CENTRAL ARIZONA SALINITY STUDY—PHASE I

Technical Appendix M

Impact of High and Variable TDS on Central Arizona Industry
Focus on Process and Cooling Water

January 2003

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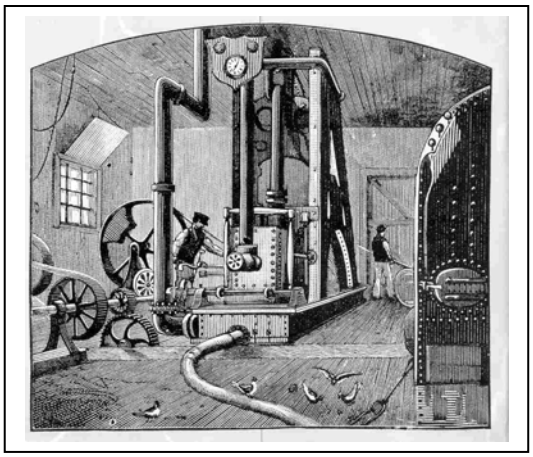
1.0 Introduction

Industry in the greater Phoenix area is dominated by electronics manufacturers, most visible being Motorola and Intel. Other manufacturing includes aerospace, automotive, food, and materials. In Arizona, the total 2001 manufacturing employment stood at 212,600, with approximately 147,000 in the Phoenix Valley. From golf clubs to semiconductor chips, any manufacturing that requires process and cooling water has to accommodate the salinity of the source water. During this extended period of drought, the objectives of water conservation as defined in the DWR are in direct conflict with operation methods that suit the high salinity of source water.

This white paper will define water use and the impact of rising salinity on process and cooling. Typical volumes, costs and issues caused by specific constituents in the water will be outlined with references to source documents of this data. Semiconductor, general manufacturing and power plant use of water for process and cooling will be examined as examples of moderate to high-volume users of water. Future trends and economic impacts are addressed as best known.

2.0 Historical Perspective and Background



The Industrial Revolution in the eastern and central United States was built using water to generate power and move machinery. The steam engine, patented by James Watt in 1769, supplied the power for mass production. Considered free, because it flowed in a river past the factory or near the power plant, water consumption was not deemed a cost of doing business. Contaminated wastewater was returned to the river without a second thought. This mentality migrated to the desert areas of the western US as the irrigated agricultural lands brought people and then industry. To compensate for the salt content of western water, companies just used more for production and cooling, diluting the effects of the salt. Water was then, and still is a cheap commodity. However, the cost of wastewater was finally recognized when EPA regulations gained enforcement clout in the mid 1980's. Today, environmental compliance can range from ½ to 8 percent of revenue, a significant part of total manufacturing and power costs. Reducing a portion of that cost by recycling wastewater within a factory has now become commonplace. Ironically, air quality compliance increases water use for washing out contaminates. Many western power plants now use lower cost treated municipal wastewater as a source of cooling and process water.

2.1 Overview of Economic Impact of Manufacturing

From the 1950's, manufacturers built factories in the Valley because land was cheap and available, labor costs were low and favorable taxes and regulations were common. In the last decade, despite competition from other states, Mexico and China

for those same employers, Arizona's manufacturing increased. From 1991 to 2001, employment increased 18% and Gross State product increased 246%. The largest manufacturing subsector is computer and electronic products. This subsector, in 2001, ranked 10th in total employment (57,378), 5th in earnings ($4.3 million) and contains the 2nd highest paying employers in the state. An abundant supply of water and power is required to keep this subsector paying taxes and salaries
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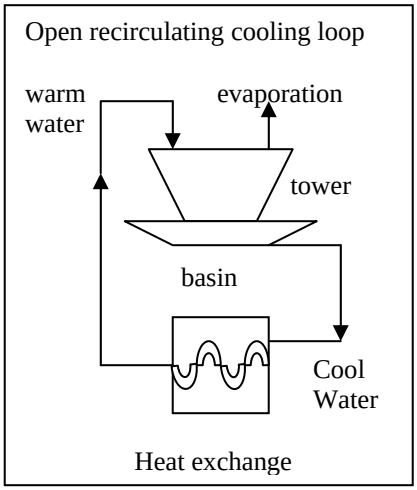
2.2 Overview of Water for Cooling

Desert heat drives the need for cooling the air for human comfort. More than mere comfort, cooling is essential for manufacturing and power generation. Electronic manufacturers control air temperature and humidity in production areas to achieve the highest product quality. Efficient power plant operation requires turbines and power generating equipment be kept cool. And water is the least expensive way to cool air and equipment.

The desert dry air provides a perfect vehicle for evaporation of water. A cooling tower is a low cost method of evaporating water and reducing its temperature. The basic function of a cooling tower is to cool a circulating stream of water by evaporating a portion of it. The cool water is pumped from a tower to equipment that generates a heat load (such as an air conditioning system). There, a heat exchange occurs. The equipment is cooled and the water becomes warmer. The warmed water returns to the tower, is re-cooled and the cycle repeats. The picture to the right is a simplified drawing of that process. Figure 1 in the Appendix, shows a detailed flow diagram with water and salt balances.



The efficiency of a tower depends upon the amount of time the water is in contact with air and control of the water quality. *Fill* supports a thin film of falling water and provides a long contact time with air. Water flows slowly along the intricate surface of the *fill*, which is typically a plastic honeycomb. A large fan at the top of the tower pulls air through the louvers and the fill. A portion of the water evaporates, cooling the remaining water about 10 degrees F. The cooler water sinks to the lowest spot in the tower basin and is supplied to the copper tubes inside of a heat exchanger. Air is cooled as it passes over the copper tubes containing the cool water. This cool air is then used to cool the building. In exchange, the water inside the tubes is warmed and flows back to the tower to start the evaporation process again.

Control of water quality is essential because evaporation in the tower, leaves behind salts, impurities and solids in the recirculating water. In addition, airborne impurities are often introduced into the tower water, intensifying the problem. The purpose of a water quality control system is to suspend those impurities and prevent

them from precipitating as *scale* onto the copper tubes in the heat exchanger or the tower itself. In addition, effective control of these contaminants is needed to prevent corrosion of metal surfaces and biological growth in the cooling system, any one of which can reduce heat transfer efficiency and increase system operating costs. Variations in makeup water quality can require changes in the chemicals used for water quality control, especially when calcium, alkalinity, chloride or silica concentrations vary by more than 10%.

Cooling tower manufacturers offer general guidelines for chemical management but specifically recommend two things – a) do not use acid unless the metal parts of the system are compatible and b) unchecked growth of algae, slimes and other micro-organisms will reduce system efficiency and may contribute to growth of potentially harmful micro-organisms including *Legionella*. Acid is the cheapest way of reducing the pH of alkaline recirculating water and keeping the calcium in solution. Using acid alone, however has proven to be costly in the long run if the dosing meter sticks in the open position and the amount of acid is sufficient to "eat" the tower. This did occur at Bank One Ballpark shortly after it opened.

Cycles of Concentration(COC)is the term used to define the number of times water is used in the tower before it is discharged as *blowdown*. Bleed is the amount of water that must be removed from the tower in order to control the salt content of the recirculating water. COC is calculated as the conductivity of the blowdown divided by the conductivity of the makeup water. Typically a conductivity meter is set to automatically open a discharge valve on the tower basin when the salt content rises to a preset level. Although, conductivity can be related to total dissolved solids, it does not accurately reflect the total salt content of the water. Chemical suppliers such as GE-Betz/Dearborn, and Odeca/Nalco blend dispersant chemicals with acid so that the alkaline pH of western water can be modulated to maximize the cycles of concentration. They publish COC's up to 6 but in practice, cycles vary between 2.5 and 4.5.

Makeup water is typically fed to a tower using a float valve so that both the evaporation and blowdown losses can be automatically replaced. Makeup water volume can be reduced significantly up to a COC between 4 and 6. The ratio of water use and COC is shown in the Table 1. At higher COC, most of the water is lost to evaporation, so the total water savings for higher COC's diminishes to a limiting value. Salinity in the makeup water limits the practical operating COC for a given water quality management program.

Table 1 – Ratio of COC to Water Use

Cycles of Concentration	Gallons per Day per Ton of Cooling
1.5	10,200 gpd
2.0	7,000 gpd
4.0	4600 gpd
6.0	4200 gpd

Another water loss can come from the backwash of a tower filtration system. Many towers have side stream filtration units to prevent buildup of solids, which are the vehicle for growth of microorganisms including *Legionella*.

2.3 Overview of Water for Process

Process water is used for rinsing, cleaning, chemically treating and generally manufacturing a product. Circuit boards, semiconductor chips, aircraft parts, medical devices, golf clubs, LCD displays, machined parts, juices and soda are all made using water. Water becomes part of the product in the case of cosmetics, juices and soda. Purification of water for process is driven by the need for consistency of product quality. The more critical the product quality, the higher the degree of purity required. Semiconductor and most electronic manufacturing uses ultrapure water, which has all of the salts removed. Beverage manufacturers purify water to different standards, and actually cannot use ultrapure water for human consumption. Ultrapure water is a very aggressive solvent and extracts metals and salts from anything it touches.

Many manufacturing processes need cooling water to maintain a specific temperature. This water is cooled in the same manner as air is cooled for air conditioning. It flows in a closed loop and is designated non-contact cooling water. Due to local regulations, most factories have eliminated discharge of this cooling water. Another use for water is for cleaning of the factory, to maintain quality and safety standards.

3.0 Issues and Trends

3.1 Power Industry Water Consumption

Power and water are still linked today in manufacturing as they were in the beginning of the Industrial Revolution. This fact may not be obvious to the casual observer of a factory building, but the link is obvious when observing the steam rising from Valley power plants. Ninety million gallons per day of secondary treated water from 91st Avenue Wastewater Treatment Plant flows to the 3.8 Gigawatt Palo Verde Nuclear Power Plant. 70,000 acre-feet are used annually for cooling water to condense steam. This water is treated to tertiary standards with filtration, trickling filters to remove ammonia, cold lime softening and clarifiers to remove the hard water salts. Table 2 below shows the amount of scale-producing constituents in the 91st Avenue effluent that are removed at Palo Verde. Each of 4 cooling units demands 15,000 gpm water flow to compensate for the evaporation rate and bleed to the solar evaporation ponds, which averages 600 gpm

per unit. (An additional 1 MGD of well water provides drinking water for the site and feeds a process water purification system.)

Table 2 – Water Quality at Palo Verde NPP			
Constituent	91st Avenue 2° Treated Effluent (m/l)	Palo Verde 3° Treated Effluent (mg/l)	Palo Verde CT Bleed (mg/l)
Calcium	162	71	1916
Magnesium	120	14	395
Silica	20	4.6	113
Conductivity (MicroSiemens/cm)	1487	1496	32,142

Because of the high demand for water at each of APS's and SRP's power plants, use of reclaim water is highly desirable. It's cheaper and it's better public relations. All types of power plants require cooling water for the generators. The volume varies with the amount of power generated and seasonal demand. Palo Verde consumes more water during the summer than 91st Avenue can produce. It may become economically feasible to recover water from the cooling tower bleed for recycle back to the towers rather than lose the water to evaporation. A brine concentrator is in operation at one of APS's sites. This is one technology that offers a lower cost option for desalinization.

Arizona's power demand has grown with the population, which has lead to new power plant generation capacity and increased water demand. Energy conservation and water conservation have not been emphasized to the public that demands abundant and clean water and pollution-free power. Power use by the semiconductor industry is described below. As a rule of thumb, it takes 8-9 gallons of water for each Kilowatt of electricity produced. A single semiconductor manufacture using over 100 million KWh/year requires approximately 1 billion gallons of water per year for power alone.

3.2 Semiconductor/Electronic Manufacturing Water Consumption

As semiconductor "chips" became more complex, tiny amounts of salt in the water became sources of contamination that cause low yields. This drove the development of water purification technologies to remove all of the salt from the source water, and created ultrapure water. A typical high volume semiconductor manufacturer uses 3 to 6 million gallons per day of water – 70% for ultrapure process water, 20% for cooling and air pollution abatement and 10% for sanitary and landscape. Water is no longer free – it has to be treated before it can be used in production processes. Then is must be treated before disposal. Ultrapure water costs approximately $15.00/1000 gallons ($4887/acre-foot), including source water, treatment and disposal costs. Yet the mentality of "more is better" persisted through the early 1990's. Conservation of water became an economic goal as water use increased with wafer size and wastewater disposal costs increased with environmental regulations. Suddenly the cost to obtain, purify, use, treat and dispose of water showed an economic payback for reuse of the water on-site. The Semiconductor

Roadmap, an industry-generated document used to focus technology and cost issues shows goals of 65% reduction in ultrapure water use, 30% reduction in ultrapure water cost and 20% reduction in power consumption.

Public perception of water use by the large semiconductor companies and "green" investors has driven investigations and investments into water conservation and reuse. Intel spent over $15million in New Mexico to keep water use to a maximum of 3.9 MGD despite increased production needs. Today most of these manufacturers recycle between 21 to 40% of their total water use. Some have invested in equipment to demonstrate good corporation citizenship and do not worry about pure economic payback. Water is still cheap, but good PR is expensive. Up to 3 million gallons per day of Intel wastewater is recharged after treatment in the Chandler RO plant, a facility purchased by Intel and run by the city. Increasing density and size of wafers (200mm and 300 mm plate-sized disks from which hundreds of chips are cut) increases the cost and use of water and drives investment to reduce both. New technology for equipment and processes are well underway and adapted by all new and refurbished plants. The new equipment uses less water in each process, which is still the cheapest way of reducing water use and operation costs. All water reuse technologies create wastewater that is higher in salinity than normal wastewater. The constituents in that wastewater include salts from the manufacturing processes and the wastewater treatment chemicals.

Figure 3 shows a typical semiconductor water and approximate salt balance based on the Motorola site in Tempe. Other facility water use is noted. Cooling towers consume the second largest volume of water in the factory. Semiconductor products must be manufactured in cleanrooms that provide dust-free air and are precisely controlled for temperature and humidity. More than 50% of the power consumed by a factory is used for the pumps, fans, cooling and heating that provides that control. The Motorola Tempe site has approximately 12,000 Tons of HVAC. Those cooling towers bleed off 60,000 gallons per day. It is estimated that makeup for evaporation averages 100,000 gpd.

This site has two specific water conservation plans. The first will add a secondary RO system to squeeze more useable water out of the ultrapure water. The second will blend some of the high quality wastewater with source water for cooling tower makeup. This will allow higher COC's in the towers. Both efforts, however, will increase the salinity of the wastewater discharged to the sewer.

3.3 General Manufacturing Water Consumption

Water consumption by general manufacturers depends upon the type of product, the processes and the size of the operation. Many manufacturing operations do not have cooling towers, but rather have packaged air conditioning systems that do not require water. For example, a machine shop uses water for cleaning the floors, washing parts and for makeup for the machine tool coolant. They will often purify the water used for cleaning and rinsing parts, but will not invest in an elaborate ultrapure water system. More likely, they will rent water softening or deionizing canisters from a vendor that replaces them periodically. If the wastewater contains no

dissolved metals, then it only needs to have the pH adjusted to meet discharge standards before release to the sewer. For this type of factory, the increase in salinity in the water over the background in the source water is minimal. Figure 4 is a simple water flow diagram for a simple, general manufacturing plant.

4.0 Future Implications and Opinions on the Future

4.1 Salt Management Today

Large manufacturers and many smaller ones rely on chemical suppliers to manage cooling tower water quality. Variations in source water, especially during this drought period likely increased chemical costs, but not significantly. Palo Verde's tertiary water treatment for removal of salts has experienced an increase in chemical costs as salinity has risen in the effluent from 91st. Avenue. However, such chemicals are purchased in bulk and likely are not be tracked closely enough to attribute and increase to rising salinity.

Many of the large semiconductor companies contract their ultrapure water system operation and maintenance to Ionics. Antiscalants and other pretreatment chemicals used to protect those membrane systems likely increased, but not significantly. The gradual increase in salinity has been absorbed and has likely been masked by the dramatic slow down in the high technology sector of the economy. Small and general manufacturers that use rented ion exchange canisters would have seen an increase in costs if their production levels remained constant. Unregulated salts in wastewater discharges are not managed or tracked, so it is difficult to confirm the salt load that is discharged to the municipal wastewater treatment facilities.

4.2 Costs, intangible and tangible

Manufacturing and specifically semiconductor plants have chosen Arizona sites based upon a number of factors. Typically, they want the impact of their facility to be less than 10% of a municipal system's total capacity to supply and treat water. They also look for a skilled labor force, good infrastructure (i.e. nitrogen lines, fiber optic cable), availability and cost of land and power, and fast and favorable environmental permitting. Water quality, in and of itself, is not a determining factor and won't be until the treatment costs exceed the targeted product cost. Intel's investment in New Mexico proves this point. They located the plant in an area that would not have the volume of water needed for a large semiconductor manufacturing plant without extensive water reuse within the factory. Intel's investment in Chandler for water recharge also demonstrates their desire to be good corporate citizens and not base a decision solely on water and wastewater capacity. Downward price pressure on semiconductor chips does require manufacturers to constantly reduce operation costs. This is being addressed in the redesign of process equipment that coincides with new chip technology manufacturing. Therefore the additional cost for reducing water use is absorbed into the equipment cost for new technology.

The estimated costs for equipment and operation of reuse of water systems in semiconductor plants is shown in Table 3 below. The range is wide and varies with the particular source of water that will be treated and reused.

Table 3 – Water Reuse Costs	
Equipment Component	Cost per million gallons processed
Carbon filtration	$70 – 1000
Particle Filtration	$20 – 100
Ion Exchange	$250 – 1000
Reverse osmosis membrane	$30 – 2000
TOTAL	$370 – 4150

These costs are independent of the rise in salinity in the source water because the plant's main ultrapure water system will be the only system that experiences a rising cost associated with salinity. In a membrane system, the osmotic pressure increases 1 psi for each 100 mg/l of TDS. As salinity rises, a given membrane system will either require more energy to pump water across the membrane to maintain a constant volume or it will lose productivity. At the same time, more salt will permeate the membrane because a given membrane material has a fixed salt flux, i.e. the percent removal of a range of salts. The increased cost of a pump and the requirement for more membrane area will increase capital investment. As calcium, magnesium, carbonates, silicates, phosphates and sulfates rise in the source water, the membrane system will be more prone to scaling and will require more frequent cleaning. This will increase operating costs.

Process water that is purified to ultrapure standards typically costs $15 per 1000 gallons produced including equipment depreciation, operation and maintenance costs to obtain, treat and discharge wastewater. A rise in that cost may not be important when it coincides with reduced overall demand for water by the new production equipment. This will not be true for manufacturers that rent ion exchange canisters. Each canister has a fixed capacity for adsorbing the hard water constituents in source water. If salinity doubles, then the cost for changing out those canisters will increase 1.5 to 2.5 times, depending upon the concentration of the constituents in that water.

Cooling water chemical costs are not measured in terms of water use, but rather cooling load. For example, Motorola Tempe spends between $100,000 and 120,000 per year to manage approximately 18,000 tons of cooling capacity.

So far, industry is coping with the rate of salinity rise experienced to date. Their investment in reuse methods and technologies to reduce their cost of operation, however, will drive up salt levels at municipal treatment plants. The costs for dealing with rising salinity in wastewater discharge will be born by municipalities as they look for options for reclaim and recharge.

4.3 Future Impact of Salinity

The feature sizes on semiconductor chips are shrinking below 130 nanometers. This means that the surface tension of water will limit its use for chemical processes and rinsing because it will no longer be able to penetrate these smaller spaces. In addition the smaller chip features do not have the mechanical strength to withstand such processes. Supercritical carbon dioxide has been researched and tested for cleaning and rinsing applications. It is anticipated that it could replace water in the next 10 to 15 years. Even if it does not replace it entirely, the water demand and therefore the impact of salinity would be reduced. The timeframe for switching away from water will be determined by the economics of using supercritical carbon dioxide compared to the quality impact of continuing to use water.

Since semiconductor plants are very visible in their communities as "big water users" they have been implementing water conservation and reuse programs for many years. This investment results in higher salt loads in their wastewater discharges that increase the burden on municipalities seeking to reclaim or recharge secondary treated wastewater. (See Figure 3) Any discharge restriction based on salinity is a disincentive for water reuse within the factory. These disincentives include the cost and availability of the technology to further remove the TDS and the related issues of increased energy consumption and solid waste disposal.

General industrial users of water have learned that process water quality is tied to product quality. The degree to which the water must be purified depends upon the technical complexity and aesthetic appeal of the specific product. Variability of water salinity increases the time and labor associated with maintaining product quality. Increased salinity increases the capital investment and/or operating costs to produce sufficient amounts of purified water. It is interesting to note that this cost will not go away if the industrial plant is moved to a "low-cost" manufacturing location, such as a third world country. It might even increase due to the other constituents in the Third World's water supply.

The desert is not going to cool down in our lifetime. And water is still the cheapest ingredient for making cool air. As salinity rises in the source water used for cooling, more chemicals will be needed to mitigate the effects of scaling, corrosion and fouling on plant equipment. In addition, the number of cooling cycles will decrease and will not meet Arizona law for water conservation. Cooling tower bleed is set by the conductivity of the water in the tower basin. Both the salt ion content and the total salinity contribute to the conductivity. As the salinity rises and ion content varies, bleed will occur more often, increasing water use. Discharges to the municipal treatment works will remain fairly constant however.

Power use and therefore the water demand at Palo Verde will be directly affected by a rise in salinity. Population growth and increased manufacturing will both increase power demand. 91st Avenue effluent will be affected by source water salinity and therefore the tertiary treatment at Palo Verde will need more chemicals to remove the salts.

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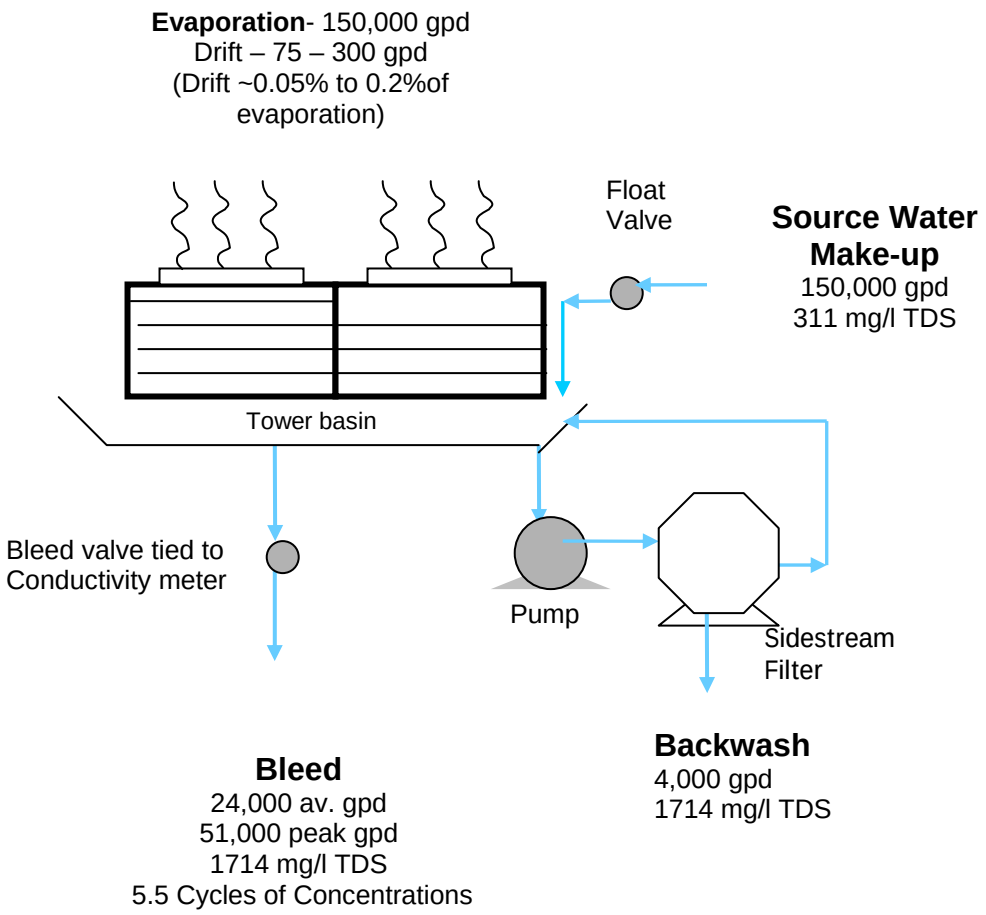
Figure 1
Typical Cooling Tower Water Flow and Salt Balance
Est. 3500 Tons of Cooling



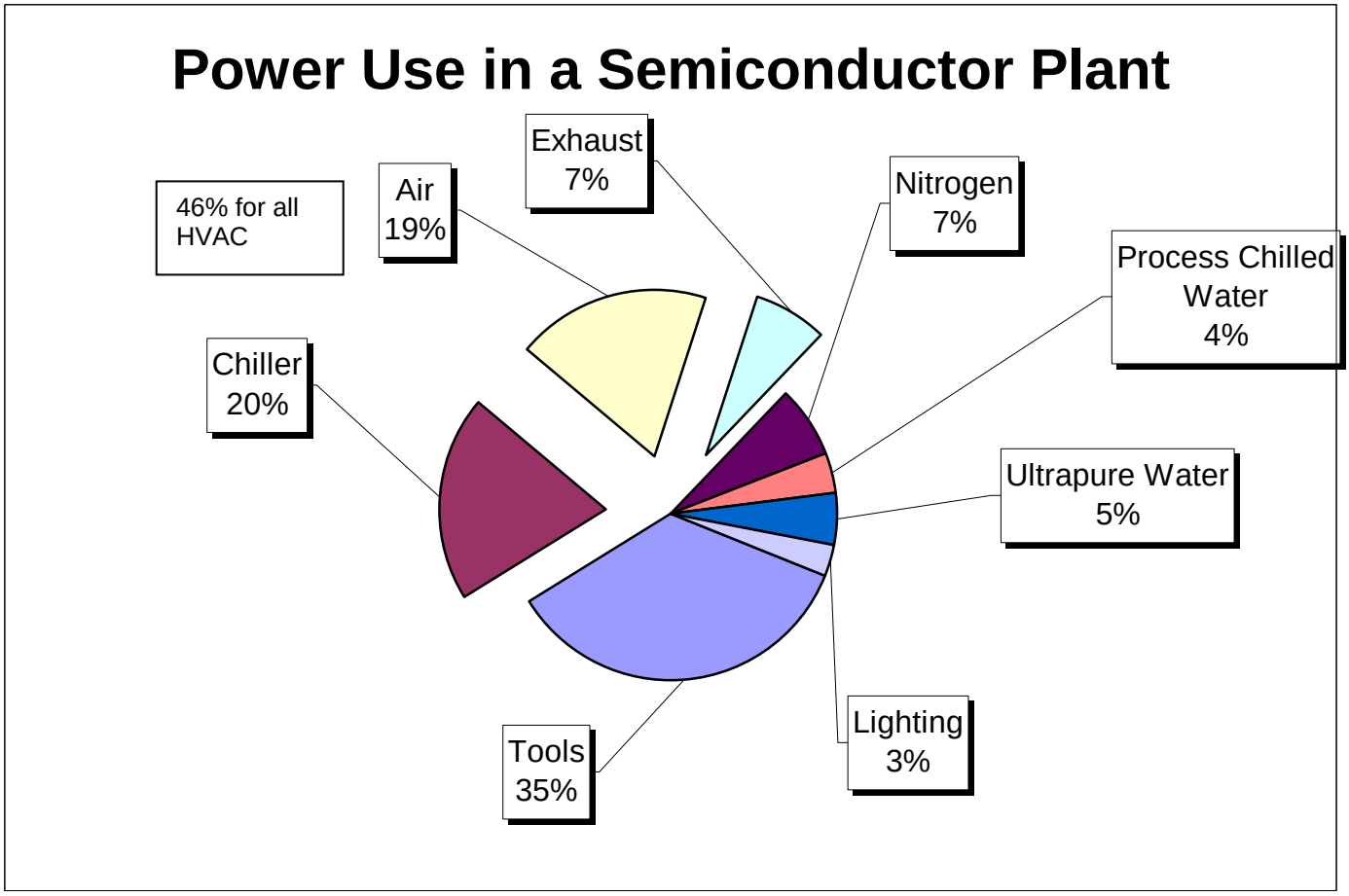
Daily Salt Balance

Makeup: 150,000 gpd x 3.85 liters/gal. = 577,500 liters/day
X 311 mg/l TDS = 180 Kg or **396 pounds of salt**

Bleed: 24,000 to 51,000 gpd (92,400 to 196,350 liters/day)
PLUS Backwash: 4,000 gpd 15,400 liters per day
X 1714 mg/l TDS = 184 to 363 Kg or **405 to 799 pounds of salt**

Each pound of salt input results in two pounds output to sewer

Figure 2


Power Use in a Semiconductor Plant
46% for all HVAC
Air 19%
Exhaust 7%
Nitrogen 7%
Process Chilled Water 4%
Chiller 20%
Ultrapure Water 5%
Lighting 3%
Tools 35%