CASE STUDY
OF A WATER DISTRIBUTION SYSTEM DESIGN

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I. Introduction

The objective of this paper is to describe a realistic design case study which is used in a course required for Civil Engineering students at the University of Tennessee, Knoxville. The class is a senior-level design-oriented class on water distribution and wastewater collection systems. The case study focuses on a hydraulically independent area of the Knoxville Utilities Board's water distribution system. The students analyze the hydraulics of the system including diurnal flow variations, fire flows, pumps and storage tanks in order to identify deficiencies and weaknesses of the system. They then propose and evaluate system improvements and submit an engineering report. The paper will discuss the case study's organization, show the tools and data that the students use, and give examples of their results.

II. Rationale for case study

The primary motivation for the development of this case study was to bring students face-to-face with a real problem in engineering analysis, in this instance, design of a water distribution system. Students chose engineering partly because they enjoy solving problems and designing solutions. Understandably, they generally want to work on real design problems in their degree programs. Based on student feedback, engineering students respond more positively to courses that involve real systems and problems, and consequently, probably learn better. Using realistic case studies is a logical response to these learning issues. In fact, most MBA programs recognize the value of case studies and use them extensively.

Our case study design also helps our Civil Engineering degree program meet several ABET 2000 goals and criteria. This design project case study helps us achieve these ABET 2000 outcomes:

1) an ability to apply knowledge of mathematics, science, and engineering
2) an ability to design a system, component, or process to meet desired needs
3) an ability to function on multi-disciplinary teams
4) an ability to identify, formulate, and solve engineering problems
5) an ability to communicate effectively
6) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

The case study also helps us meet the Civil Engineering Program Criteria 2000 (part of the ABET 2000 process) which stipulates that "graduates of the program must demonstrate an ability to perform civil engineering design by means of design experiences integrated throughout the professional component of the curriculum."

III. Description of case study

The subject of this case study is the Third Creek Repump Area in Knoxville Utilities Board’s (KUB) water system. The area is small enough for the students to analyze, but large and complex enough to require the students to grapple with real engineering design issues. The Third Creek Repump area serves about 30,000 people and is connected to the rest of the KUB system through a pump station. The area is about 7 miles long and 5 miles wide. Because Knoxville is in the valley and ridge province of east Tennessee, elevations in the area vary from about 900 to 1300 feet. Peak day flow is about 4,750,000 gallons/day. Distribution system modeling is normally performed on a skeletonized version of the system, from which all but the primary pipes have been removed. In addition, a small tank and pump station that serves a small, isolated section of the system were eliminated to focus the students’ attention on the major system components. Figure 1 shows the skeletonized system. Pipe diameters ranged from 2" to 16".

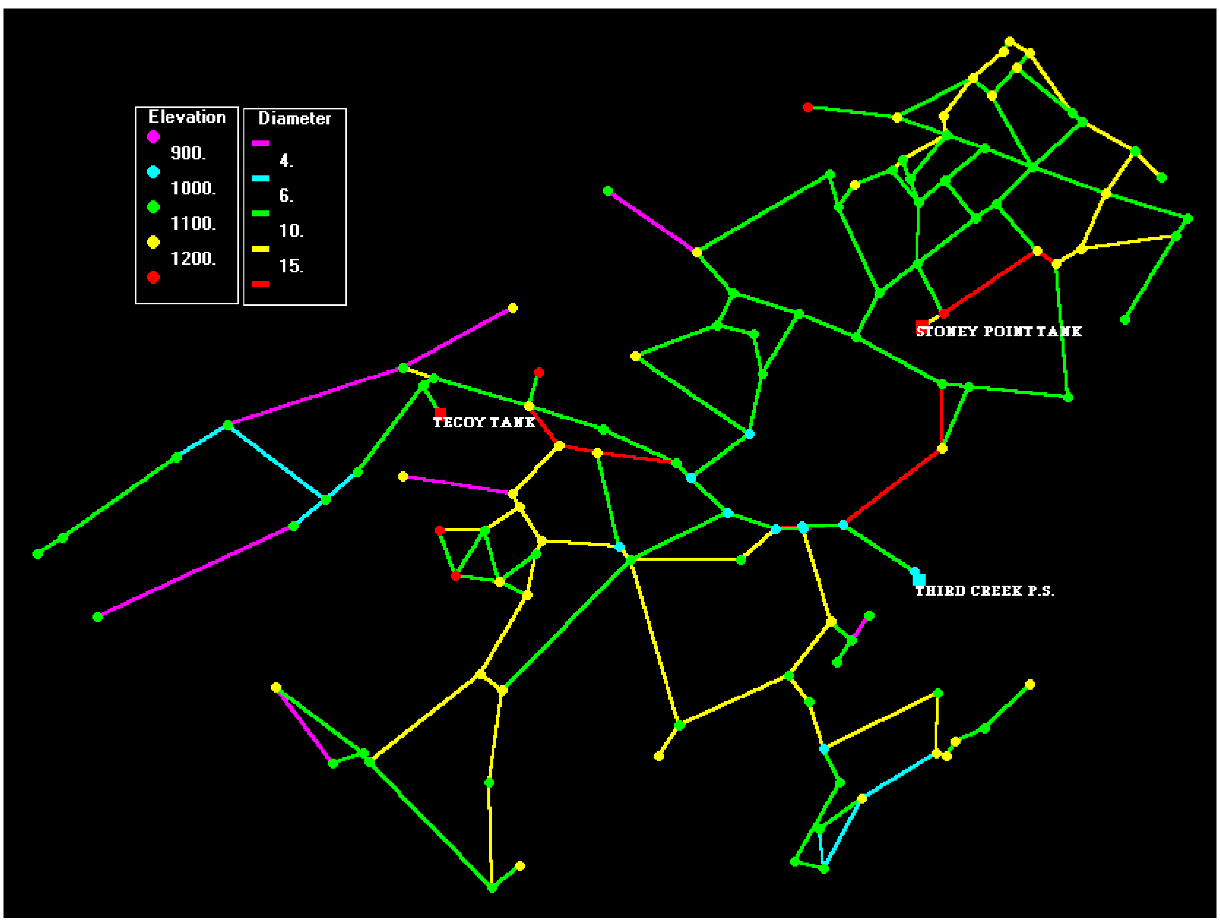

Figure 1. Skeletonized pipe system for Third Creek Repump Area

Pipes less than 6" in diameter are the legacy of small systems that have been incorporated into the Third Creek Repump area as KUB has expanded.

Water enters the Third Creek Repump area through three pumps in a pump station in the southeast part of the area labeled "THIRD CREEK P.S." in Figure 1. Two standpipes, labeled "TECOY TANK" and "STONEY POINT TANK" in Figure 1, have capacities of 500,000 gallons and 270,000 gallons, respectively. These tanks sit on hills and serve as elevated storage.

The Third Creek Repump area has several characteristics that make the analysis challenging and interesting. The 400 foot difference in topography causes lower elevation areas to have pressures in excess of 100 psi. Pressure reducing valves are installed on service lines where needed in these areas. The rapid development of the area has made it difficult to keep the system adequate for all contingencies. Also, the undersized pipes that KUB inherited have not all been replaced.

In this case study, students are required to:

1) analyze the system's ability to meet the diurnal demands on peak day while still maintaining a minimum pressure of 20 psi at all nodes
2) assess the system's ability to meet reasonable fire flows
3) based on the analysis above, design and evaluate improvements to the system, e.g., replace or provide additional pumps, build another storage tank, replace or supplement pipes in order make the system adequate

The students work in teams of up to 3 members. The students use EPANET [1] software, a public domain program developed by the U.S. Environmental Protection Agency, to analyze the performance of the distribution system. EPANET is a sophisticated dynamic water-distribution-system model capable of simulating multiple pumps, multiple storage tanks, valves, and diurnal flow variations. The model can produce several outputs including pressure contour maps and tables of pipe flows, rates of head loss, and nodal pressures for any time. Figure 2 shows a typical EPANET screen shot.

EPANET requires an input file that contains data defining the nodes, pipes, pumps, tanks, and diurnal flow patterns. It would take an unreasonably long time for the students to build the input file for the entire system. In order for the students to complete the project within a reasonable time frame, they are provided an input data file for most but not all of the nodes and pipes. The students must code the pipe and node data for a small sample area of the system as well as code data for the tanks, pumps, and diurnal flow patterns. They must estimate flows for the nodes in the sample section and properly input node and pipe data. A 24" by 36" map of the system showing major pipes and node numbers is given to each team, and AutoCAD files of the system topography, building locations, and pipe locations and sizes are made available in a computer laboratory. Figure 3 shows a typical AutoCAD file that the students can access. The students are also given size and location data for the tanks and several points off the pump curves which they must convert to the required EPANET input format. A portion of the EPANET input file is reproduced Table 1.

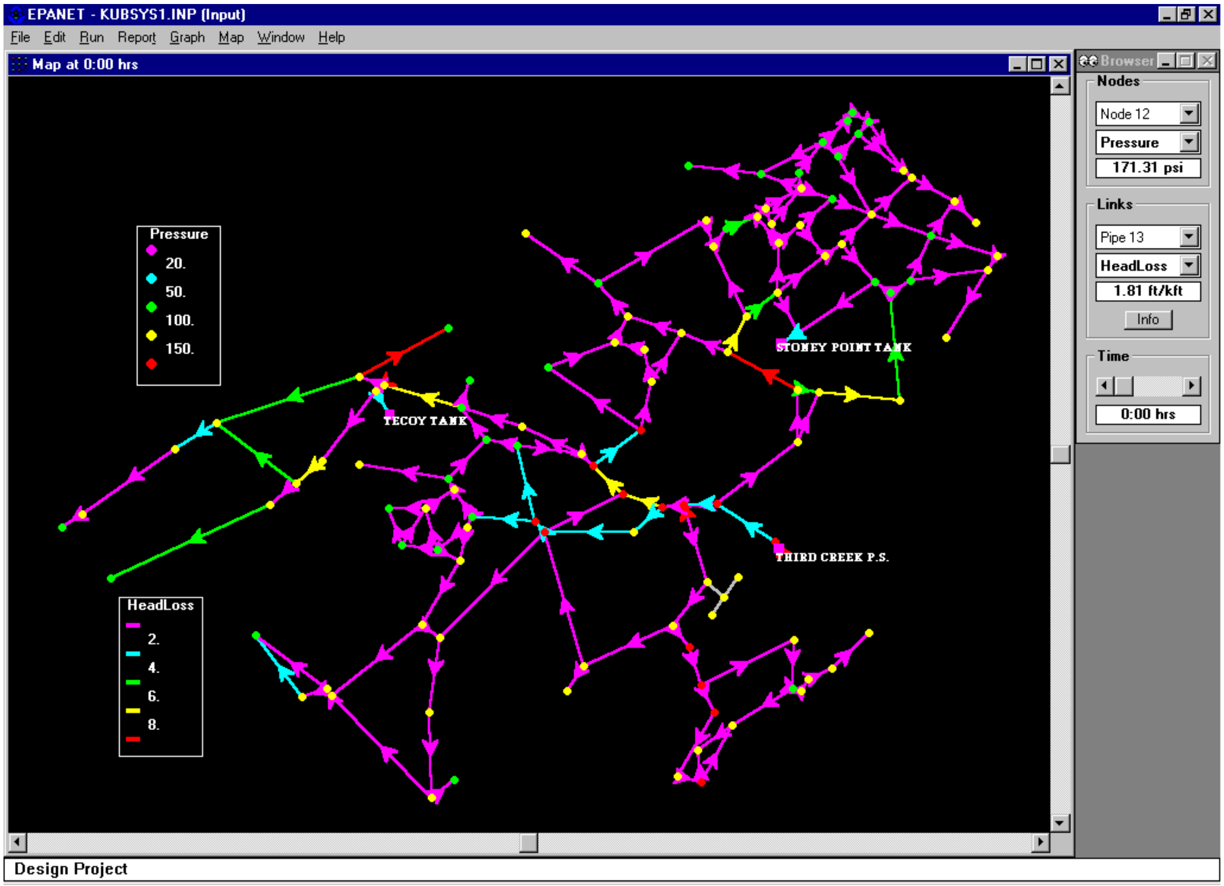

Figure 2. EPANET screen shot.

EPANET allows changes in demand during the day, i.e., diurnal variations. For example, Figure 4 shows the assumed flow pattern at one node during the day. The base average day flow is multiplied by the multipliers in the graph to produce the hourly flow variations. In order to simulate a fire at this particular node, a high multiplier is chosen over the time period of the fire (7 AM - 10 AM). Modeling the daily variations in flow allows the students to model the filling and emptying of the tanks and determine whether they will go dry at some time.

The first exercise the students complete is to assess the system's adequacy without a fire occurring. This is done on a firm capacity basis, i.e., assuming the largest pump is down for repairs. Figure 5 shows a typical student-generated pressure contour map for this condition. The students evaluate whether the system can maintain pressures greater than 20 psi (purple areas in figure) at all points and all times during the day. Usually, the students find a few minor areas that experience low pressure. They also see that much of the system is at pressures over 100 psi (red areas in figure).

The students next consider a major fire at an assigned location in the system. The students survey their assigned location by car to identify a building that would make a good fire flow test. They estimate the fire flow and duration based on procedures discussed earlier in the course. The

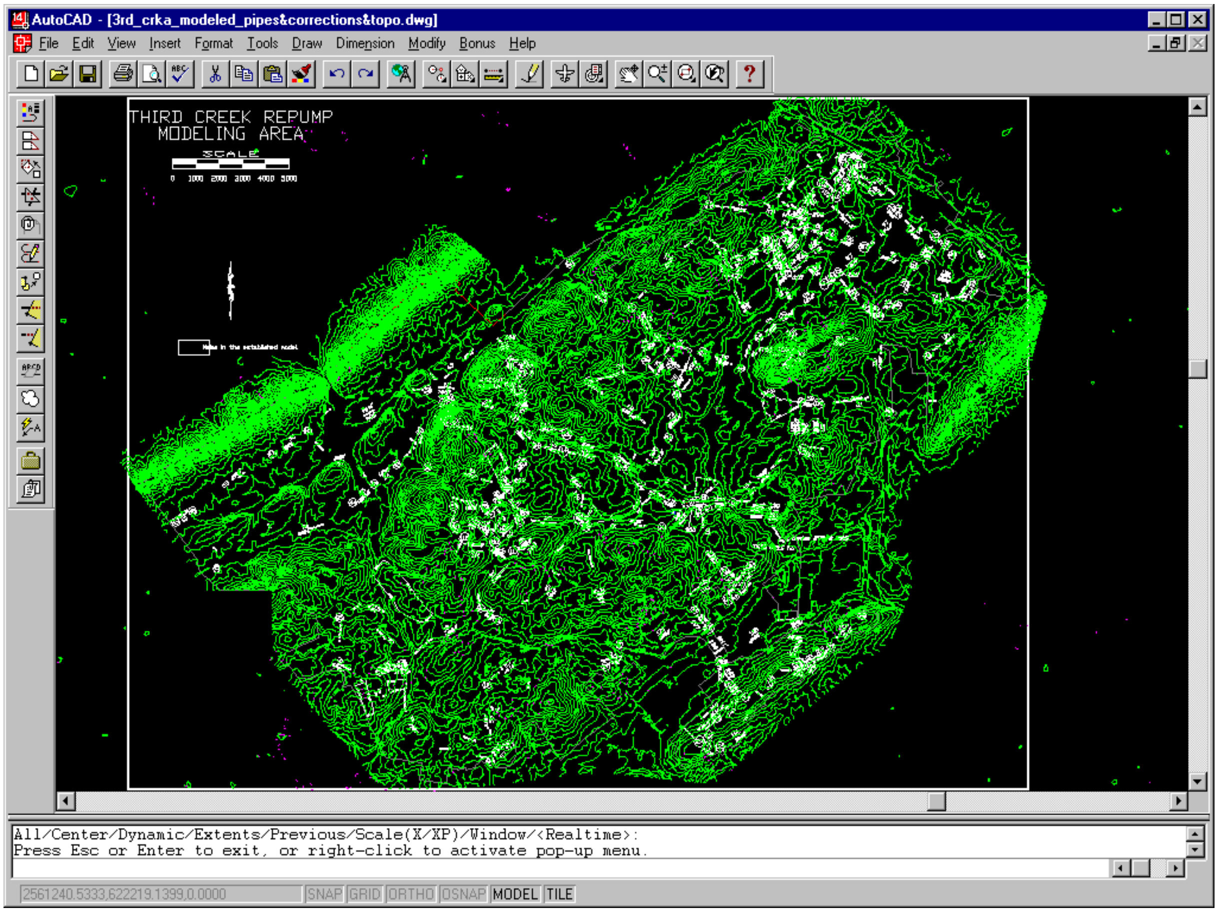

Figure 3. Example AutoCAD file.

students generally find serious low pressure problems during the fire as shown in a typical result in Figure 6. They also find that the storage tanks go dry during the fire as shown in Figure 7.

Based on their analyses, the students then decide what improvements to make to the system and test them. They are usually able to increase several pipe diameters, add an additional pump and storage tank to make the system work.

IV. Student response

Student responses have generally been enthusiastic. Some teams have taken the project as a personal challenge and have spent upwards of 40 hours per team member, although the average is less than 20 hours per team member. Overall, the students enjoy working with the EPANET computer program, and appreciate the realism of the case study. To quote one student, "I finally felt like an engineer."

V. Problems and Planned Improvements

Although the case study has been successful and the students seem to learn much from it,

Table 1. Portion of EPANET input file.

```
[TITLE]
Design Project

[JUNCTIONS]
;ID     ELEV   DEMAND
8       935    26.73
9       960    5.44
10      950    10.89
 •
 •
 •

[TANKS]
;ID     ELEV   INIT   MIN    MAX    DIAM
202     1298   16.3   0      33     51
201     1298   15.1   0      32     38
208     950

[PIPES]
;ID     NODE1         NODE2         LENGTH        DIAM ROUGH
13      8             9      1233          16     100
14      8             10     1254          6      100
18      9             13     3158.5               12     100
 •
 •
 •

[PUMPS]
;ID     NODE  NODE   SOH
230     208   209      434  409  1500  319  2750
231     208   209      399  369  1250  319  2250
232     208   209      461  434  1750  299  3500

[TIMES]
DURATION 24

[PATTERNS]
1 0.7 0.4 0.3 0.3 0.4 0.6 1.3 1.7 1.8 1.75 1.66 1.55
1 1.49 1.47 1.53 1.62 1.77 1.85 1.9 1.87 1.62 1.25 1.1 0.8
2 0.7 0.4 0.3 0.3 0.4 0.6 1.3 220 220 220  220 1.55
2 1.49 1.47 1.53 1.62 1.77 1.85 1.9 1.87 1.62 1.25 1.1 0.8
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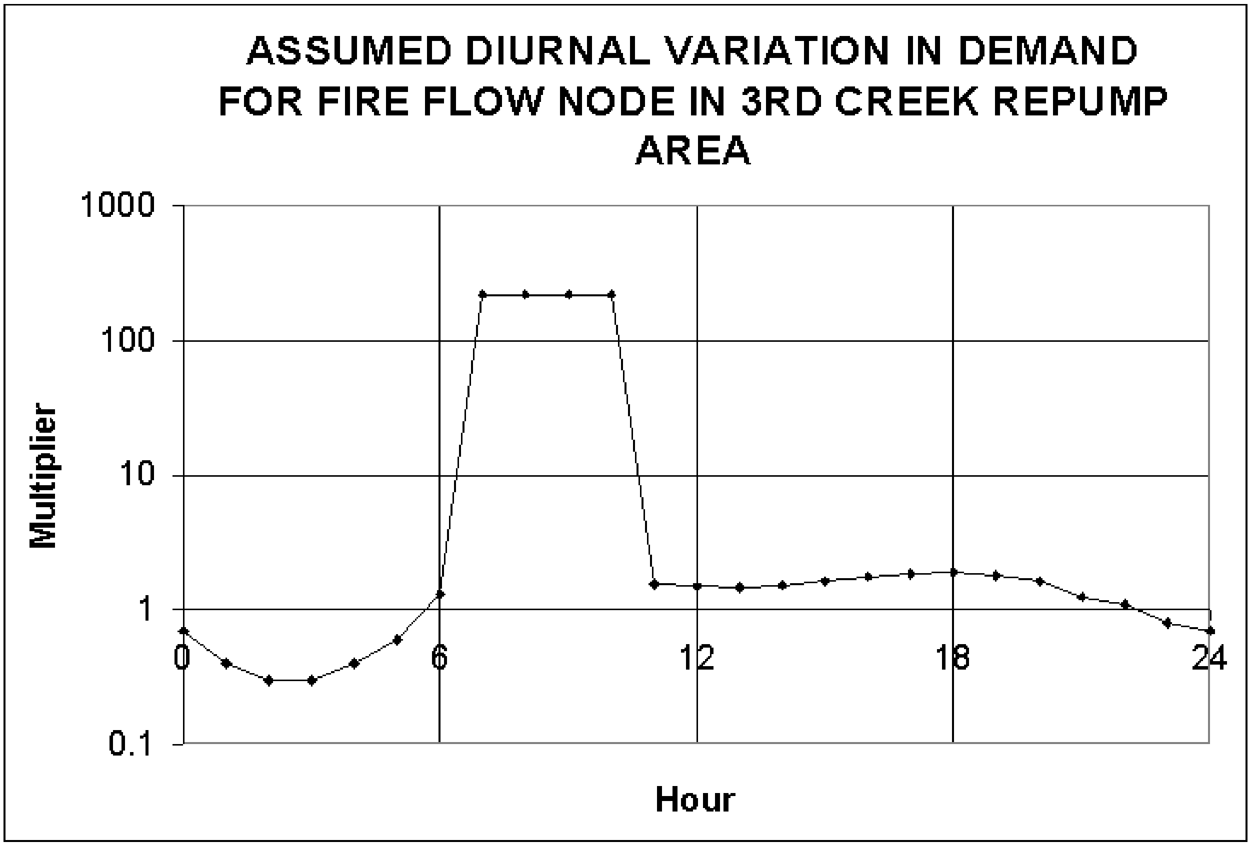

Figure 4. Diurnal variation in demand for node with fire flow.

several areas for future improvements have been identified. One goal is to get the students to better integrate what they've learned earlier, i.e., apply material they covered earlier in the semester. Students tend to approach their design improvements by trial and error without using the analytical skills that they learned earlier in the semester. Specifically, they do not analyze the storage tanks to determine required volumes for flow equalization and fire flow. They also tended not to look for pipes with higher head loss/unit length as target pipes for upgrading, nor did they make some simple single pipe line analyses to estimate how big pipes need to be. We will try to focus students more along these lines in the future.

Also, students tend to treat the EPANET program as the proverbial "black box," and showed poor ability to debug input file errors that caused the program not to run. We will try to improve their skills by giving them more pointers on debugging and on testing output to be sure it is giving reasonable answers, e.g., summing headlosses around pipe loop to see if they do sum to zero.

There is also a concern with repeated use of the same case study. The severity of this problem is limited to some extent by the fact that the seniors who take the course are often not around the next semester to pass along their material. We also have been making significant changes in the problem statement from semester to semester. So far, overt copying from the previous

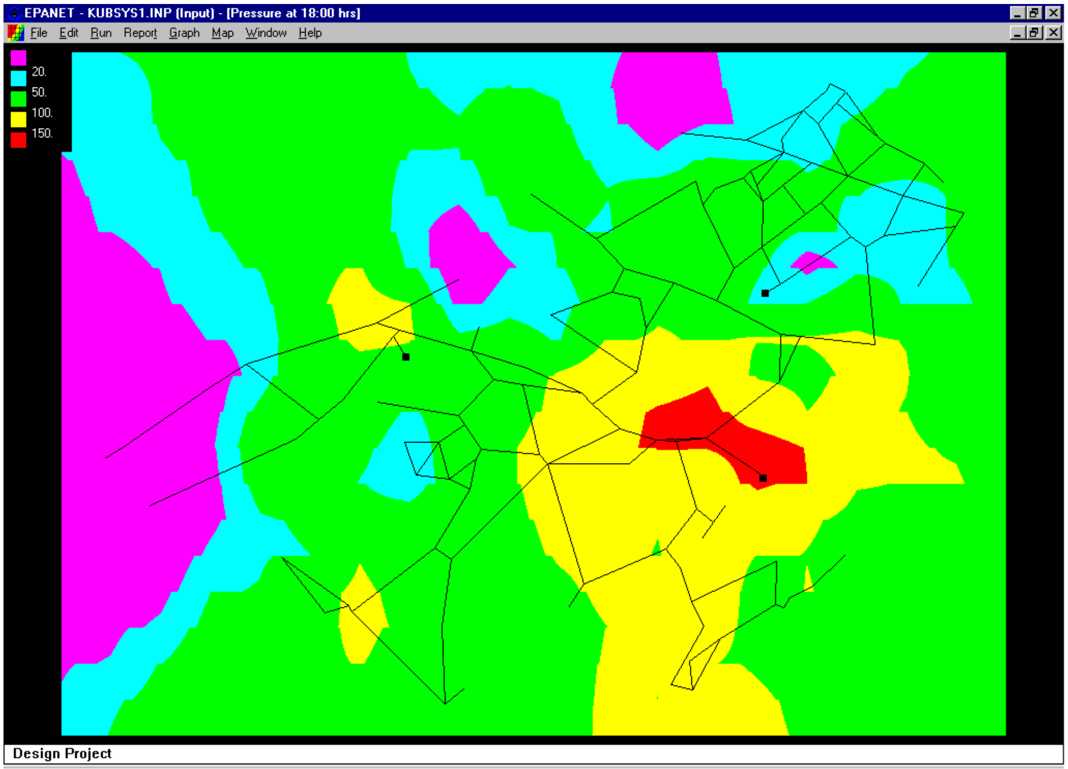

Figure 5. Typical pressure contour map for no fire flows.

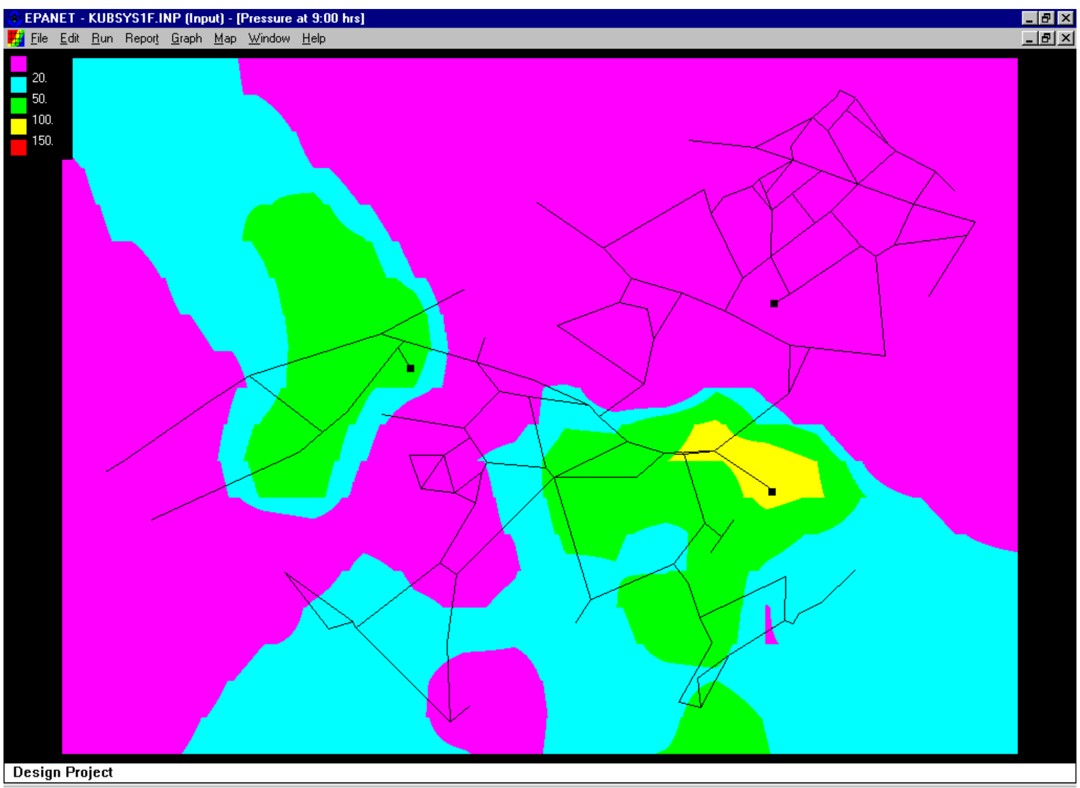

Figure 6. Typical pressure contour map with fire flow.

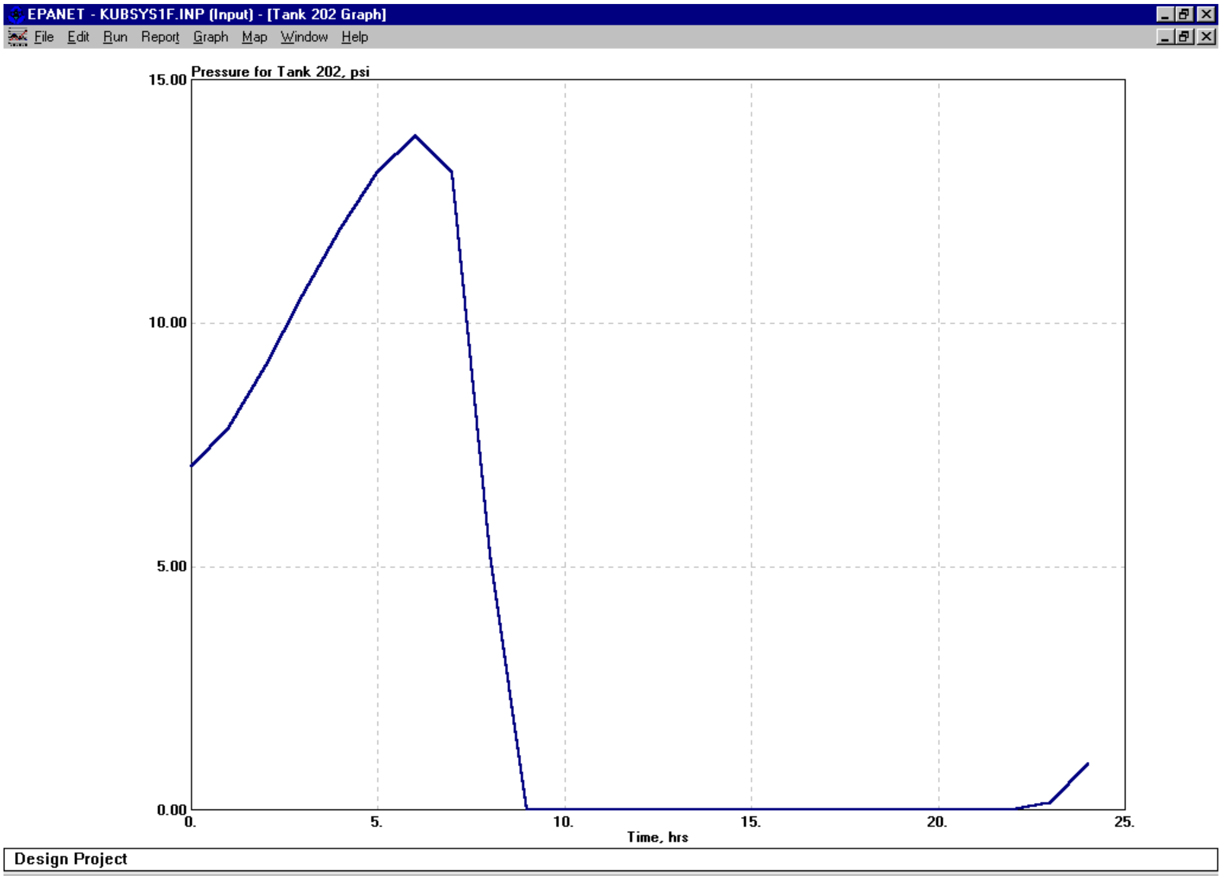

Figure 7. Typical variation in pressure in Stoney Point storage tank.

semester's projects has not been a problem. Considerable time is required to develop such case studies, and ultimately a balance will have to be struck between length of time the case study is used and development time for new case studies.

VI. Acknowledgments

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Bibliography

1. Rossman, L. EPANET Users Manual. Cincinnati, Ohio: U.S. Environmental Protection Agency (1994).
2. URL: http://www.epa.gov/ORD/NRMRL/epanet/; EPANET

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