROTECTION ACT[2]

The *Canadian Environmental Protection Act* of 1999 (CEPA, 1999) requires the Ministers of the Environment and Health to compile and publish a list of substances they consider a priority and to determine if they are "toxic" under the Act. This list is known as the Priority Substances List (PSL). Textile mill effluents (TMEs) and nonylphenol and its ethoxylates (NPEs) are both on the Second Priority Substances List (PSL2).

The management of toxic substances under CEPA, 1999 involves identifying substances that may be toxic, assessing them to determine whether they are toxic as defined in Section 64, and, for substances that are found to be toxic, establishing and applying controls to prevent harm to human health and/or the environment.

The Toxic Substances Management Policy (TSMP) guides the management of toxic substances. The policy puts forward a preventive and precautionary approach to deal with substances that enter the environment and could harm human health and/or the environment.

The TSMP categorizes toxic substances into either Track 1 or Track 2. Track 1 substances are persistent, bioaccumulative and anthropogenic. For such substances, the TSMP and CEPA, 1999 s.77(4), require virtual elimination from the environment. All other toxic substances are Track 2, and require life cycle management to prevent or minimize their release into the environment.

The risks posed by TMEs were assessed because TMEs are complex mixtures of chemicals varying in composition over time and from mill to mill. TMEs can have high concentrations of suspended solids, metals, NPEs and other organic substances, extreme pH levels, and elevated temperatures. The TME assessment did not attempt to determine the contribution of individual components of TMEs to toxicity or environmental effects. The assessment focused only on the impacts of ***whole*** effluents.

According to the *Priority Substances List Assessment Report: Textile Mill Effluents* (Environment Canada and Health Canada, March 2001, hereafter referred to as the TME Assessment Report), TMEs have a detrimental effect on aquatic life. The report indicated that all untreated effluents had detrimental effects on all organisms tested. Primary-treated TMEs were slightly less toxic than untreated effluents. Most secondary and tertiary-treated effluents produced no effects on test organisms.

Nonylphenol and its ethoxylates (NPEs) are a class of the broader group of compounds known as alkylphenol ethoxylates (APEs). NPEs are widely used and released by Canadian textile mills. They are used as surfactants, cleaning agents, or wetting and de-wetting agents. According to *Priority Substances List Assessment Report: Nonylphenol and its Ethoxylates* (Environment Canada and Health Canada, April 2001, hereafter referred to as the NPE Assessment Report), the major route for the release of NPEs to the Canadian environment is through discharge of

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[2] Much of the text in this section is adapted from documentation prepared by Environment Canada.

effluents. The report also states that textile mill effluents represent a major source of NPEs to the environment. Untreated or partially treated textile mill effluents can have high concentrations of NPEs.

The NPE Assessment Report concludes that concentrations of NPEs in untreated and partially treated TMEs discharged to the aquatic environment occur at levels that are likely to be causing harmful effects on aquatic organisms.

EC's Assessment Reports for TMEs and NPEs recommend that both these substances be declared toxic under CEPA, 1999. On June 23rd 2001, the Ministers of the Environment and Health recommended to the Governor in Council that TMEs and NPEs be declared toxic and added to Schedule 1 of CEPA, 1999.

Once the Ministers make this recommendation, the Minister of Environment must, within 24 months, propose regulations or an instrument (economic instruments, pollution prevention plans, etc.) respecting preventive or control actions. The Minister then has another 18 months to finalize the proposed regulations or instrument (section 92(1)).

Before proposing risk management instruments, Environment Canada must first establish risk management objectives for the reduction of TMEs and NPEs. Once these objectives are set, available risk management instruments must be assessed to identify the most promising instruments to achieve these objectives. Consultations with stakeholders (provincial, municipal and aboriginal governments, industry, consumers, environmental groups, etc.) will take place during the 24-month period. The proposed risk management instruments and risk management objectives must take into consideration the issues raised in the Assessment Reports, and must comply with the TSMP.

2.2 WET PROCESSING TEXTILE INDUSTRY IN CANADA[3]

According to the TME Assessment Report, in 1999 there were 145 wet processing textile mills operating in Canada, distributed as shown in Tables 2.1 and 2.2:

Table 2.1 - Wet Processing Textile Mills by Segment

Mill type	Number of mills	Percentage
Knit fabric finishing	66	45%
Woven fabric finishing	40	28%
Stock/yarn finishing	14	10%
Carpet finishing	9	6%
Wool finishing	9	6%
Non-woven fabric finishing	7	5%
Total	**145**	**100%**

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[3] This section is based on information provided in *Priority Substances List Assessment Report: Textile Mill Effluents*, Environment Canada and Health Canada, March 2001, and in *Background Study on Canadian Wet Processing Textile Mills Industry and Their Effluents*, Crechem Technologies, 2000.

Table 2.2 - Wet Processing Textile Mills by Province

Province	Number of mills	Percentage
Quebec	84	58%
Ontario	50	34%
Nova Scotia	5	3%
New Brunswick	3	2%
British Columbia	2	1%
Prince Edward Island	1	1%
Total (% corrected for rounding)	145	100%

Wet processing mills form a small but significant portion of the textile industry, based on number of employees (17.3%), revenues (21.3%), or number of plants (5.6%). In 1997, total revenue of the wet processing textile industry was an estimated $3.4 billion, and the industry contributed 0.2% of Canada's GDP. In that same year, the industry employed nearly 23,000, representing 0.17% of total employment in Canada.

In 1996, approximately 105,000 m^3 of TME were discharged daily to the Canadian environment, with 94% released to freshwater ecosystems. Eight mills discharged to estuarine or marine environments, and one mill utilized septic field disposal. As illustrated in Tables 2.3 and 2.4, most mills discharge to a municipal system, and most TMEs receive at least primary treatment.

Table 2.3 - TME Discharge

TME discharge	Treatment	Number of mills	Percentage
Discharge to municipal system	None	2	
	Primary	40	
	Secondary	84	
	Tertiary	13	
	Total	139	96%
Discharge to environment	Primary	1	
	Secondary	5	
	Total	6	4%
Total		145	100%

Table 2.4 - TME Treatment

Treatment	Effluent volume (m^3/day)	Percentage
None	137	0.1%
Primary	31,600	30%
Secondary	62,800	60%
Tertiary	10,800	10%
Total (rounded)	105,000	100%

3. EFFLUENT TOXICITY MODEL

The toxicity of Textile Mill Effluents (TMEs) arises from the combined effects of many individual chemicals. The level of toxicity of TMEs from any particular mill is dependent on the relative concentrations and toxicity of the individual chemicals, which will vary over time and from mill to mill.

Application of any technical option that affects effluent composition will affect whole effluent toxicity. However, while the impact of a technical option on effluent composition may be reasonably well understood (at least in some cases), the impact on effluent toxicity is not.

Accordingly, in order to determine the effect of a technical option on effluent toxicity, it is necessary to develop ***a model that predicts changes in effluent toxicity based on changes in effluent composition.***

This section presents the model that will be used in our analysis for this purpose. The presentation is organized as follows:

- Subsection 3.1 presents basic background information on effluent toxicity
- Subsection 3.2 presents our approach to modeling whole effluent toxicity, which is based on the toxicity of selected components of the effluent
- Subsections 3.3 and 3.4 present data on the measured toxicity and concentrations of the selected components of the effluent
- Subsection 3.5 presents the results of the toxicity model, and compares the result to actual measured data for whole effluent toxicity.

3.1 BACKGROUND

Wastewater toxicity is measured by means of a toxicity test. There are many forms and methodologies for toxicity testing (Lankford & Eckenfelder, Jr., 1990, p.18). Subchronic and acute tests are most commonly used today:

- A subchronic test is used to determine the concentration at which an effluent has an effect on survival, growth, and reproduction of test organisms. The term “subchronic” is to distinguish a 4-8 day test from a full chronic test, which lasts one or more life cycles. Depending on organisms tested, such full chronic tests range from a month to more than a year. Tests of such long duration are impractical from the regulatory point of view.

- An acute test is a short-term survival determination which involves exposure of a selected test organism, such as fish or water fleas, to a known dilution or concentration of a sample for a specific time period, typically 48 to 96 hours, but occasionally as short as 24 hours.

A number of standard subchronic and acute bioassay tests and organisms are summarized in Table 3.1.

Table 3.1 - Standard Bioassay Tests and Organisms
(Lankford & Eckenfelder, Jr., 1990, p.24)

SUBCHRONIC BIOASSAY TEST		**Test Duration**
Freshwater Organism	• Algae (Selenastrum capricorutum)	4 days
	• Ceriodaphnia dubia	7 days
	• Fathead minnow (Pimephales promelas)	7-9 days
Marine Organism	• Sheepshead minnow	7-9 days
	• Inland silverside	7 days
	• Mysidopsis bahia	7 days
	• Champia parvula	7-9 days
ACUTE BIOASSAY TEST		**Test Duration**
Freshwater Organism	• Bluegill (Lepomis macrochirus)	96 hours
	• Ceriodaphnia dubia	48 hours
	• Water flea (Daphnia magna)	48 hours
	• Daphnia pulex	48 hours
	• Fathead minnow (Pimephales promelas)	96 hours
	• Rainbow trout (Salmo gairdneri)	96 hours
Marine Organism	• Atlantic silverside (Menidia menidia)	48 hours
	• Grass shrimp (Palaemonetes pugio)	48 hours
	• Inland silverside (Menidia beryllina)	48 hours
	• Mysids (Mysidopsis bahia)	48 hours
	• Sheepshead minnow (Cyprinodon variegatus)	48 hours

Lethal concentration 50 percent (LC50) is commonly used to measure whole effluent toxicity without regard to specific chemical compounds that contribute to toxicity (USEPA, 1996, p.59). LC50 represents the volumetric percentage of an effluent in dilution water that causes mortality in 50 percent of the test population.[4] LC50 is also used to measure the aquatic toxicity of a chemical compound in an aqueous solution and is normally expressed in mg/L or ppm.

3.2 MODEL FOR TEXTILE MILL EFFLUENT TOXICITY

For predictive and regulatory purposes it is often necessary to estimate the combined effects of many single chemicals (Nordberg, 1987). It is generally assumed that individual chemicals will interact with each other when they are combined into a mixture. As a result, the effect of the interaction on the toxicity of the mixture can be one of the following three types:

1. Additive effect – the toxicity of a mixture is equal to the sum of the toxicity of its constituents, which act independently of each other.
2. Synergistic effect – a mixture exhibits greater toxicity than the sum of the toxicity of its constituents, which act synergistically with each other.
3. Antagonistic effect – a mixture exhibits less toxicity than the sum of the toxicity of its constituents, which antagonize each other.

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[4] For example, if a population of rainbow trout is exposed to 70% TME and 30% dilution water, and if 50% of the trout die during the specified test period, then the LC50 is 70%. An effluent is not considered acutely lethal if less than 50% of the trout die in 100% effluent (no dilution).

When a number of chemical compounds are combined into a single aqueous stream, as is the case with textile mill effluents, it is necessary to consider whether the toxicity of the stream is greater (synergistic) or less (antagonistic) than the sum of the toxicity of individual compounds. Although these phenomena have been observed in some cases, most effluents have been found to exhibit toxicity equal to the sum of the toxicity of individual compounds (additive) (Lankford & Eckenfelder, Jr., 1990, p.5; Lloyd, 1987). This additive relationship between whole effluent toxicity and toxicity of individual compounds is given by the equation:

$$\frac{100}{C_{LC50-TME}} = \frac{C_A}{C_{LC50-A}} + \frac{C_B}{C_{LC50-B}} + \frac{C_C}{C_{LC50-C}} + \cdots \qquad \text{Equation 1-1a}$$

or

$$\frac{100}{C_{LC50-TME}} = \sum \frac{C_i}{C_{LC50-i}} \qquad \text{Equation 1-1b}$$

where

$C_{LC50\text{-}TME}$ = LC50 of textile mill effluent, %
C_i = concentration of component *i* in effluent (*i = A, B, C, …*), ppm
$C_{LC50\text{-}i}$ = LC50 of component *i* (*i = A, B, …*), ppm

Equation 1-1a can be adopted to estimate textile mill effluent toxicity. Since numerous chemicals are found in textile mill effluents, it is impractical to determine their respective concentrations. However, these chemicals can be divided into several groups and each group can be treated as a pseudo chemical compound or represented by an appropriate toxicity value.

Specifically, the methodology below derives the toxicity of the whole effluent from the toxicity of eight groups:

Group 1: Salts from all processes
Group 2: Nonylphenol ethoxylates (NPEs) surfactants from all processes
Group 3: Non-NPEs surfactants from all processes
Group 4: Phosphates from all processes
Group 5: Dyes from dyeing process
Group 6: Dye carriers from dyeing process
Group 7: Solvents from scouring process
Group 8: Chelating agents from bleaching and scouring processes.

The rationale for selection of these eight groups, and the determination of their toxicity, are explained in Section 3.3.

The textile mill effluent toxicity is then calculated as the sum of these groups. For this purpose, the following equation is proposed based on Equation 1-1a.

$$\frac{100}{C_{LC50-TME}} = \frac{C_{Salts}}{C_{CL50-Salts}} + \frac{C_{Surfactants(NPEs)}}{C_{LC50-Surfactants(NPEs)}} + \frac{C_{Surfactants(non-NPEs)}}{C_{LC50-Surfactants(non-NPEs)}} + \frac{C_{Phosphates}}{C_{LC50-Phosphates}}$$

$$+ \frac{C_{Dyes}}{C_{LC50-Dyes}} + \frac{C_{Carriers(dyeing)}}{C_{LC50-Carriers(dyeing)}} + \frac{C_{Sol(scour)}}{C_{LC50-Sol(scour)}} + \frac{C_{Chelates(bleach/scour)}}{C_{LC50-Chelates(bleach/scour)}}$$

Equation 1-2

where

$C_{LC50\text{-}TME}$: LC50 of whole textile mill effluent, %
$C_{LC50\text{-}Salts}$: LC50 of salts from all processes, ppm
$C_{LC50\text{-}Surfactants(NPEs)}$: LC50 of NPEs surfactants from all processes, ppm
$C_{LC50\text{-}Surfactants(non\text{-}NPEs)}$: LC50 of non-NPEs surfactants from all processes, ppm
$C_{LC50\text{-}Phosphates}$: LC50 of phosphates from all processes, ppm
$C_{LC50\text{-}Dyes}$: LC50 of dyes from dyeing process, ppm
$C_{LC50\text{-}Carriers(dyeing)}$: LC50 of dye carriers from dyeing process, ppm
$C_{LC50\text{-}Sol(scour)}$: LC50 of solvents from scouring, ppm
$C_{LC50\text{-}Chelates(bleach/scour)}$: LC50 of chelating agents from bleaching and scouring, ppm
C_{Salts}: concentration of salts in effluent, ppm
$C_{Surfactants(NPEs)}$: concentration of NPEs surfactants in effluent, ppm
$C_{Surfactants(non\text{-}NPEs)}$: concentration of non-NPEs surfactants in effluent, ppm
$C_{Phosphates}$: concentration of phosphates in effluents, ppm
C_{Dyes}: concentration of dyes in effluent, ppm
$C_{Carriers(dyeing)}$: concentration of dye carriers in effluent, ppm
$C_{Sol(scour)}$: concentration of scouring solvents in effluent, ppm
$C_{Chelates(bleach/scour)}$: concentration of chelating agents in effluent, ppm

In Equation 1-2, the term on the left-hand side is defined as the ***toxic unit of whole effluent***, while each term on the right-hand side is defined as the ***toxic unit of a chemical group***. For example, the term $C_{Salts}/C_{LC50\text{-}Salts}$ represents the toxic unit of salts. Toxic unit provides a measure of the toxicity of a given component or group: the greater a toxic unit, the more toxic (Lankford and Eckenfelder, Jr., 1990, p.87).

3.3 TOXICITY OF SELECTED CHEMICAL GROUPS IN TME

This subsection presents the rationale for selection of the eight chemical groups included in the methodology presented above (Equation 1-2), and derives a base figure for the toxicity of each chemical group.

Selection Criteria

In broad terms, the eight chemical groups selected for inclusion in the model are those that contribute most significantly to effluent toxicity, either because the chemical group is *highly toxic*, or because the group is present in *high concentrations* in the effluents from Canadian mills. The specific rationale for inclusion of each group is provided in the discussion below.

Several other groups of chemicals also influence effluent toxicity, but the contribution of these groups is believed to be small relative to the eight groups included in our model. Accordingly, reductions in effluent concentrations for these other groups is unlikely to have a significant impact on effluent toxicity, compared to the impact of reductions in the eight primary groups. The specific rationale for exclusion of each of these additional groups of chemicals is included in Appendix B.

Determination of Toxicity

For each of the eight chemical groups listed in Subsection 3.2 above, the Lethal Concentration 50 percent (LC50) values have been estimated, as presented in Table 3.2.

Table 3.2 - Toxicity Data of Textile Mill Effluent

Chemical Group	**LC50 (ppm)**
Group 1. Salts from all processes	7802
Group 2. NPEs surfactants from all processes	4.6
Group 3. Non-NPEs surfactants from all processes	4.7
Group 4. Phosphates from all processes	73
Group 5. Dyes from dyeing	6.2
Group 6. Dye carriers from dyeing	2.5
Group 7. Solvents from scouring	4.5
Group 8. Chelating agents from bleaching/scouring	207

The derivation of data for each of these groups is presented in the following discussion. In all cases the focus has been on toxicity data available in the published literature. Due to the more limited availability of data on subchronic toxicity, data on ***acute toxicity*** has been used throughout. Because most textile mill effluents are discharged to a freshwater environment, in all cases data for ***freshwater organisms*** has been used (with priority given to data for freshwater fish species where available).

Because the available data does not provide LC50 for all chemicals using any single organism, it has been necessary to use LC50 data for various different species. As a result, the toxicity data for the different chemical groups is not absolutely comparable. This is considered acceptable for the purpose of this analysis, in view of the fact that data variation between different species is comparable to the variation for the same species. For example, the LC50 data of xylene (CAS No. 1330207) varies from 24580 to 46000 ppm for fathead minnow (pimephales promelas), from 6700 to 25100 ppm for rainbow trout (oncorhynchus mykiss), and from 10400 to 36000 ppm for bluegill (lepomis macrochirus) (data from USEPA web database at http://www.epa.gov/ecotox). The variation (ratio of maximum to minimum) between the three species is 2.2 based on their respective averages, i.e., 35290 ppm for fathead minnow, 15900 ppm for rainbow trout, and 23200 ppm for bluegill. On the other hand, the variation for the same species (ratio of maximum to minimum) is 1.9 for fathead minnow, 3.7 for rainbow trout and 3.5 for bluegill.

In the determination of LC50 for each group, toxicity of the key chemicals in the group has been used. Unless otherwise noted, in each case the proportion of each chemical has been assumed to be equal (e.g. the nine dye carriers used to represent that chemical group are assumed to occur in equal proportions in TMEs). The rationale for this assumption is that it provides a first approximation for a wide range of variation in chemical use by different mills and processes.

Group 1. Salts from All Processes

Salts are viewed as a major source of textile mill effluent toxicity (USEPA, 1996, p.62). The majority of salts present in effluents originate from dyeing. Sodium chloride (NaCl) and sodium sulphate (Na_2SO_4) are the only two salts used to prepare dye baths. Salts can also be produced as neutralization products of alkalis (e.g., sodium hydroxide) and acids (e.g., sulfuric acid, hydrochloric acid), but in much smaller quantities compared to dyeing. Small quantities of salts are also used in other processes such as enzyme desizing (Nettles, 1983, p.382). Based on this information, NaCl and Na_2SO_4 were selected to model the toxicity of salts in effluents.

Toxicity data for sodium chloride and sodium sulphate is given below.

Sodium chloride (NaCl, CAS No.: 7647145)
96-h LC50 toward fathead minnow (pimephales promelas) = 7650 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Sodium sulphate (Na_2SO_4, CAS No.: 7757826):
96-h LC50 toward fathead minnow (pimephales promelas) = 7960 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Assuming the two salts are used in equal proportions, the overall toxicity of salts is determined using Equation 1-1a:

$C_{LC50\text{-}Salts} = 7802$ ppm

Groups 2 and 3. NPE and Non-NPE Surfactants from All Processes

Surfactants are highly toxic and used in almost all textile processes in large quantities. As a result, they contribute greatly to effluent toxicity. These processes include desizing, scouring, mercerizing, bleaching, finishing, and dyeing (USEPA, 1996, p.61). Important surfactants are listed in Table 3.3 (USEPA-12).[5]

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[5] USEPA-12, and similarly formatted references, have been used in this draft report to identify specific documents cited in the bibliography of this report.

Table 3.3 - Surfactants Used in Textile Wet Processing (USEPA-12)

Class	Surfactant	Abbreviation
Nonionic	Nonylphenol ethoxylates	NPEs
	Diethanol cocoamide	DEC
	Linear alcohol ethoxylates	LAE
Anionic	Dodecyl benzene sulfonic acid	DDBSA
	Sodium lauryl sulfate	SLS
	Sulfated ethoxylated alcohol	SEA
	Naphthalene sulfonic acid	NSA
Cationic	Tallow amine ethoxylate	TAE
	Alkyl dimethyl benzyl ammonium chloride	ADBAC

Surfactants are divided into two groups for the purpose of effluent toxicity modelling. The first group is nonylphenol ethoxylates (NPEs) and the second group includes all other surfactants listed in Table 3.3.

The toxicity of NPEs decreases as the ethoxylate chain length increases (Environment Canada and Health Canada, 2000). A nonylphenol ethoxylate with an average chain length was selected to represent NPEs surfactants. NPEs form a homologous series and differ in number of ethoxy units (Potter, et al., 1999). The number of ethoxy units range from 1 to 20 (Lee and Peart, 1995) and 9 units can be considered an approximate average. For example, a commercial nonylphenol ethoxylate surfactant, Lissapol TN 450 supplied by ICI Australia (Melbourne, Australia), has an average of 8.5 ethoxy units (Jones and Westmoreland, 1998). The toxicity of nonylphenol ethoxylate with 9 ethoxy units (NPE9) is given below:

Nonylphenol ethoxylate with 9 ethoxy units (NPE9)
96-h LC50 toward fathead minnow = 4.6 ppm
(source: Potter, et al., 1999)

$C_{\text{LC50-surfactants(NPEs)}} = 4.6$ ppm

The overall toxicity of all other surfactants listed in Table 3.3 is calculated by Equation 1.1a:

$$\frac{C_{surfac\tan ts(non-NPEs)}}{C_{LC50-surfac\tan ts(non-NPEs)}} = \frac{C_{DEC}}{C_{LC50-DEC}} + \frac{C_{LAE}}{C_{LC50-LAE}} + \frac{C_{DDBSA}}{C_{LC50-DDBSA}} + \frac{C_{SLS}}{C_{LC50-SLS}}$$

$$+ \frac{C_{SEA}}{C_{LC50-SEA}} + \frac{C_{NSA}}{C_{LC50-NSA}} + \frac{C_{TAE}}{C_{LC50-TAE}} + \frac{C_{ADBAC}}{C_{LC50-ADBAC}}$$

or

$$\frac{1}{C_{LC50-surfac\tan ts(non-NPEs)}} = \frac{x_{DEC}}{C_{LC50-DEC}} + \frac{x_{LAE}}{C_{LC50-LAE}} + \frac{x_{DDBSA}}{C_{LC50-DDBSA}} + \frac{x_{SLS}}{C_{LC50-SLS}}$$

$$+ \frac{x_{SEA}}{C_{LC50-SEA}} + \frac{x_{NSA}}{C_{LC50-NSA}} + \frac{x_{TAE}}{C_{LC50-TAE}} + \frac{x_{ADBAC}}{C_{LC50-ADBAC}} \quad \text{Equation 1-3}$$

where

$C_{LC50\text{-surfactants(non-NPEs)}}$ = overall LC50 of non-NPEs surfactants, ppm
$C_{LC50\text{-}i}$ = LC50 of surfactant i, ppm
x_i = mass fraction of surfactant i (equal proportions for 8 surfactants)
(i = DEC, LAE, DDBSA, SLS, SEA, NSA, TAE, and ADBAC)

These eight surfactants are assumed to be used on an equal proportion basis, and their LC50 values are provided as follows:

Diethanol cocoamide (DEC)
48-h LC50 toward daphnia pulex = 2 ppm
(source: USEPA-12)

Linear alcohol ethoxylate (LAE)
48-h LC50 toward daphnia pulex = 5 ppm
(source: USEPA-12)

Dodecyl benzene sulfonic acid (DBSA)
48-h LC50 toward daphnia pulex = 20 ppm
(source: USEPA-12)

Sodium lauryl sulfate (SLS)
48-h LC50 toward daphnia pulex = 28 ppm
(source: USEPA-12)

Sulfated ethoxylated alcohol (SEA)
48-h LC50 toward daphnia pulex = 20 ppm
(source: USEPA-12)

Naphthalene sulfonic acid (NSA, CAS No.: 120183)
48-h LC50 toward rainbow trout (oncorhynchus mykiss) = 340 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Tallow amine ethoxylate (TAE, 15 mol E-0)
48-h LC50 toward daphnia pulex = 4 ppm
(source: USEPA-12)

Alkyl dimethyl benzyl ammonium chloride (ADBAC, CAS No.: 61791262)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.6 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Based on the above toxicity data and the equal proportion assumption (i.e., $x_i = 1/8$), the average toxicity of non-NPEs surfactants is determined to be:

$C_{\text{LC50-surfactants(non-NPEs)}} = 4.7$ ppm

Group 4. Phosphates from All Processes

Phosphates are salts or esters of phosphoric acid and form a group of phosphorus-containing chemicals used by wet processing mills. Phosphates are a specific group of pollutants that cause eutrophication of receiving water bodies and can contribute to effluent toxicity if present in high concentration. Phosphate salts are commonly used as bleaching agents as well as buffering agents (Nettles, 1983). Phosphate esters are a class of anionic surfactants. Phosphates are also used as water conditioners and flame retardant finishes (USEPA-12). Common phosphates and their applications are listed in Table 3.4.

Table 3.4 - Common Phosphates Used in Textile Wet Processing (USEPA, 1996, p.92)

Phosphate	Abbreviation	Use
Monosodium phosphate	MSP	Acid salt, pH
Tetrasodium polyphosphate	TSPP	Water conditioner
Trisodium phosphate	TSP	Alkali builder
Hexaphos	HP	Water conditioner
Phosphate esters	PE	Scouring surfactants
Phosphoramides	PA	Flame retardants

Toxicity data was only found for the following three phosphates:

Monosodium phosphate (MSP, CAS No.: 7558807)
96-h LC50 toward western mosquitofish (gambusia affinis) = 186 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Trisodium phosphate (TSP, CAS No.: 7601549)
96-h LC50 toward western mosquitofish (gambusia affinis) = 28.5 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Tetrasodium polyphosphate (TSPP, CAS No.: 7722885)
96-h LC50 toward western mosquitofish (gambusia affinis) = 1380 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

The overall toxicity of the three compounds is therefore used to represent the toxicity of phosphates used in textile wet processing. The LC50 is calculated using Equation 1.1a on an equal proportion basis, yielding:

$C_{LC50\text{-}phosphates} = 73$ ppm

Group 5. Dyes Discharged from Dyeing

Although most textile dyes exhibit low aquatic toxicity, some are highly toxic. As a result, dyes as a group are a significant contributor to effluent toxicity (USEPA, 1996, p.60). A study of 46 commercially important dyes showed that 29 dyes had very low aquatic toxicity (LC50 greater than 180 ppm) on fathead minnow (pimephales promelas) in 96-hour static bioassay tests, and 10 dyes exhibited high toxicity at LC50 under 10 ppm. The complete test results of the 46 dyes are presented in Table 3.5. A more extensive study of 3000 dyes also arrived at the same conclusion and found that only 3% of the 3000 dyes investigated had an LC50 to fish under 10 ppm and about 60% had an LC50 above 100 ppm (Clarke and Anliker, 1984).

The overall toxicity of dyes is determined in two steps. In the first step, dyes are grouped into seven types: sulphur, disperse, vat, acid, direct, basic, and reactive. The average toxicity for each type (except for reactive dyes) is computed using the test results presented in Table 3.5 and Eq.1.1a, i.e.:

$$\frac{C_{dye}}{C_{LC50-dye}} = \frac{C_{dye1}}{C_{LC50-dye1}} + \frac{C_{dye2}}{C_{LC50-dye2}} + \frac{C_{dye3}}{C_{LC50-dye3}} + \cdots$$

or

$$\frac{1}{C_{LC50-dye}} = \frac{x_{dye1}}{C_{LC50-dye1}} + \frac{x_{dye2}}{C_{LC50-dye2}} + \frac{x_{dye3}}{C_{LC50-dye3}} + \cdots$$

or

$$\frac{1}{C_{LC50-dye}} = \sum \frac{x_{dyei}}{C_{LC50-dyei}}$$

where

$C_{LC50\text{-}dye}$:	overall LC50 of dyes
x_{dyei}:	mass fraction of dye i
$C_{LC50\text{-}dyei}$:	LC50 of dye i

In the calculation, the dyes of each type are assumed in equal proportions (i.e., $x_{dye1} = x_{dye2} = x_{dye3} = \cdots$). In addition, all dyes with relatively low acute toxicity (LC50 >180 mg/l) have been assigned an LC50 value of 180 mg/l. This introduces a small conservative bias into the analysis.

Table 3.5 - 96-hour LC50 of Commercial Dyes Toward Fathead Minnow (Pimephales Promelas) (USEPA, 1996, p.60)

Dye Type	**C.I. Number**	**Dye**	**96-hour LC50 (mg/L)**
Sulphur	53185	Sulfur Black 1	>180
Disperse	10338	Disperse Yellow 42	>180
	11855	Disperse Yellow 3	>180
	47020	Disperse Yellow 54	>180
	61505	Disperse Blue 3	1
	62500	Disperse Blue 7	52
	Not available	Disperse Red 60	>180
Vat	53630	Vat Blue 43	>180
	59105	Vat Orange 1	>180
	59825	Vat Green 1	>180
	67300	Vat Yellow 2	>180
	69015	Vat Brown 3	>180
	69500	Vat Green 3	>180
	69825	Vat Blue 6	>180
Acid	15510	Acid Orange 7	165
	15711	Acid Black 52	7
	18965	Acid Yellow 17	>180
	20170	Acid Orange 24	130
	20470	Acid Black 1	>180
	25135	Acid Yellow 38	23
	26360	Acid Blue 113	4
	61570	Acid Green 25	6.2
	62055	Acid Blue 25	12
	63010	Acid Blue 45	>180
	Not available	Acid Yellow 151	29
Direct	19555	Direct Yellow 28	>180
	22610	Direct Blue 6	>180
	24401	Direct Blue 218	>180
	24890	Direct Yellow 4	>180
	24895	Direct Yellow 12	125
	28160	Direct Red 81	>180
	29025	Direct Yellow 50	>180
	29160	Direct Red 23	>180
	20145 or 30145	Direct Brown 95	>180
	30235	Direct Black 38	>180
	31600	Direct Black 80	>180
	40000	Direct Yellow 11	>180
	74180	Direct Blue 86	>180
	Not available	Direct Yellow 106	>180
Basic	21010	Basic Brown 4	5.6
	42000	Basic Green 4	0.12
	42535	Basic Violet 1	0.047
	48055	Basic Yellow 11	3.2
	51005	Basic Blue 3	4
Other	14645	Mordant Black 11	6
	40622	Fluorescent Brightening Agent 28	>180

For reactive dyes, no toxicity data is available for seven commonly used reactive dyes, so a different methodology is required. LC50 is assumed to be the same as the average for over 3000 dyes reported by Clarke and Anliker (1984). This is estimated to be 62.3 ppm from Eq.1-1a, with 3% of dyes exhibiting an LC50 under 10 ppm (assume an average of 5 ppm), 37% between 10 and 100 ppm (assume an average of 55), and 60% over 100 ppm (assume an average of 180 ppm).

The results of the first step calculation are presented in the second column (LC50) of Table 3.6.

Table 3.6 - Calculation for Overall Toxicity of Dyes

Dye	LC50 (ppm)	Quantity* (tonne/year)	Percentage (%)
Sulphur	180	720	18.9%
Disperse	5.8	865	22.8%
Vat	180	165	4.3%
Acid	14.8	400	10.5%
Direct	174.5	330	8.7%
Basic	0.16	65	1.7%
Reactive	62.3	1255	33.0%
Total		3800	100%

* Fintex, 2001

In the second step, the overall toxicity of the seven types is computed from the same equation as in the first step. The fraction of each type is determined and presented in the last two columns of Table 3.6, based on recent consumption quantities (Fintex, 2001). The overall toxicity of dyes is determined to be:

$C_{LC50\text{-dyes}} = 6.2$ ppm

Group 6. Dye Carriers Discharged from Dyeing

Dye carriers are used to accelerate the rate of dyeing. They are organic substances and most of them are relatively insoluble in water and therefore supplied as self-emulsifiable liquids (Datye and Vaidya, 1984, p.194). Dye carriers are highly toxic. Toxic components contained in twelve common dye carriers were identified in a study conducted by North Carolina Department of Environment, Health and Resources in the U.S. and listed below (USEPA-13):

Biphenyl
1,2-dichlorobenzene
Naphthalene
1,2,4-trichlorobenzene
2-methylnaphthalene
Perchloroethylene
4-chlorotoluene
Ethylbenzene
Methyl benzoate

Methyl p-toluate (methyl m-methylbenzoate)
1,4-dimethyl naphthalene
p-xylene
m-xylene
Butyl benzoate
Dimethyl phthalate
o-phenyl phenol
Diphenylether
Benzyl benzoate

Toxicity data was only found for the following components:

1,1’-biphenyl (CAS No.: 92524)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.5 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

1,2-dichlorobenzene (CAS No.: 95501)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.6 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Naphthalene (CAS No.: 91203)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

1,2,4-trichlorobenzene (CAS No.: 120821)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.5 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

2-methylnaphthalene (CAS No.: 91576)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.5 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Perchlorethylene (tetrachloroethylene, CAS No.: 127184)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 5.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

1-chloro-4-methylbenzene (4-chlorotoluene, CAS No.: 106434)
96-h LC50 toward harpacticoid copepod (nitocra spinipes) = 11.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Ethyl benzene (CAS No.: 100414)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 14.0 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Xylene (CAS No.: 1330207)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 8.2 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

The overall toxicity of the above nine chemicals is therefore used to represent the toxicity of dye carriers. LC50 is calculated using Eq. 1.1a on an equal proportion basis, yielding:

$C_{LC50\text{-carriers(dyeing)}} = 2.5$ ppm

Group 7. Solvents Discharged from Scouring

Solvent emulsions used in scouring contain many chlorinated solvents that have been identified as an important source of toxic chlorinated organic compounds in effluents (USEPA, 1996, p.58-62). They are toxic in nature. The following compounds have been found in solvent emulsions (USEPA, 1996, p.93; USEPA, 1979, p.153; Nettles, 1983, p.389; Carr, 1995, p.70) and, therefore, have been selected to represent solvents used in scouring:

Benzene
Chlorotoluene (1-chlor-4-methylbenzene)
Ortho-dichlorobenzene (1,2-dichlorobenzene)
Perchloroethylene (tetrachlorethylene)
Xylene.

Toxicity data for the above substances is given below:

Benzene (1,2,4-trichlorobenzene, CAS No.: 120821)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 9.2 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Chlorotoluene (1-chloro-4-methylbenzene, CAS No.: 106434)
96-h LC50 toward harpacticoid copepod (nitocra spinipes) = 11.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Ortho-dichlorobenzene (1,2-dichlorobenzene, CAS No.: 95501)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 1.6 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Perchlorethylene (tetrachloroethylene, CAS No.: 127184)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 5.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Xylene (CAS No.: 1330207)
96-h LC50 toward rainbow trout (oncorhynchus mykiss) = 8.2 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

The overall toxicity of the above five substances is used to represent the toxicity of solvents used in scouring. LC50 is calculated using Eq.1.1a on an equal proportion basis, yielding:

$C_{LC50\text{-}Sol(scour)} = 4.5$ ppm

Group 8. Chelating Agents Discharged from Bleaching and Scouring

Chelating agents are the major group of additives used in bleaching. They can be used in large quantities and are therefore considered as a contributor to effluent toxicity. Other additives include defoamers and antiredeposition agents (Olson, 1983; Carr, 1995; Nettles, 1983; Adanur, 1995). Chelating agents are also used in scouring (Nettles, 1983, p.387). Common chelating agents are ethylene diamine tetraacetic acid (EDTA), diethylene triamine pentaacetic acid (DTPA), and N-(2-hydroxyethyl)ethylenediamine triacetic acid (HEDTA). They can be obtained from Dow Chemical in the following forms (http://www.dow.com/products_services/):

Ethylenediaminetetraacetic acid
(H4EDTA, CAS No.: 60004)
Tetrasodium salt of ethylenediaminetetraacetic acid
(Na4EDTA, CAS No.: 64028)
Diammonium salt of ethylenediaminetetraacetic acid
((NH4)2EDTA), CAS No.: 20824560)
Pentasodium salt of diethylenetriaminepentaacetic acid
(Na5DTPA, CAS No.: 140012)
Diethylenetriaminepentaacetic acid
(DTPA acid, CAS No.: 67436)
Trisodium salt of N-(hydroxyethyl)-ethylenediaminetriacetic acid
(Na3HEDTA, CAS No.: 139899, no toxicity data available)

Toxicity data for these chelating agents is given below (except for Na3HEDTA):

Ethylenediaminetetraacetic acid (H4EDTA, CAS No.: 60004)
96-h LC50 toward fathead minnow (pimephales promelas) = 59.8 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Tetrasodium salt of ethylenediaminetetraacetic acid (H4EDTA, CAS No.: 64028)
96-h LC50 toward bluegill (lepomis macrochirus) = 486 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Diammonium salt of ethylenediaminetetraacetic acid
((NH4)2EDTA, CAS No.: 20824560)
96-h LC50 toward bluegill (lepomis macrochirus) = 2340 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Pentasodium salt of diethylenetriaminepentaacetic acid (Na5DTPA, CAS No.: 140012)
96-h LC50 toward bluegill (lepomis macrochirus) = 1115 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

Diethylenetriaminepentaacetic acid
(DTPA acid, CAS No.: 67436)
48-h LC50 toward water flea (daphnia carinata) = 245 ppm
(source: a USEPA web database at http://www.epa.gov/ecotox)

The overall toxicity of the above five substances is used to represent the toxicity of chelating agents used in bleaching and scouring. LC50 is calculated using Equation 1.1a on an equal proportion basis, yielding:

$C_{\text{LC50-Chelates(bleach/scour)}}$ = 207 ppm

Summary of Effluent Toxicity Model

Figure 3.1 presents a graphic summary of the effluent toxicity model, as discussed in the preceding pages.

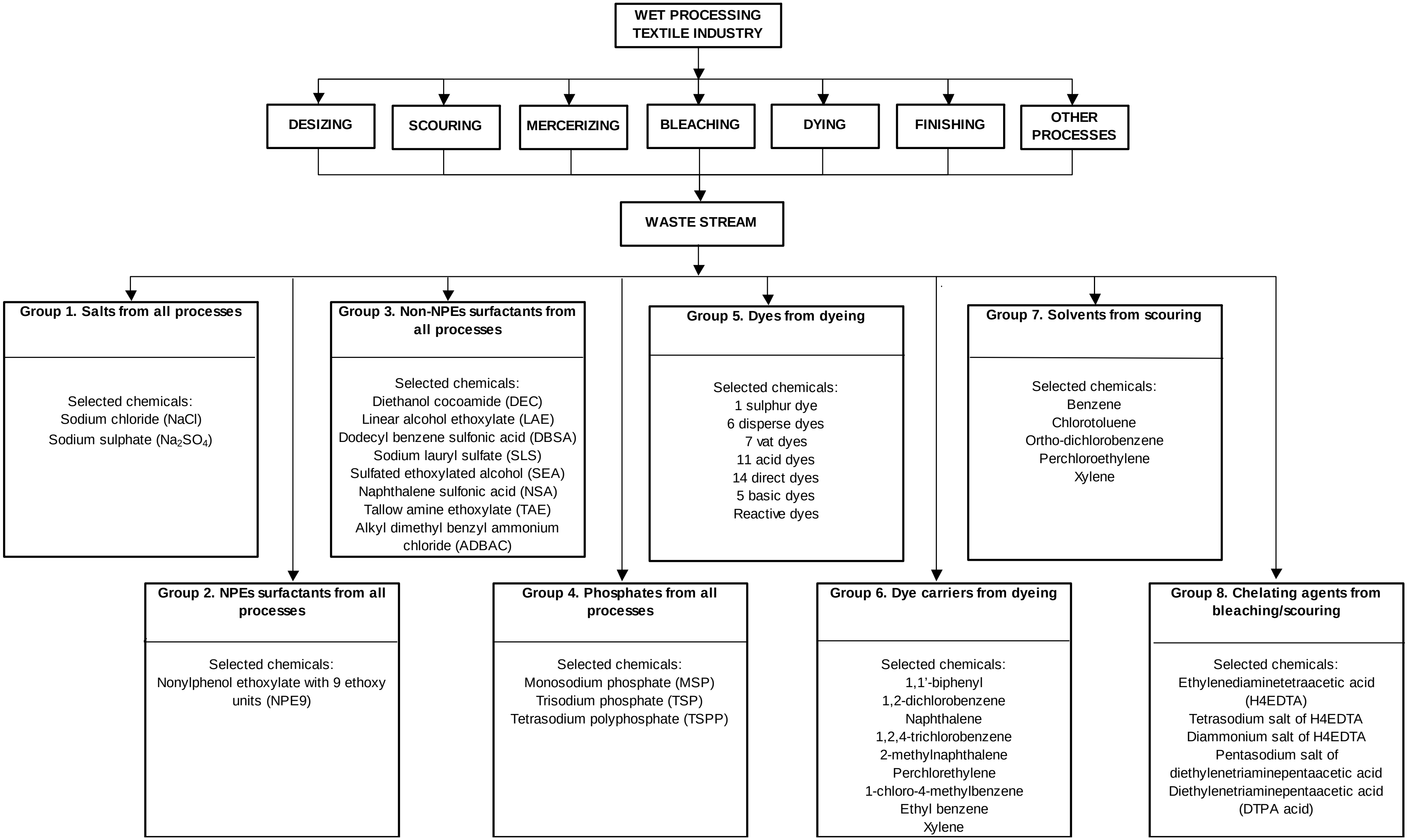
As illustrated in the figure, the industry typically includes a number of operations (desizing, scouring, bleaching, etc.) that contribute to the waste streams discharged as effluent.

For the purpose of toxicity modelling, this waste stream is subdivided into the eight chemical groups presented in the figure.

Each group, in turn, is represented by a selected group of chemicals, for which toxicity is known.

Based on this representation of the industry effluents, and on concentration data discussed in the next subsection, whole effluent toxicity can be modelled (including, in particular, the expected impact of individual BATEA on toxicity).

Figure 3.1 – Characterization of Effluent Toxicity (for Toxicity Model)



3.4 CONCENTRATION OF SELECTED CHEMICAL GROUPS IN TME

The effluent toxicity correlation (Equation 1-2) is based on the toxicity and concentration of eight groups of chemicals in textile mill effluents. The toxicity was presented above in Subsection 3.3, and typical concentrations are presented in this Subsection.

In summary form, typical concentrations for each chemical group are listed in Table 3.7. Following the table, the text describes the basis for the concentrations included in the Table.

Table 3.7 - Concentration Data for Textile Mill Effluents

Chemical Group	Concentration (ppm)
Group 1. Salts from all processes	1401
Group 2. NPEs surfactants from all processes	4.1
Group 3. Non-NPEs surfactants from all processes	28.8
Group 4. Phosphates from all processes	5.2
Group 5. Dyes from dyeing	16.8
Group 6. Dye carriers from dyeing	2.9
Group 7. Solvents from scouring	3.8
Group 8. Chelating agents from bleaching/scouring	120

Note that the concentrations presented in Table 3.7, and discussed below, are used for the purpose of ***model validation only.*** The analysis presented elsewhere in this report is based on more detailed conceentration data derived at the segment level (knit, woven, yarn, carpet and wool).

Group 1: Salts from All Processes

The average salt concentration for the Canadian wet processing industry as a whole was determined as a weighted average over five segments. These segments are knit, woven, stock/yarn, carpet and wool. The salt concentration for each segment has been estimated by Fintex (see Section 5) and is summarized in Table 3.8. The wastewater generation from each segment has also been estimated by Fintex based on Environment Canada 1997/98 survey data, and is presented in Table 3.8. Based on these values, the average salt concentration is determined to be C_{Salts} = 1,401 ppm.

Table 3.8 - Determination of Average Salt Concentration

Segment	Salt Concentration ppm	Wastewater	
		million m^3/y	percentage
Knit	1572	17.13	50.7%
Woven	2041	9.19	27.2%
Stock/yarn	650	2.55	7.6%
Carpet	0	3.35	9.9%
Wool	0	1.56	4.6%
Total (weighted average)	1401		

Group 2. NPE Surfactants from All Processes

As part of the ecological risk assessment of nonylphenol and its ethoxylates (NPEs), samples of untreated textile mill effluents were collected at a number of textile mills. The results are presented in the *Supporting Document for Textile Mill Effluents* (Environment Canada, 2000, Appendix C), and presented in Table 3.9. As shown, the sum of NPEs with 1 to 17 ethoxylate units had an average concentration of 4.1 ppm. This value is used as a representative concentration of NPEs, i.e., $C_{Surfactants(NPEs)}$ = 4.1 ppm.

Table 3.9 - Measured Concentration of NPEs in Untreated Effluent (Environment Canada 2000)

Textile Mill	**Concentration in micrograms/litre**		
	NP3-17EO	**NP1EO**	**NP2EO**
Company #1 (3 samples)	8167	101.0	140.5
	96	254.0	583.4
	189	213.0	479.0
Company #2 (2 samples)	8	0.2	0.2
	853	1241.0	0.0
Company #3 (2 samples)	210	5.4	11.8
	189	17.7	39.3
Company #4 (1 sample)	2040	36.4	36.6
Company #5 (2 samples)	1409	14.1	128.3
	3271	35.0	241.1
Company #6 (3 samples)	7905	92.8	487.0
	8811	57.9	506.0
	29600	114.0	1090.0
Company #7 (1 sample)	7090	114.0	43.8
Company #8 (2 samples)	4162	65.1	218.7
	4834	51.5	233.6
Company #9 (2 samples)	4567	69.2	252.3
	3436	25.6	171.3
Company #10 (1 sample)	271	9.0	7.3
Company #11 (3 samples)	1828	14.7	31.6
	1459	8.7	27.8
	2559	8.8	27.0
Company #12 (3 samples)	320	1.5	1.0
	50	2.3	2.3
	148	0.7	0.6
Company #13 (2 samples)	6846	18.1	204.5
	5768	39.7	276.4
Company #14 (2 samples)	3987	21.2	54.6
	1286	13.6	70.2
Average concentration	3840	91.3	185.0
Average concentration in ppm	3.8	0.1	0.2
Average concentration NP1-17 EO in ppm	4.1		

Group 3. Non-NPEs Surfactants from All Processes

The average concentration for non-NPE surfactants for the Canadian wet processing industry as a whole was determined as a weighted average over five segments. These segments are knit, woven, stock/yarn, carpet and wool. The non-NPE surfactant concentration for each segment has been estimated by Fintex (see Section 5) and is summarized in Table 3.10. The wastewater generation from each segment has also been estimated by Fintex based on Environment Canada 1997/98 survey data, and is presented in Table 3.10. Based on these values, the average non-NPEs concentration is determined to be $C_{\text{surfactants (non-NPEs)}}$ = 28.8 ppm.

Table 3.10 - Determination of Average Concentration of Non-NPE Surfactants

Segment	Non-NPEs ppm	Wastewater	
		million m^3/y	percentage
Knit	15.3	17.13	50.7%
Woven	56.0	9.19	27.2%
Stock/yarn	16.6	2.55	7.6%
Carpet	29.7	3.35	9.9%
Wool	36.0	1.56	4.6%
Total (weighted average)	28.8		

Group 4. Phosphates from All Processes

The concentration of phosphates in textile mill effluents was determined from the concentration of phosphorus. A 1997 Environment Canada/Canadian Textiles Institute voluntary survey reports phosphorus concentration in the range of 0.34 to 9.98 ppm for untreated effluents from 26 textile mills (Environment Canada and Health Canada, 2000). Assuming the phosphorus content reported in the survey is expressed as phosphates, the average is used as a representative concentration of phosphates, i.e., $C_{\text{Phosphates}}$ = 5.2 ppm.

Group 5. Dyes Discharged from Dyeing

The concentration of dyes in effluents was calculated according to the following three variables for the Canadian wet processing industry: 1) the total effluent generation, 2) the total consumption of dyes, and 3) fraction of dyes lost to effluent. The total effluent generation was determined at 37.9 million tonnes per year based on Environment Canada 1997/98 survey results (Crechem, 2000). The total consumption of dyes was estimated to be 3,800 tonnes per year and the fraction of dyes lost to effluent was estimated at 16.8% (Fintex, based on analysis in Section 5). Based on these three variables, the concentration of dyes in effluents is determined to be C_{Dyes} = 16.8 ppm. This is within the range of 10 to 60 ppm found in many reports (O'Neill et al., 1999).

Group 6. Dye Carriers Discharged from Dyeing

The concentration of dye carriers in effluents was calculated based on the total effluent generation and the total use of dye carriers for the Canadian wet processing industry. As noted above, the total effluent generation was determined at 37.9 million tonnes per year based on Environment Canada 1997/98 survey results (Crechem, 2000). Also based on based on

Environment Canada 1997/98 survey results, the total quantity of fabric dyed by the Canadian textile wet processing industry was determined at 264.2 million kg per year. This would translate into the total use of dye carriers at 111 tonnes per year, assuming the ratio of carriers to dyes remains 2.1:100 for the whole industry, based on Environment Canada/IEC survey data of six textile mills (IEC, 1982), and assuming 2 kg of dye is required for every 100 kg of fabric (Cai et al., 1990; Rucher & Gutherie, 1997; Schramm & Jantschgi, 1999). Based on these values, the concentration of dye carriers in effluents is determined to be $C_{\text{Carriers(dyeing)}}$ = 2.9 ppm, assuming all carriers are lost to effluents.

Group 7. Solvents Discharged from Scouring

The concentration of solvents in effluents was calculated based on the following three parameters for the Canadian wet processing industry: 1) the total effluent generation; 2) the total use of solvents; and 3) the fraction solvents discharged to effluents. As noted above, the total effluent generation was determined at 37.9 million tonnes per year from Environment Canada 1997/98 survey results (Crechem, 2000). Also from Environment Canada 1997/98 survey results, the total quantity of fabric scoured was determined at 65.7 million kg per year. These would translate into 197.1 million kg of scouring liquor that is picked up by textile materials, washed off, and then discharged to effluents, assuming textile materials themselves inherently take up an average of 3 times their weight in water (USEPA, 1996, p.184).

In general, scouring liquor contains about 22% solvents (Nettles, 1983, p.389). As a result, the total solvents consumed by the industry is estimated at 43,362 tonnes per year. The fraction of solvents discharged to effluents is estimated to be 0.33% according to a USEPA textile industry survey which reported 1669 pounds of xylene released to effluents and 505,752 pounds to atmosphere out of 507,421 pounds used in 1996 (USEPA-4). The concentration of solvents in effluents is therefore estimated to be $C_{\text{Sol(scour)}}$ = 3.8 ppm. This is in line with the combined concentration of three solvent compounds (benzene, 1,2-chlorobenzene and perchloroethylene), which was measured at U.S. mills in the range of 0.01 ppm to 2.6 ppm (USEPA, 1979, p.131).

Group 8. Chelating Agents Discharged from Bleaching and Scouring

The concentration of chelating agents in effluents was calculated based on the total effluent generation for the Canadian wet processing industry and total use of chelating agents. As noted above, the total effluent generation was determined at 37.9 million tonnes per year from Environment Canada 1997/98 survey results (Crechem, 2000). Also from Environment Canada 1997/98 survey results, the total quantity of fabric bleached by the industry was determined at 205 million kg per year and the total quantity of fabric scoured at 65.7 million kg per year. These figures would translate into 615 million kg of bleaching liquor and 197.1 million kg of scouring liquor that are picked up by textile materials, washed off, and then discharged to effluents, assuming textile materials themselves inherently take up an average of 3 times their weight in water (USEPA, 1996, p.184). In general, bleaching liquor contains 0.1% chelating agents (Carr, 1995, p.80-87; Nettles, 1983, p.396) and scouring liquor contains 2% (Nettles, 1983, p.387). The total chelating agents consumed by the industry is then estimated at 4,557 tonnes per year. The concentration of chelating agents in effluents is determined to be $C_{\text{Chelates(bleach/scour)}}$ = 120 ppm.

3.5 VALIDATION OF EFFLUENT TOXICITY MODEL

To validate the effluent toxicity model, it is necessary to:

1. Use the model to estimate the toxicity of typical textile mill effluents in Canada
2. Compare the estimate with measured toxicity of Canadian TMEs.

The estimated toxicity of textile mill effluents in Canada is presented in Table 3.11, based on the data derived in Subsection 3.3 and 3.4. The toxicity for each chemical group is expressed in terms of ***toxic unit***, which is the concentration (from Subsection 3.4) divided by the LC50 toxicity (from Subsection 3.3).

Table 3.11 shows that the most toxic group (highest number of toxic units) is the non-NPE surfactants. The phosphates group is least toxic.

Using Equation 1.2, the toxicity of whole effluent is determined to be 12.56 toxic units. This is equivalent to an LC50 of 8.0% for the whole TME effluent.

Table 3.11 - Toxicity Data of Textile Mill Effluent

Chemical Group	Concentration (ppm)	LC50 (ppm)	Toxic Units
Group 1. Salts from all processes	1401	7802	0.18
Group 2. NPEs surfactants from all processes	4.1	4.6	0.89
Group 3. Non-NPEs surfactants from all processes	28.8	4.7	6.13
Group 4. Phosphates from all processes	5.2	73	0.07
Group 5. Dyes from dyeing	16.8	6.2	2.72
Group 6. Dye carriers from dyeing	2.9	2.5	1.16
Group 7. Solvents from scouring	3.8	4.5	0.84
Group 8. Chelating agents from bleaching/scouring	120	207	0.58
Total			12.56

The calculated whole effluent LC50 (8.0%) is within the range reported in the literature. In support of Environment Canada's risk assessment of textile mill effluents, untreated effluents discharged from 14 mills were sampled and tested for toxicity toward rainbow trout (oncorhynchus mykiss) (Environment Canada and Health Canada, 2000). These mills involved wet processing of woven, knit, wool, stock/yarn or carpet. The test results of 24 samples obtained from the 14 mills showed that the 96-hour LC50 of untreated effluents ranged from 3.90% to 71.0% with a median of 17.7% and a mean of 24.4%. ***This is comparable with the estimated toxicity derived from the model, and confirms that the model provides credible estimates of whole effluent toxicity.***

As further validation, estimates of toxicity of *treated* effluents can be derived based on the model, and these estimates can be compared to measured toxicity. In Section 4 of this report, the model is used to calculate the toxicity reduction associated with BATEA #12: Biological Wastewater Treatment (secondary treatment). The reductions range from 83% to 85%, depending on segment.[6] Assuming 83% reduction, the whole effluent toxicity of untreated effluent would be reduced from 12.56 toxic units (Table 3.11) to 2.14 toxic units through biological wastewater treatment (reduction by a factor of 5.9).

This figure represents the expected toxicity assuming secondary treatment only, and does not yet account for toxicity reductions associated with initial primary treatment. The impact of primary treatment has not been assessed using the model, but data reported by Environment Canada (2000) showed that the 96-h LC50 for untreated textile mill effluents ranged from 3.9% to 71.0% (median 17.7%, mean 24.4%, 14 sites), while that for the primary-treated effluents ranged from 18.0% to >100% (median 75.0%, mean 65.9%, 2 sites). For purposes of model validation, if it is assumed that toxicity is reduced by a factor of 2.5 through primary treatment, and that secondary treatment further reduces toxicity by a factor of 5.9 as above, then the final effluent would have an LC50 of >100% (0.85 toxic units).[7] ***This is in line with the data reported by Environment Canada (2000) which showed LC50 of secondary-treated effluents in the range of 80.0% to >100% (median 100%, mean 97.5%, 6 sites).***

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[6] These figures represent the reduction achievable at a “typical” textile mill in each segment, derived from the segment reduction figures in Table B12.2 and the percentage of affected plants in Table B12.1.

[7] This assumes 12.56 toxic units for untreated, 5.02 toxic units for primary-treated (reduction by a factor of 2.5), and 0.85 toxic units for secondary-treated (reduction by a factor of 5.9).

4. BEST AVAILABLE TECHNOLOGIES ECONOMICALLY ACHIEVABLE

This section provides detailed information on a range of technologies and practices, each with potential to reduce effluent toxicity. Specifically, this section addresses twelve technologies/ practices falling into eight categories:

Optimization of Chemical Use	BATEA #1: Automated Chemical Dosing Systems BATEA #2: Dye Machine Controllers
Chemical Substitution	BATEA #3: NPE Surfactant Substitution BATEA #4: Dye Substitution
Advanced Dyeing	BATEA #5: Low Liquor Ratio Dyeing Machines BATEA #6: Cold Pad Batch Dyeing
Improved Quality Control	BATEA #7: Quality Control for Raw Materials
Process Alternatives	BATEA #8: Pulsating Rinse Technology
Water Recycling and Reuse	BATEA #9: Recycling and Reuse of Cooling Water and Condensate Water BATEA #10: Bleach Bath Recovery System
Chemical Recovery and Reuse	BATEA #11: Salt Bath Recovery System
Wastewater Treatment Processes	BATEA #12: Biological Wastewater Treatment

For convenience, these technologies have been labelled as BATEA 1 through 12.[8] The first 11 BATEA are pollution prevention options, while BATEA 12 is a pollution control technology.

The criteria used to select the twelve BATEA for analysis were as follows:

- Does the technology have significant impact on effluent toxicity, conventional pollutants, and/or wastewater volume?
- Does the technology have significant potential application in the Canadian industry (excluding technologies already widely adopted in Canada)?
- Does past experience indicate potential for successful application (with respect to pollution reduction and/or economic return)?

In addition to consideration of these criteria, technologies were deliberately selected from each of the broad categories listed above, in order to illustrate a range of technical options.

It must be emphasized that the BATEA presented here are only a subset of the technologies/practices that are available to the textile industry. These twelve BATEA are representative of the various alternatives that can contribute to reduced effluent, but other options also warrant consideration by individual textile mills. **Section 7 provides an overview of a wide range of additional technologies.**

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[8] Pending completion of detailed analysis, the use of BATEA terminology to describe any individual technology/practice should be considered preliminary.

Presentation of the BATEA

The balance of this section presents information for each of the twelve selected BATEA, using a standardized format as follows:

- **Description:** An overview of the BATEA, based on both literature review and direct industry experience.
- **Current Application in Canada (Benchmark):** The current extent of application of the BATEA in Canada, based on benchmarking by the project team (further details below).
- **Achievable Effluent Quality:** The estimated changes in effluent quality that can be achieved through application of the BATEA in Canadian industry (effluent volume, toxicity, NPEs, BOD, COD, and TSS).
- **Other Environmental Benefits:** Discussion of any significant additional environmental benefits associated with the BATEA.
- **Costs:** Estimated capital costs, operating costs/savings, and payback at the plant level, plus capital cost, annualized savings, and net present value at the sector/segment level.
- **Case Study:** Overview of case studies concerning the technology (or closely related technologies), based on the literature review.
- **Other Comments:** Additional relevant information (as appropriate).

Benchmarking Methodology

An important element of each of the BATEA descriptions is the section on *Current Application in Canada (Benchmark)*. Benchmarking is a valuable tool for measuring and improving the performance of a company or industry.

To determine current and potential application of the BATEA in the Canadian industry, information was sourced from manufacturers (American and Canadian), chemical suppliers, and textile industry end-users. Fintex Inc. has established relations with machinery manufacturers, chemical suppliers and textile companies worldwide, and has used its knowledge and these contacts to benchmark actual usage in the Canadian industry. We have also sourced the databases of the Canadian Association of Textile Colorists and Chemists, Textile Society of Canada, Institute of Textile Science, Centre des Technologies Textiles, and American Association of Textile Chemists and Colorists. In addition, we have reviewed key literature, including the *Assessment Report: Textile Mill Effluents* (Environment Canada and Health Canada 2000) and the Textile Mill Database (Environment Canada 1999).

As part of the benchmarking process, the project team developed a profile of the Wet Processing Textile Industry in Canada. This profile, presented below, was derived from the Environment Canada database. ***It is important to note that this profile differs somewhat from the data used in the "Priority Substances List Assessment Report: Textile Mill Effluents", as reproduced in Section 2.2 of this report.*** The differences arise for several reasons. First, limited data is provided for some mills in the database. Rather than rely on extrapolations, we have excluded these mills from our profile. In addition, based on our knowledge of the industry, we have been able to re-categorize some mills, and to reflect recent changes in the industry (such as closure of plants).

Based on these adjustments, our benchmarking considers 129 wet processing mills operating in Canada. Tables 4.1 and 4.2 present a breakdown of mill type and production by segment:

Table 4.1 – Benchmarking Profile: Wet Processing Textile Mills by Segment

Mill type	Number of mills	Percentage
Knit fabric finishing	62	48%
Woven fabric finishing	30	23%
Stock/yarn finishing	14	11%
Carpet finishing	8	6%
Wool finishing	6	5%
Non-woven fabric finishing	9	7%
Total	**129**	**100%**

Table 4.2 – Benchmarking Profile: Wet Processing Textile Production by Segment

Mill type	Production (tonnes/year)
Knit fabric finishing	95,700
Woven fabric finishing	99,200
Stock/yarn finishing	20,200
Carpet finishing	47,500
Wool finishing	7,200
Non-woven fabric finishing	19,600
Total	**289,400**

Achievable Effluent Quality and Cost Methodology

The data provided on achievable effluent quality and cost for each BATEA is a summary of more detailed information presented in Sections 5 and 6 of this report. Information on the methodology used to derive this data is included in these sections of the report.

Non-woven Fabric Finishing

Achievable effluent quality has not been estimated for the non-wovens finishing industry, because the categories of product manufactured generally do not involve wet processes (except for cooling water). Our analysis of the Textile Mill Database (Environment Canada 1999), and information from machinery and chemical suppliers, indicates that this industry uses only 200 m^3 of water per day. Furthermore, it appears that this segment generates less than 0.1% of total TMEs, and the water released does not typically carry a significant pollutant load. We examined in particular the issue of solvent use in the non-wovens segment, and established that such solvents enter the environment primarily through air emissions from drying ovens. Based on these findings, analysis of toxicity impacts has not been undertaken for the non-wovens segment.

BATEA #1: AUTOMATED CHEMICAL DOSING SYSTEMS

DESCRIPTION

Automated chemical dosing systems can deliver the right amount of the right chemical at just the right time (USEPA-5, p.85), particularly with respect to liquid chemicals used in dyeing and finishing. These systems reduce the tendency to overuse environmentally harmful chemicals and, therefore, reduce pollutant loads of discharged effluents. They also reduce handling loss and equipment cleanup. In addition, they improve the efficiency and reliability of chemical reactions in the dyebath, ensuring consistent and reproducible results. Automated dosing systems are commercially available and are being adopted by the textile industry. They have been recognized as a pollution prevention option (USEPA-2).

This technology is suitable for all segments within the wet processing textile industry. It reduces chemical usage (excluding dyes) by at least ten (10) per cent. It also reduces labour and overhead costs, increases production, and eliminates the manual handling of chemicals.

CURRENT APPLICATION IN CANADA (BENCHMARK)

As shown in Table B1.1, fifteen (15) Automated Chemical Dosing Systems are presently installed in Canada. Fourteen (14) of the units are utilized in the Knit Fabric Finishing Industry, and one (1) unit is installed in the Stock /Yarn Finishing Industry.

Table B1.1 - Automated Chemical Dosing System Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of plants in the industry	62	30	14	8	6	9
Number of units installed	14	0	1	0	0	0
Plants with automatic chemical dosing systems (% of plants)	23%	0%	7%	0%	0%	0%
Future additional potential for automated chemical dosing systems (% of plants)	32%	67%	71%	75%	67%	33%

As indicated in Table B1.1, future additional potential for automated chemical dosing systems is estimated to range from 32% of plants in the knit segment to 75% of plants in the carpet segment. This potential includes all plants where these systems are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B1.2 presents the improvement in effluent quality that is achievable through application of automated chemical dosing systems.

The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B1.1)*.

As shown in the table, automated chemical dosing systems have no impact on effluent volume. Effluent toxicity from the industry as a whole would be reduced by 2.4-6%, depending on the segment, and average NPE concentrations in industry effluents would be reduced by 3.2-7.6%, again depending on the segment. Industry wide, BOD and COD would be reduced by 375 and 1423 tonnes per year respectively.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B1.2 - Automated Chemical Dosing System: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	179	93	126	71	216	
	% Reduction	0%	0%	0%	0%	0%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.64	18.85	12.71	11.93	10.20	
	% Reduction	2.4%	5.6%	6.0%	5.5%	5.9%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	3.97	3.83	3.81	3.79	3.83	
	% Reduction	3.2%	6.6%	7.1%	7.6%	6.6%	
Conventional parameters	Industry BOD reduction (t/y)	96	150	25	78	26	
	Industry COD reduction (t/y)	371	590	125	233	103	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Automated chemical dosing systems offer benefits in the area of environmental health and safety, as a result of reduced handling of chemicals.

COSTS

Table B1.3 presents cost data for automated chemical dosing systems. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B1.1*.

As shown in the table, automated chemical dosing systems produce significant operating cost savings, resulting in a simple payback of the capital investment within 2.1 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $40.2 million and $61.7 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B1.3 - Automated Chemical Dosing System: Costs

Cost item	**Plant Size**		
	Small (8,000 kg/week)	**Medium (60,000 kg/week)**	**Large (117,000 kg/week)**
Capital cost (average per plant)	$150,000	$266,000	$450,000
Net annual operating savings (average per plant)	$72,890	$129,260	$218,670
Simple payback (medium-size plant)	2.1 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$19.7	
	15% discount rate	**10% discount rate**
Annualized savings	$6.4	$7.2
Net present value of total cost of implementation (capital and operating)	$40.2	$61.7

CASE STUDY

The benefits of automated chemical dosing systems are demonstrated by a case study at John Heathcoat & Company Ltd., one of the UK’s leaders in technical textiles. The company at its Tiverton site employs approximately 550 people and conducts weaving, knitting, dyeing and finishing (UK-1). Products include precision textiles for automotive, aviation, marine, food, medical, military and fashion applications. In 1997, the company installed a computer-controlled chemical dosing system for finishing, which feeds chemicals on demand to its five stenters. The system reduced chemical use and eliminated manual mixing and delivery. It also improved quality control and reduced machine downtime. The cost of the system was £120,490, which was paid back in 43 months through savings in chemical use at £33,850 per year or 11,475 kg per year. The company also planned to install an automated chemical dosing system for dyeing.

OTHER COMMENTS

No additional comments.

BATEA #2: DYE MACHINE CONTROLLERS

DESCRIPTION

Automatic dye machine controllers offer an effective means for enhanced control over dyeing processes. They are based on microprocessors and allow for feedback control of process parameters such as pH, color, and temperature (USEPA-5, p.85). They analyze process parameters continuously and respond more quickly and accurately than manually controlled systems. Programs can also be incorporated into dye machine controllers to determine optimum pH, salt, alkali and other chemical levels based on liquor ratio, fibre, temperature, time, dyehouse structure, etc. (UK-8). Dye machine controllers can be retrofitted for many of dye machines in mills, and their sales have now overtaken sales of dye machines (USEPA-5, p.85).

Automatic dye machine controllers control the dye cycle, including the amount of water utilized in the process, and hence the amount of water and pollutants discharged to the effluent. Automatic host controllers include dye program management and reporting systems, on line scheduling, recipe management, and costing analysis (energy, dyes, and chemicals, etc.)

CURRENT APPLICATION IN CANADA (BENCHMARK)

As indicated in Table B2.1, the percentage of plants equipped with automatic dye machine controllers varies from 25-60%, depending upon the industry segment.

Table B2.1 - Dye Machine Controllers Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of Plants in the industry	62	30	14	8	6	9
Plants with Automatic Dye Machine Controllers (%)	60%	40%	57%	25%	50%	33%
Plants with Semi-automatic Dye Machine Controllers (%)	32%	40%	36%	63%	50%	55%
Plants with Manual Control Systems (%)	5%	10%	0%	0%	17%	11%
Future additional potential for Automatic Dye Machine Controllers (% of plants)	32%	53%	29%	50%	50%	44%

Future additional potential for automatic dye machine controllers is estimated to range from 29% of plants in the yarn segment to 53% of plants in the woven segment. This potential includes all plants where these controllers are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B2.2 presents the improvement in effluent quality that is achievable through application of dye machine controllers. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B2.1).*

As shown in the table, dye machine controllers have the potential to reduce the volume of industry effluents by up to 4.3%, depending on segment.

Dye machine controllers also reduce chemical use, but because effluent volume is reduced to a greater degree, the concentration of chemicals in the effluent will increase. As a result, effluent toxicity from the industry as a whole will increase by an estimated 0.7-1.4%, depending on the segment, and average NPE concentrations in industry effluents would also increase slightly. Industry wide, BOD and COD would be reduced by 149 and 940 tonnes per year respectively.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B2.2 - Dye Machine Controllers: Estimated Achievable Effluent Quality

Parameter	**Variable**	**Canadian Textile Industry**					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	175	89	123	68	207	
	% Reduction	2.6%	4.3%	2.3%	4.0%	4.0%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.89	20.24	13.62	12.77	10.99	
	% Reduction	(0.7%)	(1.4%)	(0.7%)	(1.1%)	(1.4%)	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	4.14	4.17	4.14	4.16	4.16	
	% Reduction	(1.0%)	(1.7%)	(1.0%)	(1.5%)	(1.5%)	
Conventional parameters	Industry BOD reduction (t/y)	48	60	5	26	10	
	Industry COD reduction (t/y)	186	472	50	155	77	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Dye machine controllers offer potential benefits in the area of environmental health and safety, as a result of reduced operator involvement in process control. This technology also offers small reductions in energy usage.

COSTS

Table B2.3 presents cost data for dye machine controllers. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B2.1*.

As shown in the table, dye machine controllers produce significant operating cost savings, resulting in a simple payback of the capital investment within 3.5 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $16.6 million and $30.1 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B2.3 – Dye Machine Controllers: Costs

Cost item	**Plant Size**		
	Small (8,000 kg/week)	**Medium (60,000 kg/week)**	**Large (117,000 kg/week)**
Capital cost (average per plant)	$280,000	$450,000	$800,000
Net annual operating savings (average per plant)	$79,770	$128,200	$227,900
Simple payback (medium-size plant)	3.5 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$21.15	
	15% discount rate	**10% discount rate**
Annualized savings	$2.6	$3.5
Net present value of total cost of implementation (capital and operating)	$16.6	$30.1

CASE STUDY

Environmental and operational benefits of dye machine controllers have been demonstrated in various case studies. For example, a U.S. textile company, Amital, automated dyebath flow and temperature in a new acrylic yarn production facility (USEPA-5). The automation enabled the facility to precisely control the addition of auxiliary chemicals, such as levelling agents and retarders, to dyebaths. This resulted in clean exhausted dyebath and, therefore, eliminated the need for post-rinsing. Both water and chemical use were reduced. Another example is instrument upgrading from manual to computer control for a dyeing process implemented at Bloomsburg Mills in the U.S. (USEPA-5). Since wash time after dyeing was controlled more precisely with automated instrumentation, water use fell by 28% and energy consumption by 16%.

OTHER COMMENTS

No additional comments.

BATEA #3: NPE SURFACTANT SUBSTITUTION

DESCRIPTION

Surfactants are used extensively in textile wet processing. They function as emulsifiers, detergents, wetting agents and dispersants, and are used in desizing, scouring, bleaching, mercerizing, carbonizing, dyeing, printing, and finishing (Nettles, 1983, p.379-386; Shah, 1994, p.223; Pailthorpe, 1991; Hildebrand & Riemer, 1996; Naylor, 1995; Burke, 1999; Slade, 1998, p.210; USEPA, 1996, p.143).

Surfactants are blended into nearly every chemical specialty to improve solubility and dispersability of water-insoluble materials in processing baths, as well as to improve product compatibility with other processing assistants (USEPA-12). They are also used to ensure even, thorough and rapid wetting and penetration of processing solutions into textile substrates. Surfactants can also originate from fabric yarn or fibre itself, which usually contains contaminants and processing assistants from previous processes. The action of surfactants is to lower interfacial tension of water and other materials at phase boundaries, and this same feature causes surfactants to be toxic to aquatic life.

The main surfactants used in the wet processing textile industry fall within three classes: 1) nonionic, 2) anionic, and 3) cationic. The relative quantities used in textile processing are 33% nonionic, 59% anionic, and 7% cationic, with the remaining 1% falling into the amphoteric category (USEPA, 1996, p.142). Examples of surfactants and their toxicity data have been previously presented in Section 3.3.

Nonylphenol ethoxylates (NPEs) are an important class of surfactants for the Canadian wet processing textile industry. For industrial applications in Canada, the nonionic group is comprised primarily of alkylphenol ethoxylates (APEs) (Cureton, 1998). Generally speaking, NPEs account for 80% of APEs produced, with the remaining 20% being octylphenol ethoxylates and dodecylphenol ethoxylates (Harvilicz, 1999). If 80% of nonionic surfactants are assumed to be NPEs and 33% of total surfactants are assumed to be nonionic, NPEs would account for 26% of surfactants used by the Canadian wet processing industry.

Biodegradability or treatability is an important factor to be considered in surfactant substitution, in addition to toxicity. A surfactant of moderate or low toxicity which will not degrade (therefore passing through a treatment system) will produce more toxic waste than one of higher toxicity which is degraded fully during treatment (USEPA-12). Generally, the rule of thumb for degradability is that the more linear a molecule, the greater its degradability. Branched hydrophobes are less degradable than linear ones, and aromatic materials are least degradable. For example, under certain test conditions, NPEs (an aromatic type) degrade about 25%, while under similar conditions, linear alcohol ethoxylates (LAE) degrade 100% (USEPA-12, p.13). Moreover, the NPE Assessment Report found that wastewater treatment of NPEs results in chemical transformation to compounds that are more persistent, toxic and estrogenic than the parent NPEs (Environment Canada and Health Canada, April 2001, page 20).

For reasons of degradability, LAEs are considered as one of the best substitutes for NPEs or APEs. LAEs are derived from ethylene (easily degraded), propylene, butylene (more difficult to degrade), or vegetable triglycerides (easy to degrade) (USEPA, 1996, p.142). They are used as emulsifiers, wetters, or scouring agents. Moore et al. (1987) indicated that LAEs have many of the same properties as NPEs or APEs but without the biodegradation and bioaccumulation problems. However, use of LAEs in place of NPEs or APEs can increase the BOD load of wastewater, and mills may face some difficulty in implementing the substitution when they are required to meet a low BOD limit (USEPA-12).[9]

Use of LAEs in place of APEs is also encouraged in the European Community. APEs degrade to their parent compounds, alkylphenols (APs), in wastewater treatment processes and in the environment. The APs tend to be more toxic and show greater estrogenic activity than the APEs. In 1992, the German Association of Textile Auxiliary, Tanning Agent, and Detergent Manufacturers voluntarily ceased production of AP-containing products and recommended that LAEs be substituted in formulations (USEPA, 1996, p.147).

A range of other substitutes/alternatives for NPEs are discussed below, under the *Other Comments* subheading.

CURRENT APPLICATION IN CANADA (BENCHMARK)

In order to characterize current use of non-NPE surfactants, we interviewed the following suppliers, representing an estimated 80% of the Canadian market:

- BASF Canada Inc.
- Bayer Inc.
- Boehme-Filatex Canada Inc.
- Clariant Canada Inc.
- Cognis Canada, Corporation
- Tri-Tex Co. Inc.
- W.S. Cons-Tex Inc.
- Yorkshire Canada Inc.

Table B3.1 (overleaf) presents the percentage of clients that currently use NPE alternatives, and provides estimates of incremental costs.

Some suppliers indicated that their customers have inquired about replacements for surfactants containing AP, NP and NPE's. One supplier expects that within six (6) months all of their surfactant products will be AP, NP, and NPE-free.

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[9] Notwithstanding this potential impact, the net effect of NPE surfactant substitution on BOD load is likely to be variable. Accordingly, our analysis of NPE surfactant substitution does not assume an increase in BOD.

Table B3.1 - NPE Surfactant Substitution Benchmark

Supplier	Clients using Non-AP, NP, NPE Surfactants	Cost of the Non-AP, NP, NPE Surfactants
1	90%	+ 25%
2	90%	+ 50%
3	80%	+25 to 30%
4	90%	+ 5%
5	85 – 90%	No reply
6	50%	+ 100%
7	50%	0
8	85%	+20 to 30%

In the analysis presented below, NPE surfactant substitution has been defined as replacement of NPE surfactants with suitable non-NPE surfactants. More specifically, it has been assumed that linear alcohol ethoxylates (LAE) are substituted for NPE in most instances, in view of the degradability of LAE and the non-toxic nature of its degradation products. For applications where LAE is not an appropriate substitute, it is assumed that other non-NPE surfactants with similar characteristics (readily degradable to non-toxic degradation products) will be selected.

The reported LC50 for LAE is 5.0 ppm (see Section 3.3). However, to be conservative in our analysis, we have assumed slightly greater toxicity -- specifically, that the toxicity of the substituted non-NPEs is the same as the representative value we use for all non-NPEs (LC50 = 4.7 ppm).

The future technical potential for surfactant substitution, as just defined, is estimated to be 100% in all industry segments.

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B3.2 presents the improvement in effluent quality that is achievable through NPE surfactant substitution. The data in this table represents the *technical potential* (i.e. the improvement in effluent quality, assuming 100% substitution).

As indicated in the table, NPE surfactant substitution has no impact on effluent volume, and no definite impact on TSS, COD, and BOD.[10] As is also shown in the table, the toxicity of ***untreated*** effluent from the industry as a whole would decrease only slightly, by up to 0.2% depending on the segment. This result arises from the comparable toxicity of NPE and non-NPE surfactants, and does not reflect the degradability issues discussed above under the *Description* sub-heading.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

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[10] As discussed in the preceding footnote.

Table B3.2 - NPE Surfactant Substitution: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	179	93	126	71	216	
	% Reduction	0%	0%	0%	0%	0%	
Effluent toxicity (untreated)	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.82	19.94	13.50	12.60	10.82	
	% Reduction	0.2%	0.1%	0.1%	0.2%	0.2%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	0	0	0	0	0	
	% Reduction	100%	100%	100%	100%	100%	
Conventional parameters	Industry BOD reduction (t/y)	0	0	0	0	0	
	Industry COD reduction (t/y)	0	0	0	0	0	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

No additional comments.

COSTS

Table B3.3 presents cost data for NPE surfactant substitution. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming 100% substitution.

As shown in the table, NPE surfactant substitution does not involve any capital costs. However, due to increased costs of NPE alternatives, surfactant substitution is expected to involve increased annual operating costs, averaging $1400 for small plants, $7100 for medium sized plants, and $15,500 for large plants. For the industry as a whole, the net present value of the total costs associated with NPE surfactant substitution is negative, estimated at between $4.8 million and $6.5 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B3.3 - NPE Surfactant Substitution: Costs

Cost item	**Plant Size**		
	Small	**Medium**	**Large**
Capital cost (average per plant)	$0	$0	$0
Net annual operating savings (average per plant)	($1400)	($7100)	($15500)
Simple payback (medium-size plant)	Not applicable		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$0	
	15% discount rate	**10% discount rate**
Annualized savings	($0.8)	($0.8)
Net present value of total cost of implementation (capital and operating)	($4.8)	($6.5)

CASE STUDY

In the U.S., LAEs-based surfactants have demonstrated their effectiveness in reducing effluent toxicity. There were 14 textile mills around the City of Mount Airy in Surry County, North Carolina, and all effluents were received by the city's wastewater treatment plant (USEPA-12; USEPA, 1996, p.147). At one time, the effluent from the treatment plant was found to be high in aquatic toxicity, with an LC50 equal to 51% (48 hours LC_{50} static daphnid bioassay). APEs were believed to be the primary cause. The City therefore requested the 14 textile mills to review their use of APE-based surfactants and to reduce their discharge through substitution. Within 60 days, as a result of substituting LAEs for APEs, the toxicity of the treatment plant effluent was reduced to an LC50 greater than 90% (48 hours LC_{50} static daphnid bioassay).

OTHER COMMENTS

Alkylpolyglucosides (APGs) represent another group of substitutes/alternatives for NPEs. They comprise a relatively new class of commercial nonionic surfactants (Hirsinger & Schick, 1995; Buschmann & Wodarczak, 1995). APGs have completely different chemical nature compared to classical ethoxylated nonionics. They are prepared using renewable raw materials, mainly starch or glucose, and fats/oils such as coconut oil.

A solvent-based scouring system developed at Wooltech Ltd. in Australia offers an alternative to NPEs-based wool scouring. A solvent is selected for use in scouring and recovered for reuse (Lennox-Kerr, 1997). The circulation of the solvent within the system gives virtually no effluent. This is quite a contrast from aqueous processing that requires 5-10 kg of detergent (NPEs) per tonne of raw wool and generates a substantial volume of effluent (Jones & Westmoreland, 1998). The system also allows for some 2.5% higher yield in top making than wool scoured via aqueous processes. A full-scale production unit has been set up in Trieste, Italy with a capacity of 2,500 tonnes per year.

Simcoscour MCA is a non-nonylphenol, non-solvent, non-phosphate surfactant system for removing waxes, oils, and pectins in scouring and bleaching processes of cellulosics and their blends. The product is manufactured by SIMCO Products Inc. in Greenville, SC. For batch processes, it is used at 0.5-2.0% on the weight of fabric. For continuous processes, it is used at 0.2-0.5% on the weight of bath liquor.

There is also a series of surfactants developed in Germany by Chemishe Fabrik Tubingen that serve as replacement for APEs and are equally or more efficient (Achwal, 1990). They contain many components in formulations and are completely biodegradable. These surfactants are as follows:

Felosan APF for kier boiling used with an addition of up to 50 g NaOH/L
Felosan RG for removal of oil stains
Cotoblanc NAC which is stable to 50 g NaOH/L
Lavotan DSU for long liquors with mere turbulence
Rewettin VM functioning as silicate dispersing power

Each year many new products are introduced into the wet processing market. Table B3.4 lists a number of new products compiled from recent issues of *Textile Month*. According to supplier's claims, these products can either eliminate the need for conventional wetting agents or replace existing detergents or emulsifiers. Although no detailed data is available yet about their applications, they should be examined to determine their suitability as candidates for NPE substitution.

Table B3.4 - Potential NPEs Substitutes/Alternatives

Supplier	Product	Use	Ref.
Burlington Chemicals	Burco Scour SBO-300	cellulosics scouring & bleaching with low foaming & high wax/oil emulsification	a
Eastern Color & Chemical Co.	Ecco Cleaner HRLO	biodegradable, nonionic detergent for removing resins, waxes, oils, adhesives, ink & dyes from process equipment	a
Apollo Chemical Corp.	JWM SC-3	acidic high-foaming cleaner for high-temperature dyeing equipment as well as for emulsifying oils, dyes & grease tars	b
Sybron Chemicals	Tannex GEO	one-step batch bleaching & scouring solution, eliminating the need for scours, stabilizers, defoamers, wetters, lubricants & desizers	c
Hodgson Textile Chemicals	Hodgson ESL	polymeric emulsifier for removing waxes, starch, silicone and other oils from cellulosics & synthetics	c

a - Textile World, Feb. 2000, p.93
b - Textile World, Feb. 1999, p.95
c - Textile World, Jun. 1998, p.30

BATEA #4: DYE SUBSTITUTION

DESCRIPTION

Dyes are the major source of heavy metals found in textile mill effluents. Many dyes contain heavy metals as an integral part of dye molecules and most of them are either blue or green (USEPA-12). Examples of these dyes are listed in Table B4.1. A survey of dyes, performed in the mid 1970s, identified dyestuffs as the primary source of copper in wet processing wastewater from a major North Carolina, U.S. mill. A check of each dyestuff showed that approximately 95% of the copper in the effluent originated from 13 dyes which were manufactured with copper contents up to 4% (USEPA-12).[11]

Table B4.1 - Metal-containing Dyes (USEPA-12)

Dye	Metal	Dye	Metal
Vat blue 29	Cobalt	Ingrain blue 1	Copper
Pigment blue 15	Copper	Pigment blue 15	Copper
Ingrain blue 14	Nickel	Pigment green 37	Copper
Ingrain blue 5	Cobalt	Pigment green 7	Copper
Ingrain blue 13	Copper	Ingrain green 3	Copper
Direct blue 86	Copper	Solvent blue 25	Copper
Direct blue 87	Copper	Solvent blue 24	Copper
Pigment blue 17	Copper, Barium	Solvent blue 55	Copper
Acid blue 249	Copper	Reactive blue 7	Copper

Heavy metals contained in dyes can be divided into functional metals and impurity metals (Delee et al., 1998). Functional metals are complexed into dye structures and therefore form an integral part of dyestuffs. Impurity metals, on the other hand, are trace foreign matters introduced during dye manufacture and are present in ionic forms in dye liquors. Metal compounds are sometimes used as catalysts in the synthesis of dyes and dye intermediates, and all traces of these catalysts are not always removed (Allen et al., 1972). Although most of functional metals are exhausted onto fibre or fabric dyed, 10-15% of them can be wasted in effluents (Freeman, 1995, p.837). It has been estimated that, of some 450,000 tonnes of dyes produced worldwide, 41,000 tonnes are wasted in application (Lewis, 1999). In the meantime, all impurity metals are left in dye liquors and rinse water which are eventually discharged into effluents.

Dye substitution involves replacing metal-containing dyes with metal-free dyes, which offers a means for reducing heavy metals in mill effluents. Although situations exist where certain metal-containing dyes must be used for required colours and shades, in many cases other dyes can be substituted (USEPA-12). For instance, in the case of cellulose, metal-free vat dyes can be used for green and blue shades in place of metal-containing direct or fibre reactive dyes. There is also

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[11] Belamine F Red 3BL, Belamine B Blue LT, Pyrazol F Violet MXD, Solantine Brown BRL, Atlantic Blue 8GLN-K, Atlantic Resinfast Blue 2R, Sirius Supra Turquoise LG, Superlitefast Blue 2GLL, Direct Navy OFS, Belamaine Red 3BL, Solophenyl Brown BRL, Fastolite Blue L, and Atlantic Black NR.

possibility of replacing part of the required metal-containing dye with alternatives which do not contain metals. Although this leaves some metal in the recipe, the amount is reduced.

Further discussion of copper containing reactive and direct dyes is presented below, under the *Other Comments* subheading.

Dye substitution also involves use of new dyes with improved environmental performance. These new dyes have been developed to have lower toxicity and better levelling and exhaust characteristics, in response to the need to reduce effluent pollutant loadings. They include: 1) fibre-reactive dyes for cellulosics with stable fixation rates regardless of variation in dyeing conditions, i.e., in liquor ratio, salt or alkali quantity, temperature and time; 2) direct dyes with high fixation rates irrespective of variations in liquor ratio, salt or alkali quantity, temperature and time; 3) pale and medium-to-dark shade polyester dyes with high exhaust properties, fastness and reproducibility; 4) metal-free reactive dyes with high fixation rates and minimum salt consumption; 5) metal-free direct dyes; 6) metal-free, pre-metallized and chrome dyes; and 7) low-sulphide/sulphide-free dyes. Although these dyes may be slightly more expensive, it is worth considering potential longer-term savings arising from more efficient dye use and reduced effluent treatment costs.

CURRENT APPLICATION IN CANADA (BENCHMARK)

In order to characterize current use of metal-free dyes, we interviewed Canadian and American suppliers (six of the eight suppliers listed in the discussion of BATEA #3). Table B4.2 presents the percentage of their clients that use metal free dyes.

Table B4.2 - Dye Substitution Benchmark

Supplier	Clients using Metal-Free Dyes (%)
1	85%
2	85% (minimum)
3	90%
4	95%
5	20%
6	85%

Supplier 5 is the Canadian division of an American firm. The U.S. head office stated that 20% of their clients use metal-free dyes, and that American cities are requesting that firms implement pre-treatment before returning wastewater to municipal systems. This firm provides the same range of products to the Canadian market.

Canadian suppliers stated that clients using metal-containing dyes were doing so mainly for the turquoise, blue and violet colors.

Future technical potential for dye substitution, defined as the opportunity to replace a portion of the most toxic dyes with less toxic alternatives, has been estimated to be 100% in all industry sectors (i.e. all mills have the technical potential to undertake at least some dye substitution). For the purposes of this analysis, ***the portion of dye usage to be substituted has been set at a conservative (low) level of 7.0% average across the industry***. The derivation of this figure, and its impact on the LC50 of the dye component of TMEs, is discussed in Section 5 of this report (which provides details on the methodology for analysis of achievable effluent quality).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B4.3 presents the improvement in effluent quality that is achievable through dye substitution. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming substitution occurs *to the maximum potential described in the preceding paragraph).*

As shown in the table, dye substitution has no impact on effluent volume, NPE concentrations, BOD, COD, or TSS. Effluent toxicity from the industry as a whole would be reduced by 3.2-7.9%, depending on the segment. Higher levels of dye substitution would produce greater toxicity reductions.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B4.3 - Dye Substitution: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	179	93	126	71	216	
	% Reduction	0%	0%	0%	0%	0%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.27	19.00	12.87	11.63	10.49	
	% Reduction	7.2%	4.8%	4.8%	7.9%	3.2%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	4.1	4.1	4.1	4.1	4.1	
	% Reduction	0%	0%	0%	0%	0%	
Conventional parameters	Industry BOD reduction (t/y)	0	0	0	0	0	
	Industry COD reduction (t/y)	0	0	0	0	0	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

In addition to reduction in heavy metals in effluents, the substitution of metal-containing dyes with metal-free ones can reduce wastewater treatment costs and releases of heavy metals associated with landfilling or incineration of wastewater sludge (USEPA, 1996, p.88). It further reduces heavy metal pollution in dye manufacture and offers a cleaner production opportunity.

COSTS

Table B4.4 presents cost data for dye substitution. The first half of the table presents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the BATEA is applied *to its maximum technical potential as defined above*.

As shown in the table, dye substitution does not involve any capital costs. However, due to increased costs of alternative dyes, substitution is expected to increase annual average operating costs, by $3900 for small plants, $18,600 for medium sized plants, and $49,700 for large plants. For the industry as a whole, the net present value of the total costs of dye substitution is negative, estimated at between $14.2 million and $19.4 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B4.4 – Dye Substitution: Costs

Cost item	**Plant Size**		
	Small	**Medium**	**Large**
Capital cost (average per plant)	$0	$0	$0
Net annual operating savings (average per plant)	($3,900)	($18,600)	($49,700)
Simple payback (medium-size plant)	Not applicable		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$0	
	15% discount rate	**10% discount rate**
Annualized savings	($2.3)	($2.3
Net present value of total cost of implementation (capital and operating)	($14.2)	($19.4)

CASE STUDY

Substitution of metal-free dyes for metal-containing dyes has been demonstrated in the U.S. In a survey of 541 textile mills, 36 mills were noted to have implemented chemical substitution, most commonly substitution for dyes requiring chromium mordants and chromate oxidizers (USEPA, 1979, p.199). Use of chromate oxidizers in dyeing processes contributed to the chromium content of effluents, and this problem was eliminated by switching chromate oxidizers to hydrogen peroxide or iodates. One wool finishing mill reported that savings in labour and other costs more than offset the higher cost of dyes substituted for traditional chrome dyes.

Dye substitution can also involve use of dyes that require less auxiliary chemicals. This can be illustrated in a case study at a mill in Warren, Massachusetts (USEPA-7). In 1991, the Warren's publicly owned treatment work (POTW) failed to meet two consecutive quarterly toxicity tests, and surfactants and salts present in the mill effluent were identified as the major cause for the aquatic toxicity. The mill searched for and found several alternative dyes which used no toxic surfactants and less salt when these dyes were used in place of the previous ones, toxic surfactants were eliminated and salt was reduced by 30-70%. This not only reduced toxicity at the POTW, but also increased the production level of the mill.

OTHER COMMENTS

Copper is widely used in copper complexed reactive and direct dyes to provide turquoise shades that cannot be duplicated with other structures (Kim & Baughman, 1999; Reddig, 1997). The importance of the issue is due not only to the metal itself, but also to its discharge quantity, considering the fact that 20-50% of reactive dyes and 5-20% of direct dyes, all above the industry average, are lost during their applications (Lewis, 1999). In the U.S., copper concentrations of textile mill effluents often exceed USEPA's limits due to use of coppered dyes (Baughman, 2000). Although a large portion of copper is an integral part of dye structures which may not be toxic to aquatic life, it can be released under acidic conditions (pH = 1) (Baughman, 2000). Moreover, treatment of wastewater containing coppered dyes is expensive and the fate of copper in the resulting sludge remains a concern when the sludge is incinerated or landfilled (Reife and Freeman, 1998 & 2000). More generally, dye selection should also consider the question of degradation products, in cases where these products exhibit increased toxicity.

The copper issue becomes increasingly important as the use of reactive and direct dyes, which already account for a large portion of total dyes used, shows a continuous growth. In the 1980's, the world market shares for reactive and direct dyes were 6% and 17%, respectively, while the remaining 77% was represented by sulphur, disperse, acid, vat, azoic, basic and other dyes (Carty and Byrne, 1987). It has been predicted that reactive dyes will make up the largest revenue share at 35% for the year 2004 in Europe and direct dyes can reach 15% of the market (International Dyer, May 1999, p.25). The increase in use of reactive and direct dyes is also reflected in research effort towards industrial patents. For example, of 37 industrial dye patents found during the first 10 months of 1998, 22 industrial patents were awarded on reactive dyes and 5 patents on direct dyes (Freeman and Sokolowska, 1999).

The increase in use of reactive and direct dyes is also noted in Canada. The Environment Canada 1982 survey showed that reactive and direct dyes accounted only for 2% and 0.2%, respectively, of 1.25 million kg of dyes used by six large Canadian textile mills. In estimates developed for this present study (Table 3.6), these proportions for the Canadian textile industry increased to 33% for reactive dyes and 8.7% for direct dyes (Fintex 2001).

Use of copper-free dyes is an option to address the copper issue associated with reactive and direct dyes. Generally speaking, the application of metal-free dyes is possible and allows reasonable or equal performance (Horstmann, 1993). Restrictions are experienced in some shades such as turquoise, and in fastness levels, but more and more customers are willing to live with these restrictions. In fact, numerous substitutes are available that can offer partial or complete relief from copper-related environmental challenges (Houser et al., 1994; and Baughman, 2000). Textile mills should carefully examine chemical data provided by suppliers in order to substitute copper-free dyes for coppered dyes. Some copper-free reactive and direct dyes recommended by USEPA (1996, p.57) include Yellow 50, Yellow 106, Orange 37, Red 76, Red 80, Red 153, Blue 75, Blue 98, and Blue 106.

BATEA #5: LOW LIQUOR RATIO DYEING MACHINES

DESCRIPTION

Dyeing generates various pollutants. Most of the metals and essentially all of the salts and colour present in mill effluent are derived from dyeing operations (USEPA, 1996, p.179-183). Dyes and softeners act on fabric and unexhausted residual amounts are left in dyebaths (USEPA-5, p.79). There are also other chemicals used in dyeing, including buffering agents for pH control, acids/alkalis, lubricants and dispersing agents, and they are disposed of in effluent after use. Major chemicals used in the dyebaths are salts and sodium hydroxide along with minor amounts of hydrosulphite and acetic acid.

Waste chemicals discharged from dyeing operations are dependent upon two process parameters, liquor ratio and exhaustion. Liquor ratio is defined as the mass of dyebath used per unit mass of material being dyed (Adanur, 1995, p.166). It varies over a wide range depending on the type of dyeing process and equipment used. Exhaustion is used to express the degree of dye transfer from dyebath to fibre. It is defined as a percentage of the amount of dye originally placed in the dyebath and a high degree of exhaustion is always desirable. Table B5.1 (UK-8) shows the percentage of unfixed dyes for various textiles. Reactive dyes used for cotton have the poorest fixation rate, and since over 50% of the textile-fibre market is cotton, most coloured effluent problems arise from dyeing cotton with reactive dyes.

Table B5.1 - Percentage of Unfixed Dyes for Various Textile Fibres

Fibre	Dye	Unfixed Dye
Wool and Nylon	Acid dyes and reactive dyes for wool	7-20%
	Pre-metallized dyes	2-7%
	After chromes	1-2%
Cotton and viscose	Azoic dyes	5-10%
	Reactive dyes	20-50%
	Direct dyes	5-20%
	Pigment	1%
	Vat dyes	5-20%
	Sulphur dyes	30-40%
Polyester	Disperse dyes	8-20%
Acrylic	Modified basic dyes	2-3%

Dyeing machines can be classified into two groups: rope and open width. With the rope dyeing group, the fabric is transported through the machine in a loosely collapsed form resembling a rope (USEPA, 1996, p.179). In the open-width dyeing, the fabric is maintained in a flat and open condition at all times. Common machine types are jet and beck for rope dyeing, and beam, continuous, jig, and pad-batch for open-width.

In jet dyeing, fabric is placed in a closed tubular system (USEPA, 1996, p.184; and Hall, 1975, p.349). A jet of dye solution is supplied through a venturi to transport the cloth through the tube.

The fabric is fully immersed in a rope form in the flowing liquor. Turbulence created by the jet aids in dye penetration and prevents the fabric from touching the walls of the tube. Various recent jet machines are described by White (1998).

The latest jet machines employ low-liquor-ratio and have a number of environmental advantages. The liquor ratio of conventional jet machines ranges from 8:1 to 12:1, while the latest machines are operated at liquor ratio of 5:1 (Schramm and Jantschgi, 1999; and USEPA, 1996, p.184). Since the use of water, chemicals and energy in dyeing is a function of the bath volume, the low-liquor-ratio equipment can:

- Reduce consumption of both water and auxiliary chemicals used in dyebaths;
- Increase fixation of dyes; and
- Reduce energy requirements for heating dyebaths.

The low-liquor-ratio jet dyeing can achieve significant reduction on water and chemical use. According to a study conducted by Schramm and Jantschgi (1999), the low-liquor-ratio (5:1) jet equipment, on average, can reduce water use by 70% and chemical use by 60% in comparison with the conventional equipment (liquor ratio = 8:1), as seen in Table B5.2. The water use includes both dyebath and rinse required for removal of unfixed dyes and absorbed chemicals. Further discussion of liquor ratios is provided in the *Other Comments* subsection, below.

Table B5.2 - Water and Chemical Use Reduction with Low Liquor Ratio Jet Dyeing (Schramm and Jantschgi, 1999)

Jet Machine	New	Conventional	Reduction
Liquor Ratio	5:1	8:1	
Water Use (litres/kg of dry goods)	20.5	67.5	69.6%
Chemical Use (g/kg of dry goods)	232.4	572.2	59.4%
Exhaustion (%)	75-95%	75-95%	
Fibre Loss (%)	0.5-10%	0.5-10%	

Many benefits can be expected from low liquor ratio jet dyeing. These benefits include not only reduced use of salts and other auxiliary chemicals, but also consequent reduction in total dissolved solids in effluents. Reduction in effluent toxicity is also expected since use of salts, a primary contributor to the effluent toxicity, is reduced. As a result of reduction in chemical and water use, savings are realized for both dyeing operations and wastewater treatment. Additional labour and overhead savings will be generated by the replacement of the dye becks with modern jet dyeing machines consisting of shorter dye cycles.

Jet dyeing machines apply primarily to knit, woven and carpet finishing mills for batch processes. In this BATEA, we also consider low liquor ratio stock/yarn dyeing machines, which can have liquor ratios of 5:1. Stock dyeing is also utilized in the wool industry.

CURRENT APPLICATION IN CANADA (BENCHMARK)

Jet dyeing machines

As shown in Table B5.3, almost all the knit fabric and half the woven fabrics finishing plants are equipped with jet dyeing machines. At present there are more than four hundred (400) jet dyeing machines installed in Canada. One hundred (100) of these are low liquor ratio machines. Most “state of the art” dyehouses are equipped with this technology.

Table B5.3 - Low Liquor Ratio Jet Dyeing Machines Benchmark

	Canadian Textile Industry		
	Knit	**Woven**	**Carpet**
Number of Plants in the industry	62	30	8
Plants equipped with jet dyeing machine (%)	80%	50%	38%
Future additional potential for low liquor ratio jet dyeing machines (% of plants)	35%	27%	25%

As indicated in Table B5.3, future additional potential for low liquor ratio jet dyeing machines is estimated to range from 25% of plants in the carpet segment to 35% of plants in the knit segment. This potential includes all plants where low liquor ratio jet dyeing machines are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

Stock/yarn dyeing machines

Table B5.4 indicates that low liquor ratio stock/yarn dyeing machines are found in 22% and 17% of stock/yarn and wool plants, respectively. Future additional potential is estimated at 78% and 83%, respectively.

Table B5.4 - Low Liquor Ratio Stock/Yarn Dyeing Machines Benchmark

	Canadian Textile Industry	
	Stock /Yarn	**Wool**
Number of Plants in the industry	14	6
Plants equipped with low liquor ratio stock/yarn dyeing machines (%)	22%	17%
Future additional potential for low liquor ratio stock/yarn dyeing machines (% of plants)	78%	83%

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B5.5 presents the improvement in effluent quality achievable through application of low liquor ratio dyeing machines. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Tables B5.3 and B5.4).*

As shown in the table, low liquor ratio dyeing machines have the potential to reduce the volume of industry effluents by 10-33%, depending on industry segment. Effluent toxicity from the industry as a whole would be reduced by 2.5 to 10.5%, depending on the segment, and average NPE concentrations in industry effluents would be reduced by 2.4 to 8.3%, again depending on the segment. Industry wide, BOD and COD would be reduced by 1257 and 4943 tonnes per year respectively.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B5.5 - Low Liquor Ratio Dyeing: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	Woven	Yarn	Carpet	Wool	Non-woven
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	154	83	87	64	144	
	% Reduction	14.2%	10.6%	31.2%	10.0%	33.4%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.6	19.47	12.30	12.37	9.71	
	% Reduction	3.0%	2.5%	9.0%	2.0%	10.5%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	3.95	3.99	3.78	4.0	3.76	
	% Reduction	3.7%	2.7%	7.8%	2.4%	8.3%	
Conventional parameters	Industry BOD reduction (t/y)	526	300	136	130	165	
	Industry COD reduction (t/y)	2042	1181	690	388	642	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Low liquor ratio dyeing minimizes energy use. In general, the heating of dyebaths constitutes the major portion of the energy consumed in dyeing; therefore, low liquor ratio dyeing equipment represents major energy savings as well as reduction in steam use and the resulting air pollution from boilers (USEPA-12). Another benefit associated with low liquor ratio dyeing is reduced cycle times due to quick machine drains and fills and rapid heating and cooling (USEPA-5, p.80). This in turn also reduces energy consumption.

Low liquor ratio dyeing can reduce emissions of hazardous air pollutants. These pollutants result mostly from chemical auxiliaries rather than dyes (USEPA-2, p.II-42). Since the quantity of chemical auxiliaries required is proportional to liquor ratio used for dyebaths, lower liquor ratio means less chemicals added to dyebaths. The release of hazardous air pollutants due to use of chemical auxiliaries is related to the type of dyeing processes and substrate being dyed. It also depends on the temperature in a dyeing process at which chemicals are introduced and the shade of colour. For example, one facility found no hazardous air pollutant emissions when indigo or black sulfur dyes were used, but observed glycol and glycol ether emissions with other colours.

COSTS

Table B5.6 presents cost data for low liquor ratio dyeing. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Tables B5.3 and B5.4*.

As shown in the table, low liquor ratio dyeing produces significant operating cost savings, resulting in a simple payback of the capital investment within 1.9 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $371 million and $553 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B5.6 - Low Liquor Ratio Dyeing: Costs

Cost item	**Plant Size**		
	Small (10,000 kg/week)	**Medium (60,000 kg/week)**	**Large (120,000 kg/week)**
Capital cost (average per plant)	$928,000	$3,370,000	$4,900,000
Net annual operating savings (average per plant)	$298,000	$1,790,000	$3,580,000
Simple payback (medium-size plant)	1.9 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$135.3	
	15% discount rate	**10% discount rate**
Annualized savings	$59	$65
Net present value of total cost of implementation (capital and operating)	$371	$553

CASE STUDY

At its Lumberton, North Carolina facility, Alamac Knit upgraded jet dyeing machinery to low liquor ratio machines with shorter cycles (USEPA-5, p.80). This modification reduced dye chemicals by 60-70%.

Shrigley Dyers Ltd., a UK-based commission dyer and finisher of knitted fabric, achieved both economic and environmental benefits by installing a state-of-the-art enclosed jet dyeing machine (UK-5). The gentle action and novel liquor delivery mechanism, combined with an advanced automated process control system, enables dyeing and rinsing to be performed continuously and efficiently. Operation data showed that the water consumption of the new machine (64 m^3 per tonne of fabric) was less than half that of the conventional machine (142 m^3 per tonne of fabric) used by the company. Steam consumption also fell significantly; the average steam demand for the new machine was 980 kg/batch compared with 1,480 kg/batch for the conventional machine. The new machine takes about 20% less time to process single batch than the conventional machine and the throughput is therefore higher. The new machine was installed at a cost of £135,000 in 1996 and the investment was paid back in 1.6 years. Since the installation of the new machine in 1996, the company has reduced water use by 55% and steam use by 46%, and increased production capacity by 26%. Other benefits include improvement in control of dyeing process and product quality and reduction in number of repeats, fabric contamination, effluent generation and energy consumption.

OTHER COMMENTS

Modern Jet Dyeing Machines have Liquor-Ratio in the range of 5:1 to 8:1. Air jet dyeing machines have liquor ratio 1:1 to 3:1; however, the type of production on this type of equipment is limited in scope, and these machines are very expensive. In actual practice, even with modern "state of the art" high temperature jet dyeing machines, the practical liquor-ratio will be 6:1, compared with older jet dyeing machines at 12:1 and conventional dye beck machines with an actual liquor ratio of 16 to 24:1 (dependant upon the type of fabric being processed).

It should be noted that machine water use is only a small portion of wastewater generation from dyeing. Post-dye rinsing operations use far more water, and care must be taken to ensure that savings achieved at the machine are not counteracted by extra rinsing and washing requirements (UK-8). In other words, new equipment must be considered within the context of the whole production process and not investigated in isolation. As a reference, Table B5.7 (USEPA-12) shows typical values for liquor ratios and water consumption for various dyeing machine types.

Table B5.7 - Typical Liquor Ratios and Water Consumption of Various Dyeing Machines

Dyeing Machine	Liquor Ratio	Water Consumption (gallon/lb)
Continuous	1:1	20
Beck	17:1	23
Jet	12:1	24
Jig	5:1	12
Beam	10:1	20
Package	10:1	22
Paddle	40:1	35
Stock	12:1	23
Skein	17:1	30

Generally speaking, jet dyeing machines are rarely loaded to the full capacity of the chambers and are dependant upon various factors i.e. sensitivity of the fabric, bulkiness of the fabric and the size of the production lot.

Re-dyes are often affected by liquor ratio. The higher the liquor ratio, the less re-dyes. Machine loading is another factor that affects re-dyes. Common practice in the industry is to load the machine to 80% of its capacity and utilize the volume of the vessel to increase the liquor ratio, so as to help reduce re-dyes. Re-dyes vary from 1% to 10% dependant upon the type of fabric being processed.

BATEA #6: COLD PAD BATCH DYEING

DESCRIPTION

Pad batch dyeing is a flexible, versatile dyeing method. At the start, prepared fabric is impregnated with liquor containing premixed fibre reactive dyestuff and alkali (USEPA-12; USEPA-5). Excess liquid is squeezed out on a device known as a mangle. The fabric is then batched onto rolls or into boxes and covered with plastic film to prevent absorption of CO_2 from air and evaporation of water. The fabric is then stored for 2-12 hours. The goods can be washed with becks, beams, or other available machines. Typical production is between 75 and 150 yards a minute, depending on the construction and weight of goods involved. Pad batch dyeing is more flexible than continuous dyeing methods. Either wovens or knits can be dyed, and shades can be changed frequently because reactive dyes remain water soluble. Cleaning operations are minimal due to the flexibility of pad batch equipment and use of water soluble dyes.

Pad batch dyeing requires highly reactive “cold dyeing” fibre reactive colours (USEPA-12). Examples of brand names of such colours are Atlafix CX (Atlantic), Cibacron F (Ciba Geigy), Drimarine K (Sandoz), Intracron C (C & K), Levafix E (A) (Mobay), Procion MX (ICI), Remazol (Hoechst), and Sumafix (Wright). Equipment for pad batch dyeing consists of 1) padding unit; 2) batcher or material handling system; 3) dye/alkali mixing device; 4) A-frames, storage racks or storage boxes; and 5) wash-off device (beam, beck, continuous, etc.).

Chemical use is reduced greatly with pad batch dyeing. For salt, an amount on the order of the weight of goods is required when fibre reactive dyes are applied with conventional batch dyeing (USEPA-12; USEPA-6). This can translate into thousands of pounds of salt per day for a typical dyehouse. As an alternative, pad batch dyeing uses no salt at all for the same fibre reactive dyes and same shade on the same fabric. Other chemical specialties can also be eliminated, including lubricants, levelling agents, antimigrants, fixatives, and defoamers. Only small amounts of detergent are used in washing-off. BOD and COD loadings associated with chemical use can be reduced up to 80% compared to atmospheric becks.

Other benefits associated with pad batch dyeing include savings on water and labour. Water consumption for pad batch dyeing with beam wash-off is only 10% of the amount used to dye fabrics using beck methods, or two gallons per pound of dyed fabric (USEPA-5, p.80). In addition, labor costs can be reduced up to 80% as compared to atmospheric beck methods. Use of the pad method has been recommended to replace exhaust methods for dyeing wherever possible (UK-8).

Certain limitations can be experienced with pad batch dyeing. Although it is a cost-effective way for facilities to apply reactive dyes to cotton and rayon, this method may not achieve the desired final fabric properties for all cottons. Pad batch dyeing is also not appropriate for dyeing synthetic fabrics.

CURRENT APPLICATION IN CANADA (BENCHMARK)

Table B6.1 presents current usage of cold pad batch dyeing in Canada. This technology is principally utilized for the dyeing of woven cotton fabrics with reactive dyestuffs and alkali, primarily in the towel business. It is utilized for short lots, and continuous washing ranges are employed for washing off procedures after dyeing.

Cold pad batch dyeing can be used to process one hundred (100) per cent cotton woven fabrics, dependent upon lots size and final fabric properties required. This process may potentially be used to dye 100% cotton knits, but has not yet been proven for this application (i.e., is not yet ready for the market place).

Table B6.1 - Cold Pad Batch Dyeing Systems Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of Plants in the industry	62	30	14	8	6	9
Plants equipped with Cold Pad Batch Dyeing Process (%)	0%	7%	N/A	N/A	N/A	N/A
Future additional potential for cold pad batch dyeing process (% of plants)	0%	10%	N/A	N/A	N/A	N/A

As indicated in Table B6.1, future additional potential for cold pad batch dyeing systems is estimated to be 10% in the woven segment. This potential includes all plants where these systems are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B6.2 presents the improvement in effluent quality that is achievable through application of cold pad batch dyeing systems. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B6.1)*.

As shown in the table, cold pad batch dyeing has the potential to reduce effluent volume by 7.2% in the wovens segment. Effluent toxicity and average NPE concentrations in the wovens segment effluents would be reduced by 1.0% and 1.2% respectively. BOD and COD would also be reduced by 113 and 443 tonnes per year respectively.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B6.2 - Cold Pad Batch Dyeing Systems: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	Woven	Yarn	Carpet	Wool	Non-woven
Effluent volume	Baseline average (l/kg)	N/A	93	N/A	N/A	N/A	N/A
	Achievable average (l/kg)		86				
	% Reduction		7.2%				
Effluent toxicity	Baseline (toxic units*)		19.96				
	Achievable (toxic units)		19.76				
	% Reduction		1.0%				
NPEs	Baseline average (ppm)		4.1				
	Achievable average (ppm)		4.05				
	% Reduction		1.2%				
Conventional parameters	Industry BOD reduction (t/y)		113				
	Industry COD reduction (t/y)		443				
	Industry TSS reduction (t/y)		0				

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Energy consumption can be reduced from about 9,000 BTUs per pound of dyed fabric for beck methods to under 2,000 BTUs per pound for pad batch methods with beam washing.

COSTS

Table B6.3 presents cost data for cold pad batch dyeing. The data in the first half of the table represents typical costs for individual mills. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B6.1*.

As shown in the table, cold pad batch dyeing produces significant operating cost savings, resulting in a simple payback of the capital investment within 1.4 years for a medium sized mill. (Payback for a small mill, however, would be about 3.7 years, since capital costs do not vary greatly with mill size.) For the wovens segment as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $9.4 million and $14.1 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B6.3 - Cold Pad Batch Dyeing Systems: Costs

Cost item	**Plant Size**		
	Small (15,000 kg/week)	**Medium (40,000 kg/week)**	**Large**
Capital cost (average per plant)	$1,215,000	$1,215,000	
Net annual operating savings (average per plant)	$329,000	$878,000	
Simple payback (medium-size plant)	1.4 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$3.65	
	15% discount rate	**10% discount rate**
Annualized savings	$1.5	$1.7
Net present value of total cost of implementation (capital and operating)	$9.4	$14.1

CASE STUDY

No documented case study data has been identified.

OTHER COMMENTS

No additional comments.

BATEA #7: QUALITY CONTROL FOR RAW MATERIALS

DESCRIPTION

Quality control for raw materials involves various operational measures relating to selection of chemical and mechanical alternatives, proper chemical use and training, and proper disposal/treatment methods.

Purchasing policies can be established to prevent ordering and use of untested materials (USEPA-5, p.76). A mill can work with suppliers to reduce waste by developing purchasing codes that commit the mill to using less-polluting materials. To restrict use of hazardous chemicals, guidelines for the purity and content of chemicals, including chemical specialties which typically have unknown composition to the mill, can be established. All these precautions help reduce off-quality goods, lower reworks, and improve product consistency, leading to increased profits and reduced waste associated with reworks and remakes.

Prescreening raw materials can be implemented easily at mills. Incoming chemicals should be tested as received (USEPA-12). Prior to testing, a sample should be retained for future testing if required. In addition, the following prescreening practice should apply to each drum or shipment:

- Permanently mark the date that the drum is opened, as a visual verification that the screening has been done, and as an aid in detecting aged chemicals.
- Check pH with metre or paper.
- Check viscosity with Zahn cup.
- Check density with hydrometre.
- Visually note colour and clarity.
- Note odour.
- Check index of refraction for clear liquids.
- Compare data to previous history and vendor’s standard values.
- Enter all data on control charts for display.
- Keep carefully documented records for each chemical on a long-term basis.

The above practice can provide important data for determining environmental effects, proper handling, and emergency procedures for chemicals (USEPA-5, p.76). It can also help in the early detection of mislabelled drums and changes in chemical formulation, and reduce the occurrence of costly production mistakes due to use of untested chemicals.

Dyes and pigments may be tested before use in order to reduce reworks and associated waste. They can be tested for their tinctorial strength, fastness properties on dyed goods, colour-yield in different dyeing methods, build-up of depth in relation to dye concentration, staining of fibres in blends, rate of dyeing, compatibility, and storage stability (Datye and Vaidya, 1984, p.173). Testing is particularly important in an automated process or when dyeing is controlled by computer matching systems.

Inorganic salts and alkalis are usually analyzed for impurities. For example, iron salts may auto-oxidize the fibre in a bleaching process and should not be present in additives (Datye and Vaidya, 1984, p.173). Auxiliary chemicals, either in pure form or as mixture, should be tested for efficiency or effectiveness in use. For example, a wetting agent should be tested for the time required to wet fabric under standard conditions. If auxiliary chemicals remain on finished goods, their influence on the properties of the goods should be evaluated.

Water should be tested for pH, hardness, and dissolved solids (Datye and Vaidya, 1984, p.173). Use of demineralized water may be necessary, and can be easily obtained using a battery of anion and cation-exchange resins. The pH of demineralized water may not be neutral; a check of the pH is essential.

Maintenance chemicals are an often overlooked source of toxic wastes. Chemicals used for maintenance and cleaning are often among the most toxic, offensive materials found in textile mills (USEPA, 1996, p.97). A typical textile mill usually has some sort of approval procedure and quality control for raw materials used in processing, but may not have such controls for maintenance chemicals (USEPA-12). Controlling and evaluating these materials should not be overlooked. Typical contents of maintenance chemicals include metals, acids, methylene chloride, perchloroethylene, and other highly toxic chemicals.

Proper handling of packaging materials can further reduce on-site waste generation. Mills can work with vendors to ensure that packages are returned without being cleaned on-site (USEPA-5, p.77). Off-site cleaning transfers chemical wastes back to the production facility, which may be better able to handle wastes. For this reason, chemical specialties should be purchased in returnable, reusable containers. Purchase of chemicals in bulk containers and intermediate bulk containers eliminates waste packing materials, and reduces spillage, handling costs, and worker exposure to chemicals. Bagged chemicals and drums tend to be more susceptible to damage and spills than bulk containers.

A chemical use inventory may be established to control use of raw chemicals. Different types of chemicals and their quantities used in each process should be identified. These material inputs may be ranked by cost and by quantity consumed over a representative period (typically 3 to 12 months), depending on the seasonality of production (UK-8).

Efforts to reduce chemical use may first be directed at those materials accounting for the top 20% of costs. Once the inventory is drawn up, it is necessary to establish where each chemical is used and in what quantities. It should also be observed how chemicals are measured, transferred, mixed, added to processes, etc. As much technical data as possible should be gathered to establish BOD, COD, metal content and toxicity of each chemical. This data may be available from manufacturers and suppliers in the form of Material Safety Data Sheets. The data will help mills select those chemicals with the least effect on effluent toxicity, assess the type of effluent produced by each process, and identify areas for further investigation.

CURRENT APPLICATION IN CANADA (BENCHMARK)

As shown in Table B7.1, quality control practices have been adopted by the wet processing textile industry to varying degrees. The following points elaborate on some of the topics addressed in the table:

- Pre-screening of raw materials is sometimes carried out in the industry, especially when it has an effect on the processes in the plant.
- Textile Mills are generally unaware as to toxic chemicals (such as AP, NP and NPE's) contained in the products (surfactants, cleaners, etc.) that they purchase from suppliers.
- Reusable containers are utilized in the industry, particularly in the case of drums and totes.
- Sodium hydroxide, hydrogen peroxide and acetic acid bulk dispensing is available and utilized in the industry.
- Purchasing codes are rarely used in the industry, although large vertical mills do utilize this procedure.
- Careful handling of chemicals is well practiced in the Industry. The chemical supplier usually provides training.
- Automatic salt dispensing systems are utilized in the industry, either as brine pit installations, or as salt silo dissolving and distribution systems.
- Good housekeeping is practiced, but not as well as it should be with reference to maintenance and water and energy conservation.

Table B7.1 - Quality Control Benchmark

Quality Control Practice	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of plants in the industry	62	30	14	8	6	9
In-house quality control department (%)	80%	80%	80%	100%	83%	78%
Pre-screening of raw materials (%)	10%	10%	14%	13%	17%	11%
Pre-screening of toxic chemicals (%)	0%	0%	0%	0%	0%	0%
Re-cycling of chemical containers (%)	80%	80%	80%	75%	82%	78%
Bulk dispensing of sodium hydroxide, hydrogen peroxide and acetic acid (%)	50%	30%	29%	75%	83%	N/A
Bar coding system (purchasing codes) (%)	10%	10%	14%	25%	17%	11%
Training and careful handling of chemicals (%)	100%	100%	100%	100%	100%	100%
Salt dispensing systems (brine) (%)	10%	10%	14%	N/A	N/A	N/A
Good housekeeping techniques (%)	40%	40%	43%	62%	50%	56%

For purposes of this analysis, it has been assumed that 100% of plants have potential to improve quality control relating to raw materials. It has further been assumed that these improvements will reduce chemical usage by 5% on average, and reduce the average toxicity of certain groups of chemicals purchased.[12]

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[12] 10% increase in the average LC50 of dyes, solvents and chelates purchased. Increased LC50 implies decreased toxicity.

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B7.2 presents the improvement in effluent quality that is achievable through application of quality control for raw materials. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming improved quality control is applied to the extent described in the previous paragraph).

As shown in the table, effluent toxicity from the industry as a whole would be reduced by 6.2-9.7%, depending on the segment, and average NPE concentrations in industry effluents would be reduced by 4.9%. Industry wide, BOD and COD would be reduced by 350 and 1338 tonnes per year respectively. Quality control for raw materials (as defined here) has no direct impact on effluent volume.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B7.2 - Quality Control for Raw Materials: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	179	93	126	71	216	
	% Reduction	0%	0%	0%	0%	0%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.32	18.62	12.25	11.39	10.17	
	% Reduction	6.5%	6.7%	9.4%	9.7%	6.2%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	3.9	3.9	3.9	3.9	3.9	
	% Reduction	4.9%	4.9%	4.9%	4.9%	4.9%	
Conventional parameters	Industry BOD reduction (t/y)	148	113	17	52	20	
	Industry COD reduction (t/y)	576	443	88	155	77	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Quality control for raw material can be expected to yield a wide range of benefits related to improved chemical handling, including reduced air emissions, reductions in contaminated solid wastes, reduced risk of accidental releases, and reduced occupational exposure.

COSTS

Table B7.3 presents cost data for quality control for raw materials. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to the extent described above*.

As shown in the table, quality control will produce significant operating cost savings, resulting in a simple payback of the capital investment within 0.8 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $13.9 million and $19.9 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B7.3 - Quality Control for Raw Materials: Costs

Cost item	**Plant Size**		
	Small (8,000 kg/week)	**Medium (60,000 kg/week)**	**Large (117,000 kg/week)**
Capital cost (average per plant)	$15,000	$25,000	$30,000
Net annual operating savings (average per plant)	$4200	$32,000	$38,000
Simple payback (medium-size plant)	0.8 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$2.8	
	15% discount rate	**10% discount rate**
Annualized savings	$2.2	$2.3
Net present value of total cost of implementation (capital and operating)	$13.9	$19.9

CASE STUDY

The importance of chemical prescreening can be illustrated in an example involving use of a solvent scouring chemical specialty. This chemical specialty was manufactured to contain xylene as a solvent (USEPA-5). Without notifying its customers, the manufacturer changed xylene to chlorotoluene to cut costs and minimize labelling requirements when the manufacturer’s insurance company began to require special labelling and handling of xylene. The change had a profound impact on mill’s wastewater toxicity and air emissions. This type of impact can be avoided if incoming chemicals are prescreened.

Establishing purchasing policies has also showed effectiveness in pollution reduction. In U.K., 70% of woollen mills emitted pentachlorophenol (PCP), a harmful agricultural residue in wool (USEPA-5, p.76). A study determined that it originated from incoming greige goods. By establishing purchasing policies that no PCP-containing greige goods were acceptable, the PCP content in wastewater was decreased by 50%.

OTHER COMMENTS

Section 7 includes discussion of additional quality control activities (good housekeeping practices and training).

BATEA #8: PULSATING RINSE TECHNOLOGY

DESCRIPTION

Rinsing consumes large quantities of water in textile wet processing and generates a significant proportion of effluents. Rinsing is performed in almost all areas of textile preparation and dyeing (USEPA, 1996, p.66). It typically requires much more water than chemical processing such as desizing, scouring, bleaching and dyeing. For example, rinsing accounts for over 70% of total water used in bleaching operations (Brenner et al., 1993).

Rinsing operations are areas with great potential for wastewater reduction. It has been reported that wastewater reduction up to 70% could be achieved with careful auditing and implementation of controls (Brenner et al., 1993). Also available are many advanced rinsing methods which can save water and therefore reduce wastewater generation, while offering equal efficiency. These methods include pulsating rinsing, countercurrent rinsing, vibrating-reed jet rinsing and mechanical means for increased turbulence (Freeman, 1995, p.840; Scholl, 2001).

Conventional rinsing techniques used in textile wet processing include drop/fill batch rinsing and overflow batch rinsing. The drop/fill rinsing involves successive fill, run and drain operations in a single unit (USEPA, 1996, p.66-67; Bradbury et al., 1999). For every new batch, fresh water is used to refill the machine after spent rinse water is drained. The fabric in the machine retains a large amount of the previous bath -- up to 350% on the weight of goods (Brenner et al., 1993). In overflow rinsing, clean water is fed into a machine and drained through an overflow weir usually set near a normal running level (Bradbury et al., 1999). Overflow rinsing is inefficient in terms of water use as clean water is often fed into a machine with the control valve fully opened. It is sometimes used in combination with drop/fill rinsing in order to remove surface scum resulting from poor quality water or chemicals, or from inefficient preparation.

Pulsating rinsing offers a more efficient rinsing method than conventional techniques. Developed by Scholl (Scholl, 2001), pulsating rinsing is integrated into a dyeing system and takes place while fabric is in constant motion. Spent rinse water is periodically drained from the equipment. In pulsating rinsing, both water volume and contact time per pulse between fabric and rinse water can be accurately controlled, giving repeatable rinsing results independent of water pressure fluctuations. Since fabric stays in motion, impurities are continuously dissolved into water and water use can, therefore, be reduced by up to 30% compared to overflow rinsing and 25% compared to drop-fill-rinsing systems. In the meantime, process time associated with pulsating rinsing is much shorter than that required by fill/drain rinsing.

Pulsating rinsing is the most efficient rinsing technology available for use in the knit, woven and carpet industries. It is primarily used on jet dyeing machines, but the technology can also be applied to dye becks. This technology produces a cleaner fabric in the treatment process. It has no effect on the pollutants discharged, as it affects rinsing water only.

The cost of this technology is relatively low, as only an Analog Level Control System is required along with software changes to the Batch Controller. Operating savings include water, labour, and overhead, and a shorter dye cycle results in increased production.

CURRENT APPLICATION IN CANADA (BENCHMARK)

As illustrated in Table B8.1, pulsating rinse technology is currently in limited use in Canada, with installation in 7% and 16% of plants in the woven and knit segments respectively.

Table B8.1 - Pulsating Rinse Technology Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of Plants in the industry	62	30	14	8	6	9
Plants equipped with Pulsating Rinse Technology (%)	16%	7%	N/A	0%	N/A	N/A
Future additional potential for pulsating rinse technology (% of plants)	53%	27%	N/A	50%	N/A	N/A

As indicated in the table, future additional potential for pulsating rinse technology is estimated to range from 27% of plants in the woven segment to 53% of plants in the knit segment. This potential includes all plants where this technology is both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B8.2 presents the improvement in effluent quality that is achievable through application of pulsating rinse technology. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B8.1)*.

As shown in the table, pulsating rinse technology has the potential to reduce the volume of industry effluents by up to 3.5%, depending on segment.

Pulsating rinse technology does not affect chemical use, but because effluent volume is reduced, the concentration of chemicals in the effluent will increase. As a result, effluent toxicity from the industry as a whole will increase by an estimated 1.5-2.8%, depending on the segment, and average NPE concentrations in industry effluents would increase by up to 3.4%, again depending on the segment. BOD and COD are unaffected by this technology.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B8.2 - Pulsating Rinse Technology: Estimated Achievable Effluent Quality

Parameter	**Variable**	**Canadian Textile Industry**					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	N/A	71	N/A	N/A
	Achievable average (l/kg)	173	91		68		
	% Reduction	3.5%	1.8%		3.3%		
Effluent toxicity	Baseline (toxic units*)	7.83	19.96		12.62		
	Achievable (toxic units)	8.05	20.26		12.94		
	% Reduction	(2.8%)	(1.5%)		(2.5%)		
NPEs	Baseline average (ppm)	4.1	4.1		4.1		
	Achievable average (ppm)	4.24	4.17		4.24		
	% Reduction	(3.4%)	(1.7%)		(3.4%)		
Conventional parameters	Industry BOD reduction (t/y)	0	0		0		
	Industry COD reduction (t/y)	0	0		0		
	Industry TSS reduction (t/y)	0	0		0		

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Pulsating rinse technology offers modest energy savings due to a shorter dye cycle. These savings are estimated at $1400 per year for a medium size plant.

COSTS

Table B8.3 presents cost data for pulsating rinse technology. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B8.1*.

As shown in the table, pulsating rinse technology produces operating cost savings, resulting in a simple payback of the capital investment within 5.1 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $0.6 million and $1.8 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B8.3 – Pulsating Rinse Technology: Costs

Cost item	**Plant Size**		
	Small (8,000 kg/week)	**Medium (60,000 kg/week)**	**Large (117,000 kg/week)**
Capital cost (average per plant)	$20,000	$79,000	$160,000
Net annual operating savings (average per plant)	$3,900	$15,600	$31,500
Simple payback (medium-size plant)	5.1 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$2.7	
	15% discount rate	**10% discount rate**
Annualized savings	$0.1	$0.2
Net present value of total cost of implementation (capital and operating)	$0.6	$1.8

CASE STUDY

No documented case study data has been identified.

OTHER COMMENTS

No additional comments.

BATEA #9: RECYCLING AND REUSE OF COOLING WATER AND CONDENSATE WATER

DESCRIPTION

Cooling water and condensate water are non-process water uses. Many cooling water systems are operated on a once-through basis (UK-8). The resulting hot water is generally uncontaminated and can be sent to a clear well or an influent water line for reuse as makeup or rinse water (USEPA-12). Condensate water includes water from water-cooled bearings and heat exchangers in dyeing machines, cooling cans on continuous ranges, and cooling towers for power boilers (USEPA, 1996). In general, cooling water and condensate water can be pumped to hot water storage tanks for reuse in functions where heated water is required, such as dye makeup water, bleaching, rinsing, and cleaning (USEPA, 1979, p.196).

The recovery of cooling water and condensate not only reduces water and effluent costs, but also reduces the cost of energy and chemicals (boiler room). A disadvantage of this technology is the possibility of contamination from a leaky heat exchanger. The installation of a conductivity meter on the condensate return line at the boiler room will enable users to locate a faulty heat exchanger immediately, so that repairs can be made.

CURRENT APPLICATION IN CANADA (BENCHMARK)

As shown in Table B9.1, recycling and reuse of cooling water and condensate is widely practiced in the Canadian textile industry. In the knit industry for example, the amount of cooling water utilized in the process is equivalent to 13% of total fill and rinse water. Traditionally, jet dyeing machines are equipped with common heat exchangers that are used for both heating and cooling. This enables both the cooling water and the condensate to be recovered.

Table B9.1 - Recycling and Reuse of Cooling Water and Condensate Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of plants in the industry	62	30	14	8	6	9
Plants recovering cooling water & condensate (%)	100%	100%	100%	100%	100%	100%
Plants recovering cooling water and condensate (%)	79%	67%	79%	75%	83%	89%
Future additional potential for re-cycling and reuse of cooling water and condensate (% of plants)	21%	33%	21%	25%	17%	11%

As the table shows, future additional potential for recycling and reuse of cooling water and condensate is estimated to range from 11% of plants in the non-woven segment to 33% of plants in the woven segment. This potential includes all plants where this technology is both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B9.2 presents the improvement in effluent quality that is achievable through recycling and reuse of cooling water and condensate water. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B9.1).*

As shown in the table, recycling and reuse of cooling and condensate water has the potential to reduce the volume of industry effluents by up to 3.4%, depending on segment.

This technology does not affect chemical use, but because effluent volume is reduced, the concentration of chemicals in the effluent will increase. As a result, effluent toxicity from the industry as a whole will increase by an estimated 1.6-3.0%, depending on the segment, and average NPE concentrations in industry effluents would increase by up to 3.4%, again depending on the segment. Total BOD and COD are unaffected by this technology.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B9.2 - Recycling and Reuse of Cooling Water and Condensate Water: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	Woven	Yarn	Carpet	Wool	Non-woven
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	175	89	123	69	212	
	% Reduction	2.2%	3.4%	2.2%	2.6%	1.8%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	7.97	20.56	13.77	12.87	11.02	
	% Reduction	(1.7%)	(3.0%)	(1.8%)	(2.0%)	(1.6%)	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	4.19	4.24	4.19	4.21	4.17	
	% Reduction	(2.2%)	(3.4%)	(2.2%)	(2.7%)	(1.7%)	
Conventional parameters	Industry BOD reduction (t/y)	0	0	0	0	0	
	Industry COD reduction (t/y)	0	0	0	0	0	
	Industry TSS reduction (t/y)	0	0	0	0	0	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Average cooling water temperature from jet or package dyeing machines is 49^{o} C, compared to the average temperature for fresh water of 13^{o}C. The value of the energy reclaimed from cooling water has been estimated at $68,000 per year for a medium size plant.

COSTS

Table B9.3 presents cost data for recycling and reuse of cooling/condensate water. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B9.1*.

As shown in the table, this technology can produce significant operating cost savings, resulting in a simple payback of the capital investment within 1.7 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $9.5 million and $14.4 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B9.3 - Recycling and Reuse of Cooling Water and Condensate Water: Costs

Cost item	Plant Size		
	Small (8,000 kg/week)	**Medium (60,000 kg/week)**	**Large (117,000 kg/week)**
Capital cost (average per plant)	$85,000	$143,000	$212,000
Net annual operating savings (average per plant)	$11,000	$82,900	$161,500
Simple payback (medium-size plant)	1.7 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$4.1	
	15% discount rate	**10% discount rate**
Annualized savings	$1.5	$1.7
Net present value of total cost of implementation (capital and operating)	$9.5	$14.4

CASE STUDY

A UK-based medical textile company saved about 11,000 m^3 of water by recycling and reusing cooling and condenser water (UK-8). Savings on effluent disposal alone amounted to £3000/year, plus savings on water pumping, treatment and energy. Another Scottish cloth finisher saved approximately £5000/year by recycling cooling water from its solvent-scouring plant for use in wet processing. Apart from reducing water and effluent costs, the company also achieved savings on energy as a result of reduced demand on water preheating and pumping. In a newly commissioned plant, Chilton Scotland Ltd. in UK included a condensate recovery system and a steam boost system as a measure to save water and improve energy efficiency (UK-6).

OTHER COMMENTS

A survey of the U.S. textile industry in the 1970’s revealed that many mills reused cooling water for its energy value (USEPA, 1979). Energy savings commonly varied from 1 billion to 100 billion Btu per year, while water savings were from a few thousand to 100,000 gallons per day. The principal cost items were pumps, piping modifications, and hot water storage tanks.

BATEA #10: BLEACH BATH RECOVERY SYSTEM

DESCRIPTION

Since large quantities of water are used in wet processing operations, recycling and reuse of rinse water can greatly reduce hydraulic loadings to wastewater treatment systems, while at the same time creating savings through reduced water use, energy consumption and wastewater disposal.

There are two ways to reuse spent rinse and wash water. It can be reused in another rinse operation which accepts low-grade rinse water, or it can be reused as process water in wet processing operations with or without addition of chemicals (UK-8). Examples include 1) reuse of wash water from bleaching in caustic washing and scouring make-up and rinse water; 2) reuse of rinse water from scouring for desizing or washing printing equipment; and 3) reuse of wash water from mercerizing to prepare scouring, bleaching, and wetting-out baths (USEPA, 1979).

Reuse of processing bath can take place in both preparation and finishing operations. For a typical bleach unit processing polyester/cotton and 100% cotton fabrics, spent bath from J-box or kier can be recycled to the saturator, and discharge from continuous scouring operation can be used for batch scouring (USEPA-12). In these cases, preparation chemicals, especially optical brighteners and tints, must be selected in such a way that reuse does not create quality problems such as spotting. Storage tanks may be necessary to store process liquor for reuse in the makeup of the next similar bath (USEPA, 1979).

The bleach bath recovery system can be utilized in both the knit and woven segments, to reuse 50% of the total water used in a typical 100% cotton full bleach process, including pre-scour, bleach and neutralization. This technology does not have a major effect on pollutants discharged to the sewer (less than 5% reduction), but it is an excellent technology for reducing water usage. Savings also arise from reduced energy consumption and wastewater disposal charges.

CURRENT APPLICATION IN CANADA (BENCHMARK)

This technology applies primarily to vertical knit manufacturers. As shown in Table B10.1, it is presently installed in four (4) plants in Canada.

Table B10.1 - Bleach Bath Recovery System Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of plants in the industry	62	30	14	8	6	9
Plants utilizing bleach bath recovery system (%)	6%	0%	N/A	N/A	N/A	N/A
Future additional potential for bleach bath recovery systems (% of plants)	65%	13%	N/A	N/A	N/A	N/A

As the table shows, additional potential for bleach bath recovery systems is estimated to range from 13% of plants in the woven segment to 65% of plants in the yarn segment. This potential includes all plants where these systems are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B10.2 presents the improvement in effluent quality that is achievable through application of bleach bath recovery systems. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified in Table B10.1)*.

As shown in the table, bleach bath recovery systems have the potential to reduce the volume of industry effluents by up to 12.9%, depending on segment. This technology does not significantly affect chemical use, but because effluent volume is reduced, the concentration of chemicals in the effluent will increase. As a result, effluent toxicity from the industry as a whole will increase by an estimated 2.3-10.8%, depending on the segment, and average NPE concentrations in industry effluents would increase by up to 12.9%, again depending on the segment. BOD and COD are not affected by this technology.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B10.2 - Bleach Bath Recovery System: Estimated Achievable Effluent Quality

Parameter	**Variable**	**Canadian Textile Industry**					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	N/A	N/A	N/A	N/A
	Achievable average (l/kg)	156	90				
	% Reduction	12.9%	2.7%				
Effluent toxicity	Baseline (toxic units*)	7.83	19.96				
	Achievable (toxic units)	8.68	20.42				
	% Reduction	(10.8%)	(2.3%)				
NPEs	Baseline average (ppm)	4.1	4.1				
	Achievable average (ppm)	4.63	4.21				
	% Reduction	(12.9%)	(2.7%)				
Conventional parameters	Industry BOD reduction (t/y)	0	0				
	Industry COD reduction (t/y)	0	0				
	Industry TSS reduction (t/y)	0	0				

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

The average temperature of recovered water is estimated to be 40^{o}C, compared to the average temperature for fresh water of 13^{o}C. The value of the energy saved has been estimated at $51,000 per year for a medium size plant.

COSTS

Table B10.3 presents cost data for bleach bath recovery systems. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B10.1*.

As shown in the table, bleach bath recovery systems produce significant operating cost savings, resulting in a simple payback of the capital investment within 2.1 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology is positive, estimated at between $10.1 million and $15.5 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B10.3 - Bleach Bath Recovery System: Costs

Cost item	**Plant Size**		
	Small	**Medium**	**Large**
Capital cost (average per plant)	$80,000	$123,000	$246,000
Net annual operating savings (average per plant)	$38,500	$59,200	$118,400
Simple payback (medium-size plant)	2.1 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$5.0	
	15% discount rate	**10% discount rate**
Annualized savings	$1.6	$2.3
Net present value of total cost of implementation (capital and operating)	$10.1	$15.5

CASE STUDY

A dyeing and finishing company in UK halved its water consumption by using the spent rinse water from the bleaching process in the scouring wash, and saved £10,300/year in effluent disposal and water costs (UK-8).

OTHER COMMENTS

No additional comments.

BATEA #11: SALT BATH RECOVERY SYSTEM

DESCRIPTION

Dyebath reuse can involve the following technologies: 1) direct reuse of a whole dyebath; 2) recovery and reuse of dyestuffs; and 3) recovery and reuse of salts. This BATEA addresses the last of these technologies: recovery and reuse of salts.

The recovery of water and salts from textile dye waste process water is achievable with a nanofiltration membrane system. This technology has been developed by Koch Membrane Systems. Presently, this technology is not utilized in the textile industry in North America, but has been demonstrated in numerous pilot projects in the U.S.A. in the last ten years (Koch Membrane Systems, 2001).

In a typical textile dyeing process with reactive dyes, a wastewater solution contains about 5% salts and 250 mg/litre of spent dyestuff (Koch Membrane Systems, 2001). When NaCl is used as a salt in the dyeing process, the wastewater solution can be treated with the Koch system. The treated water (permeate) is clear, containing water and salt but no dyes or other organic species. The permeate is therefore suitable for reuse in the dyeing operation. The concentrated coloured stream consists of roughly 2% of the entire waste volume and can be landfilled.

Combined rinse water from the first, second and third washing steps usually contains 125 mg/litre of dyestuffs and can also be treated for colour removal using the membrane system, with 98% water recovery and reuse.

This technology applies primarily to the knit, woven and yarn industries, and is utilized when dyeing reactive dye stuffs on 100% cotton or cotton/polyester fabrics. This technology is only suitable when common salt (NaCl) is used in the dyeing process, and cannot be utilized with Glauber Salt (Na_2SO_4). This limitation is a factor in the absence of installations to date.[13]

CURRENT APPLICATION IN CANADA (BENCHMARK)

As noted, there are no applications of this technology to date in the Canadian textile industry. As indicated in Table B11.1, the future potential for salt bath recovery systems is estimated to range from 27% of plants in the woven segment to 65% of plants in the knit segment. This potential includes all plants where these systems are believed to be technically feasible (excluding applications that would be cost prohibitive).

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[13] Glauber salt, which costs approximately 30¢ /kg compared to common salt at 16¢ /kg, is used primarily because it does not corrode stainless steel and is also required for solubility when dyeing dark shades. The tendency in the industry today is towards a combination of both Glauber and common salt.

Table B11.1 - Salt Bath Recovery System Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of Plants in the industry	62	30	14	8	6	9
Plants utilizing Salt Bath Recovery System (%)	0%	0%	0%	N/A	N/A	N/A
Future additional potential for salt bath recovery systems (% of plants)	65%	27%	50%	N/A	N/A	N/A

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B11.2 presents the improvement in effluent quality that is achievable through application of salt bath recovery systems. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to the full potential identified in Table B11.1).*

As shown in the table, salt bath recovery has the potential to reduce the volume of industry effluents by up to 4.1%, depending on the segment. Effluent toxicity from the industry as a whole would be reduced by 0.2-0.8%, again depending on the segment. Industry wide, TSS would be reduced by 236 tonnes/year. NPE, BOD and COD are unaffected by this technology.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B11.2 - Salt Bath Recovery System: Estimated Achievable Effluent Quality

Parameter	**Variable**	**Canadian Textile Industry**					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	N/A	N/A	N/A
	Achievable average (l/kg)	172	91	122			
	% Reduction	4.1%	1.7%	3.2%			
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52			
	Achievable (toxic units)	7.78	19.93	13.50			
	% Reduction	0.8%	0.2%	0.2%			
NPEs	Baseline average (ppm)	4.1	4.1	4.1			
	Achievable average (ppm)	4.1	4.1	4.1			
	% Reduction	0%	0%	0%			
Conventional parameters	Industry BOD reduction (t/y)	0	0	0			
	Industry COD reduction (t/y)	0	0	0			
	Industry TSS reduction (t/y)	141	80	14			

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

No additional comments.

COSTS

Table B11.3 presents cost data for salt bath recovery systems. The data in the first half of the table represents typical costs for individual mills. The second half of the table presents total industry costs, assuming the technology is applied *to its full potential (as identified above).*

As shown in the table, salt bath recovery systems produce operating cost savings, but simple payback of the capital investment requires about 7 years. For the industry as a whole, the net present value of the total costs and savings associated with this technology depends on the discount rate, ranging from a cost of $8.4 million to a saving of $3.5 million.

Further details on costs, including methodology, are presented in Section 6.

Table B11.3 - Salt Bath Recovery System: Costs

Cost item	**Plant Size**		
	Small (15,000 kg/week)	**Medium (60,000 kg/week)**	**Large (10,000 kg/week)**
Capital cost (average per plant)	$420,000	$920,000	$1,422,000
Net annual operating savings (average per plant)	$32,700	$130,800	$218,000
Simple payback (medium-size plant)	7.0 years		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$41.6	
	15% discount rate	**10% discount rate**
Annualized savings	($1.3)	$0.6
Net present value of total cost of implementation (capital and operating)	($8.4)	$3.5

CASE STUDY

No case study is provided (see *Description* for discussion of pilot applications).

OTHER COMMENTS

Other technologies can reduce salt usage. For instance, the manufacturers of reactive dyes are working to reduce the level of salt required in a commercial dye bath (Textile World) while simultaneously increasing total exhaustion of the dyestuff on the fabric.

The use of Brine Salt Distribution System will reduce the amount of salt used in the dyeing process by five (5) per cent. These systems are quite common in the Canadian textile industry. They do, however, affect the liquor ratio.

The latest technology in salt distribution includes silo storage and mixing to produce a slurry of salt with a ratio of 3:1, which is then dispensed automatically to the dyeing machine. Total reduction of salt is again in the 5% range.

BATEA #12: BIOLOGICAL WASTEWATER TREATMENT

DESCRIPTION

The following definitions describe the different levels of treatment applied to TMEs in Canada (from Environment Canada *Supporting Document for Textile Mill Effluents,* 2000):

Untreated:	The combined raw process water from a facility (may have preliminary treatment such as screening, grit removal, flow equalization and/or pH neutralization).
Primary Treatment:	Removes from wastewater those pollutants that will either settle out or float. It includes sedimentation with or without chemical addition, gas flotation with or without chemical addition, and filtration.
Secondary Treatment:	Generally biological treatment, including activated sludge, trickling filter, lagoons of many types, and rotating biological contactors.
Tertiary Treatment:	Activated carbon adsorption, sand filtration, chemical oxidation, air stripping, ion exchange, polymeric adsorption, reverse osmosis, ozonation and chemical reduction.

Biological (secondary) treatment is grouped into two classes: aerobic and anaerobic. In the aerobic class, pollutants in wastewater are broken down by bacteria (aerobes) that utilize free dissolved oxygen, while in the anaerobic class, they are decomposed by bacteria (anaerobes) that utilize “chemically bound” oxygen. Biological treatment is a method of converting wastewater pollutants into non-polluting substances through biodegradation (Stephenson & Blackburn, Jr., 1998). The conversion is based on the ability of microorganisms to utilize organic carbon as a food source in breaking down (oxidizing) pollutants (USEPA, 1979).

Activated sludge is the most popular aerobic biological treatment system (Crechem 2000). It has been very successful in treating textile mill effluents (Nemerow & Dasgupta, 1991, p.405).

The activated sludge process consists of several basic components that decompose and remove pollutants from wastewater. They include 1) an aerated biological reactor for aerobic biodegradation to occur, 2) a clarifier for separation of biomass (a mass of microorganisms), and 3) a piping arrangement to return separated biomass to the biological reactor (USEPA, 1979, p.215). The aeration provides necessary oxygen for aerobic biodegradation and mixing to maintain biological solids in suspension. Biomass grows in the reactor by feeding on pollutants in wastewater, settles out in the clarifier, and returns to the reactor to eat more pollutants (Stephenson & Blackburn, Jr., 1998, p.257). Excess biomass is wasted to sludge. Besides taking pollutants as food, biomass also acts as a filter to collect colloidal and suspended solids (Theodore & McGuinn, 1992). Some metals can be collected in the sludge and volatile organic compounds can be driven off by aeration.

The activated sludge process is very effective in reducing BOD and moderate in removing COD and TSS. Operational data compiled from several U.S. textile mills showed that the activated sludge treatment could achieve reduction of BOD, COD, and TSS by 90%, 70% and 50%, respectively (USEPA, 1979, p.218). Generally speaking, the BOD/COD ratio is required to be greater than 0.4 in order to have effective biological treatment. In practice, however, effective removal of BOD and COD by activated sludge has been reported for mill effluents with BOD/COD ratios as low as 0.1 (USEPA, 1979, p.218).

Biodegradation can be effective in decomposing NPEs. Under both aerobic and anaerobic conditions, NPEs have been found to degrade to NP (Ejlertsson, 1999; Lee & Peart, 1998). 4-nonylphenol has also been reported as a primary breakdown product of NPEs at municipal sewage treatment plants (Topp and Starratt, Env. Tox. Chem. 2000). Other degradation products include nonylphenoxyacetic acid and nonylphenoxyethoxyacetic acid under aerobic conditions and mono and diethoxylates under anaerobic conditions (Ahel et al., 1994). The overall removal of NPEs by more than 90% has been reported (Naylor, 1995). It should be noted that the ultimate degradation to NP can occur and has been observed, but it is not rapid and does not meet the "readily degradable" criteria of the OECD (Maguire, 1999). On the other hand, some studies found NP can be completely decomposed by activated sludge at a higher temperature (28^{o}C) than normal conditions (15-25^{o}C) (Tanghe et al., 1998), in spite of the fact that most literature data suggests that NP is the ultimate degradation product and cannot further degrade (UK Environment Agency, 1998).

Conventional aerobic biological processes used in the textile industry are generally unsuccessful in significant dyestuff removal beyond the adsorbing capacity of the biomass (USEPA-11). One reason for this is that dyes are designed to be bio-resistant. This problem is reflected in long retention times of extended-aeration systems, which generally operate for two to three days. This is also the reason why municipal treatment systems at a detention time of 8-12 hours are much less successful in color removal.

The activated sludge process is very flexible and can be adapted to many waste treatment situations (USEPA, 1979, p.215). Factors that must be considered in design include: 1) loading criteria; 2) reactor type; 3) sludge production; 4) oxygen requirements and transfer; 5) nutrient requirements; 6) environmental requirements; 7) solids-liquid separation; and 8) effluent characteristics. Depending on these factors and their combinations, the conventional activated sludge process or its standardized modifications can be selected. The available processes that are relevant to the treatment of textile mill effluents include the conventional, complete-mix, tapered-aeration, step-aeration, modified-aeration, contact-stabilization, extended-aeration, oxidation ditch, and pure oxygen. Each of these processes is briefly described in the *Other Comments* subsection, below.

CURRENT APPLICATION IN CANADA (BENCHMARK)

As indicated in Table B12.1, 121 mills are presently discharging to MWWTP.[14] Of these, 40% are not equipped with pre-treatment. Two mills discharge untreated TME's to the environment

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[14] This number differs slightly from the data used by Environment Canada. The reason for this difference is outlined at the beginning of Section 4, in the discussion of methodology.

through a municipal wastewater collection system without wastewater treatment, and six mills are equipped with on site treatment systems (of which five are secondary and one is primary).

Table B12.1 - Wastewater Treatment Benchmark

	Plants in Canada	Percentage of Total (%)
On site treatment systems	6	4.5%
Discharge to municipal system with treatment	121	94%
Discharge to municipal system without treatment	2	1.5%
Total	129	100%

	Canadian Textile Industry					
	Knit	Woven	Yarn	Carpet	Wool	Non-woven
Number of Plants in the industry	62	30	14	8	6	9
Plants equipped with biological treatment systems (%)	3%	10%	0%	0%	17%	0%
Future additional potential for biological treatment systems (% of plants)	97%	90%	100%	100%	83%	100

As indicated in Table B12.1, technical potential for additional biological water treatment systems is high, applying in principle to all 123 plants currently without systems. (It should however be noted that it may be impractical to install the biological treatment systems in many of these plants, because of the lack of available space.)

ACHIEVABLE EFFLUENT QUALITY

Based on our effluent toxicity model (Section 3), Table B12.2 presents the improvement in effluent quality that is achievable through application of biological wastewater treatment. The data in this table represents the ***technical potential*** (i.e. the improvement in effluent quality, assuming the technology is applied *to its maximum potential as identified above).*

Industry wide, BOD, COD, and TSS would be reduced by 5,900, 17,700, and 1400 tonnes per year respectively. Table B12.2 also shows significant reduction in NPE concentrations in industry effluents (up to 85%). As noted above, NPEs do degrade in biological treatment facilities. However, many of the degradation products, including nonyl phenol, are more toxic and more persistent than the parent NPEs.

As shown in the table, biological wastewater treatment has a major impact on effluent toxicity from the industry as a whole (a much larger impact than any other BATEA). Specifically, average toxicity would be reduced by 70.5% or higher, depending on the segment. This reduction refers to TMEs at the point of discharge from the textile mill. Since many mills discharge to a municipal system with treatment, the net environmental impact of BATEA #12 would be reduced, if measured at the point of discharge from the municipal system.

As modelled, the reduction in toxicity does not consider toxicity associated with NPE degradation products. This is a reasonable simplification for modelling purposes, and the result is directionally consistent with measured toxicity of *most* samples of secondary treated effluent collected during the NPE assessment phase (which typically showed total NP/NPE concentrations below levels of concern). However, not all samples were below levels of concern, and the NPE Assessment Report found substantial concentrations of nonylphenol and lower-chain (more toxic) NPEs in sludges from MWWTPs (Environment Canada and Health Canada, April 2001, page 20). The modelled toxicity reduction, therefore, must be qualified due to factors such as bypass of treatment facilities, possible problems with poor operation, and transfer of NP and related substances to other waste streams.

Further details on achievable effluent quality, including methodology, are presented in Section 5.

Table B12.2 - Biological Wastewater Treatment: Estimated Achievable Effluent Quality

Parameter	Variable	Canadian Textile Industry					
		Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Effluent volume	Baseline average (l/kg)	179	93	126	71	216	Not analysed
	Achievable average (l/kg)	179	93	126	71	216	
	% Reduction	0%	0%	0%	0%	0%	
Effluent toxicity	Baseline (toxic units*)	7.83	19.96	13.52	12.62	10.84	
	Achievable (toxic units)	1.55	4.89	2.10	1.89	3.19	
	% Reduction	80.2%	75.5%	84.5%	85.0%	70.6%	
NPEs	Baseline average (ppm)	4.1	4.1	4.1	4.1	4.1	
	Achievable average (ppm)	0.73	0.96	0.62	0.62	1.21	
	% Reduction	82.2%	76.6%	84.9%	84.9%	70.5%	
Conventional parameters	Industry BOD reduction (t/y)	2581	1823	312	934	297	
	Industry COD reduction (t/y)	7798	5579	1229	2173	899	
	Industry TSS reduction (t/y)	530	678	70	75	41	

(* toxic units: see subsection 3.5 for explanation)

OTHER ENVIRONMENTAL BENEFITS

Wastewater treatment has well established public health and environmental benefits associated with the reduction of most (although not all) major pollutants in wastewater.

COSTS

Table B12.3 presents cost data for biological wastewater treatment. The data in the first half of the table represents typical costs for individual mills in all segments. The second half of the table presents total industry costs, assuming the technology is applied *to its maximum potential as identified in Table B12.1*.

As shown in the table, biological treatment involves substantial capital costs, ranging from $0.9 to $3.4 million per average plant, depending on size category. If applied across the industry as implied by the definition of technical potential, total capital costs would exceed $200 million.

In addition, biological wastewater treatment involves ongoing operating costs, averaging about $34,000 for small plants, $65,0000 for medium sized plants, and $129,000 for large plants. For the industry as a whole, the net present value of the total costs associated with full implementation of biological treatment is estimated at between $253 million and $271 million (depending on discount rate).

Further details on costs, including methodology, are presented in Section 6.

Table B12.3 - Biological Wastewater Treatment: Costs

Cost item	**Plant Size**		
	Small (15,000 kg/week)	**Medium (60,000 kg/week)**	**Large (250,000 kg/week)**
Capital cost (average per plant)	$905,000	$1,715,000	$3,400,000
Net annual operating savings (average per plant)	($34,400)	($65,100)	($129,100)
Simple payback (medium-size plant)	Not applicable		

Cost item (industry totals based on implementation potential in Table B1.1)	**Cost (in $ millions)**	
Capital cost	$204.4	
	15% discount rate	**10% discount rate**
Annualized savings	($40.4)	($43.2)
Net present value of total cost of implementation (capital and operating)	($253.0)	($270.5)

OTHER COMMENTS

As noted earlier, the activated sludge process has a number of variants that are relevant to the treatment of textile mill effluents. These are described below.

In the ***conventional activated sludge process***, both influent wastewater and recycled sludge enter the reactor at the head end and are aerated for a period of about 4 to 8 hours (USEPA, 1979, p.216). Aeration is constant as the mixed liquor moves through the reactor in a plug-flow fashion. Oxygen demand decreases as the mixed liquor travels along the reactor length. The mixed liquor is settled in a conventional clarifier, and the activated sludge is returned at a rate of approximately 25% to 50% of the influent flow rate.

In the ***complete-mix activated sludge process***, influent wastewater and recycled sludge enter the reactor from several points along a central channel running the length of the reactor (USEPA, 1979). The mixed liquor is aerated at a constant rate as it passes from the central channel to effluent channels at both sides of the reactor. The contents of the reactor are completely mixed and the oxygen demand remains uniform throughout. The aeration period varies from 3 to 5 hours, and the activated sludge is returned at a rate of 25% to 100% of influent flow rate.

The ***tapered-aeration process*** is a modification of the conventional process (USEPA, 1979). At the head of the reactor, where wastewater and returned activated sludge come in contact, more oxygen is required so aerators are spaced close together. As the mixed liquor traverses the reactor, the oxygen demand decreases so aeration is decreased by spacing aerators further apart.

Since the oxygen supply is decreased with the oxygen demand, a lower overall oxygen requirement is a benefit of the tapered-aeration process.

The ***step-aeration process*** is also a modification of the conventional activated sludge process (USEPA, 1979). In this modification, wastewater is introduced at several points in a compartmentized reactor while return activated sludge is introduced at the head of the reactor. Each compartment of the reactor are linked together in series. Aeration is constant as the mixed liquor moves through the reactor in a plug-flow fashion. The demand is more uniformly spread over the length of the reactor than in the conventional activated sludge process, resulting in better utilization of the oxygen supply. The aeration period is typically between 3 and 5 hours, and the activated sludge is returned at a rate of 25% to 75% of influent flow rate.

The ***modified-aeration activated sludge process*** is similar to the conventional or tapered-aeration process, except that the aeration period is shorter, usually 1.5 to 3 hours, and the food-to-microorganism ratio higher (USEPA, 1979). Activated sludge is returned at a rate of only 5% to 15% of influent flow rate. The resulting BOD removal is approximately 70%, so the process is not suitable where a high BOD removal rate is desired.

The ***contact-stabilization process*** takes advantage of the absorptive properties of activated sludge by operating the process in two stages (USEPA, 1979). The first is the absorptive phase, in which most of colloidal, finely suspended, and dissolved organics are absorbed in the activated sludge in a contact tank. Wastewater and returned stabilized sludge enter at the head of the contact tank, are aerated for a period of 20 to 40 minutes, and settled in a conventional clarifier. The second is the oxidation phase, in which the absorbed organics are metabolically assimilated providing energy and producing new cells. In this stage the settled sludge from the absorptive stage is aerated for a period of 3 to 6 hours in a stabilization tank. A portion of the sludge is wasted to maintain a constant mixed liquor volatile suspended solids concentration in the stabilization tank. Overall aeration requirements are approximately 50% of those of the conventional or tapered-aeration process. However, the process is usually not effective in treating industrial waste in which the organic matter is predominantly soluble.

The ***extended-aeration process*** is a complete-mix activated sludge process in which the aeration period is relatively long (24 to 48 hours) and the organic loading relatively low (USEPA, 1979). Because of these conditions, the process is very stable and can accept intermittent loads without upset. In smaller applications, the reactor and clarifier are generally a single-fabricated unit, and all sludge is returned to the reactor. The mixed liquor is allowed to increase in solids concentration over a period of several months and removed directly from the aeration basin. In larger applications, the reactor and clarifier are separated and some means of wasting and treating sludge is usually necessary. Reactors can be concrete with diffused aeration or a lined earth basin with mechanical aerators.

The ***oxidation ditch activated sludge process*** is an extended-aeration process in which aeration and circulation are provided by brush rotors placed across a race track-shaped basin (USEPA, 1979). Wastewater enters the ditch at one end, is aerated by the rotors, and circulates at about 1 to 2 feet per second. Operation can be intermittent, in which case purification takes place in the ditch, or continuous, in which case a separate clarifier and piping for recycling settled sludge are provided.

The ***pure oxygen activated sludge process*** is a modification of the complete-mix process in which high-purity oxygen, instead of air, is introduced directly into wastewater (USEPA, 1979). Wastewater, returned activated sludge, and oxygen under a slight pressure are introduced at the head of a fan aeration tank that is divided into stages by baffles and covered with a gas-tight enclosure. Oxygen may be mixed with the mixed liquor by recirculation through a hollow shaft with a rotating sparger device or by surface mechanical aerators. The mixed liquor passes from compartment to compartment and is discharged from the last one to a clarifier. Waste gas, which is a mixture of carbon dioxide, nitrogen, and unused oxygen, is exhausted in the last compartment. Advantages of the pure oxygen process are high efficiency, decreased sludge volume, reduced aeration tank volume, and improved sludge settleability.

5. ACHIEVABLE EFFLUENT QUALITY

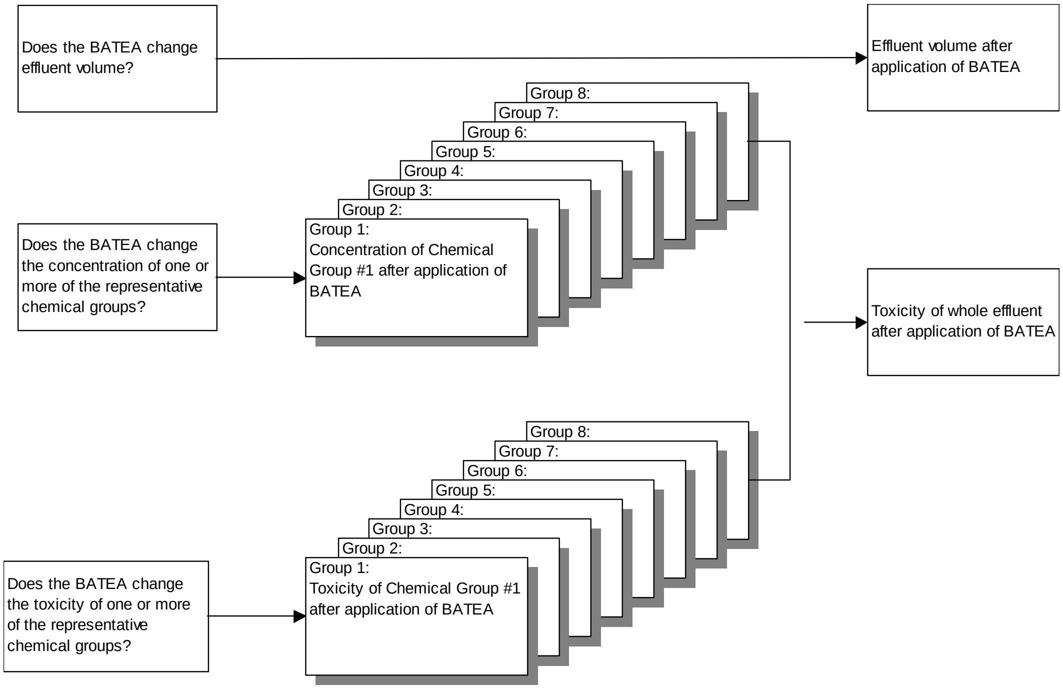
In Section 4, summary results concerning achievable effluent quality were presented for each BATEA. In this section, the methodology used in our analysis is presented, together with further detail and discussion of the results. Specifically:

- Subsections 5.1 to 5.4 describe our methodology
- Subsections 5.5 and 5.6 present the results of the toxicity analysis, for the industry as a whole and by segment.

5.1 OVERVIEW OF METHODOLOGY

The methodology for determining achievable effluent quality is based on the toxicity model presented in Section 3. In brief, this model determines the toxicity of TMEs based on the toxicity and concentrations of eight representative groups of chemicals found in TMEs. To determine the toxicity impact of any BATEA, it is only necessary to determine (1) the impact of the BATEA on effluent volume; (2) the impact of the BATEA on the concentration of each of the eight groups of chemicals in the TME; and (3) the impact, if any, of the BATEA on the toxicity of these groups of chemicals. This concept is presented graphically in Figure 5.1.

Figure 5.1 – Achievable Effluent Quality for Individual BATEA: Conceptual Approach



5.2 DATA INPUTS

To carry out the required analysis, a range of data inputs are required. In addition to toxicity data (already presented in Section 3), and technical potential for implementation of each BATEA (already presented in Section 4), key data requirements include the following:

- Current actual **water use/effluent volume** by industry segment
- Current actual **chemical use** by industry segment, for each of the eight groups of chemicals used in the model
- Plant-level **reduction of water and chemical use** for each BATEA.

Table 5.1 presents current **water use/effluent volume** by segment. This data is derived from the Environment Canada textile industry database (1999), based on the benchmarking profile presented in the introductory pages in Section 4.

Table 5.1 - Water Use /Effluent Volume by Segment

Industry Segment	Effluent volume litres/kg
Knit	179.0
Woven	92.6
Yarn	126.0
Carpet	70.5
Wool	215.9

Table 5.2 presents estimated **chemical use** or effluents by industry segment, for each of the groups of chemicals used in the model. Note that chemical use and achievable effluent quality has not been estimated for the non-wovens finishing industry, because of the limited effluent quantities from this segment (see Section 8).

Table 5.2 - Chemical Use/Effluents by Industry Segment

Chemical Group	Knit	Woven	Yarn	Carpet	Wool
Salts	281.5 g/kg	189.0 g/kg	82.0 g/kg		
Surfactants (NPE's)	4.1 ppm	4.1 ppm	4.1 ppm	4.1 ppm	4.1 ppm
Surfactants (non-NPE's)	2.7 g/kg	5.2 g/kg	3.1 g/kg	2.1 g/kg	7.8 g/kg
Phosphates	5.2 ppm	5.2 ppm	5.2 ppm	5.2 ppm	5.2 ppm
Dyes	2.08 g/kg	1.85 g/kg	1.70 g/kg	1.45 g/kg	1.56 g/kg
Carriers	0.19 g/kg	0.25 g/kg	1.85 g/kg	0.21 g/kg	0.11 g/kg
Solvents	3.8 ppm	3.8 ppm	3.8 ppm	3.8 ppm	3.8 ppm
Chelates	9.8 g/kg	31.72 g/kg	1.47 g/kg		

In the case of NPE surfactants, phosphates, and solvents, the data in Table 5.2 focuses on effluents, using concentration data derived in Section 3 of this report. In each of these cases, the best available estimates were available in this form.[15]

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[15] For NPE surfactants, chemical use was also derived based on mass balance. This approach results in somewhat higher estimates of usage, with variability between industry segments. However, because it is preferable to use actual measured data where available, we have utilized the concentrations included in Table 5.2 rather than the mass balance calculations. Because the measured data is insufficient to allow meaningful differentiation between segments, we have used the industry average concentration for all segments.

For the other chemical groups, the project team derived the chemical use by means of a mass balance approach, presented as grams of chemical per kilogram of production. This approach is illustrated in the text box below, for the example of salt use in the knit segment.

CHEMICAL USE CALCULATION
Example: Salt Usage Calculation (Mass Balance For Salts)

Different types of salts are utilized in dyebath formulations. Salts are used only for the dyeing of cotton fibres. In cotton dyebath formulations, common salt and Glauber salt are utilized to increase the exhaustion of the dyebath. Soda ash (Na_2CO_3) is added to the dyebath at the end of the dye cycle to increase the dyebath pH. One other source of salts come from the neutralization of the bleaching solution. In this case sulfuric acid is added to the wastewater to neutralize the residual caustic soda (NaOH) from the dyebath. The reactive product is sodium sulfate (Na_2SO_4).

- Salt utilized in the dyebath: The amount of common salt or Glauber salt used in the dyebath formulation is a function of the fabric shade. Light shades use less salt, dark shades use more salt.

Light shades:	20 g/l
Dark/med. shades:	60 g/l

- Salt generated from the dyebath (soda ash):

Light shades:	5 g/l
Dark/med. shades:	20 g/l

- Salt generated by effluent neutralization: 55% of cotton fabrics have to be bleached. 50 grams caustic soda has to be neutralized by sulfuric acid to bring the effluent pH to a maximum of 9.5. This will generate 50 grams of salt per kg of fabric bleached.

Summary:

Shades	Dyebath Salt Concentration (g/l)	Soda Ash Concentration (g/l)	Salt from Neutralization (g/kg)	Colour Mix (%)
Scour	0	0	0	10%
White	0	0	50	25%
Light	20	5	0	30%
Med/dark	60	20	0	35%

Calculation of average salt usage to dye cotton, based on industry average liquor ratio of 12:1:

White:	50 g/kg x 25% =	12.5 g/kg
Light shades:	(20 g/l + 5 g/l) x 30% x 12 =	90.0 g/kg
Dark/med. shades:	(60 g/l + 20 g/l) x 35% x 12 =	336.0 g/kg
Average salt usage:		438.5 g/kg

Calculation of average salt usage based on product mix for the knit industry (64.2% cotton):

Average usage = 64.2% x 438.5 g/kg
= 281.5 g/kg

Table 5.3 presents estimated **reductions of water and chemical use** at the plant level, for each BATEA. This data is based on review of the literature and knowledge of each of the BATEA by the project team. Note that the percentage reduction in chemical use refers only to those chemicals affected by the particular BATEA. For instance, NPE surfactant substitution (BATEA

#3) affects only NPE surfactants, and none of the BATEA are expected to have a significant effect on dye usage.

Table 5.3 - Potential Reductions in Chemical and Water Use (Plant Level)

#	BATEA Name	**Knit**		Woven		**Yarn**		**Carpet**		**Wool**	
		Chem %	**Water %**	**Chem %**	**Water %**	**Chem %**	**Water %**	**Chem %**	**Water %**	**Chem %**	**Water %**
1	Automated chemical dosing systems	10%	0%	10%	0%	10%	0%	10%	0%	10%	0%
2	Dye machine controllers	5%	10%	5%	10%	5%	10%	5%	10%	5%	10%
3	NPE Surfactant substitution	100%	0%	100%	0%	100%	0%	100%	0%	100%	0%
4	Dye substitution	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5	Low liquor ratio dyeing machines	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
6	Cold pad batch dyeing	n/a	n/a	83%	90%	n/a	n/a	n/a	n/a	n/a	n/a
7	Quality control for raw materials	5%	0%	5%	0%	5%	0%	5%	0%	5%	0%
9	Recycling/reuse of cooling/condensate water	0%	13%	0%	13%	0%	13%	0%	13%	0%	13%
8	Pulsating rinse technology	0%	8%	0%	8%	n/a	n/a	0%	8%	n/a	n/a
10	Bleach bath recovery system	0%	25%	0%	25%	n/a	n/a	n/a	n/a	n/a	n/a
11	Salt bath recovery system	50%	8%	50%	8%	50%	8%	n/a	n/a	n/a	n/a
12	Biological wastewater treatment	85%	0%	85%	0%	85%	0%	85%	0%	85%	0%

In addition, impact of the BATEA on **BOD, COD, and TSS** has been estimated where applicable. In this case, the approach taken has been to estimate reductions in total industry loadings, based on the following reduction factors:

1	Automated chemical dosing system	10% reduction in BOD and COD
2	Dye machine controllers	5% reduction in BOD; 10% reduction in COD (5% for knit segment)
5	Low liquor ratio dye machines	50% reduction in BOD and COD
6	Cold pad batch dyeing	50% reduction in BOD and COD (wovens only)
7	Quality control for raw materials	5% reduction in BOD and COD
11	Salt bath recovery system	20% reduction in TSS
12	Biological wastewater treatment	90%, 70%, and 50% reduction of BOD, COD, and TSS respectively

5.3 CALCULATIONS

Based on the input data in Tables 5.1, 5.2 and 5.3, the impact of the BATEA on effluent toxicity was derived as illustrated in the text box on the following page.

TOXICITY CALCULATIONS

Example: Low Liquor Ratio Dyeing Machines

STEP 1. Calculation of potential chemical & water use reduction

The calculation of chemical usage reduction for each of the BATEA is based upon (1) the reduction potential for the measure itself and (2) the level of potential implementation of the measure. In the benchmarking section it was established that the potential for replacing dyeing machines with low liquor ratio machines is 35% in the knit sector. Based on knowledge of the industry and the technology, it has also been estimated that the low liquor technology will save 50% of water and chemical use (Table 5.3). Based on this, salt and water usage reduction is as follows:

Actual salt usage from Table 5.2: 281.5 g/kg
Potential salt reduction: 50% reduction for 35% of the production
Projected salt usage:
= 281.5 g/kg – (50% x 35% x 281.5 g/kg)
= 232.2 g/kg

Average actual water usage for the knit segment from Table 5.1: 179 l/kg.
Potential water reduction: 80% of the water usage comes from the dyehouse and as for chemicals, the potential reduction of water usage will be 50% for 35% of the production.
Projected water usage:
= 179 l/kg – (80% x 50% x 35% x 179 l/Kg)
= 154 l/kg

STEP 2. Calculation Of Toxicity Reduction

In the toxicity model for TME's proposed in Section 3 of this report, toxicity for a group of chemicals is measured in toxic units, defined as the ratio of the concentration of the chemical group in the TME, divided by the LC50 of the chemical group. The total toxicity of the TME will be the sum of the toxic units for the eight chemical groups of the toxicity model.

For this BATEA, reduction of effluent toxicity arises only from the changes in chemical and water use, as calculated in Step 1. The determination of the toxicity reduction involves the following calculations:

Input data:	Salt and water data from Step 1 LC 50 for salt (from toxicity model): 7802 mg/l (see Section 3)

Actual effluent concentration of salts $= \frac{\text{281.5 g/kg x 1000 mg/g}}{\text{179 l/kg}}$ $= 1572$ mg/l

Projected effluent concentration of salts $= \frac{\text{232.2 g/kg x 1000 mg/g}}{\text{154 l/Kg}}$ $= 1508$ mg/l

Present toxicity for salt in TME $= \frac{\text{1572 mg/l}}{\text{7802 mg/l}} = 0.201$

Projected toxicity for salt with BATEA $= \frac{\text{1508 mg/l}}{\text{7802 mg/l}} = 0.193$

Percentage of toxicity reduction $= \frac{(0.201-0.193)}{0.201} = 3.6$ %

5.4 METHODOLOGY FOR TOXICITY REDUCTION BY DYE SUBSTITUTION

Dye substitution involves the replacement of more toxic dyes with less toxic alternatives. Given the large number of dyes used, and the wide range of toxicities exhibited by these dyes, analysis of the impacts of substitution can only be undertaken through a scenario approach.

Accordingly, two scenarios have been developed for illustrative purposes: base case and substitution scenarios. The base case scenario represents current usage, as described previously in Section 3 (Table 3.5). In the substitution scenario, it is assumed that 50% of dyes with an LC50 less than 100 ppm in the disperse and acid groups, and less than 1.0 in the basic group, are replaced with less toxic dyes.[16] These two scenarios are summarized in Table 5.4.

Table 5.4 - Relative Proportions of Dyes Used at Different Substitution Levels

Group	Dye	96-hour LC50 (mg/L)	Relative Proportions Within Dye Group	
			0% Substitution	50% Substitution
Disperse Group	Disperse Yellow 42	>180	1	1
	Disperse Yellow 3	>180	1	1
	Disperse Yellow 54	>180	1	1
	Disperse Blue 3	1	1	0.5
	Disperse Blue 7	52	1	0.5
	Disperse Red 60	>180	1	1
	Substitutes (combined)	5.8	0	1
	Group Total		6	6
Acid Group	Acid Orange 7	165	1	1
	Acid Black 52	7	1	0.5
	Acid Yellow 17	>180	1	1
	Acid Orange 24	130	1	1
	Acid Black 1	>180	1	1
	Acid Yellow 38	23	1	0.5
	Acid Blue 113	4	1	0.5
	Acid Green 25	6.2	1	0.5
	Acid Blue 25	12	1	0.5
	Acid Blue 45	>180	1	1
	Acid Yellow 151	29	1	0.5
	Substitutes (combined)	14.8	0	3
	Group Total		11	11
Basic Group	Basic Brown 4	5.6	1	1
	Basic Green 4	0.12	1	0.5
	Basic Violet 1	0.047	1	0.5
	Basic Yellow 11	3.2	1	1
	Basic Blue 3	4	1	1
	Substitutes (combined)	0.16	0	1
	Group Total		5	5

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[16] Within each group it is assumed that the replacement dyes, taken together, have a toxicity equivalent to the base case toxicity for the group as a whole (as previously listed in Table 3.6). In other words, the scenario assumes that certain of the more toxic dyes are partially replaced by a mix of other dyes, and that the mix exhibits "average" toxicity for the group in question.

The overall toxicity of dyes is calculated in two steps, as described previously (see Section 3.3). Based on this methodology, the overall toxicity of dyes is:

$C_{LC50\text{-dyes}}$ = 6.2 ppm at 0% substitution (as previously determined)

$C_{LC50\text{-dyes}}$ = 8.85 ppm at 50% substitution for certain dyes.

This reduced toxicity value is used in the determination of the toxicity impact of BATEA #4. It should be noted that this ***substitution scenario implies that only a small portion of dye usage is subject to substitution – approximately 7% of total usage by the wet processing textile industry.***

5.5 RESULTS OF TOXICITY ANALYSIS

Toxicity

Table 5.5 provides a summary of the results of the toxicity analysis for each of the 12 BATEA.

Table 5.5 - Toxicity and Volume Reduction

BATEA #	**BATEA Name**	**Toxicity and Volume Reduction**									
		Knit		**Woven**		**Yarn**		**Carpet**		**Wool**	
		Toxicity Reduction %	**Volume Reduction %**	**Toxicity Reduction %**	**Volume Reduction %**	**Toxicity Reduction %**	**Volume Reduction %**	**Toxicity Reduction %**	**Volume Reduction %**	**Toxicity Reduction %**	**Volume Reduction %**
1	Automated chem. dosing systems	2.4%	0.0%	5.6%	0.0%	6.0%	0.0%	5.5%	0.0%	5.9%	0.0%
2	Dye machine controllers	-0.7%	2.6%	-1.4%	4.3%	-0.7%	2.3%	-1.1%	4.0%	-1.4%	4.0%
3	Surfactant substitution	0.2%	0.0%	0.1%	0.0%	0.1%	0.0%	0.2%	0.0%	0.2%	0.0%
4	Dye substitution	7.2%	0.0%	4.8%	0.0%	4.8%	0.0%	7.9%	0.0%	3.2%	0.0%
5	Low liquor ratio dyeing machines	3.0%	14.2%	2.5%	10.6%	9.0%	31.2%	2.0%	10.0%	10.5%	33.4%
6	Cold pad batch dyeing			1.0%	7.2%						
7	Quality control for raw materials	6.5%	0.0%	6.7%	0.0%	9.4%	0.0%	9.7%	0.0%	6.2%	0.0%
9	Recycling/reuse of cooling/cond. water	-1.7%	2.2%	-3.0%	3.4%	-1.8%	2.2%	-2.0%	2.6%	-1.6%	1.8%
8	Pulsating rinse technology	-2.8%	3.5%	-1.5%	1.8%			-2.5%	3.3%		
10	Bleach bath recovery system	-10.8%	12.9%	-2.3%	2.7%						
11	Salt bath recovery system	0.8%	4.1%	0.2%	1.7%	0.2%	3.2%				
12	Biological waste-water treatment	80.2%	0.0%	75.5%	0.0%	84.5%	0.0%	85.0%	0.0%	70.6%	0.0%

The following points outline a number of key conclusions that can be drawn from this table:

- ***Eight of the BATEA reduce effluent toxicity***. With the exception of Biological Wastewater Treatment (up to 85% reduction depending on segment), the percentage reduction is in most cases below 10%. Although these reductions may not seem large on a percentage basis, it must be remembered that several of the technologies are complementary in impact (though not necessarily fully additive). Moreover, as is indicated in Section 6, most of the BATEA are cost effective from the point of view of the user, providing annual savings and short payback. In essence, the results of this analysis indicate potential for significant reductions in effluent toxicity, using economically attractive technologies and practices.

- ***Four of the technologies actually increase effluent toxicity***. This arises because these BATEA reduce effluent volume, without reducing chemical usage to the same degree (dye machine controllers) or at all (recycling/reuse of cooling/condensate water, pulsating rinse technology, and bleach bath recovery). Each of these technologies offers environmental and other benefits. Nonetheless, this analysis suggests that these technologies would not form part of a strategy focussed on reduction of effluent toxicity (with the probable exception of dye machine controllers, which do reduce total loadings of substances that contribute to effluent toxicity).

- ***The levels of toxicity reduction suggested in the table assume full implementation of the technical potential,*** as identified in our benchmarking task**.** The likelihood of this occuring is dependent on a number of factors, including choice of management instrument. Nonetheless, inherent in the concept of technical potential is recognition that other factors will mitigate against full implementation. This is particularly the case with biological wastewater treatment, which is unique among the BATEA with respect to the capital and ongoing costs. Moreover, the *net* benefits of biological wastewater treatment at the mill level will be heavily influenced by such factors as the level of treatment provided by the local MWWTP, for the majority of mills that discharge to such systems.

- ***Although the full technical potential of the modelled BATEA may not be realized, it must also be recognized that additional "unmodelled" potential exists in the case of certain BATEA.*** For instance, more aggressive dye substitution or quality control initiatives would yield greater toxicity reductions. In addition, the 12 BATEA modelled here are only a select subset of the full range of technologies that can be applied.

NPE Reductions

Several of the BATEA yield changes in the concentration of NPEs in untreated textile mill effluent, as summarized in Table 5.6. With the exception of NPE surfactant substitution (BATEA #3), the maximum reduction is under 10%.

Table 5.6 – Impact of BATEA on NPE Concentration in Untreated Effluents

BATEA	NPE Concentration Change by Segment									
	Knit		Woven		Yarn		Carpet		Wool	
	Concen-tration mg/l	*Reduction %*	*Concen-tration mg/l*	*Reduction %*	*Concen-tration mg/l*	*Reduction %*	*Concen-tration mg/l*	*Reduction %*	*Concen-tration mg/l*	*Reduction %*
1-Automated Chemical Dosing Systems	4.0	3.2%	3.8	6.6%	3.8	7.1%	3.8	7.6%	3.8	6.6%
2-Dye Machine Controllers	4.1	-1.0%	4.2	-1.7%	4.1	-1.0%	4.2	-1.5%	4.2	-1.5%
3-NPE Surfactant Substitution	0.0	100.0%	0.0	100.0%	0.0	100.0%	0.0	100.0%	0.0	100.0%
4-Dye Substitution	4.1	0.0%	4.1	0.0%	4.1	0.0%	4.1	0.0%	4.1	0.0%
5-Low Liquor Ratio Dyeing Machines	4.0	3.7%	4.0	2.7%	3.8	7.8%	4.0	2.4%	3.8	8.3%
6-Cold Pad Batch Dyeing	N/A	N/A	4.1	1.2%	N/A	N/A	N/A	N/A	N/A	N/A
7-Quality Control for Raw Materials	3.9	4.9%	3.9	4.9%	3.9	4.9%	3.9	4.9%	3.9	4.9%
9-Recycling and Reuse of Cooling Water and	4.2	-2.2%	4.2	-3.4%	4.2	-2.2%	4.2	-2.7%	4.2	-1.7%
8-Pulsating Rinse Technology	4.2	-3.4%	4.2	-1.7%	N/A	N/A	4.2	-3.4%	N/A	N/A
10-Bleach Bath Recovery System	4.6	-12.9%	4.2	-2.7%	N/A	N/A	N/A	N/A	N/A	N/A
11-Salt Bath Recovery System	4.1	0.0%	4.1	0.0%	4.1	0.0%	N/A	N/A	N/A	N/A

Normalized Data

Seven of the BATEA affect effluent volume. Three of these BATEA have no impact on chemical use, but the other four affect both effluent volume and chemical use. For these, the change in effluent toxicity shown in our tables is meaningful, but difficult to interpret due to the masking effect of volume changes. As noted above, reduced effluent volume can result in an increase in effluent toxicity, even in cases where the total load of toxic substances is being reduced (dye machine controllers). For other technologies (low liquor ratio dyeing machines, cold pad batch dyeing, and salt bath recovery), the BATEA results in a net reduction of toxicity, but to a lesser degree than would otherwise be expected, because of reduced effluent volume.

To address this masking effect, it is useful to present the toxicity reductions in a "normalized" form – that is, the toxicity reductions that would be produced by the BATEA if there were no change in effluent volume. In essence, this normalized data reflects the impact of the BATEA on the load of toxic substances discharged.

Figure 5.2 presents TME effluent toxicity reduction for the knit segment, based on normalized data as just described. Figure 5.3 presents similar data for all segments.

Figure 5.2 – Untreated TME Toxicity Reduction: Knit Segment (Normalized)

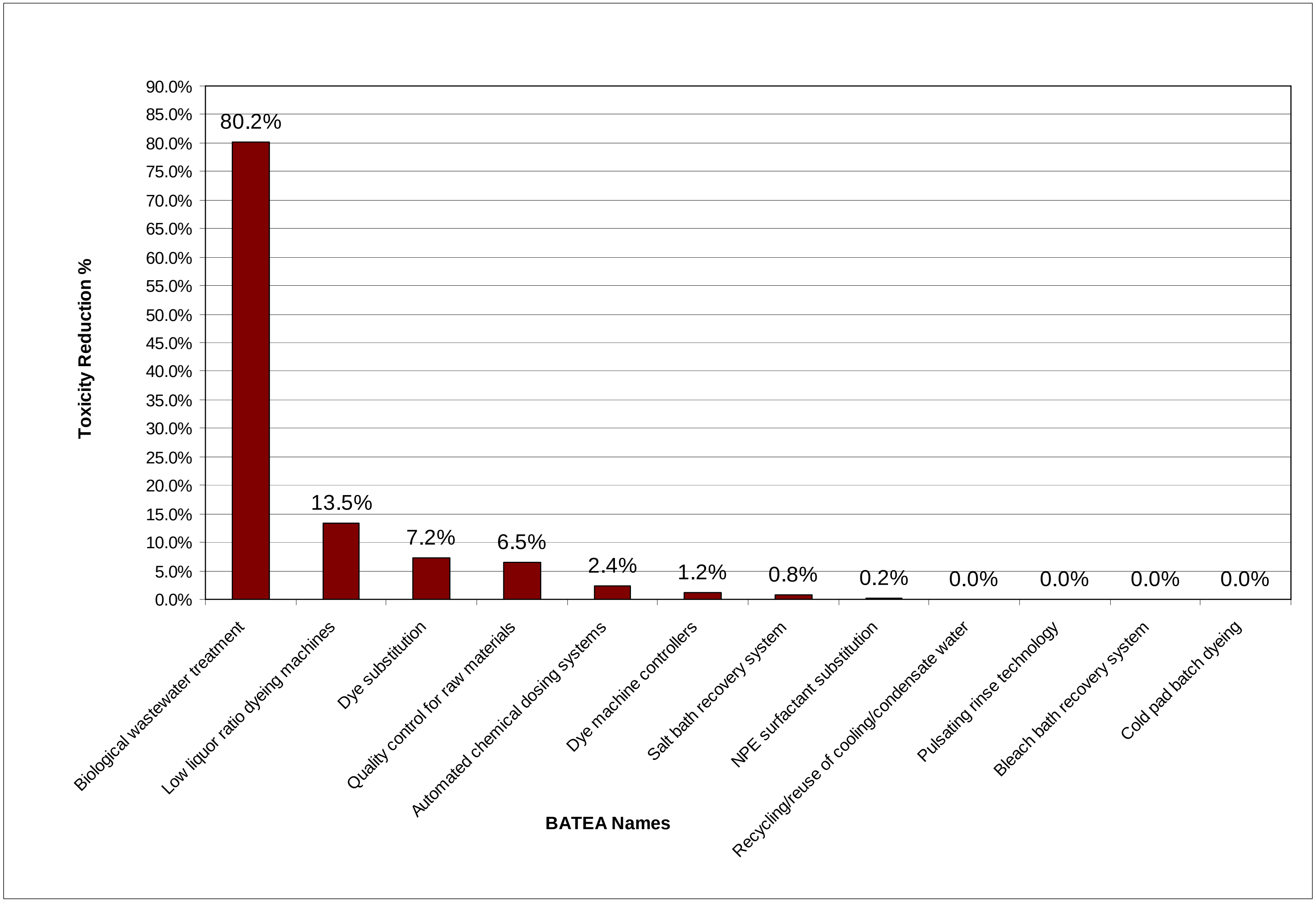
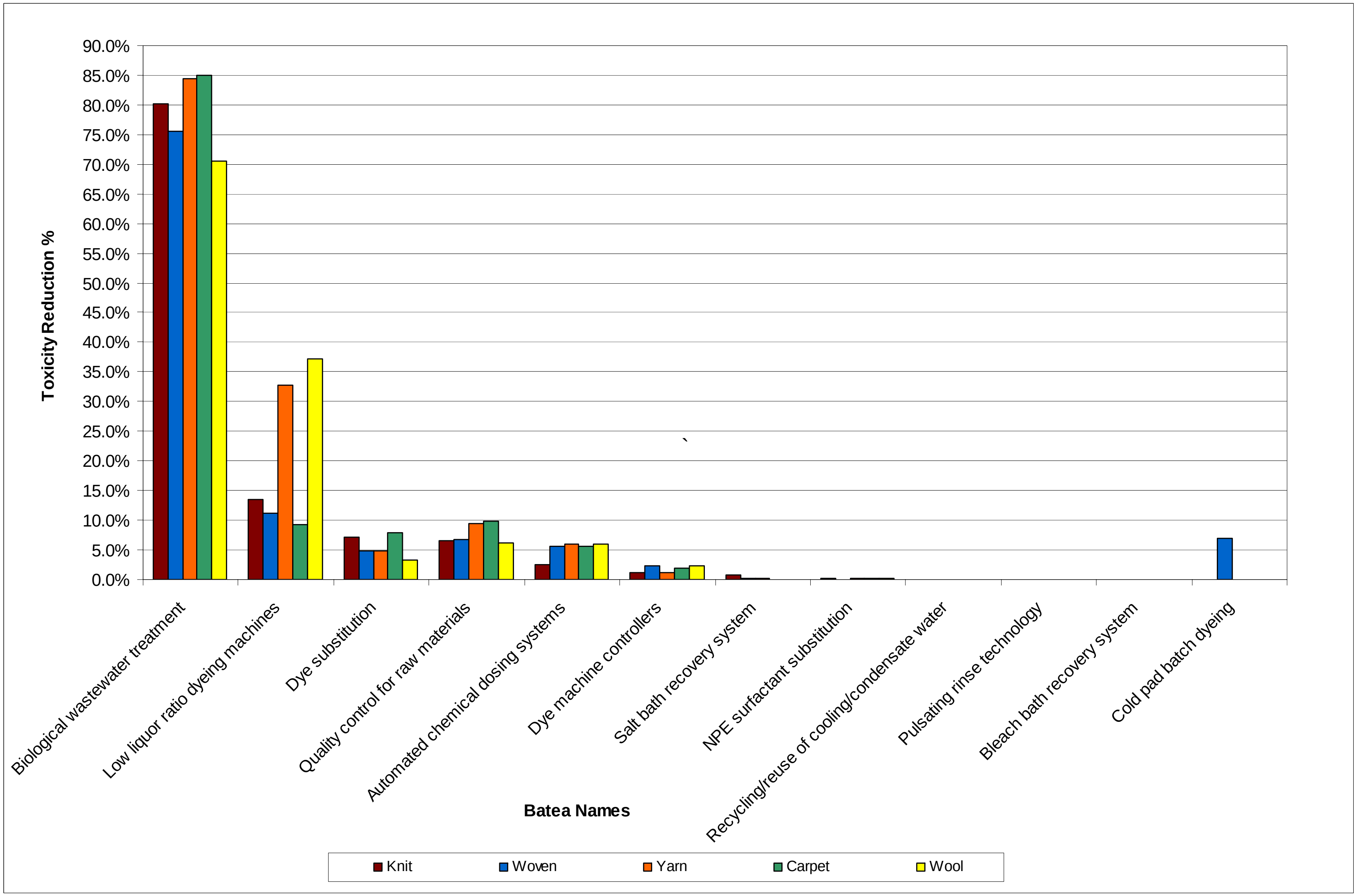


Figure 5.3 – Untreated TME Toxicity Reduction: All Segments (Normalized)



The following discussion highlights key conclusions that can be drawn from the figures:

- ***Apart from wastewater treatment, low liquor ratio dyeing machines offer the greatest potential for normalized toxicity reduction in all segments***. Quality control for raw materials, dye substitution, and several other BATEA also offer potential for significant toxicity reductions. Taken together, these pollution prevention technologies offer the potential for normalized toxicity reductions in the 30% range, using available technologies with generally short payback periods.[17]

- ***Some BATEA have little or no impact on normalized toxicity.*** Most obviously, the three BATEA that do not affect chemical use have no toxicity impact (recycling/reuse of cooling/condensate water, pulsating rinse technology, and bleach bath recovery). In addition, for most segments, the toxicity impact of salt bath recovery systems is limited, and as previously noted cold pad batch dyeing is applicable only in the wovens segment. NPE surfactant substitution also shows little impact on toxicity as presented in these graphs, because the focus here is on ***untreated*** effluent toxicity. As discussed elsewhere in this report, reduced use of NPE can be associated with reduced toxicity in ***treated*** effluent.

5.6 RESULTS OF TOXICITY ANALYSIS BY SEGMENT

The impact of the modelled BATEA varies among the segments. Most noticeably, certain BATEA apply only to certain segments. In other cases, although the expected percentage reduction in chemical and water use may be similar at the plant level, the overall impact can vary significantly between segments due to large differences in implementation potential.

Tables 5.7 through 5.11 provide detailed analysis by segment. The following discussion describes the information provided in each table:

- ***The first row of data*** in each table presents the LC50 for each of the eight chemical groups included in the toxicity model. These values match the numbers presented previously, in Section 3.

- ***The second row*** presents the estimated effluent concentration of each of the eight chemical groups included in the model. This concentration is based on current conditions in the industry, and is derived in the manner described above in Section 5.3.

- ***The third row presents*** the "toxic units" for each chemical group, based on the ratio between the numbers in the preceding two rows. This is the toxicity (as modelled), prior to application of any of the BATEA.

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[17] As has been noted, the toxicity impacts of the individual BATEA are not necessarily fully additive. However, pending further analysis, it is believed that any resulting reduction of impact would be small, and consistent with the statement made here.

- ***The remaining rows*** present similar data for each of the BATEA in turn – first the estimated effluent concentration following application of the BATEA, and second the resulting toxic units. Note that in most cases the toxic units are derived based on the original LC50 of the chemical group (the first row of data in the table), since the BATEA does not affect the LC50. In cases where the BATEA does affect LC50 (such as dye substitution as described above), the toxic units are derived based on a revised LC50.

- ***Finally, the last COLUMN*** provides the total toxic units for the segment. The first number in this column is the toxicity of the effluent without application of the BATEA; the remaining numbers measure estimated toxicity after application of each of the BATEA. These numbers are the basis for the percentage reductions provided above in Table 5.5.

Table 5.7 - Effluent Toxicity Reduction - Knitting Mills

BATEA #	**BATEA Name**		**Toxicity Parameters**								
			Salts	**Surfactants (NPE's)**	**Surfactants (non-NPE's)**	**Phosphates**	**Dyes**	**Carriers**	**Solvents (Scouring)**	**Chelates (Bleach / Scouring)**	**Total**
		LC 50	7802	4.6	4.7	73	6.2	2.5	4.5	207	
	Actual Toxicity	Conc. mg /l.	1572.72	4.10	15.33	5.20	11.63	1.05	3.80	54.98	
		Toxic units	**0.20**	**0.89**	**3.26**	**0.07**	**1.88**	**0.42**	**0.84**	**0.27**	**7.83**
1	Automated chemical dosing systems	Conc. mg /l.	1522.08	3.97	14.84	5.03	11.63	1.02	3.68	53.21	
		Toxic units	**0.20**	**0.86**	**3.16**	**0.07**	**1.88**	**0.41**	**0.82**	**0.26**	**7.64**
2	Dye machine controllers	Conc. mg /l.	1588.22	4.14	15.49	5.25	11.63	1.06	3.84	55.52	
		Toxic units	**0.20**	**0.90**	**3.29**	**0.07**	**1.88**	**0.42**	**0.85**	**0.27**	**7.89**
3	Surfactant substitution	Conc. mg /l.	1572.72	0.00	19.43	5.20	11.63	1.05	3.80	54.98	
		Toxic units	**0.20**	**0.00**	**4.13**	**0.07**	**1.88**	**0.42**	**0.84**	**0.27**	**7.82**
4	Dye substitution	Conc. mg /l.	1572.72	4.10	15.33	5.20	11.63	1.05	3.80	54.98	
		Toxic units	**0.20**	**0.89**	**3.26**	**0.07**	**1.31**	**0.42**	**0.84**	**0.27**	**7.27**
5	Low liquor ratio dyeing machines	Conc. mg /l.	1507.86	3.95	14.70	5.02	11.63	1.01	3.67	52.72	
		Toxic units	**0.19**	**0.86**	**3.13**	**0.07**	**1.88**	**0.40**	**0.81**	**0.25**	**7.60**
6	Cold pad batch dyeing	Conc. mg /l.									
		Toxic units									
7	Quality control for raw materials	Conc. mg /l.	1572.72	3.90	14.57	4.94	11.63	1.00	3.61	52.23	
		Toxic units	**0.20**	**0.85**	**3.10**	**0.07**	**1.71**	**0.36**	**0.80**	**0.23**	**7.32**
9	Recycling/reuse of cooling/condensat	Conc. mg /l.	1607.84	4.19	15.68	5.31	11.63	1.08	3.88	56.21	
		Toxic units	**0.21**	**0.91**	**3.34**	**0.07**	**1.88**	**0.43**	**0.86**	**0.27**	**7.97**
8	Pulsating rinse technology	Conc. mg /l.	1630.31	4.24	15.90	5.38	11.63	1.09	3.93	57.00	
		Toxic units	**0.21**	**0.92**	**3.38**	**0.07**	**1.88**	**0.44**	**0.87**	**0.28**	**8.05**
10	Bleach bath recovery system	Conc. mg /l.	1805.65	4.63	17.61	5.87	11.63	1.21	4.29	63.13	
		Toxic units	**0.23**	**1.01**	**3.75**	**0.08**	**1.88**	**0.48**	**0.95**	**0.30**	**8.68**
11	Salt bath recovery system	Conc. mg /l.	1111.40	4.10	15.33	5.20	11.63	1.05	3.80	54.98	
		Toxic units	**0.14**	**0.89**	**3.26**	**0.07**	**1.88**	**0.42**	**0.84**	**0.27**	**7.78**
12	Biological wastewater treatment	Conc. mg /l.	1572.72	0.73	2.72	0.92	2.06	0.19	0.67	9.74	
		Toxic units	**0.20**	**0.16**	**0.58**	**0.01**	**0.33**	**0.07**	**0.15**	**0.05**	**1.55**

Table 5.8 - Effluent Toxicity Reduction – Woven Mills

BATEA #	BATEA Name		Toxicity Parameters								
			Salts	**Surfactants (NPE's)**	**Surfactants (non-NPE's)**	**Phosphates**	**Dyes**	**Carriers**	**Solvents (Scouring)**	**Chelates (Bleach / Scouring)**	**Total**
		LC 50	7802	4.6	4.7	73	6.2	2.5	4.5	207	
	Actual Toxicity	Conc. mg /l.	2040.97	4.10	56.03	5.20	19.96	2.75	3.80	342.53	
		Toxic units	**0.26**	**0.89**	**11.92**	**0.07**	**3.22**	**1.10**	**0.84**	**1.65**	**19.96**
1	Automated chemical dosing systems	Conc. mg /l.	1905.04	3.83	52.30	4.85	19.96	2.57	3.55	319.72	
		Toxic units	**0.24**	**0.83**	**11.13**	**0.07**	**3.22**	**1.03**	**0.79**	**1.54**	**18.85**
2	Dye machine controllers	Conc. mg /l.	2075.06	4.17	56.96	5.28	19.96	2.80	3.86	348.25	
		Toxic units	**0.27**	**0.91**	**12.12**	**0.07**	**3.22**	**1.12**	**0.86**	**1.68**	**20.24**
3	Surfactant substitution	Conc. mg /l.	2040.97	0.00	60.13	5.20	19.96	2.75	3.80	342.53	
		Toxic units	**0.26**	**0.00**	**12.79**	**0.07**	**3.22**	**1.10**	**0.84**	**1.65**	**19.94**
4	Dye substitution	Conc. mg /l.	2040.97	4.10	56.03	5.20	19.96	2.75	3.80	342.53	
		Toxic units	**0.26**	**0.89**	**11.92**	**0.07**	**2.25**	**1.10**	**0.84**	**1.65**	**19.00**
5	Low liquor ratio dyeing machines	Conc. mg /l.	1980.21	3.99	54.36	5.06	19.96	2.67	3.70	332.34	
		Toxic units	**0.25**	**0.87**	**11.57**	**0.07**	**3.22**	**1.07**	**0.82**	**1.61**	**19.47**
6	Cold pad batch dyeing	Conc. mg /l.	2016.11	4.05	55.35	5.14	19.96	2.72	3.76	338.36	
		Toxic units	**0.26**	**0.88**	**11.78**	**0.07**	**3.22**	**1.09**	**0.83**	**1.63**	**19.76**
7	Quality control for raw materials	Conc. mg /l.	2040.97	3.90	53.23	4.94	19.96	2.61	3.61	325.40	
		Toxic units	**0.26**	**0.85**	**11.32**	**0.07**	**2.93**	**0.95**	**0.80**	**1.43**	**18.62**
9	Recycling/reuse of cooling/condensate	Conc. mg /l.	2113.50	4.24	58.02	5.38	19.96	2.85	3.93	354.70	
		Toxic units	**0.27**	**0.92**	**12.34**	**0.07**	**3.22**	**1.14**	**0.87**	**1.71**	**20.56**
8	Pulsating rinse technology	Conc. mg /l.	2077.66	4.17	57.04	5.29	19.96	2.80	3.87	348.69	
		Toxic units	**0.27**	**0.91**	**12.14**	**0.07**	**3.22**	**1.12**	**0.86**	**1.68**	**20.26**
10	Bleach bath recovery system	Conc. mg /l.	2096.74	4.21	57.56	5.34	19.96	2.83	3.90	351.89	
		Toxic units	**0.27**	**0.92**	**12.25**	**0.07**	**3.22**	**1.13**	**0.87**	**1.70**	**20.42**
11	Salt bath recovery system	Conc. mg /l.	1800.16	4.10	56.03	5.20	19.96	2.75	3.80	342.53	
		Toxic units	**0.23**	**0.89**	**11.92**	**0.07**	**3.22**	**1.10**	**0.84**	**1.65**	**19.93**
12	Biological wastewater treatment	Conc. mg /l.	2040.97	0.96	13.17	1.22	4.69	0.65	0.89	80.49	
		Toxic units	**0.26**	**0.21**	**2.80**	**0.02**	**0.76**	**0.26**	**0.20**	**0.39**	**4.89**

Table 5.9 - Effluent Toxicity Reduction – Yarn Stock Mills

BATEA #	BATEA Name		Toxicity Parameters								
			Salts	**Surfactants (NPE's)**	**Surfactants (non-NPE's)**	**Phosphates**	**Dyes**	**Carriers**	**Solvents (Scouring)**	**Chelates (Bleach / Scouring)**	**Total**
		LC 50	7802	4.6	4.7	73	6.2	2.5	4.5	207	
	Actual Toxicity	Conc. mg /l.	650.79	4.10	16.62	5.20	13.46	14.67	3.80	11.66	
		Toxic units	**0.08**	**0.89**	**3.54**	**0.07**	**2.17**	**5.87**	**0.84**	**0.06**	**13.52**
1	Automated chemical dosing systems	Conc. mg /l.	604.32	3.81	15.43	4.83	13.46	13.62	3.53	10.83	
		Toxic units	**0.08**	**0.83**	**3.28**	**0.07**	**2.17**	**5.45**	**0.78**	**0.05**	**12.71**
2	Dye machine controllers	Conc. mg /l.	656.59	4.14	16.76	5.25	13.46	14.80	3.83	11.76	
		Toxic units	**0.08**	**0.90**	**3.57**	**0.07**	**2.17**	**5.92**	**0.85**	**0.06**	**13.62**
3	Surfactant substitution	Conc. mg /l.	650.79	0.00	20.72	5.20	13.46	14.67	3.80	11.66	
		Toxic units	**0.08**	**0.00**	**4.41**	**0.07**	**2.17**	**5.87**	**0.84**	**0.06**	**13.50**
4	Dye substitution	Conc. mg /l.	650.79	4.10	16.62	5.20	13.46	14.67	3.80	11.66	
		Toxic units	**0.08**	**0.89**	**3.54**	**0.07**	**1.52**	**5.87**	**0.84**	**0.06**	**12.87**
5	Low liquor ratio dyeing machines	Conc. mg /l.	577.01	3.78	14.73	4.79	13.46	13.00	3.50	10.34	
		Toxic units	**0.07**	**0.82**	**3.13**	**0.07**	**2.17**	**5.20**	**0.78**	**0.05**	**12.30**
6	Cold pad batch dyeing	Conc. mg /l.									
		Toxic units									
7	Quality control for raw materials	Conc. mg /l.	650.79	3.90	15.78	4.94	13.46	13.93	3.61	11.08	
		Toxic units	**0.08**	**0.85**	**3.36**	**0.07**	**1.98**	**5.07**	**0.80**	**0.05**	**12.25**
9	Recycling/reuse of cooling/condensat	Conc. mg /l.	665.32	4.19	16.99	5.31	13.46	14.99	3.88	11.92	
		Toxic units	**0.09**	**0.91**	**3.61**	**0.07**	**2.17**	**6.00**	**0.86**	**0.05**	**13.77**
8	Pulsating rinse technology	Conc. mg /l.									
		Toxic units									
10	Bleach bath recovery system	Conc. mg /l.									
		Toxic units									
11	Salt bath recovery system	Conc. mg /l.	504.23	4.10	16.62	5.20	13.46	14.67	3.80	11.66	
		Toxic units	**0.06**	**0.89**	**3.54**	**0.07**	**2.17**	**5.87**	**0.84**	**0.05**	**13.50**
12	Biological wastewater treatment	Conc. mg /l.	650.79	0.62	2.49	0.78	2.02	2.20	0.57	1.75	
		Toxic units	**0.08**	**0.13**	**0.53**	**0.01**	**0.33**	**0.88**	**0.13**	**0.01**	**2.10**

Table 5.10 - Effluent Toxicity Reduction – Carpet Mills

BATEA #	BATEA Name		Toxicity Parameters								
			Salts	**Surfactants (NPE's)**	**Surfactants (non-NPE's)**	**Phosphates**	**Dyes**	**Carriers**	**Solvents (Scouring)**	**Chelates (Bleach / Scouring)**	**Total**
		LC 50	7802	4.6	4.7	73	6.2	2.5	4.5	207	
	Actual Toxicity	Conc. mg /l.		4.10	29.70	5.20	20.55	2.96	3.80		
		Toxic units		**0.89**	**6.32**	**0.07**	**3.31**	**1.18**	**0.84**		**12.62**
1	Automated chemical dosing systems	Conc. mg /l.		3.79	27.47	4.81	20.55	2.74	3.52		
		Toxic units		**0.82**	**5.84**	**0.07**	**3.31**	**1.09**	**0.78**		**11.93**
2	Dye machine controllers	Conc. mg /l.		4.16	30.16	5.28	20.55	3.01	3.86		
		Toxic units		**0.90**	**6.42**	**0.07**	**3.31**	**1.20**	**0.86**		**12.77**
3	Surfactant substitution	Conc. mg /l.		0.00	33.80	5.20	20.55	2.96	3.80		
		Toxic units		**0.00**	**7.19**	**0.07**	**3.31**	**1.18**	**0.84**		**12.60**
4	Dye substitution	Conc. mg /l.		4.10	29.70	5.20	20.55	2.96	3.80		
		Toxic units		**0.89**	**6.32**	**0.07**	**2.32**	**1.18**	**0.84**		**11.63**
5	Low liquor ratio dyeing machines	Conc. mg /l.		4.00	28.87	5.07	20.55	2.88	3.71		
		Toxic units		**0.87**	**6.14**	**0.07**	**3.31**	**1.15**	**0.82**		**12.37**
6	Cold pad batch dyeing	Conc. mg /l.									
		Toxic units									
7	Quality control for raw materials	Conc. mg /l.		3.90	28.21	4.94	20.55	2.81	3.61		
		Toxic units		**0.85**	**6.00**	**0.07**	**3.02**	**0.65**	**0.80**		**11.39**
9	Recycling/reuse of cooling/condensat	Conc. mg /l.		4.21	30.49	5.34	20.55	3.04	3.90		
		Toxic units		**0.91**	**6.49**	**0.07**	**3.31**	**1.22**	**0.87**		**12.87**
8	Pulsating rinse technology	Conc. mg /l.		4.24	30.72	5.37	20.55	3.06	3.93		
		Toxic units		**0.92**	**6.54**	**0.07**	**3.31**	**1.22**	**0.87**		**12.94**
10	Bleach bath recovery system	Conc. mg /l.									
		Toxic units									
11	Salt bath recovery system	Conc. mg /l.									
		Toxic units									
12	Biological wastewater treatment	Conc. mg /l.		0.62	4.45	0.78	3.08	0.44	0.57		
		Toxic units		**0.13**	**0.95**	**0.01**	**0.50**	**0.18**	**0.13**		**1.89**

Table 5.11 - Effluent Toxicity Reduction – Wool Mills

BATEA #	BATEA Name		Toxicity Parameters								
			Salts	**Surfactants (NPE's)**	**Surfactants (non-NPE's)**	**Phosphates**	**Dyes**	**Carriers**	**Solvents (Scouring)**	**Chelates (Bleach / Scouring)**	**Total**
		LC 50	7802	4.6	4.7	73	6.2	2.5	4.5	207	
	Actual Toxicity	Conc. mg /l.		4.10	36.01	5.20	7.20	0.53	3.80		
		Toxic units		**0.89**	**7.66**	**0.07**	**1.16**	**0.21**	**0.84**		**10.84**
1	Automated chemical dosing systems	Conc. mg /l.		3.83	33.61	4.85	7.20	0.49	3.55		
		Toxic units		**0.83**	**7.15**	**0.07**	**1.16**	**0.20**	**0.79**		**10.20**
2	Dye machine controllers	Conc. mg /l.		4.16	36.57	5.28	7.20	0.54	3.86		
		Toxic units		**0.90**	**7.78**	**0.07**	**1.16**	**0.21**	**0.86**		**10.99**
3	Surfactant substitution	Conc. mg /l.		0.00	40.11	5.20	7.20	0.53	3.80		
		Toxic units		**0.00**	**8.53**	**0.07**	**1.16**	**0.21**	**0.84**		**10.82**
4	Dye substitution	Conc. mg /l.		4.10	36.01	5.20	7.20	0.53	3.80		
		Toxic units		**0.89**	**7.66**	**0.07**	**0.81**	**0.21**	**0.84**		**10.49**
5	Low liquor ratio dyeing machines	Conc. mg /l.		3.76	31.50	4.77	7.20	0.46	3.48		
		Toxic units		**0.82**	**6.70**	**0.07**	**1.16**	**0.18**	**0.77**		**9.71**
6	Cold pad batch dyeing	Conc. mg /l.									
		Toxic units									
7	Quality control for raw materials	Conc. mg /l.		3.90	34.21	4.94	7.20	0.50	3.61		
		Toxic units		**0.85**	**7.28**	**0.07**	**1.06**	**0.12**	**0.80**		**10.17**
9	Recycling/reuse of cooling/condensat	Conc. mg /l.		4.17	36.66	5.29	7.20	0.54	3.87		
		Toxic units		**0.91**	**7.80**	**0.07**	**1.16**	**0.22**	**0.86**		**11.02**
8	Pulsating rinse technology	Conc. mg /l.									
		Toxic units									
10	Bleach bath recovery system	Conc. mg /l.									
		Toxic units									
11	Salt bath recovery system	Conc. mg /l.									
		Toxic units									
12	Biological wastewater treatment	Conc. mg /l.		1.21	10.60	1.53	2.12	0.16	1.12		
		Toxic units		**0.26**	**2.26**	**0.02**	**0.34**	**0.06**	**0.25**		**3.19**

6. COSTS OF BATEA

In Section 4, summary results concerning costs were presented for each BATEA. In this section, the methodology used in our analysis is presented, together with further detail and discussion of the results.

More specifically, this Section reports the impact of each BATEA on industry capital and operating costs. Impact is reported for the industry as a whole, and by industry segment, along with the estimated number of plants impacted. Appendices C and D also provide detailed information on data inputs for each BATEA, including estimates by plant size.

At the outset, it should be noted that many of the BATEA are found to be of positive value to the industry. They pay for themselves, including financing costs. This affects the reporting format of the tables. Annualized savings are reported as positive numbers, while annualized costs are reported as negative numbers. Reasons why there might be unexploited cost savings to the industry are discussed further below.

The Section is organized in the following parts:

- Subsection 6.1 presents our approach to costing
- Subsection 6.2 summarizes industry costs for the BATEA
- Subsection 6.3 provides an analysis of these costs
- Subsection 6.4 presents a variance analysis of the estimates
- Subsection 6.5 disaggregates the costs by market segment.

6.1 APPROACH TO COSTING

Costing of each BATEA was undertaken by means of the following steps:

- **Define a small, medium and large plant size** for the BATEA in question. Plant size was usually defined in terms of thousands of kilograms of relevant throughput per week. Relevant plant-size varied between BATEA.

- **Estimate plant level capital costs for small, medium and large plants.** Industry expert knowledge of project team members (Fintex) was applied to make this estimate.

- **Estimate operating savings/cost impacts for medium size plant.** A detailed calculation was made for the typical, or medium size, plant. This calculation was done in two stages. First, industry standard cost items were included, comparable to the usual commercial analyses of the relevant products used to implement the BATEA. Second, as a conservative measure where relevant, additional operating cost items were added where expert members of the Project team felt they were material.

- **Pro-rate operating savings/costs for small and large plants.** Depending on the nature of the cost impacts, pro-rating was either by kilograms throughput, or by capital costs.

Once the plant level cost impacts were known, they were multiplied by the number of relevant plants to obtain industry cost impacts. Relevant plants were those estimated to be in a position to use the BATEA, but not yet having implemented in it. The calculation was undertaken separately for small, medium, and large plants in each industry segment. The tables in this section include results by plant size and market segment.

Industry Growth Assumptions

In order to clearly identify the costs to current stakeholders, the cost estimates assume the continued operation of plants currently in production. Zero growth is assumed. This assumption will be reviewed in the context of the broader benefit/cost analyses and projections in the next steps of this project.

Unexploited Cost Savings in the Industry

One of the interesting results that can emerge from control studies is that there are available technologies that reduce pollutants and save the private sector money at the same time. In this study, nine of the twelve BATEA selected for examination show a positive rate of return to the industry.

From an economic perspective, a natural question to ask is why profit-maximizing private firms have not already implemented such measures. If it really pays, would firms not already have implemented such measures? In a world where information was freely acquired and assessed, this would be the case. However, in reality, there is a cost to acquiring information, and further costs to assessing and processing technical information. In an industry where segments have seen significant declines, such as textiles, there are additional cost barriers since management capacity and innovative capacity may have been trimmed back to reduce costs. Without the previous assurance that the savings are there to be realized, firms may not take the steps to discover effective means of reducing costs that are identified in this study.

One of the positive contributions of government to national productivity is the ability to bring these savings to the attention of stakeholders, to the benefit of both the public good, and private profitability.

Replacement of Old Equipment

Some of the BATEA call for the introduction of new capital equipment that may replace previous capital equipment. A potential error in benefit/cost analysis is to count the cost of the new equipment as a completely new incremental cost to the industry. If the old equipment is near the end of its life, and is due for replacement anyways, then the true incremental capital cost of the BATEA is only the additional cost of the new equipment relative to the replacement equipment that otherwise would be purchased (plus an adjustment for the requirement to replace the old equipment sooner than planned).

For the purposes of this analysis, this impact was ignored. After reviewing the BATEA selected, it was noted that where capital equipment was being replaced, the relevant existing equipment tended to have a remaining lifetime in excess of 20 years. Those textile plants remaining in production in Canada tend to be centred on established capital investments that can be maintained over the long run.

Thus, any savings from saved replacement costs are remote in time. Omitting this consideration from the analysis results in more conservative cost estimates, and changed the analysis very little. The main impact of replacing capital, where relevant, is on reduced operating costs.

Other Capital Costs

For the purposes of this analysis, any one-time costs were treated as capital costs. This includes the one-time cost of installation or retaining expert advice. For example, in the case of Improved Quality Control for Raw Materials (BATEA #7), the capital cost is the cost of retaining expert advice to review systems, recommend improvements, and train staff.

Time Horizon

A time horizon of 20 years is used to assess net present value, and annualized costs. This was based on the assessment of the expert members of the team that capital equipment relevant to any of the BATEA had a likely life span of at least 20 years. No terminal or salvage values have been assumed for the end of the 20 year period, as technology and market circumstances may have changed substantively by then. Since most of the BATEA are cost saving, the setting of terminal or salvage values to zero makes the estimates conservative with respect to net benefits.

Discount Rates

Time is money. To evaluate the net present value of a stream of costs and benefits over time, it is necessary to discount future costs and benefits by a rate of interest reflecting the cost of capital over time. Two discount rates are used.

First, as per Treasury Board Secretariat guidelines, a social discount rate of 10% is used. This is an after-inflation minimum rate of return that is expected from government initiatives. It reflects the estimated cost to society of capital, after accounting for the distortionary impacts of the taxation system.

However, the cost of capital to private firms is higher than the social discount rate. Stakeholders will be interested in knowing the proposed net costs and benefits of BATEA to themselves, after accounting for financing costs. Although secured rates of borrowing are usually lower than 10%, the total cost of capital to firms is an average of the cost of borrowing and the cost of attracting equity investment. Greater debt incurred increases the rate of return necessary to attract equity investment. There is no authoritative source for cost of capital to the textile industry. This study uses a conservative estimate of 15% real, after-inflation, rate of return. The calculations using 15% will be used to support later analysis of any re-distributive impacts of government initiatives between textile industry stakeholders and other economic stakeholders, and impact on small businesses. Both these forms of analysis are required to meet federal government standards for implementing wise and effective policy (e.g., in the case of regulation, they are a requirement for Regulatory Impact Analysis Statements).

6.2 INDUSTRY COSTS

Table 6.1 reports the cost of BATEA for the industry as a whole, broken down by plant size. This table format is used for the balance of this section. All dollar numbers are reported in Year 2001 constant dollars. Columns are defined as below:

- **Plant Size.** Identification of plant size category. Small, medium and large are defined based on the throughput for each BATEA, as discussed in methodology above.

- **# of Plants.** The estimated number of plants that are in a position to implement the BATEA, but have not already done so.

- **Capital Cost.** The sum of capital equipment, training, and other one-time costs incurred across plants for implementing the BATEA.

- **Operating Saving (Cost).** The sum of annual cost impact of each BATEA over the affected plants. Savings are entered as positive numbers. Costs are negative numbers, shown in brackets as per accounting convention. Totals are also provided for the combined savings generated by all pollution prevention BATEA (#1 to #11). Note, however, that these combined totals are not meant to imply that implementation of all eleven BATEA together would yield these total savings, since savings across the 11 BATEA are unlikely to be fully additive. (This qualification applies equally to similar totals for annualized savings and net present value.)

- **Simple Payback in Years.** The number of years that it takes for a plant to recover its initial investment in the capital costs through the annual savings generated, without counting financing costs. Simple payback is calculated by dividing Capital Costs by Operating Savings. It is only relevant where there are savings. Payback is a common private sector heuristic for assessing the impact of capital improvements. Fractions of a year are expressed as a decimal, rather than months. For example, 2.20 indicates two and two tenths of a year. The payback entry for BATEA #1 to #11, at the bottom of the table, represents a weighted average for these BATEA.

- **Annualized Savings (Costs).** The net annual cost or savings, once the cost of capital is converted to annual cost using the discount rate and an amortization period. The amortization period used is 20 years. The number under the social discount rate of 10% is the estimated annualized cost to society, including the impacts of the taxation system on capital markets. The number under the 15% is the estimated annualized cost experienced by the textiles industry. (See discussion of discount rates under Methodology above). Again, a positive number reflects a net annual saving. A negative number is in brackets. Note that where there are no up front capital costs, such as in the Chemical Substitution BATEA (#3, #4), the annualized cost is the same as the annual cost, and unaffected by the choice of a 10% or 15% discount rate.

Table 6.1 - Industry Cost Impacts ($ Millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	13	1.95	0.95	2.06	0.6	0.7	4.0	6.1
		Medium	26	6.92	3.36	2.06	2.3	2.5	14.1	21.7
		Large	24	10.80	5.25	2.06	3.5	4.0	22.0	33.9
		TOTAL	63	19.67	9.56	2.06	6.4	7.2	40.2	61.7
2	Dye Machine Controllers	Small	25	7.00	1.99	3.51	0.9	1.2	5.5	10.0
		Medium	19	8.55	2.44	3.51	1.1	1.4	6.7	12.2
		Large	7	5.60	1.60	3.51	0.7	0.9	4.4	8.0
		TOTAL	51	21.15	6.03	3.51	2.6	3.5	16.6	30.1
3	NPE Surfactant Substitution	Small	54	0.00	(0.07)	#N/A	(0.1)	(0.1)	(0.5)	(0.6)
		Medium	39	0.00	(0.28)	#N/A	(0.3)	(0.3)	(1.7)	(2.3)
		Large	27	0.00	(0.42)	#N/A	(0.4)	(0.4)	(2.6)	(3.6)
		TOTAL	120	0.00	(0.77)	#N/A	(0.8)	(0.8)	(4.8)	(6.5)
4	Dye Substitution	Small	54	0.00	(0.21)	#N/A	(0.2)	(0.2)	(1.3)	(1.8)
		Medium	39	0.00	(0.72)	#N/A	(0.7)	(0.7)	(4.5)	(6.2)
		Large	27	0.00	(1.34)	#N/A	(1.3)	(1.3)	(8.4)	(11.4)
		TOTAL	120	0.00	(2.28)	#N/A	(2.3)	(2.3)	(14.2)	(19.4)
5	Low Liquor Ratio Dyeing Machines	Small	19	17.63	5.67	3.11	2.9	3.6	17.8	30.6
		Medium	16	53.92	28.64	1.88	20.0	22.3	125.3	189.9
		Large	13	63.70	46.54	1.37	36.4	39.1	227.6	332.5
		TOTAL	48	135.25	80.85	1.67	59.2	65.0	370.8	553.1
6	Cold Pad Batch Dyeing	Small	1	1.22	0.33	3.69	0.1	0.2	0.8	1.6
		Medium	2	2.43	1.76	1.38	1.4	1.5	8.6	12.5
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	3	3.65	2.09	1.75	1.5	1.7	9.4	14.1
7	Quality Control for Raw Materials	Small	59	0.89	0.25	3.54	0.1	0.1	0.7	1.2
		Medium	41	1.03	1.30	0.79	1.1	1.2	7.1	10.1
		Large	29	0.87	1.11	0.79	1.0	1.0	6.1	8.6
		TOTAL	129	2.78	2.66	1.04	2.2	2.3	13.9	19.9
8	Pulsating Rinse Technology	Small	20	0.40	0.08	5.07	0.0	0.0	0.1	0.3
		Medium	21	1.66	0.33	5.07	0.1	0.1	0.4	1.1
		Large	4	0.64	0.13	5.07	0.0	0.1	0.1	0.4
		TOTAL	45	2.70	0.53	5.07	0.1	0.2	0.6	1.8
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	12	1.02	0.13	7.70	(0.0)	0.0	(0.2)	0.1
		Medium	11	1.57	0.91	1.73	0.7	0.7	4.1	6.2
		Large	7	1.48	1.13	1.31	0.9	1.0	5.6	8.1
		TOTAL	30	4.08	2.17	1.88	1.5	1.7	9.5	14.4
10	Bleach Bath Recovery System	Small	21	1.68	0.81	2.08	0.5	0.6	3.4	5.2
		Medium	19	2.34	1.12	2.08	0.8	1.2	4.7	7.2
		Large	4	0.98	0.47	2.08	0.3	0.5	2.0	3.0
		TOTAL	44	5.00	2.41	2.08	1.6	2.3	10.1	15.5
11	Salt Bath Recovery System	Small	25	10.50	0.82	12.84	(0.9)	(0.6)	(5.4)	(3.5)
		Medium	23	21.16	3.01	7.03	(0.4)	0.7	(2.3)	4.5
		Large	7	9.95	1.48	6.73	(0.1)	0.4	(0.7)	2.6
		TOTAL	55	41.61	5.30	7.84	(1.3)	0.6	(8.4)	3.5
12	Biological Wastewater Treatment	Small	58	52.49	(1.99)	#N/A	(10.4)	(11.1)	(65.0)	(69.5)
		Medium	41	70.32	(2.67)	#N/A	(13.9)	(14.9)	(87.0)	(93.0)
		Large	24	81.60	(3.10)	#N/A	(16.1)	(17.3)	(101.0)	(108.0)
		TOTAL	123	204.41	(7.76)	#N/A	(40.4)	(43.2)	(253.0)	(270.5)
	Total Pollution Prevention (BATEA 1-11)			235.88	108.55	2.2	70.9	110.0	443.6	688.3
	Total Pollution Control (BATEA 12)			204.41	(7.76)	#N/A	(40.4)	(43.2)	(253.0)	(270.5)

- **Net Present Value (Cost).** Net costs or savings over 20 years, reduced to a single value in today's dollars. Again two discount rates are used, one for net cost to society, and the other is costs or savings as experienced by the private sector. The Net Present Value on a social basis tends to be higher, since the social cost of capital is cheaper than the cost experienced by private stakeholders. Note this NPV is for direct savings/costs only and does not include the potential benefits of reduced pollution. Later modules of this study will address the broader question of Net Present Value of overall benefits and costs.

6.3 ANALYSIS OF BATEA COSTS

Positive Returns to Many BATEA

The most striking feature of BATEA costs is that many of them pay for themselves very quickly. With the exception of chemical substitution (BATEA #3, #4) and treatment of wastewater (BATEA #12), the selected BATEA generate a positive payback for private sector stakeholders. Payback ranges from an average of 7.8 years for Salt Bath Recovery Systems down to about one year for improved Quality Control of Raw Materials. Smaller plants generally experience a lower rate of return and longer payback period, but the benefits remain. The longest payback period is 12.8 years for small plants implementing the Salt Bath Recovery System.

A more realistic appreciation of cost is the annualized cost column that includes the costs of financing. Here we see that the Salt Bath Recovery System (#11) joins #3, #4, and #12 as a negative cost impact. Its annualized cost is $1.3 million for the industry as a whole. Although #11 generates savings, plants experience a net increase in costs once financing costs are counted. However, we should also note that from a social perspective, the actual cost of capital is cheaper, and there is actually a net saving of an estimated $0.6 million per year.

Many Plants Have Not Implemented Cost Saving BATEA

As might be expected, a fair proportion of textiles plants have already implemented BATEA that generate net savings. However, a large proportion also has not. The number of plants who can implement a cost-saving BATEA ranges from a low of three for Cold Pad Batch Dyeing (#6), to a high of 129 for Improved Quality Control of Raw Materials (#7)

Potential Reach Greater in Measures Which Cost

In the case of the BATEA that generate net costs, the number of plants currently implementing is low. There are an estimated 120 plants with an opportunity for Chemical Substitution (#3, #4), and 123 plants who have not made use of Biological Wastewater Treatment (#12). Implementing these BATEA would therefore reach a large number of plants, suggesting there may be more widespread potential improvements in water quality from these measures (subject to their actual technical impact on water quality).

No Capital Costs for Use of Less Toxic Materials

The two pollution prevention BATEA that impose net costs on the industry involve the substitution of current chemicals with less toxic chemicals. These are BATEA #3 – Surfactant

Substitution and BATEA #4 – Dye Substitution. The relevant chemicals are available in the market presently, at a higher cost, and may be used with current production systems.

The absence of capital costs is an advantage since, as an industry that has been in decline within Canada, the textiles industry may prefer BATEA that does not risk new capital commitments.

Pollution Prevention Cheaper than Pollution Control

Eleven of the 12 BATEA selected are pollution prevention measures. BATEA #12 involves post-production pollution control. The bottom two lines of Table 6.1 contrast the different costs. The combined capital costs of the eleven prevention measures is $235.9 million, and generates annual savings for the industry as a whole of $108.6 million per year[18].

In contrast, BATEA #12 has substantive capital costs on its own, of an estimated $204.4 million, and generates an operating cost as well of $7.8 million annually to the industry.

Cost Impacts Uneven Between Plants

The bottom line suggests that it is possible to devise a package of BATEA that provide net savings to the industry, while improving water quality. This is a positive situation, but it should be remembered that the impact on individual plants will vary substantially. In addition, such a package may not meet objectives for a desired level of effluent quality, necessitating stronger measures with less favourable cost impacts.

We should also note that a positive package for the industry as a whole would not necessarily mean positive impacts on all plants. Plants that have already implemented the available cost saving measures of the proposed BATEA will experience cost increases if they also implement other measures such as Chemical Substitution, or Biological Wastewater Treatment.

Costs By Plant Size

Smaller plants do not realize benefits from as many of the BATEA as do larger plants. The Recycling and Reuse of Cooling and Condensate Water (#9) yields savings, but the savings are not enough to outweigh the financing costs of the initial capital investment for the lower scale of small plants. Small plant losses are also higher than larger plants when implementing Salt Bath Recovery Systems (#11).

Capital costs are also of separate interest because plants may see themselves as constrained in their ability to raise new capital. Table 6.2 provides a plant-level picture of the capital costs for each BATEA. The estimates by plant size are the same across different market segments.

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[18] As noted previously, operating costs savings of the eleven pollution prevention BATEA are not likely to be fully additive.

Table 6.2 - Capital Costs for Individual Plants

BATEA	Name	Plant Size	Capital Cost per Plant
1	Automated Chemical Dosing Systems	Small	$ 150,000
		Medium	$ 266,000
		Large	$ 450,000
2	Dye Machine Controllers	Small	$ 280,000
		Medium	$ 450,000
		Large	$ 800,000
3	NPE Surfactant Substitution	Small	$ -
		Medium	$ -
		Large	$ -
4	Dye Substitution	Small	$ -
		Medium	$ -
		Large	$ -
5	Low Liquor Ratio Dyeing Machines	Small	$ 928,000
		Medium	$ 3,370,000
		Large	$ 4,900,000
6	Cold Pad Batch Dyeing	Small	$ 1,215,000
		Medium	$ 1,215,000
		Large	$ 1,215,000
7	Quality Control for Raw Materials	Small	$ 15,000
		Medium	$ 25,000
		Large	$ 30,000
8	Pulsating Rinse Technology	Small	$ 20,000
		Medium	$ 79,000
		Large	$ 160,000
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	$ 85,000
		Medium	$ 143,000
		Large	$ 212,000
10	Bleach Bath Recovery System	Small	$ 80,000
		Medium	$ 123,000
		Large	$ 246,000
11	Salt Bath Recovery System	Small	$ 420,000
		Medium	$ 920,000
		Large	$ 1,422,000
12	Biological Wastewater Treatment	Small	$ 905,000
		Medium	$ 1,715,000
		Large	$ 3,400,000

The largest up-front costs are required for Low Liquor Ratio Dyeing Machines (#5), ranging from $928,000 to $4,900,000 depending on plant-size. The lowest is Quality Control of Raw Materials (#7), which is essentially an audit of current processes, re-design of procedures to best practices, and training of employees. All of these have a relatively quick payback period, as shown in Table 6.1.

Biological Wastewater Treatment (#12) has both high capital costs and, as discussed above, a large negative impact on operating costs. Capital costs range from $905,000 for a small plant to $3,400,000 for a large plant.

Savings Greater from A Social Perspective

As discussed under methodology, there is a difference between the private sector's experience in financing costs, and the true cost of capital to society as a whole. Thus there is a difference in Table 6.1 between assessment of impacts at an interest rate of 10% (social), and 15% (private). Under the lower cost of capital from a social perspective, the net impact on costs is much more positive.

This is best assessed through annualized cost, which accounts for the combined impact of capital costs and operating cost impacts as an annual equivalent impact. For the sum of all pollution prevention measures, the annualized savings on a private basis is $70.9 million. On a social basis, the annualized savings is a higher $110.0 million. Similarly, the Net Present Value of the savings is $443.6 million on a private basis, and a higher $688.3 million on a social basis.

6.4 VARIANCE ANALYSIS OF ESTIMATES

The tables in this chapter report best estimates. It is also important to assess the degree of certainty surrounding those estimates, and their implications for whether BATEA, or a combination of BATEA, yield net savings or costs within the industry.

Assumptions on Uncertainty of Estimates

For a given plant size and BATEA, the cost estimates in the Appendix are reasonably accurate. Providing such estimates is the regular business of industry expert members of the project team (Fintex). However, there are two sources of uncertainty in moving to industry impacts:

- **Accuracy of cost estimates for model plants.** For the plant chosen as a model for estimating purposes, the project team considers its estimates very reliable. The technology and the material inputs are well known. However, there is uncertainty with respect to how accurately the model plant represents small, medium and large plants in the industry. With the exceptions of the BATEA on chemicals substitution (#3, #4), the project team feels the estimates are fairly accurate representations of the industry. Based on familiarity with the industry and individual Canadian plants, the project team estimates that net savings and costs are likely within plus or minus 10% of the true values.[19]

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[19] At a confidence interval of 80%. See further discussion below on quantifying risk.

For BATEA on chemicals substitution, the cost estimates are less certain. While the substitute chemicals are expected to be more expensive, the relative cost increase is dependent on volatile commodity prices and the choice of alternative chemicals. The project team estimates the true cost differential is within plus or minus 40% of the best estimate.[20]

- **Number of plants who can implement the BATEA.** These estimates were based on the knowledge of expert members of the team regarding the individual textiles plants operating in Canada. Given the level of familiarity with the industry, it is estimated that the number of plants is accurate within plus or minus 10%.[21]

Estimated industry costs assume full implementation of the BATEA by those firms who are able to and have not yet done so. In the implementation of any practical plan, there will be an additional risk that some firms will not implement the desired measures. This will reduce both costs and benefits of the BATEA selected. The rate of non-implementation may vary according to the policy instrument selected (from information sharing, to voluntary industry programs, to formal regulation). Assessment of this risk will be undertaken in later stages of the study, along with consideration of which policy instruments are most appropriate for the textiles industry.

Approach to Quantifying Variance in Estimates

Risk was quantified for all the estimates in the model, using a Monte-Carlo Analysis.[22] Key results are reported further below. Key assumptions were:

- **Confidence Interval.** Risk ranges, such as plus or minus 20%, were developed in the context of an 80% confidence interval. Thus, if the risk range is plus or minus 20%, then the estimate is 90% certain to exceed the lower estimate and 90% likely not to exceed the upper estimate.

- **Errors Independent between BATEA.** Estimation errors may be negative in one BATEA and positive in a number. There is no coefficient of correlation.

Results of Analysis

- *Variation for All BATEA Except #3 and #4*

The assessment of plus or minus 10% on the number of plants and plus or minus 10% on the cost impacts per plant has a joint impact on the estimated savings (cost) for each BATEA. The result is a confidence interval that is somewhat greater than plus or minus 10%. Figure 6.1 illustrates the results for the Annualized Private Sector Cost of implementing Automated Chemical Dosing Systems (BATEA #1). Annualized cost is the most illustrative because it combines the impact of

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[20] Ibid.

[21] Ibid.

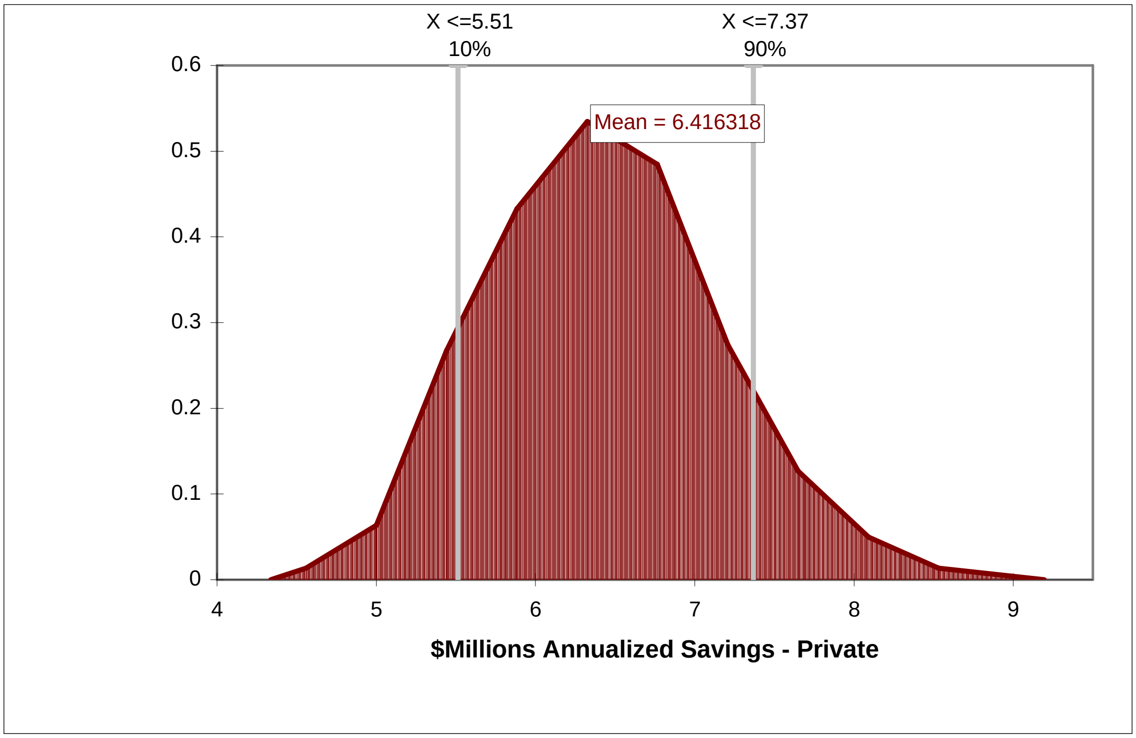
[22] Monte Carlo analysis involves taking the input values of a variable (in this case cost impacts on plants, and the number of plants), and varying them randomly. The resulting values of the output variables (such as total cost impact on the industry) are then observed and plotted as a probability distribution around the best estimate. For this simulation, 1,000 random iterations were used.

capital and operating costs into a single annualized saving (cost). Figure 6.1 is assessed on a private sector basis (i.e., financing costs for capital are valued at a real interest rate of 15%).

As reported in Table 6.1, the best estimate of the annualized savings generated by Automated Chemical Dosing Systems is $6.4 million per year for the industry as a whole. Figure 6.1 also shows the boundaries of the confidence interval. It is 90% likely that annualized savings are at least $5.51 million, and 10% likely that the annual savings exceed $7.37 million. In proportionate terms, the resulting range is plus or minus 15% from the best estimate.[23]

Other BATEA, other than chemical substitution, have similar risk ranges of plus or minus 14%.

Figure 6.1 – BATEA #1 Automated Chemical Dosing System



- *Variation for Chemical Substitution BATEA*

Figure 6.2 provides similar results for Dye Substitution (BATEA #4), a measure that introduces net costs to the industry. Annualized costs are 90% likely to be less than $3.2 million, and 10% likely to be less than $1.37 million. The best estimate of annualized costs is $2.27 million. As noted above, the cost estimates for substitution measures like #4 are more uncertain, resulting in a cost range of approximately plus or minus 40%. Surfactant Substitution (BATEA #3) has a similar percentage risk range around its best estimate annualized cost of $0.8 million to the industry.

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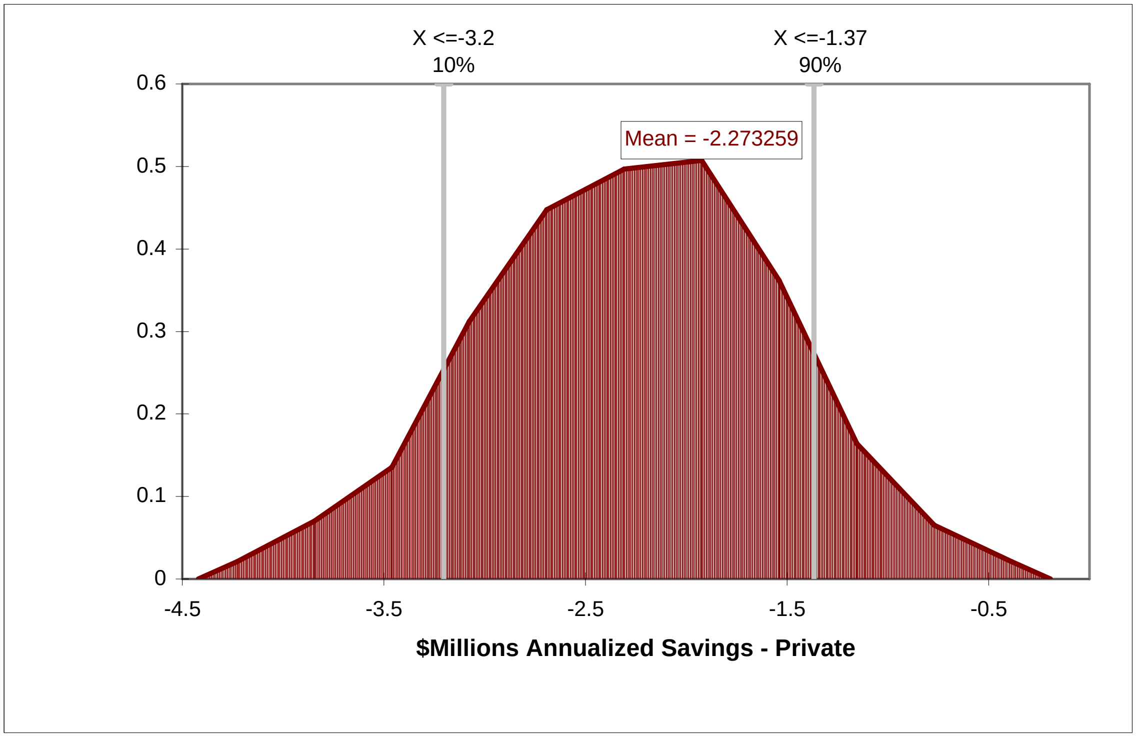
[23] At an 80% confidence interval.

Figure 6.2 – BATEA #4 Dye Substitution



- *Lower Variation for Combinations of BATEA*

Because the potential error of cost estimates is independent between BATEA, the cost impact of combinations of BATEA will tend to be more stable than the individual elements of the combination.[24]

Figure 6.3 illustrates the potential variation of combined annualized cost for the pollution prevention BATEA (#1 to #11). The annualized cost saving is 90% likely to exceed $62.4 million, and 10% likely to exceed $79.2 million. The best estimate is $70.9 million, consistent with Table 6.1. (As noted previously, operating costs savings of the eleven pollution prevention BATEA may not be fully additive.)

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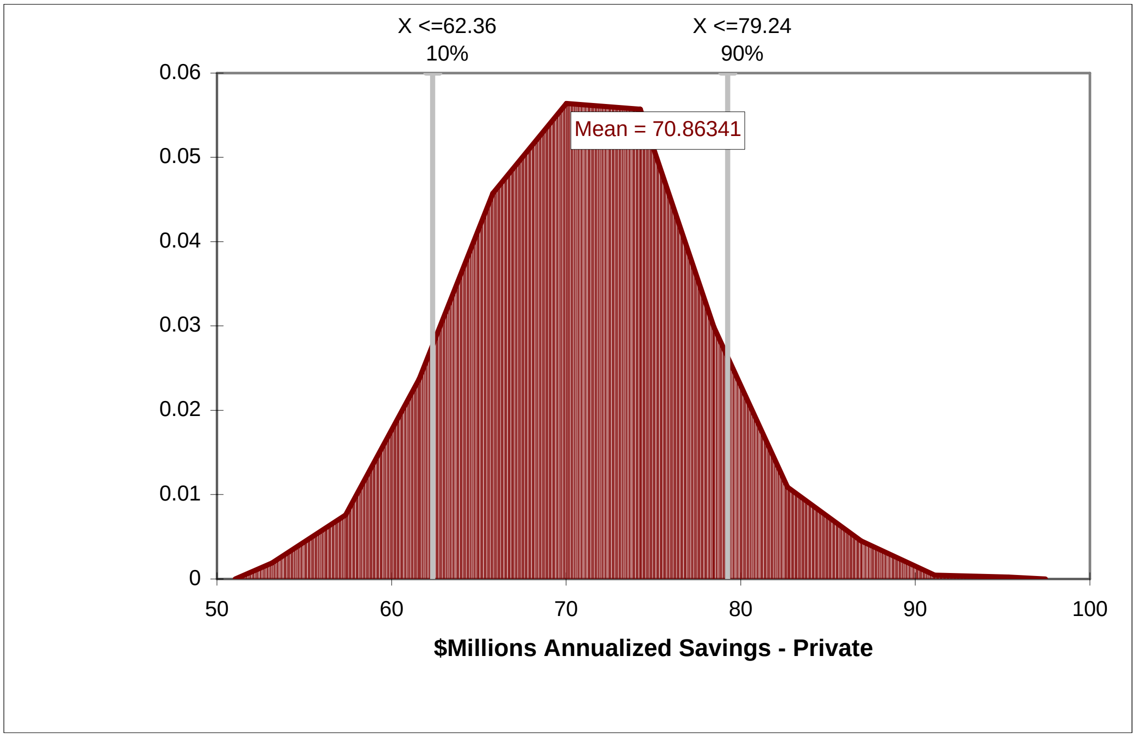
[24] This is the same statistical principal as rolling dice: the expected average value of rolling one dice or 1,000 dice is the same, but the average result from 1,000 dice is far more likely to be very close to the expected value.

Figure 6.3 – Combined Pollution Prevention BATEA #1 to 11: Annualized Savings



- *No Risk of Negative NPV of Cost Impacts*

Table 6.1 showed that that the sum of the cost impacts of combined pollution prevention measures is estimated to produce a positive net benefit. Figure 6.4 goes further to check if there is a measurable risk that the Net Present Value of cost impacts would turn negative. The distribution indicates that there is not. It is 90% likely that Net Present Value would exceed $608.1 million, and 10% likely that it would exceed $765.5 million. The likelihood of a negative NPV is shown as close to nil.

Figure 6.5 goes a step further by adding the BATEA #12, a measure with significant negative cost impacts, to the total. The result is the Net Present Value of all BATEA combined, evaluated on a social basis with cost of financing reflecting a 10% interest rate. Again, the entire distribution appears above zero, suggesting a possibility of negative returns of close to nil.

Figure 6.4 – Combined Pollution Prevention BATEA #1 to 11: Net Present Value

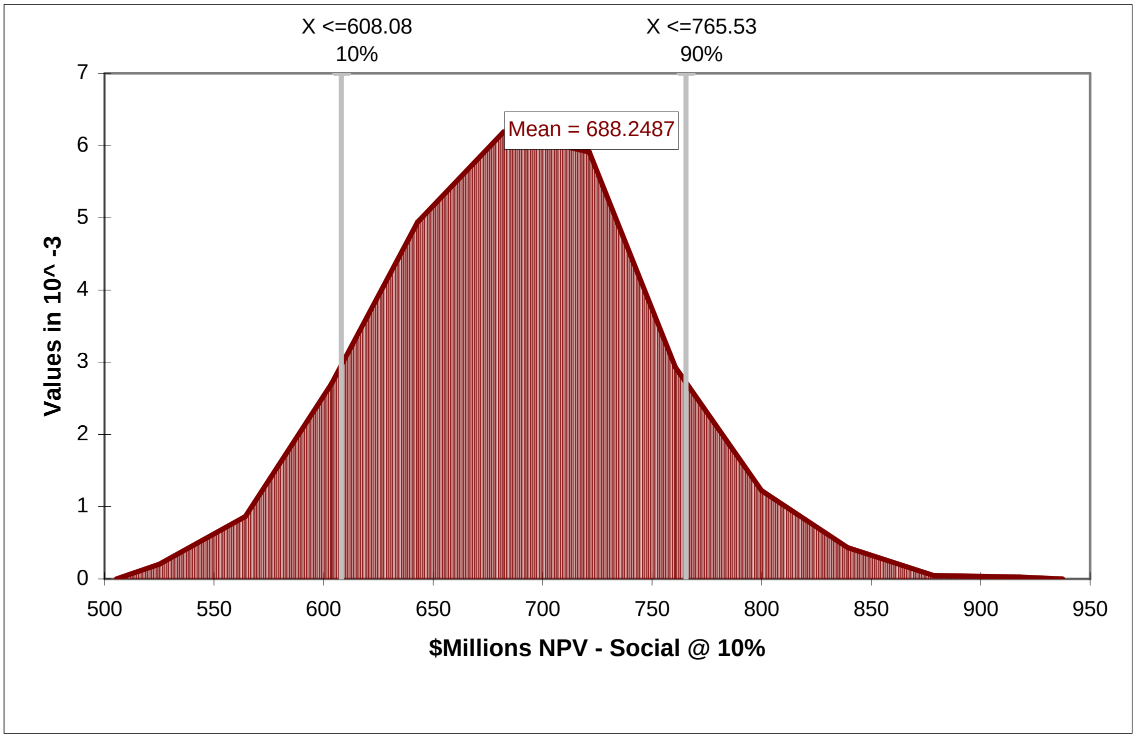
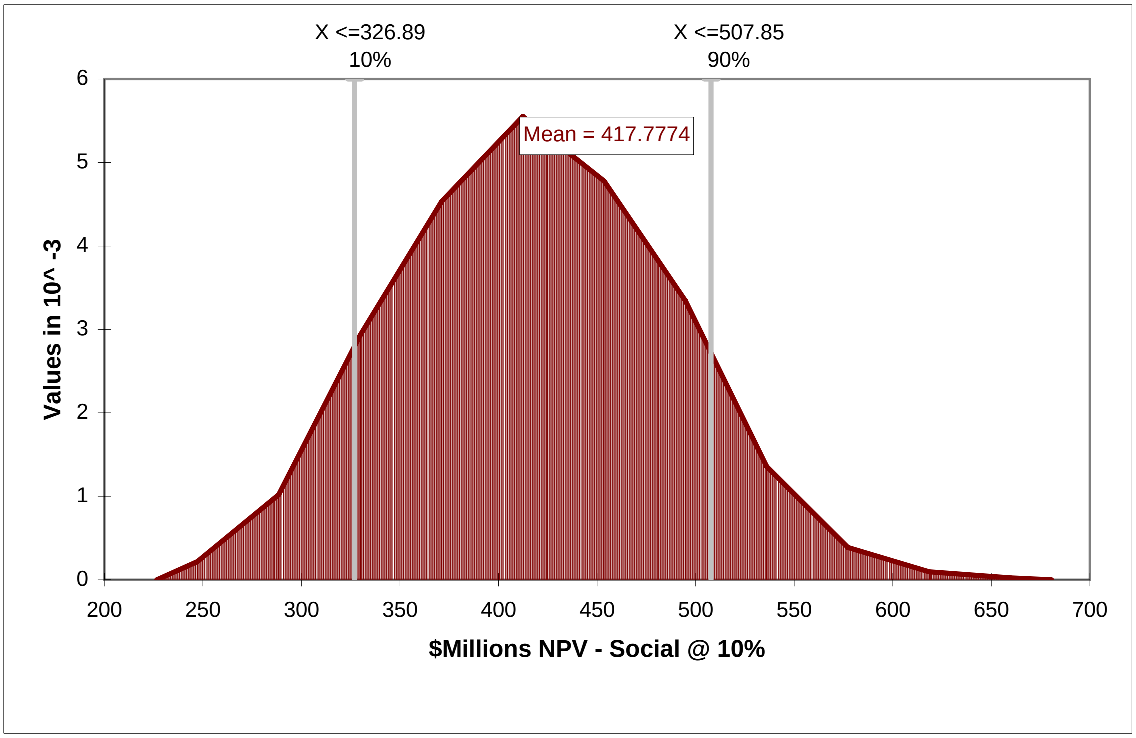


Figure 6.5 – Combined All BATEA #1 to 12: Net Present Value



6.5 COST BY MARKET SEGMENT

Cost impacts were estimated separately for each market segment: knit, woven, yarn, carpet, wool, and non-woven. Results are reported in Tables 6.3 to 6.8 on the following pages.

Costs Common for Plants of Given Size

At the plant level, there is little distinction between the impacts of most BATEA in different industry segments. As noted in the discussion of Table 6.2, the capital cost of all BATEA has been treated as the same for a given plant size across segments. Operating cost impacts are the same for a given plant size too, except for the Chemical Substitution BATEA (#3, #4).

Thus the relative saving or burden by industry segment is largely a function of the number and size of plants for which the BATEA is relevant.

Some BATEA Apply Only to Some Segments

The following BATEA have limited application by segment:

- #6 Cold Pad Batch Dyeing only has impact on the Woven segment (3 plants)
- #8 Pulsating Rinse Technology only has impact on Knit, Woven, and Carpet (45 plants total)
- #10 Bleach Bath Recovery System only has impact on Knit and Woven (44 plants)
- #11 Salt Bath Recovery System only has impact on Knit, Woven and Yarn (55 plants)

Coverage of Segments Good Across BATEA

Although some individual BATEA are limited in their potential for gains in water quality by segment, the overall set impacts most plants in each industry segment. In particular, the Chemical Substitution BATEA (#3, #4) impact all but the few plants in the non-woven segment. All plants are affected by Quality Control of Raw Materials (#7). The general pattern of net savings for combined Pollution Prevention BATEA (#1 to #11) also occurs in each of the industry segments.

Table 6.3 - Knit Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	6	0.90	0.44	2.06	0.3	0.3	1.8	2.8
		Medium	12	3.19	1.55	2.06	1.0	1.2	6.5	10.0
		Large	2	0.90	0.44	2.06	0.3	0.3	1.8	2.8
		TOTAL	20	4.99	2.43	2.06	1.6	1.8	10.2	15.7
2	Dye Machine Controllers	Small	12	3.36	0.96	3.51	0.4	0.6	2.6	4.8
		Medium	8	3.60	1.03	3.51	0.5	0.6	2.8	5.1
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	20	6.96	1.98	3.51	0.9	1.2	5.5	9.9
3	NPE Surfactant Substitution	Small	31	0.00	(0.05)	#N/A	(0.0)	(0.0)	(0.3)	(0.4)
		Medium	25	0.00	(0.21)	#N/A	(0.2)	(0.2)	(1.3)	(1.7)
		Large	6	0.00	(0.13)	#N/A	(0.1)	(0.1)	(0.8)	(1.1)
		TOTAL	62	0.00	(0.39)	#N/A	(0.4)	(0.4)	(2.4)	(3.3)
4	Dye Substitution	Small	31	0.00	(0.10)	#N/A	(0.1)	(0.1)	(0.6)	(0.8)
		Medium	25	0.00	(0.42)	#N/A	(0.4)	(0.4)	(2.6)	(3.6)
		Large	6	0.00	(0.28)	#N/A	(0.3)	(0.3)	(1.7)	(2.3)
		TOTAL	62	0.00	(0.79)	#N/A	(0.8)	(0.8)	(5.0)	(6.8)
5	Low Liquor Ratio Dyeing Machines	Small	10	9.28	2.98	3.11	1.5	1.9	9.4	16.1
		Medium	10	33.70	17.90	1.88	12.5	13.9	78.3	118.7
		Large	2	9.80	7.16	1.37	5.6	6.0	35.0	51.2
		TOTAL	22	52.78	28.04	1.88	19.6	21.8	122.8	186.0
6	Cold Pad Batch Dyeing	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0
7	Quality Control for Raw Materials	Small	31	0.47	0.13	3.54	0.1	0.1	0.4	0.7
		Medium	25	0.63	0.80	0.79	0.7	0.7	4.4	6.1
		Large	6	0.18	0.23	0.79	0.2	0.2	1.3	1.8
		TOTAL	62	1.27	1.16	1.10	1.0	1.0	6.0	8.6
8	Pulsating Rinse Technology	Small	16	0.32	0.06	5.07	0.0	0.0	0.1	0.2
		Medium	15	1.19	0.23	5.07	0.0	0.1	0.3	0.8
		Large	2	0.32	0.06	5.07	0.0	0.0	0.1	0.2
		TOTAL	33	1.83	0.36	5.07	0.1	0.1	0.4	1.2
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	7	0.60	0.08	7.70	(0.0)	0.0	(0.1)	0.1
		Medium	6	0.86	0.50	1.73	0.4	0.4	2.3	3.4
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	13	1.45	0.57	2.53	0.3	0.4	2.1	3.4
10	Bleach Bath Recovery System	Small	19	1.52	0.73	2.08	0.5	0.6	3.1	4.7
		Medium	17	2.09	1.01	2.08	0.7	1.0	4.2	6.5
		Large	4	0.98	0.47	2.08	0.3	0.5	2.0	3.0
		TOTAL	40	4.60	2.21	2.08	1.5	2.1	9.2	14.2
11	Salt Bath Recovery System	Small	19	7.98	0.62	12.84	(0.7)	(0.4)	(4.1)	(2.7)
		Medium	17	15.64	2.22	7.03	(0.3)	0.5	(1.7)	3.3
		Large	4	5.69	0.87	6.52	(0.0)	0.3	(0.2)	1.7
		TOTAL	40	29.31	3.72	7.88	(1.0)	0.4	(6.0)	2.3
12	Biological Wastewater Treatment	Small	31	28.06	(1.07)	#N/A	(5.5)	(5.9)	(34.7)	(37.1)
		Medium	25	42.88	(1.63)	#N/A	(8.5)	(9.1)	(53.1)	(56.7)
		Large	4	13.60	(0.52)	#N/A	(2.7)	(2.9)	(16.8)	(18.0)
		TOTAL	60	84.53	(3.21)	#N/A	(16.7)	(17.9)	(104.6)	(111.9)
	Total Pollution Prevention (BATEA 1-11)			103.18	39.29	2.6	22.8	37.0	142.7	231.3
	Total Pollution Control (BATEA 12)			84.53	(3.21)	#N/A	(16.7)	(17.9)	(104.6)	(111.9)

Table 6.4 - Woven Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	4	0.60	0.29	2.06	0.2	0.2	1.2	1.9
		Medium	8	2.13	1.03	2.06	0.7	0.8	4.3	6.7
		Large	8	3.60	1.75	2.06	1.2	1.3	7.3	11.3
		TOTAL	20	6.33	3.08	2.06	2.1	2.3	12.9	19.9
2	Dye Machine Controllers	Small	6	1.68	0.48	3.51	0.2	0.3	1.3	2.4
		Medium	8	3.60	1.03	3.51	0.5	0.6	2.8	5.1
		Large	2	1.60	0.46	3.51	0.2	0.3	1.3	2.3
		TOTAL	16	6.88	1.96	3.51	0.9	1.2	5.4	9.8
3	NPE Surfactant Substitution	Small	13	0.00	(0.01)	#N/A	(0.0)	(0.0)	(0.1)	(0.1)
		Medium	9	0.00	(0.04)	#N/A	(0.0)	(0.0)	(0.3)	(0.4)
		Large	8	0.00	(0.16)	#N/A	(0.2)	(0.2)	(1.0)	(1.3)
		TOTAL	30	0.00	(0.21)	#N/A	(0.2)	(0.2)	(1.3)	(1.8)
4	Dye Substitution	Small	13	0.00	(0.04)	#N/A	(0.0)	(0.0)	(0.2)	(0.3)
		Medium	9	0.00	(0.17)	#N/A	(0.2)	(0.2)	(1.1)	(1.4)
		Large	8	0.00	(0.63)	#N/A	(0.6)	(0.6)	(3.9)	(5.3)
		TOTAL	30	0.00	(0.83)	#N/A	(0.8)	(0.8)	(5.2)	(7.1)
5	Low Liquor Ratio Dyeing Machines	Small	4	3.71	1.19	3.11	0.6	0.8	3.8	6.4
		Medium	4	13.48	7.16	1.88	5.0	5.6	31.3	47.5
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	8	17.19	8.35	2.06	5.6	6.3	35.1	53.9
6	Cold Pad Batch Dyeing	Small	1	1.22	0.33	3.69	0.1	0.2	0.8	1.6
		Medium	2	2.43	1.76	1.38	1.4	1.5	8.6	12.5
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	3	3.65	2.09	1.75	1.5	1.7	9.4	14.1
7	Quality Control for Raw Materials	Small	13	0.20	0.06	3.54	0.0	0.0	0.2	0.3
		Medium	9	0.23	0.29	0.79	0.3	0.3	1.6	2.2
		Large	8	0.24	0.31	0.79	0.3	0.3	1.7	2.4
		TOTAL	30	0.66	0.65	1.02	0.5	0.6	3.4	4.8
8	Pulsating Rinse Technology	Small	4	0.08	0.02	5.07	0.0	0.0	0.0	0.1
		Medium	4	0.32	0.06	5.07	0.0	0.0	0.1	0.2
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	8	0.40	0.08	5.07	0.0	0.0	0.1	0.3
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	4	0.34	0.04	7.70	(0.0)	0.0	(0.1)	0.0
		Medium	4	0.57	0.33	1.73	0.2	0.3	1.5	2.2
		Large	2	0.42	0.32	1.31	0.3	0.3	1.6	2.3
		TOTAL	10	1.34	0.70	1.91	0.5	0.5	3.0	4.6
10	Bleach Bath Recovery System	Small	2	0.16	0.08	2.08	0.1	0.1	0.3	0.5
		Medium	2	0.25	0.12	2.08	0.1	0.1	0.5	0.8
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	4	0.41	0.20	2.08	0.1	0.1	0.8	1.3
11	Salt Bath Recovery System	Small	4	1.68	0.13	12.84	(0.1)	(0.1)	(0.9)	(0.6)
		Medium	4	3.68	0.52	7.03	(0.1)	0.1	(0.4)	0.8
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	8	5.36	0.65	8.20	(0.2)	0.0	(1.3)	0.2
12	Biological Wastewater Treatment	Small	13	11.77	(0.45)	#N/A	(2.3)	(1.8)	(14.6)	(15.6)
		Medium	9	15.44	(0.59)	#N/A	(3.1)	(2.4)	(19.1)	(20.4)
		Large	5	17.00	(0.65)	#N/A	(3.4)	(2.6)	(21.0)	(22.5)
		TOTAL	27	44.20	(1.68)	#N/A	(8.7)	(6.9)	(54.7)	(58.5)
	Total Pollution Prevention (BATEA 1-11)			42.20	16.70	2.5	10.0	16.0	62.3	100.0
	Total Pollution Control (BATEA 12)			44.20	(1.68)	#N/A	(8.7)	(6.9)	(54.7)	(58.5)

Table 6.5 - Yarn Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	3	0.80	0.39	2.06	0.3	0.3	1.6	2.5
		Large	7	3.15	1.53	2.06	1.0	1.2	6.4	9.9
		TOTAL	10	3.95	1.92	2.06	1.3	1.5	8.1	12.4
2	Dye Machine Controllers	Small	2	0.56	0.16	3.51	0.1	0.1	0.4	0.8
		Medium	1	0.45	0.13	3.51	0.1	0.1	0.4	0.6
		Large	1	0.80	0.23	3.51	0.1	0.1	0.6	1.1
		TOTAL	4	1.81	0.52	3.51	0.2	0.3	1.4	2.6
3	NPE Surfactant Substitution	Small	3	0.00	(0.00)	#N/A	(0.0)	(0.0)	(0.0)	(0.0)
		Medium	3	0.00	(0.00)	#N/A	(0.0)	(0.0)	(0.0)	(0.0)
		Large	8	0.00	(0.05)	#N/A	(0.1)	(0.1)	(0.3)	(0.5)
		TOTAL	14	0.00	(0.06)	#N/A	(0.1)	(0.1)	(0.4)	(0.5)
4	Dye Substitution	Small	3	0.00	(0.00)	#N/A	(0.0)	(0.0)	(0.0)	(0.0)
		Medium	3	0.00	(0.01)	#N/A	(0.0)	(0.0)	(0.1)	(0.1)
		Large	8	0.00	(0.16)	#N/A	(0.2)	(0.2)	(1.0)	(1.3)
		TOTAL	14	0.00	(0.17)	#N/A	(0.2)	(0.2)	(1.1)	(1.5)
5	Low Liquor Ratio Dyeing Machines	Small	2	1.86	0.60	3.11	0.3	0.4	1.9	3.2
		Medium	2	6.74	3.58	1.88	2.5	2.8	15.7	23.7
		Large	7	34.30	25.06	1.37	19.6	21.0	122.6	179.0
		TOTAL	11	42.90	29.24	1.47	22.4	24.2	140.1	206.0
6	Cold Pad Batch Dyeing	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0
7	Quality Control for Raw Materials	Small	3	0.05	0.01	3.54	0.0	0.0	0.0	0.1
		Medium	3	0.08	0.10	0.79	0.1	0.1	0.5	0.7
		Large	8	0.24	0.31	0.79	0.3	0.3	1.7	2.4
		TOTAL	14	0.36	0.41	0.87	0.4	0.4	2.2	3.2
8	Pulsating Rinse Technology	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	1	0.09	0.01	7.70	(0.0)	0.0	(0.0)	0.0
		Medium	1	0.14	0.08	1.73	0.1	0.1	0.4	0.6
		Large	1	0.21	0.16	1.31	0.1	0.1	0.8	1.2
		TOTAL	3	0.44	0.26	1.72	0.2	0.2	1.2	1.7
10	Bleach Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0
11	Salt Bath Recovery System	Small	2	0.84	0.07	12.84	(0.1)	(0.0)	(0.4)	(0.3)
		Medium	2	1.84	0.26	7.03	(0.0)	0.0	(0.2)	0.4
		Large	3	4.27	0.61	7.03	(0.1)	0.1	(0.5)	0.9
		TOTAL	7	6.95	0.93	7.44	(0.2)	0.1	(1.1)	1.0
12	Biological Wastewater Treatment	Small	3	2.72	(0.10)	#N/A	(0.5)	(0.4)	(3.4)	(3.6)
		Medium	3	5.15	(0.20)	#N/A	(1.0)	(0.8)	(6.4)	(6.8)
		Large	8	27.20	(1.03)	#N/A	(5.4)	(4.2)	(33.7)	(36.0)
		TOTAL	14	35.06	(1.33)	#N/A	(6.9)	(5.4)	(43.4)	(46.4)
	Total Pollution Prevention (BATEA 1-11)			56.40	33.04	1.7	24.0	35.9	150.4	224.9
	Total Pollution Control (BATEA 12)			35.06	(1.33)	#N/A	(6.9)	(5.4)	(43.4)	(46.4)

Table 6.6 - Carpet Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	2	0.30	0.15	2.06	0.1	0.1	0.6	0.9
		Medium	2	0.53	0.26	2.06	0.2	0.2	1.1	1.7
		Large	2	0.90	0.44	2.06	0.3	0.3	1.8	2.8
		TOTAL	6	1.73	0.84	2.06	0.6	0.6	3.5	5.4
2	Dye Machine Controllers	Small	2	0.56	0.16	3.51	0.1	0.1	0.4	0.8
		Medium	1	0.45	0.13	3.51	0.1	0.1	0.4	0.6
		Large	1	0.80	0.23	3.51	0.1	0.1	0.6	1.1
		TOTAL	4	1.81	0.52	3.51	0.2	0.3	1.4	2.6
3	NPE Surfactant Substitution	Small	4	0.00	(0.01)	#N/A	(0.0)	(0.0)	(0.1)	(0.1)
		Medium	2	0.00	(0.02)	#N/A	(0.0)	(0.0)	(0.1)	(0.2)
		Large	2	0.00	(0.04)	#N/A	(0.0)	(0.0)	(0.3)	(0.3)
		TOTAL	8	0.00	(0.08)	#N/A	(0.1)	(0.1)	(0.5)	(0.6)
4	Dye Substitution	Small	4	0.00	(0.07)	#N/A	(0.1)	(0.1)	(0.4)	(0.6)
		Medium	2	0.00	(0.12)	#N/A	(0.1)	(0.1)	(0.8)	(1.0)
		Large	2	0.00	(0.21)	#N/A	(0.2)	(0.2)	(1.3)	(1.8)
		TOTAL	8	0.00	(0.40)	#N/A	(0.4)	(0.4)	(2.5)	(3.4)
5	Low Liquor Ratio Dyeing Machines	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	2	9.80	7.16	1.37	5.6	6.0	35.0	51.2
		TOTAL	2	9.80	7.16	1.37	5.6	6.0	35.0	51.2
6	Cold Pad Batch Dyeing	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	0.00	0.0	0.0	0.0	0.0
7	Quality Control for Raw Materials	Small	4	0.06	0.02	3.54	0.0	0.0	0.0	0.1
		Medium	2	0.05	0.06	0.79	0.1	0.1	0.3	0.5
		Large	2	0.06	0.08	0.79	0.1	0.1	0.4	0.6
		TOTAL	8	0.17	0.16	1.08	0.1	0.1	0.8	1.2
8	Pulsating Rinse Technology	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	2	0.16	0.03	5.07	0.0	0.0	0.0	0.1
		Large	2	0.32	0.06	5.07	0.0	0.0	0.1	0.2
		TOTAL	4	0.48	0.09	5.07	0.0	0.0	0.1	0.3
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	2	0.42	0.32	1.31	0.3	0.4	1.6	2.3
		TOTAL	2	0.42	0.32	1.31	0.3	0.4	1.6	2.3
10	Bleach Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
11	Salt Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
12	Biological Wastewater Treatment	Small	4	3.62	(0.14)	#N/A	(0.7)	(0.8)	(4.5)	(4.8)
		Medium	2	3.43	(0.13)	#N/A	(0.7)	(0.7)	(4.2)	(4.5)
		Large	2	6.80	(0.26)	#N/A	(1.3)	(1.4)	(8.4)	(9.0)
		TOTAL	8	13.85	(0.53)	#N/A	(2.7)	(2.9)	(17.1)	(18.3)
	Total Pollution Prevention (BATEA 1-11)			14.41	8.62	1.7	6.3	9.4	39.5	58.9
	Total Pollution Control (BATEA 12)			13.85	(0.53)	#N/A	(2.7)	(2.9)	(17.1)	(18.3)

Table 6.7 - Wool Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	1	0.15	0.07	2.06	0.0	0.1	0.3	0.5
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	3	1.35	0.66	2.06	0.4	0.5	2.8	4.2
		TOTAL	4	1.50	0.73	2.06	0.5	0.6	3.1	4.7
2	Dye Machine Controllers	Small	1	0.28	0.08	3.51	0.0	0.0	0.2	0.4
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	2	1.60	0.46	3.51	0.2	0.3	1.3	2.3
		TOTAL	3	1.88	0.54	3.51	0.2	0.3	1.5	2.7
3	NPE Surfactant Substitution	Small	3	0.00	(0.00)	#N/A	(0.0)	(0.0)	(0.0)	(0.0)
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	3	0.00	(0.03)	#N/A	(0.0)	(0.0)	(0.2)	(0.3)
		TOTAL	6	0.00	(0.04)	#N/A	(0.0)	(0.0)	(0.2)	(0.3)
4	Dye Substitution	Small	3	0.00	(0.01)	#N/A	(0.0)	(0.0)	(0.0)	(0.1)
		Medium	0	0.00	0.0	#N/A	0.0	0.0	0.0	0.0
		Large	3	0.00	(0.07)	#N/A	(0.1)	(0.1)	(0.4)	(0.6)
		TOTAL	6	0.00	(0.08)	#N/A	(0.1)	(0.1)	(0.5)	(0.7)
5	Low Liquor Ratio Dyeing Machines	Small	3	2.78	0.90	3.11	0.5	0.6	2.8	4.8
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	2	9.80	7.16	1.37	5.6	6.0	35.0	51.2
		TOTAL	5	12.58	8.06	1.56	6.0	6.6	37.8	56.0
6	Cold Pad Batch Dyeing	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
7	Quality Control for Raw Materials	Small	3	0.05	0.01	3.54	0.0	0.0	0.0	0.1
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	3	0.09	0.11	0.79	0.1	0.1	0.6	0.9
		TOTAL	6	0.14	0.13	1.06	0.1	0.1	0.7	0.9
8	Pulsating Rinse Technology	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	1	0.21	0.16	1.31	0.1	0.1	0.8	1.2
		TOTAL	1	0.21	0.16	1.31	0.1	0.1	0.8	1.2
10	Bleach Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
11	Salt Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
12	Biological Wastewater Treatment	Small	2	1.81	(0.07)	#N/A	(0.4)	(0.3)	(2.2)	(2.4)
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	3	10.20	(0.39)	#N/A	(2.0)	(1.6)	(12.6)	(13.5)
		TOTAL	5	12.01	(0.46)	#N/A	(2.4)	(1.9)	(14.9)	(15.9)
	Total Pollution Prevention (BATEA 1-11)			16.31	9.49	1.7	6.9	10.3	43.1	64.5
	Total Pollution Control (BATEA 12)			12.01	(0.46)	#N/A	(2.4)	(1.9)	(14.9)	(15.9)

Table 6.8 - Non-Woven Segment Cost Impact ($millions)

BATEA	Name	Plant Size	# of Plants	Capital Cost	Operating Saving (Cost)	Simple Payback Period In Years	Annualized Saving (Cost)		Net Present Value (Cost)	
							Private @ 15%	Social @10%	Private @ 15%	Social @10%
1	Automated Chemical Dosing Systems	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	1	0.27	0.13	2.06	0.1	0.1	0.5	0.8
		Large	2	0.90	0.44	2.06	0.3	0.3	1.8	2.8
		TOTAL	3	1.17	0.57	2.06	0.4	0.4	2.4	3.7
2	Dye Machine Controllers	Small	2	0.56	0.16	3.51	0.1	0.1	0.4	0.8
		Medium	1	0.45	0.13	3.51	0.1	0.1	0.4	0.6
		Large	1	0.80	0.23	3.51	0.1	0.1	0.6	1.1
		TOTAL	4	1.81	0.52	3.51	0.2	0.3	1.4	2.6
3	NPE Surfactant Substitution	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
4	Dye Substitution	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
5	Low Liquor Ratio Dyeing Machines	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
6	Cold Pad Batch Dyeing	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00		0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
7	Quality Control for Raw Materials	Small	5	0.08	0.02	3.54	0.0	0.0	0.1	0.1
		Medium	2	0.05	0.06	0.79	0.1	0.1	0.3	0.5
		Large	2	0.06	0.08	0.79	0.1	0.1	0.4	0.6
		TOTAL	9	0.19	0.16	1.15	0.1	0.1	0.8	1.2
8	Pulsating Rinse Technology	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
9	Recycling and Reuse of Cooling Water and Condensate Water	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	1	0.21	0.16	1.31	0.1	0.1	0.8	1.2
		TOTAL	1	0.21	0.16	1.31	0.1	0.1	0.8	1.2
10	Bleach Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
11	Salt Bath Recovery System	Small	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Medium	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		Large	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
		TOTAL	0	0.00	0.00	#N/A	0.0	0.0	0.0	0.0
12	Biological Wastewater Treatment	Small	5	4.53	(0.17)	#N/A	(0.9)	(0.7)	(5.6)	(6.0)
		Medium	2	3.43	(0.13)	#N/A	(0.7)	(0.5)	(4.2)	(4.5)
		Large	2	6.80	(0.26)	#N/A	(1.3)	(1.1)	(8.4)	(9.0)
		TOTAL	9	14.76	(0.56)	#N/A	(2.9)	(2.3)	(18.3)	(19.5)
	Total Pollution Prevention (BATEA 1-11)			3.37	1.40	2.4	0.9	1.4	5.4	8.6
	Total Pollution Control (BATEA 12)			14.76	(0.56)	#N/A	(2.9)	(2.3)	(18.3)	(19.5)

7. ADDITIONAL TECHNOLOGIES/PRACTICES

This section presents information concerning a number of additional technologies/practices that can be used to reduce effluent volume and/or toxicity from the wet processing textile industry. The technologies/practices described in the following pages are organized in the same broad categories as the twelve BATEA addressed in detail in Section 4 of this report. Specifically, the following technologies are discussed:

1. Optimization of Chemical Use	Recipe Optimization Bulk Storage Systems
2. Chemical Substitution	Overview Size and Desize Substitution Phosphate Substitution Thickener Substitution Dye Auxiliary Substitution Dye Carrier Substitution Solvent Substitution Replacement of Chemical Treatment with Other Treatment
3. Advanced Dyeing	Improved Scheduling of Dyeing Operations
4. Improved Quality Control	Good Housekeeping Practices Employee Training
5. Process Alternatives	Countercurrent Rinsing Process Stream Separation Continuous Knit Bleaching Ranges Change in Operating Conditions
6. Water Recycling and Reuse	Process Water Recovery
7. Chemical Recovery and Reuse	Dyebath Reuse Caustic Recovery Size Recovery Solvent Recovery Return Colour Systems for Printing
8. Wastewater Treatment Processes	Equalization Coagulation

The remainder of this section describes these 25 technologies. In addition, other alternatives are available but not discussed in this report. These include:

- ***Preparation Operations:*** Continuous vs. batch operations; combining/reducing process steps; quick-change padders on continuous ranges; low bath ratio batch bleaching with built-in bath reuse.

- ***Dyeing Operations:*** Direct dyebath monitoring and real-time control; continuous knit dyeing ranges.

- ***Finishing Operations:*** Low wet pickup (vacuum extraction); low add-on finishing; mechanical finishing as an alternative to chemicals; chemical finishing alternatives.

- ***Printing Operations:*** Inkjet printing and transfer printing.
- ***General:*** Automated mix kitchens for making print pastes and finish mixes and for dye dispensing; foam processing for mercerizing, bleaching, dyeing, and finishing; longer process runs and water supply modulation.

7.1 OPTIMIZATION OF CHEMICAL USE

Recipe Optimization

The objective of recipe optimization is to minimize ***chemical overuse***. Chemical overuse often leads to increased effluent strength, because most of chemicals used in textile processing are not retained on fibre but are washed off (UK-8). This in turn increases effluent treatment cost. Chemical overuse can be attributed to recipes that are not properly prepared or formulated to be fail-safe under extreme conditions. To optimize chemical use, recipes should be checked to determine if chemicals are mixed to specification and if they are vital to a given process. If recipes are mixed manually, it is necessary to check how operators measure and control dosing. If automatic dosing systems are used, they should be calibrated. In some cases recipe optimization can lead to 20-50% reduction in chemical use with corresponding 30-50% reduction in effluent BOD.

Recipe optimization can also minimize ***unnecessary chemical use***. Sometimes chemicals are added to counteract undesired side effects of other chemicals (USEPA-12). For example, defoamer is often added to reduce foaming caused by other chemical specialties. In many cases, it is more judicious to reduce, substitute, or remove offending chemicals via recipe optimization than to add more chemicals to offset undesired side effects. Such conservative use of chemicals can reduce waste loads and processing costs.

Recipe optimization can further eliminate ***chemical misuse***. A good example of chemical misuse is frequently seen with levelling agents and retarders (USEPA-12). These chemicals are used with a wide variety of dyes to ensure even and level dye exhaustion onto substrates. However, these chemicals are sometimes misused, resulting in lower exhaustion and more colour in wastewater. In many cases, use of these chemicals can be avoided and the same level of exhaustion can be obtained by proper temperature control.

Bulk Storage Systems

Bulk storage of sodium hydroxide, hydrogen peroxide and acetic acid is well recommended in the textile industry. These chemicals are used in the knit, woven and yarn textile industries. Sulphuric Acid is stored in totes and is utilized in the wool industry. Bulk storage results in chemical savings of 5% and reduces the amount of manual handling of these chemicals. In some instances, the chemical supplier will provide both the Storage Tank and the Filling Systems.

As indicated in Table 7.1, future additional potential for bulk storage systems is estimated to range from 17% of plants in the wool segment to 71% of plants in the yarn segment. This potential includes all plants where bulk storage systems are both technically feasible and not currently installed.

Table 7.1 - Bulk Storage System Benchmark

	Canadian Textile Industry					
	Knit	**Woven**	**Yarn**	**Carpet**	**Wool**	**Non-woven**
Number of plants in the industry	62	30	14	8	6	9
Plants utilizing bulk storage facilities (%)	50	30	29	75	83	N/A
Future additional potential for bulk storage systems (% of plants)	50	70	71	25	17	N/A

7.2 CHEMICAL SUBSTITUTION

Overview

The objective of chemical substitution is to replace process chemicals resulting in high pollutant loads with others that are less polluting. Chemical substitution is the primary focus for pollution prevention in the wet processing textile industry (USEPA-5, p.78; USEPA, 1996, p.88). It eliminates chemical waste and the need for costly pollution control equipment. Opportunities for chemical substitution vary substantially among mills because of differences in environmental conditions, processes, product, and raw materials. For any substitution, a careful evaluation should be made to ascertain that one pollution problem is not being substituted for another (USEPA, 1979).

Chemical substitution can be applied to almost every process in textile wet processing. Table 7.2 (Table 5 in UK-8) presents various options that have been used by the industry to reduce BOD and improve effluent quality. As a reference, BOD data for important textile chemicals is provided in Table 7.3 (Appendix 1 in UK-8).

Table 7.2 - Chemical Substitution Options Used by Textile Companies

Application	Current Material	Substitute Material
Sizing	Starch	PVA/acrylates
Acid desizing	Enzymatic	Mineral acids
Washing	Soaps (140% BOD)	Synthetic detergents (0-2.2% BOD)
Neutralizing scoured goods	Soda ash	Sodium acetate (converts mineral goods acidity into organic acidity)
pH adjustment in disperse dyeing and pigment printing	Acetic acid	Ammonium sulphate (although salt concentration increases, the ammonium serves as a nutrient in biological treatment)
Textile printing	Gum-thickening	Emulsion thickening (full or partial)
Oxidation of vat dyestuffs	Acetic acid	Sodium bicarbonate in conjunction with peroxide or perborate
Finishing	Temporary starch-based finishes	Durable resin finishes
Dyeing of blended varieties in pale shades	Two-stage dyeing using two different classes (e.g., polyester using disperse, and cellulosics using vats, reactives)	Single class dyestuffs like Indigosol, pigments
Polyester dyeing	Other carriers	Monochlorobenzene
Dye bath acid	Acetic acid (0.64 kg BOD/kg) Carding oils and anti-static lubricants	Formic acid (0.12 kg BOD/kg) Non-ionic emulsifiers

Table 7.3 - BOD Data for Important Textile Chemicals

Substance	Composition	Use	BOD
Acetic acid, 56%	CH_3COOH	Dyeing	33%
		Scouring	36%
B-2 gum	Starch dextrins	printing ink, size	61%
Dyes			
Alizarine cyanine		Acid dye	near zero
Byaform blue 2B		Direct dye	near zero
Calcogene black (GXCF conc.)		Sulphur dye	10%
Celliton fast (Blue AF100%)		Acetate colour	3%
Erie brillian (Black 5150%)		Direct dye	8%
Fast red salt 3GL	Insoluble azo compound		2%
Khaki carbanthrene (2G)		Vat dye	0
Naphthol AS-BR		Prepare	10%
Ethanol	C_2H_5OH	Solvent	125%
Ethyl acetate	$C_2H_5CO_2CH_3$	Solvent	66%
Formic acid 85%	$HCOOH$	Scouring	2%
Gelatin	Gelatin	Size	100%
Glue	Glue	Size	66%
70% hydroxyacetic acid	$HOCH_2COOH$		7%
Hydroxy ammonium sulphate	$NH_2OH_2SO_4$		4%
Monchlorobenzene	C_6H_5Cl	Swelling agent	3%
Oxalic acid	$H_2C_2O_4\ 2H_2O$	Rust removal	14%
Phenol	C_6H_5OH	Dyeing	200%
Picking oil		sizes, spinning, carding oils	13%
Red oil	Sulphonated castor oil	Soap making, carding	>68%
Salicylic acid	$C_6H_4(OH)COOH$	Dyeing	141%
Soap nonpareil	Fatty acid soap	Scouring, fulling, washing	140%
Sodium alginate	Size	Thickening agent	36%
Sodium hydroxulphite	$Na_2S_2O_4$	Reducing, stripping	22%
Special textile flake	Sodium salt of fatty acid	Detergent	112%
Surfactant DN-40		Scouring	15%
Sulphonated castor oil	Castor oil		52%
Sulphuric acid	H_2SO_4	Dyeing	0
Tall oil soap		Soap	147%
Tallow	Tallow	Soap making	152%
Tergitol 4	$C_4H_9CH(C_2H_5)$ $C_2H_4CH(SO_2Na)$ $CH_2CH(CH_3)_2$		0
Triethanolamine	$(HOCH_2CH_2)_3N$	Emulsifier, dispersing agent	10%
Wheat starch	Starch	Printing, inks, size	55%
Wool oil	Mineral oil + base	Spinning	3%

Most of BOD in textile preparation comes from sizes, knitting oils, and natural impurities that are removed from greige fabrics (USEPA, 1996). Table 7.4 (Table 4-23, USEPA, 1996) shows typical BOD levels from preparation processes.

Table 7.4 - BOD from Preparation Processes

Process	Kg of BOD/1000 Kg of production
Desizing starch	67
Desizing starch mixed size	20
Desizing PVA or CMC	0
Scouring	40-50
Bleaching with peroxide	3-4
Bleaching with hypochlorite	8
Mercerizing	15

Size and Desize Substitution

Sizing and desizing are two related processes encountered in textile wet processing. In the sizing (slashing) process, sizes are applied to warp yarns that undergo weaving operations in order to improve their strength and bending behaviour at the high speed of a modern loom machine (Carr, 1995; USEPA, 1996). In the desizing process, sizes are removed using desizes.

Starch is the most commonly used size and starch desizing with enzymes has been recognized as the single greatest source of effluent BOD at many textile mills. In the slashing process, warp yarns for cotton and cotton blends normally contain 10-15% by weight of goods added as starch size and filament synthetics require 3-5% (USEPA, 1996). This starch size is then removed with enzymes. Enzymes are specific biocatalysts capable of accelerating chemical reactions (Olson, 1983). Amylases are enzymes commonly used for desizing of starch-sized cotton by hydrolyzing starch to water-soluble, highly degradable monosaccharide glucose (Ellis, 1995). Starch desizing with enzymes can generate a high BOD of 67 kg per 1000 kg of fabric processed, and result in effluent BOD loadings in the range of 500,000 to 600,000 ppm (USEPA, 1996). The desizing process often accounts for more BOD than all other processes combined, i.e., contributing more than 50% of the BOD load in wastewater from wet processing (Milner, 1997; Freeman, 1995, p.837; and Nemerow & Dasgupta, 1991, p.393).

Size substitution is the principal means for effluent BOD reduction. Starch can be replaced with various synthetic sizes that have inherently lower BOD levels than natural starch (USEPA, 1996). For instance, typical effluent BOD loadings associated with synthetic sizes are only 2-6% of those associated with starch, i.e., 10,000-30,000 ppm for the former compared to 500,000-600,000 ppm for the latter. With synthetic sizes, effluent BOD loadings can be reduced by well over 90% and even over 99% if size recycling is implemented.

These synthetic sizes include polyvinyl alcohol (PVOH or PVA), polyvinyl acetate (PVAc), polyacrylic acid (PAA), polyester (PET), carboxymethyl cellulose (CMC), hydroxyethyl cellulose (HEC), and carboxymethyl starch (CMS) (USEPA-12). However, they differ considerably in BOD and COD contents as well as degree of degradation during desizing. PVA and CMC are low-BOD, recoverable sizes and should be considered as primary substitutes for starch (USEPA, 1996). Some U.S. mills have used synthetic warp sizes in place of starch (USEPA, 1979).

Use of synthetic sizes is commonly coupled with size recycling and reuse. Since synthetic sizes are effectively unchanged by the desizing process, they can be recovered from processing baths and reused for further sizing operation (Carr, 1995). Membrane separation has been successful in recovering and reusing PVOH (USEPA-11). Synthetic sizes are usually removed with hot water wash, although alkali is sometimes used to increase solubility (USEPA, 1996). However, unlimited recycling is impossible, due to contamination and molecular weight degradation of size materials (Becker and Brunert, 1980, in Carr, 1995). Traditionally, PVOH recovery applies to vertically integrated mills, especially in the United States, South America, and the Far East. Typical investment runs from $ 800,000 to $1,300,000 U.S., with potential paybacks in the five (5) to eight (8) years range. Warp size recovery generally would reduce the BOD and COD by approximately 20-50% of the total load discharged to the effluent.

Use and recycling of synthetic sizes are limited by two factors. The first one is feasibility; recycling of synthetic sizes is only feasible for vertically integrated operations or where special contract agreements are drawn up (Carr, 1995). It is of little interest to commission dyers and finishers that do not have outlet for recovered sizes and control over the type of size used on the goods processed. The second limiting factor is cost; recoverable sizes, primarily PVOH, are more expensive than starch (USEPA-12). It is difficult for a non-vertically integrated weaver to use these more expensive sizes that are to be recovered by another independent processor at a later time. It is also difficult for a non-vertically integrated wet processor to buy expensive recovery equipment in hope that a weaver will use recoverable sizes. Therefore, as noted previously, size recovery systems are found typically in vertically integrated operations.

Two alternative starch desizing methods can provide non-vertically integrated processors with a means for reducing effluent BOD loadings when starch is used as a sizing agent by an independent weaver. These methods are 1) use of other types of enzymes than amylases to degrade starch to ethanol; and 2) use of hydrogen peroxide to decompose starch to carbon dioxide and water (Freeman, 1995; USEPA-5). The first method employs special enzymes, developed for the home laundry market, to degrade starch to ethanol instead of glucose (USEPA-12). This offers an additional benefit of recovering ethanol for use as a solvent or fuel.

The second alternative, hydrogen peroxide-based desizing, employs equipment and procedures similar to that used for conventional enzyme processes (Olson, 1983). It requires that processing baths be controlled at alkaline conditions with a pH level equal to 10-11.5. An open width desizing range, which is very versatile and conventionally used for starch desizing with enzymes, can be adopted for oxidative starch desizing with hydrogen peroxide (USEPA-12). The wastewater discharge will have very low BOD loadings. Precise control of process parameters such as temperature, dwell time, and chemical concentration is required and made possible with microprocessor-controlled chemical feed systems and temperature and speed sensors. However, the oxidative desizing method can cause damage to cotton fibre (USEPA, 1996).

Another desizing technique is to use a low-temperature plasma for PVOH. With this technique, about 60% of the applied size is broken down to harmless gases and removed by passing woven fabric through a low-temperature plasma and the remaining 40% is removed by conventional wet processing (AATCC, 1973 in Carr, 1995). Unfortunately, this technique is additional to those normally used, presents an added cost to the goods, and uses more energy for plasma generation.

Size and desize substitution applies only to the woven industry. It has potential application in six of the thirty woven mills in Canada (the 20% that presently use size or a form of modified size).

As noted above, warp size recovery is generally suitable for vertically integrated apparel fabric mills that carry out both slashing and desizing, and is applicable to plants with production in excess of 30 millions meters of fabric per year. This technology is used world wide; however, it does not apply to the Canadian textile industry at the moment because less than 3% of the industry have both weaving and slashing followed by desizing.

Phosphate Substitution

Phosphates are salts or esters of phosphoric acid and form a group of phosphorus-containing chemicals used by wet processing mills. Phosphate salts are commonly used as bleaching agents as well as buffering agents (Nettles, 1983). Phosphate esters are a class of anionic surfactants. Phosphates are also used as water conditioners and flame retardant finishes (USEPA-12). The discharge of phosphates causes a high content of phosphorus in mill effluents, which is a common problem for nutrient-sensitive receiving waters (USEPA, 1996). Removal of phosphorus compounds from effluents is important, because these compounds play a critical role in the natural process of lake aging, i.e., lake eutrophication (Ramalho, 1977).

Although it is a necessary nutrient for biological treatment, the phosphorus content of textile mill effluents often exceeds its required quantity. One example is the effluent discharged by Blue Ridge-Winkler Textiles in Pennsylvania, USA, which contained 448 mg/L BOD, 59.0 mg/L phosphorus (P) and 15 mg/L nitrogen (N) (Rinker, 1975). In other words, the BOD/P/N ratio of the effluent was 100/13.2/3.3, whereas practical biological treatment operations only require 0.5-1 kg P and 3-5 kg N per 100 kg BOD (Fresenius et al., 1989). It should also be noted that the activated sludge process, although primarily intended for removal of organic contaminants, removes both phosphorus and nitrogen, since biological cells contain approximately 2.0% phosphorus and 12% nitrogen by weight (Ramalho, 1977).

The concentration of phosphorus in mill effluents can be reduced using non-phosphorus chemical substitutes. For example, acetic acid, a buffering agent, can substitute for monosodium phosphate for pH control and ethylene diamine triacetic acid (EDTA) can replace hexaphos for water conditioning (Freeman, 1995, p.839). Listed in Table 7.5 are available substitutes for phosphates and the phosphorus concentration in treated effluent can be reduced from 7.7 ppm to less than 1 ppm (USEPA, 1996). In almost every case, there are alternatives to the use of phosphates (USEPA-12). The exception to this is flame retardants and substitution is not generally possible.

Table 7.5 - Available Substitutes for Phosphates

Phosphate	Use	Substitute
monosodium phosphate	acid salt, pH	acetic acid
tetrasodium polyphosphate	water conditioner	soda ash
phosphoric acid	strong acid	hydrochloric acid
trisodium phosphate	alkali builder	caustic, soda ash
Hexaphos	water conditioner	EDTA, silicate
phosphate surfactants	scouring	ethoxylates, amines
Phosphates	flame retardants	varies
Phosphonamides	flame retardants	varies

Phosphate substitution is a common trade-off between phosphorus and other pollutants in mill effluents. For example, substituting acetic acid for monosodium phosphate lowers the phosphorus nutrient content of wastewater but increases the BOD and acidity (USEPA, 1996, p.92). In considering such substitution, a mill must examine site-specific conditions. Nevertheless, BOD and pH are generally easier to treat than phosphates, and the wastewater with acetic acid can be handled more easily by most treatment systems. In this case, the substitution results in a better waste stream compared with the original, phosphate-rich discharge. In other circumstances, however, substitution may produce a negative effect.

Thickener Substitution

Printing is a common operation encountered in wet processing textile mills. It is found in knit, woven and carpet finishing (USEPA, 1979). For knit and woven fabric production, screen printing is the most common technique, although others such as roller (gravure), ink jet and heat transfer printing are also seen commercially (Adanur, 1995, p.173; and Freeman, 1995, p.834). Rotary screen printing is now the leading technology, and accounts for over 60% of the estimated 25 billion square meters printed worldwide (Mock, 1996). Market share increases every year, mainly at the expense of roller printing which holds less than 14%. Flat screen printing holds a steady 19% of the market, mainly for bedding and large patterns for draperies. New technologies such as ink jet printing and heat transfer printing are still a small portion of the market. For carpet printing, special techniques are used, including foam, spray, and ink drop methods (USEPA, 1996).

Printing operations account for significant amounts of BOD and oil and grease. They generate 7 to 30 kg of BOD per 1000 kg of cotton processed as a result of colour-shop waste disposal and printing afterwash with soap and detergent (Nemerow and Dasgupta, 1991). Oil and grease is a class of pollutants present in mill effluents. For every 1000 kg of fabric processed, the amounts of oil and grease discharged are 3.8-9.1 kg for woven mills, 3.5-6.6 kg for knit mills, and 1.1 kg for carpet mills (USEPA, 1996). Oil and grease cause troublesome taste and odour problems (USEPA, 1979). Scum lines from these agents are formed on water treatment basin walls and other containers. Fish and water fowl are adversely affected.

As a thickener for screen printing pastes, kerosene is a source of BOD and oil and grease. In general, each kg of emulsified mineral oil has a 20 kg BOD load (Nemerow and Dasgupta, 1991, p.397). In addition, organic solvents, which also contribute to the BOD load of mill effluents, are used to clean printer screen when oil-based pastes are used (USEPA, 1996, p.193).

Synthetic thickeners have been developed to substitute for kerosene. The rheology requirements for screen printing pastes are quite specific (USEPA, 1996, p.198). The pastes must be thixotropic, moving easily through a screen when exposed to shearing force but remaining immobile (e.g., stationary on the fabric during steaming) when not under shearing force. Thixotropy is traditionally achieved by using water emulsified in oil, about 30 parts water to 70 parts oil, along with an emulsifier/surfactant. As a substitute, a synthetic polymer, often an acrylic copolymer, can give the same properties as those achieved by kerosene (USEPA, 1996, p.47; and Carr, 1995, p.33).

The substitution of synthetic thickeners for kerosene can reduce a large quantity of pollutants. A relatively small percentage of synthetic polymer (about 2%) is required for thickening printing pastes to produce the correct rheology for printing, compared with 70% kerosene in the oil-based method (USEPA, 1996). The substitution reduces not only substantial amounts of oil and grease, also atmospheric release of hydrocarbons from drying and curing ovens. Compared in Table 4.10 are typical recipes for oil- and synthetic polymer-based print pastes (Norman and Seddon, 1991).

As indicated in Table 7.6 (Norman and Seddon, 1991), use of synthetic polymer-based printing pastes would lead to elimination of a number of chemicals discharged into mill effluents in comparison with oil-based pastes. Emulsifier, kerosene and catalyst are totally eliminated, although binder and pigment remain unchanged between the two methods. By comparison, total chemicals are reduced by 80%. The polymer-based method uses a substantial amount of water to replace kerosene and is therefore much cleaner than the oil-based method.

Table 7.6 - Comparison of Oil and Synthetic Polymer-Based Printing Pastes

Ingredient	Oil-Based (part)	Synthetic Polymer-Based (part)	Difference (part)
Water	100	815	-715
Emulsifier	10	0	10
Binder	150	150	0
Kerosene	700	0	700
Thickener	0	15	-15
Pigment (dye)	20	20	0
Catalyst	20	0	20
Total printing paste	1000	1000	0

Dye Auxiliary Substitution

Effluent pollutants can be reduced by dye auxiliary substitution. For example, sodium sulphide is used to convert water-insoluble dyes to the soluble form for application of sulphur dyes to textiles (USEPA-5, p.79). To reduce the sulphide content of its effluent, a textile mill in the U.S. investigated substitutes for sodium sulphide and succeeded in replacing 100 parts sodium sulphide with 65 parts alkaline solution containing 50% reducing sugars plus 25 parts caustic soda. As a result, sulphide levels in the effluent were reduced substantially, to below 2 ppm.

Dye Carrier Substitution

Dye carriers are utilized primarily for dyeing Nomex and when processing polyester/cotton fabrics in atmospheric dyeing machines.

To date, there is no known substitute for dye carriers when processing Nomex fabrics. The alternative when dyeing polyester or polyester/cotton fabrics in atmospheric jigs or beams is change of equipment to new low liquor ratio high temperature dyeing machines (see also discussion in Section 5.4).

Solvent Substitution

The emphasis in solvent substitution is placed on replacing chlorinated organic solvents with non-chlorinated alternatives. Most frequently, solvents are used as water emulsions during the processing of textile substrates (USEPA-12). Typical solvent emulsions include scouring agents and dye carriers for synthetic fibres, especially polyester. Examples of solvents are methyl naphthalene, trichlorobenzene, chlorotoluene, ortho-dichlorobenzene, perchloroethylene, methyl ester of cresotinic acid, butylbenzoate, biphenyl, etc. These solvents can become part of the wastewater stream through spent processing bath discharge, batch chemical dumps, spills, leaks, and clean up (drums, tanks, etc.). For scouring, chlorinated solvents can be replaced with non-chlorinated solvents, such as xylene for chlorotoluene (although xylene is also a substance of concern). Since solvents are exhausted into textile substrate and later evolved from driers as airborne volatiles, the substitution can also reduce air emissions of chlorinated compounds. In addition, wastewater treatment is simplified with less chlorinated solvents (USEPA-5, p.88).

Replacement of Chemical Treatment with Other Treatment

Replacing chemical treatment with mechanical or other non-chemical treatment can reduce waste. It is not unusual for some textile mills to add chemicals to counteract undesired side effects of other chemicals (USEPA-5, p.79). In many cases, this practice can be avoided. For example, JP Stevens and Company Inc. substituted chemical biocides, used in disinfecting air washers and cooling towers, with the use of ultraviolet light. Test results showed reduced discharge of biocides to sewer, reduced pH and foaming problems in wastewater, reduced chemical inventory and handling, and improved workplace air quality and worker safety. The facility also showed enhanced air washer performance and more consistent control of workplace air quality. Based on chemical savings, the payback period is expected to be 11 to 18 months.

7.3 ADVANCED DYEING

Improved Scheduling of Dyeing Operations

Dyeing operations can be scheduled to minimize chemical waste resulting from machine cleaning. In dyeing operations, startup, stopoff and colour change often result not only in loss of substrate and potential off-quality work, but also in chemically intensive machine cleaning (USEPA, 1996, p.104). Machine cleaning contributes significantly to effluent pollutant loadings, particularly for change in polyester colour sequence and oligomer build-up (USEPA-5, p.86). The frequency of machine cleaning and mix dumps can be reduced with a well-planned dyeing schedule, resulting in minimum discharge of chemical waste associated with startup, stopoff and colour change (UK-8). However, minimizing machine cleaning may not be possible in some cases because of the need for flexible schedules to meet changing market demands. This applies primarily to commission dyers, in particular the knit industry.

The need for dyeing machine cleaning is contingent upon the sequence of colours used in dyeing operations. The best dyeing sequence, which requires the least machine cleaning, is to run the same colour repeatedly on one machine (USEPA-5, p.86; UK-8; USEPA, 1996, p.104). The second-best sequence is to group colours within families (red, yellow, blue), then run the dyes within one colour family from lighter to darker values and from brighter to duller chromas. When the darkest, dullest colour of the family is reached, the machine is thoroughly cleaned and prepared for a next cycle starting with light, bright shade.

Scheduling systems may be used in scheduling dyeing operations. These systems are capable of planning changeovers with minimum machine cleaning and users can receive some guidance while making their scheduling decisions (USEPA, 1996). With scheduling systems, process engineers and schedulers can control pollutants at the production scheduling and planning stage.

In the Canadian wet processing industry, weekly scheduling invariably includes the selection of dyes to run commencing with light shades and finishing the week with dark shades. This results in one only cleaning operation per week. Production planning and scheduling is practised in 80% of the knit, woven, yarn, wool and non-woven industries and 100% in the carpet industry. Typically, this responsibility falls under the jurisdiction of the Quality Control Department.

7.4 IMPROVED QUALITY CONTROL

Good Housekeeping Practices

Good housekeeping is an important pollution prevention measure. Improper work habits of chemical mixing operators can account for 10% to 50% of mill’s total effluent load in BOD, COD, metals, and organic solvents (USEPA-5, p.88). Improvement in housekeeping generally costs little or nothing and improves employee morale, workplace safety, and product quality.

Equipment maintenance is an important good housekeeping practice that reduces pollutant loads of mill effluents. Properly maintained equipment produces good work, less reworks, and less off-quality materials, minimizing waste associated with reworks and remakes (USEPA-12). Equipment maintenance reduces spills, leaks, and other processing bath losses that can contribute significantly to waste loads. In addition, proper selection of methods and chemicals used for maintenance can minimize discharge of toxic chemicals such as machine cleaners, solvents, degreasers, cutting oils and lubricating oils (especially knitting oils).

Process conditions and instruments should be checked on a regular basis. Most textile processes take place under high temperature (over 90^oC) and/or pressure conditions over a considerable period of time (UK-8). These conditions should be checked against their optimum set points. When instruments are installed to ensure uniformity of conditions, they should be calibrated to show the true conditions.

As a means for reducing effluent strength, ***chemical waste*** should be kept out of drains. Although they may seem trivial, chemicals that are spilled, dumped, or leaked into drains can be significant (USEPA-12). Proper clean-up practices for drums, tanks, and print screens, especially capturing offensive wastes such as print paste in dry or concentrated form, can reduce a large quantity of pollutants at source. Solvents in non-aqueous application are frequently used for machine cleaners, parts degreasers, and laboratory use. Waste solvents should never be disposed of in a sanitary sewer. Instead, solvent recovery bottles should be available for later pickup and proper disposal. It is usually a cost advantage to keep different types of solvents separate (e.g., chlorinated solvents vs. non-chlorinated solvents), since disposal methods vary.

Good inventory management can reduce waste by using all materials efficiently and reducing accidental releases of stored materials. Material use, contamination and dispersal can be reduced by designating a material storage area, limiting traffic through the area, and giving one person the responsibility to maintain and distribute materials.

Water and chemical conservation is another important good housekeeping practice. It consists of maintaining close control over mill operations to minimize accidental loss of process chemical baths and avoiding the preparation of larger batches than required (USEPA, 1979, p.197). It also includes reduction of dirt, grease, and rust in production areas to avoid additional washing and processing of soiled materials. Use of liquid level controls, flow indicators and metres, and automatic shut-off devices can also reduce water consumption.

Water conservation can also be achieved by eliminating unnecessary water use. Maintenance checklists should be established and priorities for repair should be set (UK-8). Although small, constant leaks may look insignificant, the associated water loss can be substantial when they continue 24 hours/day and seven days/week and are multiplied over a whole site. Circulating cooling water should be turned off when machines are not operating. Running taps and hoses should be turned off and hoses can be equipped with hand triggers. All these measures will save both water and energy. Other sources of water waste include broken or missing valves, excessive water use in washing operations, and defective toilets, water coolers, etc. (USEPA-12). It is not unusual to find situations where 10% to 30% reduction in water can be realized.

There are case studies on water conservation. For an example, employees at a small hat-dyeing company often left hoses running after hats had been cooled (UK-8). By attaching hand triggers to the hoses, they were able to reduce water and effluent costs by £2000/year. Another example is that employees at a dye house often left a tap running in summer to keep drinks cool. A half-inch diameter pipe running for ten hours a day could cost the company £2500 a year in water and effluent charge and it would be much cheaper to buy a refrigerator.

Another case study on water conservation was conducted at Welbeck Fabric Dyers, a UK-based textile company. The company found that two softers used in the preparation area accounted for 20% of the company’s water consumption and used significantly more water than recommended by the manufacturer (UK-3). In the softers, fabric is relaxed and partially scoured before dyeing by immersion in a series of water baths set at different temperatures. Prior to taking good housekeeping practices, valves were left fully opened to ensure the baths remained topped up. A detailed examination revealed that excess hot water overflowed from the baths and was mainly discharged to the effluent collection system. By using optimum valve settings determined from a series of tests, the company not only ensured product quality, also reduced 34,000 m^3 of water a year which represented 31% reduction in water use for the preparation area. This further resulted in reduction in effluent generation and energy consumption.

Employee Training

Employee training programs should be implemented at mills as a means for pollution prevention. These programs should inform workers of the environmental impact of chemicals and identify those most harmful to the environment (USEPA-5, p.88). Workers should be trained in proper procedures for handling these chemicals (e.g., pasting, dissolving, and emulsifying). These procedures should be subject to auditing and record keeping.

Employee training is practiced by the industry. For instance, Interface Fabrics Ltd., a UK-based textile company, has adopted employee training as a component of its overall environmental management (UK-2). Employees are briefed on the company’s environmental policy and their role in implementing environmental initiatives. They are encouraged to suggest improvements and to report any adverse conditions. All employees are required to be aware of possible environmental consequences of their actions. Process reports and information about new initiatives are posted regularly on notice-boards. Departmental meetings are also held to provide an opportunity to raise environmental issues.

7.5 PROCESS ALTERNATIVES

Countercurrent Rinsing

Continuous rinsing provides another efficient means for water use, while offering equal efficiency. Countercurrent flow is the most common configuration of continuous rinsing. It involves introducing clean water into the last of a series of rinsing steps, then running the spent water from the last step to the next preceding step and so on up the line (USEPA, 1996, p.110). In this way, the cleanest fabric is rinsed with the cleanest water, and the most contaminated fabric is rinsed with the least-pure water. Compared to drop/fill rinsing which uses fresh water for every single step, countercurrent rinsing can save water and therefore reduce wastewater by 50% for 2-step operations, 67% for 3-step, 75% for 4-step and 80% for 5-step (USEPA-5, p.81).

Countercurrent rinsing equipment is suitable for continuous processes. It can be retrofitted to any multistage continuous washing operation, whether it is installed for different fabrics or for different processes (e.g., soaper, range, and J-box) (USEPA-5, p.81). For example, a series of wash boxes can be installed on a continuous range through which water flows in the direction opposite to that of textile goods (USEPA, 1979, p.197). In this way, water is discharged when it contains the greatest amount of impurities and other undesirable matter. This system is a standard procedure in wool scouring and also a common practice in scouring, mercerizing, bleaching, or dyeing on continuous ranges. A survey of U.S. textile mills revealed that countercurrent rinsing was the most popular measure taken by mills to reduce water use in wet processing operations.

Countercurrent rinsing has been reported to have great impact on wastewater reduction. For example, a desize-scour-bleach range used by a textile mill typically consumed 11,000 gallons of water per hour and rinsing stages accounted for 90% of the total water consumption, as given in Table 7.7 (USEPA, 1996, p.67). By adopting the countercurrent rinsing principle, water use and wastewater generation was reduced by 6,000 gallons per hour, resulting in more than 60% savings in fresh rinse water. In U.K, countercurrent rinsing is an established technique common on continuous ranges and many case studies showed that it can save 20-30% of water in continuous dyeing (UK-8).

Table 7.7 - Water Reduction for a Typical Bleach Range via Countercurrent Rinsing

	Water Use without Countercurrent Rinsing (gal/h)	Water Use with Countercurrent Rinsing (gal/h)
Saturators	550	550
Steamer and J Boxes	150	150
Washers (desize, scour, bleach)	9,900	3,900
Dry Cans	450	450
Total	11,050	5,050

There are also two variants of countercurrent rinsing equipment: 1) horizontal or inclined washers and 2) vertical washers. Horizontal washers work for woven fabrics in a narrow weight range (USEPA-5, p.85). They operate by spraying clean washwater on the top (final) pass of fabric as it makes a series of horizontal traverses upward. The unprocessed fabric enters at the bottom traverse. Both horizontal and vertical washers are based on the same concept of countercurrent rinsing, whereas the efficiency of the former can double that of the latter using the same amount of water (UK-8). However, some of horizontal or inclined washers have lost their wide acceptance due to mechanical problems and a few manufacturers have gone back to the vertical configuration (USEPA-12).

Countercurrent Rinsing is primarily utilized in continuous processes and applies to the knit, woven and carpet industries. All modern ‘state of the art’ scouring, mercerizing, bleaching and continuous dyeing ranges are equipped with countercurrent rinsing systems.

As indicated in Table 7.8, future additional potential for countercurrent rinsing is limited to an estimated 20% of plants in the woven segment to 25% of plants in the carpet segment. This potential includes all plants where bulk storage systems are both technically feasible and not currently installed (excluding applications that would be cost prohibitive).

Table 7.8 - Countercurrent Rinsing Benchmark

	Canadian Textile Industry					
	Knit	Woven	Yarn	Carpet	Wool	Non-woven
Number of plants in the industry	62	30	14	8	6	9
Plants equipped with continuous processes (%)	7	83	N/A	100	N/A	N/A
Plants equipped with countercurrent rinsing systems (%)	7	60	N/A	75	N/A	N/A
Future additional potential for countercurrent rinsing technology (%)	0	20	N/A	25	N/A	N/A

Process Stream Separation

Separation of different process streams offers easy treatment of wastewater. Since certain treatment methods (e.g., neutralization) are waste stream specific, they are more effective in treating separate streams than combined (USEPA-12). Also, chemical recovery systems are generally more suitable for concentrated waste streams than diluted. In addition, mixing hazardous and non-hazardous (or hard to treat and easily treatable) wastes can create unnecessarily large volumes of hazardous (or hard to treat) wastes.

Highly dispersible wastes can frequently be handled at source. These wastes include 1) print paste; 2) waste solvents from machine cleaning; 3) still bottoms from solvent recovery; and 4) batch dumps of unused finish mixes (USEPA-12). They can readily be captured in dry or concentrated form for disposal. In some cases, they may have salvage or recycle/reuse value.

In general, uncontaminated water should be separated from process wastewater. In textile wet processing operations, non-contact cooling water and steam condensates can be returned to either a hot water holding tank or a clear well (USEPA-6). If neither is available, these streams should be segregated from wastewater streams that require treatment, since they are relatively clean and do not generally require treatment. In addition, waste streams from roof drains and parking lot drains can sometimes be treated and discharged separately from process wastewater (USEPA-12). This results in less hydraulic loading of mill effluents.

Process Stream Separation is well practiced in the Canadian wet processing textile industry.

Continuous Knit Bleaching Ranges

Continuous knit bleaching ranges consume less water, energy, and chemicals than batch preparation equipment. These machines feature inherent countercurrent water use and improvement over old rope bleaching units, including better fabric transport, better chemical metering systems, and better filtering of bleaching baths (USEPA-5, p.86). Recent models have shown improved flexibility in production capacity and low capacity machines are also available for small operations.

This technology applies only to the knit industry and is practised by only four plants out of sixty two in Canada. This represents 7% of the industry. Generally speaking, the knit industry is a batch type of business. Continuous knit bleaching ranges are utilized by large producers i.e. Gilden in Canada and Fruit of the Loom and Sara Lee in the U.S.A.

Change in Operating Conditions

Change in operating conditions of textile wet processing can lead to reduction in water and chemical use. These conditions include temperature, pressure, and residence time. Besides environmental benefits, production efficiency can also be improved with change in these conditions (USEPA-5, p.82).

This technique has been widely used in dyeing operations. For example, dye carriers are required for use of disperse dyes on synthetic substrates such as polyester and reduced under high temperature and super-atmospheric pressure dyeing conditions (USEPA-2). Another example is the use of pressure dye machines (USEPA-1979, p.201). These machines are more efficient in dye use, resulting in reduced requirement for water and toxic dye carriers as compared to atmospheric dyeing. In addition to dyeing, hot mercerization in place of conventional cold mercerization often enables elimination of separate scouring treatment (UK-8).

Environmental and economic benefits of change in operating conditions are demonstrated in a number of case studies. A Turkish textile mill adopted a 3-step high temperature rinsing operation at 95^oC and, therefore, eliminated overflow rinsing, neutralization and detergent washing which were previously required after dyeing (USEPA-3). The change helped the mill save US$90,710 through reduction in water and chemical use, while giving the same quality of colour and shade. Another case study was carried out at a U.S. mill on improvement in dyeing exhaustion by extending the length of time fabrics were dyed by 15 minutes (USEPA-5, p.82). Results showed 60% reduction in BOD and COD, a 20% in fats, oil, and grease, and 98% reduction in ammonia-nitrogen. This resulted in savings of US$35,000 annually.

Atmospheric dyeing machines are utilized in the Canadian industry for the dyeing of cotton, rayon and nylon fabrics. Pressure dyeing machines are utilized for the dyeing of polyester and polyester/ cotton fabrics. It is estimated that less than 5% of the industry utilizes atmospheric dyeing machines to process polyester with carriers. Hot water rinsing is more efficient then cold water rinsing and is practiced in the industry when and where the hot water is available.

7.6 WATER RECYCLING AND REUSE

Process Water Recovery

Process water recovery can be achieved using various purification methods. These methods include membrane separation, absorption, coagulation/flocculation, etc. Current purification equipment can achieve recovery levels of up to 70% and the recovery can be in the range of 80-90% for some dye processes (UK-8). One major issue in process water recovery is associated with salts used in dye processes. These salts can build up and affect the evenness of dyeing. However, some salts can be recycled, offering additional material savings.

Membrane separation is one of many commercially available separation methods that can be used for water purification and chemical recovery. Most common industrial-scale membrane separation operations are performed on liquid or semi-solid applications (UK-7). Membrane separation technologies are usually categorized according to membrane pore size. These categories in the order of decreasing pore size are microfiltration, ultrafiltration, nanofiltration and reverse osmosis. In reality, boundaries between these categories are not uniform as performance specifications vary from supplier to supplier.

Membrane separation has many advantages. It is particularly effective for recovery and reuse of both water and raw materials (UK-7). Use of a membrane system can reduce production cost, increase market competitiveness and reduce environment impact. Membrane separation units are compact and their modular construction means that they can be scaled up or down easily. Their commercial availability as small-scale, free-standing units suitable for use by small to medium-sized companies is progressively increasing. Furthermore, the technology is available as modular turnkey (off-the-shelf) plant.

Membrane separation systems also have some drawbacks. In general, more expensive and specialized membrane systems are necessary for high temperature applications in order to minimize fouling (UK-7). Another important constraint is a long payback period compared with some other alternatives when water cost is low.

Use of membrane separation for process water recovery has been reported. Sara Lee Knit Products Corp. in the U.S. employed ultrafiltration/nanofiltration to remove effluent colour and the treated effluent is reused in the dyeing process (USEPA-10). The company used mainly reactive dyes for dyeing cotton and the discharge from dyebaths ranged in true colour from 5,000 to 70,000 ADMI. An ultrafiltration/nanofiltration system was installed to generate a clean, sodium chloride-containing peameate stream which was reused in the dyeing process. The peameate accounted for 95% of the influent and the filtrate was further treated to remove solids by precipitation using ferrous sulphate and cationic polymer. The capital investment for an 80 gallon-per-minute system was estimated at US$580,000 and the operating cost at US$139,000 per year. Savings in water and salts were estimated to be US$350,000 per year. In UK, nanofiltration has also been used for process water recovery from dyeing effluents (UK-7).

The viability of process water recovery has been demonstrated by the industry. Courtaultd Socks, a UK-based textile company, installed an absorption system to recover water from dyehouse effluent for use in scouring baths (UK-4). The absorption system consists of layers of synthetic inorganic clay particles which are effective in removing reactive dyes and other organic compounds. Clear, warm water is obtained and then used in scouring baths. Sludge (clay particles plus absorbed organics) was also generated and can be safely discharged to sewer. Since the recovered water is at 40^{o}C as compared to fresh water at 10^{o}C, it can raise the starting temperature of any operation by up to 30^{o}C and thus reduce the energy needed for heating. This also means that less time is required for machines to heat up. With such an absorption system, the company has achieved net cost savings of £54,000 per year with a payback period of 2.7 years, reduced water consumption by over 60,000 m^3 per year and wastewater generation by 50%, lowered COD of the final effluent, and increased production efficiency.

In the U.S., process water recovery has been explored with enhanced wastewater treatment systems. Flynt Fabrics and Finishers Inc. in North Carolina invested in a treatment system for wastewater reuse within the facility (UK-8). The system consists of an aeration basin, a coagulation/flocculation tank and a bag filter. The aeration basin is used primarily to remove effluent colour using a reducing agent, known as COLOR-ACT 5319F marketed by Clariant Corp. The agent effectively breaks double bonds of dye structure, reducing effluent colour to 100 ATMI in the aeration basin. Solids present in the decolorized wastewater are removed in the coagulation/flocculation tank followed by the bag filter. The company expected the treatment would enable the facility to recover 60% of the total wastewater for reuse. The total capital investment for the 300,000-500,000 gallon-per-day system was US$512,000 and the operating cost was US$382,500 per year. Assuming the water/sewer cost was US$3.00 per 1,000 gallons, the water savings were estimated at US$270,000 per year.

7.7 CHEMICAL RECOVERY AND REUSE

Chemical recovery and reuse can reduce both production cost and effluent pollution level. They involve little modification of existing processes, while offering significant savings in raw materials and energy, which translates into less waste (USEPA-5; USEPA, 1979). Chemical recovery and reuse have been applied successfully in three major areas: 1) dyebath reuse; 2) caustic recovery in mercerizing process; and 3) size recovery (UK-8). Other areas include solvent recovery (USEPA, 1996) and reuse of processing baths other than dyeing (USEPA-12).

Dyebath Reuse

Dyebath reuse can be one of the following: 1) direct reuse of a whole dyebath; 2) recovery and reuse of dyestuffs; and (3) recovery and reuse of salts (BATEA #11). The last two forms of dyebath reuse usually requires a separation technology such as membrane.

Direct reuse of a whole dyebath involves use of exhausted hot dyebath for dyeing further batches of textile materials. At the end of a dyeing cycle, hot exhausted dyebath is saved by pumping it to a holding tank (USEPA-5; UK-8). It is then analyzed for residual chemicals and unexhausted dyestuffs to ensure proper shade in the next dyeing cycle. This analysis can be performed using a spectrophotometer, available for under US$10,000, and guidelines based on specific production experience. After the analysis, the dyebath must be reconstituted by adding water, auxiliary chemicals, and dyestuffs. Batch dyeing systems which have been reported for possible dyebath reuse are summarized in Table 7.9 (USEPA-12).

Table 7.9 - Batch Dyeing Systems Reported for Possible Dyebath Reuse

Product	Fibre	Dye	Machine
Knit fabric	Polyester	Disperse	Jet
	Cotton	Reactive or direct	Beck
	Polyester/cotton	Disperse/reactive or direct	Beck
Yarn package	Polyester	Disperse	Package
	Polyester/cotton	Disperse/reactive or direct	Package
Socks	Nylon/Spandex	Acid	Paddle
Pantyhose	Nylon/Spandex	Disperse/acid	Beck
Carpet	Nylon	Disperse/acid	Beck
	Polyester	Disperse	Beck
Woven fabric	Aramid	Basic	Jet
Skein	Acrylic	Basic	Skein

Several factors must be considered when direct reuse of a whole dyebath is to be implemented. The easiest dyes to mange are those that undergo minimum changes during dyeing processes (USEPA-12). These dyes include acid dyes for nylon and wool, basic dyes for acrylic and certain copolymers, direct dyes for cotton, and disperse dyes for synthetic polymers. Other classes such as vat, sulphur and fibre reactive dyes are more difficult for dyebath reuse. The easiest situation to manage is the reuse of a dyebath to repeat the same shade with the same dye and equipment on the same fibre. It is also possible to reuse a dyebath to produce a darker or lighter shade with the same dye selection on the same fibre. A more difficult situation would involve addition of new colorants to replenish a dyebath. This may lead to potential problems with shade matching and metamerism.

The number of reuse cycles for a dyebath is limited by build-up of impurities. These impurities include natural impurities in cotton and wool, knitting oils, winding waxes and emulsions, fibre finishes, size materials and the like (USEPA-12). Impurities can also accumulate from dye diluents, salt build-up from addition of acid and bases for pH control, steam contaminants for direct steam heated baths, and emulsifier systems from exhausted chemical specialties. Many impurities are surfactants, and these can cause stripping and/or retarding of dye exhaust if allowed to build-up excessively. Other problems such as spotting and excessive foaming can occur if too many reuse cycles are attempted. The usual range of reuse cycles is 5 to 25.

Direct reuse of a whole dyebath can be economically feasible. It is an attractive alternative to pretreatment systems for dyehouses that discharge to MWWTPs (USEPA-12, USEPA-5, p.82). In many cases, dyehouses operating in cities do not have enough space to construct pretreatment systems. In general, dyebath reuse requires a smaller capital outlay than wastewater pretreatment and can reduce effluent BOD and COD loadings by up to 33%. At the same time, dyebath reuse saves the cost for dyes, chemicals, and energy. Depending on dyeing equipment, fabric type, and the range of shades, dyebath reuse could save about US$21,000 per year for a dyeing machine, as illustrated in Table 7.10 (Table 17, USEPA-5) which also presents example costs for dyebath reuse. The payback period is generally 13 to 20 months.

Table 7.10 - Example Costs and Savings for Direct Reuse of a Whole Dyebath

Description of Cost/Savings	Value (US$)
Total Costs	
Lab and support equipment	9,000
Machine modifications, tanks, pumps, pipes	15,000-25,000
Annual operating costs	1,000-2,000
Total Savings (Annual)	
Dyes and chemicals	15,000
Water	750
Sewer	750
Energy	4,500

The economic benefit of direct reuse of a whole dyebath has been demonstrated in a number of case studies. In the U.S., Adams-Millis Company reused dyebath for dyeing nylon pantyhose in rotary drum dyeing machines at their High Point and Franklinton, North Carolina mills (USEPA-5, p.83). As a result, water use was decreased by 35% which saved US$0.02 per pound of production, and energy use was reduced by 57%. Also in the U.S., Bigelow Carpets reused carpet dyebath in a two dyeing machine arrangement by moving dyebath back and forth from one machine to the other (USEPA-5, p.84). This allowed dyebath reuse for over 20 cycles and reduced production cost by US$60,000 per year. In the meantime, effluent BOD, colour and other pollutants were also reduced. Another example is a facility at Amital which, by reusing both dyebath and non-contact cooling water, reduced water consumption from 320,000 to 102,000 gallons per day and, at the same time, increased production from 12 to 20 batches per day (USEPA-5, p.84). In addition, energy use for heating dyebath was decreased substantially. The investment for the reuse of dyebath and non-contact cooling water generated savings about US$13,000 a month and paid for itself in 30 days.

Membrane technology is also commercially viable for ***dyestuff recovery and reuse***. A facility of Cone Mills at Greensboro, North Carolina, U.S. discharged a wastewater stream with a colour index of 3,000 ADMI before treatment due to the presence of indigo and sulphur dyes (USEPA-9). Since indigo and sulphur dyes form much larger compounds than other dyestuffs, a portion of these dyes can be recovered by ultrafiltration. The company invested in an ultrafiltration system at US$1.5 million (1998) capable of processing 100 gallons of wastewater per minute and recovering 100,000 pounds of indigo and sulphur dyes (USEPA-9). The system provided a payback by reducing the amount of dyestuffs purchased and also reduced effluent pollutants.

Dye bath reuse applies primarily in the carpet industry for dye beck applications when processing polyester or nylon. The dye bath can be re-cycled four times prior to discharge. As the tendency in the carpet industry is towards continuous dyeing, it is unlikely that this technology will be practised in Canada because of lot sizes, shade variation and contamination.

The re-use of dye-baths in the knit industry is not practised worldwide. Recycling of dyebaths in the woven industry on continuous dye ranges is practised, especially in the seat belt business. However, when the run is finished, the dye bath is discharged to the effluent. Generally speaking, the re-use of dyebaths is not widely practised in the textile industry due to contamination and shading problems.

Caustic Recovery

Caustic recovery after mercerizing is quite common, especially in large finishing operations (USEPA, 1979). Mercerizing is a process of treating cotton fabrics and certain blends with a concentrated (20% or more) caustic solution. Since mercerizing is often a continuous process, the resulting wastewater is easy to segregate and caustic recovery up to 98% can be achieved (USEPA-12).

The practice of caustic recovery has proven its economic viability. A yarn finishing company invested in a new process which reused a rinse bath three times following mercerizing rather than dumping the bath water after each use (USEPA-5, p.84). The spent rinse water was then processed in an evaporator and the concentrated caustic soda (Na_2CO_3) was reused in mercerizing. This enabled the company reduce suspended solids by 80%, COD by 55%, and neutralizing soda in wastewater by 70%. It also resulted in reduction in hydrochloric acid used for neutralizing the effluent. The investment in the new process generated annual savings of US$189,000 with a payback period under one year.

Caustic recovery is generally suitable for vertically integrated apparel fabric mills. It can be utilized for recovery of caustic from mercerizing in both the woven and knit industries. This technology is used worldwide; however, it does not apply to the Canadian industry at present.

Mercerization is applied primarily on cotton fabrics. With regards to the knit industry most manufacturers in Canada purchase mercerized yarn when required from the United States. In the woven industry, the mercerization of 100% cotton fabrics, which applies to the apparel business, is non-existent in Canada. The technology could be applied to manufacturers who have three-stage bleaching ranges in the woven textile industry, which represents only two mills in Canada. This technology reduces the amount of salts discharged to the effluent.

Total capital expenditures costs are approximately $300 000 to $500 000.

Size Recovery

Size recovery is described under the heading of Size and Desize Substitution.

Solvent Recovery

Distillation is commonly used for solvent recovery. Waste solvents originate from all types of parts and machine cleaning as well as from processing uses such as solvent scouring ranges and dry cleaning (USEPA, 1996, p.97). Clean solvent vapour is obtained from the top of a distillation column and condensed for reuse. Sludge, residue, and still bottom should be kept separate from other wastes and disposed of separately.

Return Colour Systems for Printing

Return Colour Systems are utilized in all the printing plants in Canada. When the production run is completed, the remaining paste in the drum is returned to the colour shop to be re-used in a later production run. The actual pollutants discharged to the sewer come from the continuous belt cleaning process and the washing of the screens, colour pipes and drums. This represents less than 5% of the total chemicals utilized in the process.

The wash water from the belt cleaning system can be re-cycled with the use of membrane technology in order to reduce the BOD and colour in the waste stream. This is an expensive technology costing in the range of plus $200 000 per machine with simple paybacks in the 8-10 year range; it is not practised in the industry.

Seven plants in Canada are operating Rotary Screen Printing Machines (woven and carpet). Five plants in Canada are operating Flat Bed Screen Printing Machines (flags and banners). Two plants in Canada are operating Roller Printing Machines. Ink jet printing is still in its infancy in the textile industry and is the technology of the future. Transfer printing is utilized in the industry for specialized fancy products.

7.8 WASTEWATER TREATMENT PROCESSES

Equalization

Equalization is a preliminary wastewater treatment method designed to reduce variation in effluent streams. This is accomplished by holding effluents for a period of time (for instance, an eight hour period) before discharge, while the mill operation passes through the various manufacturing processes. Equalization can result in more effective treatment, because treatment technology is more efficient when operated at or near uniform hydraulic, organic, and solids loading rates (USEPA, 1979, page 212).

Coagulation

Coagulation is a chemical process by which chemicals are employed to destabilize suspended materials so that particles contact each other and agglomerate (USEPA, 1979, p.227). Colloidal particles are a significant constituent of most textile mill effluents. Besides fibre, they include colour bodies, soaps, mineral fines, oil and grease, and microscopic organisms (USEPA, 1979, 227). In addition, considerable amounts of latex are present in wastewater from carpet mills, other adhesive-related processing mills, and non-woven processing facilities. In excess, these pollutants are not suitable for discharge to receiving waters and can upset tertiary treatment processes or result in inefficient operation of these processes. Coagulation is commonly employed to remove colloidal particles.

In wastewater treatment, the coagulation process consists of three steps: 1) precipitation and coagulation; 2) flocculation; and 3) solids removal. In the first step, colloidal particles are transformed or coagulated to microflocs either by pH adjustment (such as acid cracking), and/or through use of coagulants (Norman & Seddon, 1991). These microflocs are then aggregated into large agglomerates by flocculation. Flocculation involves adsorption of flocculating agents onto particle surfaces. The adsorption enables the formation of loops and tails which are physical bridges across particles, thus binding them together into a flocculent-particle matrix or floc. The final step of the treatment is to remove solid agglomerates by various means, including gravity sedimentation, filtration, centrifugation, and air flotation.

The most effective inorganic coagulants for wastewater treatment are alum (aluminium sulphate), copperas (ferrous sulphate), lime (calcium hydroxide), ferric chloride), and ferric sulphate (USEPA, 1979, p.227). The multivalent cations, Al+3, Fe+3, and Fe+2 enter into a series of hydrolytic reactions to form multivalent positively charged hydrous oxide species that are adsorbed onto the negatively charged colloid. This neutralizes the colloidal system and allows the particles to agglomerate.

In addition to the coagulants noted above, polyelectrolytes (polymers) may be used as coagulant aids or as sole coagulants (USEPA, 1979, p.227). These compounds contain repeating units of small molecular weight, combined to form a molecule of colloidal size. Each of the repeating units carries one or more electrical charges or ionizable groups. Because of their large size, the major benefit of polyelectrolytes is an increase in floc size. It is generally agreed that a “bridging” mechanism is responsible for flocculation enhancement. One end of the polymer molecule attaches itself to the surface of a suspended particle at one or more sites and the free end is able to adsorb onto yet another suspended particle forming a “bridge” between the two. This union increases the mass of the colloidal-polymer system and increases the settling velocity. As the particle settles, it entraps other colloids and polymers and thus clarifies the wastewater with a “sweep floc” effect.

In practice, a coagulating/flocculating agent is usually applied with simultaneous pH adjustment in order to form a floc. Common situations are ferrous sulphate at pH = 9, ferric chloride or sulphate at pH = 6-9, and aluminium sulphate at pH = 6 (Eilbeck & Mattock, 1987, p.263). Chemicals used for pH adjustment include lime, sulphuric acid and sodium carbonate (Nemerow & Dasgupta, 1991, p.403; and Koprivanac et al., 2000). Lime can be also used as a coagulating/flocculating agent and has been claimed to be superior to aluminium sulphate.

Calcium chloride has been found effective in coagulating wool-scouring wastewater and acid cracking at a pH < 4 can provide a means for recovering wool grease (Eilbeck and Mattock, 1987, p.264).

Coagulation is an effective means for removing a large portion of conventional pollutants. It has been used as an important primary treatment method for solids removal from textile mill effluents (Eilbeck & Mattock, 1987, p.12). Operation data compiled from several U.S. textile mills showed that the coagulation treatment could achieve reduction of BOD, COD, and TSS by 90%, 80% and 70%, respectively (USEPA, 1979, p.218). In addition, most heavy metals will precipitate at high pH as hydroxides and lime is usually used to this end (Stephenson & Blackburn, 1998, p.239). Ferrous sulphide can also remove some heavy metals to lower levels than hydroxide precipitation. Removals down to 0.05 ppm or less are possible for cadmium, chromium, copper and nickel (Lankford and Eckenfelder, Jr., 1990, p.117).

Coagulation also allows for removal of dyes in effluents. An experimental study conducted by Papic et al. (2000) showed that reactive dyes (R. Red 45 and R. Green 8) at an initial concentration of 1.5 g/L in wastewater could be removed by 90% through a flocculation process using a commercial cationic polymer flocculant Levafloc R. Similar removal was also reported by Karcher et al. (1999) for other reactive dyes (R. Black 5, R. Blue 2, R. Orange 96, and R. Red 120) using a cage compound (sorbent), known as cucurbituril, in the presence of calcium. Other methods for dye removal include activated carbon (Al-Degs et al., 2000), treatment with Fentons reagent (H_2O_2 and Fe^{2+}) (Jank et al., 1998) and photocatalytic degradation in the presence of TiO_2 (Poulios and Aetopoulou, 1999).

Organic coagulants or organic polymers are usually favoured for colour removal from effluents (USEPA-11). Although higher in cost, they are more effective and tend to produce less sludge than their inorganic counterparts. However, excessive polymer use may be toxic to aquatic life. As an alternative, electrochemical methods, which employ degrading iron and/or aluminium electrodes, have been evaluated on different dyes and performed well for disperse, direct, and acid dyes. However, they appear to be difficult in removing reactive dyes.

Coagulation has been reported to be very effective in removing surfactants. Jones and Westmoreland (1999) found that over 95% of NPEs detergent and wool wax and greater than 98% of pesticide residues present in wool scouring wastewater could be transferred into sludge using a proprietary polymeric flocculant. The NPEs contained in the resulting sludge could further degrade through a composting process to below detectable levels (Jones & Westmoreland, 1998). The principal degradation pathway involved the oxidative hydrolytic shortening of the poly(ethylene oxide) chain of the hydrophile to produce low levels of the biorefractory metabolites nonylphenol (NP), nonylphenol monoethoxylate (NP1EO), nonylphenol diethoxylate (NP2EO), nonylphenoxy acetic acid and nonylphenoxyethoxy acetic acid. It should be indicated that the metabolites NP, NP1EO, NP2EO are more toxic than higher ethoxylates.

The effectiveness of coagulation in removing effluent pollutants has been demonstrated in case studies. A full scale investigation of alum coagulation treatment of effluents from a knit fabric finishing mill under the support of an USEPA Demonstration Grant showed that BOD, COD, TOC and TSS were removed by 50-70% and colour by 60% (USEPA, 1979, p.232). The coagulation process, however, had a very low removal rate for dissolved solids at 3% and was not capable of removing phenols. By adding a coagulation system to its existing activated sludge treatment, a facility of Cone Mills at Greensboro, North Carolina, U.S. increased the colour removal efficiency from 50% to 97% (USEPA-9). The coagulation system employed a polyamine coagulant and an anionic powder flocculant. The capital investment for the system was US$890,000 plus an operating cost of US$250,000 per year.

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