July 5, 1999

Señor Julio Zúñiga, Project Engineer
Atlas Eléctrica, S.A.
Heredia, Costa Rica

Dear Señor Zúñiga:

Enclosed is our report entitled Water Conservation at Atlas Eléctrica, S.A. It was written at Atlas Eléctrica, S.A. during the period May 17 through July 2, 1999. Preliminary work was completed in Worcester, Massachusetts, prior to our arrival in Costa Rica. Copies of this report are simultaneously being submitted to Professors Keil, Gerstenfeld and Vernon-Gerstenfeld for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We appreciate the time which you have devoted to us.

Sincerely,

Jill G Eastman

Jill Eastman

Brian McElhinney

Katrina Miller

Katrina Milier

Report Submitted to:

Professor Thomas Keil
Professor Arthur Gerstenfeld
Professor Susan Vernon-Gerstenfeld

Costa Rica Project Center

By

Jill Eastman

Brian McElhinney

Katrina Miller

In Cooperation With

Julio Zúñiga, Project Engineer

Atlas Eléctrica, S.A.

WATER CONSERVATION AT ATLAS ELÉCTRICA, S.A.

July 5, 1999

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of Atlas Eléctrica, S.A. or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

This report, prepared for Atlas Eléctrica S.A., provides recommendations on how Atlas Eléctrica S.A. can reduce water consumption in their factory. This report contains detailed analyses of all water consuming processes in the factory, information on pollutants and regulations and possible methods for using the wastewater produced in the plant. There were four areas identified to reduce public water consumption. Implementing all four recommendations will cut Atlas' water consumption by 11%, thereby fulfilling the original goal of the project.

Authorship Page

Every member of the group participated in all aspects of the writing of this project. Katrina Miller focused on the calculations and conclusions of the project. Brian McElhinney focused on the chemical and environmental aspects of the project. Jill Eastman focused on the cost-benefit analysis and the overall formatting of the project. No section was completed by a single team member.

Acknowledgements

Our team would like to acknowledge many individuals for their assistance on this project. First, we would like to thank our advisor, Professor Thomas Keil, for his invaluable guidance throughout the course of the project. Our liaison, Julio Zúñiga, provided us with the access to much of the information and many of the individuals we needed to complete the project as well as providing focus for the team. Manuel González answered any and all questions we asked in outstanding English and provided us with most of our hard data. Gerardo González provided us with information on the laws and regulations regarding water pollution in Costa Rica as well as clarified Atlas' previous attempts to reduce their water consumption. Finally, we would like to thank Pablo Solís for providing us with all of our overall consumption data.

Table of Contents

	List of Tables	1
	List of Figures	2
	Executive Summary	3
1.0	Introduction	6
2.0	Literature Review	9
	2.1 Introduction to Literature Review	9
	2.2 Current Process	9
	2.3 Alternative Cleaning Methods	11
	2.4 Water Pollution	12
	2.4.1 Current Water Usage in Costa Rica	13
	2.4.2 Phytoremediation of Wastewater	14
	2.4.3 Pollutants in Atlas Industrial Wastewater	16
	2.4.4 Water Conservation	18
	2.5 Plants Atlas Intends to Irrigate	19
	2.5.1 Drip Irrigation Systems	19
	2.6 Reusing Plant Graywater for Toilets	19
	2.7 Importance of Human Preparation for Change in Processes	21
	2.8 Management of Change	21
	2.9 Proper Training and Human Vs. Automated Labor in Developing Countries	23
3.0	Methodology	25
4.0	Results and Analysis	32
	4.1 Introduction to Results and Analysis	32
	4.2 Monthly Public Water Consumption	32
	4.3 Monthly Public Water Cost	33
	4.4 Phosphating Process Effluent Data	35
	4.5 Pickling Process Effluent Data	39
	4.6 Zinc Plating Process Effluent Data	43

4.7 General Environmental Law 45
4.8 Possible Areas for Consumption Reduction 49
5.0 Conclusions and Recommendations 51
5.1 Introduction to Recommendations 51
5.2 Recycling Water in the Phosphating Process 51
5.3 Recycling Water in the Pickling Process 52
5.4 Reusing Cooling Water 54
5.5 Miscellaneous Water Conservation 55
5.6 Cost-Benefit Analysis 55
5.7 Conclusions 56
5.8 Recommendations for Future Projects 56
6.0 Appendices
Appendix A: Mission and Organization of Atlas Eléctrica 58
Appendix B: Comparative Figures Between Costa Rica and Other Central American Countries 62
Appendix C: Flow Rate and Water Quality Calculations 65
Appendix D: Location of Water Meters 66
7.0 References 67

List of Tables

Table 2.1	Costa Rican Water Standards From the Reglamento de Vertido de Aguas Residuales (1997)	13
Table 4.1	Monthly Public Water Consumption in Meters Cubed	33
Table 4.2	Monthly Public Water Cost in Colones	34
Table 4.3	Phosphating Process Description	35
Table 4.4	Phosphating Rinse Tank Effluent Data	36
Table 4.5	Phosphating Chemical Tank Effluent Data	37
Table 4.6	Analysis of the Phosphating Process	38
Table 4.7	Pickling Process Description	39
Table 4.8	Pickling Process Rinse Water Effluent Data	40
Table 4.9	Pickling Process Chemical Tank Effluent Data	41
Table 4.10	Analysis of the Enameling Process	42
Table 4.11	Zinc Electroplating Process Effluent Data	43
Table 4.12	Zinc Electroplating Process Description	44
Table 4.13	Analysis of the Zinc Electroplating Process	44
Table 4.14	Cooling Water Flow Rates	49
Table 4.15	Sink Flow Rates	50
Table 5.1	Quality Effects of Using the Final Rinse Water in the Initial Rinse of the Phosphating Process	52
Table 5.2	Quality Effects of Using the Second Rinse Water in the Initial Rinse of the Pickling Process	54
Table B.1	Central American Populations, 1998	62
Table B.2	Costa Rican Economics, 1987	62
Table B.3	Central American Economics, 1987	63
Table B.4	Costa Rican Economics, 1995	63
Table B.5	Central American Economics, 1995	64

List of Figures

Figure 2.1	Photograph of Skimmer Tank in the Phosphating Process	10
Figure 2.2	Current Water Usage in Costa Rica	14
Figure 4.1	Photograph of Entrance to the Phosphating Tunnel	35
Figure 4.2	Schematic of Phosphating Process	38
Figure 4.3	Photograph of Pickling Tanks	39
Figure 4.4	Photograph of Zinc Electroplating Process	43
Figure 5.1	Diagram of Water Reuse in the Phosphating Process	51
Figure 5.2	Diagram of Water Reuse in the Pickling Process	53
Figure A.1	Net Profit Chart	59
Figure A.2	Organizational Chart	61

Executive Summary

This report, prepared for Atlas Eléctrica, S.A. by students from Worcester Polytechnic Institute, provides recommendations on how Atlas can reduce the consumption of publicly supplied water in their Costa Rican plant. Atlas manufactures refrigerators, ranges and ovens. The company was incorporated in 1976. The report includes background information on a variety of relevant topics. Following the background is our information on data collection, analysis of the data and finally conclusions and recommendations on how Atlas can cut their consumption of public water.

The objective of this project, set in April 1999, was to reduce the total consumption of publicly supplied water in the plant by 10 to 15%. Secondary objectives were to reduce the amount of pollution entering the Rio Bermúdez, to reduce the scale of the proposed treatment plant by recycling wastewater and to prevent summer water shortages in the city of Heredia.

The report includes a literature review containing background information on a variety of pertinent topics. Data on the three washing processes used in the plant is included in Section 2.2. The three processes are phosphating, pickling and zinc electroplating metal parts. Following the section on the washing processes is data on alternative cleaning methods which may be used by Atlas. Information on water pollution and eutrophication is also incorporated into the report. Data on current water supply and usage in Costa Rica is presented in Figure 2.2. An explanation of phytoremediation, using plants to clean polluted water or soil can be found in Section 2.4.2. The pollutants in Atlas' wastewater are analyzed in the following section, Section 2.4.3, including information on the quantities of chemicals as well as their hazards. A short section on water conservation is then followed by information on the types of plants Atlas has suggested irrigating. General information on drip irrigation systems, which could be used to irrigate these plants, has been researched and can be found in Section 2.5.1. Finally, information on managing the implementation of these changes into Atlas' factory has been included.

In 1998, Atlas consumed 135,836 cubic meters of water. A similar amount can be expected to be consumed in 1999. The 1998 cost of water was $67,184.88. The current processes used to treat metal can be improved in order to reduce the overall plant water consumption. In addition, there are numerous areas at the Atlas plant where pipes are constantly leaking and dripping. Also, Atlas uses fresh public water to irrigate their property during the dry season.

We determined a method to recycle the final rinse water of the phosphating tunnel in an earlier rinse. Upon analysis of our data we determined that 2,268,000 gallons of water could be saved every year in the phosphating tunnel if the recycling recommendation is implemented. This option translates into a savings of $4,200 per year.

In the pickling line we feel it is possible to reuse the degreaser rinse water from the second rinse tank by putting it into the first rinse tank after it is used, rather than pumping it directly into the river. This reuse option would save 950,000 gallons a year, a monetary savings of $1,799 yearly.

We feel it is feasible to run the cooling water from the foam injection machine into the reserve tanks with a short section of pipe, or to use this water to feed a drip irrigation system for the plant grounds. This option would conserve 189,000 gallons of publicly supplied water every year and save $358 per year, since the cooling water is clean and is currently pumped into the ground without recycle.

There are also numerous leaks around the plant, which if corrected, could save approximately 500,000 gallons of water per year. These corrections would save $947 dollars per year. A sink that cannot be turned off, so the faucet runs constantly, is one example of such leaks.

In conclusion, if all four recommendations are implemented, Atlas will save 3,907,000 gallons of water and $7,400 every year. This would result in a 11% decrease in the current water consumption at Atlas, thereby fulfilling the initially stated goal of the project.

1.0 Introduction

Atlas Eléctrica, S.A. is a Costa Rican manufacturing company that would like to reduce their consumption of public water primarily because there are water shortages during the summer which can cause delays in production. Public water usage also incurs large expenses on the part of Atlas Eléctrica, S.A. and they wish to reduce this cost in order to allow further increases in production. There are three processes where large quantities of water are being used in the plant. The three processes are: phosphating, pickling, and zinc electroplating steel. We focused on the phosphating process because it accounts for 60% of the total water used in the plant. Some minor areas also exist where water is used carelessly such as cooling systems and leaking faucets. In addition, we examined the effects the wastewater produced in the plant have on the local environment and people.

The goals of this project were to make recommendations to Atlas Eléctrica about how to reduce the usage of public water by 10-15% and how to reduce the amount of polluted water being released into the Bermúdez River. We collected data on the amounts and types of chemicals being released into the environment and the expected costs of implementing various strategies designed to reduce water consumption. As of November 1999 the local government has ordered Atlas Eléctrica to install a water treatment plant in order to meet more stringent governmental regulations on pollution. We advised Atlas on how to redirect this treated water back into the plant, thereby further reducing public water consumption as well as pollution. We identified ways to reduce the flow of water entering the treatment plant in order to decrease the size and cost of the treatment plant. Possible methods we have identified to reduce public water consumption are: redirecting the final rinse water in the phosphating process back into the initial rinse, reusing the water from the second rinse in the first rinse of the pickling process, and watering the gardens with treated wastewater or cooling water. Motion sensors were also researched to determine the feasibility of their use in the phosphating line.

Reducing public water consumption as well as pollution is important because both will help to cut down on water shortages, improve the health of the local people and make the Bermúdez River cleaner. Keeping the river clean is important because people rely on the river for water and food. Also, many animals rely on the river as a habitat and food source. Costa Rica as a country is very concerned about the environment and so the people will appreciate Atlas Eléctrica's effort to reduce emission of pollutants. During the dry season, reducing public water consumption is necessary to sustain water pressure in the public water supply. The plant places a heavy strain on the public water supply and deprives the local people of water they need for everyday life.

Our methodology begins with analyzing the current usage of water. We have collected data on monthly consumption of public water and cost. The data was obtained by interviewing the head of coating processes, Manuel González, the maintenance department, and our liaison, Julio Zúñiga. We also collected data on the different water consuming processes as well as the chemical properties of the water being discharged into the Bermúdez River. This data was collected by observing the three processes, talking with professional employees and obtaining written documents describing consumption patterns and chemical uses. The data was organized into easy-to-read graphical formats to prepare it for analysis. We constructed plans showing the locations of water meters and pipes, using existing floor plans and interviews with maintenance personnel. These plans were used to help us determine ways to reroute plant water.

Research was also performed on drip irrigation systems as a possible method for reusing some of the water leaving the factory. Types of vegetation were matched with comparable irrigation systems.

Our recommendations are presented in the form of a cost-benefit analysis for each possible solution. Predicted water use reductions were also included for each solution. Diagrams for redirection of wastewater were presented. The impact on the local people from the Atlas Industrial plant was presented, including the impact of pollution as well as the benefits of stable jobs and a reliable public water supply.

This report was prepared by members of Worcester Polytechnic Institute Costa Rica Project Center. The relationship of the Center to Atlas Eléctrica S.A. and the relevance of the topic to Atlas Eléctrica S.A. are presented in Appendix A.

2.0 Literature Review

2.1 Introduction to Literature Review

The purpose of this literature review is to provide background information for this project. This section outlines the current and alternative procedures for cleaning metal and the environmental effects of industrial pollutants such as phosphorus, heavy metals, and organic solutions. Also, information on drip irrigation systems has been provided. This section also contains information on possible methods of reusing the wastewater produced at Atlas Industrial's plant. Information on the importance of human preparation for change and the differences between automated and manual labor has been included as well.

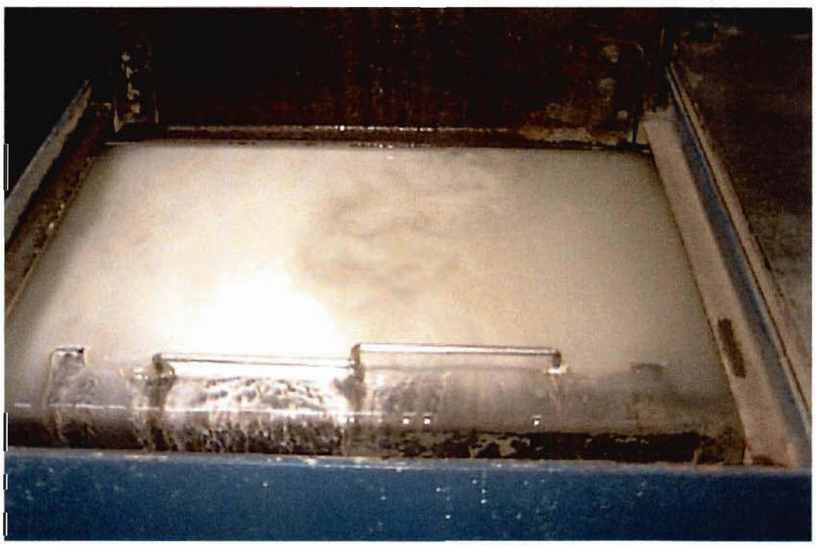
2.2 Current Process

The processes of interest in this project were three cleaning stages used to prepare metal pieces for painting, pickling and zinc plating. Atlas Eléctrica used 131,977 cubic meters of water in 1997 (4) and 135,836 cubic meters of water in 1998. (12) The cost to Atlas for this water in 1998 was $67,184.88 U.S. (12) These three processes utilize 92% of the total public water entering the plant. The other 8% is used in administrative areas such as the cafeteria and bathrooms. (4)

The painting preparation line is known as the phosphating process. This process uses the majority of the water in the plant (60%). In the phosphating process, the parts are manually hung from a line that passes through a tunnel with seven sections. The individual steps are explained in Table 4.3. This project focuses on the rinse stages in the process. The solutions are stored in separate tanks with floats to control the liquid levels. The solutions flow through fine mesh screens and then into pumps. From the pumps the solutions are forced up riser pipes and through strategically positioned high-pressure nozzles that scrub the parts.

The solution then falls on sloped boards and drains back into the tank. The top layer of tanks 2, 3 and 5 are skimmed off and discarded because they contain high levels of contaminants. This water is piped directly into the

Figure 2.1 Photograph of Skimmer Tank in the Phosphating Process



Bermúdez River. This discarded water is constantly replaced by fresh water from the public water source. The water in the final rinse is all discarded constantly because the rinse water must be extremely pure. The water in tanks 1 and 4 is changed once every two months. The water in tank 6 is changed daily.

The pickling process is a very old process used to coat range tops with a corrosion resistant shield. There are seven steps in this process as well. These steps are outlined in Table 4.7. The cooktops are loaded into steel cages and dipped into each tank several times. The entire process is manually controlled. The tanks are all side by side and the cage is transferred from one to the next by an overhead conveyor. See Figure 4.3. The antiquity of this process makes it very difficult to reuse the wastewater produced in this process.

The third process, zinc electroplating, is very minor in comparison to pickling and phosphating. It also involves seven steps which are outlined in Table 4.12. This process involves small metal parts which are used on the interiors of the refrigerators, cooktops and ranges. Two employees work constantly on this process, transferring large strainers from one tank to the next. The tanks hold relatively small quantities of water and two are never changed.

2.3 Alternative Cleaning Methods

Alternatives to the current cleaning system include a soaking tank or using a counterflow system. A counterflow system takes the water from the final rinse and applies it to one of the earlier rinses, rather than just emptying it into the river without reuse. Solvent cleaning, emulsion cleaning, abrasive cleaning and acid cleaning are other alternatives that do not use the alkali cleaning solution.

2.4 Water Pollution

Water pollution is a worldwide problem and it affects every organism on earth. There are thousands of synthetic chemicals and human wastes in most large bodies of water. Developing countries need guidance on how to avoid wasting and polluting water. PCBs and DDT were banned in the United States during the 1970s and water use laws have been developed in the Southwestern U.S. Costa Rica has adopted similar strategies and regulations to prevent their water resources from being ruined. Atlas Eléctrica S.A. currently releases suspended solids, chromium, zinc, phosphates, oils, grease, degreaser, sealer, porcelain enamel and hot water into the Bermúdez River. Many of these chemicals are released at levels which are within current standards, but a few are over the acceptable level. New standards are being imposed on Atlas Industrial's wastewater in November 1999. (9) These changes have caused Atlas Industrial to consider building a chemical treatment plant onsite to reduce the levels of some pollutants.

Table 2.1 Costa Rican Water Standards From the Reglamento de Vertido de Aguas Residuales (1997)

Analysis	Maximum Permissible Concentration
Biochemical oxygen demand (mg/l)	300
Chemical oxygen demand (mg/l)	1000
total suspendable solids	500
total sedimentary solids	1
Combined solids	1500
Greases & oils	100
pH	6 to 9
Temperature	<40 C
Chromium	2.5
Zinc	10
Sulfates	500
Chlorides	500
Residual anionic detergent by-products	10
Phenols	5

Atlas Industrial S.A. Plan Voluntario de Cumplimiento. January 1998.

Recycling or reusing industrial wastewater in numerous ways are important steps in preventing natural resource destruction. Recycling and reusing wastewater reduce the amount of water being polluted, while providing good jobs for the local people.

2.4.1 Current Water Usage in Costa Rica

The following data (Fig 2.2) shows that there are currently no water shortages in Costa Rica, but water quality needs to be improved. Compared to other Central American countries, Costa Rica does not have major water quality problems, but improvements can and should be made before larger problems arise. (30)

Figure 2.2 Current Water Usage in Costa Rica

(Supply and demand of water in Costa Rica (1992))

Water Supply:

Renewable supply (cubic miles): 23

Total use (cubic miles): <1

Water Usage:

Agriculture: 89%

Industry: 7%

Domestic & Municipal use: 4%

Access to safe water:

Urban: 100%

Rural: 82% (30)

2.4.2 Phytoremediation of Wastewater

Some of the pollutants currently generated by Atlas' production methods can be safely remediated through carefully designed biological systems, within certain limits. Phytoremediation is a process that uses plants and their associated bacteria to remove pollutants from wastewater and contaminated soils. (15) The process involves using the sludge produced (which contains high amounts of heavy metals) as well as the wastewater itself (which contains high amounts of phosphorus). Studies have shown that land plants (crops, trees, grasses) are capable of removing 20-40% of the phosphorus from the water and sludge by incorporating it into their own tissues, if conditions are correct. (16) The correct conditions are different for every species, but the main factor is keeping the pH between 6 and 8. This phosphorus is therefore transformed from waste into useful plant matter, with little or no effort from Atlas.

Long-term studies have shown very low uptake of heavy metals by crops grown in graywater systems. (16) A team at NASA found an exception, large amounts of sodium ions (Na^+) accumulating in the water. This can eventually lead to a situation that is toxic to plants, because they do not utilize sodium. (34) The levels of uptake of other heavy metals during phytoremediation are within acceptable Canadian standards. These limits are important because much of the research on this data has been conducted in Canada, a country with a very high standard of life. Also, the accumulation of heavy metals over time has shown to *not* be detrimental to the growth of plants. (16) As long as sludge application sites are properly prepared, rotated and applied (not immediately before heavy rains) the heavy metals will not create a health hazard to people living or working in the area. (15)

There are also chemical treatment programs for removal of phosphorus from industrial wastewater. Although these processes do remove a higher percentage of phosphorus than land treatment, they are more costly and result in other environmental problems that must be taken into account. The chemicals most commonly applied are: lime, ferric iron (3+) and aluminum. Aluminum and iron are much more expensive than lime, which sells for $34.50-$44.35 per ton in Canada. (16) Similar differences in cost can be anticipated in the Central American market as well. These processes also generate higher percentages of heavy metals in the sludge, which could cause problems in the frequency of dumping per site. (16)

2.4.3 Pollutants in Atlas Industrial Wastewater

Currently, Atlas Eléctrica S.A. uses a variety of chemicals in the phosphating process. The commercial names of these chemicals are provided in Figure 4.2. The pollutants include phosphates, degreasers, surfactants, nitrates, alkaline solutions, hot water (>40C), acids and heavy metals such as iron, zinc and zirconium. (17) The Costa Rican laws governing the permissible effluent levels of these pollutants can be found in Tables 4.4 and 4.5.

Phosphorus, a nutrient vital to the growth of all plants, causes great problems when present in excess amounts. Plants use phosphorous to promote root growth and to generate flowering structures. (14) Microphytes, such as algae, use phosphorous to promote very rapid growth. Aquatic plants in general grow very rapidly when fed an excess of phosphorous. This effect makes phosphorous the limiting nutrient in their growth. Plants are capable of concentrating phosphorus in their tissues at a maximum of .2% dry mass. (25) This means 100 grams of dry plant matter will contain .2 grams of phosphorus.

When phosphorus is placed in natural water bodies in high concentrations it generates massive algal blooms. These algal blooms choke out other native plant growth by absorbing all available sunlight. Also, the algae use up the dissolved oxygen in the water, which causes the fish, amphibians, insects and reptiles in the water to die. This situation is known as eutrophication. Eutrophic water bodies have more life in them than they can sustain over a long period and can be quickly destroyed. (22)

Nitrogen causes problems similar to those of phosphorous, as it is another of the three key nutrients in plant growth. Nitrogen does not cause as rapid growth in aquatic plants as phosphorous, but in sustained quantities it can cause very detrimental eutrophication.

Surfactants and degreasers cause the surface tension and cohesive nature of water to be reduced. They cause these problems by disrupting the hydrogen bonding between water molecules. Both classes of chemicals are dangerous because they increase the mobility of polluted water in soil. (15) These chemicals could pose a serious threat to potable groundwater supplies in the area. Both chemicals increase the solubility of nonpolar molecules, such as fossil fuels and their derivatives, in water while decreasing the solubility of polar molecules such as phosphates. (16) This situation presents obvious health hazards to any organisms coming into contact with this water.

Iron (Fe) is another pollutant that appears in the wastewater from Atlas. Iron is a microelement which plants require in small quantities to survive. Plants can fix .01% of their body mass in iron, which on a large scale could help to remove a significant amount of iron from Atlas' wastewater. (21) Plants can tolerate excessive amounts of iron without a large effect on their growth but will quickly die if no iron is available. Zinc is another element which is required in small quantities, but is detrimental when present in excess quantities. Plants can only fix extremely small amounts of zinc. (15) Zirconium is not utilized by plants and is not naturally found in significant quantities.

Alkaline salts and acidic washes are also used in the processes, therefore the pH of the wastewater would have to be monitored to ensure it does not drop out of the 6-8 range. Anything beyond those two values would too acidic or to basic for plant growth. Conifers, such as pines, prefer acidic soils while grasses prefer a more alkaline (basic) pH in their soil. This difference may present a problem if the same source is used to irrigate both.

2.4.4 Water Conservation

Water is plentiful during the winter months in Costa Rica. However, during the summer months, the public water supply is less abundant. Recycling water can help prevent this shortage from happening. Dan Williams, an expert on hydrology and land use, estimates that in the past 50 years ill-conceived development has diminished the world's supply of drinkable water by more than a third. (10) The water has not disappeared, it has just become too polluted for human consumption and in some cases for human contact. Making use of all available sources, such as groundwater, can help prevent any one source from being overused.

2.5 Plants Atlas Intends to Irrigate

The plants Atlas intends to irrigate are trees, rose bushes and grass. Currently, these plants are watered with public water during the dry season. These are three very different types of plants with very different nutritional needs. (25) These differences may present problems when deciding which plants to irrigate.

2.5.1 Drip Irrigation Systems

Drip or low-volume irrigation can be a very efficient way to water plants. The drip irrigation option makes productive use of up to 95% of delivered water compared to only 70% efficient with conventional systems. (24) Low-volume irrigation delivers water directly to the root of the plant. Direct delivery prevents water loss through evaporation and water seeping below the roots of plants. Drip irrigation is useful for watering most plants with the notable exception of grass.

2.6 Reusing Plant "Graywater" for Toilets

One potential application for reusing the wastewater produced in the washing processes is as graywater. Graywater is wastewater containing soaps (phosphates) from appliances such as baths, showers, clothes washers and sinks. (10) Blackwater is wastewater from toilets and dishwashers. (10) The difference between blackwater and graywater is that blackwater contains high levels of organic matter and bacteria, which makes it unsuitable for any sanitary uses. Existing plumbing structures can be modified to isolate blackwater and make graywater available for reuse in toilet flushing or irrigation.

The average American home could save 41,000 gallons of recyclable water a year if a graywater system were installed. (10) This means that Atlas could potentially save hundreds of thousands or millions of gallons of water every year, which in turn translates into tens of thousands of dollars (American) in savings every year for Atlas.

By isolating the blackwater from graywater, graywater could be used for irrigating plants as well as supplying toilet and dishwasher water.

The initial capital cost of installing a graywater system has proven to be a good investment. Larry Callahan, General Manager of the Post Ranch Inn in Big Sur, California, says, "Every system I've completed has paid off within a year". (7) This means that in one year or less Atlas will be saving money and reducing their water consumption.

An interesting new study by NASA scientists at the Kennedy Space Center has shown that wheat, potatoes and soybeans are all capable of growing in graywater with no additional nutrients added. (34) In fact, they grew better in graywater systems than they did with freshwater systems. The root mats were able to absorb all available phosphates within six hours after the plants were given sufficient time to establish themselves. This happens because of the rhizosphere microbial activity found in their roots. (34) Also, any bacteria entering the system through human contact did not survive and was not found in the plants, showing that the systems are safe for human use. (34) This data supports the use of a graywater system at Atlas Industrial as a means to reduce overall water consumption in the plant.

2.7 Importance of Human Preparation for Change in Processes

While the technical aspects and environmental impacts of changes in manufacturing processes are very important, how humans will be effected by the changes is also pertinent information. Humans will be in charge of implementing the new technology and adapting to new expectations and responsibilities. Workers will need to learn how the new process is supposed to work and to learn how to make the process work to fit their style and competence level. Training workers is a major issue that all plants face every time they choose to change a process or implement new equipment. The extent to which Atlas manages change and trains employees on the importance of saving water and curbing pollution as well as on the procedure for running the new equipment and processes will ultimately determine success or failure of their endeavor.

2.8 Management of Change

When considering changing a major process or adding an entirely new process, it is very important to consider what affect these changes will have on the production workers and the managers.

> If workers are viewed as integral to the technology and productivity equation and critical to the firm's success, investing in their development through training and other measures is likely to occur and to produce synergistic results. If workers are seen as expensive and expendable, the introduction of new technologies may meet with worker resistance and conflict. (5, p. 251)

Change affects work environments as well as social relationships. Before, during, and after a change is being made, management needs to conduct interviews with workers from all aspects of production to ensure that everyone is comfortable with the changes and understands why the changes are being made. If underlying feelings of discomfort and confusion are looked over, mistrust and a decrease in contentedness, as well as a decrease in productivity will occur. (13)

The laborer's position stands that if they feel comfortable in their jobs, they will be content and willing to put forth effort. The key to achieving the appropriate comfort level is by training. (5) In technical, industrial companies, each individual task is complex and vital to the production of the end product. Workers need to be trained specifically and carefully. Follow-up measures should also be taken to assure quality and comfort after the initial training stages.

Response to change varies by industry, individual and experience. Some industries are constantly changing due to technological advances, so individuals must expect and adapt quickly to each change. Flexibility is key, and flexibility due to change is based on experience with modification. Experience is gained by proper training instigated by people in leadership positions.

2.9 Proper Training and Human vs. Automated Labor in Developing Countries

In order to optimize the use of technology and manual labor in manufacturing, the operators and the managers must be properly trained. Workers' current habits should be taken into consideration when in the market for new technology. Disrupting work habits that have been used and perfected over the years in the life of a production worker would be degrading to the success of the company as a whole. Adopting a full time trainer for each plant would be very beneficial for a company. Quality would be increased and the workers would be more confident in their ability if they have positive reinforcement from an expert on how things should be done. "...managers should consider training an integral part of their production investment strategies, for it can help to realize the technology's full productivity potential." (5, p. 249)

In developing countries, often the equipment and machines are designed in a developed country and shipped to the developing country without instruction on the proper usage of the equipment. Therefore, in order to train both management and production workers in the new processes or the new equipment, the production process should be broken down into its stages and sub-processes. The technology should first be separated from the process. Some operations, such as the transformation of raw materials stage of production, need to have automated controls since human error will most affect product quality and process efficiency. This automation would cut down on the depth of the training necessary. Yet, other operations, such as handling stages, have little influence on quality, so human manual labor can be used efficiently. Use of technical substitution or traditional human labor should be carefully considered in each stage and sub-process of production.

"Many opportunities for technical substitution are not realized because of lack of information about technological alternatives." (5, p. 245) Managers should carefully research and analyze the costs and benefits of using automated controls or human labor. Some costs to consider for automated controls are: repairs, replacement when the machinery is obsolete and operator training. Costs to consider when looking at human labor are: effective training, overtime, benefits and insurance. Human labor is important because people need to be employed to earn money in order to live, but automated tools may make production easier and more cost-efficient for some companies. The unemployment rate of countries should be carefully considered before considering downsizing and replacing humans by machines.

3.0 Methodology

In order to evaluate the current water usage at Atlas Industrial, S.A. and to make recommendations for future reuse and recycling options, this team considered many factors. First, this team became familiar with the plant, its processes and where water is used. Then the team looked in more detail into the specific processes where water is wasted and made recommendations for change. We also researched alternate sources of water for use in the plant and made recommendations based on a cost-benefit analysis.

In order to familiarize ourselves with the plant and its processes, we walked through the plant with Pablo Solís, of the facility and machinery maintenance department. Later, our liaison, Julio Zúñiga, Project Engineer, took us on another tour and identified possible sites for the reduction of water consumption. A third tour was conducted by Manuel González, head of coating processes, who focused specifically on the three washing processes. While walking through the plant, the team looked for leaking pipes and water waste. We also looked into employee practices concerning the handling of water in the different areas of the plant.

We performed unstructured interviews with engineers, chemists, maintenance personnel, the records department and production employees. We also conducted a structured interview with Señor Gerardo González, chemical engineer. We presented Jorge Rodriguez, general manager, with a list of written questions to be answered. We chose to conduct unstructured interviews because most of the information we gathered was technical and a formal sit-down interview was not necessary to collect this data. Also, the employees we interviewed are very busy and the interviews work better if they are given a list of questions which they can answer at their leisure. Many of our questions required research by these people and the answers were given to us in written formats, such as water bills.

Engineers were interviewed in order to gather information on various topics. Schematics of the plant and the plumbing system were obtained. Also, the engineers acted as our intermediaries with the rest of the employees. They helped us obtain the equipment we needed to complete our analyses of the processes in the plant. Finally, the engineers guided us as to which direction our project should take.

The chemists were also very important to our project. In-depth information on the three washing processes as well as an annual report were given to us by the chemists. Also, equipment was supplied to us so that we could measure the flow rates of some of the processes. Data on the quality of the water leaving the plant as well as government standards for industrial wastewater were also provided by the chemists. The total flow per minute of water into the plant was also gathered through interviews with the chemists. The chemists provided further aid by arranging an interview with the chemical engineer in charge of the proposed treatment plant, Gerardo González.

The maintenance personnel aided us by giving us an initial tour of the plant. Data on the location of the water meters was provided by the maintenance department as well. The destination of water out of the meters and into the plant was provided by the maintenance personnel.

Our interviews with the records department were used to determine the consumption and cost of public water in the plant. They provided us with monthly water bills from January 1998 through April 1999. The quantity of water flowing through each meter from January 1998 through April 1999 was also provided by the records department.

Production worker interviews were performed in order to gather more detailed information on how the processes are performed. We identified areas where individual employee practices resulted in unnecessary water usage. The contents of some of the washing tanks in the enameling process were obtained through a production worker interview.

We presented Sr. Rodriguez, general manager, with a list of questions because he is very busy and it was not possible to conduct a formal interview with him. He is often out of the plant, travelling to other countries to discuss business matters.

We conducted a structured interview with Gerardo González, chemical engineer, to gather information on the proposed treatment plant. We decided on a structured interview because he usually works in an office setting and had many important documents available to us in his office. Sr. González provided us with a large amount of valuable information on many aspects of our project. He explained the planned treatment plant for the chemical tanks in great detail. Sr. González provided us a copy of the current laws regarding industrial pollution standards in a variety of settings. Also, he explained many of Atlas' previous attempts to reduce public water consumption and why they have failed. He explained a few more possibilities for reduction which Atlas has created and gave us some ideas on areas for us to concentrate. He pointed out community problems regarding construction of the treatment plant and its proximity to nearby homes. Finally, Sr. Gonzalez identified another goal of our project, to reduce the flow of water entering the treatment plant in order to reduce the size and therefore cost of the treatment plant.

We examined records of flow rates and compared them to overall water consumption. We compared monthly water consumption with monthly water cost and determined the cost of public water. This data was then used to predict potential savings from public water use reduction. The location of the water meters was determined and used to decide where the most water was being used, in other words, a water audit was performed. We used this information to decide on which processes to concentrate.

We organized all of the information gathered from organizational records, observations, interviews, and water audit into a database. Once the information was put into the database, we analyzed the data and made recommendations to Atlas Industrial. We placed the process information, water bills, meter records and cooling water flow rate data into spreadsheet format.

The process information was analyzed by calculating the quantity of water each step used on a per minute and daily basis. This data was then used to determine which steps used the most public water per day. We then focused on these high-use steps as possible solutions to the problem. The process information was also organized to display the chemical composition of the water in the different tanks.

Composition and flow rates were used to find the recycled water flow rates found in the recommendations section. We assumed that public water contained no contaminants in these calculations. In the pickling process we determined a flow rate by setting an arbitrary maximum limit of 150 mg/L for suspended solids. Suspended solids were chosen because the ratio between the level of solids in the first and second rinse are the closest to one, with the exceptions of trace contaminants. We determined the flow rates of municipal and recycled water entering the first rinse by performing a material balance on suspended solids. We then found water quality using the flow rates and the water quality of the recycled water. In the phosphating process, the predicted water quality of the first rinse, was determined by adding the contaminants in the final rinse to those already in the rinse water. Complete calculations for both processes are provided in Appendix C.

Water bills were organized by month and meter and can be found in the results section. (Table 4.1) Two spreadsheets were created, one showing the consumption of water per meter per month and the other showing the cost of water per meter per month. The monthly totals were combined to yield public water consumption and cost for 1998 totals per meter as well as for the entire plant. The cost total was divided by the total consumption to determine an average price per cubic meter of public water. The conversion rate we used was $1 US= ¢280 CR, this was the approximate conversion rate for June 1999.

The meter records were analyzed in spreadsheet format to determine which meters were being used most efficiently and also to see which processes use water most consistently. Interviews were conducted with the maintenance personnel to determine where each meter was located and where each meter delivers water in the plant. Using AutoCad, the location and direction of water meters and pipes were drawn on the plant floor plan.

In the plant there is a cooling system for a foam injection machine which runs its water directly into a drain in the floor and into the river. This water is clean and can be used for other purposes. We analyzed the flow of water coming out of this hose by timing how long it takes to fill a 5 gallon bucket with this water. These tests were performed at different times on 3 different days in order to gather an accurate average. There is also a heavily leaking faucet located close to the cooling water pipe. The leak rate of this faucet was determined by measuring the volume of water lost in a one minute period. This test was repeated five times and an average was generated. We researched drip-type irrigation systems as one means of reusing the cooling water.

Research was also performed on drip irrigation systems to make use of plant wastewater. We counted the number of trees and shrubs around the factory. From this data we found the number off emission devices and the water needed to irrigate the plants around the factory, by using a table provided in "Low-Volume Irrigation Design and Installation Guide" a Rain-bird guide.

In conclusion we proceeded with several steps. We familiarized ourselves with the plant by doing several tours. We conducted both structured and unstructured interviews with engineers, scientists and maintenance personnel. We measured flow rates of water in different areas of the plant during different times of day. We collected information regarding the cost and consumption of public water. All data was organized and analyzed in spreadsheet format in order to make rational recommendations to Atlas Industrial, S.A.

4.0 Results and Analysis

4.1 Introduction to Results and Analysis

In the four week period from May 15 to June 15, 1999, we gathered the necessary data to complete this project. We collected data on the cost and consumption of public water at Atlas Eléctrica's Heredia plant. We also learned where the water meters are located and to which sections in the plant each meter delivers water. We also gathered information on the manufacturing processes using water, the current environmental laws in Costa Rica and identified possible areas for reduction. The following sections detail and analyze all of the information we collected.

4.2 Monthly Public Water Consumption

We obtained the water bills for the period of January 1998 to April 1999 from the records department. The data was analyzed in spreadsheet format to determine yearly consumption by meter as well as for the whole plant. The 1999 data was not included because it is incomplete and inconsistent.

Table 4.1 Monthly Public Water Consumption in Meters Cubed

Month	Meter Number						
	8	**80**	**707604**	**707605**	**707626**	**776151**	**Total**
January, 1998			1908	87	0	7640	9635
February			2279	735	0	8730	11744
March			828	1622	0	6280	8730
April			1147	2074	1	7550	10772
May			834	2241	92	8497	11664
June			422	3499	557	8103	12581
July			1217	2409	730	8103	12459
August			1166	1751	0	8103	11020
September			1080	3031	0	12084	16195
October			1151	664	0	12690	14505
November	3996		1021	321	0		1342
December	9793		922	478	0		1400
1998 Totals	**13789**	**0**	**13975**	**18912**	**1380**	**87780**	**135836**

Heredia, City of. Monthly water bills for Atlas Industrial. 1998-1999.

Table 4.1 displays the consumption of water in meters cubed by month and meter. Totals for 1998 are in bold. Meter number 776151 was replaced by meter number 8 in November 1998.

Atlas used about 135,836 meters cubed in 1998. However in November and December the major meter for the plant was broken. Water consumption for the plant during those two months is unclear.

4.3 Monthly Public Water Cost

The water bills for the period of January 1998 to April 1999 were also analyzed in spreadsheet format to determine yearly cost by meter as well as for the whole plant. As with the consumption, the 1999 data was not included because it is incomplete and unclear.

Table 4.2 Monthly Public Water Cost in Colones

Month	Meter Number						
	8	**80**	**707604**	**707605**	**707626**	**776151**	**Total**
January, 1998			257505	11670	1950	1031325	1302450
February			307590	99150	1950	1178475	1587165
March			111705	218895	1950	847725	1180275
April			154770	279915	1950	1019175	1455810
May			112515	302460	12345	1147020	1574340
June			56895	472290	75120	1093830	1698135
July			164220	325140	98475	1093830	1681665
August			157335	236310	1950	1093830	1489425
September			145725	409110	1950	1631265	2188050
October			155319	89565	1950	1713075	1959909
November	539385		137760	43260	1950		722355
December	1723463		162167	84023	2535		1972188
1998 Totals	**2262848**	**0**	**1923506**	**2571788**	**204075**	**11849550**	**18811767**
					280 Col/$	**dollars**	**67184.88**

Heredia, City of. Monthly water bills for Atlas Industrial. 1998-1999.

The cost of water is organized by meter and month as well as in total. A conversion rate of 280 colones to 1 U.S. dollar was used to determine the yearly cost for 1998 in dollars.

In 1998, Atlas spent 18,811,767 colones on water, or $67,105. Dividing the total amount spent by total meters cubed consumed, we determined that the cost of water is approximately 140 colones per cubic meter or $0.50 per cubic meter.

4.4 Phosphating Process Effluent Data

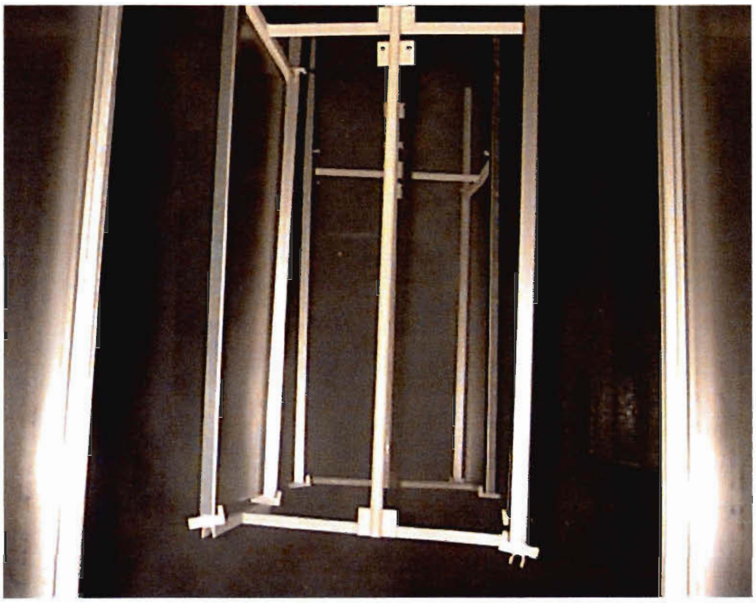


Figure 4.1 Photograph of Entrance to the Phosphating Tunnel
A refrigerator frame is passing into the tunnel.

The phosphating process utilizes a variety of chemicals which are released in acceptable levels on a continuous basis. At times, the chemical tanks are emptied and larger amounts of chemicals are released into the effluent water. Table 4.3 outlines the individual steps in the phosphating process.

Table 4.3 Phosphating Process Description

Tank Number	**Tank Volume**	**Product Used**	**Purpose**	**Flow Rates**	**Tank Renovation**
(Steps)	**(Gallons)**	**(Name)**	**(Use)**	**(Gl/min)**	**(Bath Life)**
1	1200	Alkaline Degreaser	Steel Cleaner	N/A	Every 2 months
2	400	Water	Rinse	15	Daily
3	400	Phosphoric Acid	Rinse	N/A	Daily
4	750	Phosphate	Corrosion Protection	N/A	Every 2 months
5	400	Water	Rinse	20	Daily
6	400	Zirconium Sealant	Sealing Rinse	N/A	Daily
7	N/A	Direct Water	Final Rinse	20	N/A
		(Not Recycled)			

González, Manuel. Personal Communication. 20 May 1999.

Table 4.4 Phosphating Rinse Tank Effluent Data

Comparison of Current Costa Rican Effluent Standards with the Phosphating Process Effluent Data

Chemical Name	**Current Costa Rican Standards (mg/L)**	**Concentration Found In Effluent (mg/L)**
Biochemical Oxygen Demand	300	3.375
Chemical Oxygen Demand	1000	5.8
Total Suspended Solids	500	15.75
Reaction to Blue Metal	10	3.38
Zinc	10	0
Greases & Oils	100	6
Phosphates	Not currently regulated	6.145
Combined Solids	1500	0
Nitrates	Not currently regulated	438.25
Sedimentary Solids	1	0
pH	6 to 9	6.4
Fluorine	10	2.8

Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

The rinse water produced in the phosphating process meets current Costa Rican water quality standards as shown in Table 4.4. Information is provided for all of the chemicals for which data was available.

Table 4.5 Phosphating Chemical Tank Effluent Data

Comparison of Current Costa Rican Standards with the Phosphating Process Chemical Tank Effluent Data

Chemical Name	**Current Costa Rican Standards (mg/L)**	**Concentration in Degreaser Effluent (mg/L)**	**Concentration in Phosphating Effluent (mg/L)**	**Concentration in Sealant Effluent (mg/L)**
Biochemical Oxygen Demand	300	2106.7	3.9	0
Chemical Oxygen Demand	1000	17,016.90	10,038	10.2
Total Suspended Solids	500	226	324.7	14
Reaction to Blue Metal	10	26.8	0.46	0
Zinc	10	0	0	0
Greases & Oils	100	72.8	32.9	0
Phosphates	Not currently regulated	95.3	2060.2	0
Combined Solids	1500	12,423	8376	615
Nitrates	Not currently regulated	0	0	0
Sedimentary Solids	1	<0.1	<0.1	<0.1
pH	6 to 9	10.1	5.9	7.2
Fluorine	10	0	0	169

Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

The degreaser and phosphate tanks are emptied on a bi-monthly basis, and the sealant tank is emptied daily because of quality control issues. This information is presented in Table 4.3.

Atlas Eléctrica buys all of it's chemicals from Parker Hispania. Figure 4.2 details the exact names of the chemicals used in each step of the phosphating process.

Figure 4.2 Schematic of Phosphating Process

Degreaser	Rinse Water	Acid Rinse	Rinse Water	Sealant	Rinse Water
Bonder VP 10035 TA72		5% H3PO4		Bonder NLD 6800 Gardolen 6800/1 Gardolen 6800/1M Hexaflouric Acid	

Parker Hispania, S.A. Hojas de Datos de Seguridad – DIN. 10 January 1995.

From Table 4.3 daily and yearly water consumption data can be found. This consumption data is presented in Table 4.6.

Table 4.6 Analysis of the Phosphating Process

Total Flow Rate is 55 Gallons/Minute

The tunnel runs 9 hours per day	29700 Gallons / Day
Tanks 2, 3, 5 & 6 are changed daily	1600 Gallons / Day
Total water use per day	31300 Gallons / Day
The factory operates 280 days/year	8764000 Gallons/ Year
Tanks 1& 4 are changed bi-monthly	11700 Gallons/ Year
Total yearly water usage	8775700 Gallons/ Year

Analysis of Table 4.4 shows that the rinse water effluent produced in the phosphating process currently meets Costa Rican Standards for all chemicals used in the process. Table 4.5, which details each chemical tank used in the phosphating process, shows serious violations of Costa Rican environmental law. For this reason Atlas has begun developing a chemical treatment plant. Areas of particular concern include biochemical and chemical oxygen demand, phosphates, combined solids and fluorides.

4.5 Pickling Process Effluent Data

Figure 4.3 Photograph of Pickling Tanks
The operator is shown running the conveyor from degreaser tank to rinse tank.

The pickling process utilizes 3 rinse tanks and 4 chemical tanks. This information is outlined in table 4.6. The data we gathered on the quality of the effluent produced by this process is provided in Tables 4.7 (rinse water) and 4.8 (chemical tanks).

Table 4.7 Pickling Process Description

Tank Number	Tank Volume	Product Used	Purpose	Flow Rates	Tank Renovation
(Steps)	**(Gallons)**	**(Name)**	**(Use)**	**(Gl/min)**	**(Bath Life)**
1	550	Alkaline Degreaser	Steel Cleaner	N/A	Every 2 weeks
2	550	Alkaline Degreaser	Steel Cleaner	N/A	Every 3 weeks
3	550	Hot Water	Rinse	10	Daily
4	550	Cold Water	Rinse	14	Daily
5	400	Hydrochloric Acid	Pickling	N/A	Never
6	550	Water	Rinse	8	Daily
7	550	Sealer	Corrosion Protection	N/A	Daily
			for Porcelain Enamel		

González, Manuel. Personal Communication. 20 May 1999

Degreaser tank 2 is dumped into degreaser tank 1 when tank 1 is emptied. Degreaser tank 2 is refilled. After 1 week degreaser tank is filled with clean degreasing solution. After 2 more weeks the filling pattern is repeated. Therefore, effluent data on degreaser tank 2 is not given, but is included in the degreaser tank 1 information. Also, the hydrochloric acid tank is never dumped and so is not included in the effluent tables. The following tables, 4.7 and 4.8, give specific information on the concentrations of pollutants in the effiuent water produced in the pickling process.

Table 4.8 Pickling Process Rinse Water Effluent Data

Comparison of Current Costa Rican Standards with the Enameling Process Effluent Data

Chemical Name	Current Costa Rican Standards (mg/L)	Concentration In Enameling Rinse Water Effluent (mg/L)
Biochemical Oxygen Demand	300	4.15
Chemical Oxygen Demand	1000	57.5
Total Suspended Solids	500	87.7
Reaction to Blue Metal	10	10.3
Zinc	10	0
Greases & Oils	100	3.76
Phosphates	Not currently regulated	0.26
Chlorine	500	0.11
Nitrates	Not currently regulated	0
Sulfates	500	73.3
pH	6 to 9	6.83
Fluorine	10	0

Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

The rinse water effluent produced by the enameling process currently meets Costa Rican standards for water quality. The exception is reaction to blue metal, which is very slightly above the legal limit.

Table 4.9 Pickling Process Chemical Tank Effluent Data

Comparison of Current Costa Rican Standards with the Pickling Process Chemical Tank Effluent Data

Chemical Name	**Current Costa Rican Standards (mg/L)**	**Concentration in Degreaser Tank 1 Effluent (mg/L)**	**Concentration in Sealant Tank Effluent (mg/L)**
Biochemical Oxygen Demand	300	4750	49
Chemical Oxygen Demand	1000	28807	418.5
Total Suspended Solids	500	407	14
Reaction to Blue Metal	10	3228	0
Zinc	10	0	0
Greases & Oils	100	7110	0
Phosphates	Not currently regulated	0	0
Chlorides	500	0	0
Nitrates	Not currently regulated	0	1.71
Sulfates	500	898	0
pH	6 to 9	12.9	8.85
Fluorine	10	0	2.8

Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

The chemical tank effluent from the enameling process currently exceeds numerous limits existent in Costa Rican law. This is one of the areas targeted by the proposed chemical treatment plant, since the current situation is environmentally unacceptable.

From Table 4.7 the total water used in the pickling process can be derived and is shown in Table 4.10.

Table 4.10 Analysis of the Pickling Process

	Total Flow Rate	32 Gal/min	
The pickling process runs 15 hours per day		28800 Gallons / Day	
Tanks 3, 4, 6, & 7 are changed daily		2200 Gallons / Day	
Total water use per day		31000 Gallons / Day	
The factory operates 280 days/year		8680000 Gallons/ Year	
Tank 1 is changed bi-weekly		14300 Gallons/ Year	
Tank 2 is changed tri-weekly		9533 Gallons / Year	
Total yearly water usage		8703833 Gallons/ Year	

Table 4.8 shows that the rinse water produced by the enameling process is in violation of current Costa Rican laws. The level of the reaction to blue metal test exceeds current legal limits. The levels of the other chemicals present in this water are below the current maximum levels. This water would be useful for a graywater system.

The chemical tanks used in the enameling process contain excessive concentrations of numerous chemicals. This data is shown in Table 4.9. The biochemical and chemical oxygen demands are both well above the limits. The degreaser effluent is particularly harmful, greatly exceeding the limits for greases & oils, sulfates, pH and reaction to blue metal. The chemicals in this water are prime targets for the future treatment plant. Furthermore, the chemical concentrations make this water highly unsuitable for reuse in any of the applications we have recommended.

4.6 Zinc Electroplating Process Effluent Data

Figure 4.4 Photograph of Zinc Electroplating Process

The zinc electroplating process is a relatively small scale operation which produces allowable concentrations of all but one of the chemicals in its effluent water. The level of zinc exceeds current Costa Rican standards.

Table 4.11 Zinc Electroplating Process Effluent Data

Comparison of Costa Rican Standards with Pollutant Levels in the Zinc Electroplating Process Effluent

Chemical Name	Maximum Permissible Concentration (mg/L)	Concentration in Zinc Electroplating Effluent (mg/L)
Biochemical Oxygen Demand	300	37
Chemical Oxygen Demand	1000	529
Total Suspended Solids	500	33
Greases & Oils	100	23
Chromium	2.5	<0.34
Zinc	10	29.3

Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

The zinc electroplating process involves numerous steps which are displayed in table 4.10. The zinc electroplating process is a batch process, and so each tank is operated independently of the others. The process is manually controlled and the pieces of metal are transferred from tank to tank via 5 gallon buckets perforated with many half inch diameter holes for drainage.

Table 4.12 Zinc Electroplating Process Description

Tank Number	Tank Volume	Product Used	Purpose	Flow Rates	Tank Renovation
(Steps)	**(Gallons)**	**(Name)**	**(Use)**	**(Gl/min)**	**(Bath Life)**
1	60	Alkaline Degreaser	Steel Cleaner	N/A	Every 2 weeks
2	60	Water	Rinse	3	Daily
3	60	Hydrochloric Acid	Pickling	N/A	Never
4	200	Zinc Electroplating	Zinc Deposit	N/A	Never
5	60	Water	Rinse	3	Daily
6	60	Chromium Sealer	Oxidation Protection	N/A	Every week
7	60	Hot Water	Remove Excess Cr	N/A	Daily

González, Manuel. Personal Communication. 20 May 1999.

Daily and yearly water use data can be derived from Table 4.12 and is shown in Table 4.13.

Table 4.13 Analysis of the Zinc Electroplating Process

	Total Flow Rates =	6 Gal/min	
The zinc electroplating process runs 9.5 hours per day		57 Gallons / Day	
Tanks 2, 5 & 7 are changed daily		180 Gallons / Day	
Total water use per day		237 Gallons / Day	
The factory operates 280 days/year		14300 Gallons/ Year	
Tank 1 is changed bi-weekly		1560 Gallons/ Year	
Tank 6 is changed weekly		3120 Gallons/ Year	
Total yearly water usage		18980 Gallons/ Year	

The zinc electroplating process uses, in comparison to phosphating and enameling, a negligible amount of public water. The process currently generates unacceptable concentrations of zinc in its effluent. This forces Atlas to include this effluent in the treatment plant design. Otherwise, the process is well within legal standards.

The zinc which is currently being wasted in this process could be filtered out mechanically or chemically, purified and run back into the process. This would be doubly beneficial for Atlas, by both reducing the amount of zinc purchased as well as eliminating the need to run this wastewater through the treatment plant. This would allow Atlas to build a slightly smaller treatment plant.

4.7 General Environmental Law

We obtained a copy of the current laws and regulations regarding the Costa Rican environment and pollution. This information was translated and relevant portions have been included in the following section.

Chapter 12: Water

Article 50: Public Domain of Water

Water is part of the public domain, so it's conservation and sustainable use are of social interest.

Article 51: Criteria

For the conservation and sustainable use of water, the following criteria, along with others should apply:

a). protect, conserve and if possible, recuperate aquatic ecosystems and the elements that intervene in the hydrologic cycle.
b). protect the ecosystems that allow a regular hydrologic regimen
c). maintain the equilibrium of the water system, protecting all of the components of the river basins

Chapter 13: Soil

Article 53: Criteria

To protect and profit from the soil, the following criteria, along with others, must be taken into consideration:

a). the adequate relationship between potential use and the economic capacity of the soil and subsoil.
b). practical control of erosion and other forms of degradation
c). the practices or works of conservation of soil and water that prevent the deterioration of the soil.

Article 55: Restoration of Soil

The State should format the execution of the plans for restoration of soil in national territories.

Chapter 15: Pollution

Article 59: Environmental Pollution

Pollution is all of the alteration or modification of the environment that damages human health, crimes against natural resources or crimes that affect the environment in general of the State. The discharge and emission of contaminants, will be adjusted, obligatorily, to meet the regulations for emission. The State adopts the necessary rights to prevent or correct environmental pollution.

Article 60: Prevention and Control of Pollution

To prevent and control environmental pollution, the State, the municipalities, and other public institutions, are given priority, along with others, to establish and operate adequate services in the fundamental areas for environmental health like:

a). the supply of water for public consumption
b). the sanitary disposal of human waste, industrial wastewater and plumbing wastewater
c). the reuse and management of waste
d). the control of atmospheric pollution
e). the control of sound pollution
f). the control of chemical and radioactive substances

The services will be presented in the form of laws and specific regulations that determine and see that the population and it's organizations abide by the rules.

Article 64: Prevention of Water Pollution

In order to avoid water pollution, the authorities will regulate and control the use so that the profiting from the water will not alter the quantity and quality of the resource, following the corresponding limits.

Article 65: Treatment of Residual Water

Residual water from whatever origin should receive treatment before it is to be discharged into rivers, lakes, oceans and other bodies of water; furthermore, the acceptable quality should be established for the body receiving the waste, following the actual use and the potential use and for the future use in other activities.

Article 66: Responsibility for Treatment of Waste

Whenever the use or profiting from the water makes it susceptible to producing pollution, the responsibility of treatment of the waste is put on whoever produced the pollution. The authorities will determine what is considered adequate technology and establish the necessary deadlines for which the technology should be implemented.

Article 67: Pollution or Deterioration of River Basins

The people, physical or jurisdictional, public or private, will be obligated to adopt adequate laws to impede or minimize the pollution or deterioration of river basins, following the classification of actual use and potential use of water.

Article 68: Prevention of Soil Pollution

It is the obligation of the people, physical or jurisdictional, public or private, to avoid soil pollution by accumulation, storage, reuse, transport or inadequate final disposal of toxic substances or other substances that put the environment in danger. (1)

The current laws in Costa Rica give its citizens a right to a clean environment. Regulations are set to prohibit excessive pollution. Atlas is building a treatment plant in order to limit dumping contaminants into the river, thus, cleaning the area for the local people, as well as to meet present and future regulations. Many of the articles of the general law outlined in Section 4.8 refer to “prevention and protection” which Atlas takes seriously and tries hard to comply with.

4.8 Possible Areas for Consumption Reduction

Water is run through machinery in the plant to prevent overheating. The cooling water for a foam injection machine currently flows out of the cooling system and into the river. Flow rates are given in Table 4.11 along with the dates and times the samples were taken.

Table 4.14 Cooling Water Flow Rates

Date	Time of Day	Trial #	Volume(Gal)	Time(minutes)	Flow Rate
5/31/99	11:00	1	5	3.39	1.474926
5/31/99	11:00	2	5	3.334	1.4997
5/31/99	11:00	3	5	3.372	1.4828
6/1/99	9:30	4	5	5.466	0.914746
6/1/99	9:30	5	5	5.077	0.984834
6/1/99	9:30	6	5	4.919	1.016467
6/1/99	12:30	7	5	3.896	1.283368
6/1/99	12:30	8	5	3.695	1.35318
6/1/99	12:30	9	5	4.062	1.230921
				Average Rate	**1.248993**

There is a sink near the drain for the cooling water. The faucet for this sink cannot be fully turned off. The flow rates for this faucet in the most closed position are listed in table 4.12 as are the dates and times the samples were taken.

Table 4.15 Sink Flow Rates

Trial #	Volume	Time	Volumetric Flow Rate	Date	Time of Day
	mL	Minutes	Gallons/Minute		
1	950	1	0.250859375	6/7/99	12:00
2	1000	1	0.2640625	6/7/99	12:03
3	890	1	0.235015625	6/7/99	12:06
4	950	1	0.250859375	6/7/99	12:09
5	930	1	0.245578125	6/7/99	12:12
Conversion Factor =		**0.000264063**	**Gallons/mL**		
Avg Flow Rate =		**0.249275**	**Gallons/Minute**		

There are several other pipes and joints that leak, but flow rates were not gathered for these leaks.

From Tables 4.14 and 4.15 the average flow rates of cooling water and faucet leaks can be determined. The cooling water is released at an average of 1.25 gallons per minute. The leaking faucet drips at .25 gallons per minute. Together the pipe and faucet waste 788,400 Gallons of water per year. Along with the other leaks throughout the factory, over 1,000,000 gallons of water are wasted per year.

5.0 Conclusions and Recommendations

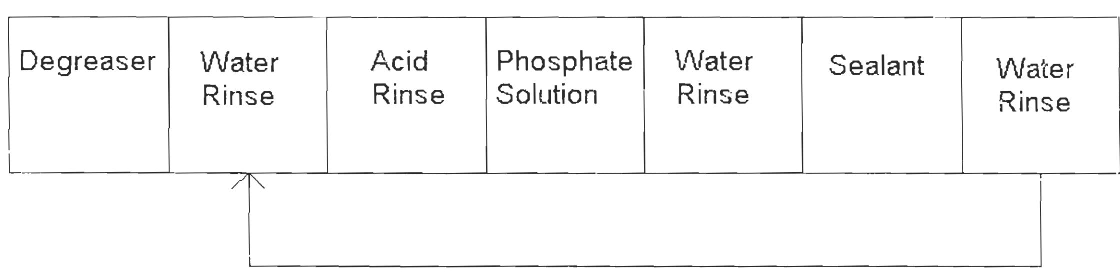
5.1 Introduction to Recommendations

After weeks of research and observation at Atlas Eléctrica, we have produced four recommendations for changes in public water consumption. Two of the washing processes and the non-recycled cooling water yielded changes, in addition to simpler housekeeping changes. Each of the four recommendations are detailed in the following sections.

5.2 Recycling Water in the Phosphating Process

Washing processes account for the majority of Atlas's water consumption. The washing processes are also where the most water is wasted. The most obvious of these wastes is the final rinse of the phosphating process. This water is very clean; however, it is not recycled. We recommend pumping the water from the final rinse into the initial rinse, as shown in Figure 5.1.

Figure 5.1 Diagram of Water Reuse in the Phosphating Process



Recycling the final rinse water at a rate of 15 gallons per minute will have a small effect on the water quality of the initial rinse, shown in Table 5.1. By recycling the water from the final rinse into the initial rinse, the public water going into the initial rinse will be eliminated. This recycling option will save Atlas 2,268,000 gallons of water per year, and approximately 1,176,000 colones or $4,200. The initial investment of pipes running from the final rinse to the initial rinse would be approximately $370 plus manpower. Thus, the savings the first year would be $3,830.

Table 5.1 Quality Effects of Using the Final Rinse Water in the Initial Rinse of the Phosphating Process

Chemical Name	Current Concentration Found In Rinse 1 (mg/L)	Predicted Concentration Found In Rinse 1 (mg/L)
Biochemical Oxygen Demand	3.6	3.6
Chemical Oxygen Demand	<5.8	<10.6
Total Suspended Solids	16	31.5
Reaction to Blue Metal	1.3	1.6
Greases & Oils	6.3	<6.9
Phosphates	4.16	4.16
Fluorine	0	2.8

Compiled by the project team. Complete calculations provided in Appendix C.

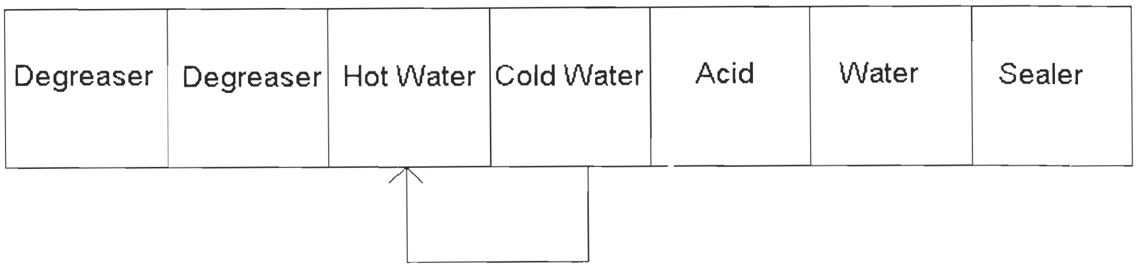
The decrease in the water quality within the first rinse is shown in terms of milligrams per liter.

5.3 Recycling Water in the Pickling Process

The next process where we recommend recycling the water is in the pickling process. Water in the second rinse is much cleaner than in the first rinse. 3.77 gallons per minute of the second rinse can be mixed with 6.23

gallons per minute of public water and pumped into the first rinse, as shown in Figure 5.2.

Figure 5.2 Diagram of Water Reuse in the Pickling Process



This recycling option will reduce Atlas's yearly water consumption by 950,000 gallons, which translates to a savings of 503,788 colones or $1,799 per year. The initial outlay of running pipes between the two rinses would be $66 plus manpower. Thus, the savings the first year would be approximately $1,733. One downside of this option is that it will slightly decrease the water quality in the first rinse. The difference, under the assumption that public water contains no contaminants, is shown in Table 5.2. The dirtier the initial rinse can be, the more water can be recycled. Recycling this water has another drawback. The water in the initial rinse is heated. The second rinse is at room temperature. To offset the temperature difference, the incoming public water must be heated.

Table 5.2 Quality Effects of Using the Second Rinse Water in the Initial Rinse of the Pickling Process

Chemical Name	**Current Concentration in Pickling Rinse Water Effluent (mg/L)**	**Predicted Concentration In Pickling Rinse Water Effluent (mg/L)**
Biochemical Oxygen Demand	6	6.4
Chemical Oxygen Demand	126.6	129.4
Total Suspended Solids	127	143
Reaction to Blue Metal	28.9	29.5
Greases & Oils	<0.5	unknown
Phosphates	0.45	0.53
Sulfates	220	220

Compiled by the project team. Complete calculation provided in Appendix C.

The decrease in the water quality within the first rinse is shown in terms of milligrams per liter.

5.4 Reusing Cooling Water

The cooling water has two possibilities for reuse. The first is to extend the pipe out to the reserve tank near the compression area. This would only require some piping and would save Atlas 189,000 gallons of water per year. The cost of the pipes is $290 plus manpower. Reusing this water would save Atlas 100,227 colones or $358 yearly, or $68 the first year in order to cover the initial outlay costs. The other option for this water would be to use it in a drip irrigation system for the trees and bushes surrounding the plant. The irrigation system would require the installation of a storage tank, a pump, PVC pipe, underground tubing and emission devices. The initial investment in the irrigation system is

$60 for the pipes and $1,200 for the drip irrigation system plus manpower, thus the payback period would be just under four years. This system would save water lost in the inefficient irrigation practices Atlas currently uses, in addition to the 189,000 gallons saved by just reusing the water.

5.5 Miscellaneous Conservation

Our final recommendation is to fix the leaky faucets and valves throughout the plant. There are a large number of small leaks throughout the plant that could be fixed by replacing washers or o-rings, which cost under $.25 per part. Examples of these leaks are valves in the tunnel and a sink whose faucet cannot be turned off. The sink that cannot be turned off is located behind the dryer in the plant. The amount of water this would save is unknown but is expected to be over 500,000 gallons per year, which is 265,152 colones or $947 per year.

5.6 Cost-Benefit Analysis

In total, if all four recommendations are put into use, Atlas would reduce their yearly water consumption by approximately 3,907,000 gallons, which is a savings of 2,071,894 colones or $7,400 per year. Implementing the four ideas, with the drip irrigation option, the total initial outlay costs are $1700. The total initial outlay costs, with the reservoir option would be $500. First year savings with the irrigation option would be $5700, or $6900 with the reservoir option. Atlas would cut their annual public water consumption by 11% if all four recommendations were implemented. This reduction would provide a financial benefit for Atlas as well as aiding the local community by preventing water shortages during the summer.

5.7 Conclusions

We do not recommend that Atlas install a motion sensor system in the phosphating tunnel because the systems are expensive, require complex controls and have limited saving potential. However, we do recommend that Atlas install solenoid valve pH sensors in the phosphating tanks. This is an option which Atlas has already researched. The initial cost is low and the systems do not require heavy maintenance.

We recommend that Atlas research and observe the manufacturing practices of similar corporations. It may be possible to eliminate the final rinse as corporations in Europe do not use it and do not have a resulting decrease in quality.

5.8 Recommendations for Future Projects

Other issues Atlas should look into in the future and could be elaborated on through future Interactive Qualifying Projects are outlined below. The first area that needs to be looked into is the feasibility of chemical recycling which would eliminate the necessity of the treatment plant. Another possible project would be to have students look into sales trends in order to predict the market for each color of refrigerator. This project would allow Atlas to buy pre-painted sheet metal and would eliminate the need for the phosphating tunnel, dryer and painting sections.

6.0 Appendix A

Mission and Organization of Atlas Eléctrica

Atlas Eléctrica, S.A. is a Costa Rican manufacturing corporation. The primary products of Atlas are ranges, cook tops, refrigerators and microwaves. Sixty-six percent of the products are exported to four other Latin American countries. Atlas currently employs 800 people at their facility in Heredia. Atlas was incorporated under the Bolsa Nacional de Valores in 1976. (4) In 1995 Electrolux bought a 20% share in Atlas, with the option to increase their shares in the future. Other brands under the Electrolux conglomerate are Westinghouse and Kenmore.

Vision: *Atlas Eléctrica will be a leader in the markets in which it participates. Our products will be competitive in the world market and will be focused on the improvement of the quality of life of our consumers.*

Mission: *To design, manufacture and market products that will improve the quality of life of our consumers. We will achieve this by:*

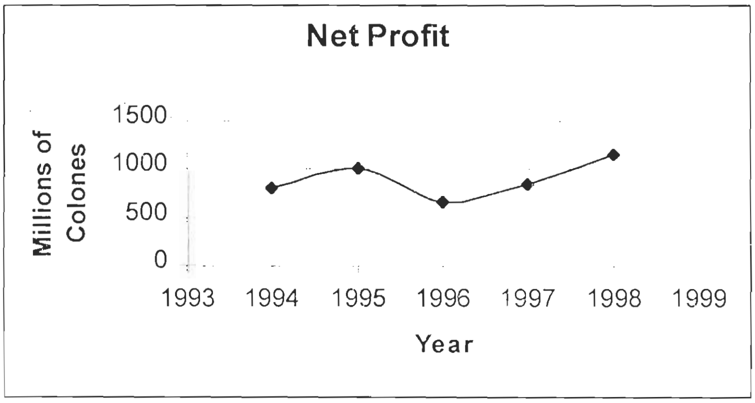
- Obtaining competitive profitability for our shareholders
- Safe-guarding the interests of our customers and employees
- Investing in the development of our human resources
- Assuming a proactive role in the marketing of our products
- Assuming a responsible position in preserving the environment

Values:

Ethical behavior	Excellence	Leadership
Pro-activity	Boldness	Creativity
Innovation	Good Citizenship	

In 1998, Fred Aspinall, Chairman of the Board of Atlas Eléctrica, reported that sales increased over 1997 by 34% and net profit increased over 1997 by 26%. (33)

Figure A.1



Zúñiga, Julio. Private Communication. 5 April 1999.

One of Atlas's mission statements is to, "assume a responsible position in preserving the environment." Atlas just set a precedent for other countries in the world by replacing all CFCs in their refrigerators with ozone-friendly gases in 1998. The Montreal Protocol set a 2005 deadline for all countries to substitute ozone-friendly gases for their ozone-depleting gases in all their products, so Atlas met the deadline almost seven full years ahead of schedule.

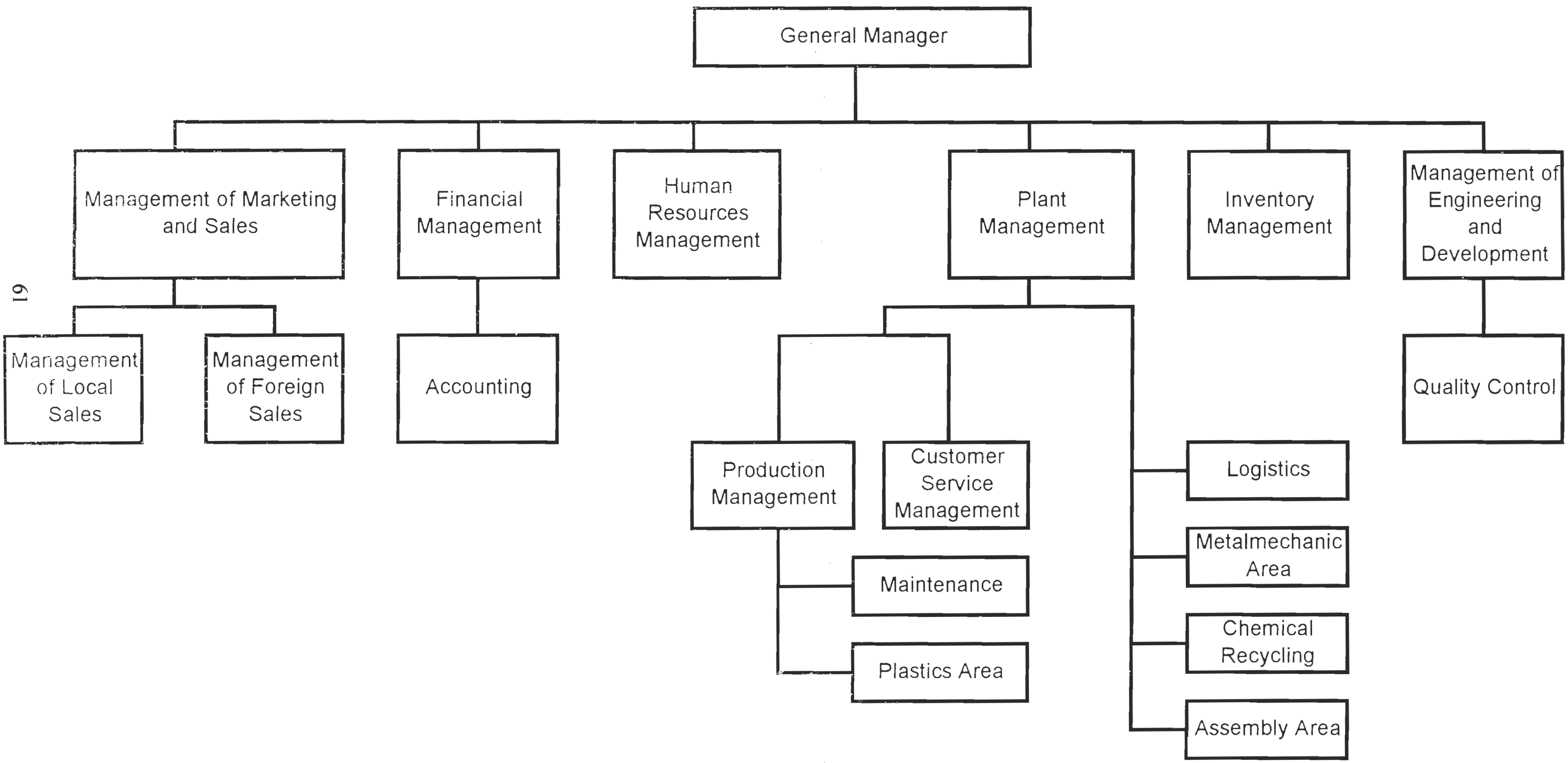
Also in 1998, Atlas expanded its network of service centers to include four new centers in Costa Rica. The company has also added service centers in Guatemala, El Salvador, Honduras and Nicaragua, where all employees are trained by Atlas employees from Costa Rica.

Atlas Industrial, the plant of Atlas Eléctrica, uses a large amount of water in metal coating processes. The entire plant uses approximately 100 gallons of water per minute. (9) They desire to reduce their overall water consumption and by doing so, reduce overhead costs as they expect production to increase 30% in 1999. Reducing the overall public water consumption at Atlas would allow expansion of production facilities, thereby creating more jobs. Also, reducing the public water cost will provide capital needed to construct a chemical treatment plant in November 1999. This reduction in public water consumption will also benefit the administration of Atlas because it will improve the company's relations with the local people, many of whom work at Atlas and utilize the same source of public water in their homes and schools.

At Atlas we worked closely with our liaison, Julio Zúñiga, project engineer. Sr. Zúñiga is head of projects in the development department. We also worked closely with Manuel González, plant chemist. Sr. González is in charge of the recovery of chemicals in the washing processes and works directly under the general director of the plant. An organizational chart is included as Figure A.2.

Figure A.2
Organizational Chart

Atlas Eléctrica, S.A.



Atlas Eléctrica, S.A. Organigrama. 3 June 1999.

6.0 Appendix B

Comparative Figures Between Costa Rica and Other Central American Countries

Definitions of terms and acronyms to better understand economic interpretation:

GNP Gross National Product

GDP Gross Domestic Product

PQLI Physical Quality of Life Indicator

The PQLI Index measures development in non-economic terms. The index takes countries' literacy rate, infant mortality rate and life expectancy into account. In 1981, the average PQLI for developing countries was 61 and the PQLI for developed countries was 96. (5, p.24)

Table B.1 Central American Populations, 1998

Populations	**Costa Rica**	Mexico	Guatemala
1998	**3,650,000**	95,831,000	11,562,000
El Salvador	Nicaragua	Honduras	Panama
6,059,000	4,464,000	6,147,000	2,767,000

World Resources Institute. World Resources 1998-1999. New York: Oxford University Press, 1998, p.245.

Table B.2 Costa Rican Economics, 1987

Costa Rica

GNP/Capita 1987	**GNP/Capita Growth 1965-1987**	**Industry as a Percentage of GDP 1987**	**PQLI Index 1985**
1,610	**1.5**	**29**	**91**

Austin, James E. Managing in Developing Countries. New York: The Free Press, A Division of Macmillan Co., Inc., 1990, p. 377.

Table B.3 Central American Economics, 1987

	GNP/Capita 1987	GNP/Capita Growth 1965-1987	Industry as a Percentage of GDP 1987	PQLI Index 1985
Panama	2,240	2.4	18	Not available
Mexico	1,830	2.5	34	80
Guatemala	950	1.2	Not available	Not available
El Salvador	860	-0.4	22	69
Nicaragua	830	-2.5	34	71
Honduras	810	0.7	24	63

Austin, James E. Managing in Developing Countries. New York: The Free Press, A Division of Macmillan Co., Inc., 1990, pp. 376-377.

Unlike most developing countries, Costa Rica has been stable for decades, as has Mexico. Most likely, the stability of Costa Rica can be attributed to their lack of a military and ability to solve conflicts peacefully. A democratic government also contributes to stability, since most governments that fail are authoritarian. (5, p. 58)

Table B.4 Costa Rican Economics, 1995

Costa Rica

GNP/Capita 1995	GDP/Capita Growth 1985-1995	Industry as a Percentage of GDP 1995
2,610	4.5	24

World Resources Institute. World Resources 1998-1999. New York: Oxford University Press, 1998, p.237.

Table B.5 Central American Economics, 1995

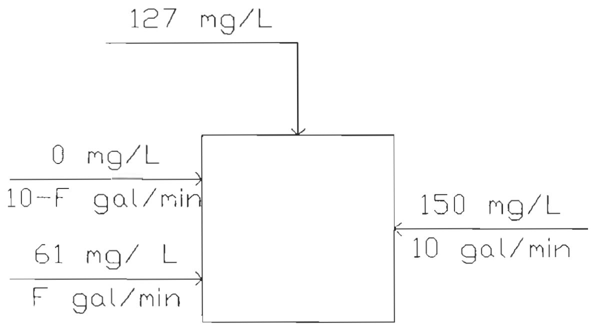
	GNP/Capita 1995	GDP/Capita Growth 1985-1995	Industry as a Percentage of GDP 1995
Panama	2,750	2.3	15
Mexico	3,320	1.0	26
Guatemala	1,340	3.3	19
El Salvador	1,610	4.0	22
Nicaragua	380	Not available	20
Honduras	600	3.2	33

World Resources Institute. World Resources 1998-1999. New York: Oxford University Press, 1998, p.237.

In many developing countries the macroeconomic situation and business environment are significantly affected by loans and economic aid provided by developed country governments and such multilateral agencies as the International Monetary Fund (IMF) and the World Bank. (5, p. 2)

6.0 Appendix C
Flow Rate and Water Quality Calculations

Pickling Process Calculations



127 + [61F + 0(10-F)]/10 = 150
F = 3.77Gal/min
F = flow rate from rinse 2

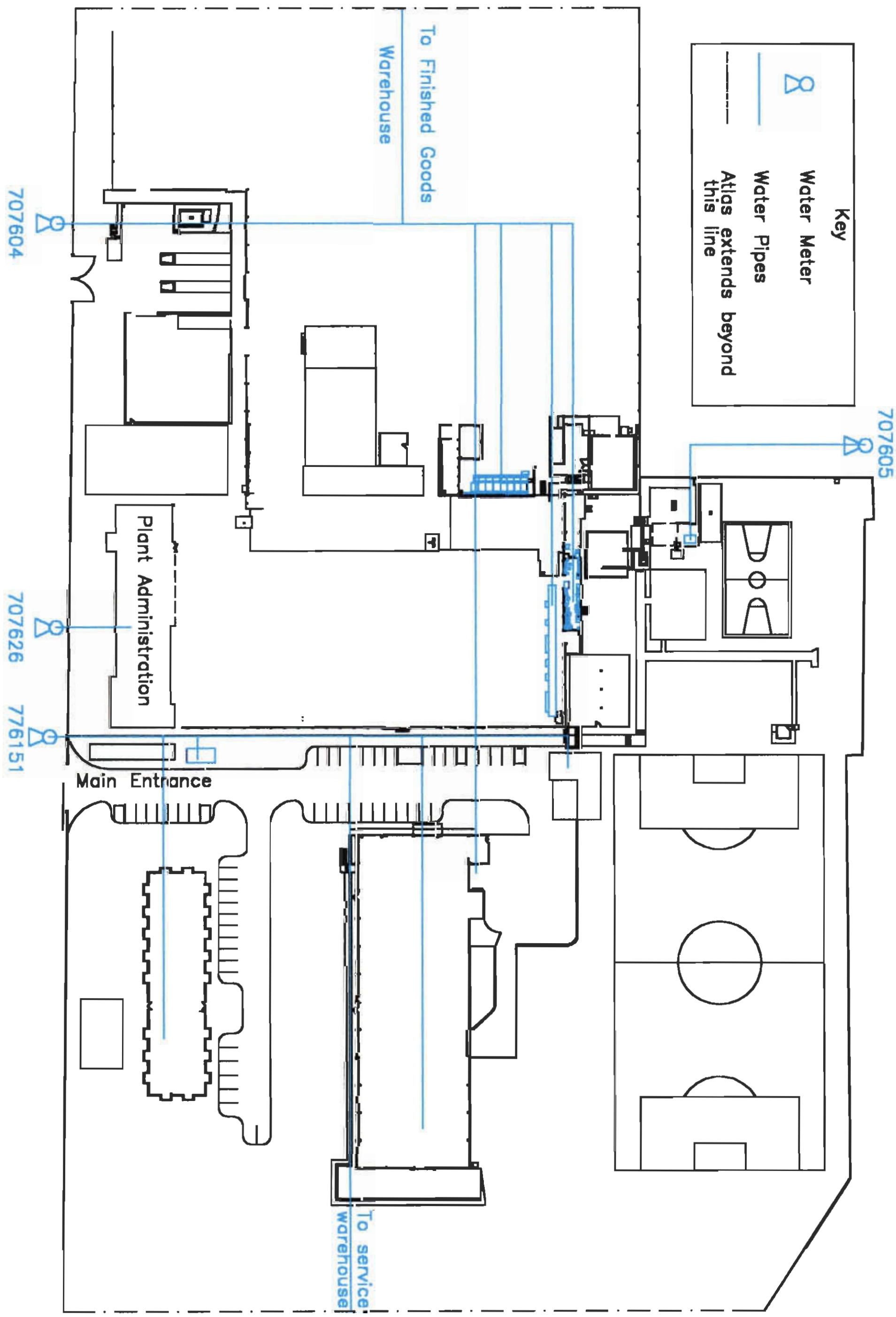
Biochemical Oxygen Demand
6 + (.377 * 1.45) 6.54665
Chemical Oxygen Demand
126.6 + (.377*10.9) 130.7093
Reaction to Blue Metal
28.9 + (.377*2.01) 29.65777
Greases & Oils
Negligable
Phoshpates
.45 + (.377* .33) 0.57441

Phosphating Process Calculations

Chemical Oxygen Demand
<5.8 +<5.8 = <11.6
Suspended Solids
16 +15.5 = 31.5
Greases & Oils
6.3 + <0.6 = <6.9

6.0 Appendix D

Location of Water Meters



7.0 References

(1) La Asamblea Legislativa de la Republica de Costa Rica. Official Journal: General Laws Regarding the Environment. 1995.

(2) La Asamblea Legislativa de la Republica de Costa Rica. Official Journal: Specific Regulations Regarding the Environment. 1995.

(3) Atlas Eléctrica, S.A. Organigrama. 3 June 1999.

(4) Atlas Industrial, S.A. Plan Voluntario de Cumplimiento. January 1998.

(5) Austin, James E. Managing in Developing Countries. New York: The Free Press, A Division of Macmillan Co., Inc., 1990.

(6) DeLollis, Nicholas J. Adhesives for Metal: Theory and Technology. New York: Industrial Press, Inc., 1970.

(7) Freeman, D.B. Phosphating and metal pre-treatment. New York: Industrial Press, Inc., 1986.

(8) Gerstenfeld, Arthur. Personal Interview. 9 Apr. 1999.

(9) González, Manuel. Personal Communication. 20 May 1999.

(10) Gould, Kira L. "The Future: Why are we Flushing Toilets with Water Good Enough to Drink?" Architectural Record Oct. 1998: 236.

(11) Hart, Fred. Personal Interview. 7 Apr. 1999.

(12) Heredia, City of. Monthly water bills for Atlas Industrial. 1998-1999.

(13) Huber, George P., et al. "Understanding and Predicting Organizational Change." Organizational Change and Redesign. Ed. George P. Huber and William H. Glick. New York: Oxford University Press, Inc., 1993.

(14) Kramer, Paul J. and Theodore T. Kozlowski. Physiology of Woody Plants. Orlando: Academic Press, Inc., 1979.

(15) Kruger, Ellen L., Todd A. Anderson and Joel R. Coates. Phytoremediation of Soil and Water Contaminants. Washington D.C. American Chemical Society,1997.

(16) Loher, Raymond C., Colleen S. Martin and Walter Rast. Phosphorus Management Strategies for Lakes. Ann Arbor: Ann Arbor Science Publishers, Inc., 1980.

(17) Parker Hispania, S.A. Hojas de Datos de Seguridad – DIN. 10 January 1995.

(18) Parker Hispania, S.A. Product Information Sheet – Bonder VP 10035. 8 April 1994.

(19) Parker Hispania, S.A. Product Information Sheet – Gardobond 1041 L. 1 March 1996.

(20) Parker Hispania, S.A. Product Information Sheet – Gardolene D 6800/1. 27 February 1996.

(21) Parker Hispania, S.A. Product Information Sheet – TA 1041/1. 27 March 1980.

(22) Phillips, Leonard E. Jr. Urban Trees: A Guide for Selection, Maintenance, and Master Planning. San Francisco: McGraw-Hill, Inc., 1993.

(23) Rain Bird Sprinkler Manufacturing Corporation. 1998 Price List Landscape Irrigation Equipment. 28 September 1998.

(24) Rain Bird Sprinkler Manufacturing Corporation. Low-Volume Irrigation Design and Installation Guide. 1996.

(25) Salisbury, Frank B., Cleon W. Ross. Plant Physiology 4th Ed. Belmont, Ca. 1992.

(26) Spring, Samuel. Preparation of Metals for Painting. New York: Reinhold Publishing Corporation, 1965.

(27) The Toro Company, Irrigation Division. Finished Goods Price List. December 1998.

(28) Walker, Jack M. Handbook of Manufacturing Engineering. New York: Marcel Dekker, Inc., 1996.

(29) Weathers, Pam. Personal Communication. 6 Apr. 1999.

(30) World Resources Institute. Environmental Almanac. Boston: Houghton Mifflin, 1992.

(31) World Resources Institute. World Resources 1998-1999. New York: Oxford Univ. Press, 1998.

(32) Zúñiga, Julio. Private Communication. 26 Mar. 1999.

(33) Zúñiga, Julio. Private Communication. 5 April 1999.

(34) http://atlas.ksc.nasa.gov/celss/rr/gray.htm Loader, Karen. "Gray Water Recycling Directly Through Hydroponic Systems." NASA, KSC. 1997.

(35) http://www.conservancy.com/GW2000/Carlisle/methodology.htm Miami Conservancy District. "Groundwater 2000 Special Feature." 10 February 1999.