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A Dynamic Systems Simulation Approach to Risk Mitigation for Critical Infrastructure at the United States Military Academy

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ABSTRACT

The United States Military Academy at West Point is responsible for the education and training of the United States Corps of Cadets – future leaders in our Nations defense as Army officers. Like many U.S. Military installations, West Point provides its own freshwater management for consumption by the cadets, faculty, and staff. In recent years, the freshwater supply at the Academy has reached critical levels – causing concern about the Academy's ability to conduct effective operations during peak summer months. As a result, the freshwater conservation plan was recognized as needing improvement. With the use of Systems Dynamics a Management Flight Simulator was built to analyze the current system and serve as a decision support system for future operations.

INTRODUCTION

The United States Military Academy at West Point, like many other U.S. Military posts, manages its own freshwater resources for consumption during daily operations and by the military members living on the installation. The Directorate of Housing and Public Works (DHPW), Natural Resource Division, is tasked with the operation and upkeep of all freshwater treatment and delivery systems. Further, the Natural Resource Division has oversight of the many freshwater sources on the West Point military reservation that provide the untreated water essential for the daily operations at the Academy.

A prolonged period of below average precipitation in the Hudson Valley during the summer of 1999, combined with a light snowfall the previous winter, caused significant concern about the freshwater supply at the United States Military Academy. The peak demand of the summer months and extensive forest fires on and around the Academy reservation caused the freshwater supply at the Academy to reach critical lows in the late summer months.

As a result of the critical levels of freshwater, the Directorate of Housing and Public Works implemented a phased water conservation plan to mitigate the risk of catastrophic shortages that might inhibit the Academy's ability to complete mission essential training for the freshmen and sophomore classes. As conservation measures began, the picturesque landscape of the West Point's academic area began to tinge with brown.

Though the water conservation plan proved successful, the DHPW was concerned about the validity of their conservation plan and timing of the implementation of each phase. DHPW's internal assessment of the summer's events concluded the following:

- The water conservation plan was implemented later than prudent
- Criteria to trigger the conservation plan was not clearly identified
- Criteria to escalate the phases of the conservation plan was not clearly identified
- The conservation plan was heavily dependant upon the community's willingness to comply with unenforceable conservation measures
- The freshwater system was more vulnerable than previously thought

As a result of their concerns, the Directorate of Housing and Public Works approached the Department of Systems Engineering for assistance in analyzing the problem and recommending solutions. The project was accepted and integrated into the Engineering Management Program in the form of an undergraduate capstone experience. A four cadet, multidisciplinary team with faculty mentor applied system dynamics simulation to the modeling of the West Point freshwater system.

APPROACH

A Systems Approach using a traditional Systems Engineering Design Process (SEDP) was the methodology chosen for the management and monitoring of the project. The SEDP provides a framework for approaching problems in a logical, systematic process. This framework guides the modelers through a top-down, iterative, life-cycle approach to defining the problem, generating alternatives, planning for the implementation of the best alternative, and finally managing the project through completion. The SEDP is well suited for System Dynamics in that it provides a framework to deal with large-scale, complex, multidisciplinary problems that are not amenable to solution by single functional engineers. Design is, by its nature, a creative process. The SEDP is an organized approach to creativity that enables modelers to choose appropriate "tools." Systems Dynamics simulation was chosen as the appropriate "tool" to assess the Directorate of Housing and Public Work's conservation policies. Figure 1 shows the Systems Engineering Design Process.

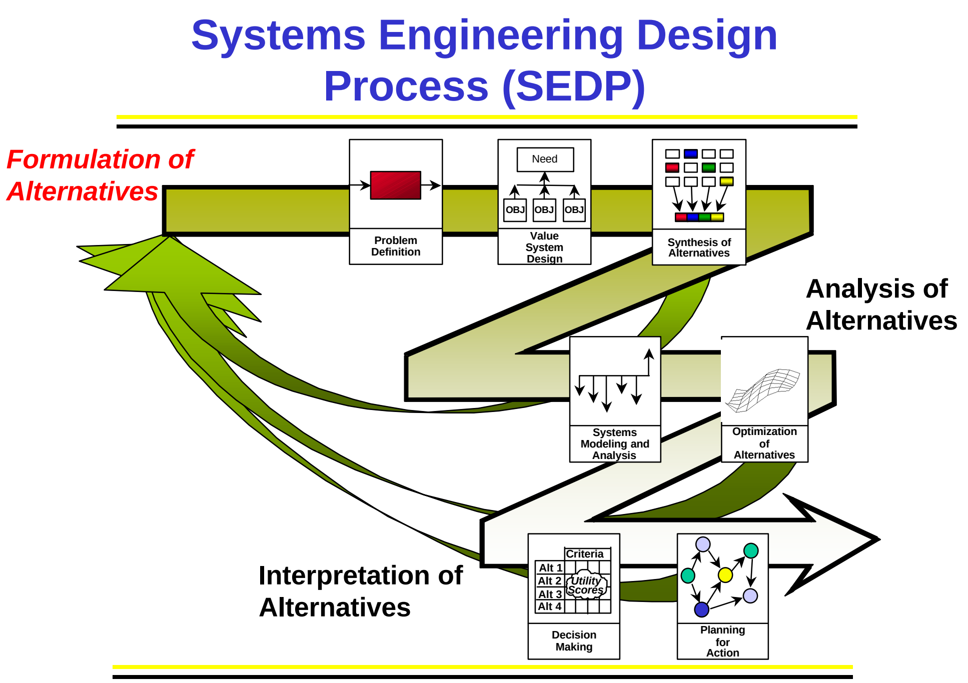

Figure 1 - Systems Engineering Design Process

PROBLEM DEFINITION

The initial statement of work as proposed by the Directorate of Housing and Public Works was to provide an assessment of the DHPW's current water conservation contingency policies and make recommendations for improvements. To ensure the validity of the initial concept of proposed work, stakeholders and stakeholder needs were identified.

STAKEHOLDER ANALYSIS

The purpose of stakeholder analysis is to identify those organizations, communities and individuals who might be affected by the systems. This allows for the refinement of the scope and bound of the problem and revision of the problem statement to include greater resolution of the problem domain. Table 1 shows a summary of the stakeholders and their stake in the system.

Stakeholder		**Objective(s)**
Client	Directorate of Housing and Public Works	To provide clean and potable water to the West Point community for on demand consumption.
Decision Maker	Chief, DHPW, Natural Resources Division	To provide clean and potable water to the West Point community for on demand consumption.
Sponsor	Directorate of Housing and Public Works	To provide clean and potable water to the West Point community for on demand consumption
Analysts	Capstone Team and Faculty Advisor	Facilitate learning/educational process and provide the client with a worthwhile product
Users	West Point community, cadets, faculty and staff	Clean and potable water readily available for consumption and use at any given time
Customer	Officer of the Directorate of Intercollegiate Athletics	Water readily available for the maintenance of athletic facilities and for consumption during summer athletic camps
Customer	Department of Admissions	Sufficient water readily available to maintain the West Point academic grounds in support of Academic Workshops and to provide additional water to the surrounding community for stimulation of growth
Partner	Town of Highland Falls	To obtain sufficient quantities of water from the Popelopen watershed to stimulate economic growth

Table 1 - Stakeholders and Stakeholder Objectives

SYSTEM CONCEPTUALIZATION

PHYSICAL COMPONENT

West Point's freshwater system is self-contained. The raw/untreated water is obtained from the Popolopen-Queenboro Watershed, which lies entirely on the West Point Reservation. On post, water treatment plants provide the West Point community with potable water. The Lusk Reservoir treatment facility is gravity fed from a series of lakes, while other treatment facilities have water pumped into them. Once it reaches the treatment plants, the water goes through a five-stage process for purification.

1. Flocculation – This stage serves two purposes: coagulation and flocculation. Aluminum sulphate is added to the water as it enters the accelator/flocculator. Gently revolving paddles cause the sulphate to form a gelatinous substance that is filtered out as the water rises vertically to the exit accelator. This stage frees the water of most of the suspended material. The flocculation stage has a one-hour detention time.

2. Sedimentation – The sedimentation stage removes most of the impurities of the water by sedimentation. Water is detained for a period of four hours in the baffled settling basin. Alum is added to remove color, while a descending floc sweeps turbidity and bacteria down with it.

3. Filtration – Rapid sand filters strain out the remaining bacteria and suspended particles.

4. Dosing Pit – This tank provides a place where the filtered water can receive chemical treatment before entering the clear well and going to the

consumer. Soda ash, fluoride, and a final dose of chlorine are all added to the water.

5. Clear Well – The clear well provides a place where the water can be tested. Daily chemical, bacteriological, and physical tests are necessary to control the purification process, and required under the Safe Drinking Water Act. Figure 2 below is a diagram of the Lusk Reservoir treatment plant. Other plants are identical with some minor exceptions to the number of settling tanks.

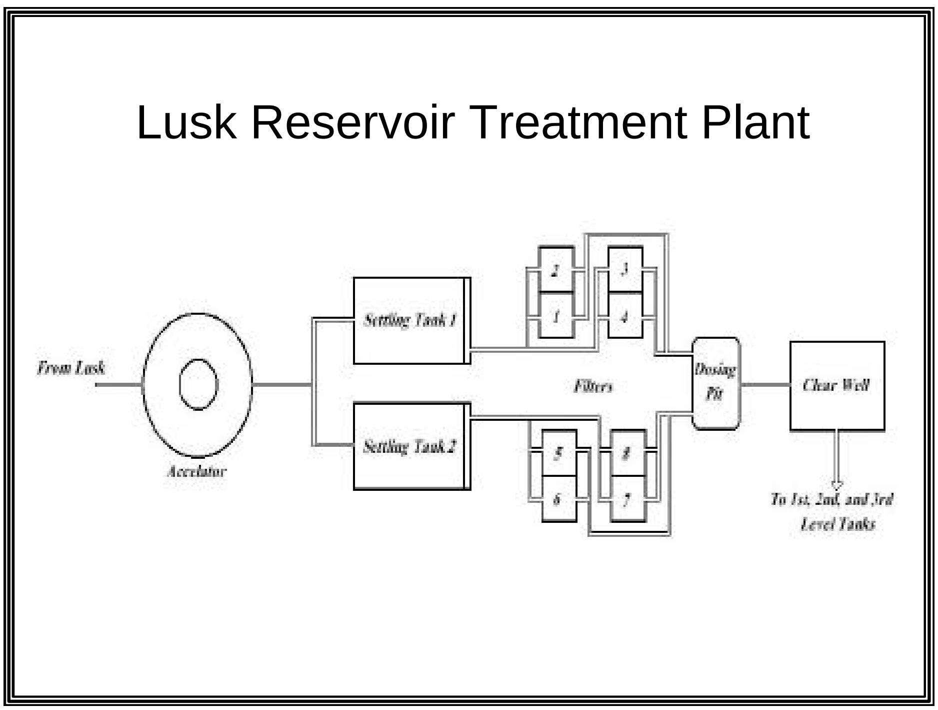

Figure 2 - Lusk Resevoir Treatment Facility

Following treatment, water is transported to a series of tanks on the West Point reservation. There is an alignment of treatment facility to storage tank to consumer location that allows the reasonable economy of effort while providing treated water. The systems does allow for the pumping of water between tanks and facilities. For the purpose of distribution management, the consumer area is divided into five levels. Table 2 shows the levels for distribution of treated water.

LEVEL 1	**LEVEL 2**	**LEVEL 4**
Target Hill Athletic Field	Old PX	Gray Ghost Housing Area
North Athletic Field	Cemetary	New Brick Housing Area
Daly Field	BOQs/Five Star	Keller Army Hospital
Clinton Field	Fire Station	Laundry Plant
Doubleday Field	Dunover Court Housing Area	Ski Slope
Plain	Lee Road Housing Area	
Buffalo Soldiers Field	West Point School	
Arvin Gym	Band Housing Area	
Waterfront Housing	Old Brick Housing Area	
Administrative Buildings		**LEVEL 5**
Visitor's Center		Child Development Center
BOQs	**LEVEL 3**	New PX Complex
Olmsted/Spellman Hall	Michie Stadium	Shoppette/Class VI
Hotel Thayer	Lusk Area Housing	Commissary
Academic Buildings	Holleder Center	Stony Lonesome I
West Point Club	Lichtenburg Tennis Center	Stony Lonesome II

Table 2 - Water Distribution Levels

Figure 3 shows the treated water distribution levels on the West Point Garrison map.

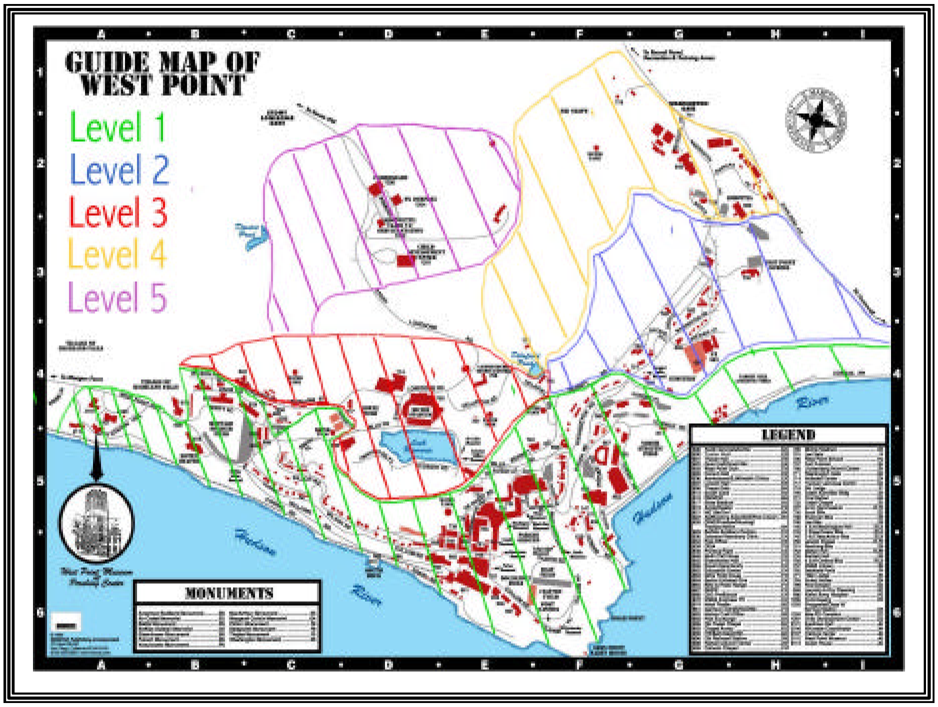

Figure 3 - Water Distribution Levels (West Point Map)

The treated water is delivered to the consumer through an extensive network of tanks and pipelines. Prudence dictates that the physical structure of the entire delivery system not be fully described in the paper.

POLICY COMPONENT

The Directorate of Housing and Public Works has long had a phased water conservation policy. Though seldom implemented, the policy has long thought to be adequate enough to mitigate the risk of on-demand delivery of potable water to all consumers. The three phases of the water conservation plan are:

1. Phase I – Restricts the use of water for washing of paved surfaces, privately owned vehicles, watering of residential lawns, and the use of water for ornamental purposes.
2. Phase II – Restricts the use of water for the filling/use of swimming pools and the washing of all vehicles (government and private).
3. Phase III – Restricts the use of water for watering landscaping and athletic field. Sets the maximum usage at 50 gallons per person per day.

Unfortunately, many of the conservation measures in the phased policy are relatively unenforceable in the West Point community. Despite a reasonable expectation that most of the community will follow the guidelines for the sake of doing what is best for the community and environment, DHPW does not have the resource to monitor, enforce, and gather data on the success of the policies. This lack of a feedback and analysis tool further hinders the ability to escalate and trigger the phased conservation policy.

MODEL DEVELOPMENT

The development of the Systems Dynamics simulation was conducted in PowerSim®.

DATA COLLECTION

Fortunately, the Directorate of Housing and Public Works maintains an extensive repository of water utilization data over past years. However, the utilization data was an aggregate, by level, of total usage. Unlike the civilian sector, West Point does not meter usage at residences or many facilities at the

Academy. This presented two problems – 1) determining the percent of the aggregate usage that each logical grouping of consumers used periodically and 2) determining the expected percent reduction of usage for each phase of the conservation plan. The first was determined through a statistical analysis of relative usage for number of families, people in the organization, or facilities. The second was determined through statistical analysis from the few measurable usage areas on the West Point grounds.

Originally, customer usage was modeled as a stochastic element within PowerSim®. However, with the need for responsiveness to changing customer trends, the model was revised to incorporate a time series forecast for each level.

An attempt to use average rainfall data for the Hudson Valley region to determine the levels of the numerous freshwater sources was made. However, the data did not exist to show the correlation between rainfall, runoff, and changes in levels of the freshwater sources. Thus, the levels of the sources became a needed input by the user to initiate a run of the simulation. Actual levels are measured bi-weekly by the office of the Directorate of Housing and Public Works. This decision provided greater accuracy of initial values for each run to the simulation.

MODEL STRUCTURE

The system was broken into sub-systems for each level and treatment facility. This allowed for an organized development pallet to facilitate model maintenance and troubleshooting throughout the model's life-cycle. Each level was neatly organized and labeled. Figure 4 shows an example structure for Level 2 of the freshwater system.

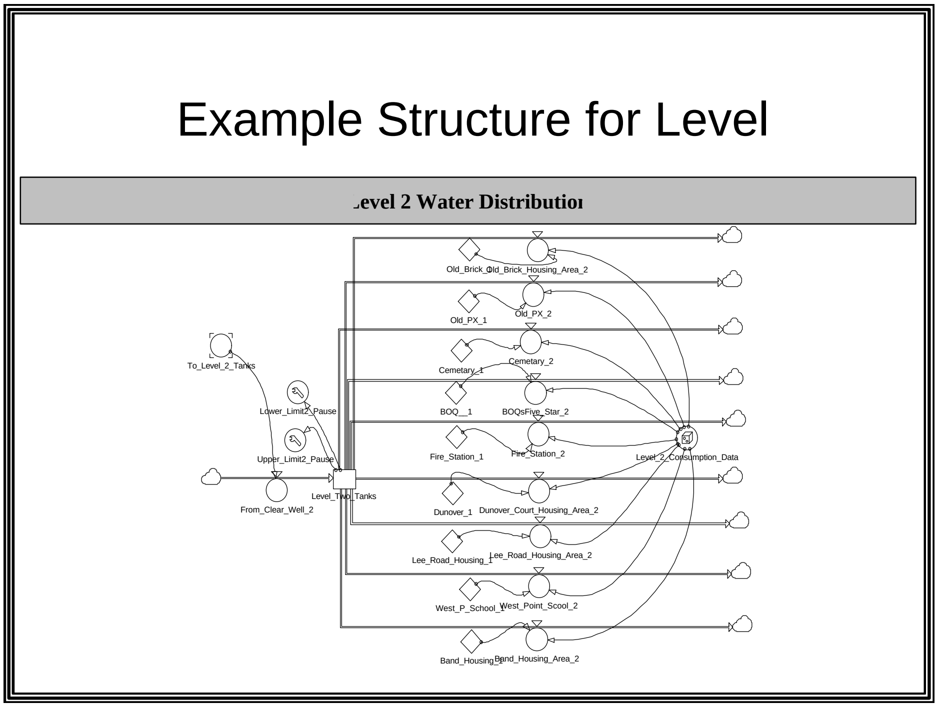

Figure 4 - Example of Level Structure

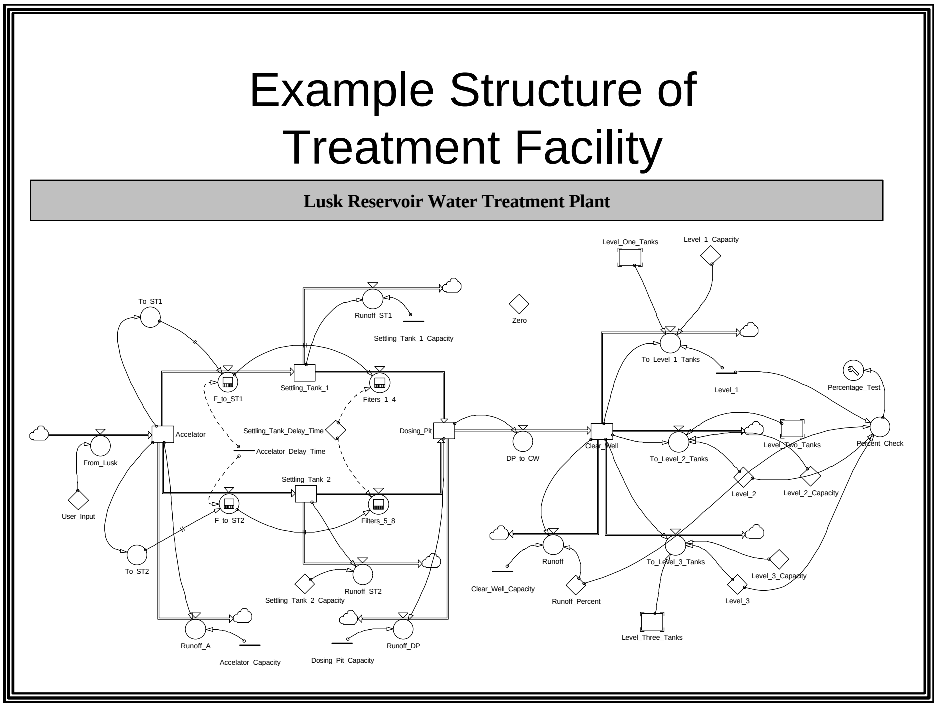

Figure 5 - Example Treatment Facility Structure

Figure 5 shows an example structure for a treatment facility.

USER INTERFACE

The user interface was modeled to allow for visual monitoring of all key aspects of the systems to include built in triggers to alert the user of approaching and bypassed thresholds. There are two main components of the user interface- 1) Monitors and 2) Controls.

After entering the current levels of the freshwater sources on the West Point reservation, the user can run the simulation and monitor levels in the treatment facilities and storage tanks. Figure 6 shows an example of a treatment facility monitor.

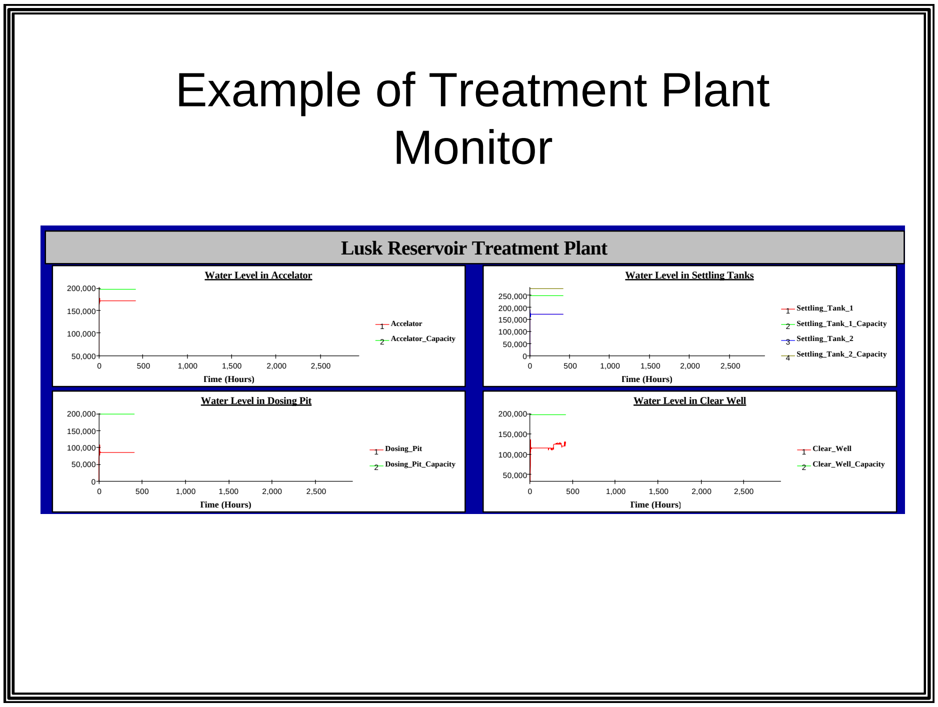

Figure 6 - Example Treatment Facility Monitor

Upon treatment the water flows to various storage tanks upon the grounds.

Figure 7 shows an example of storage tank monitors.

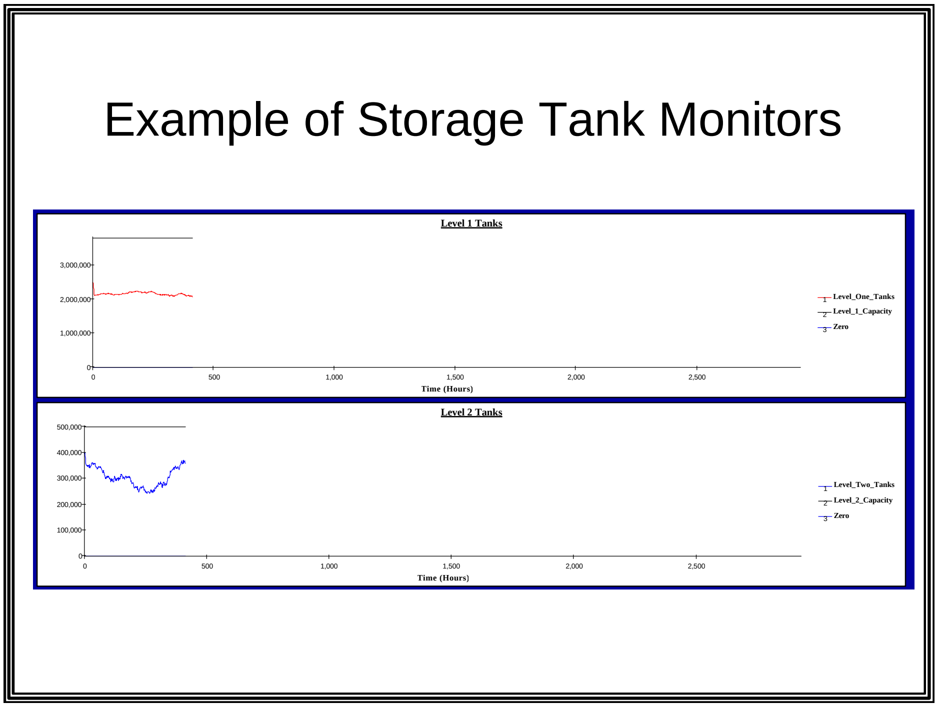

Figure 7 - Storage Tank Monitors

In keeping with the initial purpose of the model, to validate the phased conservation policy at the Academy, controls are used to toggle the appropriate phase of the policy. Figure 8 shows an example control panel for the conservation policy.

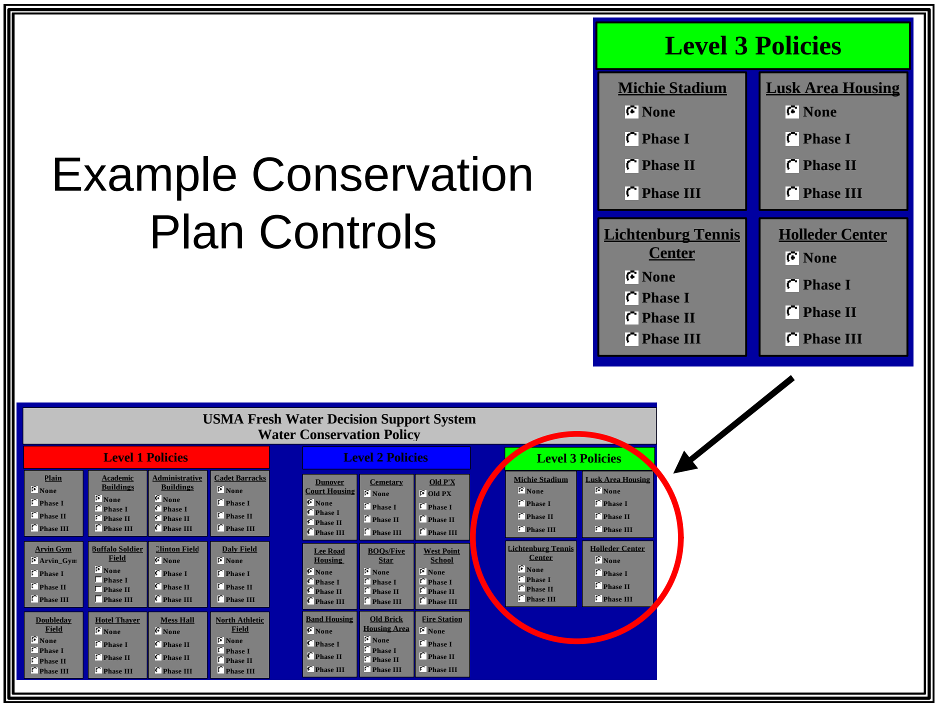

Figure 8 - Conservation Plan Controls

Additionally, controls were designed to allow the user to replicate an increased or decrease output from the treatment facilities. Figure 9 shows an example treatment facility control panel.

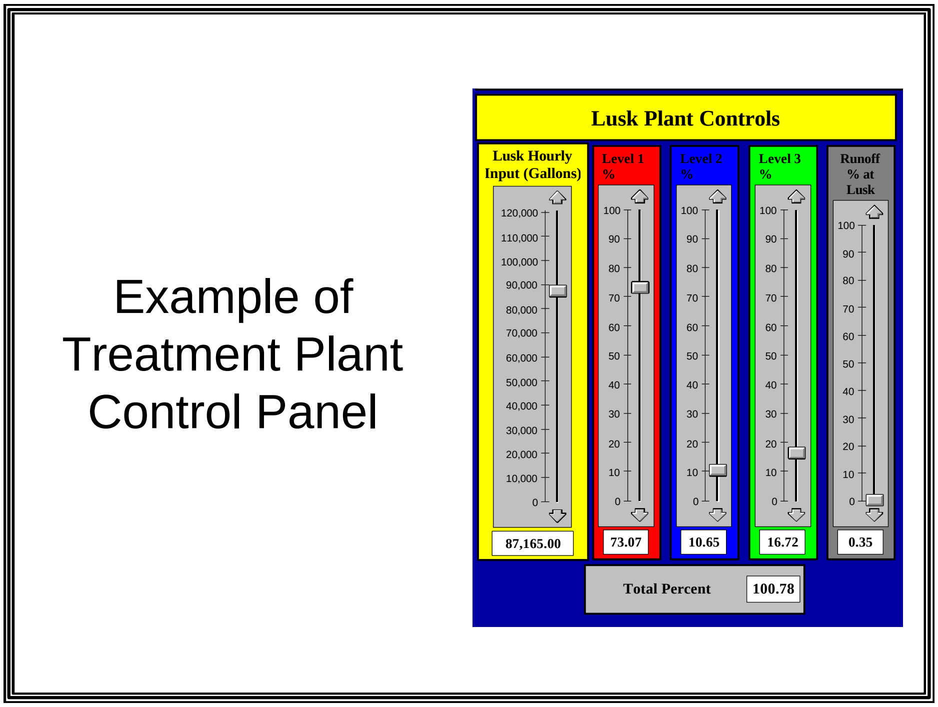

Figure 9 - Treatment Facility Controls

MODEL IMPLEMENTATION

MEETING ORIGINAL NEEDS

The model was delivered through an evolutionary delivery cycle, allowing the users to provide input to development on multiple occasions. As a result of client visibility and input during the development process, the delivery of the system went very smoothly. The process also helped in the validation and verification of the model. Immediately, the client realized that the model provided tremendous insight and enhanced visibility of the freshwater system. This allowed for greater flexibility in implementing the conservation plan. Particularly, the plan can now be implemented at sub-system level if desired. The potential is that conservation goals can be simulated, implemented, and met with minimal impact to the community. “What if” scenario simulation will allow for constant assessment of ongoing conservation measures and facilitate in decision triggers to adjust the conservation phase. In addition to meeting the proposed problem, the client quickly realized that the model was versatile enough for use in related areas.

EXTENSION OF MODEL USE

Like all military facilities, West Point is always conscious of security and protecting the men, women, and families who work and reside at the Academy. The Directorate of Housing and Public Works quickly realized that the model had the potential to simulate catastrophic “what-if” scenarios that could pose a threat to the community. The model allows for taking resources off-line and simulating the recovery of the system. This ability in the model has allowed for significant analysis of system recovery, mitigating the risk of future disruption of the Academy’s mission and the potential threat the human well-being.

CONCLUSION

This was the first time that Systems Dynamics was used during a capstone experience in the Department of Systems Engineering at the United States Military Academy. The effort proved tremendously successful from all perspectives, client, faculty, and cadet. In addition to providing an outstanding product to the client that benefits the community, the capstone experience reinforced the value of Systems Dynamics in the analysis of complex, real-world problems.

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