OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

21709

Distr.
RESTRICTED

ISED/R.72
9 December 1996

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ORIGINAL: ENGLISH

143p.
tables
graphs
diagrams

INDUSTRY AND WATER: OPTIONS FOR MANAGEMENT AND CONSERVATION

Technical report: Findings and recommendations*

Based on the work of

Peter Rogers and Nagaraja Harshadeep, consultants on Industry and Water Management

Backstopping Officer: G. Ramsay
Chemical Industries Branch

United Nations Industrial Development Organization
Vienna

---

* This document has not been edited.

V.96-88134

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This report was prepared under the sponsorship of UNIDO, Vienna, Austria. We are especially grateful for the help that Mr. Grant Ramsey and Ms. Ritu Kumar of UNIDO who helped us get access to various UNIDO and other documents and for their comments on various drafts of this paper. We would also like to thank others at UNIDO who provided useful suggestions when we embarked upon this venture. We would also like to thank Ms. Moon Kim, an undergraduate at Harvard University for her help in library research and in preparing useful graphs for this study.

Industry and Water: Options for Management and Conservation

EXECUTIVE SUMMARY

Peter Rogers and N. Harshadeep

Industrial Water Use

Water resources have come under increasing competition worldwide as burgeoning populations with increasing affluence demand more water in the form of agriculture, industry, domestic and hydropower needs. The problem is exacerbated by decreasing supplies of clean freshwater. The system resilience has dropped for many river basins as the systems are less able to absorb shocks caused by natural variability under these conditions of increased demand and decreased supply. Reservoirs are under stress due to the constraints placed on them that cannot be satisfied. Increasing competition in water use is a fact of life in many countries and is inevitable for others in the near future. Water has become a major bone of contention both among different users and regions in a state or country and also across international borders.

In recent years, many international organizations have been heavily involved in water policy. However, this interest has been primarily in domestic and agricultural water supply, and rural and urban sanitation. Not much attention has been paid to industrial water until now because water had always been considered of minor importance to most industries and, hence, of little concern for the governments. But if we look at recent facts, they speak otherwise. Although it is true that agriculture accounts for most water withdrawals (69% worldwide), industry is fast catching up, accounting for 23% of all withdrawals. This varies tremendously for different countries depending upon their size, population, stage of development, economic opportunities, and national priorities. For example, Pakistan, with a per capita withdrawal of 2000 m3 has a ratio of 98:1:1 for agriculture, industry, and domestic uses, whereas the United states, with approximately similar annual per capita withdrawals of 1900 m3 has the ratio of 42:45:13. Many of the developing countries are on the path of rapid industrialization and industrial water use is rising. In many developed countries, industrial water use accounts for a significant proportion of all withdrawals (the figure is about 45% for the U.S. and about 23% globally). Industrial water use in developed countries is, however, dropping indicating rising water use efficiencies.

Although the industrial sector accounts for only 10% to 15% of the aggregate annual water demand in developing countries, water is a critical input for process and cooling requirements in a number of major industries. As documented in case studies from Nigeria and India, water shortages, unreliable supplies and high prices adversely affect the expansion of small and medium industries resulting in loss of employment opportunities for the poor. In a number of regions in India (Madras, Hyderabad), China (Beijing, Tianjin), and Indonesia (Jakarta), and countries in the Middle-East, water supply and prices are emerging as one of the major constraints to growth of industries.

Despite the overall apparent shortage of water, there are few incentives for efficient use of water in large and medium industries in many regions. This is because most countries have not developed instruments (either regulations or economic incentives) and related institutional structures for internalizing the externalities which arise when one user affects the quantity and quality of water available to another group. Industrial water tariffs are typically based at best on average cost pricing (rather than marginal cost pricing) and ignore the opportunity cost of water (i.e., benefit foregone in alternative uses). Similarly, the effects of damages caused by industries in polluting surface and groundwater are ignored in determination of water tariffs and typically there are no pollution taxes and/or effluent charges to be paid by industrial polluters in developing countries. As a result, excessive quantities of water are used, and excessive pollution is produced. The industrial pollutants can have major environmental and health effects particularly in areas where pollution loads are high compared with the low-flow in rivers in some months.

Many countries are now realizing just how much is being spent on subsidizing irrigated agriculture. This is leading to a rethinking of strategies to manage resources, such as water, with such a vast differences between the price charged and the real opportunity costs foregone. Allocative efficiency implies the utilization of a scarce resource like water in sectors that generate the most value-added from the water use. This means that industrial and urban uses be given priority over agriculture in water-scarce regions.

Just as industry is catching up with agriculture as a primary withdrawer of water, another quiet revolution is occurring. The concern regarding water quality in many water sources is shifting from biological to chemical contamination. Although pathogens, primarily from municipal waste, are still a very serious cause of disease in developing countries, industrial discharges are increasingly becoming a serious problem. It is not uncommon to see rivers being treated as sewers in the industrial areas of many cities. Dissolved oxygen levels are so low as to preclude aquatic life in the receiving waters and groundwater sources are becoming contaminated with toxic chemical plumes. Sediments in lakes and rivers have become repositories of many hazardous wastes. Aquatic flora and fauna, especially in coastal zones are especially vulnerable to the effects of these pollutants and the food web connects them back to human consumption.

Yet another revolution that is occurring is in the options open to regulators to deal with the problems caused by industrial water use - both due to water consumption and due to effluent discharge. The number of options available to the regulators has increased tremendously. Traditional command and control approaches involving quotas on water withdrawal, limits on discharges, and mandating technologies for processes and treatment have now been augmented with more innovative approaches involving both quantity-based (e.g. bubbles, offsets, tradable permits) and price-based (e.g. effluent charges, more effective water pricing) incentives. This has added more instruments in the regulator's arsenal in order to effect the desired changes taking into account various technical and economic factors. This necessarily involves a paradigm shift in the approach to industrial water and wastewater regulation - from expensive standards that provide little incentives for innovation to more comprehensive performance standards that achieve the same ends at lower costs to society.

Some of these options have been considered in many areas with varying degrees of success. However, they are often poorly designed or implemented. For example, water and wastewater charges are often lumped together in the water-use billing. This gives little incentive or dis-incentive for the industry to be concerned about the effluents. Worse still, due to extremely poor monitoring about water use and effluent quantities and qualities, the charges are tacked on as surcharges on products, giving industries little incentive to better manage their input and effluent water. Industries are rarely involved in decision-making on water and wastewater regulations and are constantly adapting to changing regulations that are often set with little systematic considerations. Lax monitoring and enforcement gives industries little incentive to actually comply with the command and control regulations.

Each of these options have different effects - raising water charges have a different effect than instituting or raising wastewater disposal charges. Effluent discharge limits have a different effect than using economic incentives to achieve the same end. In addition, the implications to the industries, regulatory authorities and the water system are different under different systems. It is important to develop a more integrated planning approach to take into account the merits and problems associated with each approach.

The shift in thinking from the means to the end requires new kinds of analytical and methodological tools as well. Information technologies provide better ways to collect, manage, analyze and disseminate data and interface with models to help policy makers to assess priorities, set standards and monitor progress. Similar techniques used by industry could help them make a comprehensive analysis of all their options in a more flexible regulatory environment and plan ahead for changes in the regulatory requirements. More innovative approaches such as tradable permits would necessarily require the use of adequate models of river basin planning to help determine parameters such as prices and quantities of permits and “exchange rates” to effect a desired outcome under various scenarios.

Inter-sectoral concerns in water use are rarely addressed as agriculture, due to national goals of self-sufficiency or rural employment, is often a highly protected sector in which governments continue to subsidize inputs (e.g. water, energy, fertilizers) and outputs (e.g.

guaranteed crop prices) with little concern regarding the costs imposed on government coffers. Inter-sectoral reallocation of water from usually lower value-added sectors such as agriculture to higher value-added sectors of domestic and industrial uses are beset with many socio-political and equity problems, although the economic and efficiency benefits may be enormous. Because of this, it is highly unlikely that developing countries would set up any kinds of systematic water markets to allow for inter-regional and inter-sectoral trading. However, it still is true that small reductions in agricultural allocations could go a long way to satisfying the growing urban needs. Water-loss reduction measures in agriculture could be much more cost-effective in saving water than inducing urban water loss reduction; but farmers have little incentive to conserve at the low prices that they are charged for water. Cross-subsidization where industries are charged higher rates for water use or wastewater disposal to pay for agricultural conservation may be economically distortionary as there is usually little correspondence between the surcharge paid and the benefit derived by each industry and the farmers have little incentive to have an interest in the conservation as they derive little benefit from the process.

One way out of this deadlock could be to propose a system of water loss reduction markets. This would take advantage of the current situation in a unique and innovative way and avoid many of the problems with direct cross-subsidization. This would involve the setting up of an intermediate agency (initially comprising primarily of agricultural interests) that would handle all water transactions on a regional basis. The way the market would work is that industrial interests (either singly or as a regional association) would pay the agency at a certain price for reliable supplies of water and the agency would use this money to pay for conservation and better management practices in agriculture and conveyance. The measures undertaken, the prices set and the sequencing of projects would be based on both potential supplies of water (in terms of identifying water saving potential in agriculture and the costs and efficiencies associated with them) and potential demands (in terms of assessing industrial willingness-to-pay for the saved water). Such a system would be a truly "win-win" situation as all parties would be better off with no party being worse off. Industries would benefit from more reliable supplies of cheap water, and farmers would benefit from the distribution of profits from the agency's operation. This would lead to the development of innovative proposals for saving water losses. However, the real benefits lie elsewhere: the need for unnecessary regulations governing water use would be reduced, there would be a shift towards the inclusion of economics in water-use decision-making in all sectors, and a rise in comprehensive river-basin planning. Such a system could also become more inclusive to include storage, distribution and use losses in the domestic and industrial environment, identify conservation and recycling possibilities in industry include water quality and wastewater concerns, and include concepts of "industrial ecology" in determining mutually beneficial adjustments in various sectors. In the longer term, a logical extension of such thinking would lead to more efficient inter-sectoral allocation while addressing equity concerns.

It is important to stress that it is very important to promote a way of thinking about a problem rather than propose and be cornered into particular solutions. Only such approaches would encourage innovation and be responsive to changes in conditions, requirements, costs, processes, options, concerns and technical advancements. This integration of technical, social and economic concerns is necessary in order to achieve more sustainable development of water resources for the next century and cope with the expansion of industry in developing countries.

Where Does The Water Go?

At a time when there was no other source of power to provide energy to industries, many industries were located on rivers and used the river flow in clever ways to operate machinery in a flow-through process to produce a variety of products. Soon, the flexibility offered by electrical power allowed industries to be located far from water sources. Then the primary uses of water in industry included both consumptive and non-consumptive ones such as cooling, heating, process, consumption, transportation, solvent, waste disposal, and also for energy.

If we examine the total water use in a few industries in terms of the specific use that the water is put to, we find that a substantial portion of the water (from 30% in the sugar industry to

91% in industrial organic chemical manufacture in the U.S.) is used not for the actual industrial processes, but for substantially non-consumptive uses such as non-contact cooling. This is encouraging, because under appropriate regulations or incentives, it is possible in many cases to have closed-cycle systems for cooling. The remainder of the water is usually used for process-related items, that are very sensitive to the process technologies employed. The major industries that use a lot of water are pulp and paper and petro-chemical industries, and, to a lesser extent, fertilizer, sugar and the iron and steel industries.

An examination of the water use in selected industries reveals that there are orders of magnitude variation in the amount of water required for a unit quantity of different products. Water consumption varies widely within the same kind of industry. For example, the water use in the sugar beet industry worldwide varies from about 2 in Israel to eight times that in the U.K. or Finland. Thus, speaking in general terms of a change in water use based upon averages may be very misleading in specific cases.

A lot of water is recycled by industry (defined as a share of the gross water use contributed by recycled water), and the actual consumptive use is small. Most of the water is either recycled or discharged as wastewater. Much of the water discharged does have the potential to be recycled, and is increasingly being used as such for additional supplies where water is scarce, as in Israel. However, due to the often poor water quality of the effluent from water used in contact processes, it is easier to recycle domestic sewage than industrial water. Examination of the average and maximum recycling rates, reveals that there are efficient industries such as synthetic rubber and petroleum refineries where the range is small, but there are industries such as cane sugar with wide ranges that have the potential for large improvements in water use.

In planning for the future, one needs to keep in mind the fact that changing needs could result in demands for new kinds of industrial products and obsolescence of existing products, changing patterns of industrial water demand. In addition, technological changes and changes in factors governing inputs and processes could result in completely different water use patterns.

Economics and Technology

A comprehensive approach to water policy is incomplete without recognizing the influence of prices. Water is a scarce resource and economics is the science of managing scarce resources. At the 1992 UN Dublin Conference on Water, water was finally widely recognized by governments as an economic good. It is often forgotten that we cannot specify supply and demand solely in quantity terms; we also need the price at which the particular quantity would be produced or demanded. Except for a tiny portion of our basic consumption, water is indeed substitutable at high enough prices. It is not a free good as popularly perceived.. It is imperative that prices be high enough if recycling and conservation are to be voluntarily encouraged. Inappropriate agricultural water policies lead to the inefficient over-consumption of subsidized water in sectors which obtain little value from the water. The opportunity costs of the water for its higher value-added uses are almost never considered in water projects. This leads to the expansion of supplies to meet projected demands without considering if it is more cost- effective to encourage demand-management measures rather than incrementally increase supply.

Economic thinking gives us another perspective on water scarcity and makes us realize that we will never run out of fresh, clean water. If the price the users of water paid reflected the opportunity costs of the water, the debate would shift from the traditional questions such as "What is the extra water needed to meet the projected demand?", "Can we provide X units of water to region Y annually for Z purpose?", "What projects or program do we need to provide the water?" and "How much will it cost to provide the water?" to questions like "What is the opportunity cost of water in each region?", "Which are the regions where there is a water crisis, i.e., with a high user cost?" "Is it worth supplying extra water at price P per cubic meter to region Y - will Z use it at that price?" "How much do government subsidies and other economically distortionary policies really cost?" and "What policies and technical options should be pursued to achieve the goals of efficiency and equity?"

Technology and economics have always played a determining role in the interaction of industry and water. To understand where in industrial water use systems economic instruments may be effectively applied one needs to have information of where the major savings can come from. Iron and steel are by far the largest water users followed by petroleum refining, textiles, and pulp and paper with much lower total use. Even though developing countries use such a small portion of the total water, they pretty much follow the same priority of water uses. Globally, looking at the quantities used, industrial water consumption would seem to be mainly a developed country problem. However, this static picture hides the rapid rates of industrialization in large countries like China, India, Indonesia, and Brazil. All of these and the other developing countries, already have large demands placed upon their water resources and the industrial water demand arriving last will have difficulty in assuring supplies.

In the pulp and paper industries the bulk of the water use is process related with only a smaller fraction going to non-contact cooling. The situation in the industrial organic chemicals industry is radically different with the bulk of the water going to non-contact cooling. The implications of these for changing water use are radically different. The are many easy technical options for non-contact cooling which are very price sensitive, hence, pricing on the input side in these industries could lead to large water savings at relatively low costs. If the bulk of the water goes for process related activities, the policy options are less clear. For example, it will be necessary to change the process technology to achieve significant savings. These are likely to be expensive and are less input price responsive that cooling water options. In this case, both input and output pricing may be indicated as well as some form of product environmental charge.

Before arriving at any conclusions based upon these considerations, it is also necessary to look at the fate of industrial water use. Pulp and paper industries in developed countries typically already recycle significant amounts of their waste water, the industrial organics recycle less and discharge more. This clearly indicates more attention to regulating and pricing of the effluent of this industry. Of course, as the report demonstrates it is not easy to separate the input and output policies without looking at specific cases. Then some blend of policies, including regulation and water and effluent pricing, usually turns out to be the preferred policy.

Backstopping Technology

In any area of resource development there exists a backstopping technology. For energy resources it is solar energy. For water resources the backstop technology is desalination. Desalination, like all backstopping technologies (technologies of last resort) is the most expensive technology to produce water. However, it is often used as an excuse for the lack of rational water management. More often than not, the costs of desalination cannot be justified by the additional benefits it provides - it is often more efficient to undertake simple demand management steps; however, the latter is often not politically acceptable.

Desalination is limited spatially given the requirements for seawater or brackish water and cheap energy. Traditional desalination technologies include the multi-stage flash process and the reverse osmosis process, that together account for about 86% of the 13 million cubic meters of desalinated water produced every year. However, given recent claimed cost-cutting innovations in the desalinization process, it may turn out that desalination will be a relatively inexpensive supply option for industries in arid regions of the world. Certainly, if desalination is economically viable anywhere in any economy, it will be for industrial water use because industrial water users are typically willing to pay several times the amount that agriculturalists and urban dwellers are willing to pay.

Regulation and Economic Instruments

The problems of industrial water management are often fairly obvious ones: lack of effective regulations, enforcement, and appropriate incentives on the part of government and a lack of management skills on the part of industry. The primary problem is that most countries have promulgated regulatory policies, but few have any instruments (regulations, economic incentives, and disincentives) to enforce them. In addition, water has traditionally been considered a common property good and as a result the full price of water is seldom charged to consumers. Even where tariffs are charged, they are usually based upon average costs and also ignore the opportunity costs of water or the real costs of the externalities of wastewater disposal. These factor have led industries to use water inefficiently. Industries have not needed to employ conservation and recycling measures as water has been too inexpensive. Recently, increasing concerns over increasing water scarcity and environmental concerns, and the competition among the users for the scarce resources has led to the consideration of more rational water management strategies.

Policy Options

How much do these policy options change the water demanded and wastewater disposed of by industries? It is not an easy task to determine the effects of price and non-economic instruments on industrial water management strategies. This is because their use has been so rare. It is also difficult to exactly determine how much a change in water prices would affect the water demanded in industry. Basic economics tells us that a rise in water tariffs would lead to a drop in the water demanded - exactly how much depends on the price elasticity of demand of industrial water. These elasticities are notoriously difficult to determine empirically as it is difficult to control for other variables even in the rare cases when industrial prices have been raised enough to actually make an impact. The effect of policy options is usually obtained by the various case studies involving the examination of the response of nations, regions, industry types and individual firms to changes in one or a set of water policies. Such analyses at least indicate the kinds of policies that have been successful in the past and the industries or regions that appear to be most responsive to policy changes. This kind of information is necessary before any kind of efficient water policy portfolio can be drafted for the various industries in different spatial regions.

Policy Instruments

There are a large number of policy options that potentially deal with regulated industrial water and wastewater. The objective of the policymaker is to find that particular configuration

that fits best into the local conditions. No one policy, set of policies, is necessarily a priori better than any other set. One needs to explore the details associated with particular industries.
The broad set of options available to the policy can be further collapsed to the following four:

- Traditional Command and Control Legislation and Regulation which specifies the water quality standards for rivers/lakes, for effluent discharged into water bodies and for providing the machinery for implementation of these regulations;
- Quantitative restrictions (quotas) on water consumption and/or effluent discharged by each industry or a group of industries;
- Economic Incentives influencing the behavior of entrepreneurs by setting appropriate levels of water prices (tariffs), effluent charges, pollution taxes on water and groundwater extraction charges;
- Subsidies such as providing tax benefits or investment support or low-interest loans for investments in effluent treatment plants installed by a single unit or by a group of industries (or by a municipality) for common treatment facilities.

These four sets of policy tools for rationing water and managing wastewater can be broadly classified into the two sets of pricing and quantity tools. Which of these policy tools should be used to manage industrial water demand? The answer usually depends on the players involved, the specifics of the industry and water sources and receiving bodies, monitoring and enforcement capabilities of the institutions involved, and acceptability. Industries, for example, prefer lower cost options of course, but are also interested in stable expectations; they understandably find it harder to deal with uncertainty in the price they have to pay or investing in personnel and equipment for wastewater management that are secondary to the primary business of the industry. These effects are especially acute in small-scale and cottage industry, for whom many developing countries have lax environmental regulations. However, it does not make much sense to have some plants that are mandated to discharge very clean effluent located next to a small-scale tannery operation releasing toxic untreated effluent into the same receiving body of water without considering the system-wide economic costs of control. For example, if the cost of control for one firm is very high (the small scale plant) and it were allowed to trade with another firm with lower control costs (modern large scale plant) so that the second firm would control more than would be required under a command and control system and then is compensated by the first firm that pollutes more than it is allocated. This will produce a much more economically efficient pollution control regime than the simple waste allocation and command and control. The same behavior could, of course, be effected by using varying effluent charges. However, the setting of the efficient effluent charges requires much more government intervention than a permit trading scheme.

Effluent charges and tradable permits have varying impacts. Effluent charges usually lead to a known amount of money being spent on pollution control, but may not lead to a desired level of clean-up. Tradable permits, on the other hand, can start with a desired level of clean-up that is then allocated as permits to the individual firms in the area, and the total cost of control is not exactly known a priori. Effluent charges generate revenue that has to be used in some way - regressively by removing it from the industrial system, or progressively by ploughing it back into the system, possibly by subsidizing pollution control equipment or research, although this introduces its own distortions.

Tradable permits have the problem of initial allocation which could be given according to prior use, sold by auction (generating revenue), or other methods. In theory industries will then trade with the permit holders until an efficient allocation of effluents is attained. Transaction costs in trading may not be as insignificant as assumed by the theory and may limit trade, especially in cases where there is no established mechanism for trading or due to limitations in information availability or exchange. These mechanisms have had some success in managing air pollution from sulfur dioxide in the U.S., although the current trading prices of the permits appear to be much lower than predicted by the economic analysis. Water pollution is, however, significantly different and technically more complex. For example, one-to-one trades as allowable in air pollution are usually not possible in water pollution due to stronger locational considerations in river basins as opposed to air-sheds. A detailed hydrologic basin model is required by the government regulators before trading parameters can be established. The experiences in the U.S. with an experiment on the Fox River in Wisconsin were not encouraging. Nevertheless, the USEPA has recently announced its willingness to act as a broker to facilitate such water permit trading on a nationwide basis . Of course, intra-plant (bubbles) trading is attractive in for large integrated industries.

Simulation of Policy Impacts

The report discusses the various non-economic command and control policies and contrasted them with the economic instruments available to influence industrial water policy. In order to asses how much these different economic and non-economic policies may influence industrial water use decisions we have devised a set of simple policy simulators. These simulators, or Decision Support System models, can simulate the effects of operating an industrial plant under the control of these instruments and assessing their economic and environmental impacts. For instance, they can be used to equilibrate economic and non-economic instruments -- how much would have to be charged as an effluent fee to induce the same environmental behavior as a strict command and control embargo on discharge of pollutants? They could also be used to find the right mix of quantitative and economic standards and indicate potentially important areas for R&D.

The simulation models provide mechanisms for gaining insight into specific problems and to the generic problems of industrial water and wastewater management. As mentioned above, there are many different policy options that can be explored with these models. What the models show is that one can arrive at the desired outcome (from a local government's part) by either a strict regulatory or a pricing approach. The choice of which to take (or a combination) would be conditioned upon an understanding of the local situation and an assessment of which approach would in reality be more cost-effective. Such models are powerful tools for the integration of economic and technological choices in determining optimal mixes of hardware and software options and identifying “win-win” situations for the various stakeholders.

Just a few of these options have been analyzed here. We have developed models to analyze options for two cases - a tannery and a paper and pulp industry. The base case for a small tannery was a minimally regulated situation and it led to a minimum cost to industry of $36,256 per year. We compared alternative regulatory approaches to the same problem. The first comparison is with the classical command and control approach, where untreated effluents were limited to about 50% of the base case. This led to an increase in the optimal minimum cost for the tannery of $46,397. When the untreated effluents were completely banned the cost rose to $47,327. The model shows that it is possible to achieve a similar environmental outcome (in terms of water quality) more efficiently using the economic tool of effluent pricing. An effluent fee of $0.35 per m3 for untreated discharge and $0.10 for treated discharges leads to a cheaper solution ($44,035) with similar environmental benefits.

For a pulp and paper mill (producing 30,000 tons of paper per year), a minimally regulated base case cost $68,616 per year. We examined the effects of technical advances in conservation technology on the water use and effluent discharge patterns of the industry. We found that with technological advance, industries could save about one third of their expenditure on water and wastewater management. Furthermore, we also found the provision of subsidies by the regulatory authority to encourage the use of advanced technology increased adoption of conservation technologies by industries, and hence, lowering water consumption and producing better effluent quality at a lower cost to the industry.

Many sensitivity calculations can be made, each shedding new light on the industry-water system. For example, when we performed a sensitivity on surface water treatment costs ranging from $\$0.01/m^3$ to $\$0.15/m^3$, we observed that the use of treated surface water fell sharply with the rising price from about 44,500 m^3/yr, that was near the maximum allowable to about 8,500 m^3/yr, after which the system ran out of substitution possibilities in our scenario. The surface water was substituted primarily by a rise in the use of untreated municipal water and treated groundwater. There was also an increase in the use of internally recycled water, although the proportion re-treated fell.

The important point here is that by performing such a sensitivity analysis, we were able to derive a demand curve for treated surface water. From this curve, it is possible to determine the price elasticity of demand for that particular commodity - treated surface water. In this case, the elasticity works out to be about -2.58. This high elasticity can be attributed to the high degree of substitutability that that is possible . Note that cross-elasticities (e.g. effect of raising the cost of treated surface water supply on the demand for treated groundwater, ceteris paribus) can also be derived by using the results of sensitivity analysis. It is important to note that the elasticity is a function of the technical options and regulatory parameters specified in the system, and an accurate computation of the elasticity is dependent upon developing realistic options in the scenarios considered.

If we now wish to observe the effect of raising the effluent charge for disposing of one kind of effluent - untreated wastewater, we can do so by repeatedly running the model while performing a sensitivity on that parameter. For the tannery case, we see that the discharge pattern is insensitive for charges up to $0.14/m3, but after that, there is a gradual decrease in the quantity of untreated sewage to surface waters up to a charge of $0.16/m3, after which there is a sharp drop to achieving zero-discharge of untreated wastewater into surface waters. This is achieved by a slight switch to disposing of this sewage into the sewers at a higher cost, until that option is exhausted, after which the effluent is treated and thereupon discharged to the surface waters.

Similar to a demand curve derived above, we can derive an effluent discharge curve that displays the discharged quantity as a function of the cost of disposal. It is also possible to calculate a price elasticity of effluent generation, although they have to be interpreted in the appropriate ranges. Such an analysis would also help decision-makers set appropriate effluent charges by determining the ranges in which the effluent discharge patterns would be insensitive or determining the threshold fees after which the desired effects can be observed.

The analytical approaches used demonstrate the power of simple programming models to enhance decision making both at the level of the industry and of regulators. The intention of the model was to illustrate its use in a couple of case studies. It is possible to make such models much more complex to increase their capabilities. For example, the model could be made seasonal or monthly to include temporal aspects (stochasticity could also be handled using stochastic or fuzzy optimization models and follow-up simulation modeling); process change options could be more explicitly defined; water quality parameters could be more disaggregated to handle specific process standards and to better handle environmental externalities; the production level could become a variable, opening up the path to maximizing net benefits instead of minimizing costs to produce a certain quantity of product; the industry could be considered as part of a larger system to illustrate some of the principles of river basin planning, industrial ecology; integrated supply-side and demand-side management; more integrated surface water and groundwater conjunctive use including recharge from effluents; inter-sectoral issues; the examination of various economic and regulatory instruments (command and control, bubbles, offsets, tradable permits, etc.), comprehensive analysis of pollution to various media, consideration of multiple objectives, game-theoretic analyses from the point of view of various stakeholders, etc.; the possibilities are only limited by the imagination. However, another computational limitation could be the software and hardware capabilities, although this is far less so that even in the recent past.

The current model itself represents a major step in the right direction towards analyzing the complex issues in water management in industry. Tools such as these tend to be a good forum for collecting and organizing data, assessing options, thinking rationally, clarifying objectives, identifying which constraints are flexible and which are inflexible, developing scenarios for the future, integrating the views of various stakeholders, identifying negotiating positions, determining tradeoffs between various objectives, analyzing when objectives are in conflict and which issues are not worth disputing about, developing effective policy mixes and response strategies, identifying areas of incomplete knowledge and research, etc. They make the best use of the available data and are an important step in integrating economics with technological options.

Role of UNIDO in Comprehensive Industrial Water Management and Conservation

The role that UNIDO can play in industrial water and waste water policy and management is largely determined by UNIDO's unique role in the UN family of institutions as the only agency dealing directly with industrial problems. Other specialized agencies deal with many other aspects of water and waste management, but none has the specific industrial mandate of UNIDO. For example, UNEP deals with the environmental dimensions of water, notably water pollution and ecosystem effects, UNDP deals with the economic resource aspects of water, FAO deals with the irrigation uses of water, UNICEF and WHO deal with the health and sanitation aspects of water, and UNDESP deals with the social and economic aspects of water policy. The ILO and to a lesser extent UNESCO support capacity building, training, and educational activities in the area of water and public health. ESCAP, ECLA, ECA, ECE, and ECSCWA deal with the regional water supply and water quality issues for Asia, Latin America, Africa, Europe, and West Asia.

In the wider UN family of affiliated institutions, the World Bank and the regional development banks in Asia (ADB), Africa, and Latin America (IADB) all deal with the economic, social, resource, and environmental aspects of water from a development investment point of view. Each of them also deal with industrial development projects involving water and wastewater management. Also non-UN affiliated institutions such as the European Union (EU), the OECD, and the Organization of American States (OAS) also support major activities on environment with limited activities in water management. It also appears that NAFTA will become increasingly involved with industrial water pollution issues.

There are several areas that UNIDO should explore for institutional involvement and for expansion of existing activities. Coordination between the various international, regional and local organizations is needed to avoid expensive and confusing duplication of effort and to promote an enabling environment for rational water management.

Role in Water Supply

In the past UNIDO has been involved in technical advising on the details of water supply infrastructure. This technical help has ranged from advice to demonstration projects. Other areas on the supply side that merit consideration are the reduction of transmission losses and providing advice on leak detection. Technical support for industrial process treatment planning, design, and implementation including manufacturing support would be helpful. Desalination is an area where industrial involvement is absolutely required and is an area of supply management that affects both the supply of water but requires a great deal of technical expertise for both the economic and engineering analysis.

Role in Water Demand

UNIDO has past experience in a wide variety of manufacturing and other industries. UNIDO's experiences with process optimization and cleaner production demonstrations in India and other countries have been very successful and point to a wider involvement in these activities. More training, software development, and demonstrations are needed. Simple technical assistance programs to identify recycling/conservation options for various industries would by themselves be very instrumental in demonstrating to industries (and governments) the benefits of recycling. Active research could be supported in the area of closed-loop systems - in pulp and paper industries and water cooling. The development and encouragement of industry-wide recycling services (ex-plant rather than in-plant) looks like a very fruitful area. This ex-plant development should emphasize the revenue aspects for industry groups and non-governmental agencies. Policy advice to governments, particularly local governments, would help promote these developments.

Role in Water Quality

In addition to the conventional concerns with wastewater management, emphasis should be placed upon cleaner production or pollution prevention. Materials recovery facilities - e.g. chromium in leather industry, waste exchanges, and waste clearing houses will help reduce the total loads of toxic chemicals in the environment and speed the rate of clean-up. Other areas deserving of attention are the design of appropriate wastewater treatment plants, the identification of costless options and "win-win" situations, the development of combined wastewater treatment for a groups of small industries, and the reuse of "wastes" by other industries.

Other Supportive Roles

Monitoring

In the area of monitoring, UNIDO should encourage monitoring to assess transmission losses, industrial water use (and change over time), effluent quality and loading of different pollutants. These will be required for all policy assessment. In addition, the sequence of training, equipment supply, self-monitoring, and regulatory monitoring needs to be fully integrated into the plans.

Loss Reduction

UNIDO can play an important role in loss reduction in industry. Losses in water use in industry can be classified as *physical* (lost water in storage, distribution, leaks and inefficient use and collection systems), *financial* (water and wastewater utility losses due to under-pricing, non-billing and non-collection of costs associated with maintaining the system) and *economic* (due to water not being allocated to its highest-value uses). Adequate monitoring, data management, and analysis of options are essential components in developing approaches to reduce each of these kinds of losses. It is useful to make a comparative evaluation of the various “hardware” and “software” options used in different kinds of industries around the world to improve water use efficiency, and UNIDO could help provide such information.

Setting Standards

There is a clear role for UNIDO in helping countries set standards for each industry type keeping in mind location, receiving water body, plausible treatment options, effect on industry, expected compliance, etc. Also the type of standard - e.g. concentration, loading, performance, are items that have great importance in determining outcomes. UNIDO could also play an important role in providing international validation and comparative evaluation to help set local water quality standards.

Training Programs (Capacity Building)

UNIDO has a long history of successful capacity building via a variety of different training programs. These programs will need expanding with more emphasis being placed upon the software of pricing, incentives, regional and intersectoral dimensions, and the role of stakeholders, rather than simply on the technology side.

Case Studies

In order to convince government and industry to change the ways of doing business, it is essential to generate sets of case studies showing the options available and their likely consequences before any agreements are reached between government and industry.

Policy Advising

There is also opportunity for UNIDO to become involved in regional industrial water policy advice. This may include helping to advise on regulations and tariffs (on both water use and wastewater generation) to effect desired behavior.

International Water Conflicts

It is also clear that in the near future, there will be a lot of international attention focused on solving regional water problems by getting stakeholders together in river basins to help determine fair and efficient allocation of scarce water resources. This presents a role for UNIDO as the industrial representative in meetings with other international organizations representing other water users, or with national or regional agencies.

Creation of Water and Waste Markets

There may also be a role in helping the creation and operation of water and waste markets in appropriate places at the required time. UNIDO's ability to marshall industrial support for the creation of such markets would help ensure success. UNIDO could play an important role in the creation of innovative markets to help industries take advantage of the savings from water loss reduction (in areas like agriculture where there are many low-cost options for saving considerable quantities of water) to augment industrial water supplies and increase inter-sectoral allocation efficiency.

Eco-Labeling

A totally new area could be that of eco-labeling. It is common for manufacturers or some NGOs to make eco-labels that reflect the relative achievement and sometimes, resource use in manufacture of the product in an effort to influence consumer behavior. It is possible to disaggregate existing labels or to create new ones to reflect the water use efficiency in the production of the final product. The development of this kind of public information system is an area for UNIDO technical expertise.

Clearing House for Technology and Best Practices

Perhaps the most important role that UNIDO can fill is to act as a central clearing house for information on different aspects of industrial water use. This would include any new technology that would enhance conservation and recycling options in various types of industries, reviews of past experience in technology policies, results of demonstration programs, consultants rosters, and costs (capital versus operation and maintenance versus replacement). This would involve substantial collaboration with the private sector, academia, other R&D organizations, and other relevant international and regional organizations.

The nexus between water and industry is an area that not much attention is paid to; however, proper planning and flexibility in terms of the regulatory and industrial response structure can prevent this from becoming a crisis situation. There are enough options both for regulators and industry to adequately address concerns arising from industrial water use and effluent disposal. Nevertheless, it is necessary to analyze these options systematically in a technical and economic framework to achieve the right mix of quantitative and economic regulations for the regulators and the right mix of technical choices for the industry that would meet the regulations and any other objectives of the industry at the lowest cost. UNIDO could play an important role in helping regulators and industries to have access to information to perform such analyses through its extensive experience, current programs and future objectives.

Chapter 1

Industrial Water: Issues and Problems

Introduction

Water resources have come under increasing competition worldwide as burgeoning populations with increasing affluence demand more water in the form of agriculture, industry, domestic and hydropower needs. The problem is exacerbated with decreasing supplies of clean freshwater (van der Leeden, et al., 1990, and Glieck, 1993). The system resilience has dropped for many river basins as the systems are less able to absorb shocks in water supply under these conditions of increased demand. Reservoirs are under increased stress due to increasing demands and constraints placed on the system that cannot be satisfied. Increasing competition in water use is a fact of life in many countries and is inevitable for others in the near future. Water has become a major bone of contention both among different users and regions in a state or country and also across international borders. Some have gone so far as to predict that the next war in the Middle-East would be about water and not oil.

In recent years, many international organizations have been heavily involved in water projects in various parts of the world (See Chapter 6). However, this interest has been primarily in domestic and agricultural water supply, and in both rural and urban sanitation projects. Not much attention has been paid to industrial water until recently, because water had always been considered of minor importance to most industries. However, if we look at the recent facts, they speak otherwise. Table 1.1 shows a regional and sectoral breakdown of water use worldwide (Gleick, 1993). Although it is true that agriculture accounts for most water withdrawals (69% worldwide), industry is fast catching up, accounting for almost a quarter of all withdrawals worldwide. Many of the developing countries are on the path of rapid industrialization and industrial water use is rising. In many developed countries, industrial water use accounts for a significant proportion of all withdrawals (the figure is about 45% for the U.S. and about 23%

globally). Industrial water use in developed countries is, however, dropping indicating a rising water use efficiency (National Association of Manufacturers, 1965).

Many countries are now realizing just how much is being spent on subsidizing irrigated agriculture (United Nations, 1992). This is leading to a rethinking of strategies to manage resources, such as water, with such vast differences between the price charged and the real opportunity costs foregone. Allocative efficiency implies the utilization of a scarce resource like water in sectors that generate the most value-added from the water use. This means that higher-value urban uses, such as industry, be given priority over agriculture in water-scarce regions, although actual shifts in allocation may be beset with political and social problems.

Industrial Water Use

Just as industry is slowly catching up with agriculture as a primary withdrawer of water (Strzepek and Bowling, 1995), another quiet revolution is occurring. The concern regarding water quality in many water sources is shifting from biological to chemical contamination. Although pathogens, primarily from municipal waste, are still a very serious cause of disease in developing countries, industrial discharges are increasingly becoming a serious problem (Carmichael and Strzepek, 1984, ChemInform, 1992). It is not uncommon to see rivers being treated as sewers in the industrial areas of many cities. Dissolved oxygen levels are so low as to preclude aquatic life in the receiving waters. Groundwater sources are becoming contaminated with toxic chemical plumes (USEPA, 1994, Eckenfelder, 1989). Sediments in lakes and rivers have become repositories of many hazardous wastes. Aquatic flora and fauna, especially in coastal zones are especially vulnerable to the effects of these pollutants. The food web connects these problems of aquatic life back to humans.

In most countries, industrial regulations have been passed to address the problem of water quality. Although most developing countries have strong laws and regulations on industrial discharges, they are seldom effectively enforced. There is a need for policy reform to combat the threat of industrial pollution. For instance, there are many innovative economic policy instruments that could help in the determination of alternative approaches. For example, recycling and conservation measures can be encouraged in industry by means of more appropriate pricing policies for water and wastewater discharge (discussed in Chapter 3).

Although these measures are very important in their own right to help regulate the effects of the industrial sector on water resources and would remain important components in any set of approaches in the future, there is a need for a more comprehensive management of water resources (Beard and Maxwell, 1982). "Comprehensive management" as a concept has been as often used as "sustainable development", and is often also used without an operational sense. By comprehensive management, we mean the consideration of all the important issues that govern water use. This depends on the scale of the problem definition (at the level of an industry or household, neighborhood, city, river basin, nation, international river basin, etc.). For example, in a river basin, this would imply a joint consideration of all supplies (groundwater, surface water, desalination, recycling, etc.), demands (major water uses including: agricultural, industrial, domestic, hydropower, cooling, recreation, flood control, etc. as adjusted for conservation measures where applicable) and transfers (among various users and regions of a river basin and inter-basin transfers) where multiple objectives would have to be simultaneously optimized under a set of physical, policy, legal, economic, financial and technical constraints.

Although the industrial sector accounts for only 10% to 15% of the aggregate annual water demand in developing countries, water is a critical input for process and cooling requirements in a number of major industries (Hettige et al., 1995). As documented in case studies from Nigeria and India, water shortages, unreliable supplies and high prices adversely affect the expansion of small and medium industries, resulting in loss of employment opportunities for the poor[1]. In a number of regions in India (Madras,

---

[1] As noted by Lee and Anas (1990), in Nigeria, actual unit cost (0.52 naira per gallon) for small firms was much higher than the actual cost (0.02 naira per gallon) for large firms which inhibited the growth and birth of new small firms. In a note on water use by three major industries in Madras, Manu (1991) found that due to water shortage, one unit had to cut down production by one-third while water availability was a

Hyderabad), China (Beijing, Tianjin), and Indonesia (Jakarta), and countries in the Middle-East, water supply allocations and prices are emerging as one of the major constraints to growth of industries. Other case studies are provided in UNIDO (1993a and 1993b).

Despite the overall apparent shortage of water, there are few incentives for efficient use of water in large and medium industries in many regions. This is because most countries have not developed instruments (either regulations or economic incentives) and related institutional structures for internalizing the externalities which arise when one user affects the quantity and quality of water available to another group. Industrial water tariffs are typically based at best on average cost pricing (rather than marginal cost pricing) and ignore the opportunity cost of water (i.e., benefit foregone in alternative uses). Similarly, the effects of damages caused by industries in polluting surface and groundwater are ignored in the determination of water tariffs and typically there are no pollution taxes and/or effluent charges to be paid by industrial polluters in developing countries. As a result, excessive quantities of water are used, and excessive pollution is produced. Industrial pollutants can have major environmental and health effects particularly in areas where pollution loads are high compared with the low-flow in rivers in some months.

In view of the conflicts in the use of water and pollution of surface and groundwater sources, new supplies have to be obtained from long distances (ranging from 50 to 180 kilometers in metropolitan areas in many countries), involving high investment costs in pipeline transportation and pumping of water. Both the quantity and quality problems mean that the costs of supplies of adequate quality are rising rapidly with the cost of a unit of water from "the next project" often being 2 to 3 times the cost of a unit from "the current project". Hence, in many situations, demand-side management measures such as loss reduction, water conservation and recycling is likely to be more cost-effective than investments in augmenting water supply. Further, investments in water conservation, recycling and reuse provide environmental benefits (over and above the economic benefits of lower costs) since these result in reduction in water pollution loads. Thus, conservation

---

major constraint on expansion of capacity in the other two units (Madras Refineries and Madras Fertilizers).

and recycling of water in industries provide opportunities where there is no conflict between the objectives of economic efficiency and environmental improvement.

Economics and Technology

Technology and economics have always played a determining role in the interaction of industry and water. At a time when there was no other source of power to provide energy to industries, many industries were located on rivers and used the river flow in clever ways to operate machinery in a flow-through process to produce a variety of products. Soon, the flexibility offered by electrical power allowed industries to be located far from water sources. Then the primary uses of water in industry included both consumptive and non-consumptive ones such as cooling, heating, process, consumption, transportation, solvent, waste disposal, and also for energy.

To understand where in the industrial water use systems economic instruments may be effectively applied, one needs to have information on where the major savings can come from. Figure 1.1 shows the best estimate of global water use by industrial sector. Iron and steel are by far the largest water users followed by petroleum refining, textiles, and pulp and paper with much lower total use. Even though developing countries use such a small portion of the total water, they pretty much follow the same priority of water uses. Globally, looking at the quantities used, industrial water consumption would seem to be mainly a developed country problem. However, this static picture hides the rapid rates of industrialization in large countries like China, India, Indonesia, and Brazil. All of these and the other developing countries, already have large demands placed upon their water resources and the industrial water demand arriving last will have difficulty in assuring supplies.

Figure 1.2 shows how water use technology is currently employed in some of the major industrial groupings. From a policy perspective, this figure gives some indication of where the potential for water savings lie. For example, in the pulp and paper industries the bulk of the water use is process related with only a smaller fraction going to non-contact cooling. The situation in the industrial organic chemicals industry is radically different with the bulk of the water going to non-contact cooling. The implications of these for changing water use are radically different. The are many easy technical options for non-contact cooling which are very price sensitive, hence, pricing on the input side in these industries could lead to large water savings at relatively low costs. If the bulk of the water goes for process related activities, the policy options are less clear. For example, it will be necessary to change the process technology to achieve significant savings. These are likely to be expensive and are less input price responsive that cooling water options. In this case, both input and output pricing may be indicated as well as some form of product environmental charge. Technical options are further explored in Xie et al., (1995).

Before arriving at any conclusions based upon these considerations, it is also necessary to look at the fate of industrial water use; this is shown in Figure 1.3. Here we get a sense of how well the industry is already doing in recycling and disposing of its wastes. Now the comparison of the policy instruments to be used for the two industries above could change. Pulp and paper industries in developed countries typically already recycle significant amounts of their waste water, the industrial organics recycle less and discharge more. This clearly indicates more attention to regulating and pricing of the effluent of this industry. Of course, as Chapter 5 demonstrates it is not easy to separate the input and output policies without looking at specific cases. Then some blend of policies usually turns out to be the preferred policy.

A comprehensive approach is incomplete without recognizing the influence of prices. Water is a scarce resource and economics *is* the science of managing scarce resources. The most important contribution of recent approaches to water management, articulated at the 1992 UN Dublin Conference on Water, is that water is finally being widely recognized by governments as an economic good. It is often forgotten that we cannot specify supply and demand solely in quantity terms; we also need the price at which the particular quantity would be produced or demanded. Except for a tiny portion of our basic consumption, water is indeed substitutable at high enough prices. It is not a free good as popularly perceived. It is imperative that prices be high enough if recycling and conservation are to be voluntarily encouraged. Inappropriate agricultural water policies lead to the inefficient overconsumption of subsidized water in sectors which obtain little value from the water. The opportunity costs of the water for its higher value-added uses are almost never considered in water projects. This leads to the expansion of supplies to meet "projected demands" without considering if it is more cost- effective to encourage demand-management measures rather than incrementally increasing supply.

Economic thinking gives us another perspective on water scarcity and makes us realize that we will never run out of fresh, clean water. If the price the users of water paid reflected the opportunity costs of the water, the debate would shift from the traditional questions such as "What is the extra water needed to meet the projected demand?", "Can we provide X units of water to region Y annually for Z purpose?", "What projects or program do we need to provide the water?" and "How much will it cost to provide the water?" to questions like "What is the opportunity cost of water in each region?", "Which are the regions where there is a water crisis, i.e., with a high user cost?", "Is it worth supplying extra water at price P per cubic meter to region Y - will Z use it at that price?" "How much do government subsidies and other distortionary policies really cost?" and "What policies and technical options should be pursued to achieve the goals of efficiency and equity?"

How does one compare this with claims about how the world is running out of water? Like the doomsday predictions of the 1973 Club of Rome, these observations are borne out of concern for the future of mankind, but fail to take rational economic thinking into account. For example, we know that in many coastal regions where most of mankind lives, even in the arid middle-east, it is not possible to "run out of water" because we always have an infinite source of supply by sea-water desalination. This means that water cannot be worth more than the cost of desalinating it and transporting it to the point of use. What we mean is that we will never run out of water; clean water would simply become more expensive to obtain. This does not in any way imply that water is something that is not worth worrying about; on the contrary, we now need to treat it as an economic commodity and examine if its use for a particular purpose is worth the real cost of providing it. Even with projected sharply-falling desalination costs, it would still be rare to recommend desalination if allocative efficiency is the criterion. It would make much more economic sense to transfer allocations from less productive uses of cheaper sources of water to more productive ones.

Approach Taken in This Report

This report examines the nexus between industry and water, primarily to provide a synoptic view of the role of industry in water consumption and wastewater management. In terms of conceptual scale, the discussion is fairly general but focuses on specifics in order to demonstrate key concepts; in terms of geographical scale, the discussion is on a global or regional basis but with a number of actual cases to illustrate spatial variation. However, before we delve into this issue further, it is worth defining the term "industry". Used in a loose sense, industry could include anything from traditional manufacturing industries to mining, hydropower generation, etc. Given the purposes of this report, we focus primarily on manufacturing industries. One can also conceive of a recycled water industry where recycled water itself may be considered a product for sale.

In this report we have chosen to view industrial water use from the perspective of an individual industry (Figure 1.4) with input and output links to the environment. This is similar to that taken in Bhatia et al., (1994). We have also taken the approach of local regulation which focuses on the regulation of the environmental outputs and the inputs of a single firm using a variety of economic and regulatory tools. We have not considered the regional control and regulation of industries. The policy tools examined relate to input, effluent, recycling, and the technology of the industrial process (as exemplified by consumptive use and losses). Chapter 5 analyses two major water-using industries (pulp and paper, and tanneries) as examples of the application of modeling techniques to integrate technical and policy choices in an economic framework. Appendix 1 gives a compendium of global, regional and industry specific data. These data reflect the magnitude of the industrial water problem, both in its supply and waste disposal dimensions. They also reflect the paucity of the data resources that are needed for effective decision-making as related to the use of water in industry.

TABLE 1.1: Sectoral Breakdown[2] of Annual Water Withdrawals (in Km^3)

(sectoral percentages in parentheses)

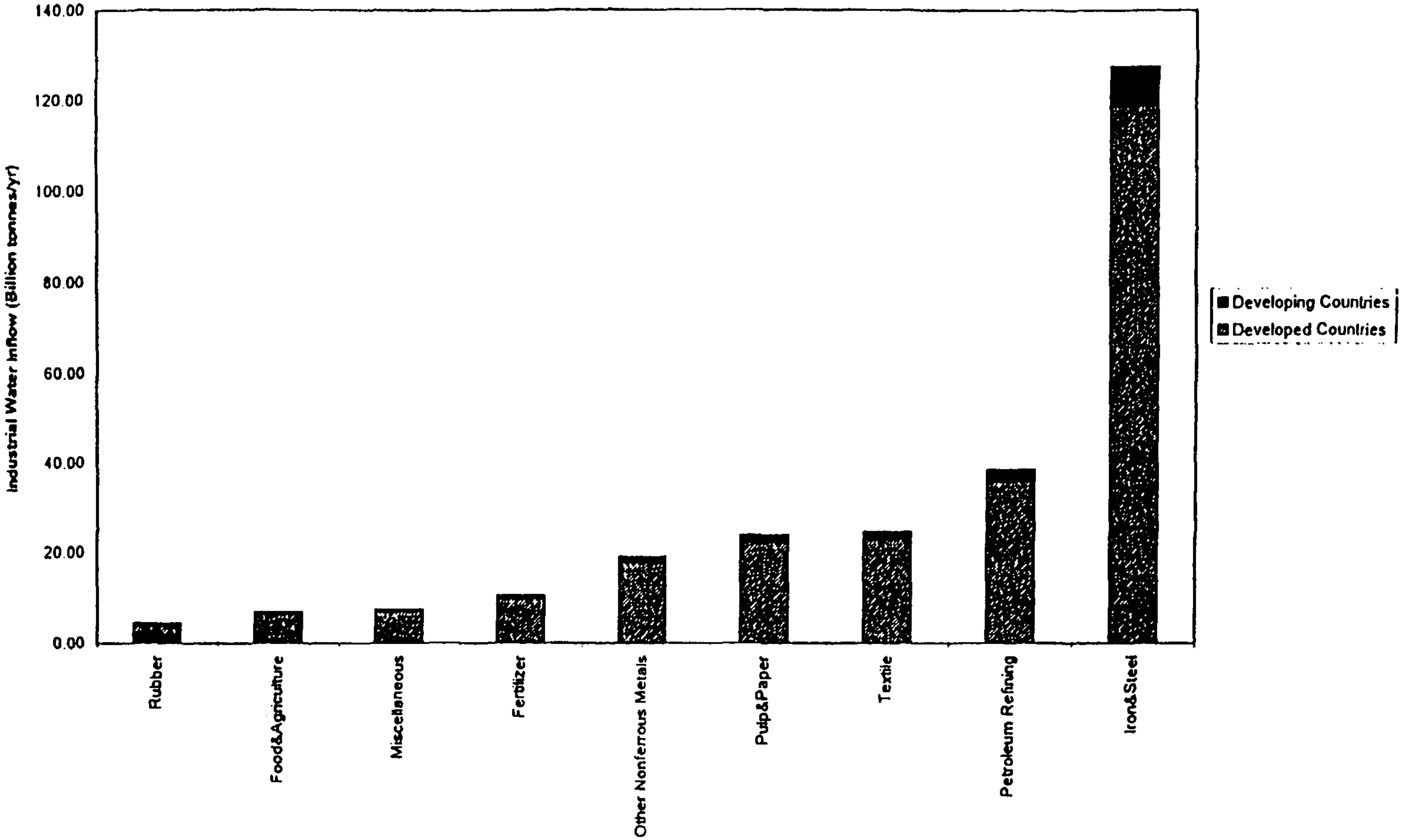
Region	Sector		
	Agriculture	Industry	Domestic
Africa	127 (88%)	7 (5%)	10 (7%)
Asia	1317 (86%)	123 (8%)	92 (6%)
N.&Central America	912 (49%)	782 (42%)	168 (9%)
South America	79 (59%)	31 (23%)	24 (18%)
Europe	118 (33%)	194 (54%)	47 (13%)
U.S.S.R. (former)	232 (65%)	97 (27%)	25 (7%)
Oceania	7.8 (34%)	0.5 (2%)	15 (64%)
World	2236 (69%)	745 (23%)	259 (8%)

---

[2] A distinction must be made between measured and derived data - many of the data used in water resources planning are derived from an examination of related parameters; agricultural water use is rarely measured - it is often estimated by assumptions about the crop types, planting patterns, water consumption rates, regional climatology and method of irrigation (Glieck, 1993)

FIGURE 1-1

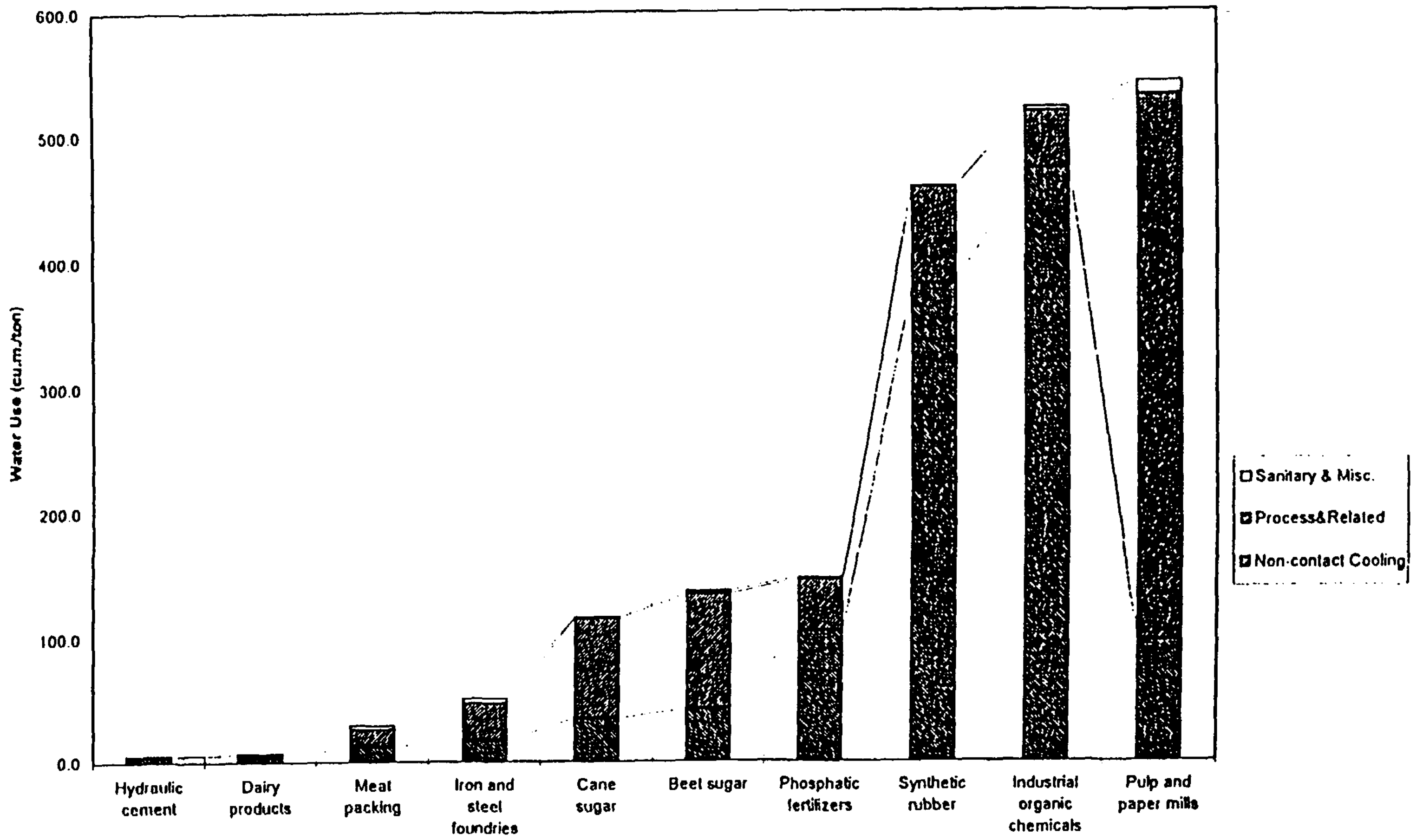
Global Industrial Water Use



Source: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, 1993.

FIGURE 1-2

Industrial Water Use Breakdown



Source: van Der Leeden, F., F. Troise and D.K. Todd, The Water Encyclopedia, Lewis Publishers, 1990.

FIGURE 1-3

Industrial Water Use (by fate)

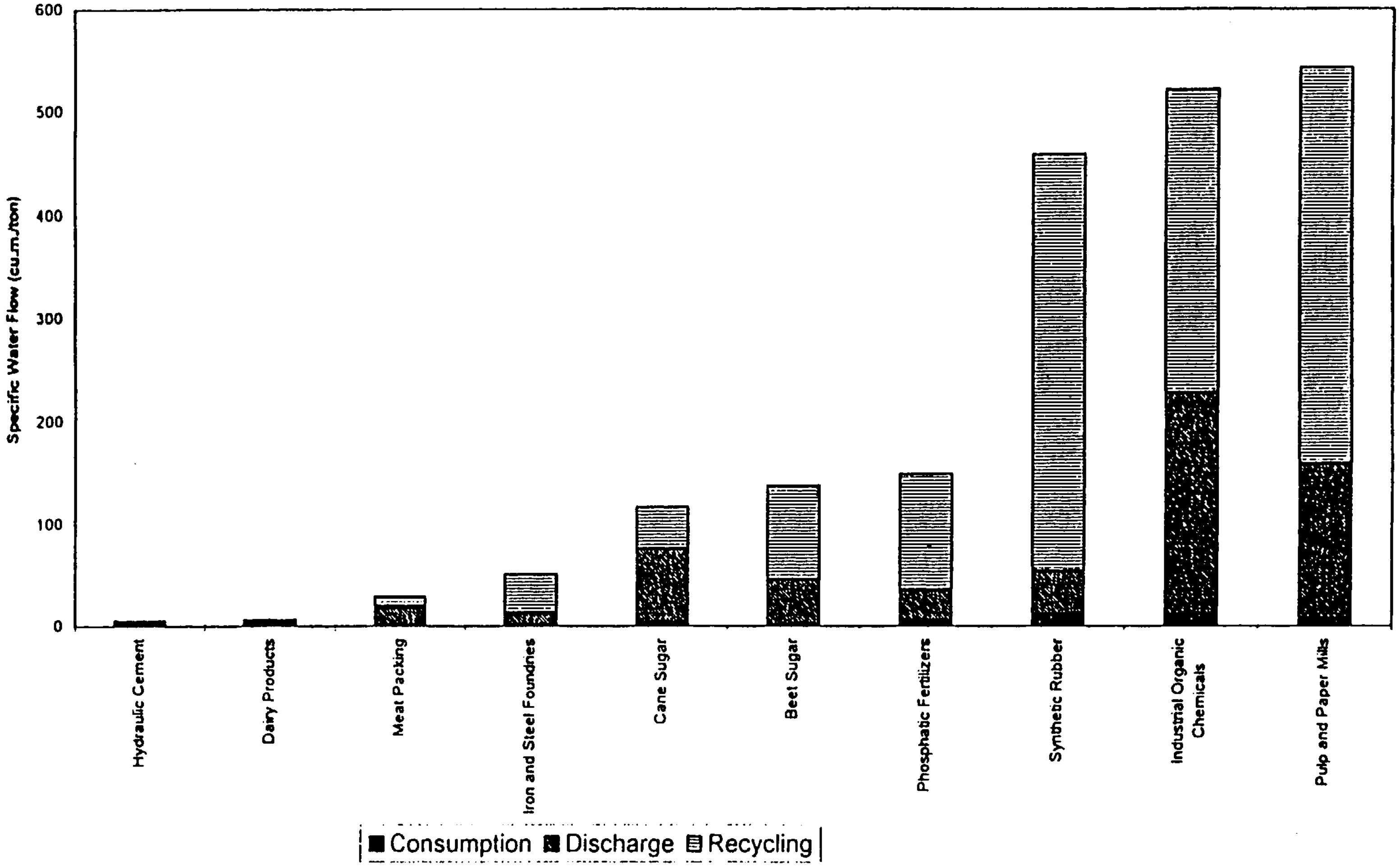
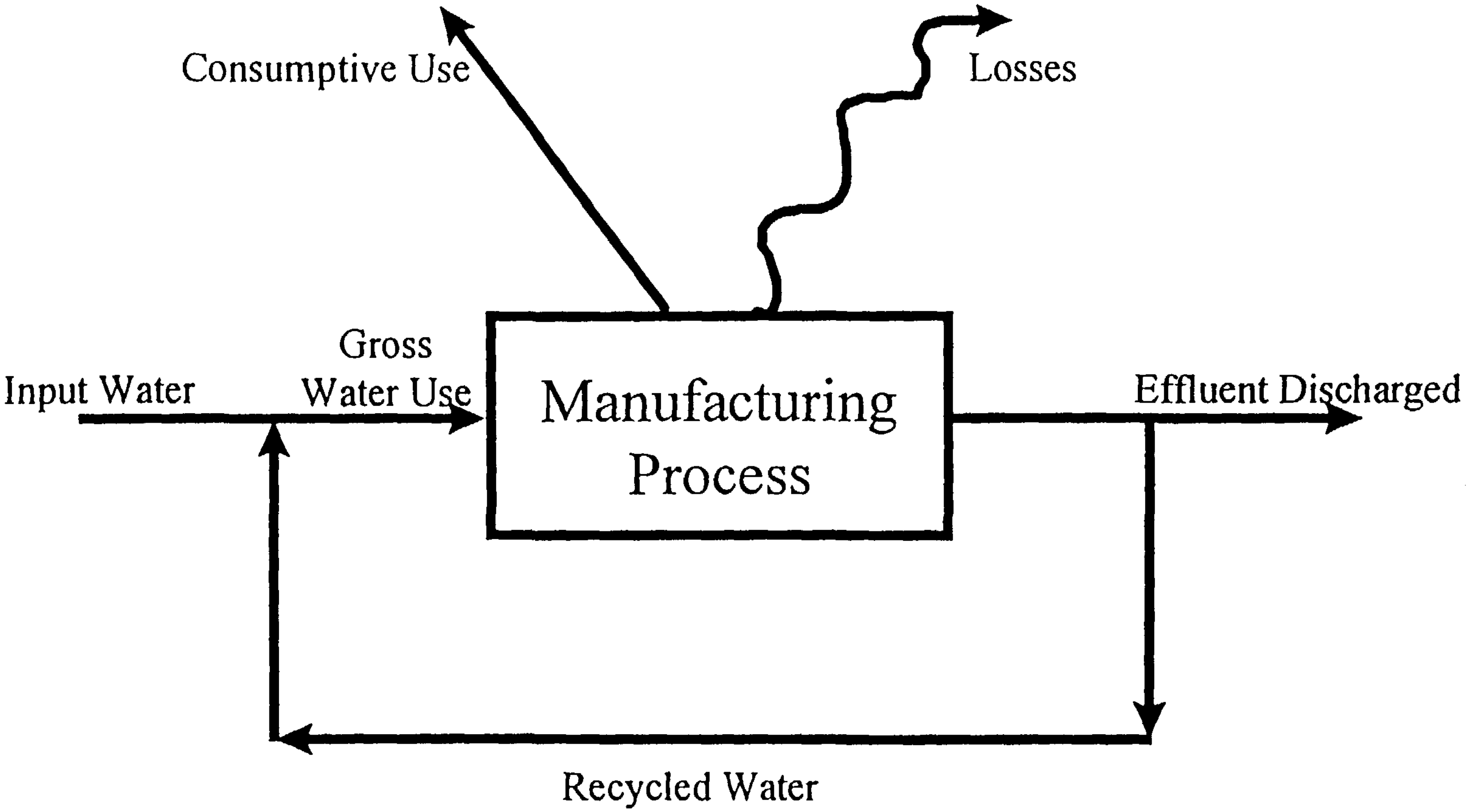


FIGURE 1-4
Schematic of Industrial Water User



Chapter 2

Intersectoral Aspects of Water Use

Water Supply

Freshwater resources available for human uses make up less than 1% of 1% of the total water on the Earth, amounting to about 40,000 cubic kilometers per year of runoff from all sources (L'vovich, 1979). If we examine global data on freshwater, we find a great deal of heterogeneity in the water resources of countries. For example, Brazil alone accounts for 13% of the global renewable freshwater supply. This spatial variability is exacerbated by temporal variability; for example, about 80-90% of the rainfall in parts of India occur during a 3-month monsoon period. In addition, there is great stochasticity in the water supplies, with many areas of the world experiencing severe droughts even as others simultaneously experience floods. Although climate, geology and geography are important factors in determining water supplies, they are often outweighed by political factors. For example, Egypt, which contributes little to the Nile River, harnesses almost all of its flow from up-stream Sudan, Ethiopia, and the other up-stream riparians. It is difficult to define, justify, and use terms such as "Internal Renewable Water Resources" (which is 40,673 km^3 globally or 7,420 m^3 per capita) as used by the World Resources Institute (1995) as supplies without including the fuzzier question about who controls the water that is transported from one region or country to another. To complicate this further, most available data report supplies of water without reference to whether they are a sustainable supply or not (in terms both of quantity and quality), confuse supply and demand, and lump some supplies at varying costs together (but not others, such as an almost infinite supply of desalinated sea water) to arrive at a supply figure. In reality, one should use sustainable yields based upon long term annual averages, especially of groundwater resources (although the question of fossil water is trickier). In addition, there should be a more thorough consideration of which resources become exploitable at different prices, like the mineral literature does for oil, coal, and other extractable minerals, and a better assessment of the natural variation in the supplies and the storage in reservoirs and other impoundments on a temporal basis.

From economics we learn about increasing marginal cost curves—the best supply options are chosen first and the worse ones later. In practical cases, this is usually represented by a "staircase" diagram with the supply projects arrayed in terms of increasing cost. A practical example based on the City of Phoenix, Arizona, water supply is given in Martin et al., (1984). As expected, the cost of going to the next step on the supply curve of clean water is increasing in many stressed regions and is often as much as 2-3 times the currently most expensive supply step. The examples of this are legion (Bhatia, Cestti, and Winpenny, 1995). In Shanghai, water intakes were moved 40 km upstream at a cost of $300 million to avoid the "pollution shadows" around the city that threatened water intakes. In Beijing, water may have to be brought in from a sources 1000 km away. In Mexico City, water may have to be pumped from a depth of 2000 m to supplement the current 180 km pipeline from the Cutzamala River which is pumped up over an elevation difference of 1000m. In Amman, water is expected to be pumped from 40 km away and up over 1200 m in elevation. Projects for increasing supply, especially around built-up areas, have become prohibitively expensive. It has been estimated by traditional methods that the provision of water supply in urban areas of developing countries alone would require an investment of $11-14 billion per year for the next 30 years (Bhatia and Falkenmark, 1993). In addition, projects for increasing supply, such as dams, have become associated with many environmental (inundation of forests, loss of biodiversity, water quality, and aquatic life affected), social (resettlement, inundation of cultural/historic sites, loss of recreational activities - such as white-water rafting) and physical (sedimentation, salinity, waterlogging, seismic activity) problems.

Water Demand

Water demands are increasing globally. It is difficult to estimate water demand. The current approaches of exogenously specifying demand based on potentially irrigable land area and assumed cropping patterns for agriculture, sectoral economic growth scenarios for industry and population with an assumed per-capita consumption for households does not consider the demands to be at particular water prices. It is important not only to consider price elasticities of demand for water, but also income elasticities (for the domestic sector) and the effect of subsidies, taxes and the lumping together of wastewater treatment charges with water use charges.

Total water withdrawals are about 3,240 km^3 globally (8% of the renewable supply), amounting to 644 m^3 per capita, well below the 1000 m^3 per capita cutoff that has been rather arbitrarily proposed as being some kind of a minimum threshold (Falkenmark, 1989). As in supply, there is great spatial variability in demand, ranging from 7 m^3/capita/year for Haiti to 4575 m^3/capita/year for Iraq. It is important to draw the distinction here between water withdrawal and consumptive use. For example, the consumptive use in agriculture is the total amount of water used by the plant plus the amount of water lost in evaporation, seepage and other losses. Depending upon the efficiency of the actual field irrigation, agriculture may consume directly as much as 50% of the applied water. Seepage water requires special consideration - how does one deal with supplies in a downstream region that are fed by the "losses" in an upstream region? In the case of domestic and industrial users, a large percentage of the water (as much as 85-90%) is return flow and can be re-used after appropriate treatment.

What will future demands look like? In agriculture, the reasons for an increase in the demands are that there are more mouths to feed as well as increased demand due to improved standards of living, that there are many more potentially irrigable areas than there is water for, and that subsidies encourage waste of water. Table 2.1 gives an outline of the various forces that could lead to increases or decreases of demand for water.

Intersectoral Allocation

Globally, agriculture accounts for 69% of the freshwater withdrawals, industry for 23% and the domestic sector for the remaining 8%. This varies tremendously for different countries depending on their size, population, stage of development, economic opportunities and national priorities. For example, Pakistan, with a per-capita withdrawal of 2000 m^3 has the ratio 98:1:1 for agriculture, industry and domestic uses, whereas the United States, with approximately similar annual per-capita withdrawals (1900 m^3) has the ratio 42:45:13.

We see that the industrialized western hemisphere has a very high industrial proportion of water withdrawals as compared with the other nations of the world. We can expect to see this trend in the future in the rest of the world as well. This would parallel the shift in the relative employment of the labor force in the various sectors or the change in the sectoral contribution to GDP when countries move from the ranks of the developing countries into the ranks of the industrialized ones.

Taking these predictions into account, if we try to balance supply and demand and arrive at a shortfall, is this proof of water scarcity and, hence, a trigger for drastic action? Should one consider options to reduce the demand? Which demand sectors should one target? We need to make tradeoffs in such conflict situations. What would help do this is some idea of the shape of the demand curves for the various types of demand and what the losses would be in each sector for a decrease in supply, i.e., what is the regret (in monetary, social, political, and other terms) in allocating less water in each sector. We could then choose a strategy which gives the best overall solution accounting for socio-economic preferences while keeping track of the trade-offs between the sectors. In many cases, there may be satisfactory solutions that yield overall benefits without affecting anyone too severely. This may lead us to rethink the term "water scarcity" and consider whether it is a real problem or a merely a manifestation of the mismanagement of water.

Water conflicts are all but too common under conditions of scarcity or perceived scarcity. Many times, solutions proposed to resolve these conflicts are economically infeasible, technically challenging, and politically intractable. Frederick (1986) discusses the institutional barriers to efficient allocation of water.

Examples of water conflicts in the Third World abound (Bhatia, Cestti, and Winpenny, 1995):

- Cities of the North China Plain, such as Beijing and Tianjin, have demands in the industrial, agricultural and domestic sectors that are fast outstripping current supply at current prices. Beijing is expected to have a shortage of more than half a million cubic meters a day.

- The Subernarekha River Basin in Northern India exemplifies many conflicts among competing uses in agriculture, industry, domestic and power. The construction of additional supply and distribution facilities in the form of dams, barrages and canals still have to contend with increasing demands in urban and agricultural water use. Many water-intensive industries are located in this industrial belt and problems of both water availability and effluent discharge abound. Recently, more economically efficient policies such as bubbles and offsets are being tried to augment or replace traditional command and control measures for the regulation of wastewater discharges from industrial groups. The problems in this river basin are indicative of others in many other parts of India.

- The arid and politically-sensitive Middle-East region faces a grave situation in trying to balance the limited surface and groundwater supplies with burgeoning demands in domestic, industrial and agricultural water uses. Israel, Jordan and Palestine share important water resources and allocative problems arise both among and within the various regions of these countries and the various demands within each region. Many seemingly fantastic projects have been proposed to relieve the water problem. Are they feasible? Are they necessary? What connections are worth building? When and where would desalination and recycling become viable? What is the real shadow price of the water in various districts? What is the monetary value of implicit agricultural subsidies? Recently, the Harvard Middle-East Water Project has developed a system called the Water Allocation System (WAS) (Harshadeep, 1995) that attempts to answer such questions by optimizing water management over the entire region.

Water and Industry

Water is an important input to all industrial processes. Even though water is often considered a unitary resource, it is actually available at many different levels of quality in most places. Most industrial processes try to match the water used by its quality and suitability for specific parts of the industrial process in question. Also the effluent produced by industrial processes are of widely differing quality. Typically there is a hierarchy involved with higher quality water being useable for all lower quality uses; to recycle water for a higher level of quality use, therefore, usually requires some sort of treatment.

Figure 2.1 shows a hypothetical water supply and waste disposal system for a single industry. In this diagram water is brought in from the outside, it is pumped from the industry's own wells, it is mixed with recycled water and introduced into the industrial process. In the process a fraction of the water is lost either to evaporation or to its incorporation into the product. The remaining water can then be either disposed of directly as wastewater, recycled directly, recycled after treatment, or treated and disposed of to the outside environment. The choice of how much to bring in from outside, how much to treat, and how much to recycle depend upon the costs of water supply, waste treatment, and the level of regulation imposed upon the industry by local or national environmental regulations. Figure 2.2 gives a schematic of the view of the same industry from an external point-of-view, such as a regulator or municipal authority might take. In this case the parameters of concern are how to set the prices of the water supplied, and the level of effluent allowed from the various sources or the setting of effluent fees and sewer charges. In Figure 2.3 the regional case of multiple industries in a river basin which have the option of treating, recycling, and using municipal sewers is outlined. The setting of the effluent charges should be directly related to the environmental damages caused by the several polluters and these are clearly related to their locations in the river basin. The bulk of the literature focuses upon the first and the last of these two cases.

TABLE 2.1
FACTORS LEADING TO INCREASES OR DECREASES IN WATER DEMAND

	Factors Leading To Future Demands	
Sector	**Increasing**	**Decreasing**
Agriculture	• More mouths to feed, and increased standard of living • Many potentially irrigable areas to come on-line • More irrigation water needed to counter problems of salinization • Subsidies encouraging inefficient use and wastage of water • National policies of self-sufficiency, employment in the agricultural sector, national pride in agriculture or agricultural products • Cheap sources of water may emerge (such as recycled treated domestic or industrial water or a new desalination technique) • View of water as free/Religious or other reasons with the same effect	• Technological changes - irrigation systems, storage and conveyance systems, agriculture itself (hydroponics, etc.) • Currently irrigated areas lost to salinization and waterlogging • Pricing reforms/removal of subsidies would encourage crops to be grown in suitable regions • Revision of distortionary national policies • Subsidization of conservation measures in agriculture • Basin-wide planning of water • Decreasing agricultural labor force, increase in yields, switch to less water-intensive crops, social changes (preference of certain kinds of crops, vegetarianism, etc.)
Industry	• More products to make for a burgeoning population with increased incomes • Increasing economic activity by sector may require proportionally more process water • More cooling water may be required for increased power generation • More cheap water may become available from agriculture • Cheap alternative supplies of water may become available	• Technological change - many processes may become "zero-use" in terms of water requirement as alternatives are explored • Pricing reforms/removal of subsidies • Higher wastewater charges could have the same effect • Recycling and conservation techniques may become more advanced, cheaper, common and come on-line at higher water and wastewater charges • Many industrial water systems may become closed-loop
Domestic	• More mouths to drink; growth of cities • Increased living standards • Higher demands if cheaper water is available • Increasing affluence would increase the demand for water - income elasticity of water demand has to be considered • Pent-up demand has to be satisfied • Changing social attitudes (popularity of soft drinks, new games like golf!) • Subsidies, ill-structured block rates • Cheap new sources of water	• Technological change - less water may be required for domestic uses (e.g. in dishwashers, washing machines) •Reducing unaccounted-for-water • Other conservation measures (such as low-flow showerheads and faucets, etc.) • Increasing affluence may also replace some water-based systems with non water-based ones (e.g.: water-based "Desert Coolers", common in North India replaced with Air-Conditioners) • Metering/Pricing Reform • Recycling at least for non-drinking uses

Table 2.2: Freshwater Resources and Withdrawals
Sources: World Resources Institute (1995); Rogers and Lydon (1994)

Region	Annual Withdrawals			Sectoral Withdrawals (%)		
	Total (km^3)	Proportion of Water Resources (%)	Per Capita (m^3/captia)	Domestic	Industry	Agriculture
World	3240	8	644	8	23	69
Africa	144	3	245	7	5	88
Asia	1531	15	519	6	8	86
Arab World	174	-	792	7	5	88
North & Central America	697	10	1861	9	42	49
South America	133	1	478	18	23	59
Europe	359	15	713	13	54	33
Former USSR	358	8	1280	7	27	65
Oceania	23	1	905	64	2	34

FIGURE 2-1
Tannery from Industrialist's Point of View

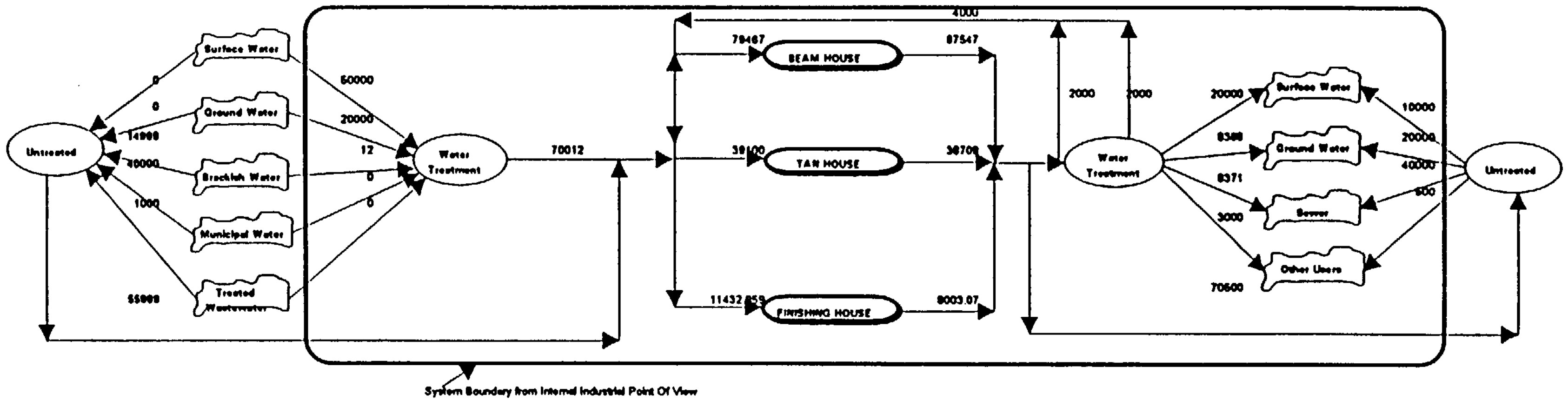


FIGURE 2-2
Tannery from Local Government's Point of View

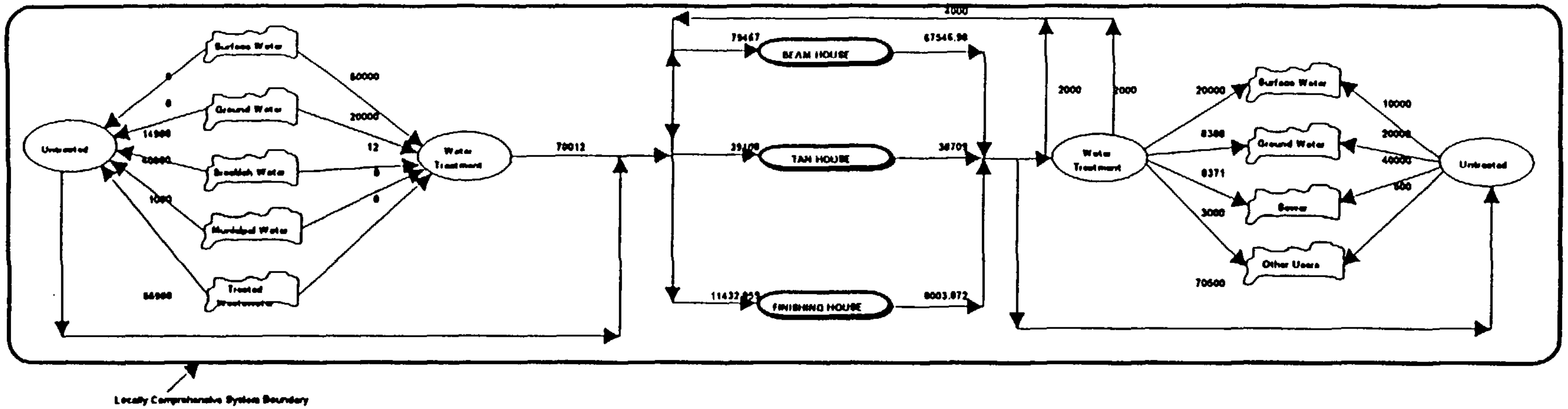


FIGURE 2-3
Industry from a Regional Environmental Authority's Point of View

Chapter 3

Policy Instruments for Managing Industrial Water: Regulation and Pricing

Introduction

As discussed earlier, industrial water use and its consequent pollution is becoming a dominant theme in many countries of the world, particularly the newly industrializing countries. In response, many governments and jurisdictions are rushing to develop policy instruments that will best suit their own domestic situation (see O'Connor (1996a) for an introduction to the subject) This is not an easy task because of the historical development of a patchwork of sometimes conflicting approaches. Table 3.1 is a partial listing of the myriad possible instruments available in various settings. These are presented in two categories, non-economic and economic policy instruments. On close examination of this table, however, one sees many ambiguities that make the simple dichotomy less than exact. for example, "Bubbles/Offsets/Banking" could be either type of policy instrument depending upon how they are actually implemented. Regardless of how these instruments are finally divided up, it is commonplace to say that the instruments are broadly split into two groups; regulation and pricing. Of course with a commodity like water which shares many of the properties of private goods, common property goods, and even public goods, it is fruitless to talk about pricing without regulation. It should be remembered that dealing with water will always require some government regulation. Given this caveat, it is also true that if the twin benefits of lower costs for industry and cleaner water for society are to become available then industrial users (entrepreneurs) must be provided incentives to invest in water conservation and waste water treatment plants. These incentives will always involve a judicious mix of regulatory policies, economic incentives and fiscal instruments.

The Economics of Water Management

Modern economic theories imply that efficient use of resources takes place at that level of water use where the demand curve intersects the supply curve. Rogers (1996) gives a comprehensive review of the field. Figure 3.1 shows hypothetical demand and supply curves for an industry. At the point of intersection two important pieces of information are available; the price at which the resource use is efficient and the correct quantity to use which would imply this price. Knowledge of either piece of information should be sufficient to lead a consumer to an efficient solution. when applied to water and wastewater we immediately run into problems. First and foremost, the theory assumes a freely functioning market for water. This is almost never the case, and in fact cannot take place over a wide range of water uses and users. The conceptual model should, however, not be discarded because it does give the user and the regulators some sense of what efficient solutions would be like in an unconstrained case and, hence, can be helpful in providing signals to the lead the consumer in the direction of some "second-best" solutions.

The simple economic model is most helpful in giving signals about the intersectoral allocation of the water resources between the different uses; agriculture, municipal, and industrial. for each of these uses there is indeed some notion of demand curves and one can look for allocations that tend toward allocating the water to those uses with the highest marginal value. The simple model works less well in areas involving allocation between the above uses and water quality and ecosystem use of the resource. Now we have less clear ideas of the demand curves, and hence the signal for efficient allocation s greatly reduced. The economic model is very powerful, however, in intra-sectoral allocations in all three of the sectors mentioned above. Here pricing ranging from average-cost to full-cost pricing can send powerful signals leading to efficient use of the resource. By and large, the economic model should be used as stringently as possible in dealing with industrial water supply and wastewater management. However, in every case it is important to consider a full range of options before choosing any one or set of options.

Policy Instruments

The broad set of options available to the policy can be further collapsed to the following four:

- Traditional **Command and Control Legislation and Regulation** which specifies the water quality standards for rivers/lakes, for effluent discharged into water bodies and for providing the machinery for implementation of these regulations;
- **Quantitative restrictions** (quotas) on water consumption and/or effluent discharged by each industry or a group of industries;

- **Economic Incentives** influencing the behavior of entrepreneurs by setting appropriate levels of water prices (tariffs), effluent charges, pollution taxes on water and groundwater extraction charges;
- **Subsidies** such as providing tax benefits or investment support or low-interest loans for investments in effluent treatment plants installed by a single unit or by a group of industries (or by a municipality) for common treatment facilities.

These four sets of policy tools for rationing water can be broadly classified into "pricing" and "quantity" tools. Table 3.2 (based upon Dale and Dixon, 1986) shows them schematically arrayed by their implied economic efficiencies. The table shows how this simple classification scheme could be applied to the range of policy tools available for implementing water conservation and recycling in industry allowing for effluent regulation as well as water inputs. For example, all or some of the price policies for industrial input water are in use. The most attractive for ease of implementation and its high level of efficiency is volumetric pricing. The figure also shows that a high level of allocative efficiency can be obtained by the control of quantities supplied through auctioning-off of water rights. On the wastewater side of the ledger, high levels of efficiency can be achieved by effluent charges (pricing column) and tradable permits (the quantity column).

Dale and Dixon (1986) showed that, when demand was uncertain, price rationing is preferred (has lower social costs measured in welfare terms) to quantity rationing when the elasticity of demand is greater (in absolute value) than the elasticity of supply. In other words, when demand is inelastic (compared to supply), mistakes in quantity rationing will tend to miss the correct "price" by a wide margin and result in large welfare losses.

There are a large number of policy options that potentially deal with regulated industrial water and wastewater. The objective of the policymaker is to find that particular configuration that fits best into the local conditions. No one policy, set of policies, is necessarily *a priori* better than any other set. One needs to explore the details associated with particular industries. In the chapter which follows we have attempted to do this for two fairly typical industries.

Water Policy Options

Few studies are available on industrial water demand which relate water consumption to output, water price, employment and type of technology used. Gibbons (1986) provides an overview of the whole area of study. Williams and Suh (1986) have examined the effect of price on industrial water demand by using three alternative price measures (the average revenue price, price based on a typical bill, and the marginal price). The results of this and other studies are summarized in Table 3.3. The price elasticities are typically higher than the price elasticity estimates obtained for residential and commercial demand (e.g. elasticity coefficient of -0.48 to -0.18 for residential demand). Industrial demand for water is more price responsive than residential and commercial demand. The relatively high price elasticity of industrial water demand reveals that industrial customers are more likely to find alternative sources of supply or to recycle water in the production process in adjusting to price changes. Of course, agricultural water demand may be most responsive and generally has a higher absolute elasticity than industrial demand. LeMoigne et al, (1992)review the role of water markets in water policy.

Wastewater Policy Options

Which of these policy tools should be used to manage industrial water demand? The answer usually depends on the players involved, the specifics of the industry and water sources and receiving bodies, monitoring and enforcement capabilities of the institutions involved, and acceptability (O'Connor, 1996b). Industries, for example, prefer lower cost options of course, but are also interested in stable expectations; they understandably find it harder to deal with uncertainty in the price they have to pay or investing in personnel and equipment for wastewater management that are secondary to the primary business of the industry. These effects are especially acute in small-scale and cottage industry, for whom many developing countries have lax environmental regulations. However, it does not make much sense to have some plants that are mandated to discharge very clean effluent located next to a small-scale tannery operation releasing toxic untreated effluent into the same receiving body of water without considering the system-wide economic costs of control. For example, if the cost of control for one firm is very high (the small scale plant) and it were allowed to trade with another firm with lower control costs (modern large scale plant) so that the second firm would control more than would be required under a command and control system and then is compensated by the first firm that pollutes more than it is allocated. This will produce a much more economically efficient pollution control regime than the simple waste allocation and command and control. The same behavior could, of course, be effected by using varying effluent charges. However, the setting of the efficient effluent charges requires much more government intervention than a permit trading scheme.

Effluent charges and tradable permits have varying impacts. Effluent charges usually lead to a known amount of money being spent on pollution control, but may not lead to a desired level of clean-up. Tradable permits, on the other hand, can start with a desired level of clean-up that is then allocated as permits to the individual firms in the area, and the total cost of control is not exactly known *a priori*. Effluent charges generate revenue that has to be used in some way - regressively by removing it from the industrial system, or progressively by ploughing it back into the system, possibly by subsidizing pollution control equipment or research, although this introduces its own distortions.

Tradable permits have the problem of initial allocation which could be given according to prior use, sold by auction (generating revenue), or other methods. In theory industries will then trade with the permit holders until an efficient allocation of effluents is attained. Transaction costs in trading may not be as insignificant as assumed by the theory and may limit trade, especially in cases where there is no established mechanism for trading or due to limitations in information availability or exchange. These mechanisms have had some success in managing air pollution from sulphur dioxide in the U.S. Water pollution is, however, significantly different and technically more complex. For example, one-to-one trades as allowable in air pollution are usually not possible in water pollution due to stronger locational considerations in river basins as opposed to airsheds. A detailed hydrologic basin model is required by the government regulators before trading parameters can be established. The experiences in the U.S. with an experiment on the Fox River in Wisconsin were not encouraging (Sessions and Stuart, 1975). Nevertheless, the USEPA recently announced its willingness to act as a broker to facilitate such water permit trading on a nationwide basis (USEPA, Jan. 1996). Of course, intra-plant (bubbles) trading is attractive in for large integrated industries.

Some Case Studies

The experience in many developing countries has shown, however, that the " fragmented "command-and-control" approach to management of water resources has failed, both economically and environmentally. Hence, there is a pressing need to use economic incentives and fiscal instruments in achieving economic efficiency in the use of water resources. In order to promote these, however, it is necessary to be able to show that better economic management of wastewater will also greatly assist in improving the quality of the environment. Bhatia, et al. (1994) demonstrate with the help of empirical case studies, the role of economic incentives such as water tariffs, effluent charges and tax/subsidy mechanisms in achieving the twin benefits of lower costs and better water quality.

When using economic incentives, however, care should be taken not to induce other undesirable outcomes. Sims (1979) reported on the case of a choice between a system based upon sewer charges which are based upon charges above some threshold, or normal level, as opposed to a "pure" effluent charge scheme based upon the total amount of waste discharged. He demonstrates that the former charge system (which is the current approach to sewer effluent charges in North America, China, and parts of Europe) introduces significant undesirable economic incentives which lead to consuming more water than would otherwise be the case to dilute the wastes than with the latter case of "pure" effluent charges. The sewer effluent charge scheme outlined by Sims gives a positive subsidy to firms for using the capacity of the municipal treatment plant. He gave the example of a Canadian industry where the welfare loss due to this "supra-optimal" use of water induced a 50% increase in the volume of water used to carry waste away.

Elliot (1973) considered the choice between no effluent charge and one relying upon the scheme outlined above. He found that system worked quite well in managing the demand for water in several food processing industries. Table 3.4 shows the price elasticities of both water demanded and effluent produced to increases in the price of water and in the sewer surcharge. This table shows the “jointness” of the input and output of typical food processing industries. The most interesting aspect is that raising the water and the normal sewer charge had a much larger impact than just focusing on the effluent fees, and that it had a larger impact on the effluent than on the water use itself.

Dasgupta et al., (1996) provide a very elegant and innovative cross-sectoral analysis of industrial water pollution abatement in China. Based upon data from 200 factories scattered across China, the team at the World bank estimated a joint abatement cost function which relate the total costs to treatment volume and the simultaneous effect of reductions in suspended solids, chemical oxygen demand, biological oxygen demand, and other pollutants. Using this function they analyzed the cost-effectiveness of current pollution control policy in China. They concluded that:

1. The benefits of stricter discharge standards should be weighted carefully against the costs. For the sample of 260 plants, a shift across the existing range of standards could entail a present-value difference of $330 million in abatement costs.
2. Emissions charges as low as $1/ton would be sufficient to induce 80% abatement of suspended solids for cost-minimizing factories. Charges of $3, $15, and $30 per ton would be sufficient to induce 90% abatement of TSS, COD, and BOD.
3. The results suggest that China's changing to a full emissions charge system would greatly reduce overall abatement costs. The current overall abatement rate could be attained under a charge system at a reduced annual cost whose present-value is $344 million.

TABLE 3.1

Possible Instruments to Influence Industrial Water Policy

Non-Economic Command and Control Policies

- Water use quotas
- Wastewater generation quotas
- Effluent standards
- Mandated recycling percentage
- Maximum specific water use quotas
- Encouragement of research, development, production and adoption of conservation, recycling, and wastewater treatment measures
- Bubbles/Offsets/Banking
- Industrial Ecology - management within industrial complexes
- Licensing of water supply/wastewater disposal
- Enabling conditions - coordinating institutions, legislation, macroeconomic framework
- Technology transfer of efficient equipment/processes
- Information availability and exchange - on products, processes, waste exchanges
- Development of alternative supply options (e.g.: domestic wastewater, desalination)
- Privatization of the water sector (supply, distribution, collection, treatment and disposal)

Economic Policies

- Water supply tariffs
- Effluent charges/taxes (as a function of Quality and Quantity)
- Penalties for violation of quotas
- Tradable permits
- Subsidies on research, development, production and adoption of conservation/recycling processes (including water saving devices/processes)
- Subsidies on research, development, production and adoption of wastewater treatment technologies
- Cross-subsidization of agricultural water conservation

Table 3-2: Economic Efficiency of Policy Tools for Water and Wastewater Management

	Water Policy Variable		Wastewater Policy Variable	
	Price	**Quantity**	**Price**	**Quantity/Quality**
High	Volumetric Pricing	Auctioning Water Rights	Effluent Charges	Tradable Permits Bubbles/Offsets
			Tax Incentives	
	Tax Incentives			
Economic Efficiency				Performance Standards
		Water-Use Standards		Effluent Standards
	Flat-Rate Pricing			
		Water Rights		Technology Standards
	Surcharge on Surrogate (e.g. Product)		Flat-Rate Pricing	
Low		Quotas		

TABLE 3.3

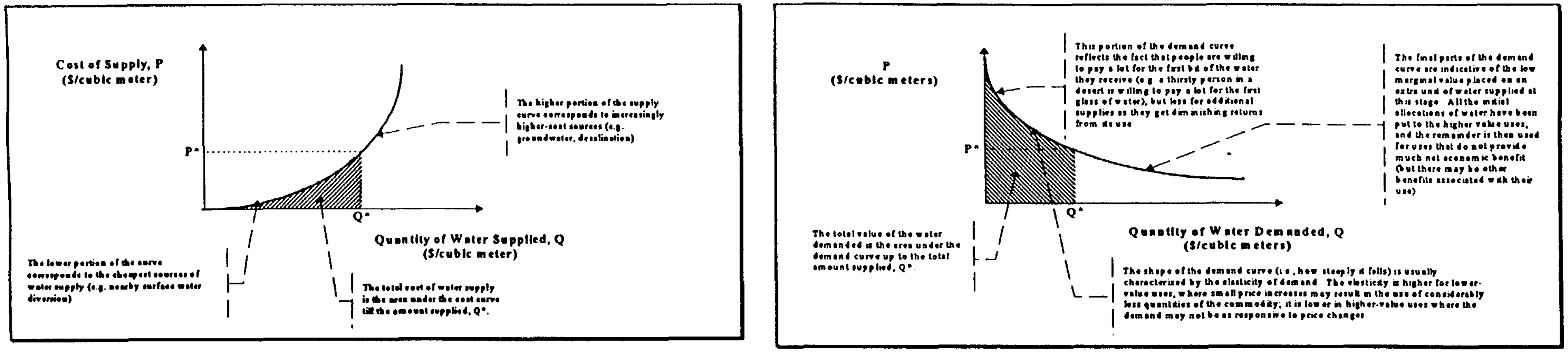
Price Elasticities for Industrial Water

Price Elasticity	Comments	Reference
-0.721 -0.43 -0.72 to -0.98	Average Price (USA) Marginal Price Bill Price	Williams and Suh (1986)
-0.98	Paper & Chemical Plants (USA) Average Price	Ziegler (1984)
-0.77 -0.88 -0.96	Petroleum Industry (USA) Steel Industry Chemical Industry	Leone et al. (1974)
-0.958	Chemical Industry (UK)	Rees (1969)
-1.32	Cross-Sectional Industrial Data (India)	Gupta et al., (1991)
-0.49	Cross-Sectional Industrial Data (Jamshedpur, India)	Bhatia, Cestti and Winpenny (1995)
-0.45	Steel and Related Industries (India)	Metaplanners (1992)

Table 3-4: Elasticities for Water and Effluent Charges in Food Processing Industries (Elliot, 1973)

Increase In	Reduction in Water Use	Reduction in BOD
BOD Surcharge	0.44	0.51
Water And Normal Sewer Charge	0.63	0.75

Figure 3-1: Economics of Water



The higher portion of the supply curve corresponds to increasingly higher-cost sources (e.g. groundwater, desalination)

The lower portion of the curve corresponds to the cheapest sources of water supply (e.g. nearby surface water diversion)

The total cost of water supply is the area under the cost curve till the amount supplied, Q*.

This portion of the demand curve reflects the fact that people are willing to pay a lot for the first bit of the water they receive (e.g. a thirsty person in a desert is willing to pay a lot for the first glass of water), but less for additional supplies as they get diminishing returns from its use

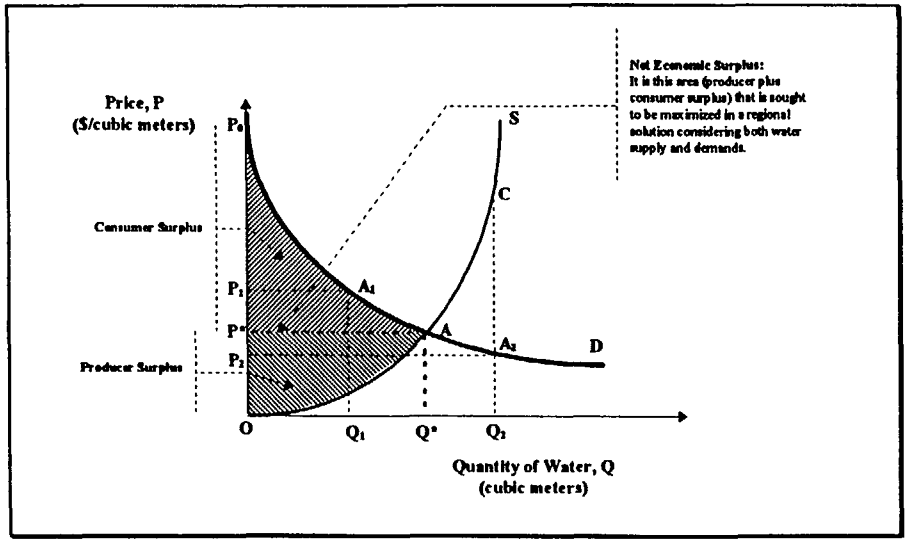
The final parts of the demand curve are indicative of the low marginal value placed on an extra unit of water supplied at this stage. All the initial allocations of water have been put to the higher value uses, and the remainder is then used for uses that do not provide much net economic benefit (but there may be other benefits associated with their use)

The total value of the water demanded is the area under the demand curve up to the total amount supplied, Q*.

The shape of the demand curve (i.e., how steeply it falls) is usually characterized by the elasticity of demand. The elasticity is higher for lower-value uses, where small price increases may result in the use of considerably less quantities of the commodity; it is lower in higher-value uses where the demand may not be as responsive to price changes

a) Supply Cost Curve for Water

b) Demand Curve for Water



Net Economic Surplus:
It is this area (producer plus consumer surplus) that is sought to be maximized in a regional solution considering both water supply and demands.

c) Equilibrium between Water Supply and Demand

Chapter 4

Efficiency and Conservation in Industrial Water Supply and Wastewater Management

---

Introduction

Although the proportion of industrial water use is generally higher in developed countries compared to developing countries, this may not necessarily imply that developing countries would also increase their industrial water use in the coming years. This is because water can be used more efficiently. This leads the need for a few important new concepts - those of *active* and *passive demand management*. *Active* demand management measures are those initiated by industries in response to some direct stimuli such as a change in water tariffs, regulations on water use, water use efficiency, percent recycling, effluent charges, etc. We define *passive* demand management measures as those that are inadvertently adopted by industry due to a general improvement in water-use efficiency in newer equipment, or in response to other incentives such as energy or other input conservation. Industries might buy these new equipment merely from taking a traditional cost-efficiency point of view; however, in general these also tend to be efficient from the point of view of specific water use or pollutant generation. Due to this second type of demand management, we may expect at least a steady increase in water use efficiency in the developing countries over time as equipment and processes obsolesce and are replaced by newer, more efficient, technologies. The *active* demand management techniques are akin to *software* and the *passive* techniques are similar to *hardware*. Yet another way of characterizing these two approaches is that of *permanent* conservation and *behavioral* conservation.

UNEP and UNIDO (1991) is a good example of a manual explaining how it is possible to conserve industrial water using *passive,* or *permanent,* demand management.

Conventional Sub-Sectoral Approach

The conventional sub-sector approach to managing industrial water supply and recycling is that shown in Figure 2.1 and to a lesser extent in Figure 2.2. For Figure 2.1 the accounting stance is that of the individual profit-maximizing firm. There are several different conditions under which this system can function.

- The first case is where the industry sees only a charge for the water it purchases and there are no other charges or regulations imposed upon the firm. This situation is rapidly disappearing throughout the world as environmental awareness develops.
- A more usual situation occurs where the firm sees the price of water and is faced with some restriction on the amounts and types of pollutants that it emits.
- A typical more restrictive situation is where the firm now is not allowed to emit any untreated effluent, but may emit a certain amount of treated effluent.
- Other variants on this theme are that the firm is allowed to discharge untreated effluent up to a certain concentration level free to the municipal sewer for treatment with a surcharge for any effluent above that particular "strength."

Economists have for a long time argued that more efficient systems can be devised using pricing of input water and of effluent, both treated and untreated. Finally, complex economic tools such as effluent permit trading schemes have been implemented for air pollution in the U.S., and only rarely for water pollution in other settings. The polluters are awarded effluent permits for a certain amount of effluent, calculated by a regional authority to be the total amount of effluent that can be tolerated by the system (characterized by Figure 2.3), and they can either treat their own wastes or purchase effluent permits from those industries that are efficient waste treaters. In this way the system is essentially self-regulating with the creation of a market for the permits.

Integrated Sector-Wide Approach

In order to attain the economic efficiencies made possible by pricing policies for water and for wastewater a wider approach must be taken than simply one industry or group of industries. Efficient pricing requires that the true marginal costs be used and that the opportunity costs and externalities be properly accounted for. It is only possible to do this by considering a wider grouping of industries and activities. One needs to consider a system wide enough to include all of the external effects. It is generally considered that a region of at least the size of the river basin be used for such calculations. This is the idea behind the sketch in Figure 2.3. This will make it possible to consider explicitly economic and environmental linkages among user sectors such as agriculture, industry, power plants households and commercial establishments. The economic linkages would require that while setting tariffs in one sector (say, industry), the **opportunity cost of water** (or benefits foregone in alternative use such as irrigation) are taken into account. This would also require considerations of (i) encouraging water conservation in agriculture and transfer the water thus saved for industrial uses; (ii) the effect of conservation and recycling in one use (say, industry) **on the return flows and** availability of water for other uses[1/].

The environmental linkages require that quality considerations in the use of water by different sectors should be explicitly analyzed[1/]. This would require estimating the damages caused by one user (say industry) to other users such as domestic water supply or agriculture. Further, the effects of water pollution on aquatic life, wild life and environmental quality have to be explicitly evaluated.

It is possible to achieve substantial conservation in industry under appropriate conditions. What are these conditions? Appropriate signals include water tariffs, effluent charges and regulations on water use, recycling and disposal. Bhatia, Cestti and Winpenny (1995) report that there are examples of licenses, water-use and effluent discharge quotas and the introduction of water-saving technologies that have decreased industrial water consumption by as much as 40-70% in specific cases. The response to the introduction of these economic and regulatory stimuli are due to the high price elasticities of demand in industry as shown in Table 3.3 (industrial elasticities are generally much higher than those of domestic water demand). How does this reduction occur? It is mostly in the form of conservation and recycling measures that become economically viable under appropriate prices for the raw water or charges for effluent.

[1/] Once-through-use of water provides large quantities of water to the receiving water body, however, multiple use of water by recycling produces significantly less throughput. In agriculture this effect is often pronounced when irrigation efficiencies are raised and drainage water recapture is practiced, then the downstream farmers who previously relied upon drainage water due to inefficient upstream usage are left without water. The quantities made available by the various conservation techniques need to be adjusted for reduction in return flows.

[2/] Not all sources of water are of equal quality and desirability for various uses. Hence, the supply curve must discount the low quality sources to high quality users. However, when one does this one ends up with two or three different markets for the different users not one water market. This is further complicated by the fact that a single industry can use several different qualities of water in one plant for different aspects of production.

Case Studies on Water Conservation (based on Bhatia, Cestti and Winpenny, 1995):

- The Zuari Agro-Chemical Limited produces fertilizer in Goa, India and is a large water user. A hike in water prices to $0.12 per m3 and regulations on disposal resulted in the halving of the 22,000 m3/day water demand over the 1982-1988 period including an almost 100% effluent recycling. The current 10.3 m3/nutrient ton specific water use is 60% less than a competing firm in another part of India with a water price of $0.01 per m3 and no effluent discharge regulations.

- Madras in South India has suffered from prolonged water shortage and many industries have had to pay up to $0.30 per m3 for an irregular supply of water. The responses of two major industrial units, the Madras Refineries Limited (MRL) and Madras Fertilizers Limited (MFL), has been to adopt significant conservation and recycling measures, as water supply constrained their operation and expansion plans.

The conservation measures included a doubling in the number of cooling water cycles to six, processing condensate recovery, hydrolyzed stripping and the use of regenerated water. MRL has managed to double annual production capacity to 5.6 MT while maintaining its current water use of 2.5 mgd - a halving of specific water use. MFL has done better by doubling capacity while cutting water use by 10% to 13,600 m3/day.

The recycling responses in MRL and MFL are not internal; rather, they involve the tertiary treatment and use of wastewater obtained from the water supply and sewerage agency. This source is expected to meet about a third of their needs. However, this requires a size consistent with the economies of scale in such operations. For example, Manali Petrochemical Limited, a much smaller company, could not economically recycle municipal sewage and had to rely on higher-priced secondary water sources and reduce output. The optimization models that we demonstrate in Chapter 4, indicate why each of these kinds of responses may be logical.

- The previous case illustrates that external recycled water could be an unconventional source of water. Under the *industrial ecology* concept (Frosch, 1995), where industries can have interdependencies paralleling biological ecosystems, it is an accepted fact that what may be waste for one company may be the input to another. This waste and input could be water. A rather recent contention is that wastewater recycling could be considered an industry unto itself, providing an alternative supply of water where economical. A well-publicized case of this involves the Vallejo region of Mexico City, where a group of 26 industrial units (generating a wide variety of products from paper to chemicals to electronic supplies) decided to establish an alternative to the municipal piped water supply by creating a new company called Aguas Industriales de Vallejo to renovate and operate an old municipal wastewater treatment plant at a cost of under $U.S. 1.0 million. Interestingly, the equity was put up by each company in proportion to its water requirement at the rate of about $0.25 per m3/year. The wastewater is provided from the Departamento del Distrito Federal at the rate of about 8,600 m3/day of which the contributing industries receive about 5180 m3/day and the government about half that for its role. The resulting water supply is sold 25% cheaper than the municipal water.

- In the Subernarekha river basin, the steel city of Jamshedpur in Bihar, India, there is inefficient water use and heavy pollution, primarily from an Iron and Steel Industry. A policy simulation exercise determined that raising water tariffs from the current $0.066 to $0.01 per m3 and the effluent charges from $0.001 to $0.04 per m3 would result in halving the water purchased and a 91% reduction in effluent discharged.

- In Jakarta, Indonesia, an automobile (Toyota-Astra Motor) company using 300,000 m3 of water per year (50% from groundwater at $0.6/m3, 33% from piped water at $1.2/m3 and 17% from tankers at $2.4/m3), expects a tripling in production by the end of the decade, which in turn, is expected to require an additional 420,000 m3 of water. Groundwater cannot be used due to heavy contamination; piped water is in short supply and tankers are expensive. By means of conservation and recycling measures, the company plans to cut water intake by 40% and pollution control costs by 25%.

- The Southern Cross Textile industrial unit in Jakarta was located near the river, as is the case with other textile units in Jakarta. There exists no water tariffs for river water use and river water provides 88% of its 8200 m3/day water intake, leading to an inefficient water use efficiency of 560 m3/ton of product (compared to 180 m3/ton in efficient industries). The firm believes that it could cut water intake by more than a third relatively painlessly, but lacks any incentive to do so. This illustrates two points - one the importance of giving the right regulatory signal to spur an increase in industrial water use efficiency, and second, the fact that many industries may be able to make large water use reductions relatively easily, leading to the view that even mild economic or other regulatory incentives could result in substantial savings in industrial water use.

- Recycling and conservation measures could be invoked either by water tariffs or wastewater charges, whether they were intended for that purpose or not. Sao Paulo, Brazil, provides a classic case of poor integrated planning. In the early 1980s, wastewater charges were hiked for industries in the Sao Paulo area to help pay for a large, new wastewater treatment plant that was built due to environmental considerations. Most industries (pharmaceutical, food processing, diary) responded with a halving of both water consumption and effluent discharges within a two-year period. The resulting drop in water use and wastewater generated had the unexpected side-effect of almost bankrupting the local water and wastewater utility by causing losses of $0.4 million.

- Water shortage in many Chinese cities has let to the serious consideration of conservation and recycling measures. With "propaganda, education, and various economic, administrative, and legislative measures," Tianjin has decreased its specific industrial water use from 54,000 m3/million $ output to 22,000 m3/million $ output (the corresponding figures for Beijing were 132,000 to 50,000 m3/million $ output). This was in response to strongly-enforced water use and effluent generation quotas per production unit with a penalty of 10-50 times the normal charge for those who exceeded their allocation of specific water use or wastewater generation, and a water audit program to monitor industries for leaks and conservation/recycling effectiveness.

- In Israel, conservation and recycling are a way of life to maintain its urban and agricultural infrastructure. Soon after its creation, Israel started formulating a comprehensive water legislation that led to the enactment of the Water Law in 1959. In the two decades after 1962, it managed to cut its specific water use by two-thirds from about 7,100 m3/million $ output to about 2,100 m3/million $ output. Thus, Israel has managed to sustain its rapid industrial expansion without substantially increasing its industrial water use. This was in response to strict policies imposed by Israel's Water Commission, including:
    - A dictate that all water resources are under control of the state.
    - A licensing system for industrial water, where the allocation depends on the production parameters (types of input, process, equipment, product).
    - Mandatory water metering.
    - Imposition of a penalty pricing system for violators
    - Introduction of water-saving technologies
    - Subsidizing financing for investment in water-saving processes and equipment.

  Water conservation was achieved mainly by the recirculation of cooling water and steam, pressure reducers and reuse of treated industrial wastewater (Gabbay, 1992)

This chapter provides plenty of evidence of the abilities of industries to respond to water scarcities. The price elasticities reported in Table 3.3 show that, while water is strictly speaking inelastic (that is the elasticity is less than unity in absolute value) in most cases, it is still likely to be quite price responsive. This is particularly important, since in most of the case studies the actual prices paid for water have been well below the long-run marginal costs. We would expect that as the price of water is raised in response to currently perceived scarcities, then water will become more price

Chapter 5

Simulations of Two Water Intensive Industries

Introduction

As mentioned earlier, there is not a large data base on the consequences of actual implementation of economic policies to improve industrial water supply and waste water disposal. Therefore, in order to demonstrate the impacts of some of the policy tools discussed in Chapter 3, we have chosen to follow a next-best course of action and create realistic simulation models of two important water-using industries; tanneries and pulp and paper mills, to demonstrate these effects. No modeling, however, really supplants good observational data, but in the absence of such data, modeling offers the best approach. The models developed here are optimization models that simulate the optimal behavior of industrial managers to changed external conditions on prices of water inputs and waste discharges and the availability of water quantities and effluent capacities. The models also allow the plant managers to invest in conservation and recycling technologies in response to external regulations or prices on input water and effluent charges. However, on the other side of the same coin, regulators can use the same model to design effective regulatory policies that would achieve the desired outcome at minimum cost to the industry and society. We chose to consider tanneries and pulp and paper because these are both heavy water-using and polluting industries which are widespread in the developing world. They also span the range of sizes, with the tanneries typically being low-capital low-tech, and quite small, while technological imperatives such as economies-of-scale tend to create large-scale relatively high-tech pulp and paper mills. They are also well documented; see for instance Nemerow (1978), Huang (1981), Pandikar (1991), Haskoning (1992), and USEPA (1995).

Industrial Water and Wastewater Models

The tannery we chose to model is a fairly small, but typical in the developing world, plant of 2,300 tons of raw hides per year. In Figure 5.1, we show a schematic of the tannery with an emphasis on the water inputs, the process water flow through the tannery, and the disposal of effluents after use. We have allowed the plant to have its own treatment plant for influent water and a wastewater treatment plant for treatment before disposal. Of course, we allow the plant managers to choose these treatment plants and their scale depending upon the water qualities, needs, and regulatory regimes they face. Figure 5.1 also shows a whole range of water input and effluent output options. The sources of supply can be surface water, groundwater, brackish water, municipal water supply, treated wastewater from some other industry or internal recycling of wastewater (treated or untreated). The effluents can be disposed of into surface water, groundwater, the municipal sewer, sold to other users, or internally recycled. It is unlikely that any one particular industrialist would face so many options for a specific plant all of the time; they are, however, likely to be faced by some industrialists some of the time. Hence, for the sake of completeness all have been included. The figure also shows the conservation and recycling options available to the plant managers. Again, we have given the managers a wide range of choices that may not obtain in all cases. The actual technological processes followed; the beam house, the tan house, and the finishing process are typical of tanneries of this size and are discussed in great detail in Nemerow and Das Gupta (1990) and industry handbooks (COWIconsult, 1989).

The numbers shown on the various linkages in both figures reflect optimally chosen flows of process water or wastewater based upon a set of imposed economic conditions and the logic of the technical process itself (referred to henceforth as a *scenario*). In the base case scenario, the plant manager attempts to minimize the total costs of meeting the water demands of each of the processes subject to the amounts of water available from the various sources and allowed to be sent to the various sinks with no particular set of environmental regulations in place. Following the flow chart in Figure 5.1, the optimal choices of the tannery managers are to treat in-plant some ground and surface waters, to take some from the various untreated sources, and take 1000 m^3 of treated municipal water. On the effluent side, the tannery would treat some of its wastes for disposal to the sewer and to sell to other water users. The remainder is disposed of untreated to the sewer, and to the surface and ground waters. Within the plant itself, the managers recycle both the treated and untreated waste streams. Of course, the actual choices depend upon the regulatory regime with input prices differing for different water sources and different effluent controls and/or prices for using the various sinks. They also depend upon the costs of within plant treatment and the costs associated with recycling within the plant itself. The data used in these models are based on typical numbers from such plants, and some assumptions had to be made to limit the size of the model and due to insufficient available data. However, the benefit of programming in a user-friendly environment is that the data can be easily changed to reflect growing knowledge and understanding, and technological and policy innovation.

Use of the Model

In the literature, we have found some examples of the consideration of industrial water use on a global scale or those that are very detailed process overviews for particular industries. We are yet to discover a treatment of water use process flows in selected industries that illustrate the policy options for water management. We have developed a simple set of illustrative case studies to examine the effect of various pricing and other regulatory policy options on particular industries.

With the help of such a model, we would like to obtain more information on the following issues:

- From a policymaker's viewpoint, what combination of policy options would induce the industry to behave in a particular manner if it were a rational actor trying to maximize its net benefits?
- From an industry manager's point of view, what would its best response be to any external policies, given the technical options at her disposal?
- What effects do water charges and effluent charges have on the lifecycle of the water in the industry? Is there a difference in their effects or is the widely practiced current system of combined water and wastewater charges charged for water supply reasonable? What kinds of substitution effects take place among the various supply, treatment, use and disposal options?
- What is the effect of subsidizing the conservation and treatment technologies?
- How can one derive a demand curve (and compute the price elasticity of demand), indicating the quantity of a particular type of influent water supply demanded at various prices?
- How can one derive the effluent discharge curve, indicating the quantity of that type of effluent discharged at various effluent charges?
- How can the model be used as a guide to policy-makers to set effective water prices and disposal fees?

In order to make the model as simple to use as possible, it has been written using the Microsoft EXCEL spreadsheet and its ancillary optimizing routines. Table 5.1 shows the basic spreadsheet which organizes the data input to the model. On the tables we have marked the location of the different parameters that are required to get the model to work. On the computer screen of course, the spreadsheet is color coded so that the user knows exactly which cells on the spreadsheet contain required input data that can be varied when using the model, which cells are reserved for the output of the model, and which represent structural assumptions of the model which can also be changed. The model embeds the EXCEL mathematical programming solver. The model is non-linear, as it takes into account the supply of internally recycled water, which is some proportion (the proportion is also a decision variable) of the water demanded (that is also unknown). However, many of the other relationships, such as the unit costs used in the model are linear, but they could easily be made non-linear with no loss of generality of the model.

Model Overview

Tools Used: This model was developed on a common spreadsheet (Excel) for easy access. These spreadsheets now have reasonably powerful optimization tools that are useful for small, illustrative problems. However, we would have to handle larger problems using a more powerful optimization package such as GAMS (Generalized Algebraic Modeling System).
Type of Model: The model is a simple non-linear optimization model and makes many simplifying assumptions. The intention is not to model exactly the processes within a plant, but to demonstrate how rationally-acting plant managers would react to various water and wastewater policy regulations using a comprehensive "cradle-to-grave" comprehensive analysis of the water from a plant's point of view.
Type of Industry: The industries chosen are typical industries in Pulp&Paper (Kraft process) and a Tannery.
Water Sources: We include a wide variety of water sources that can be chosen by the industries. These include surface water, groundwater, brackish and municipal water at different qualities. In addition, the industry can purchase treated wastewater and can also internally recycle treated or untreated wastewater. We specify the costs and maximum available quantities of each source of water (except for the internally generated wastewater, that is an endogenous variable and is what makes the problem a non-linear optimization problem).
Water Treatment: The water that enters the plant can be treated to upgrade its quality for certain process that require cleaner water.
Water Use: We define the water flow within each industry. We specify the specific water usage for each process (amount of water used per unit of product). The total size of the plant (in terms of either the quantity of raw material or product) is also specified elsewhere. We specify which sources of water are suitable for each process.
Conservation: Conservation takes the form of a reduction in the specific water use for each process. This reduction takes place within an allowable range for a specified annualized cost.
Wastewater Generation: A portion of the water taken up by each unit process is used for consumptive purposes or is lost. The remainder is assumed to be generated as wastewater.
Wastewater Treatment: The wastewater generated from each process can either be treated or remain untreated. This water can then be discharged outside the plant or be recycled.
Recycling: Water can be recycled at a price either before or after treatment.
Wastewater Disposal: Treated or untreated wastewater can be disposed of into many sinks, including surface water, groundwater, or sewers. In addition, there is an option to sell the wastewater to other users (using an industrial ecology viewpoint), or for recycling in-plant. All disposal is charged various effluent fees (these may be negative in the case of sale of the wastewater). In addition, there are limits on the amount of wastewater that can be disposed of in each method.

Model Components

Objective Function: The objective function minimizes the total cost of handling the water in the system, including the purchase of the water, the water treatment, exercising conservation options, wastewater treatment, recycling and wastewater disposal.

Constraints: The constraints on the system include bounds on the supply of water, disposal of wastewater and the amount recyclable or conserved. In addition, they specify the amounts of water required for each process at a given production level (in reality, this itself might be a function of the water handling costs).

Parameters: The parameters are the specified information in each of the models and include information on the prices, bounds, demands, etc. as outlined in the first page of the spreadsheets.

Policy Options: The policy options that can be varied are the tariffs for water supply, effluent charges for wastewater disposal, regulations on availability of water from different sources, and wastewater discharge limits.

Results: The model provides the industrial water policy maker an excellent opportunity to examine each of these policy options in isolation or in tandem to determine what kind of option would be most effective in eliciting a desired behavior. In addition, such models would be useful for the industrial water managers to determine how they could best react to changes in water or environmental policies.

[Note: See the following box on model formulation for more details on the objective function, constraints, decision variables and parameters.]

Model Formulation

$$\textit{Minimize} \quad \textit{Total Costs} \; = \; \sum_{s,p} CQ_s * QU_{s,p} + \sum_{s,p} (CQ_s + CQT_s) * QT_{s,p} +$$
$$\sum_{p} CCONS_p * CONS_p + \sum_{p,d} CE_d * EU_{p,d} + \sum_{p,d} (CE_d + CET_d) * ET_{p,d}$$

Subject to:

$$\sum_{s} QU_{s,p} * USUITABILITY_{s,p} + \sum_{s} QT_{s,p} * TSUITABILITY_{s,p} \geq QD_p \qquad \forall \{p\}$$

$$QD_p = SWU_p * (1 - CONS_p) * SIZE \qquad \forall \{p\}$$

$$\sum_{p} \{QU_{s,p} + QT_{s,p}\} \geq QMAX_s \qquad \forall \{s\}$$

$$CONS_p \leq CONSMAX_p \qquad \forall \{p\}$$

$$(1 - LOSS_p) * QD_p = E_p \qquad \forall \{p\}$$

$$E_p = \sum_{d} \{EU_{p,d} + ET_{p,d}\} \qquad \forall \{p\}$$

$$\sum_{p} \{EU_{p,d} + ET_{p,d}\} \leq EMAX_d \qquad \forall \{d\}$$

$$\sum_{p} QU_{\text{"recycled-untreated"},p} = \sum_{p} \{EU_{p,\text{"pre-process"}} - EU_{p,\text{"other users"}}\}$$

$$\sum_{p} QU_{\text{"recycled-untreated"},p} \leq QMAXRECU$$

$$\sum_{p} QT_{\text{"recycled-treated"},p} = \sum_{p} \{ET_{p,\text{"pre-process"}} - ET_{p,\text{"other users"}}\}$$

$$\sum_{p} QT_{\text{"recycled-treated"},p} \leq QMAXRECT$$

where:

s = sources of water {Surface, Groundwater, Brackish, Municipal, External Treated Wastewater, Internal Recycling of Treated Wastewater, Internal Recycling of Untreated Wastewater}

p = process components of the industry {Beamhouse, Tanhouse and Finishing House for the Tannery Case}

d = effluent discharge destinations {Surface water, Groundwater, Sewer, recycled to pre-process, sold to other users}

$QU_{s,p}$ = Quantity of untreated input water demanded from source s for process p (m^3/yr.)

$QT_{s,p}$ = Quantity of input water demanded from source s for process p undergoing pre-process treatment (m^3/yr.)

CQ_s = Price of input water from source s ($\$/m^3$)

CQT_s = Cost of pre-process treatment of input water from source s ($\$/m^3$) - function of quality of input water

$QMAX_s$ = Maximum availability of water to the industry from source s (m^3/yr.)

$USUITABILITY_{s,p}$ = Suitability of untreated input from source s to process p {0-unsuitable; 1-suitable} - function of water supply quality, and process needs

$TSUITABILITY_{s,p}$ = Suitability of treated input from source s to process p {0-unsuitable; 1-suitable} - function of water supply quality, treatment level, and process needs

SIZE = Quantity of raw stock (tons or raw stock/yr.)

SWU_p = Specific Water Use in process p (m^3/ton of raw stock)

$CCONS_p$ = Cost of conserving water (i.e., reducing specific water use) in process p ($\$/m^3$/yr.)

$CONS_p$ = Conservation Level (proportion of input water conserved) in process p (fraction in [0,1])

$CONSMAX_p$ = Maximum Conservation Level possible in process p

QD_p = Total quantity of water from all sources demanded for process p (m^3/yr.)

$LOSS_p$ = Losses (use in product, evaporation, leakage, etc.) in process p (% of QD_p)

$EU_{p,d}$ = Quantity of untreated effluent from process p discharged to destination d (m^3/yr.)

$ET_{p,d}$ = Quantity of effluent from process p discharged to destination d undergoing post-process treatment (m^3/yr.)

E_p = Total Effluent discharged from process p (m^3/yr.)

$EMAX_d$ = Maximum allowable discharge to destination d (m^3/yr.)

CE_d = Disposal fee for disposal of effluent to destination d ($\$/m^3$)

CET_d = Post-process treatment costs to treat effluent before disposal to destination d ($\$/m^3$) - function of effluent quality

QMAXRECU = Maximum recycling of untreated effluent (m^3/yr.)

QMAXRECT = Maximum recycling of treated effluent (m^3/yr.)

Model Results

The model was executed within Excel while considering a range of scenarios in both the Tannery and Pulp and Paper examples. Such models provide opportunities to change many factors and it is easy to submerge oneself in model outputs. In this study, we report on only a few of the results that would be indicative of the power of such models. We have endeavored to avoid duplication in performing the same kinds of analyses on both examples; rather we use both models to examine different kinds of options and scenarios.

Figure 5.1 shows the flow chart reporting the optimal values of the effluent treatment decisions for the Tannery example in terms of m^3 per year for the base case optimal solution with an annual cost of $36,256. For a pulp and paper mill (producing 30,000 tons of paper per year), a minimally regulated base case cost $68,616 per year.

With any programming model, once the basic model is built, a wide variety of sensitivity analyses can be carried out very easily. The approach taken in this model is even more flexible because not only can one produce tabular output, but one can immediately show the decision makers graphical output as on Figure 5.1. The models developed here are interactive Decision Support Systems models (DSS) that should have great use in training managers to be sensitive to considering all of their options.

Just a few of these options have been analyzed here. The base case for both the industries considered were minimally regulated situations with only some effluent constraints constraining the outcome. In the following two boxes we compared this to a variety of regulatory and pricing approaches.

Many more options can be considered and one of the interesting aspects about using a modeling approach is that these models can be operated on a PC anywhere and provide results that are responsive to new data and ideas as they develop. The Excel files containing the model have been submitted with this report and could be used to develop training exercises in the use of such analytical techniques to help both regulators and industries assess their options in a more comprehensive manner for mutual benefit.

Model Runs- Tannery

Four cases were considered in the example of the Tannery:

- Base Case1: with prices for input water and effluents as shown in Table 5-1 and default conservation options.
- Case A1: Base Case1 with command & control regulations to limit the disposal of untreated effluent to surface waters, ground waters and sewers and of treated effluent to surface and ground waters to 3000 m^3/yr.
- Case B1: Base Case1 with economic disincentives - \$0.25/m^3 disposal fee for untreated effluent disposal and \$0.10/m^3 disposal fee for treated effluent disposal to surface and ground waters.
- Case C1: Same as case A1 except that the limit is reduced from 3000 m^3/yr to zero-discharge for the disposal of untreated effluent to surface waters, ground waters and sewers and limit treated effluent disposal to surface and ground waters to be 6000m^3/yr and 9000 m^3/yr respectively.
- Case D1; Same as case B1, except that the disposal fees are now \$0.35/m^3 for untreated effluent disposal.

The economic results are summarized in Table 5-2 and Figures 5-2 through 5-4. The following points are of interest:

- When we stipulate command & control (c&c) regulations to limit the disposal of effluent as in Case A1, we see that the industries have to bear an additional cost of about \$10,100 per year over the Base Case1. From the regulatory agency point of view, the desired decrease in the effluents of concern is achieved, but also at a loss to its revenue of about \$4,500 per year due to lower effluent fee collection.
- If, instead, we attempt to achieve the same outcome by raising the disposal fees for the effluents of concern (as in Case B1), we see that it is possible at a lower cost to both the industry and the regulatory agency. This is possible because, instead of going on to an expensive conservation option for the finishing house as in Case A1, an increase in recycling is seen along with a re-arrangement of the effluent generation pattern, which achieves just about what was mandated by the c&c stipulations. The industry is able to switch to a different pattern of water supply and effluent generation while saving conservation costs[1], and the regulatory agency would collect more from water supply charges and effluent fees than in Case A1.
- When we force a c&c approach requiring zero discharge on the targeted effluents (Case C1), this can only be achieved by further driving up the costs to the industry (\$11,000) in terms of higher conservation and effluent treatment costs. The regulatory agency also loses about \$4,900 per year (over the Base Case1) as a result of this policy due to lower effluent generation.

If we try to replicate the use of economic incentives to achieve the same objective (Case D1), we see that just as in Case B1, a switching of influent and effluent patterns benefiting both industry (in terms of lower conservation costs) and the regulatory agency (in terms of water supply charges). However, if we compare Cases B1 and D1, we note that although the costs and benefits for industry are exactly the same, the implications for the regulatory agency are quite different. This is because of the multiple possibilities in switching in effluent treatment and disposal patterns that can cost the same to industry. In this case, at no extra cost to the industry, we get much better water quality (but less revenue to the regulatory authority) when we give a new set of economic (dis)incentives for effluent disposal.

---

[1] Note that conservation costs are an annualized capital cost - hence, the objective here is to estimate how an industry would plan for conservation under a set of scenarios - not to evaluate the day-to-day responses to technical and policy stimuli.

Model Runs - Pulp & Paper

Four cases were considered in the example of the Pulp & Paper Industry:

- Base Case2: with prices for input water and effluents as shown in Table 5-3 and default conservation options.
- Case A2: Base Case2 with technical advances that enables greater conservation (from a maximum conservation reduction of 50% to 90% of the specific water use) and reduces conservation costs in the wood preparation, kraft pulping, screening and washing & thickening processes (from an annualized cost of $140 to $30 per unit specific water use percent decrease).
- Case B2: Case A2 with zero discharge limits on untreated wastewater disposal to surface and ground waters.
- Case C2: Same as Case B1, but in addition to the discharge limits, the conservation technologies are subsidized in wood preparation (from $30 to $5 per unit specific water use percent decrease), screening (to $0.5), and washing & thickening (to $10).

The economic results are summarized in Table 5-4 and Figures 5-5 through 5-7. The following points are of interest:

- We have used the models to simulate the effect of technological change on the system. In Case A2, we see that with the conservation options now becoming more effective and cheaper, the industries would benefit. The industry would adopt more of these conservation practices as it is now worthwhile to do so even at notional water supply and effluent fees. They pay higher total conservation costs (although they get a bigger bang for the buck); however they can reduce the water demanded and effluent generated, with a net savings over $27,600 every year. The regulatory authority would correspondingly lose revenue from water supply charges and effluent fees of over 35,000 over the Base Case2[2].
- Again, as in the Tannery example, when we stipulate command & control (c&c) regulations to limit the disposal of effluent as in Case B2, the industries have to bear an additional cost of about $14,000 per year over Case A2. From the regulatory agency point of view, the desired decrease in the effluents of concern is achieved with an increase in revenue of over $6,500 over Case A2. This is because of additional fees collected from water supply and effluent charges as the consumption and disposal patterns shift.
- Models such as these also allow for the examination of the sensitive issues of subsidizing conservation or treatment options. In the Case B2, we again have the technical advances in the conservation options, and the zero discharge limits; however, we increase the incentives to the industries to use the new technological options by subsidizing some of the conservation options in an attempt to enhance their adoption. We see that as a result of this policy, the industry decides to enhance its conservation measures undertaken (here by undertaking maximum conservation in wood preparation, where it was not economically worthwhile to do so earlier). The industry saves about $8,300 over the Case B2; however, the regulatory agency loses almost $11,000 in revenues.

This illustrates the need for such analyses to identify such "win-win" or "don't lose as much-don't lose as much" scenarios, both from the point of view of industry and the regulatory authorities. For example, comparing Cases B1 and A1 for the tannery, where economic incentives are compared with command and control regulations to achieve the same environmental goal, the economic incentives approach both the industry and the regulatory agency (a win-win situation).

---

[2] It is necessary to remember again that the objective here is to minimize industry costs; the revenue to the regulatory authorities is not in the objective function and the model makes no attempt to maximize this revenue. If this were indeed our objective, we would have to have information on the costs of current supply, current supply capacity, incremental costs of augmentation both for water supply and wastewater disposal, and of the water quantity and quality implications of changes in the industry's water demands to the water resources system.

Also, we should note that in computing the net revenue to the regulatory authorities, we need to consider their point on the supply curve for water supply, i.e. their current O&M costs and incremental costs (incl. capital costs) in augmenting supply, to get the net revenue for them. Also, this model focused only on an industry. We could envisage similar models that could be applied or extended to the objectives of the regulatory agencies. Other objectives that could be considered include water quality, fisheries, etc. that may depend on the amount and quality of water as impacted by use in industry. We could also expand the models to include other sectors and areas to derive comprehensive basin-wide models where the options for supply augmentation and demand-side management would be increased.

The experiences with the use of such modeling techniques also indicates the flexibility of the water use system - options that the authorities have in terms of inducing desired behavior, and options that the industries have in terms of responding to these and other stimuli. The regulatory authority could have options ranging from changes in water supply charges to introducing or modifying effluent fees; but they also have a whole new range of options in terms of subsidies on conservation and other options. If there are currently subsidies on the water use or effluent fees, the regulatory authorities may consider the possibility of transferring some of these subsidies to the conservation, recycling or treatment options as a transitionary step to correct some of the skewed economic incentives in the system.

The industries also can take advantage of changes in regulatory modes and of technological changes (in fact, the right enabling environment may also enable the industries themselves to invest in R&D in these areas), to improve their overall economic position. Flexibility in command and control approaches (e.g. bubbles) and the introduction of economic incentives and disincentives could send the correct signals to effect the desired final outcome rather than just a narrow focus on industry actions.

The models also indicate the need to approach the system from the point of view of the various stakeholders to assess the optimal strategies for each player. It is also necessary for the regulatory organizations to analyze the situation both from a large-scale (to internalize the externalities and maximize the social good) and from a small-scale (to provide industry with more options to comply). In evaluating the social good, it is also necessary for the regulatory agencies using models such as these to be more comprehensive in the analysis of costs, benefits and water qualities and move from financial to economic prices.

Sensitivity Analyses

One of the most important uses of such an optimization model is to observe the effects of changes in the parameters of the model. We report here on the tale of two simulations to illustrate the obvious and subtle uses that such a model can be put to.

Sensitivity to Treated Surface Water Cost

This was performed by determining the sensitivity of the results to the treated surface water cost (see Figure 5-8). We performed the sensitivity in the range of surface water treatment costs from \$0.01/m^3 to \$0.15/m^3. We observe that the use of treated surface water (called **Qtr-sw** in Figure 5-8) fell sharply with the rising price from about 44,500 m^3/yr. that was near the maximum allowable to about 8,500 m^3/yr., after which the system ran out of substitution possibilities in our scenario. The surface water was substituted primarily by a rise in the use of untreated municipal water and treated groundwater (called **Quntr-mun** and **Qtr-gw** respectively in the figure). There was also an increase in the use of internally recycled water (**Quntr-trir**), although the proportion re-treated fell (**Qtr-trir**).

The important point here is that by performing such a sensitivity analysis, we were able to derive a demand curve for treated surface water. Figure 5-9 shows such a derived demand curve where we can observe the quantity of water demanded at various prices. As we had mentioned, the demand curve becomes vertical at around 8,500 m^3/yr. because we have not allowed for further substitution possibilities; in reality, this constraint could be relaxed. Note that the demand curves need not show decreasing returns to scale due to the various non-linearities involved in recycled water and due to the conservation and substitution possibilities.

From this curve, it is possible to determine the *price elasticity of demand* for that particular commodity - treated surface water. In this case, over the non-vertical portion of the curve, the elasticity works out to be about -2.58. This high elasticity can be attributed to the high degree of substitutability that we have allowed in that portion. Note that cross-elasticities (e.g.

effect of raising the cost of treated surface water supply on the demand for treated groundwater, *ceteris paribus*) can also be derived by using the results of sensitivity analysis. It is important to note that the elasticity is a function of the technical options and regulatory parameters specified in the system, and an accurate computation of the elasticity is dependent upon developing realistic options in the scenarios considered.

Sensitivity to Disposal Charge for Untreated Wastewater

If we now wish to observe the effect of raising the effluent charge for disposing of one kind of effluent - untreated wastewater, we can do so by repeatedly running the model while performing a sensitivity on that parameter. We see (Figure 5-10) that the discharge pattern is insensitive for charges up to $0.14/m^3, but after that, there is a gradual decrease in the quantity of untreated sewage to surface waters (in the figure this is called, **Quntr-sw**) up to a charge of $0.16/m^3, after which there is a sharp drop to achieving "zero-discharge" of untreated wastewater into surface waters. This is achieved by a slight switch to disposing of this sewage into the sewers (called, **Quntr-sewer**) at a higher cost, until that option is exhausted, after which the effluent is treated and thereupon discharged to the surface waters (called, **Qtr-sw**).

Similar to a demand curve derived above, we can derive an effluent discharge curve, Figure 5-11, that displays the discharged quantity as a function of the cost of disposal. These curves would tend to be stepped in a system such as this one, as linear substitution possibilities are explored. It is also possible to calculate a price elasticity of effluent generation, although they have to be interpreted in the appropriate ranges. Such an analysis would also help decision-makers set appropriate effluent charges by determining the ranges in which the effluent discharge patterns would be insensitive or determining the threshold fees after which the desired effects can be observed.

Further Comments on the Model

This chapter has attempted to demonstrate the power of simple programming models to enhance decision making both at the level of the Industry and of regulators. The intention of the model is to illustrate its use in a couple of case studies. It is possible to make such models much more complex to increase their capabilities. For example, the model could be made seasonal or monthly to include temporal aspects (stochasticity could also be handled using stochastic or fuzzy optimization models and follow-up simulation modeling); process change options could be more explicitly defined; water quality parameters could be more disaggregated to handle specific process standards and to better handle environmental externalities; the production level could become a variable, opening up the path to maximizing net benefits instead of minimizing costs to produce a certain quantity of product; the industry could be considered as part of a larger system to illustrate some of the principles of river basin planning, industrial ecology; integrated supply-side and demand-side management; more integrated surface water and groundwater conjunctive use including recharge from effluents; inter-sectoral issues; the examination of various economic and regulatory instruments (command and control, bubbles, offsets, tradable permits, etc.), comprehensive analysis of pollution to various media, consideration of multiple objectives, game-theoretic analyses from the point of view of various stakeholders, etc.; the possibilities are only limited by the imagination. However, another computational limitation could be the software and hardware capabilities, although this is far less so that even in the recent past. The construction of more advanced models (we were at the limit of Excel 5.0's capabilities for the current model) would require a more powerful optimizer such as GAMS (Generalized Algebraic Modeling System), that can be easily integrated with spreadsheets for graphical output (Harshadeep, 1995). The new generation of matrix generating languages allow for sophisticated coding that is well-suited to the development of decision support system interfaces.

However, the current model itself represents a major step in the right direction towards analyzing the complex issues in water management in industry. Tools such as these tend to be a good forum for collecting and organizing data, assessing options, thinking rationally, clarifying objectives, identifying which constraints are flexible and which are inflexible, developing scenarios for the future, integrating the views of various stakeholders, identifying negotiating positions, determining tradeoffs between various objectives, analyzing when objectives are in conflict and which issues are not worth disputing about, developing effective policy mixes and response strategies, identifying areas of incomplete knowledge and research, etc. They make the best use of the available data and are an important step in integrating economics with technological options.

As mentioned above, there are many different policy options that can be explored with these models. This chapter presents the design of such a model and its use and the outcomes of sensitivity studies based upon this model. What the models show is that one can arrive at the desired outcome (from a local government's part) by either a strict regulatory or a pricing approach. The choice of which to take would be conditioned upon an understanding of the local situation and an assessment of which approach would in reality be more cost effective. Such models are powerful tools for the integration of economic and technological choices in determining optimal mixes of "hardware" and "software" options and identifying "win-win" situations for the various stakeholders.

TABLE 5-1

Basic Data Sheet for Tannery

Size of Tannery (tons of raw stock per year):	2300			
INPUT WATER	*PRICES ($/m3)*	*QUALITY (0-Bad, 1-Better...)*	*TREATMENT UNIT COST ($/m3)*	*MAX QTY (m3/yr)*
Untreated				
Surface	$0.15	1		50000
GW	$0.10	2		20000
Brackish	$0.03	0		15000
Municipal	$0.20	3		40000
External Treated WasteWater	$0.05	1		1000
Internal Recycling - Untreated	$0.00	0		1035.14873
Internal Recycling - Treated	$0.00	1		1035.14873
Treated				
Surface	$0.30	3	$0.15	
GW	$0.20	3	$0.10	
Brackish	$0.33	3	$0.30	
Municipal	$0.25	3	$0.05	
Treated WasteWater	$0.25	3	$0.20	
Internal Recycling - Untreated	$0.17	3	$0.17	
Internal Recycling - Treated	$0.05	3	$0.05	
TOTAL				
Water Supply Surcharge ($/m3)	0			
Treatment Subsidy	0%			
Effluent Surcharge ($/m3)	0			
POST-PROCESS TREATMENT				
Untreated				
To Surface Water	$0.03	0		10000
To GW	$0.04	0		20000
To Sewer	$0.15	0		40000
To Pre-Process	$0.00	0		2000
To Other Users	($0.05)	0		500
Treated				
To Surface Water	$0.02	1	$0.15	20000
To GW	$0.03	1	$0.15	50000
To Sewer	$0.05	1	$0.15	50000
To Pre-Process	$0.00	1	$0.20	2000
To Other Users	($0.15)	1	$0.15	3000

TABLE 5-2

Results of the Tannery Model

Tannery					
Industry Viewpoint	Base Case 1	Case A1	Case B1	Case C1	Case D1
		Discharge Limits	Econ Incentives-low	Zero-Discharge Limits	Econ Incentives-high
Water Supply and Treatment Costs	15065	13407	15065	13407	15065
Conservation Costs	14000	21000	14000	21000	14000
Effluent Treatment and Disposal Costs	7191	11990	14970	12920	14970
Total Cost to Industry	36256	46397	44035	47327	44035
Savings over Base Case1	0	-10141	-7779	-11071	-7779
Regulatory Agency Viewpoint					
Revenue from Water Supply	11733	10876	11733	10877	11733
Revenue from Effluent Fees	6917	3310	6325	2890	2890
Net Revenue to Agency	18650	14186	18058	13767	14623
Net Revenue Increase (over Base Case1)	0	-4464	-592	-4883	-4027
Total Savings for Industry & Reg Ag (over Base Case2)	0	-14605	-8371	-15954	-11806

TABLE 5-3

Basic Data Sheet for Pulp and Paper Plant

Size of Paper Mill (tons of paper per year):	30,000.00			
INPUT WATER	*PRICES ($/m3)*	*QUALITY (0-Bad, 1-Better...)*	*TREATMENT UNIT COST ($/m3)*	*MAX QTY (m3/yr)*
Untreated				
Surface	$0.15	1		100000
GW	$0.10	2		200000
Brackish	$0.03	0		15000
Municipal	$0.20	3		400000
External Treated WasteWater	$0.05	1		1000
Internal Recycling - Untreated	$0.00	0		300
Internal Recycling - Treated	$0.00	1		400
Treated				
Surface	$0.30	3	$0.15	
GW	$0.20	3	$0.10	
Brackish	$0.33	3	$0.30	
Municipal	$0.25	3	$0.05	
Treated WasteWater	$0.25	3	$0.20	
Internal Recycling - Untreated	$0.17	3	$0.17	
Internal Recycling - Treated	$0.05	3	$0.05	
TOTAL				
POST-PROCESS TREATMENT				
Untreated				
To Surface Water	$0.03	0		50000
To GW	$0.04	0		20000
To Sewer	$0.15	0		400000
To Pre-Process	$0.00	0		2000
To Other Users	($0.05)	0		500
Treated				
To Surface Water	$0.02	1	$0.15	20000
To GW	$0.03	1	$0.15	50000
To Sewer	$0.05	1	$0.15	500000
To Pre-Process	$0.00	1	$0.15	2000
To Other Users	($0.15)	1	$0.15	3000
TOTAL				

TABLE 5-4

Results of Pulp and Paper Model

Pulp & Paper Industry				
Industry Viewpoint	**Base Case 2**	**Case A2**	**Case B2**	**Case C2**
		Technical Advance	**A2+Discharge Limits**	**A2+Econ. Incentives**
Water Supply and Treatment Costs	36954	8798	15463	13038
Conservation Costs	14000	29913	29323	26574
Effluent Treatment and Disposal Costs	17662	2275	10206	7114
Total Cost to Industry	68616	40986	54992	46726
Savings over Base Case2	0	27630	13624	21890
Regulatory Agency Viewpoint				
Revenue from Water Supply	31814	8748	10373	7946
Conservation Subsidy Cost to Govt	0	0	0	-5437
Revenue from Effluent Fees	14667	2300	7231	4139
Net Revenue to Agency	46481	11048	17604	6648
Net Revenue Increase (over Base Case2)	0	-35433	-28877	-39833
Total Net Revenue to Industry & Reg Ag	-22135	-29938	-37388	-40078
Total Savings for Industry & Reg Ag (over Base Case2)	0	-7803	-15253	-17943

FIGURE 5-1

Water and Waste Flows in a Small Tannery

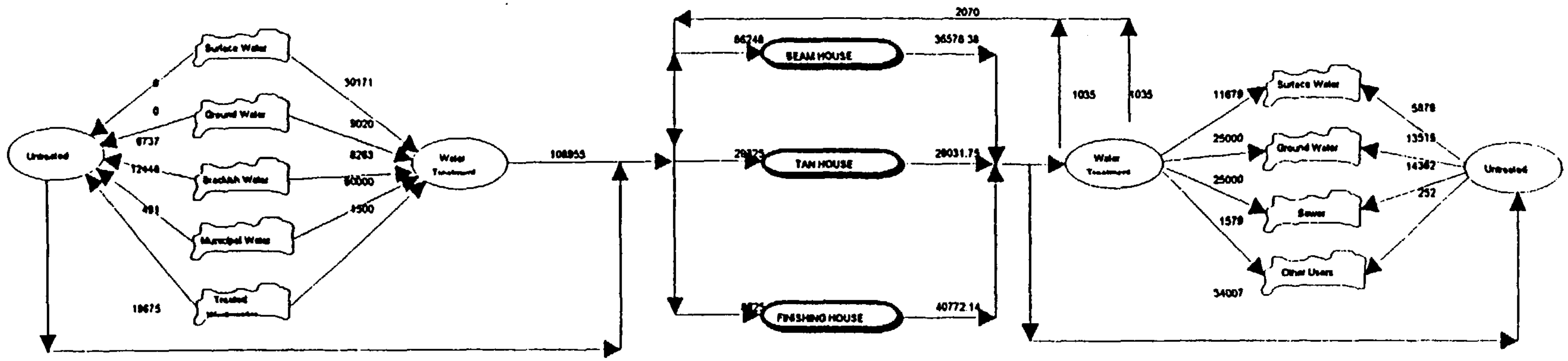


FIGURE 5-2

Net Costs to Industry and Reg. Agency
Tannery

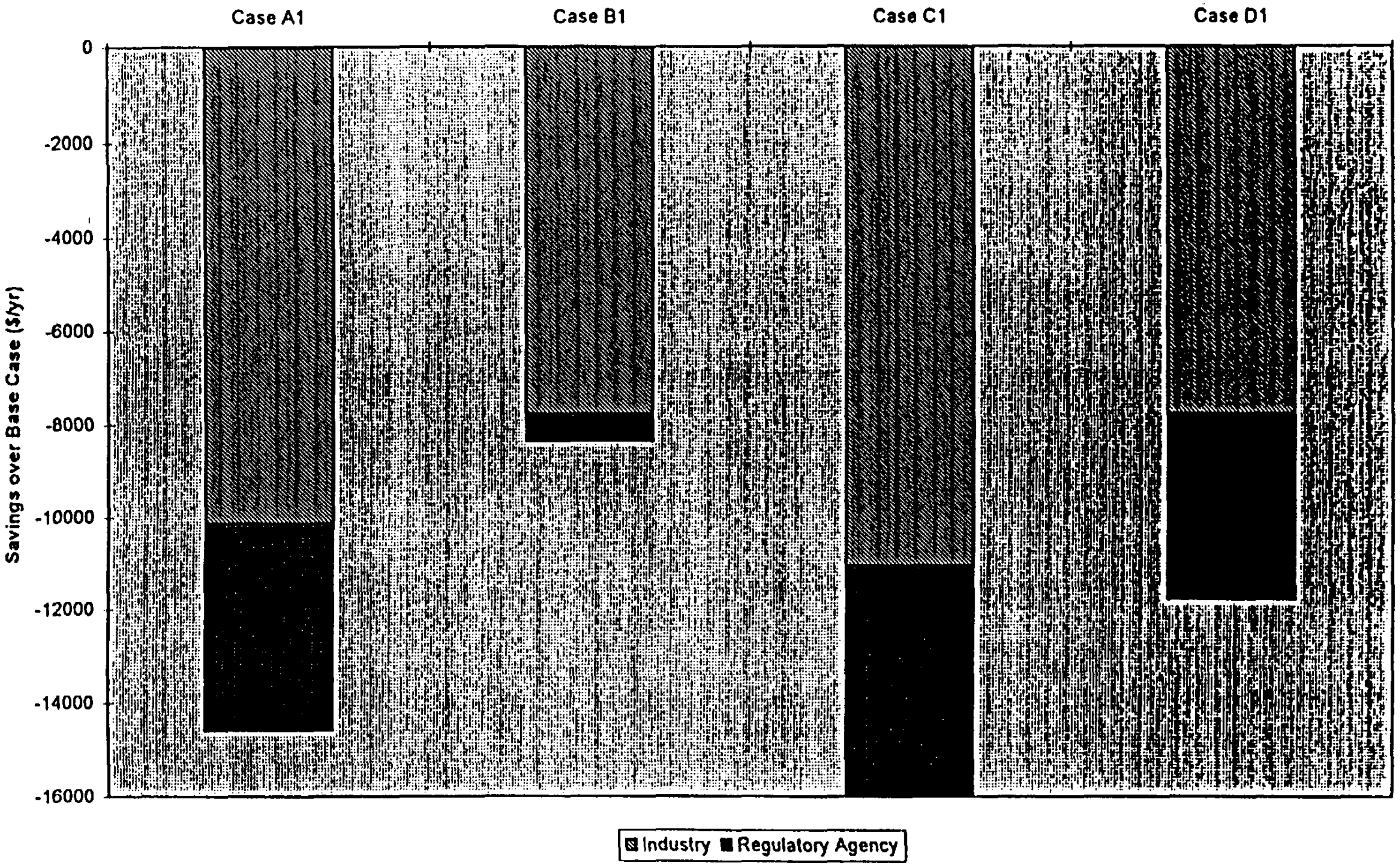


FIGURE 5-3

Industry Cost Breakdown
Tannery

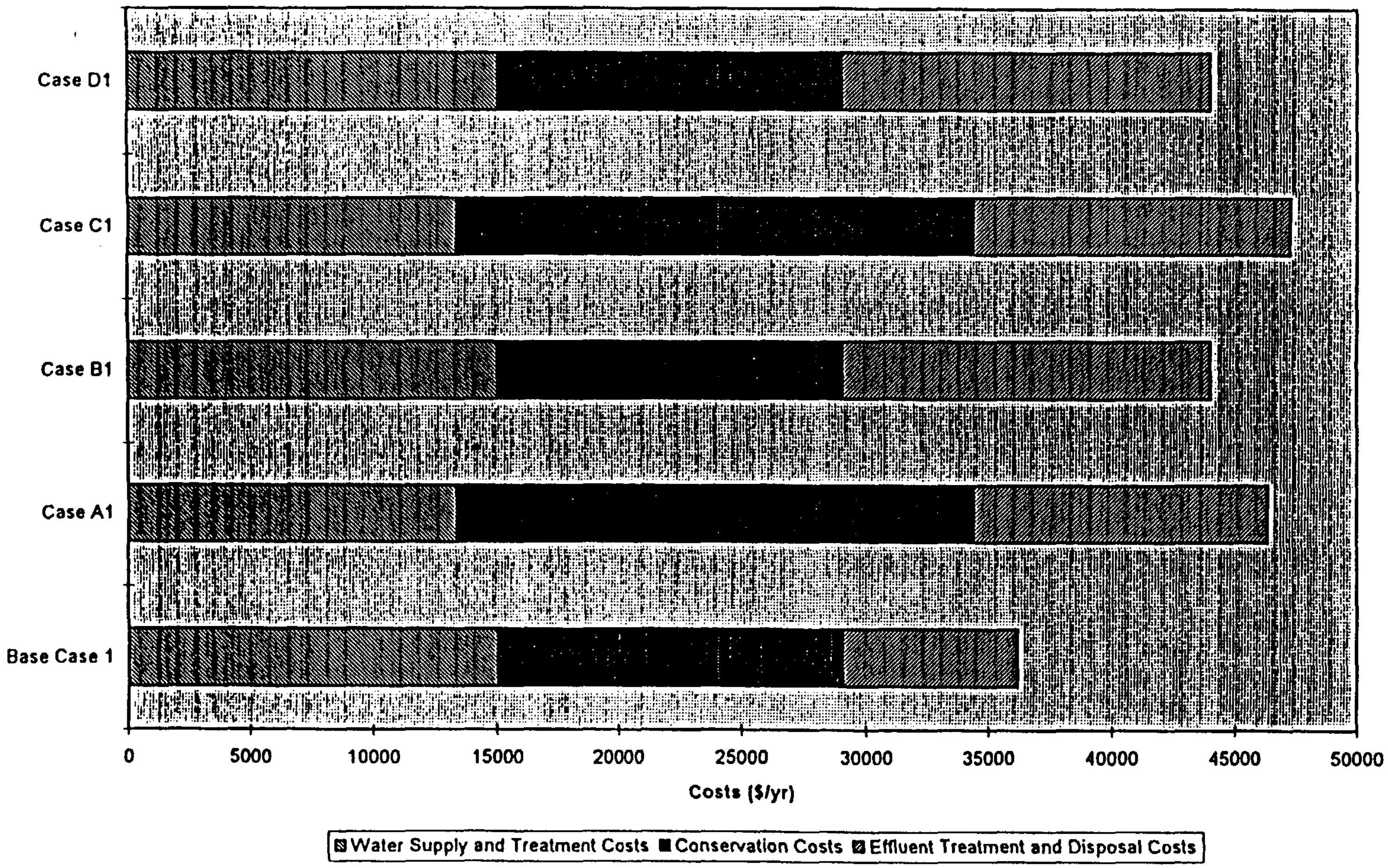


FIGURE 5-4

Regulatory Agency Revenue Breakdown
Tannery

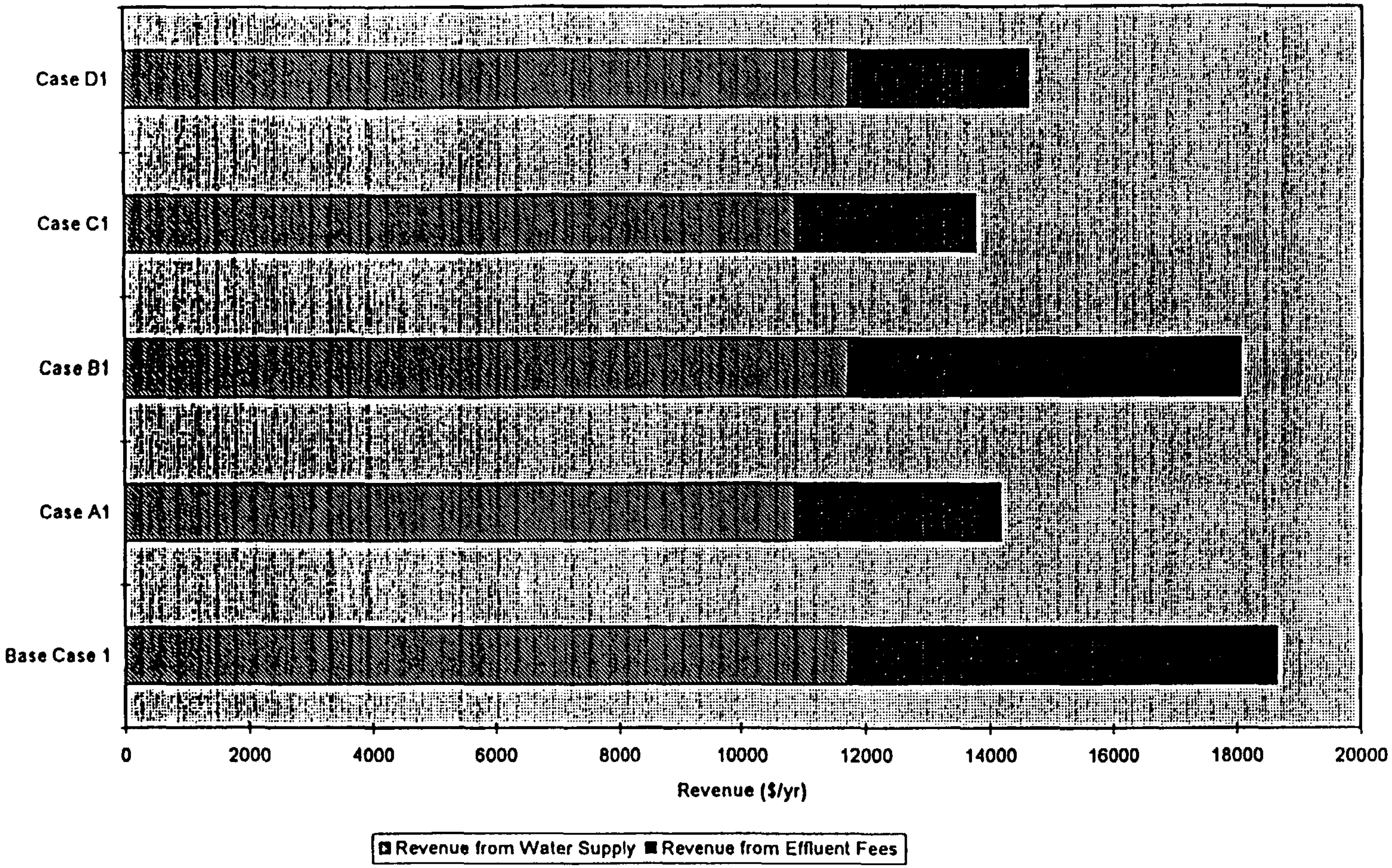


FIGURE 5-5

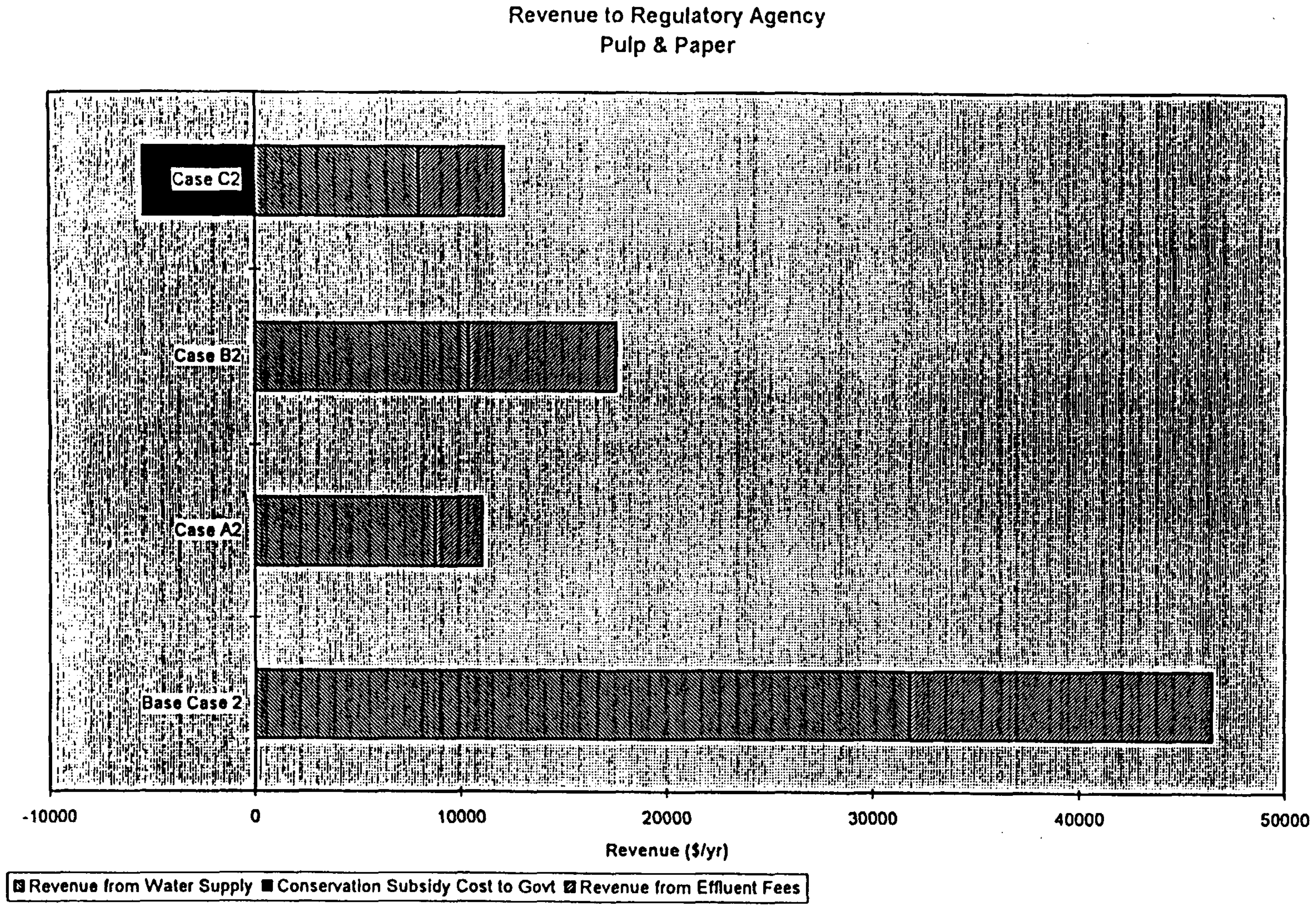

Revenue to Regulatory Agency
Pulp & Paper
Case C2
Case B2
Case A2
Base Case 2
-10000
0
10000
20000
30000
40000
50000
Revenue ($/yr)
▨ Revenue from Water Supply ■ Conservation Subsidy Cost to Govt ▨ Revenue from Effluent Fees

FIGURE 5-6

Costs from an Industry Viewpoint
Pulp & Paper

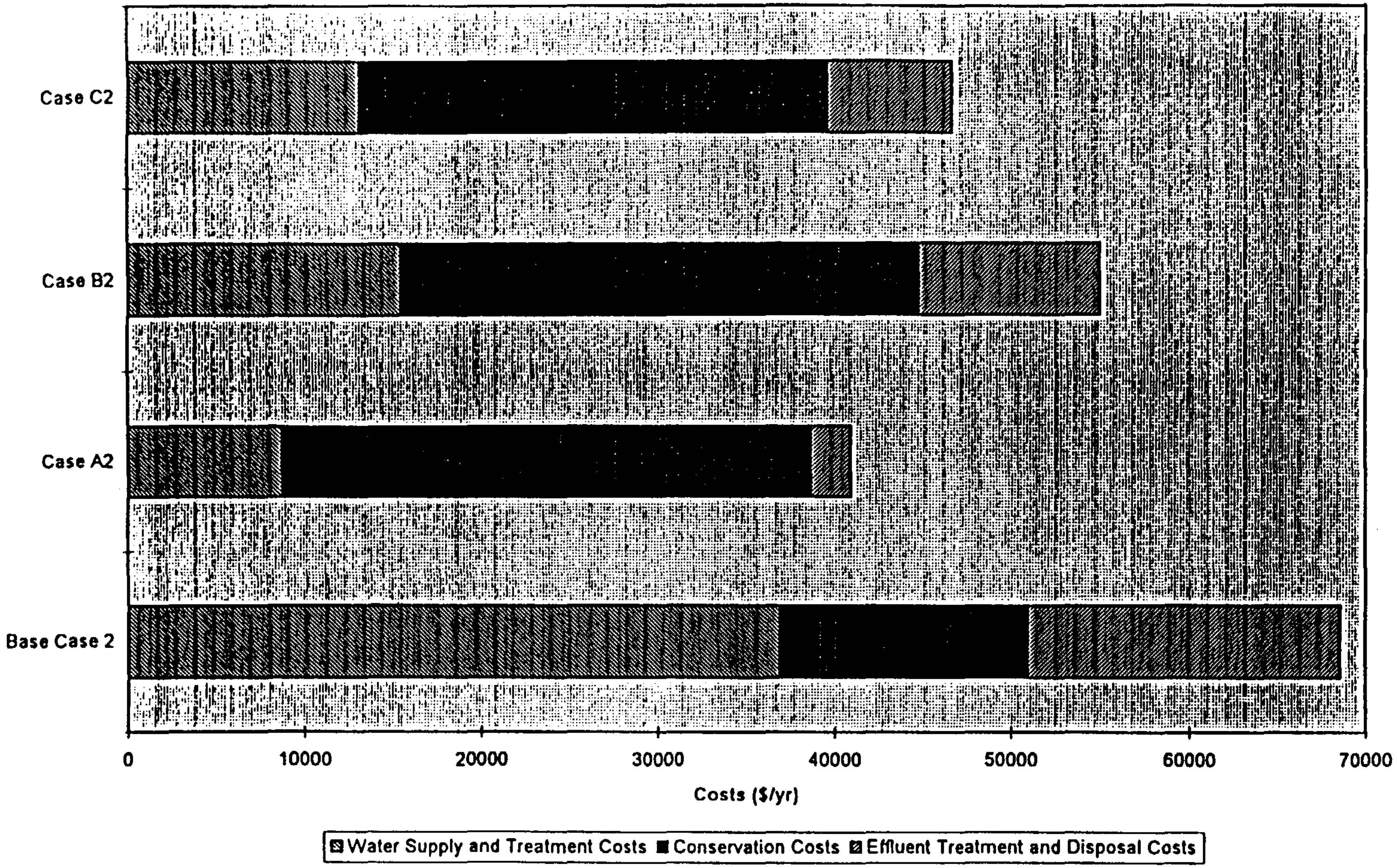


FIGURE 5-7

Net Total Savings to Industry and Reg. Agency
Pulp & Paper

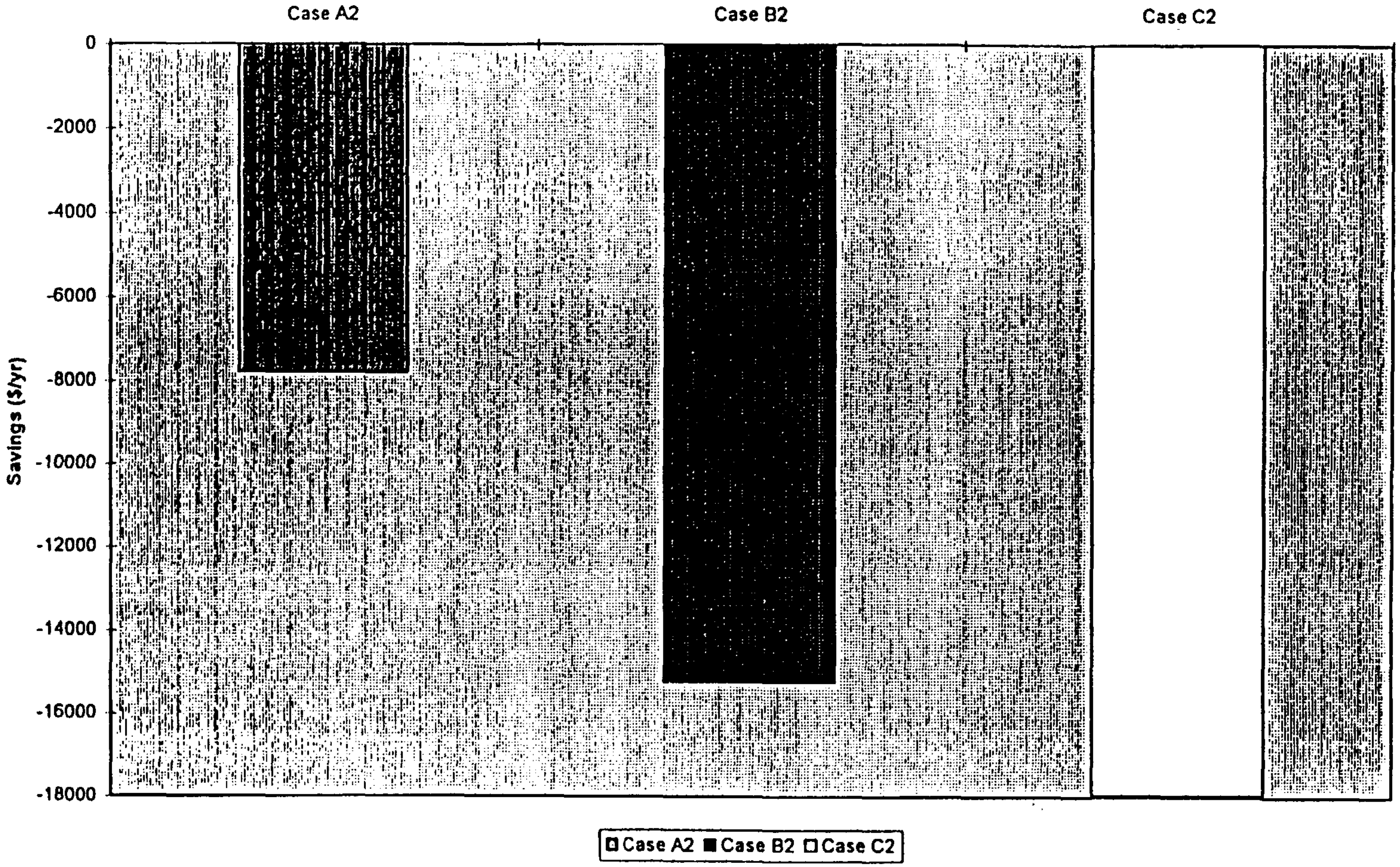


FIGURE 5-8

Water Supply Pattern Sensitivity to Treated Surface Water Cost - Tannery

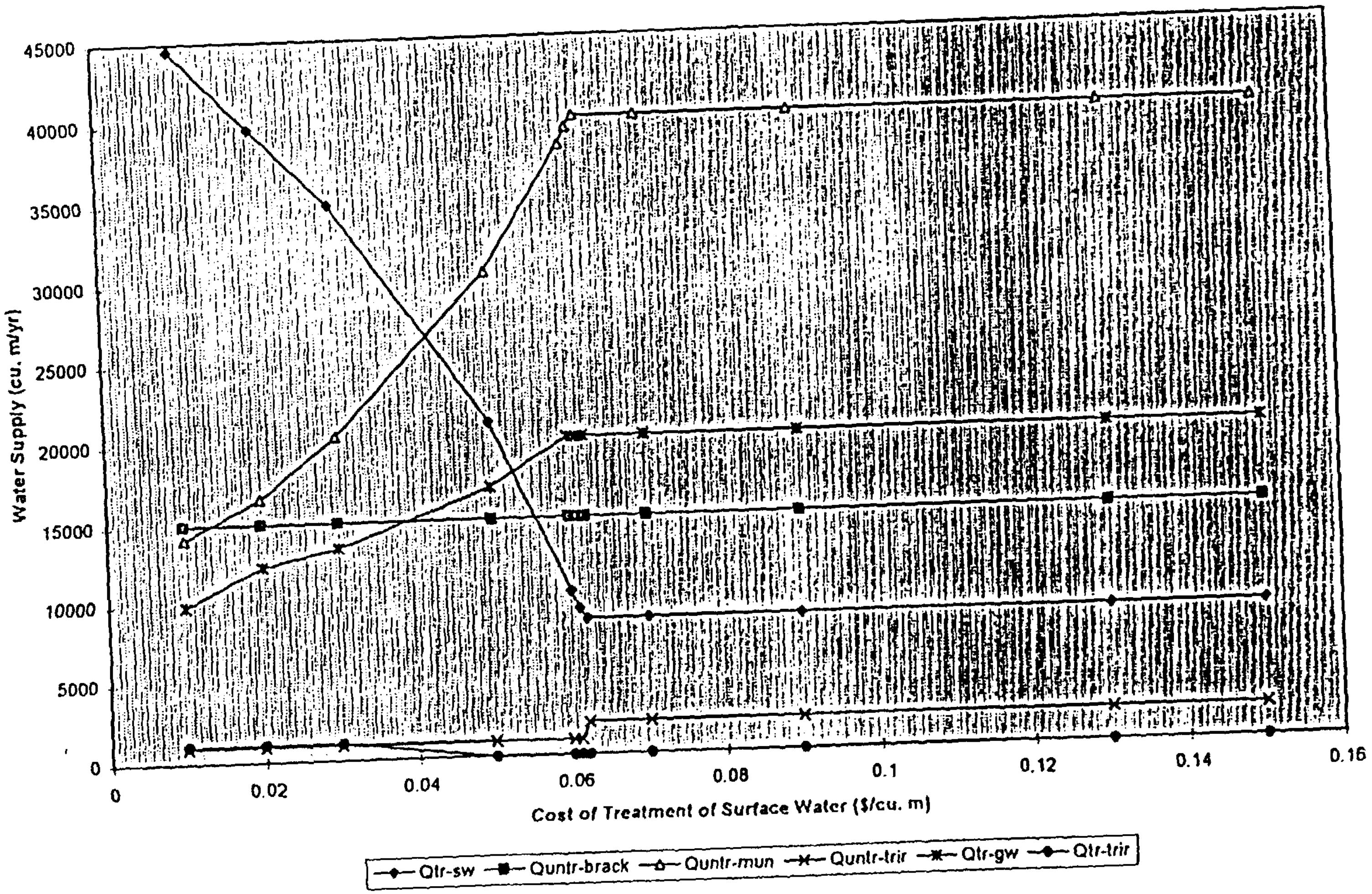


FIGURE 5-9

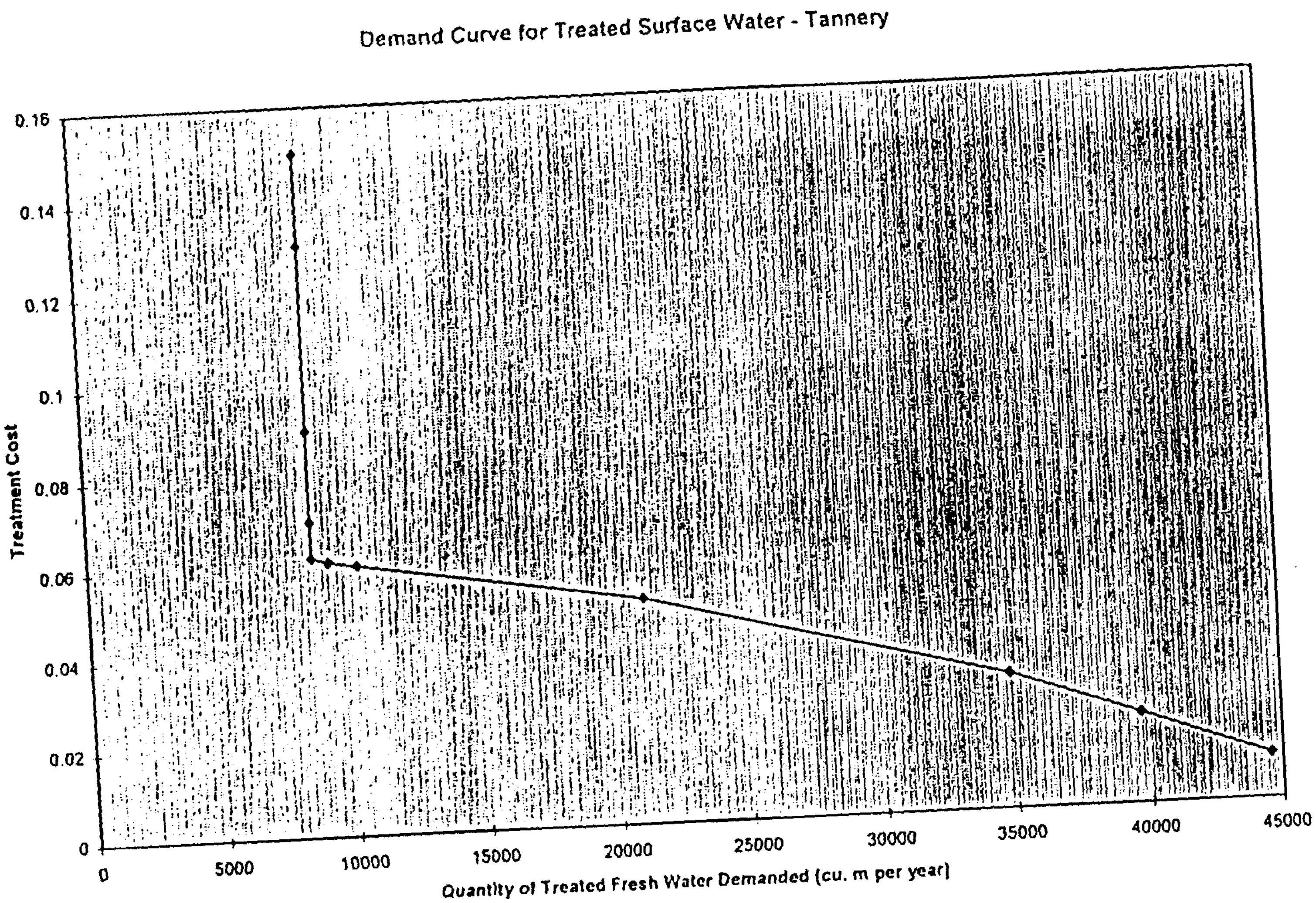

Demand Curve for Treated Surface Water - Tannery
Treatment Cost
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
Quantity of Treated Fresh Water Demanded (cu. m per year)

FIGURE 5-10

Effluent Discharge Curve

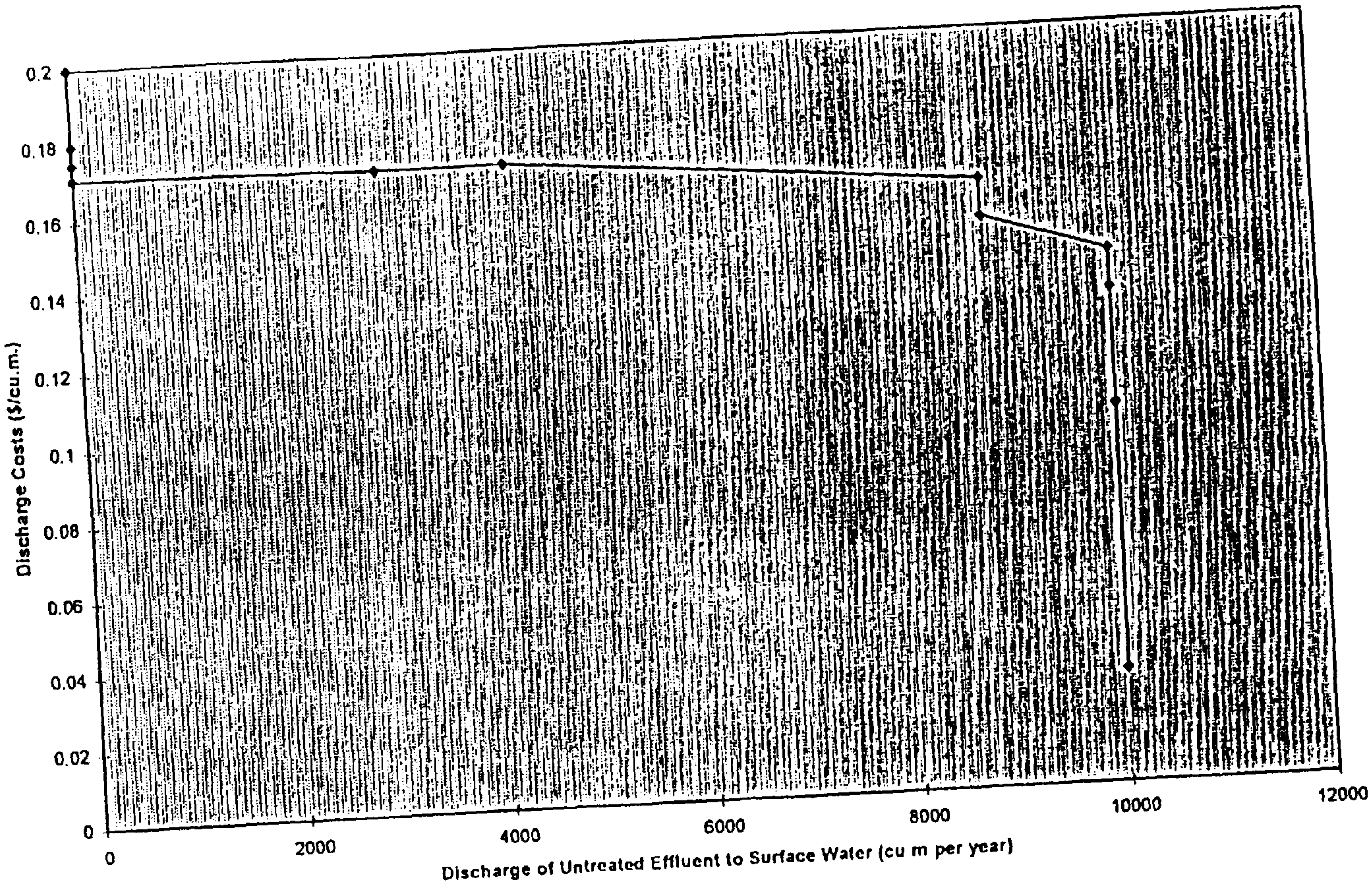
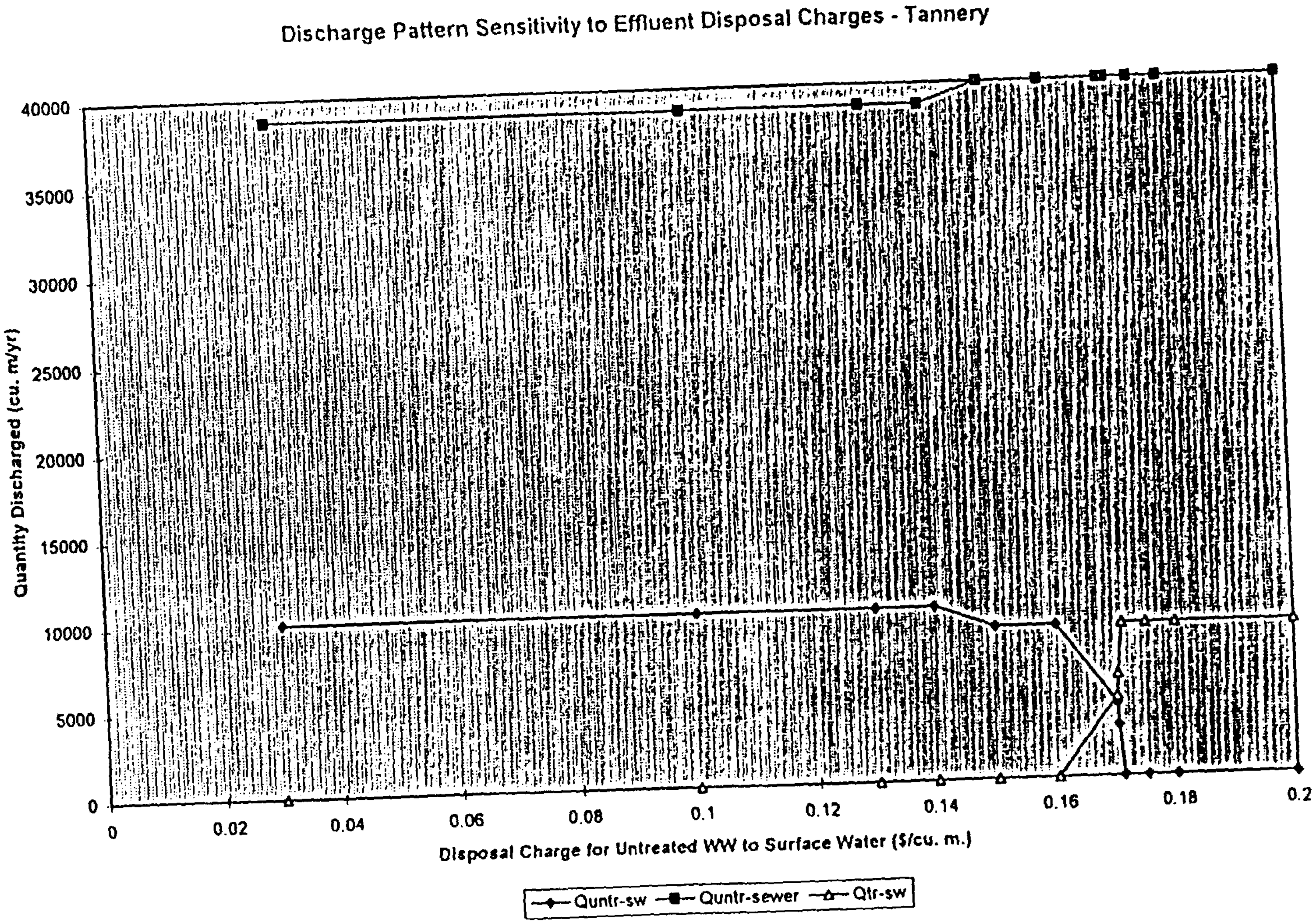


FIGURE 5-11


Discharge Pattern Sensitivity to Effluent Disposal Charges - Tannery
Quantity Discharged (cu. m/yr)
40000
35000
30000
25000
20000
15000
10000
5000
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Disposal Charge for Untreated WW to Surface Water ($/cu. m.)
Quntr-sw
Quntr-sewer
Qtr-sw

Chapter 6

Role of UNIDO

Introduction

The role that UNIDO can play in industrial water and waste water policy and management is largely determined by UNIDO's unique role in the UN family of institutions as the only agency dealing directly with industrial water problems. Other specialized agencies deal with many other aspects of water and waste management, but none has the specific industrial mandate of UNIDO. For example, UNEP deals with the environmental dimensions of water, notably water pollution and ecosystem effects, UNDP deals with the economic resource aspects of water, FAO deals with the irrigation uses of water, UNICEF and WHO deal with the health and sanitation aspects of water, and UNDESP deals with the social and economic aspects of water policy. The ILO and to a lesser extent UNESCO support capacity building, training, and educational activities in the area of water and public health. ESCAP, ECLA, ECA, ECE, and ECSCWA deal with the regional water supply and water quality issues for Asia, Latin America, Africa, Europe, and West Asia.

In the wider UN family of affiliated institutions, the World Bank and the regional development banks in Asia (ADB), Africa, and Latin America (IADB) all deal with the economic, social, resources, and environmental aspects of water from a development investment point of view. Each of them also deal with industrial development projects involving water and wastewater management. Also non-UN affiliated institutions such as the European Union (EU), the OECD, and the Organization of American States (OAS) also support major activities on environment with limited activities in water management. It also appears that NAFTA will become increasingly involved with industrial water pollution issues. The regional institution for the South Asian countries, SARC, has carefully avoided entanglement with trans-boundary water issues. On the contrary, the Southern African regional grouping, ZANU, has embraced the regional trans-boundary water issues. Finally, the CIGAR agricultural institutes around the world deal with various agricultural aspects of water use, with IIMI being specifically devoted to irrigation management issues.

During 1996 two new international institutions concerning water were created. One started by the World Bank and the UNDP is called the Global Water Partnership and is intended to coordinate all of the disparate multilateral and bilateral programs dealing with water: water and sanitation, irrigation, hydropower, navigation, and water quality. The second institution, called the Global Water Council, mainly founded by the NGOs and the consulting community will emphasize broad thinking about future scarcity issues of water. While there is a potential for overlap, both of these institutions could become important players in the global water scene.

Based upon our conversations with various staff members of the institutions, and a review of their water policy statements (for example the statement by the FAO, World Bank, and UNDP (1995), it has become clear that, while there is a tremendous concern for water in general by the international, the regional agencies, and the newly created Global Water Partnership and Council, there is no one clear voice speaking up for industrial water policy. This lacuna could be filled by UNIDO.

Of course, over the years UNIDO has been heavily involved in the industrial water sector without being overly self-conscious about it. Indeed, one of the five development objectives of UNIDO articulated in the 1994 Annual Report (UNIDO, 1995b), is Environmentally Sustainable Industrial Development. Water and water policy are one very important aspect of this and UNIDO participates in the UN's Administrative Committee on Coordination (ACC) Subcommittee on Water Resources. UNIDO will, upon request, supply industry-related data and studies to the Subcommittee's Global Freshwater Assessment Study. Out of a total 1994 technical cooperation budget of $101 million (UNIDO 1995c), only $646,000 was spent directly on Environment and Energy, but $44 million was spent on all the industrial sectors including Energy and Environment. Of a total of 71 genuinely environmental projects approved in 1993, 13 were for Montreal Protocol-related CFC phase-out programs, and the remainder were for end-of-pipe pollution abatement, environmental education, cleaner production, environmental impact assessment, and energy conservation.

Since 1990, **Cleaner Production** has been one of UNIDO's four subprograms of the environment program (see UNIDO, 1995a). The emphasis has been on process improvements which aim to reduce waste generation in order to increase the competitiveness of industry.

Cleaner production builds on process optimization by justifying process improvements on environmental as well as financial grounds. Over this time period UNIDO has assisted several large- and medium-scale enterprises in process optimization in textile dyeing, printing, and finishing in Brazil (UNIDO, 1995a). Due to the process optimization, cost reductions as high as 40% were achieved with significant reduction of water polluting effluents and a reduction in energy use. Other examples from the leather sector in Kenya and pesticide production in Poland testify to the success of this approach.

As mentioned above, UNIDO is heavily involved in promoting **Environmentally Sustainable Industrial Development** (ESID) and is working with a number of countries to develop strategies to overcome the effects of inefficiencies induced by subsidies , incorrect pricing, and preferences for traditional end-of-pipe pollution control technologies. UNIDO is cooperating with UNEP and the World Bank in the preparation of guidelines for the preparation of guidelines for pollution prevention and abatement in more than 50 industrial sectors. Recognizing the need for well trained, equipped and informed public and private sector institutions, UNIDO is providing institutional support to governmental and non-governmental organizations to push cleaner production. One method of doing this is to set-up National Cleaner Production Centers (NCPC) in 20 countries over the next five-year period in collaboration with UNEP. These NCPCs will play a catalytic role in cleaner production by providing technical information and advice, stimulating the demonstration of cleaner production techniques and technologies, and training industry and government professionals.

UNIDO has already instituted successful programs in Sri Lanka (Central Environment Authority), Egypt (Suez Cement Company), and India (National Productivity Council) dealing with aspects of cleaner production. In India, UNIDO has supported demonstration projects in the three sectors of agro-based pulp and paper, pesticide formulation, and textile dyeing and finishing. The 12 participating industries implemented 210 options costing $300,000 which resulted in monetary savings of $3 million. A handsome return, generally within a six-month period. The details of this program called DESIRE (Demonstrations with Small Industries of Reductions in Emissions and Wastes) are given by van Berkel et al., (1995).

Brynolf and Murawski (1990) report on a typical regional technical assistance project specifically in the area of purification of industrial wastewater. The agro-industries; abattoirs, breweries, sugar refineries, tanneries, and textiles in seven African countries (Botswana, Ethiopia, Lesotho, Uganda, Tanzania, Zambia, and Zimbabwe) were studied from the point of view of plant-level and policy-level improvements. The recommendations of the technical assistance ranged widely over specific plant improvement recommendations and broad prescriptions for government policy and interventions. Buljan (1993) reports on a specific industry-focused study of the leather sector across many countries. The report gives the technical options and their costs for many different cases based upon specific plants in Kenya, Costa Rica, Mozambique, Pakistan, India, and Tunisia.

Future Roles for UNIDO

The future possible roles for UNIDO in Industrial Water Policy and Management will be based upon its historical role and the emergent issues associated with the current concerns associated with sustainable development. We envisage the five major areas for UNIDO involvement outlined below.

Role in Water Supply

- Supply Infrastructure

In the past UNIDO has been involved in technical advising on the details of water supply infrastructure. This technical help has ranged from advice to demonstration projects. For example, in Iran UNIDO provided help with work on pipe size standardisation. Other areas on the supply side that merit consideration are the reduction of transmission losses and providing advice on leak detection. Technical support for industrial process treatment planning, design, and implementation including manufacturing support would be helpful. Desalination is an area where industrial involvement is absolutely required and is an area of supply management that affects both the supply of water but requires a great deal of technical expertise for both the economic and engineering analysis. For example, a recent paper by Lennox and Stauffer (1995) lays out the factors that make the decision to choose desalination as a supply option so complex. They demonstrate that, depending upon the assumptions made for a specific case, the costs can range from $2 to $6 per 1000 gallons; a range that makes the water supply possible or totally out of reach for most consumers.

Role in Water Demand

- Conservation/Recycling Measures

UNIDO has past experience in a wide variety of manufacturing and other industries. As mentioned above, the experiences with process optimisation and cleaner production demonstrations in India and other countries have been very successful and point to a wider involvement in these activities. More training, software development, and demonstrations are needed. Simple technical assistance programs to identify recycling/conservation options for various industries would by themselves be very instrumental in demonstrating to industries (and governments) the benefits of recycling. Action research could be supported in the area of closed-loop systems - in pulp and paper industries and water cooling. The development and encouragement of industry-wide recycling services (ex-plant rather than in-plant) looks like a very fruitful area. This ex-plant development should emphasise the revenue aspects for industry groups and non-governmental agencies. Policy advice to governments, particularly local governments, would help promote these developments.

Role in Water Quality

- Wastewater Management

In addition to the conventional concerns with wastewater management, emphasis should be placed upon cleaner production or pollution prevention. Materials recovery facilities - e.g. chromium in leather industry, waste exchanges, and waste clearing houses will help reduce the total loads of toxic chemicals in the environment and speed the rate of clean-up. Other areas deserving of attention are the design of appropriate wastewater treatment plants, the identification of costless options and "win-win" situations, the development of combined wastewater treatment for a groups of small industries, and the reuse of "wastes" by other industries.

Role in the Comprehensive Management of Water

Monitoring

In the area of monitoring UNIDO should encourage monitoring to assess transmission losses, industrial water use (and change over time), effluent quality and loading of different pollutants. These will be required for all policy assessment. In addition, the sequence of training, equipment supply, self-monitoring, and regulatory monitoring needs to be fully integrated into the plans.

Setting Standards

There is a clear role for UNIDO in helping countries set standards for each industry type keeping in mind location, receiving water body, plausible treatment options, effect on industry, expected compliance, etc. Also the type of standard - e.g. concentration, loading, performance, are items that have great importance in determining outcomes. UNIDO could also play an important role in providing international validation for the local water quality standards.

Case Studies

In order to convince government and industry to change the ways of doing business, it is essential to generate sets of case studies showing the options available and their likely consequences before any agreements are reached between government and industry.

Policy advising

There is also opportunity for UNIDO to become involved in regional industrial water policy advice. This may include helping to advise on regulations and tariffs (of both water use and wastewater generation) to effect desired behavior.

It is also clear that in the near future, there will be a lot of international attention focused on solving regional water problems by getting stakeholders together in river basins to help determine fair and efficient allocation of scarce water resources. This presents a role for UNIDO as the industrial representative in meetings with other international organizations representing other water users, or with national or regional agencies.

There may also be a role in helping the creation and operation of water and waste markets in appropriate places at the required time.

A totally new area could be that of "eco-labeling." It is common for manufacturers or some NGOs to make "eco-labels" that reflect the relative achievement and sometimes, resource use in manufacture of the product in an effort to influence consumer behavior. It is possible to dis-aggregate existing labels or to create new ones to reflect the water use efficiency in the production of the final product. This is an area for UNIDO technical expertise.

Clearing House for Technology

Perhaps the most important role that UNIDO can fill is to act as a central clearing house for information on different aspects of industrial water use. This would include any new technology that would enhance conservation and recycling options in various types of industries, reviews of past experience in technology policies, results of demonstration programs, consultants rosters, and costs (capital versus operation and maintenance versus replacement). This would involve substantial collaboration with the private sector.

Training Programs (Capacity Building)

UNIDO has a long history of successful capacity building via a variety of different training programs. These programs will need expanding with more emphasis being placed upon the software of pricing, incentives, regional and inter-sectoral dimensions, and the role of stakeholders, rather than simply on the technology side.

Chapter 7

Conclusions and Recommendations

Introduction

The lion's share of the industrial water use is accounted for by developed countries. And fragmentary evidence indicates that the amounts used are declining significantly in those countries. The evidence would indicate that a much more rapid increase in industrial water use is taking place in the developing countries. This change is an important component of the current concern with a "water crisis." Most developing countries have a strong agricultural infrastructure that already demands the major share of their water resources and has, in many cases essentially pre-empted any other water use increasing beyond its current level. As the industrial needs grow rapidly (it is these nations that are experiencing more rapid industrial and economic growth than the stagnating, or declining, industrial growth rates in the developed world), so does the need for additional supplies of water. Along with potentially huge quantities of water required for industrial growth (and municipal growth), there is a concern about the environmental impacts, in terms of the pollution generated. Due to either lax environmental regulations or more often than not, lax enforcement, many industries in the developing world pollute unchecked, turning once pristine rivers into industrial sewers.

The developed countries appear to be experiencing a different trend. The trend in industrial water use in the developed countries seems to follow the controversial Kuznet's curve kind of inverted U curve logic (World Bank, 1992). It is certainly true that specific industrial water use (water use per unit product) is decreasing in many developed countries. This is due to both active and passive conservation as described in this report. Fig 7.1 shows the trends in total water use in the manufacturing sector in the U.S. We see a curve that does indeed resemble some kind of inverted-U shape, suggesting that the total water use increases with rapidly expanding industrialization, and later decreases owing to increases in efficiency due to perceived resource scarcities. However, there is little econometric basis for this and we need more (and recent) data to further examine this kind of conjecture, to ascertain, if it is happening in the developed countries, where and when will it occur in the developing countries..

Why Does Industry Need Water? What Does it Use it for?

If we examine the total water use in a few industries in terms of the specific use that the water is put to, we find that a substantial portion of the water (from 30% in the sugar industry to 91% in industrial organic chemical manufacture in the U.S.) is used not for the actual industrial processes, but for substantially non-consumptive uses such as non-contact cooling. This is encouraging, because under appropriate regulations or incentives, it is possible in many cases to have closed-cycle systems for cooling. The remainder of the water is usually used for process-related items, that are very sensitive to the process technologies employed. The major industries that use a lot of water are pulp and paper and petro-chemical industries, and, to a lesser extent, fertilizer, sugar and the iron and steel industries.

An examination of the water use in selected industries reveals that there are orders of magnitude variation in the amount of water required for a unit quantity of different products. Water consumption varies widely within the same kind of industry. For example, Appendix 1 shows the water use in the sugar beet industry worldwide and we see that the specific water use in cubic meters per ton varies from about 2 in Israel to eight times that in the U.K. or Finland. Thus, speaking in general terms of a change in water use based upon averages may be very misleading in specific cases.

We note in Appendix 1 that a lot of water is recycled by industry; (defined as a share of the gross water use contributed by recycled water). The actual consumptive use in industry is small. Most of the water is either recycled or discharged as wastewater. Much of the water discharged does have the potential to be recycled, and is increasingly being used as such for additional supplies where water is scarce, as in Israel. However, due to the often poor water quality of the effluent from water used in contact processes, it is easier to recycle domestic sewage than industrial water. If we examine the average and maximum recycling rates, we see that there are efficient industries such as synthetic rubber and petroleum refineries, but there are industries such as cane sugar that show a lot of demonstrated potential possible improvement.

Backstopping Technology

In any area of resource development there exists a backstopping technology. For energy resources it is solar energy. For water resources the backstop technology is desalination.

Desalianation, like all backstopping technologies (technologies of last resort) is the most expensive technology to produce water. It is often touted as one of the most impressive examples of the triumph of man's innovation over nature's adversity. However, it is often used as an excuse for the lack of rational water management. More often than not, the costs of desalination cannot be justified by the additional benefits it provides - it is often more efficient to undertake simple demand management steps; however, the latter is often not politically acceptable.

Desalination is limited spatially given the requirements for seawater or brackish water and cheap energy. Traditional desalination technologies include the multi-stage flash process and the reverse osmosis process, that together account for about 86% of the 13 million cubic meters of desalinated water produced every year. However, given recent claimed cost-cutting innovations in the desalinization process (see article by Dabbagh et al., in Rogers and Lydon, 1994), it may turn out that desalination may be a serious supply option for industries in arid regions of the world. Certainly, if desalination is economically viable anywhere in any economy, it will be for industrial water use because industrial water users are typically willing to pay several times the amount that agriculturists and urban dwellers are willing to pay.

Regulation and Economic Instruments

The problems of industrial water management are often fairly obvious ones; lack of effective regulations, enforcement, and appropriate incentives on the part of government and a lack of management skills on the part of industry. The primary problem is that few countries have any instruments (regulations, economic incentives, and disincentives) to regulate and enforce water use and wastewater disposal. In addition, water has traditionally been considered a common property good and as a result the full price of water is seldom charged to consumers. Even where tariffs are charged, they are usually based upon average costs and also ignore the opportunity costs of water or the real costs of the externalities of wastewater disposal. These factor have led industries to use water inefficiently. Industries have not needed to employ conservation and recycling measures as water has been so inexpensive. Recently, increasing concerns over increasing water scarcity and environmental concerns, and the competition among the users for the scarce resources has led to the consideration of more rational water management strategies. This has led, as discussed in Chapter 3 to more rational and innovative approaches being implemented. The data presented in Chapter 3 hint at the possibility of large scale economizing in industrial water use.

In Chapter 3 we discussed the various non-economic command and control policies and contrasted them with the economic instruments available to influence industrial water policy. In Table 3.1 we gave a comprehensive listing of all of the possible instruments that may be used to influence industrial water policy. In order to asses how much these different economic and non-economic policies may influence industrial water use decisions we have devised a set of simple policy simulators in Chapter 5. These simulators, or Decision Support Models, can simulate the effects of operating an industrial plant under the control of these instruments and assessing their economic and environmental impacts. For instance, they can be used to equilibrate economic and non-economic instruments—how much would have to be charged as an effluent fee to induce the same environmental behavior as a strict command and control embargo on discharge of pollutants?

Basic economics tells us about the demand curves for water and wastewater discharge, but there a few empirical studies that will actually provide us with the actual elasticities. This is the situation where a clever optimizing model should be able to create plausible synthetic demand curves.

Policy Options

How much do these policy options change the water demanded and wastewater disposed of by industries? It is not an easy task to determine the effect of non-economic policies on industrial water management strategies. This is because it is rare that only one control policy change in isolation can be observed. It is also difficult to exactly determine how much a change in water prices would affect the water demanded in industry. Basic economics tells us that a rise in water tariffs would lead to a drop in the water demanded - exactly how much depends on the price elasticity of demand of industrial water. These elasticities are notoriously difficult to determine empirically as it is difficult to control for other variables even in the rare cases when industrial prices have been raised enough to actually make an impact. The effect of policy options is usually obtained by the various case studies involving the examination of the response of nations, regions, industry types and individual firms to changes in one or a set of water policies. Such analyses at least indicate the kinds of policies that have been successful in the past and the industries or regions that appear to be most responsive to policy changes. This kind of information is necessary before any kind of efficient water policy portfolio can be drafted for the various industries in different spatial regions.

The models in Chapter 5 provide mechanisms for gaining insight into specific problems and to the generic problems of industrial water and wastewater management. As mentioned above, there are many different policy options that can be explored with these models. This chapter presents the design of such a model and its use and the outcomes of sensitivity studies based upon this model. What the models show is that one can arrive at the desired outcome (from a local government's part) by either a strict regulatory or a pricing approach. The choice of which to take would be conditioned upon an understanding of the local situation and an assessment of which approach would in reality be more cost effective. Such models are powerful tools for the integration of economic and technological choices in determining optimal mixes of "hardware" and "software" options and identifying "win-win" situations for the various stakeholders.

Simulation of Policy Impacts

The report discusses the various non-economic command and control policies and contrasted them with the economic instruments available to influence industrial water policy. In order to asses how much these different economic and non-economic policies may influence industrial water use decisions we have devised a set of simple policy simulators. These simulators, or Decision Support Models, can simulate the effects of operating an industrial plant under the control of these instruments and assessing their economic and environmental impacts. For instance, they can be used to equilibrate economic and non-economic instruments--how much would have to be charged as an effluent fee to induce the same environmental behavior as a strict command and control embargo on discharge of pollutants?

The simulation models provide mechanisms for gaining insight into specific problems and to the generic problems of industrial water and wastewater management. As mentioned above, there are many different policy options that can be explored with these models. What the models show is that one can arrive at the desired outcome (from a local government's part) by either a strict regulatory or a pricing approach. The choice of which to take would be conditioned upon an understanding of the local situation and an assessment of which approach would in reality be more cost effective. Such models are powerful tools for the integration of economic and technological choices in determining optimal mixes of hardware and software options and identifying win-win situations for the various stakeholders.

Just a few of these options have been analyzed here. We have developed models to analyze options for two cases - a tannery and a paper and pulp industry. The base case for a small tannery was an essentially unregulated situation and it led to a minimum cost of $36,256 per year. We compared this to regulatory approaches on the same problem. The first comparison is with the classical command and control approach, where untreated effluents were limited to about 50% of the base case. This led to an increase in the optimal minimum cost for the tannery of $46,397. When the untreated effluents were completely banned the cost rose to $47,327. The model shows that it is possible to achieve a similar environmental outcome (in terms of water quality) more efficiently using the economic tool of effluent pricing. An effluent fee of $0.35 per m3 for untreated discharge and $0.10 for treated discharges leads to a cheaper solution ($44,035) with similar environmental benefits.

For the paper and pulp mill (30,000 tons of product per year). A minimally regulated base case cost $68,616 per year. We examined the effects of technical advances in conservation technology on the water use and effluent discharge patterns of the industry. We found that with technological advance, industries could save about one third of their expenditure on water and wastewater management. Furthermore, we also found the provision of subsidies by the regulatory authority to encourage the use of advanced technology led to the adoption of conservation technologies by industries, and hence, lower water consumption and better effluent quality at a lower cost to the industry.

Many sensitivity calculations can be made, each shedding new light on the basic problem. For example, when we performed the sensitivity in the range of surface water treatment costs from $0.01/m3 to $0.15/m3, we observed that the use of treated surface water fell sharply with the rising price from about 44,500 m3/yr. that was near the maximum allowable to about 8,500 m3/yr., after which the system ran out of substitution possibilities in our scenario. The surface water was substituted primarily by a rise in the use of untreated municipal water and treated. There was also an increase in the use of internally recycled water, although the proportion re-treated fell.

The important point here is that by performing such a sensitivity analysis, we were able to derive a demand curve for treated surface water. From this curve, it is possible to determine the price elasticity of demand for that particular commodity - treated surface water. In this case, the elasticity works out to be about -2.58. This high elasticity can be attributed to the high degree of substitutability that that is possible . Note that cross-elasticities (e.g. effect of raising the cost of treated surface water supply on the demand for treated groundwater, ceteris paribus) can also be derived by using the results of sensitivity analysis. It is important to note that the elasticity is a function of the technical options and regulatory parameters specified in the system, and an accurate computation of the elasticity is dependent upon developing realistic options in the scenarios considered.

If we now wish to observe the effect of raising the effluent charge for disposing of one kind of effluent - untreated wastewater, we can do so by repeatedly running the model while performing a sensitivity on that parameter. For the tannery case, we see that the discharge pattern is insensitive for charges up to $0.14/m3, but after that, there is a gradual decrease in the quantity of untreated sewage to surface waters up to a charge of $0.16/m3, after which there is a sharp drop to achieving zero-discharge of untreated wastewater into surface waters. This is achieved by a slight switch to disposing of this sewage into the sewers at a higher cost, until that option is exhausted, after which the effluent is treated and thereupon discharged to the surface waters.

Similar to a demand curve derived above, we can derive an effluent discharge curve that displays the discharged quantity as a function of the cost of disposal. It is also possible to calculate a price elasticity of effluent generation, although they have to be interpreted in the appropriate ranges. Such an analysis would also help decision-makers set appropriate effluent charges by determining the ranges in which the effluent discharge patterns would be insensitive or determining the threshold fees after which the desired effects can be observed.

The analytical approaches used demonstrate the power of simple programming models to enhance decision making both at the level of the industry and of regulators. The intention of the model was to illustrate its use in a couple of case studies. It is possible to make such models much more complex to increase their capabilities. For example, the model could be made seasonal or monthly to include temporal aspects (stochasticity could also be handled using stochastic or fuzzy optimization models and follow-up simulation modeling); process change options could be more explicitly defined; water quality parameters could be more disaggregated to handle specific process standards and to better handle environmental externalities; the production level could become a variable, opening up the path to maximizing net benefits instead of minimizing costs to produce a certain quantity of product; the industry could be considered as part of a larger system to illustrate some of the principles of river basin planning, industrial ecology; integrated supply-side and demand-side management; more integrated surface water and groundwater conjunctive use including recharge from effluents; inter-sectoral issues; the examination of various economic and regulatory instruments (command and control, bubbles, offsets, tradable permits, etc.), comprehensive analysis of pollution to various media, consideration of multiple objectives, game-theoretic analyses from the point of view of various stakeholders, etc.; the possibilities are only limited by the imagination. However, another computational limitation could be the software and hardware capabilities, although this is far less so that even in the recent past.

The current model itself represents a major step in the right direction towards analyzing the complex issues in water management in industry. Tools such as these tend to be a good forum for collecting and organizing data, assessing options, thinking rationally, clarifying objectives, identifying which constraints are flexible and which are inflexible, developing scenarios for the future, integrating the views of various stakeholders, identifying negotiating positions, determining tradeoffs between various objectives, analyzing when objectives are in conflict and which issues are not worth disputing about, developing effective policy mixes and response strategies, identifying areas of incomplete knowledge and research, etc. They make the best use of the available data and are an important step in integrating economics with technological options.

Future Considerations for UNIDO

The role that UNIDO can play in industrial water and waste water policy and management is largely determined by UNIDO's unique role in the UN family of institutions as the only agency dealing directly with industrial water problems. Other specialized agencies deal with many other aspects of water and waste management, but none has the specific industrial mandate of UNIDO. For example, UNEP deals with the environmental dimensions of water, notably water pollution and ecosystem effects, UNDP deals with the economic resource aspects of water, FAO deals with the irrigation uses of water, UNICEF and WHO deal with the health and sanitation aspects of water, and UNDESP deals with the social and economic aspects of water policy. The ILO and to a lesser extent UNESCO support capacity building, training, and educational activities in the area of water and public health. ESCAP, ECLA, ECA, ECE, and ECSCWA deal with the regional water supply and water quality issues for Asia, Latin America, Africa, Europe, and West Asia.

In the wider UN family of affiliated institutions, the World Bank and the regional development banks in Asia (ADB), Africa, and Latin America (IADB) all deal with the economic, social, resources, and environmental aspects of water from a development investment point of view. Each of them also deal with industrial development projects involving water and wastewater management. Also non-UN affiliated institutions such as the European Union (EU), the OECD, and the Organization of American States (OAS) also support major activities on environment with limited activities in water management. It also appears that NAFTA will become increasingly involved with industrial water pollution issues. The regional institution for the South Asian countries, SARC, has carefully avoided entanglement with trans-boundary water issues. On the contrary, the Southern African regional grouping, ZANU, has embraced the regional trans-boundary water issues. Finally, the CIGAR agricultural institutes around the world deal with various agricultural aspects of water use, with IIMI being specifically devoted to irrigation management issues.

We recommend that there are several areas that UNIDO should explore for institutional involvement and for expansion of existing concerns. These are discussed in the following sections outlined below.

Role in the Comprehensive Management of Water

As discussed in the previous chapter, UNIDO could play a unique role in a number of aspects dealing with water use in industry. These include roles in examining:

Industrial Water Supply
Industrial Water Demand
Water Quality
Other Supportive Roles

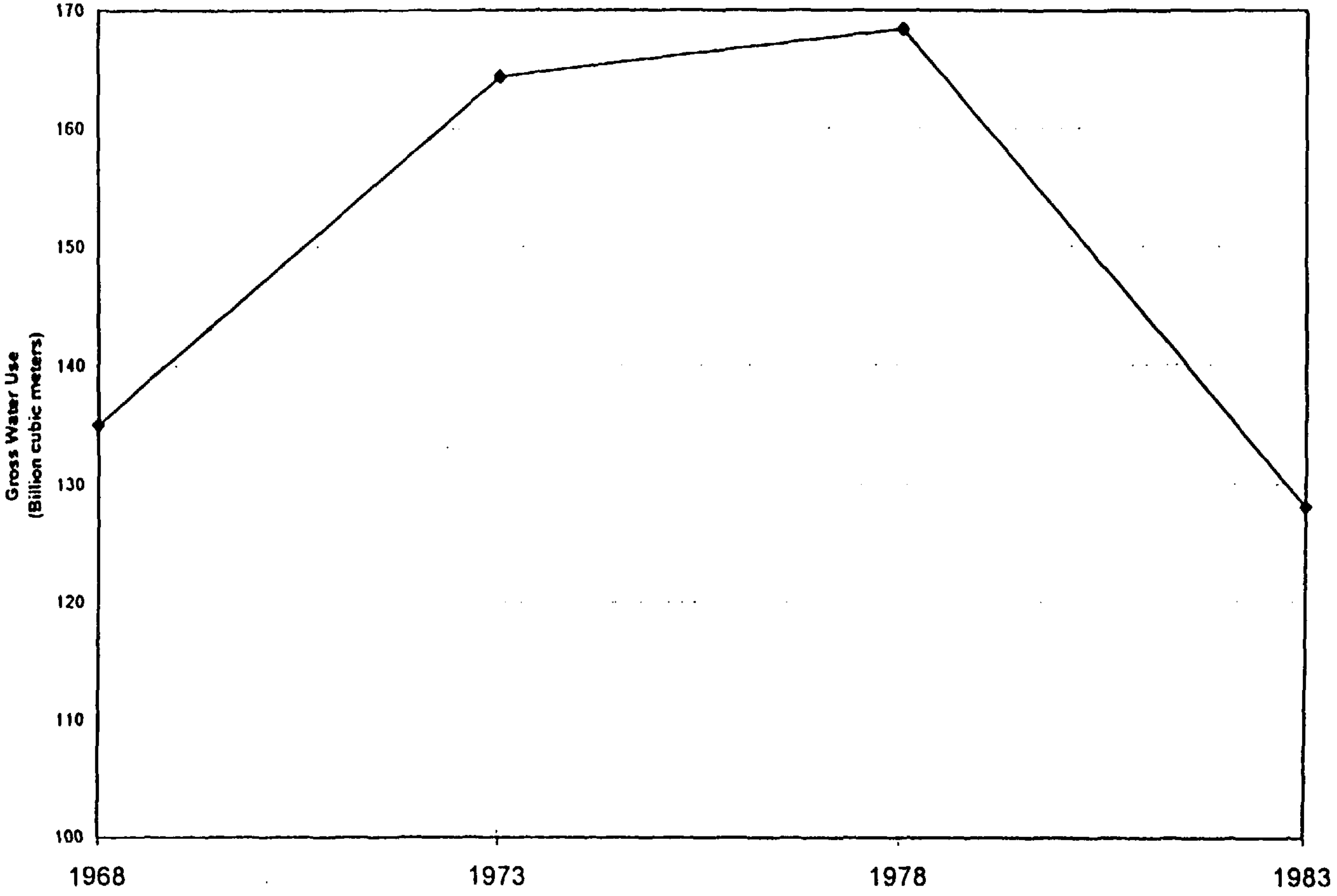
- Monitoring
- Loss Reduction
- Setting Standards
- Training Programs (Capacity Building)
- Case Studies

- Policy advising
- International Water Conflicts
- Creation of Water and Waste Markets
- Eco-Labeling
- Clearing House for Technology

The nexus between water and industry is an area that not much attention is paid to; however, proper planning and flexibility in terms of the regulatory and industrial response structure can prevent this from becoming a crisis situation. There are enough options both for regulators and industry to adequately address concerns arising from industrial water use and effluent disposal. Nevertheless, it is necessary to analyze these options systematically in a technical and economic framework to achieve the right mix of quantitative and economic regulations for the regulators and the right mix of technical choices for the industry that would meet the regulations and any other objectives of the industry at the lowest cost. UNIDO could play an important role in helping regulators and industries to have access to information to perform such analyses through its extensive experience, current programs and future objectives.

FIGURE 7-1

Trends in Water Use in Manufacturing (US)



BIBLIOGRAPHY

Beard, L.R. and W.H.C. Maxwell (Ed.), *Water Resources Management in Industrial Areas*, Selected Papers from the International Symposium, 7-11 September 1981, Lisbon, Portugal, International Water Resources Association (IWRA), Tycooly International, 1982.

Bhatia, R. and M. Falkenmark, *Water Resource Policies and the Urban Poor: Innovative Approaches and Policy Imperatives*, Water and Sanitation Currents, UNDP-World Bank Water and Sanitation Program, The World Bank, 1993.

Bhatia, R., R. Cestti, and J. Winpenny, *Water Conservation and Reallocation: Best Practice Cases in Improving Economic Efficiency and Environmental Quality,* Water and Sanitation Currents, UNDP-World Bank Water and Sanitation Program, The World Bank, 1995.

Bhatia, R., P. Rogers, J. Briscoe, B. Sinha, and R. Cestti, *Water Conservation and Pollution Control in Indian Industries: How to use water tariffs, pollution charges and fiscal incentives*, Water and Sanitation Currents, UNDP-World Bank Water and Sanitation Program, The World Bank, 1994.

Brynolf, L.V., and T. Murawski, *Programme on Purification of Industrial Waste Water*, UNIDO, ID/WG.507/9(SPEC.),Regional Meeting on Management of Industrial Water, Paris, France, 10-14 December, 1990.

Buljan, Jakov., *Technical Assistance in Management of Leather Industry Waste*, UNIDO, presented at the XXV National Tanning Symposium, Acapulco, Mexico, 27-31 October, 1993.

Carmichael, J.B. and K.M. Strzepek, *Industrial Water Use and Treatment Practices*, Cassell Tycooly, 1987.

ChemInform, *Identification and Brief Description of the Emissions (Water, Air and Wastes) from the different sectors of the Organic Chemical Industry*, Prepared for the Commission of the European Communities, 1992.

COWIconsult, *The Technical and Economic Aspects of Measures to Reduce Water Pollution caused by the Discharges from the Pulp and Paper Industry*, Prepared for the EEC, 1989.

Dale, L.L., and J.A. Dixon, *Economic Efficiency and the Choice of Water allocation Techniques*, North China Water Project, East-West Center, Honolulu, 1986.

Dasgupta, S., M Huq, D. Wheeler, and C. Zhang, *Water Pollution Abatement by Chinese Industry*, Policy Research Working Paper No. 1630, The World Bank, Policy Research Department, August 1996.

Eckenfelder, W.W., *Industrial Water Pollution Control*, Second Edition, McGraw-Hill Book Company, 1989.

Elliot, R. *Economic Study of the Effect of Municipal Sewer Surcharges on Industrial Wastes and Water Usage*, Water Resources Research, 9,5, pp.1121-1131, October 1973.

Falkenmark, M., *Natural Resource Limits to population Growth: The Water Perspective*, IUCN, Gland, Switzerland, 1989.

FAO, *Water Sector Policy Review and Strategy Formulation: A General Framework*, World Bank, UNDP and FAO Study, FAO Land and Water Bulletin 3, FAO, 1995.

Fredrick, K.D., *Scarce Water and Institutional Change*, Resources for the Future, Inc., Washington, D.C., 1986.

Frosch, R.A., *Industrial Ecology: Adapting Technology for a Sustainable World*, Environment, Vol. 37, No. 10, December 1995.

Gabbay, S. (Ed.), *The Environment in Israel, National Report to the United Nations Conference on Environment and Development*, State of Israel Ministry of Environment, 1992.

Gibbons, D.C., *The Economic Value of Water*, Resources for the Future, Inc., Washington, D.C., 1986.

Gleick, P.H., *Water in Crisis: A Guide to the World's Fresh Water Resources*, Oxford University Press, 1993.

Gupta, D.B., M. Murty, and R. Pandey, *Water Conservation and pollution Abatement in Indian Industries*, National Institute for Public Finance and Policy, New Delhi, India, April 1991.

Harshadeep, N., *Comprehensive Multi-Objective River Basin Planning: Fuzzy and Game-Theoretic Approaches*, PhD. thesis Harvard University, 1995.

Haskoning,. O., *Technical and Economic Study on the Reduction, Based on Best Available Technology, of Industrial Emissions from the Pulp Industry*, Prepared for the European Commission, 1992.

Hettige, H., et al., *The Industrial Pollution Projection System*, Policy Research Working Paper No, 1431, Policy Research Department, World Bank, Washington, D.C., March 1995.

Huang, C.P. (Ed.), *Industrial Waste: Proceedings of the Thirteenth Mid-Atlantic Conference*, Ann Arbor Science, 1981.

Hudson, J.F., E.E. Lake and D.S. Grossman, *Pollution-Pricing*, Lexington Books, 1981.

Kneese A.V., R.U. Ayres, and R.C. D'arge, *Economics and the Environment: A Materials Balance Approach*, Johns Hopkins Press, 19XXX.

Laplante, B., and P. Rilstone, *Environmental Inspections and Emissions of the Pulp and Paper Industry: The Case of Quebec*, policy research Working paper, No. 1447, policy research Department, World Bank, Washington, D.C., April 1995.

Lee, K.S., and A.Anas, *Impacts of Infrastructure Deficiencies on Nigerian Manufacturing: Private Alternatives and Policy Options*, World Bank Publication, December 1990.

Le Moigne, G., K.W. Easter, W.J. Ochs and S.Giltner, *Water Policy and Water Markets*, World Bank Technical Paper 249, The World Bank, 1992.

Leone, R.A., J.R. Ginn, and A. Lin, *Changing water Use in Selected Maunfacturing Industries*, National Bureau of Economic Research, Washigton, D.C., October 1974.

L'vovich, M.I., *World Water Resources and Their Future*, Trans. by the American Geophysical Society, Ed. R.L. Nace, American Geophysical Society, Washington, D.C., 1979.

Martin, W.E., H.M. Ingram, N.K. Laney and A.H. Griffin, *Saving Water in a Desert City*, Resources for the Future, Inc., Washington, D.C., 1984.

Manu, Y., *Back-to-Office Report*, World Bank Internal Paper, Washington, D.C., 1991.

Meadows, D.H., *The Limits to Growth*, Universe Books, New York, 1972.

Metaplanners and Management Consultants, *A Report on water policies for Metropolitan Areas: A Case Study in Jamshedpur*, Patna, India, 1992.

National Association of Manufacturers and the Chamber of Commerce of the United States, *Water in Industry*, in cooperation with the National Technical Task Committee on Industrial Wastes, 1965.

Nemerow, N.L., *Industrial Water Pollution: Origins, Characteristics, and Treatment*, Addison- Wesley, 1978.

Nemerow, N.L. and A. Dasgupta, *Industrial and Hazardous Waste Treatment*, Van Nostrand Reinhold, 1991.

O'Connor, D., *Applying Economic Instruments in Developing Countries: From Theory to Implementation*, OECD Development Centre, Paris, France, May 1996a.

O'Connor, D., *A Note on Economic Instruments for Industrial Wastewater Management in Thailand's Fish Canning, Leather Tanning, and Palm Oil Industries*, OECD Development Centre, Paris, France, April 1996b.

Panadiker, D.H.P., *Pollution Control in Indian Industry*, B.R. Publishing Corporation, 1991.

Rees, J.A., *Industrial Demand for Water: A Study of South East England*, London School of Economics and Political Science, 1969.

Rogers, P., *Comprehensive Water Resources Management: A Concept Paper*, Policy Research Working Papers, WPS 879, The World Bank, 1992.

Rogers, P., *Water: The Economic and Financial Context*, Presented at a Regional Consultation Meeting, *Towards a Policy for Water Resources Development and Management in the Asian and Pacific Region*, The Asian Development Bank, Manila, 10-14 May, 1996.

Rogers, P. and P. Lydon (Eds.), *Water in the Arab World: Perspectives and Prognoses*, Harvard University Press, 1994.

Sims, W.A., *The Welfare Loss of an Input Distortion: The Case of Sewer Effluent Charges*, Land economics, 55,3, pp. 379-387, August 1979.

Strzepek, K.M., and O.P. Bowling, *Global Assessment of the Use of Freshwater Resources for Industrial and Commercial Purposes*, A Study for the United Nations Industrial Development Organization, Vienna, Austria, September 1995.

Teerink, J.R. and M. Nakashima, *Water Allocation, Rights and Pricing: Examples from Japan and the United States*, World Bank Technical Paper 198, The World Bank, 1993.

Tietenberg, T., *Environmental and Natural Resource Economics*, Fourth Edition, Harper Collins Publishers, 1992.

United Nations, *State of the Environment in Asia and the Pacific 1990*, United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand, 1992.

UNEP and UNIDO, *Audit and Reduction Manual for Industrial Emissions and Wastes*, Technical Report Series 7, 1991.

UNIDO 1993a, *Industrial Pollution Management*, Project Document, NEP/91/029/a/01/99, July, 7, 1993.

UNIDO 1993b, *Industrial Pollution Reduction Programme in Sri Lanka*, Project Document, DG/SRL/91/019/A/01/99, February 1, 1993.

UNIDO 1995a, *UNIDO Activities in the Field of Cleaner Production*, Energy and Environment Branch, Industrial Sectors and Environment Division, March 1995.

UNIDO 1995b, *Annual Report of UNIDO, 1994*, Industrial Development Board, Programme and Budget Committee, 15 March, 1995.

UNIDO 1995c, Report by the Director General, *Annual Report of UNIDO, 1994: Interim Programme Performance Report for the Biennium 1994-95*, Industrial Development Board, Programme and Budget Committee, 24-28 April, 1995.

UNIDO 1995d, *Environmental Policies and Industrial Competitiveness: Are They Compatible?*, Global Forum on Industry: Perspectives for 2000 and Beyond, Prepared by the UNIDO Secretariat, New Delhi, India, 16-8 October, 1995.

USEPA, News Release, *Trading Water Pollution Permits*, January 1996.

USEPA, *Profile of the Pulp and Paper Industry*, EPA Office of Compliance, Sector Notebook Project, EPA 310-R-95-015 September 1995.

USEPA, *Toxic Release Inventory 1987-1992*, CD-ROM User's Manual, EPA 749-R-94-003, December 1994.

van Berkel, R., S.P. Chandak, P. Sethi, and R Luken., *From Waste to Profits: Towards Financial and Environmental Dividends from Waste Minimization in Small Industries in India*, Final Report of Project Desire (**DE**monstrations in **S**mall **I**ndustries for **R**educing Wast**E**), IVAM Environmental Research, University of Amsterdam, October 26, 1995.

van der Leeden, F., F.L. Troise, and D.K. Todd, *The Water Encyclopedia*, Second Edition, Lewis Publishers, 1990.

Williams, M., and b. Suh, *The Demand for Urban Water by Consumer Class*, Applied Economics, 18, pp. 1275-89, 1986.

World Bank, *World Development Report 1992: Development and the Environment*, Oxford University Press, 1992.

World Resources Institute, *World Resources 1994-95*: A Guide to the Global Environment, Oxford University Press, 1995.

Xie, M., U. Kuffner, and G. Le Moigne, *Using Water Efficiently: Technological Options*, World Bank Technical Paper 205, 1993.

Ziegler, J.A., and S.E. Bell, *Estimating the Demand for Intake Water by Self-Supplied Firms*, Water Resources Research, 20, 1, pp. 4-8, 1984.

Appendix A

Compendium of Industrial Water Data

Global industrial water use is rising both in the developed world and in developing countries. It is obvious that the lion's share of the water withdrawal is accounted for by developed countries (see Figure A-1). This, of course, in no way implies that developing countries do not have to worry about industrial water use. Most developing countries have a strong agricultural infrastructure that demands a major share of their water withdrawal. However, their industrial needs are growing as it is these nations that are experiencing rapid economic growth. Along with potentially huge quantities of water required for industrial growth, there is a concern about its environmental impacts, in terms of the pollution generated. Due to either lax environmental regulations or more often than not, lax enforcement, many industries in the developing world pollute unchecked, turning once pristine rivers into industrial sewers. This is true in many industrializing cities world-wide - from Shanghai to Madras.

The trend in developed countries seems to follow the Kuznet's curve kind of logic. However, it is as controversial here as in the environmental field. It is certainly true that specific industrial water use (water use per unit product) is decreasing in many countries. This is due to both active and passive conservation as described later in this report. Figure A-2 shows the trends in total water use in the manufacturing sector in the U.S. We see a curve that does resemble some kind of inverted-U shape, suggesting that the total water use increases with rapidly expanding industrialization, and later decreases owing to increases in efficiency. However, there is little econometric basis for this as we need more (and recent) data to further examine this kind of conjecture.

U.S. manufacturing water use by industry (Figure A-3) indicates that the primary consumers of water in the U.S. are the petro-chemical, paper, and fabrication industries. However, along with this sectoral breakdown, one must keep in mind that the water consumption varies widely within the same kind of industry. For example, we examined the water use in the sugar beet industry worldwide (Figure A-4) and we can see that the specific water use in cubic meters per ton varies from about 2 in Israel to eight times that in the UK or Finland.

An examination of the water use per ton of product in selected industries (Figure A-5) reveals that there are orders of magnitude variation in the amount of water required for a unit quantity of different products. Thus, one cannot speak in general terms of a change in specific water use on an average basis; unfortunately, many countries report their successes either in terms of some kind of industry-wide specific water use (cu.m. per ton of product) or in terms of cu.m. per million $ of product. While the latter unit is preferable, it still has some fuzziness due to accounting for changes in prices, etc.

Why does industry need water? If we examine the water use in a few specific industries in the U.S. in terms of the use that the water is put to (Figure A-6 and Table A-1), we find that a substantial portion of the water (from 30% in the Sugar industry to 91% in Industrial Organic chemical manufacture) is used not for the actual industrial processes, but for substantially non-consumptive uses such as non-contact cooling. This is encouraging, because under appropriate regulations or incentives, it is possible in many cases to have closed-cycle systems for cooling. The remainder of the water is usually used for process-related items, that are very sensitive to the process technologies employed. The major industries that use a lot of water in the U.S. (Figure A-7) are pulp and paper and petro-chemical industries, and, to a lesser extent, fertilizer, sugar and the iron and steel industries.

If we examine the water use from the point of view of its ultimate fate (Table A-2, and Figures A-8 and A-9), we note that there is a lot of water is recycled by U.S. industry; however, there are few data on the recycling rate in industry since the 1970s. We can see that the actual consumptive use in industry is small. Most of the water is either recycled or discharged as wastewater. Much of the water discharged does have the potential to be recycled, and is increasingly being used as such for additional supplies where water is very scarce, as in Israel. However, due to the often poor water quality of the effluent for water used in contact processes, it is easier to recycle domestic sewage than industrial water. In the U.S., if we examine the average and maximum recycling rates (defined as a share of the gross water use contributed by recycled water), we see that there are efficient industries such as synthetic rubber and petroleum refineries, but there are industries such as cane sugar that show a lot of demonstrated potential possible improvement (Figure A-10). If we examine the waste characteristics of selected industries (Table A-3), we see that there is a wide variation in each industry type. The primary pollutants of interest that are normally considered are BOD, COD, suspended solids, total dissolved solids, oil, nitrogen and other toxics. This illustrates the need for wastewater treatment; however, as Figure A-11 shows, more than half of the wastewater is discharged untreated in 1983.

Hydroelectric power

Hydroelectricity generation is a very important industry worldwide, and, although it represents a non-consumptive use of water, it is an important determinant in the timing and management of water resources. Large dams have been built worldwide on almost every major and minor river system that offer the three factors essential for major hydropower development - the availability of sufficient head, sufficient discharge, and sufficient demand. The American continent accounts for almost half of the world's production of about 8 exajoules, that translates to an annual energy production of about 2.1 Million Gwh (see Figures A-12 and A-13). The continents of Asia and Europe account for the remainder. The installed capacity follows the same spatial pattern (Fig A-14).

Desalination

Desalination is one of the most expensive technologies used to provide fresh water. It is indeed often touted as one of the most impressive examples of the triumph of man's innovation over nature's adversity. However, it is often used as an excuse for the lack of rational water management. More often than not, the costs of desalination cannot be justified by the additional benefits it provides - it is often more efficient to undertake simple demand management steps; however, the latter is often not politically acceptable. Desalination is limited spatially given the requirements for seawater or brackish water (Figure A-15). Traditional desalination technologies include the multi-stage flash process and the reverse osmosis process, that together account for about 86% of the 13 million cubic meters of desalinated water produced every year (Figure A-16). However, given recent cost-cutting innovations in the desalinization process, it may turn out that desalination may be a serious supply option in arid regions of the world.

TABLE A-1
TYPE OF WATER USE IN SELECTED US INDUSTRIES

Industry	Gross Water Use			Breakdown of Industrial Water Use (%)			Breakdown of Industrial Water Use (cu.m./ton)		
	customary units		cu.m./ton	Non-contact Cooling	Process&Related	Sanitary & Misc.	Non-contact Cooling	Process&Related	Sanitary & Misc.
Hydraulic cement	1360	gal/ton	5.7	82%	17%	1%	4.6	0.96	0.06
Dairy products	0.85	gal/lb	7.1	53%	27%	19%	3.8	1.9	1.4
Meat packing	3.6	gal/lb	30.0	42%	46%	12%	12.6	13.8	3.6
Iron and steel foundries	12400	gal/ton	51.7	34%	58%	8%	17.6	30.0	4.1
Cane sugar	28100	gal/ton	117.1	30%	69%	1%	35.1	80.8	1.2
Beet sugar	33100	gal/ton	138.0	31%	67%	2%	42.8	92.4	2.8
Phosphatic fertilizers	35602	gal/ton	148.4	71%	28%	1%	105.4	41.6	1.5
Synthetic rubber	55	gal/lb	458.5	83%	17%	0%	380.6	78.0	0.0
Industrial organic chemicals	125000	gal/ton	521.1	91%	9%	1%	472.4	45.2	3.5
Pulp and paper mills	130000	gal/ton	541.9	18%	80%	2%	97.5	433.5	10.8

TABLE A-2
FATE OF WATER USE IN SELECTED US INDUSTRIES

	Water Use (cu.m./ton)					
Industry	Gross	Intake	Consumption	Discharge	Recycling	Recycling Rate
Hydraulic Cement	5.7	3.5	0.6	2.8	2.2	39%
Dairy Products	7.1	4.3	0.3	4.0	2.8	39%
Meat Packing	30.0	18.3	0.8	17.5	11.7	39%
Iron and Steel Foundri	51.7	12.6	1.1	11.5	39.1	76%
Cane Sugar	117.1	76.1	4.0	72.1	41.1	35%
Beet Sugar	138.0	46.3	1.6	44.6	91.7	66%
Phosphatic Fertilizers	148.4	35.3	5.3	29.9	113.1	76%
Synthetic Rubber	458.5	54.2	11.7	42.5	404.3	88%
Industrial Organic Che	521.1	227.2	11.7	215.5	293.9	56%
Pulp and Paper Mills	541.9	158.4	7.5	150.9	383.5	71%

TABLE A-3
EMISSION OF WASTES IN SELECTED US INDUSTRIES

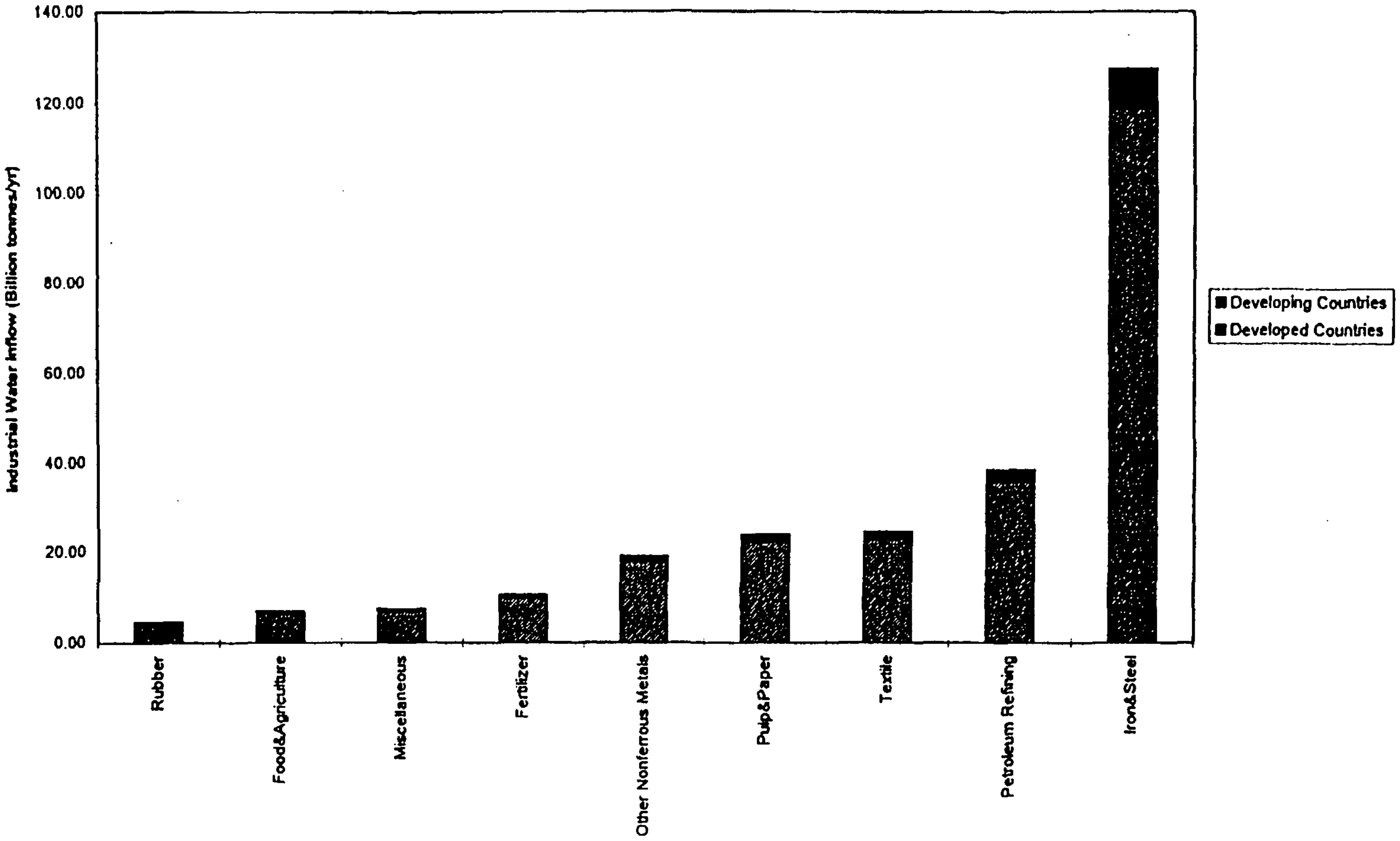
Waste Characteristics of Selected Industries

Source: Gleick (1993)

Industry Type	Example	Waste Vol (cu.m./ton)	BOD5 (kg/ton)	SS (kg/ton)	TDS (kg/ton)	Oil (kg/ton)	Nitrogen (kg/ton)	COD (kg/ton)
Agricultural&Livestock Production	Duck Feedlot	0.04	1.4	14.6			0.51	
	Beef Feedlot	20.2	250	1716			80.3	
Food Manufacturing	Grain Mill	0.6	1.1	1.6				
	Dairy Processing	2.4	5.3	2.2	3.3			
	Slaughterhouse	5.3	6.4	5.2		2.8	1.58	
	Cane Sugar	28.6	2.6	3.9				
	Beet Sugar	23.4	20	75				
	Yeast Products	150	1125	18.7	2250	127.5		
Beverage Industry	Alcohol Distilleries	63	220	257	385			
	Soft Drinks	7.1	2.5	1.3				
Textiles & Leather	Wool (w.scouring)	544	314	196	481	191		1140
	Cotton	317	155	70	205			
	Leather Tanneries	52	89	138	351	20	15	258
Wood Products	Fibreboard	20	125	20				
Pulp&Paper	Sulfate (kraft) Pulp	61.3	31	18	166			
	Sulfite Pulp	92.4	130	26	258			
	Semichemical Pulp	47	27	12.5	134			
	Paper Mills	54	8	23	37			
	Paper Mills (improved)	12.5	4	11.5	15			
Industrial Chemicals	PVC	12.5	10	1.5				
	Erythromycin	4000	13800	5600				
Non-metallic Minerals	Glass	45.9		0.7	8			4.6
	Cement (Wet)	5.1		0.9	6.6			
Basic Metals	Iron&Steel (Blast Furnace)	14.4		15.8		0.09		
Fabricated Metal Products	Household Appliances	55	19.3	8.3	23	3.4		82

FIGURE A-1

Global Industrial Water Use



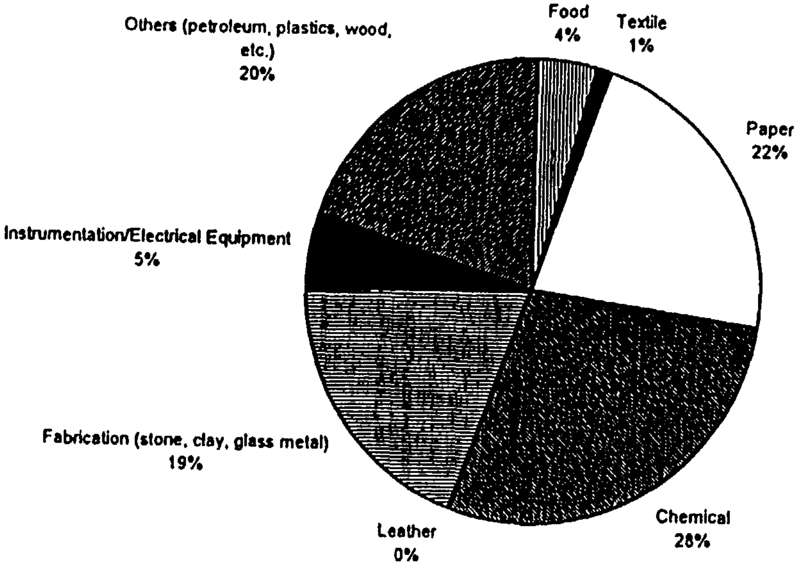
Source: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, 1993.

FIGURE A-2

Trends in Water Use in Manufacturing (US)

FIGURE A-3

Water Use by Industry
(1983 U.S. Manufacturing)

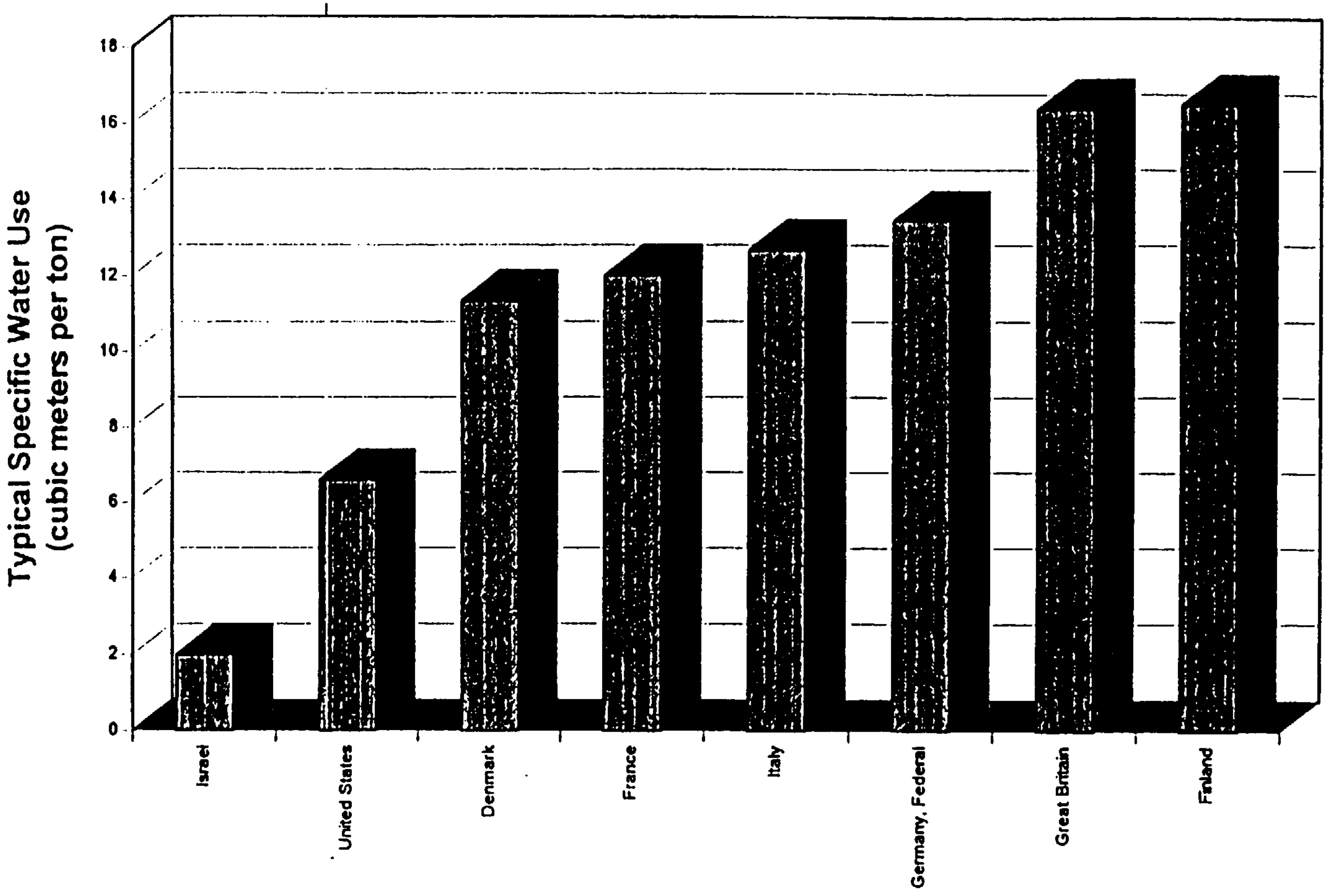


Total U.S. Manufacturing Water Use (1983) = 128.1 Billion

Source: van der Leeden, F., F.L. Troise and D.K. Todd, The Water Encyclopedia, Second Edition, Lewis Publishers, 1990

FIGURE A-4

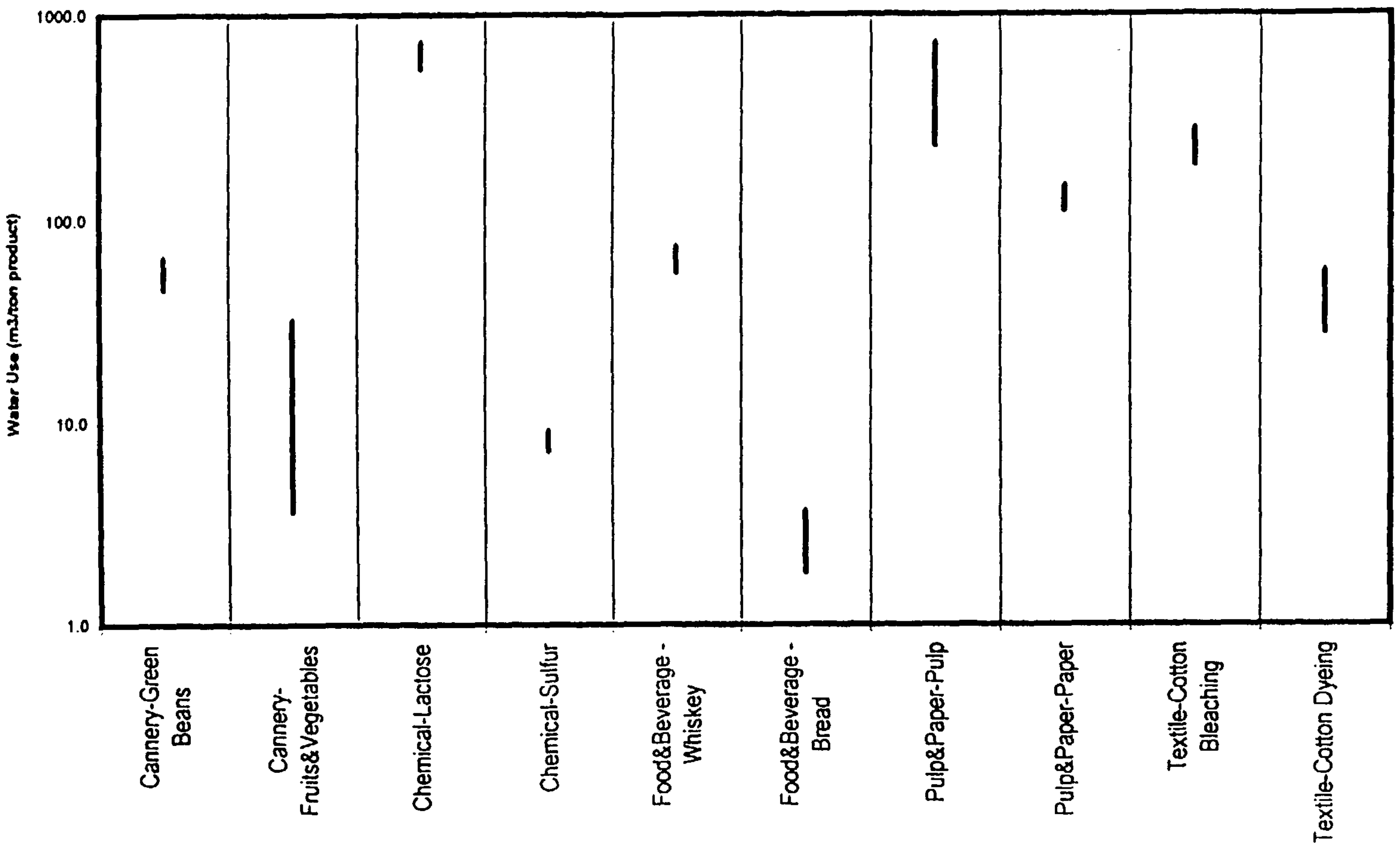
Spatial Variation in Water Use - Sugar Beet Industry



Source: van der Leeden, F., F.L. Troise and D.K. Todd, The Water Encyclopedia, Second Edition, Lewis Publishers, 1990

FIGURE A-5

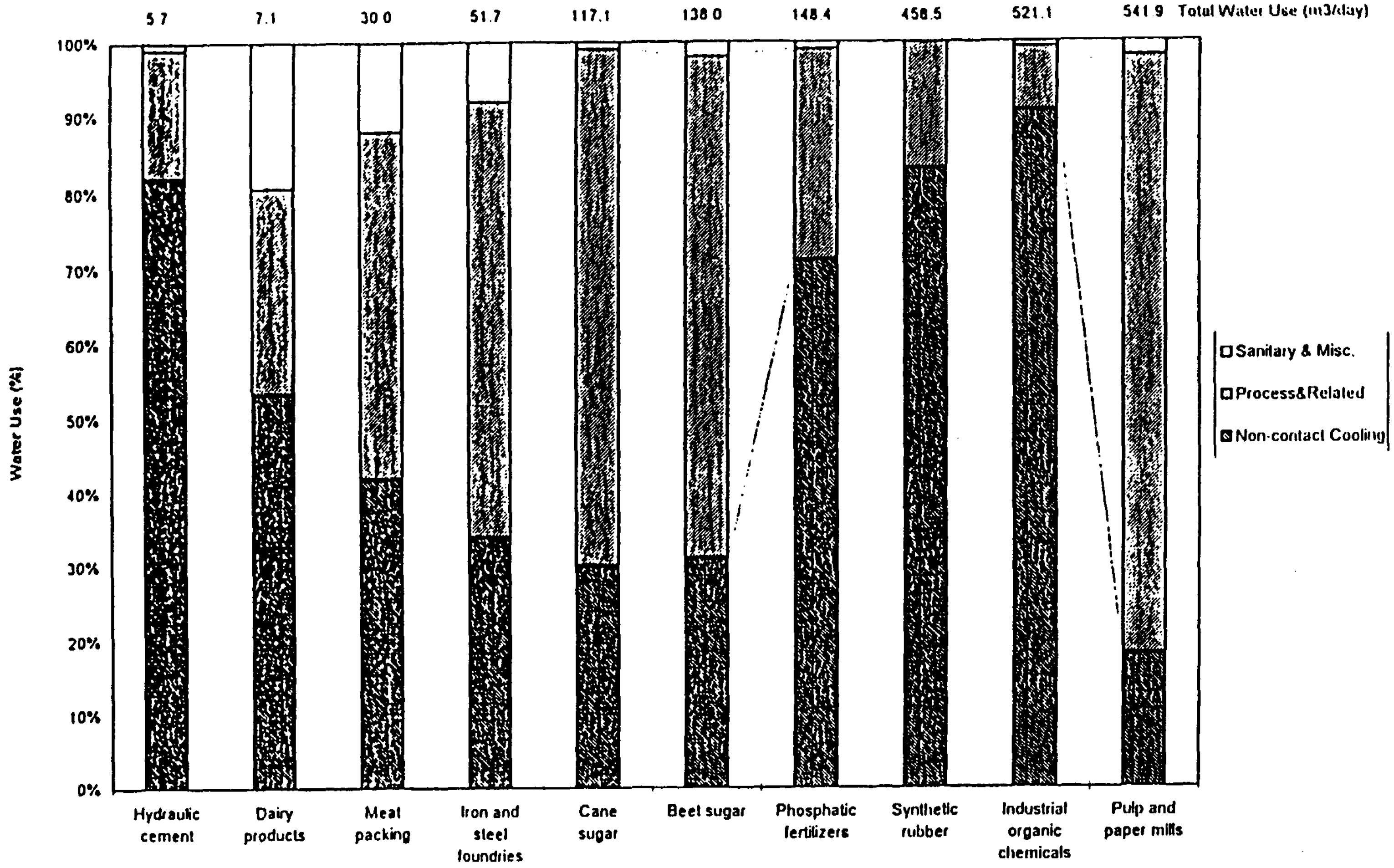
Water Use in Selected Industries



Source: Metcalf Eddy, Wastewater Engineering: Treatment, Disposal, Reuse, Third Edition, G. Tchobanoglous and F.L. Burton (Eds.), McGraw-Hill, 1991

FIGURE A-6

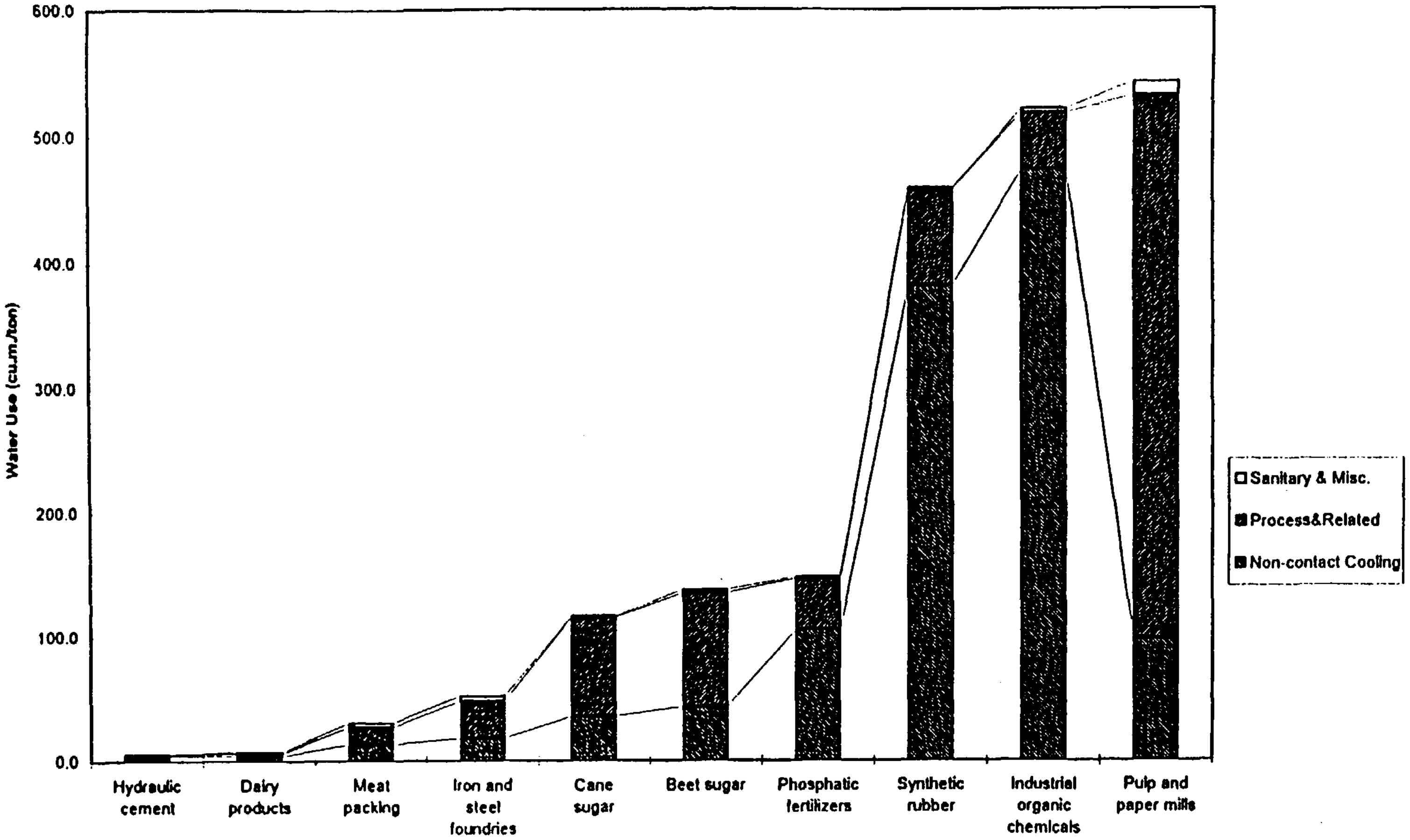
Industrial Water Use Breakdown



Source: van Der Leeden, F., F. Troise and D.K. Todd, The Water Encyclopedia, Lewis Publishers, 1990.

FIGURE A-7

Industrial Water Use Breakdown



Source: van Der Leeden, F., F. Troise and D.K. Todd, The Water Encyclopedia, Lewis Publishers, 1990.

FIGURE A-8

Industrial Water Use (by fate)

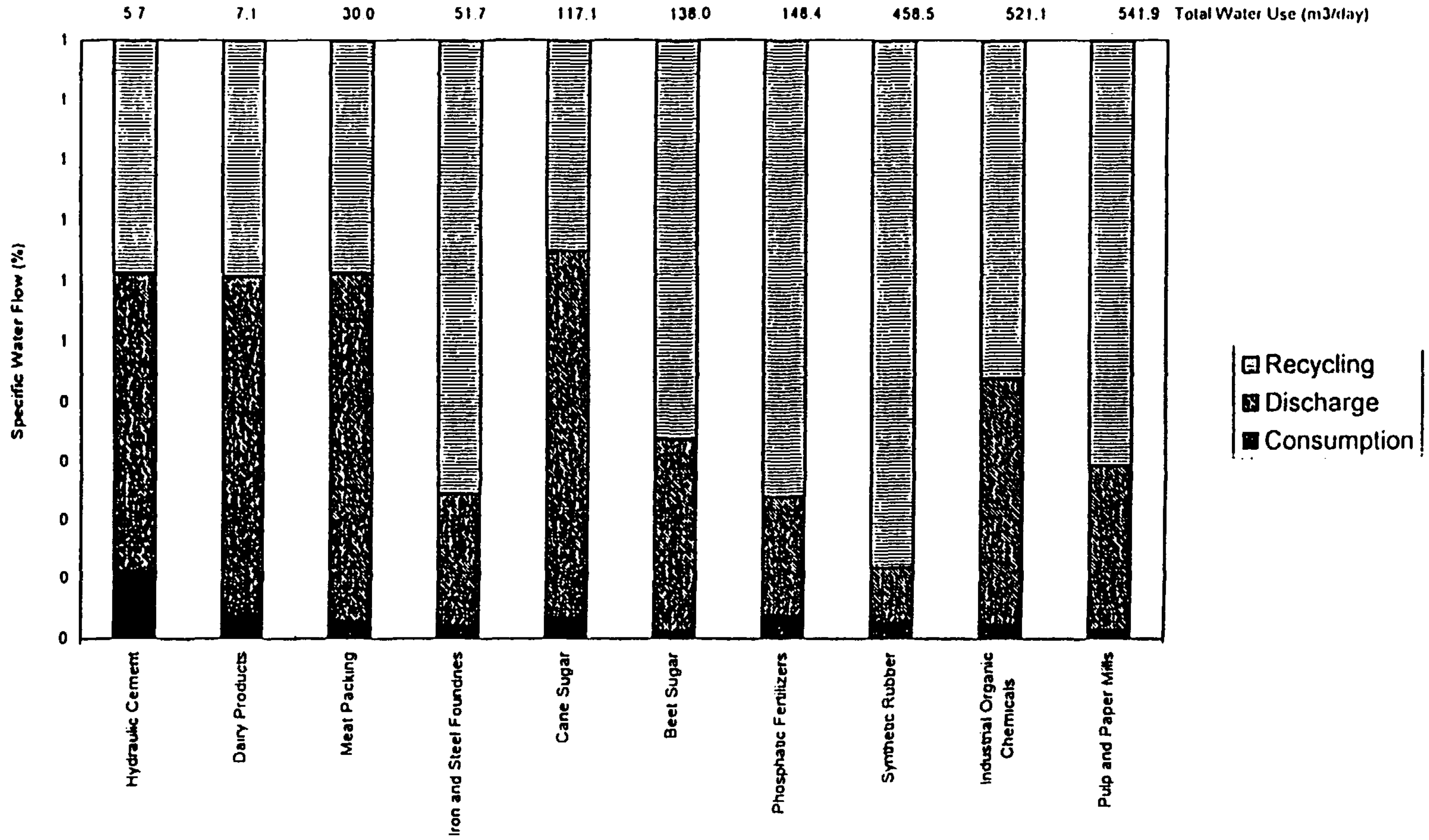


FIGURE A-9

Industrial Water Use (by fate)

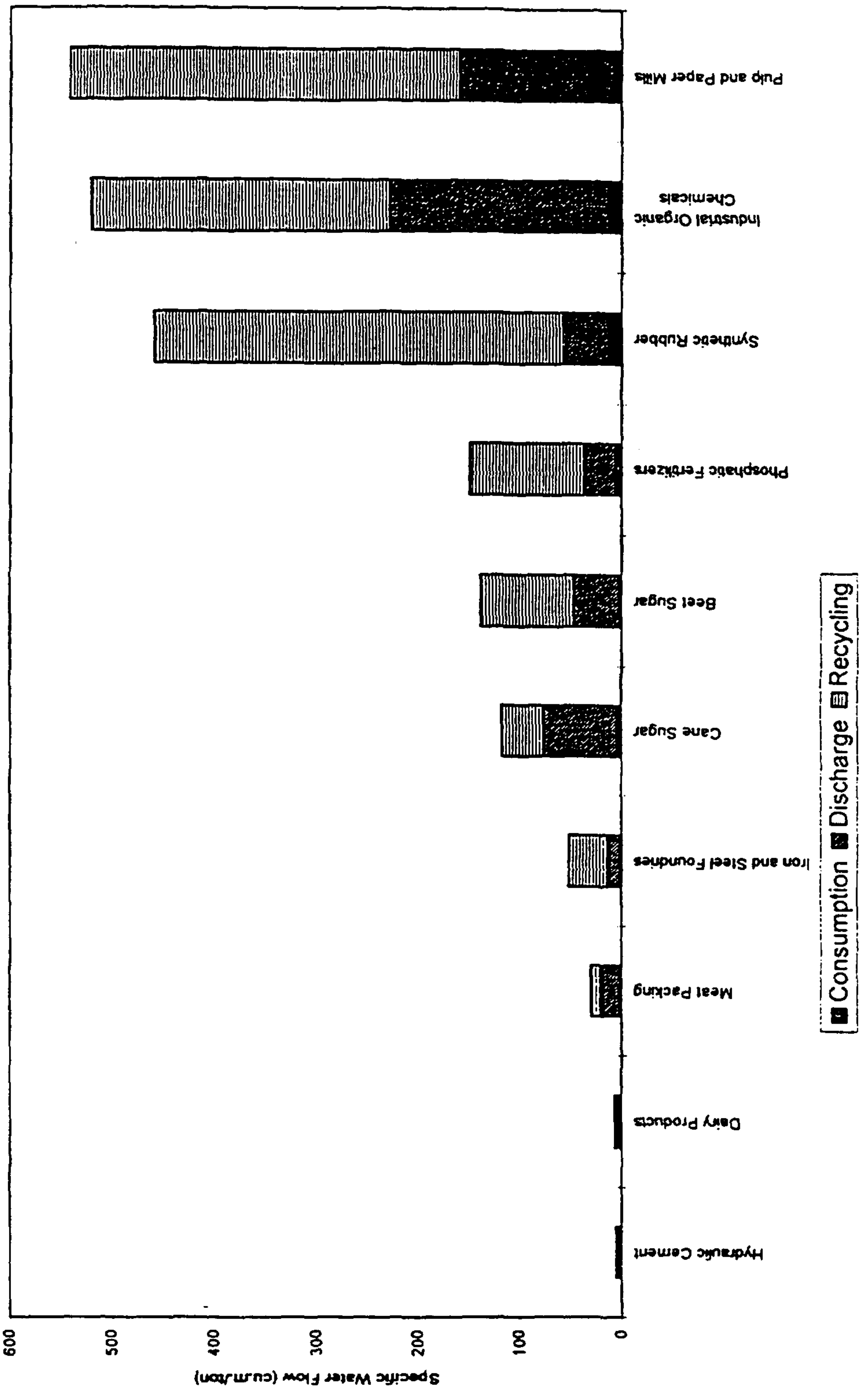
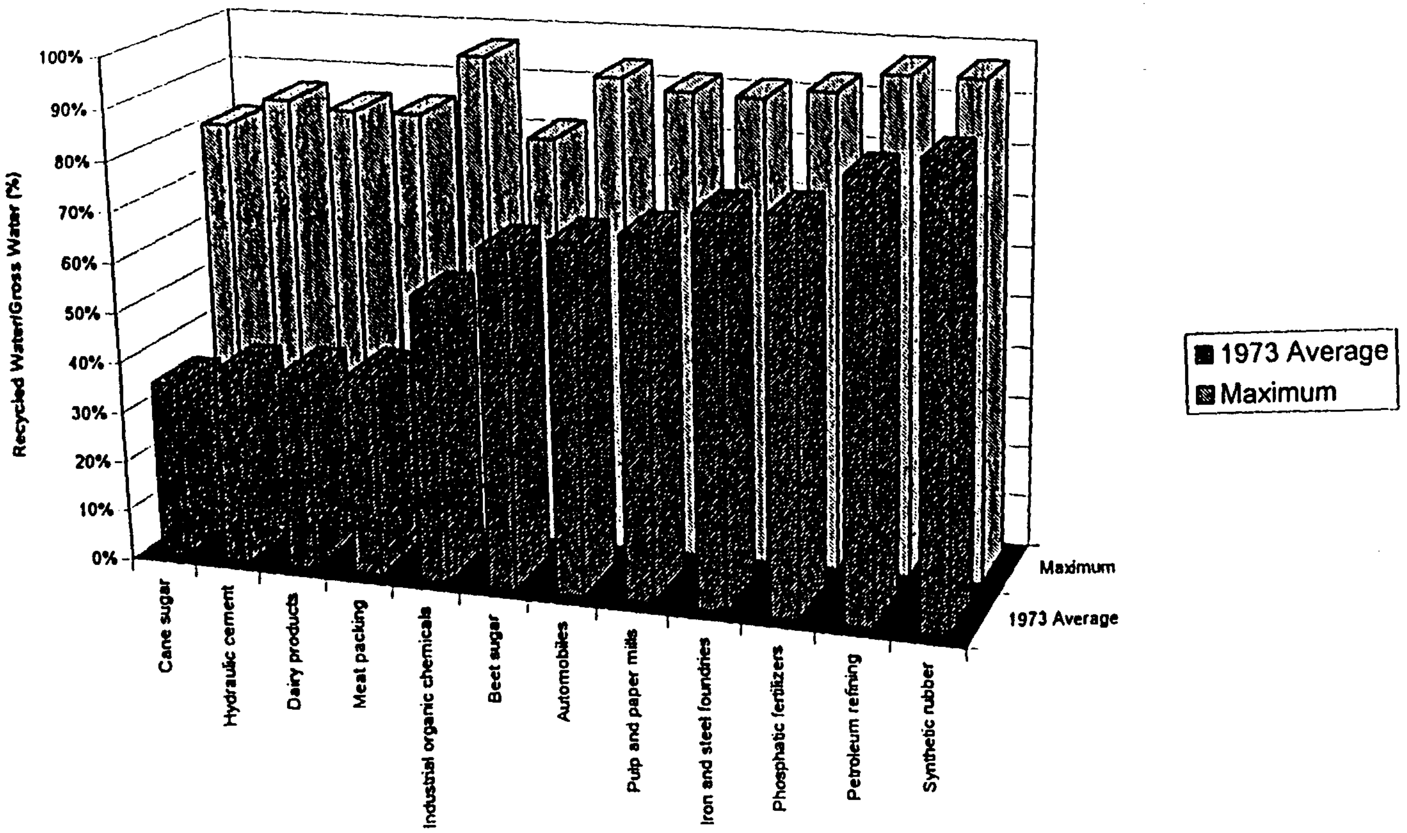


FIGURE A-10

Recycling Rates in Selected Industries (U.S.)

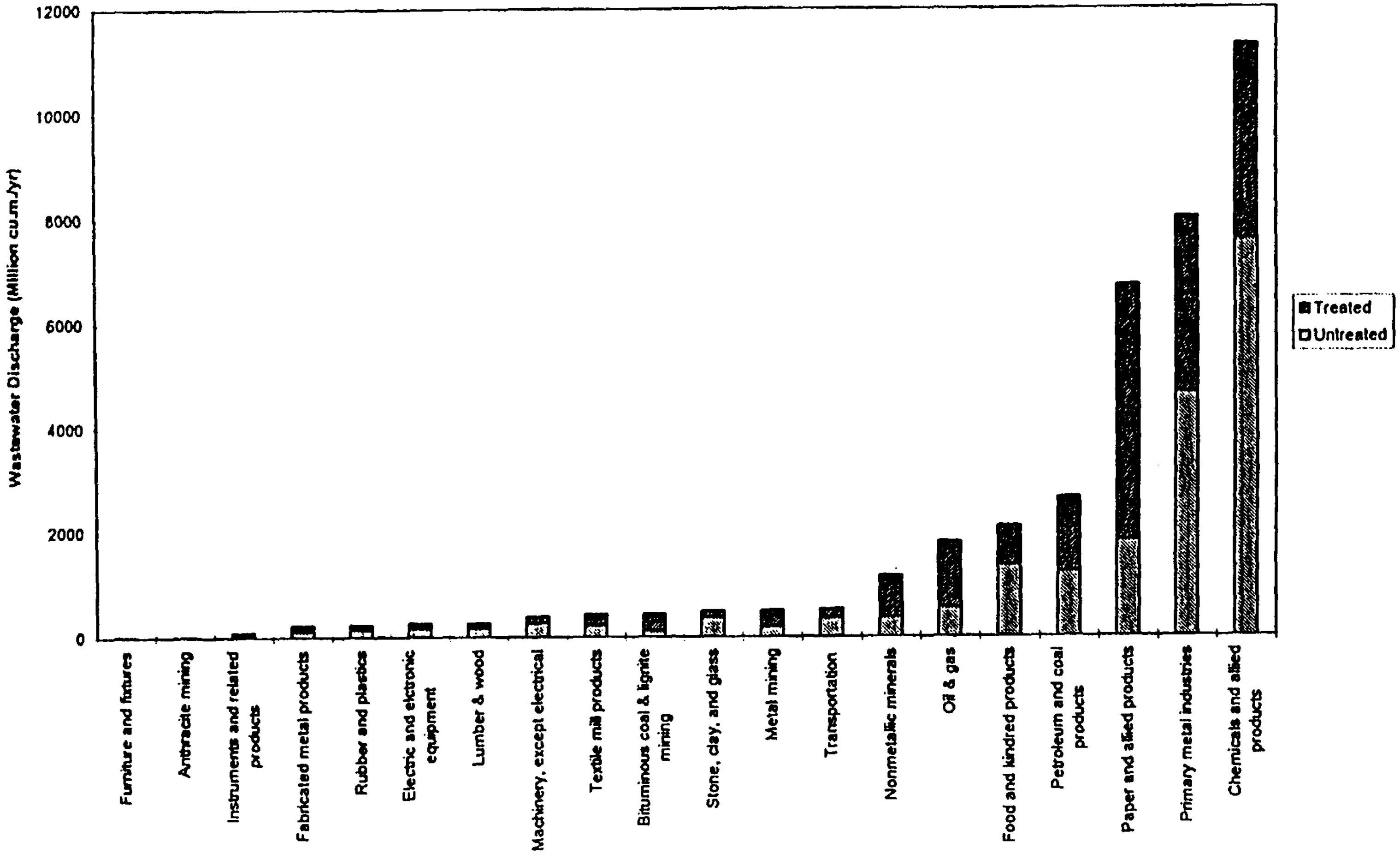


Source: van Der Leeden, F., F. Troise and D.K. Todd, The Water Encyclopedia, Lewis Publishers, 1990.

FIGURE A-11

Wastewater Discharge

U.S. Industries (1983)

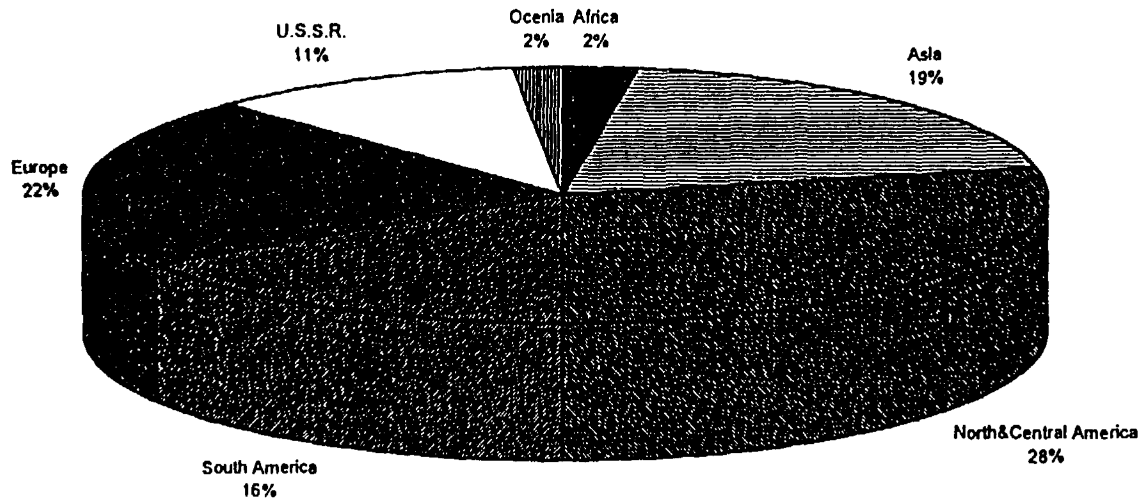


Source: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, 1993.

FIGURE A-12

Global Hydrolectric Production

World Total (1991) = 8.048 ExaJoules

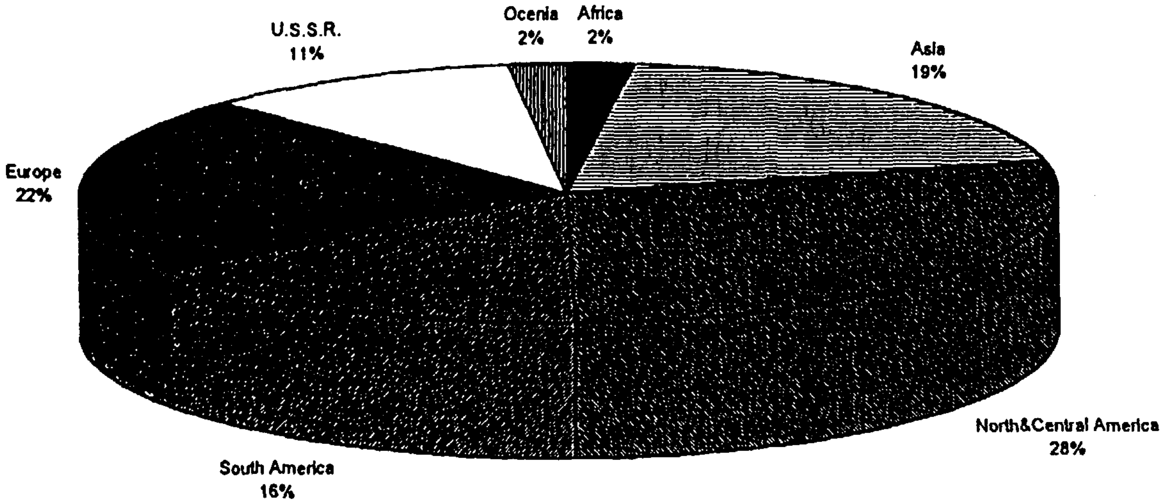


Source: World Resources Institute, World Resources 1994-95: A Guide to the Environment, 1994

FIGURE A-13

Global Hydrolectric Production

World Total (1989) = 2.1 Million GWh/yr

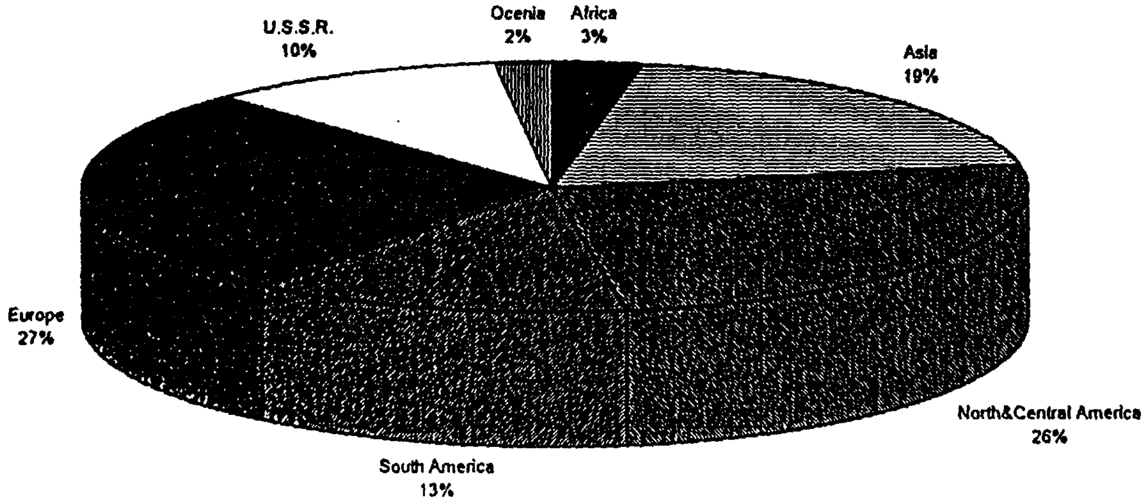


Source: World Resources Institute, World Resources 1994-95: A Guide to the Environment, 1994

FIGURE A-14

Global Hydrolectric Installed Capacity

World Total (1990) ≈ 624 GW



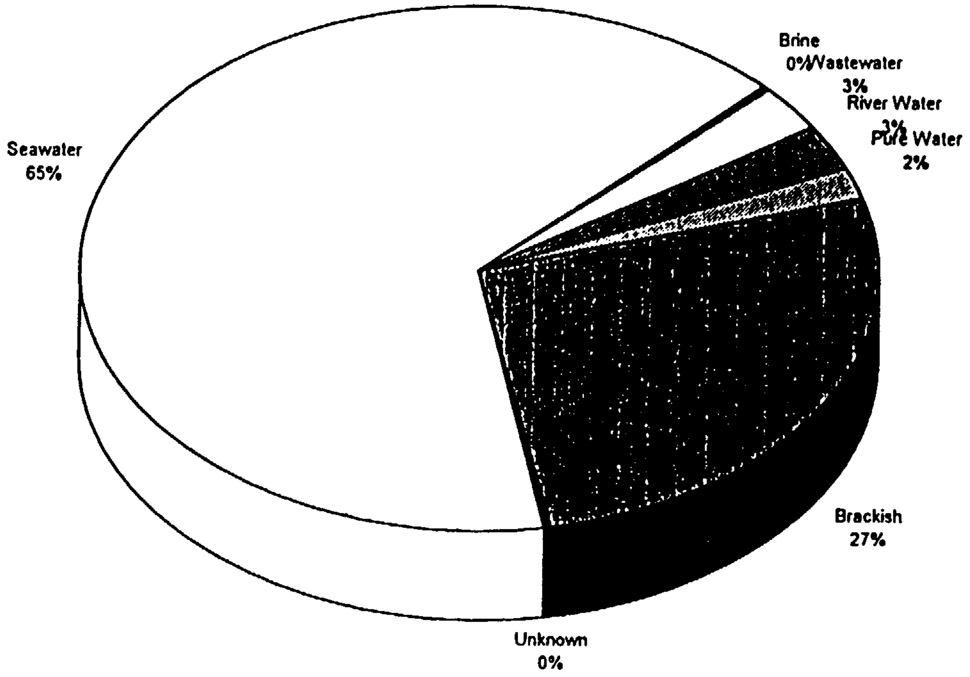
Source: World Resources Institute, World Resources 1994-95: A Guide to the Environment, 1994

FIGURE A-15

Global Desalination Capacity

by Source

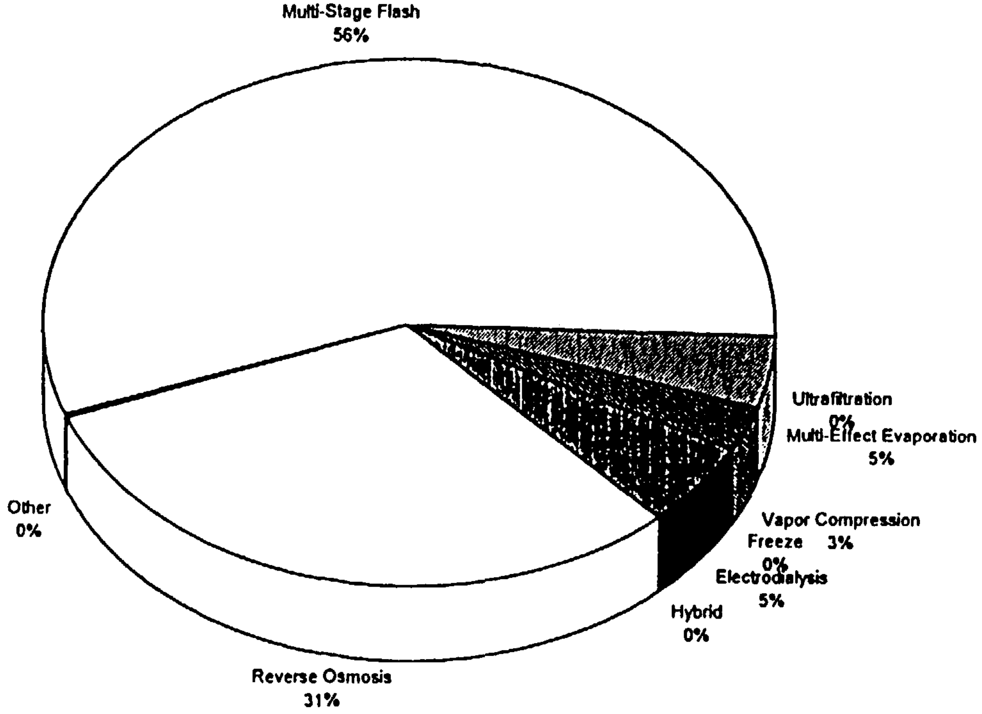
Total Capacity (1990) = 13.3 MCM



Source: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, 1993.

FIGURE A-16

Global Desalination Capacity
by Process
Total Capacity (1990) = 13.3 MCM



Source: Gleick, P.H. (Ed.), Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, 1993.