Maximizing Commercial Hydraulic Software Simulation in Thermal Distribution System Continuous Commissioning®

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KEYWORD

Continuous Commissioning, Hydraulic Simulation, Energy Management and Conservation, Thermal Distribution System

ABSTRACT

Since a district thermal distribution system normally serves tens of buildings, sometimes up to hundreds, potential impacts of a crucial utility decision can be overwhelming. Without disturbing the actual system, hydraulic simulations have long been adopted, and are even more helpful upon today's technology and information system platform. Through simulations, analyses can be performed to predict system responses for proposed actions with accuracy. Options can be explored to provide guidance in making the final engineering decision well before time, people, and money are invested.

The Energy Systems Laboratory has conducted a number of Continuous Commissioning® (CC) [1] projects on the thermal distribution systems of Texas A&M University at College Station, University of Texas at San Antonio, and other sites. These projects include: 1. condenser water (CW) system troubleshooting, 2. chilled water (CHW) and heating hot water (HHW) loops expansion, 3. satellite plant HHW system innovative operation and potential expansion, and 4. domestic hot water (DHW) system balancing. This paper intends to demonstrate through these case studies how hydraulic simulations successfully assisted in the decision-making process regarding thermal distribution systems' operation, troubleshooting, and master planning.

ACRONYM LIST

CC	Continuous Commissioning
CHW	Chilled Water
CW	Condenser Water
CWP	Condenser Water Pump
DP	Differential Pressure
CUP	Central Utilities Plant
DHC	District Heating and Cooling
DHW	Domestic Hot Water
ESL	Energy Systems Laboratory
HHW	Heating Hot Water
SS3	South Satellite Plant #3
TAMU	Texas A&M University
TEP	Thermal Energy Plant
UTSA	University of Texas at San Antonio
WC1	West Campus Plant #1
WC2	West Campus Plant #2
WC4	West Campus Plant #4

INTRODUCTION

Continuous Commissioning® began as part of the Texas LoanSTAR program at the Energy Systems Laboratory (ESL) at Texas A&M University (TAMU). Based on current usage, instead of design intent, this process identifies and implements optimal operating strategies. The CC process was first developed and applied to the air/water sides of building HVAC systems, and later extended to central CHW and HHW distribution loops and utilty plants. This brings more challenges and bigger opportunities, since it targets the performance of the entire system with all major components – all buildings, distribution loops and central plants [1][2].

The thermal distribution network is the most expensive portion of a District Heating System (DHC) system. It usually constitutes 50 to 70% of the total cost [3]. Since it usually serves tens of buildings, sometimes up to hundreds, potential impacts of even minor changes can be staggering. Its performance has always been a major concern for facility O&M staff, engineers and managers.

These kinds of systems are usually so complex that it is difficult to understand the operation of and

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interaction within them. It is not practical to conduct experiments on an existing one or one that has not been built yet. Commercial hydraulic simulations have long been adopted and are increasingly accepted as a reliable source of information in making engineering and operational decisions [4].

Software used in this paper is a typical commercial hydraulic simulation software. It can analyze a variety of pressure piping systems, such as water distribution systems, industrial cooling systems, oil pipelines, or any network carrying an impressible newtonian fluid in full pipe from purily hydraulic point of view. It not only provides simulation models for pipes, tees, heat exchangers, pumps and valves, but also is capable of handling controls of some of its components, such as controlling variable speed pumps and modulating control valves to maintain pressure or flow.

In the past years, CC has been performed on several thermal distribution systems of TAMU at College Station and the University of Texas at San Antonio (UTSA) and other sites [5]. These projects cover various engineering problems, such as trouble shooting, expansion, renovation, and operation of different type of thermal distribution systems. Using commercial hydraulic simulation software, options can be explored to provide guidance in making the engineering decision well before time, people, and money are invested in thermal distribution systems' operation, troubleshooting, and master planning. The cost of modeling a system is usually insignificant in comparison to the capital investment involved in the installation and construction of a new system.

CASE 1, CW SYSTEM TROUBLESHOOTING

Hydraulic simulation was conducted to identify the optimal design for the planned additions to the UTSA 1604 campus central CHW distribution system [5]. As another part of the same project, the UTSA downtown campus CW system troubleshooting is also a successful story.

The UTSA downtown campus consists of three buildings, and a fourth is under construction. The buildings receive CHW and HHW from the campus thermal energy plant (TEP). The TEP consists of three chillers, three cooling towers, two boilers, two heat exchangers, and primary/secondary distribution loops.

All the CW lines were traced and measured in the field. The physical structure of the simulation model (Figure 1) is built upon field notes and design blueprints. There are three pumps (CWP2, CWP3, CWP4) connected to a common header to serve Chiller #2 and #3. According to the control program, CWP2 serves chiller #2 and CWP4 serves Chiller #3. CWP3 serves as a backup pump for CWP2. CWP1 solely serves Chiller #1. After the CW pipe goes out of the TEP, it goes along the basement hallway and then up to the three identical cooling towers located on the roof of the building. According to the control program, there are six operation stages. The detailed schedule is listed in .

Field tests were conducted to measure the CW flow rate on each chiller under different stage operation by using ultrasonic flow meter. Field measurement results and the results of calibrated simulation model are listed in Table 2.

The original intent of this project was to size a pump to replace the CWP1, because the facility owner believed that the CWP1 was undersized so that Chiller #1 could not get adequate CW supply. However, the simulation model results indicate that the pipes, which connect Chiller #1 to the loop, have excessive friction losses. If assuming normal friction losses and 100% opened valves, the simulated CW flow rate for Chiller #1 will be 1,862 GPM, which is significantly higher than the measured value (1,360 GPM). The plant personnel were called to verify in the field whether all manual valves of Chiller #1 were fully opened. It turned out that a balancing valve was 75% shut. That explains why the simulation model indicates large friction losses on Chiller #1 CW pipes. After fully opening this valve, Chiller #1 received adequate flow and the cost of replacing the existing the existing CWP1 was avoided.

Table 1: Chiller Operation Schedule at UTSA TEP

Stage	Chiller #1	Chiller #2	Chiller #3	Total Capacity (Ton)
1	On			515
2		On		800
3			On	1,000
4	On		On	1,515
5		On	On	1,800
6	On	On	On	2,315

Table 2: Summary of Field Measured and Simulated CW Flow Rate at UTSA TEP

Stage	Flows (GPM)					
	Chiller #1		Chiller #2		Chiller #3	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
1	1,361.0	1,360	-	-	-	-
2	-	-	2,808.7	2,800	-	-
3	-	-	-	-	3,037.0	3,050
5	-	-	2,109.0	2,115	2,289.0	N/A

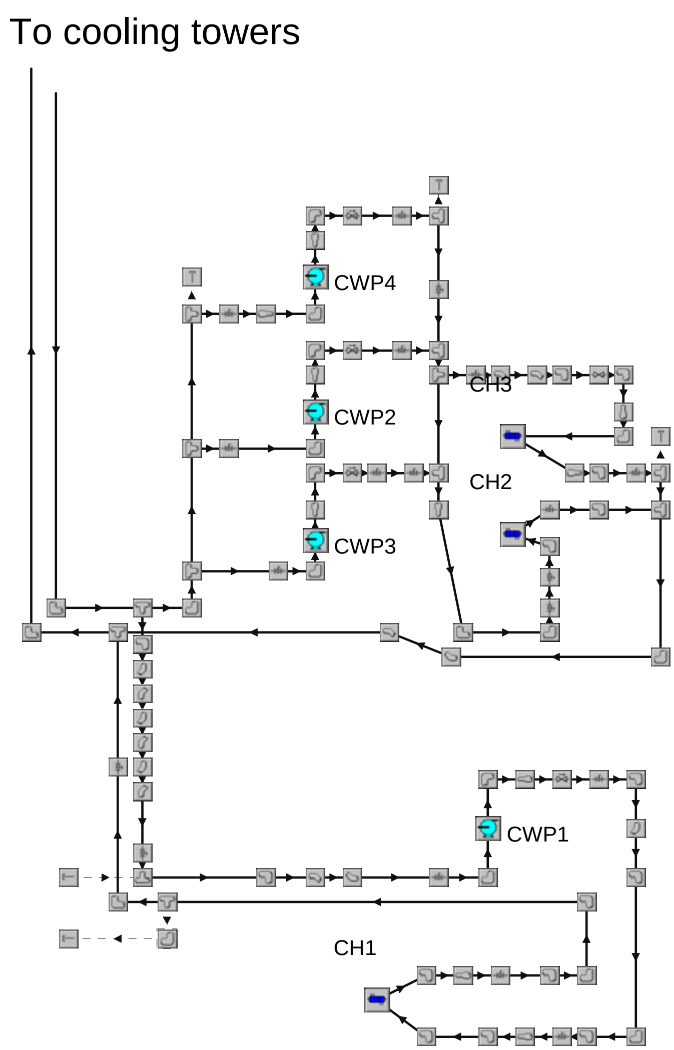

Figure 1: UTSA TEP CW Loop Model

CASE 2, CHW AND HHW LOOPS EXPANSION

As shown in Figure 2, the TAMU West Campus has its own central CHW and HHW distribution loops. There are twenty-eight buildings with more than 3.0 million square feet of building space and three thermal plants, i.e. West Campus Plant 1 (WC1), West Campus Plant 2 (WC2), and West Campus Plant 4 (WC4). WC1 and WC2 have a total installed cooling capacity of 14,000 tons. WC 1 has three identical 400HP boilers for producing hot water. WC4 produces HHW only through steam heat exchangers.

Because of the potential for three new buildings along Agronomy Road (Figure 3), evaluation of the West Campus CHW and HHW piping expansion opportunities was required. Simulations were conducted to predict the system responses and to explore various options. Information regarding existing underground infrastructure was collected and considered in the simulation models.

The CHW and HHW expansion lines needed to be selected carefully as the underground infrastructure were already crowded in that area. Two possible piping layouts were evaluated based on the available information. The locations of the three proposed buildings are illustrated in Figure 3.

Option 1

Figure 3 shows the schematic piping layout for option 1. The solid dark blue lines represent the existing CHW loop. The proposed pipes (dashed green lines) will go along the west side of Agronomy Road with existing underground electric cables, domestic cold water and other underground infrastructure. Simulation results are listed in Table 3.

Option 2

Figure 3 also shows the schematic piping layout for option 2. Simulation results are listed in Table 4. The proposed pipes (dash-dotted red lines) will go along a parking lot, where there are less underground electric cables, domestic cold water and other underground infrastructure.

Results and Discussion

- Taking into account the future West Campus development at this area, 18” CHW pipes and 10” HHW pipes seems the best choice for both options.

- Option 1 will have shorter overall pipe lengths than option 2. However, the underground infrastructure and electrical cables under Agronomy Road already have been crowded, which need extra attention when doing construction.

- Option 2 will have longer pipe lengths but crosses area that is less crowded with underground piping and electric cables. The disadvantage of this option is that it still requires CHW/HHW pipe to cross Agronomy Road for future buildings along the east side of Agronomy Road.

Table 3: Summary of CHW Pipe Pressure Losses for Different Pipe Sizes for Option 1

BLDG #	Building Name	GPM	Pipe Length (ft)	Pressure Losses (psi)				
				18" main	16" main	14" main	12" main	10" main
B1	Transportation Building	250	2,454	0.99	1.43	2.30	3.36	7.09
B2	State Chemist Lab	333	5,064	1.54	2.47	3.94	7.40	19.89
B3	Staff Building	500	5,616	2.55	3.54	5.22	8.64	24.75

Note: The pipe length is the total pipe length from WC2 to the specific building, including the return line.

Table 4: Summary of CHW Pipe Pressure Losses for Different Pipe Sizes for Option 2

BLDG #	Building Name	GPM	Pipe Length (ft)	Pressure Losses (psi)				
				18" main	16" main	14" main	12" main	10" main
B1	Transportation Building	250	2,388	2.73	3.09	3.80	4.67	7.70
B2	State Chemist Lab	333	5,598	1.63	2.69	4.28	8.50	23.71
B3	Staff Building	500	6,156	2.64	3.78	5.57	10.51	28.61

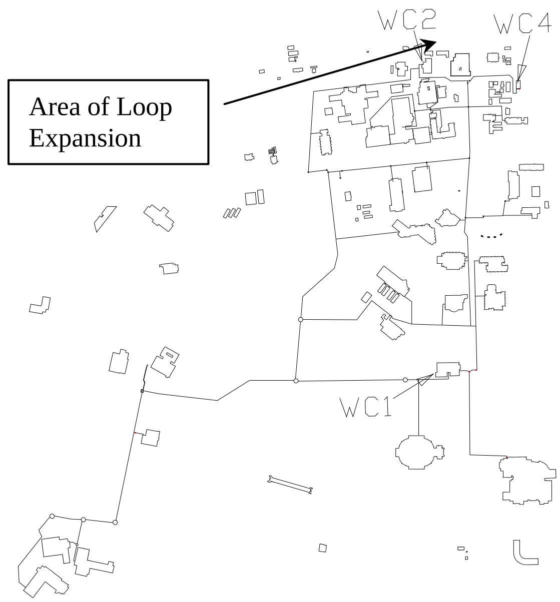

Figure 2: West Campus Central CHW/HHW Loops

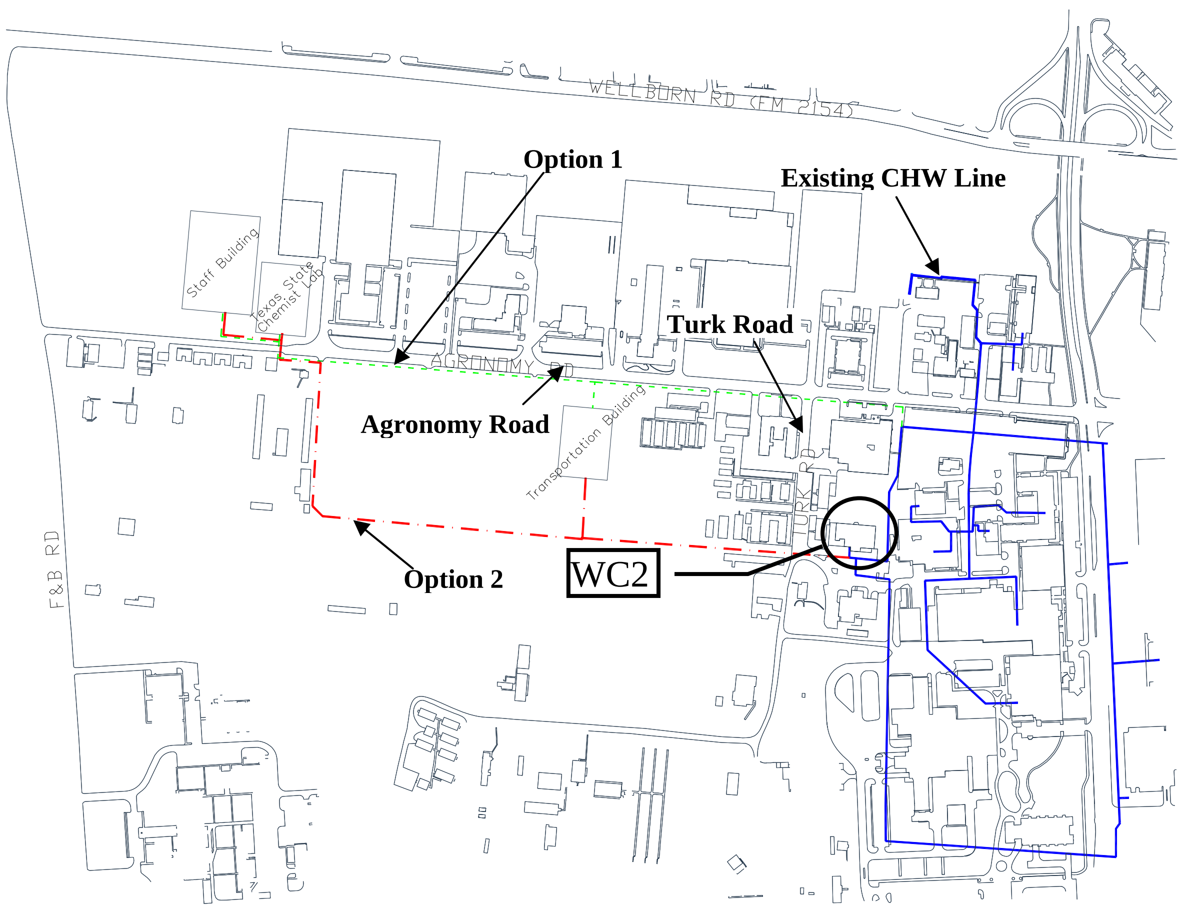

Figure 3: Agronomy Road CHW/HW Loop Expansion, Option 1

CASE 3, HHW SYSTEM INNOVATIVE OPERATION AND POTENTIAL EXPANSION

The TAMU utility system has grown to many times its original size over the years. Although the Central Utilities Plant (CUP) on the Main Campus has been in operation since 1917, other plants were built as the university expanded. Currently, TAMU Main Campus central HHW system serves 115 buildings with more than 10.0 million square feet of dormitories, offices, labs and other spaces. Figure 4 shows the system layout of the central HHW distribution system.

As part of its cogeneration system, CUP has six heat exchangers with 330 MMBtu/hr heating capacity, which utilizes 20 psig steam to produce heating hot water.

After years of campus expansion, the loop differential pressure (DP) at the Kyle Field area and the Corps Dorm Area, located at the farthest point of the loop, dropped very low. Figure 5 is the South Satellite Plant #3 (SS3) HHW piping diagram, which indicates the piping structure before CC, after CC and for future expansion. The simulation results are summarized in Table 5.

According to the simulation results, without the SS3, even if the CUP HHW pumps run at full speed and can provide HHW at 67 psid as they are designed to do (ignoring the pressure drop at the heat exchangers in the CUP), the building primary DP at Corps Dorm area will still be below -40 psid (-92ft). However, the HHW pumps at this area have a design head range from 60 to 78ft. This means that the CUP alone could not provide sufficient HHW to buildings in this area. The simulated HHW flow of CUP east loop (14" pipe) is over 7,000 GPM. For 14" pipe, the design capacity is 6,000GPM, assuming 4ft/100ft friction losses. From a purely hydraulic point of view, the CUP lacks the capacity to meet the campus demand.

However, before the completion of the SS3 expansion, a temporary solution was required. The CC measures for SS3 were: (1) to install a VFD controlled 150 HP booster pump (2) to shut the valve on the SS3 south loop supply line and (3) to partially open the valve on the SS3 east loop return line. Though there is no heat source at the SS3, the booster pump can increase the pressure on the supply side at this area. Therefore, it could improve the primary building DP distribution at Kyle Field area and Corps Dorm area. Because the booster pump essentially circulates return water to the supply line directly, the temperature distribution will be affected as well. In order to keep the SS3 HHW supply temperature from dropping too low, the valve on its east loop return line was only partially opened.

The system was balanced by manually adjusting the pump speed and position of the SS3 east loop return line valve. During winter heating season, the booster pump normally runs at about 50%. The valve on the SS3 east loop return line was normally 15% open. The simulation results are listed in Table 5. As the team expected, the simulation results confirmed the improvement on the primary building DP distribution.

These CC measures have been implemented for a couple of years. They achieved great success by keeping the system in balance, especially at the Kyle Field area and the Corps Dorm area, and avoided extra cost for rental boilers. Analytical results from the HHW system simulation pointed out that although CUP has adequate thermal capacity, it is reaching its hydraulic capacity under the current system configuration. According to the university master plan, the TAMU Main Campus will expand significantly over the next few years. Though the SS3 booster pump helped significantly, it is only a temporary solution. The expansion of the SS3 is the long term solution to resolve the challenge.

CASE 4, DHW SYSTEM BALANCING

The TAMU central DHW system serves sixty-eight buildings with more than 6.0 million square feet of building space. In the last five years, more and more students have complained about "cold showers" in their dorms. Hydraulic simulation was conducted to better understand the system characteristics and to decide the best direction of CC. Follow-up system-wide balancing and fine-tuning finally resolved this problem, for details please see [7].

CONCLUSIONS

Utilization of commercial hydraulic software simulation in thermal distribution system has proven to be helpful and beneficial for engineers, managers and facility O&M staffs, by predicting system responses for proposed actions. In comparison to the capital investment involved in installing and construction of a new system, modeling a system is very cost effective. It is also realized that a properly contructed simulation model is a valuable asset to the facility owner.

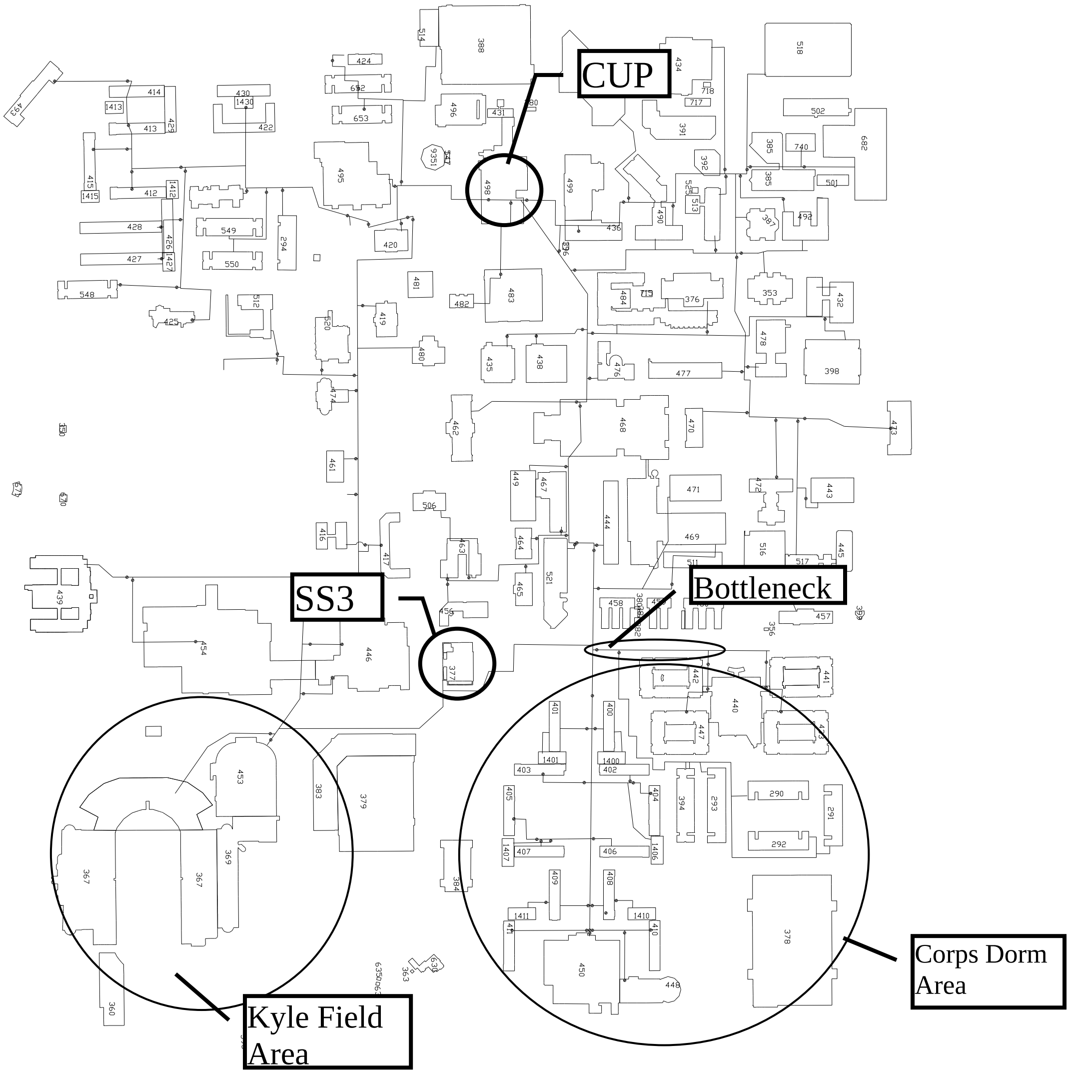

Figure 4: TAMU Main Campus HHW Distribution System

Table 5: Simulation Results Summary for TAMU HHW SS3 Expansion

	Before CC	After CC	Future SS3 Expansion
CUP Flow (GPM)	0	10,391	7,880
SS3 Flow (GPM)	0	1,489	4,000
CUP DP (psid)	67	50	50
SS3 DP (psid)	-20	15	61
CUP East Loop (GPM) (14”)	7,019	5,528	4,726
CUP West Loop (GPM) (14”)	4,861	4,863	3,154
SS3 East Loop (GPM) (10”)	-2	1,489	2,291
SS3 South Loop (GPM) (10”)	2	0	1,709
Corps Dorm Area Primary DP (psid)	-40	-17	11
Kyle Field Area Primary DP (psid)	-24	-23	34

Note: 10” pipe capacity is 3,000 GPM (Assume maximum pipe friction losses: 4ft/100ft)
14” pipe capacity is 6,000 GPM (Assume maximum pipe friction losses: 4ft/100ft)

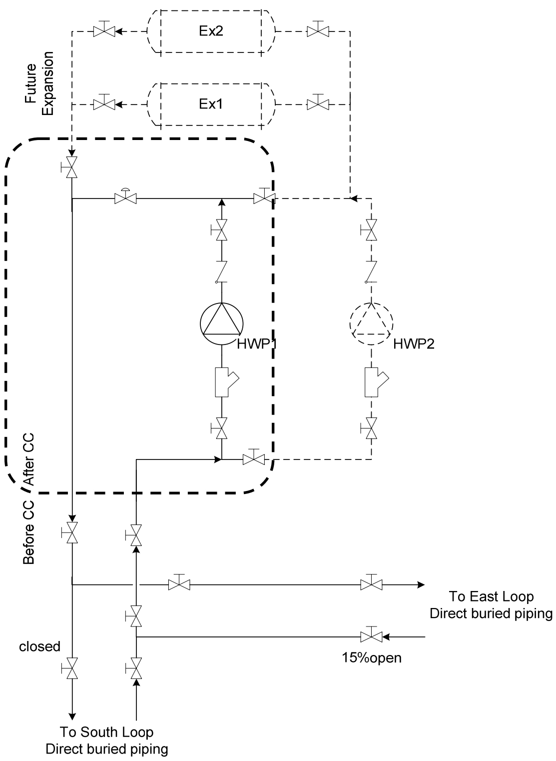

Figure 5: SS3 HHW System Piping Diagram

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