WaterSim

A computer simulator and integrated educational module for semiconductor manufacturing systems

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Abstract:

The WaterSim program is an easy-to-use graphical user interface, a unique simulation module, and an integrated educational module that was developed at the Institute of Systems Research (ISR) at the University of Maryland. WaterSim simplifies the process of semiconductor manufacturing while teaching students engineering principals and the importance of recycling. The module was created to eliminate esoteric simulation codes and hard to understand models which have made it difficult to teach engineering principles to students. As a participant in the Research Experience for Undergraduates (REU) program at the ISR at the University of Maryland, my role in the WaterSim project was a three-fold process. My first role was to create integrated html educational material for the simulator. My second role was to learn about the simulation techniques that are being developed at ISR and integrate them with the Center for Environmentally-Benign Semiconductor Manufacturing (CEBSN) at the University of Arizona. This process involved creating simulation based learning models with DELPHI and Vissim based software. Thirdly, my role was to research the effects of recycling in ultra pure water (UPW) systems and its effects on a semiconductor manufacturing system. The results of this 8-week research include:

- A beta-version of an easy to use graphical user interface called WaterSim
- An integrated educational manual with written material
- The formulation of web based tutorials that exploit WaterSim's major features
- An installation program specific to WaterSim that simplifies the distribution of the product
- Knowledge of Vissim and Delphi software to create simulations

Introduction:

WaterSim was developed as a joint collaboration with the Institute for Systems Research (ISR) at the University of Maryland and the Center for Environmentally-Benign Semiconductor Manufacturing (CEBSN) at the University of Arizona. The WaterSim program is designed to teach engineering processes to students. The ultra pure water (UPW) recycling simulator simplifies the process of water based silicon wafer manufacturing. Through a real time module, the simulator educates the student on several levels.

- The student will analyze in depth how a water based process in a semiconductor manufacturing plant works
- The student will learn the importance of recycling from an economical, environmental, and strategic business standpoint
- The student will learn about control systems and how one can determine when it is necessary and important to recycle
- The student will uncover and analyze the underlying principles of a mass balance system and formulate them into material balances

In keeping with the mission of this project, it was important to design a simulator that exploited the two centers key strengths. ISR has been developing software components and templates for constructing learning modules. These modules have been developed to include effective graphical user interfaces (GUI) and hyper linked education tutorials. The CEBSN has focused on developing new environmentally sensitive processes along with the development of systems aimed at solving current environmentally harmful manufacturing techniques. Combined, these two centers have developed a simulation tool that can be used for education, research, or design manufacturing. In this report, the Watersim program will be exploited from all angles, as this report will feature the components that make up the module, the reasons for creating the WaterSim module, and a future outlook for the project. This report begins with a general description of the WaterSim module, a description of my involvement in the project with research summaries, and a reference to future plans and goals for WaterSim.

WaterSim Description:

The graphical user interface for the WaterSim program can be found in figure 1.1 Please refer to this figure throughout the WaterSim description

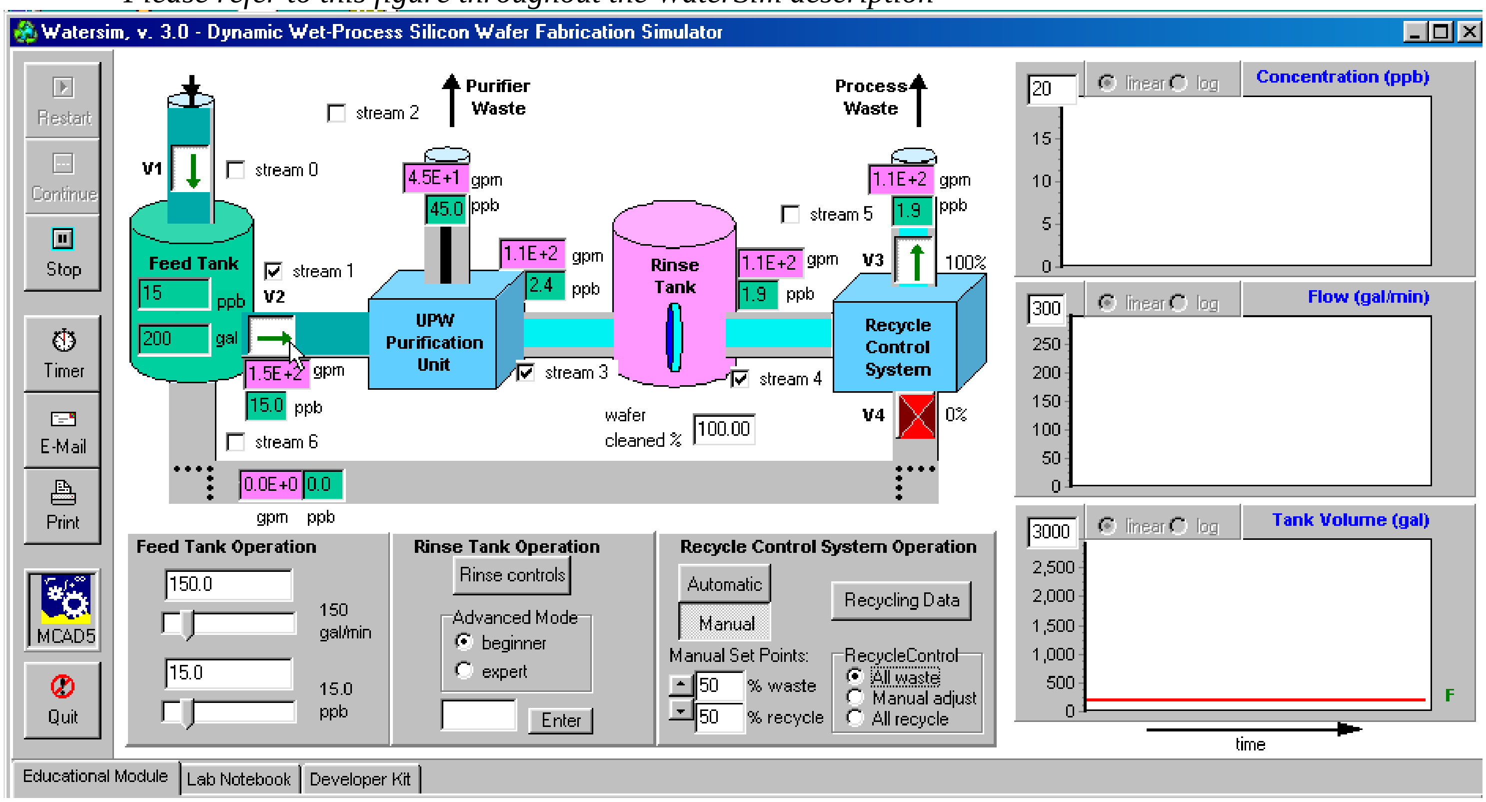

Figure 1.1- GUI Graphical User Interface for the WaterSim module

As described earlier in this report, WaterSim module simulates the process of a semiconductor manufacturing system. The GUI for the simulator consists of a simple UPW system. The WaterSim module begins with an influx of water to a holding tank known as the feed tank. In most cases, a source to the feed tank consists of a municipal or ground water supply. Once the water in the holding tank is released, the water begins to flow through a series of processes. The first process involved is the UPW Purification Unit. In the UPW Purification Unit, water is purified to ultra pure standards. While the unwanted waste stream exits out of the system, the purified water proceeds to the next process. (note: the main function of the UPW unit is described in detail later on in this report)

Once the water has been purified, WaterSim directs the water to the rinse tank. The rinse tank uses the UPW to clean the surface of a silicon wafer and render a contaminant and defect-free semiconductor. WaterSim collects the waste from this stream and directs it to the Recycle Control System. This system gives the user the choice to either discharge the rinse water back into the aquifer or recycle the water back into the system. A recycling loop in the WaterSim program feeds the water back into the Feed Tank. The process is then recreated.

WaterSim contains several key modules, visuals, and graphs to enhance the students learning experience. The data in the Watersim program is formulated into three formats: a graphical version, a numerical version and automated version. Adjacent to every steam in the simulator is a box that graphically displays the volumetric flow rate of the stream, in gal/min (gpm), and the concentration of impurities in the stream in parts per billion (ppb). The display of a stream's graph can be traced by placing a check mark next to the name of the stream's box. The WaterSim module is also animated to immediately display the conditions occurring in the UPW system. As a stream of clean contaminant-free water flows through the system, the color of water flowing through the pipes of the UPW unit is an aqua color. As contaminants enter the system and the water becomes "dirty", the water quickly changes to a darker color such as dark green or black. The wafer cleaning process is also animated. The student can see the process of a wafer dipping into a FAB unit as a dirty wafer. After several seconds, the wafer reappears cleaner than before. These animations have been included in the WaterSim module to help the student better visualize the semiconductor manufacturing process.

Input data to the WaterSim module includes fixed constants and variables that change over a period of time. The fixed constants within the system include the rinse tank control options and recycle control system operation buttons. Fixed constants are defined as values that may only be changed through human interaction. In the rinse tank control options, the tank volume along with the waste from the wafer can be set as a fixed constant. The values controlling the water distribution in the recycle control system can be fixed to an "all waste," "all recycle," or "manual adjust" feature. The volumetric flow rate and the concentration level of each stream is a variable that changes over time. An important use of WaterSim is to teach the basics and understanding of how these values vary over a period of time. This concept is called mass balances.

As stated by the conservation of mass, mass can not be created nor destroyed. Therefore, the input flow to a system cannot enter at 20 gal/min and exit at 30 gal/min. With the idea of mass balances, there evolves the idea of material balances around a particular system. The general balance equation states: Input (mass entering the system) + generation (mass produced within the system) – output (mass leaving the system) – consumption (mass leaving the system) = accumulation (mass buildup in the system). Within the Watersim program, the simulator focuses on the idea that in most cases processes do not change as a function of time. This is called the steady state condition: $dQ/dt = 0$, $dC/dt = 0$ (This states that the change in volumetric flow rate and concentration over a period of time is 0)

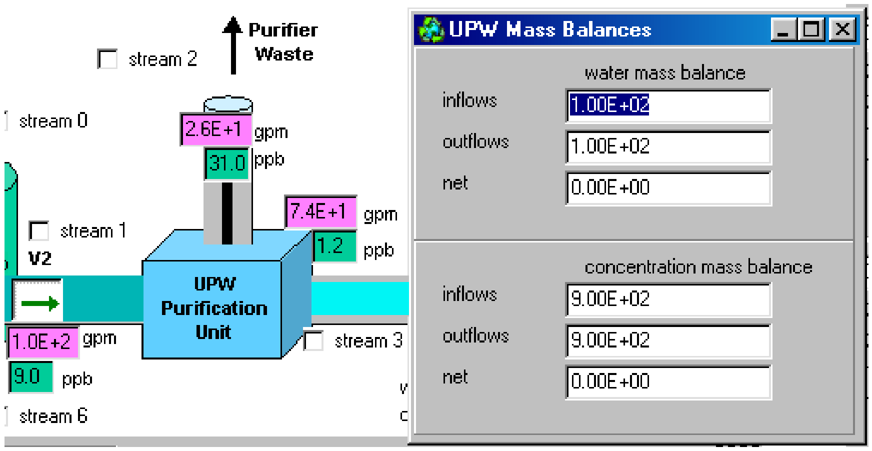

Figure 1.2 - Mass Balances- At Steady State

The example in figure 1.2 displays how mass balances are calculated in WaterSim. The inflow streams are added and subtracted by the outflow stream. The net calculated stream of 0 infers a steady state condition.

WaterSim also allows a student to construct their own recycling ratios based on concentration and volumetric flow rates in each stream. A diagram of this process is depicted below in figure 1.3. A student can monitor the flow rate and concentration in each stream, then elect to construct a series of ratios based on WaterSim's data.

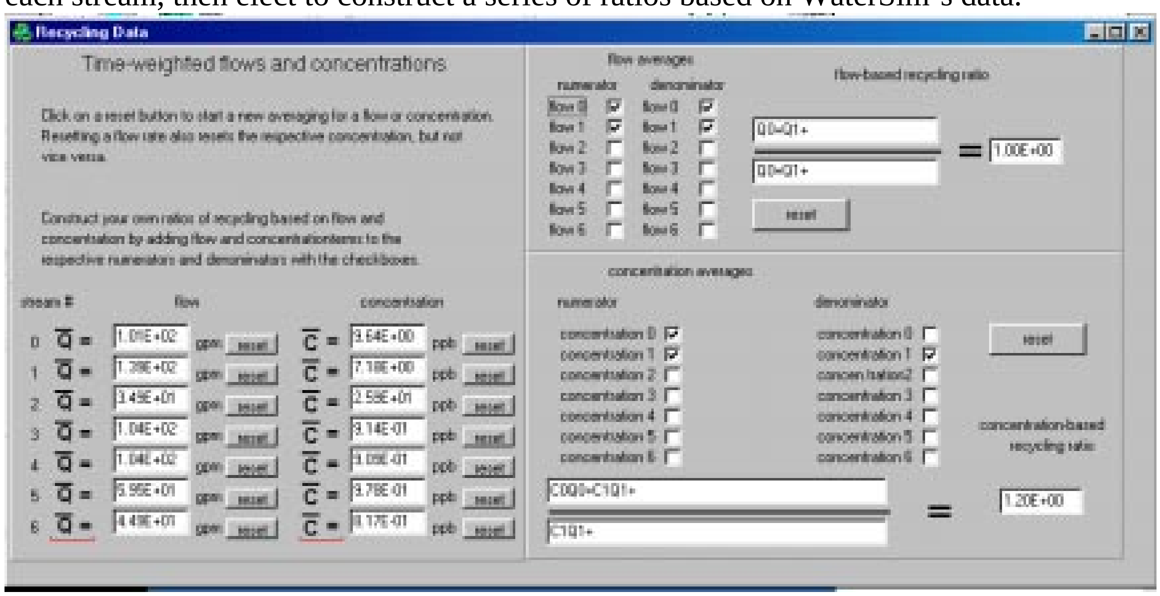

Figure 1.3 - Recycling Data

The educational module (figure 1.4) is a user-friendly html document integrated into the WaterSim program. Intergraded as an Active X component, this module acts as a learning tool for a student who seeks to obtain in-depth information about the semiconductor manufacturing process. Active X is a "cross-platform" that can communicate between various programs such as Windows and Internet Explorer. This educational module was also designed to provide a comprehensive guide to the components involved in the wafer fabrication and UPW purification systems and to provide an analysis of the recycling process.

As I created this model, it was my intent on developing an easy to navigate web-based document that would optimize a student's learning experience. This model completes the task as it is interacts with the student through tutorials, easy to access reference materials, and integrated hyper linked text. The integrated hyper linked text was designed in previous ISR simulation modules. As an integrated feature, the text in the educational module can be hyper linked to highlight a referenced object or area of the WaterSim module. This feature works by moving the mouse cursor over the hyper linked word.

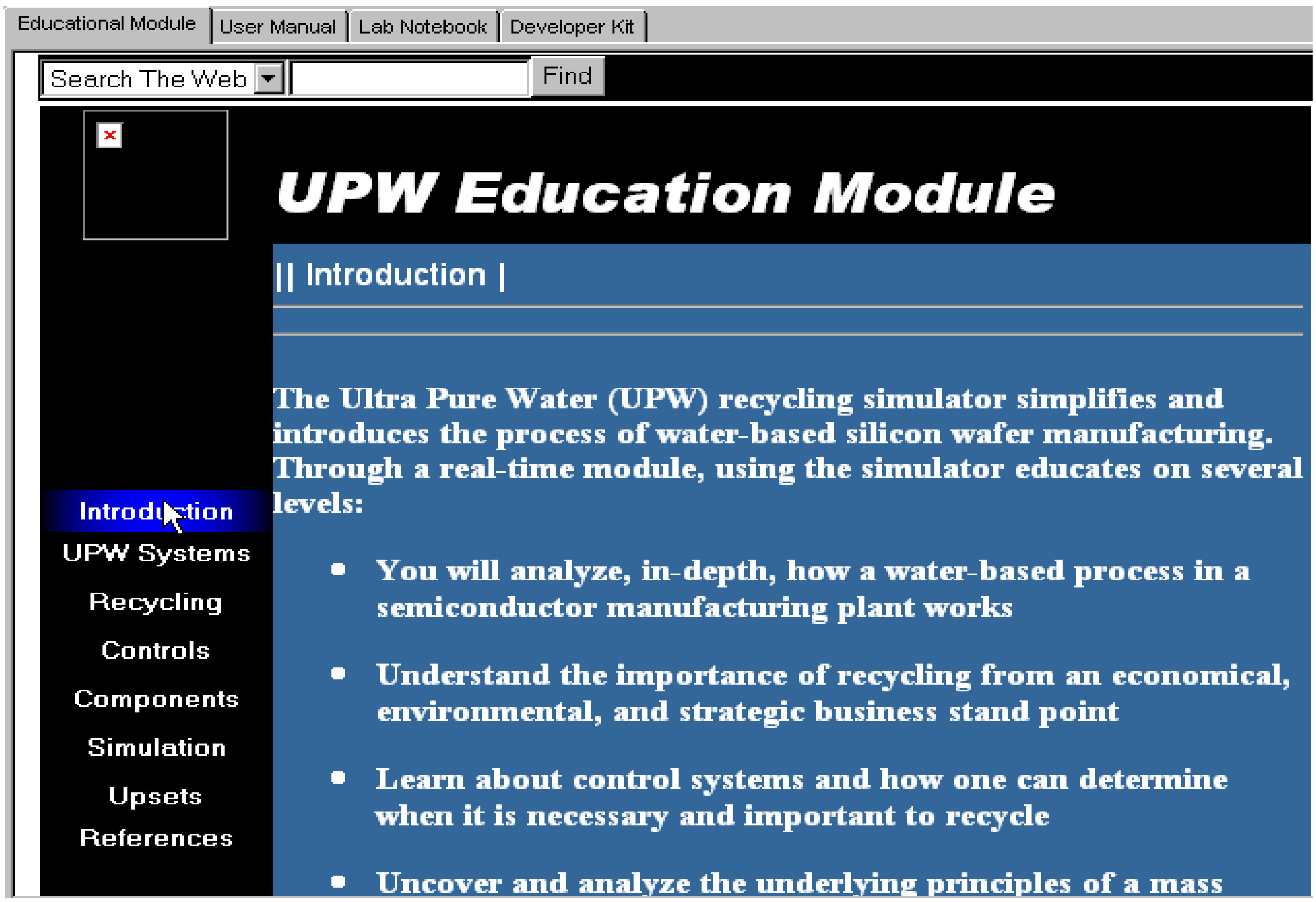

Figure 1.4- Integrated UPW Educational Module (HTML)

Research Topics and Summaries:

Part of my role at the University of Maryland was to conduct research on the effects of fabrication wastewater on the environment and the issue of recycling in a semiconductor manufacturing system. This next section summarizes my research conducted in this area.

The need for water recycling in water-barren regions such as Arizona may be as obvious as it is essential. But, the effects and benefit of recycling extend beyond the realm of the environment. Semiconductor plants accrue significant economic benefits relating to cost and processing by adopting recycling. Without recycling, semiconductor plants discharge millions of gallons of treated water per day. This treated water, purchased from the municipal water supply, could depress the financial "bottom line" for many semiconductor plants.

While it may be economically unfeasible to dispose of waste down the drain, there are environmental concerns about the effect of contaminant rinse water on aquifers and ground water supplies. Many southwest cities such as Phoenix, AZ, Albuquerque, NM, and Austin, TX, seek to attract high profile semiconductor plants to their cities despite the large demand percentage of the cities' ground water supplies posed by plant operations. Each plant uses over 5-6 million gallons of water a day and discharges great volumes of contaminated rinse water into the cities' groundwater supply (Sacred Water 1997). In the Phoenix area alone, a fifteen-mile plume of contamination lies in the ground water supply; thus depleting the available ground water supply by about 25% (Sacred Water 1997). Semiconductor plants in the Phoenix area have contributed to 60% of the contamination in ground water supplies.

The discharge of contaminated water to the subsurface is an important economical "hidden" cost for the semiconductor manufacture. For example, the rough estimate to clean up contaminated ground water in Phoenix is over $800 million dollars (Sacred Water 1997). It is vital, as the semiconductor industry continues to expand that semiconductor plants begin to recycle their FAB unit rinse streams.

From an economic standpoint, it is beneficial for a company to recycle the rinse water. Due to the rigorous initial purification technique, most of the product stream from a FAB unit can be purified a second time. FAB unit rinse streams contain significantly less contaminant than that of the municipal water supply; however, the occurrence and accumulation of recalcitrant impurities has made it difficult to recycle FAB rinse streams. These impurities, which may consist of chloroform, trichloroethane, and ethylene glycol, cannot be removed through the traditional UPW system. In fact, many of these impurities hinder the performance of the system by fouling the resins and membranes of the UPW system. The recycling process proliferates the concentration of recalcitrant impurities. With this in mind, techniques and new devices have been developed to remove such impurities from the system.

As a chemical engineering student, I found it beneficial to research the process of an UPW system. Through this research, I was able to understand the simulation processes involved in creating a simulated UPW system. The following text is a brief summary and synopsis of the UPW purification system implemented in the WaterSim module.

The UPW system provides very clean water for manufacturing processes by treating a water supply with a series of purification techniques. Semiconductor manufacturing requires that the output source of water meet stringent standards: a resistivity level of 18 mega ohms-cm, inorganic ion concentration must be at or below 1 ppb, total organic carbon (TOC) $\leq$ 100 ppb level, and no microorganisms (Allton 1997).

The ultra pure water acts as an intensive solvent solution capable of dissolving and removing surface contamination from a silicon wafer. Because even slight contamination on the surface of a silicon wafer renders a device ineffective, the UPW system must perform optimally to produce water that meets the necessary manufacturing water quality criteria.

The UPW system consists of several parts: pretreatment system, primary pure water supply system, and a polished loop. The pretreatment step is effective in optimizing the feed water for reverse osmosis treatment. Large suspended particles, high concentrations of organic matter, radon and neutral forms of radioactive inert gas can be removed by either filtration or activated carbon techniques. Without the pretreatment process, municipal water impurities could clog the membrane and result in membrane fouling.

The primary treatment loop continues the water treatment with the processes of reverse osmosis and ion exchange. Reverse osmosis removes over 98% of all dissolved solids, TOC, silica, and particles from the feed water stream (DeGenova 1999). Ion exchange process reduces hardness by removing calcium, magnesium, and other polyvalent cations in exchange for sodium or hydrogen (Pontius 562).

The polish loop maintains the ideal purity content by removing contaminants with the help of several purification techniques (Kin, K-T and Shadman, F 2000. These processes include UV treatment, degassifier, and ultra filtration (UF). The UV treatment operates at different wavelengths to remove organic compounds, destroy bacteria, and convert ozone and hydrogen peroxide to dissolved oxygen and water (DeGenova 1999). The degassifier removes carbon dioxide, oxygen, and other volatile compounds, while the UF, a membrane separation technique, is placed at the end of the system to remove colloidal silica, endotoxins or pyrogens created in earlier stages of the system (DeGenova 1999).

Future Plans:

With a robust simulator complete, there are several directions the project is heading. Although the basic principle is to teach engineering principles to undergraduate level students, this module has been built with complex features capable of accommodating the needs of graduate level students along with practicing engineers and or scientists. In future versions of WaterSim, practicing engineers will have the ability to create and simulate a replica of a UPW system unique to their specifications. An ideal example would be that of a UPW engineer integrating new processes to an existing manufacturing system. The WaterSim program would be able to integrate this new design and then analyze the efficiency of the new processes on the system. Simulations could be made to determine the economical and environmental impact of the processes while predetermining the effectiveness of the new design.

Although nutrient concentrations in UPW systems are low, bacterial growth, biofilms, and biofouling is a major concern for many semiconductor manufacturing plants. In the last few weeks of my research at ISR, I researched the effects of bacterial growth in a UPW unit and begun the process of modeling and creating bacteria in WaterSim. Simulating the process of bacterial growth is difficult to model because of its non-linearity attributes.

Bacterial growth affects several aspects of the UPW system. It contributes to system upsets, corrodes the pipe walls, and leads to defect semiconductors. The development of bacterial growth hinders the performance of the UPW system by diminishing the water flux through a reverse osmosis membrane. Biofilm has been shown to impede the motion of molecules into the system. This type of fluid motion leads to an increase in fluid frictional drag and causes an increase in the pressure-dissipating element. In extreme cases, biofilm can lead to a physical collapse of system.

Through future research in the area of bacterial growth and the UPW system, I would like to simulate a system that monitors the growth of bacteria throughout the UPW system. I would like to determine how bacterial growth adhering to a pipe wall effects the flow of water in terms of shear velocity and fluid frictional drag. I would also like to analyze the economical impact of bacterial growth. Several questions could be raised and answered from this research. For example, how much money can be saved in defect wafers and corroded pipes by quick containment of bacterial growth? Also, can minimizing the amount of bacterial growth maximize the ability to effectively recycle fabrication rinse water? These questions have guided my research over the past few weeks and would make for interesting questions to continue to research and analyze in the future.

Finally, a continuing effort is being made to create tutorials and learning projects to exploit the learning capabilities of the Watersim module. While several of these tutorials are already complete, this continuing process will be updated in future versions of the Watersim module. This part of the educational material will also be coded with hyper linked text as mentioned in an earlier section of this report.

Conclusion:

The WaterSim module started as a developmental idea between ISR and CEBSM. With the collaboration of the two centers, the ability to combine a powerful simulation technique and teach engineering principles in a user-friendly setting has become a reality. WaterSim has shown that it is possible to create a simulation tool that can effectively teach complex or basic engineering principles to several levels of engineering students. The simulation's easy to use and understand GUI allows the user to focus his or her attention on learning about the processes and engineering principles. This is a sizable step from esoteric modules created in FORTRAN or C that made it difficult for the user to understand and control the simulation.

Through an 8-week program at the Institute for Systems Research, I have been able to help generate a beta test version of the WaterSim program in which I have integrated an educational module into the simulator. My research topics have included a study in UPW systems, the recycling effort in semiconductor manufacturing systems, and bacterial growth in UPW systems and industrial waste systems. I have analyzed the simulation techniques that are being developed at the ISR and will take those processes back to the center at the University of Arizona. WaterSim is an on going project. Future versions of WaterSim will continue to enhance the module's operability, integrated educational tools, and ability to educate engineering principles.

Acknowledgements:

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