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Illinois Sustainable Technology Center

Softener Feed Water Reduction

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Carus Corporation

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
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Abstract

Business Case:
Founded in 1915, Carus Corporation is an environmental services company located in LaSalle, Illinois, that manufactures a range of products for municipal and industrial markets. Our site currently uses approximately 1,360 gallons of water per minute daily, which is equivalent to 1,958,400 gallons a day or 675 million gallons a year, based on 345 days of operation. We are being charged a rate of $0.798 per 100 cubic feet of water used, including the city's 5% utility tax. The estimated water cost for 2014 was $720,763. We have been tasked with coming up with a water reduction plan to reduce our water usage.

Problem Statement:
In 2015, we began a new water contract with the city that increases our water usage rate to $1.145 per 100 cubic feet. If we continue to use water at our current rate, 2015's total water cost will be equivalent to $1,033,725. This is an increase of $312,962 at our current water usage.

Goal/Objective Statement:
Our goal was to develop a water reduction plan to reduce our current usage by utilizing spent non-contact cooling water from our crystallizer hot well to feed our water softeners in the boiler house. Previously, we used raw city water to feed the water softeners, which consume approximately 100 gallons of water per minute.

Savings:
Factoring in the increased cost of water in our new contract (adding $312,962 per year), we saved $86,600 to $100,200 per year by reducing our water usage by 56.6 to 65.5 million gallons.

Introduction

Carus Corporation, an environmental services company located in LaSalle, Illinois, supplies materials to the water, industrial, air, and soil remediation markets. Product production at our LaSalle site currently uses approximately 1,360 gallons of water per minute daily, which is equivalent to 1,958,400 gallons a day or 675 million gallons a year (based on 345 days of operation). As part of the manufacturing process, 47 million gallons of water per year are used to meet boiler house and other process water requirements. Use of raw city water for these processes will cost the company over $1,000,000 in 2015. To reduce costs and reduce water waste, we have developed a water reduction plan.

This water currently used is raw city water that is run through water softeners and then treated with a reverse osmosis system. The treated water is used for steam production in our boiler house and for other water applications throughout the site. The average running rate for the boiler is 31,000 pounds of steam per hour, year round. The LaSalle site operates two plants, Pilot (PP) and Cairox (CX), which process different products. PP is batch-oriented and makes specialty chemicals, whereas the CX process is continuous and produces one chemical. Steam is generated and used by the entire site.

Instead of using raw city water, in order to conserve water and save money on water costs, we endeavored to recycle water that had already been utilized by our crystallizer vacuum system as non-contact cooling water. By recycling this “used” non-contact cooling water to feed water softeners and the reverse osmosis system, we estimated that we would be able to save 47-52 million gallons of city water annually.

Methods

In order to achieve our water savings goals, a new pumping station (pump, motor and base) were installed. This allowed us to feed the recaptured water through a new supply line to the boiler feed water softener location. The new system required programmable logic controller (PLC) controls for automatic valves, water quality measurements, tank level control, and safety systems to prevent feed water contamination and supply water loss. Modifications were made to the existing crystallizer vacuum system weir box to ensure that level was not lost and to allow for adequate pump suction head.

We utilized a VFD (Variable Frequency Drive) for the pump motor to minimize the need to run the motor at 100% output. This also allowed us to input a pressure set point on the pump discharge to achieve the desired output and not to over tax the equipment.

Programming was changed so that when starting the system, the pump runs for three minutes allowing it to slowly build pressure. The program also checks for water quality and the hot well tank level before allowing the system to switch, shutting off the raw city feed and utilizing the recycled water from the crystallizer hot well. An added benefit of this was to prevent a sudden shock to the current operating scheme.

Total water flow used on the entire site was monitored, along with specific water usage in the two plants (PP and CX) individually.

For the overall project, Six Sigma methodology was used, including but not limited to:

- SIPOC (Suppliers-Inputs-Process-Outputs-Controls);
- High Level Flow Design – a flow chart of operations;
- Data Collection – gallons of water per minute used on a daily basis;
- Sustainability;
- FEMA (Failure Modes and Effects Analysis);
- Two-sample T-tests performed in Mini Tab, a software for statistical analysis;
- DMAIC methodology (Define, Measure, Analyze, Improve and Control); and
- PI (Process Information Database), allowing automatic and continuous data collection from the process at selected time intervals (2-3 sec.) and auto-calculation of daily flow rates.

Results and Conclusions

After making the aforementioned modifications, we achieved the following results:

- We saved 133 gallons of water per minute, averaged across the entire site, and 114 gallons of water per minute in the Cairox Plant alone (Appendix A).
- We saved 56.6 to 65.5 million gallons of water per year, based on an operating period of 345 days.
- Based on a water rate of $1.145 per 100 cubic feet in 2015, this equates to a financial savings of $86,600 to $100,200 per year.
- Our costs to modify equipment, $132,915, will be paid back within 8.4 months, with the help of ISTC grant funds in the amount of $63,446.

These results were better than our original savings estimates of 104.4 gallons per minute and 51,865,920 gallons per year, equating to an annual savings of $79,388 annually. We had estimated that payback would take longer – 9.6 months – as well.

It was determined that the savings were better than expected due to the fact that the amount of water that we were measuring initially did not include the amount of water that was being used during water softener re-generation. Once we analyzed the entire process, we found that this process was consuming a significant amount of water.

Appendix A

Daily Water Usage for Carus Corporation

Table A-1: Summary of pre- and post-project water usage.

	Monitoring start date	Monitoring end date	Average site-wide GPM	Average PP GPM	Average CX GPM
Pre-project	6/1/2014	12/31/2014	1,377.84	440.62	937.22
Post-project	1/8/2015	6/4/2015	1,245.19	422.33	822.86
Differences			**132.65**	**18.29**	**114.36**

Table A-2: Average GPM prior to project start.

Data time start	Data time stop	Site GPM	PP GPM	Difference
6/1/14 0:00	6/2/14 0:00	1,326	373	953
6/2/14 0:00	6/3/14 0:00	1,299	350	949
6/3/14 0:00	6/4/14 0:00	1,191	247	945
6/4/14 0:00	6/5/14 0:00	1,313	369	944
6/5/14 0:00	6/6/14 0:00	1,368	405	963
6/6/14 0:00	6/7/14 0:00	1,373	406	968
6/7/14 0:00	6/8/14 0:00	1,323	362	961
6/8/14 0:00	6/9/14 0:00	1,386	423	963
6/9/14 0:00	6/10/14 0:00	1,345	381	963
6/10/14 0:00	6/11/14 0:00	1,355	415	939
6/11/14 0:00	6/12/14 0:00	1,396	451	945
6/12/14 0:00	6/13/14 0:00	1,340	405	935
6/13/14 0:00	6/14/14 0:00	1,379	423	957
6/14/14 0:00	6/15/14 0:00	1,342	377	965
6/15/14 0:00	6/16/14 0:00	1,380	429	952
6/16/14 0:00	6/17/14 0:00	1,354	389	965
6/17/14 0:00	6/18/14 0:00	1,452	490	961
6/18/14 0:00	6/19/14 0:00	1,414	468	946
6/19/14 0:00	6/20/14 0:00	1,423	470	953
6/20/14 0:00	6/21/14 0:00	1,408	461	946
6/21/14 0:00	6/22/14 0:00	1,352	406	946
6/22/14 0:00	6/23/14 0:00	1,254	291	963
6/23/14 0:00	6/24/14 0:00	1,247	296	952
6/24/14 0:00	6/25/14 0:00	1,424	465	959
6/25/14 0:00	6/26/14 0:00	1,499	543	956
6/26/14 0:00	6/27/14 0:00	1,408	465	942
6/27/14 0:00	6/28/14 0:00	1,374	411	963
6/28/14 0:00	6/29/14 0:00	1,331	351	979
6/29/14 0:00	6/30/14 0:00	1,393	425	968
6/30/14 0:00	7/1/14 0:00	1,413	461	951
7/1/14 0:00	7/2/14 0:00	1,409	438	970
7/2/14 0:00	7/3/14 0:00	1,378	426	952
7/3/14 0:00	7/4/14 0:00	1,292	343	950
7/4/14 0:00	7/5/14 0:00	1,297	350	947
7/5/14 0:00	7/6/14 0:00	1,259	304	955
7/6/14 0:00	7/7/14 0:00	1,294	343	952
7/7/14 0:00	7/8/14 0:00	1,307	345	962
7/8/14 0:00	7/9/14 0:00	1,354	414	940
7/9/14 0:00	7/10/14 0:00	1,378	433	944
7/10/14 0:00	7/11/14 0:00	1,397	448	949
7/11/14 0:00	7/12/14 0:00	1,260	310	950
7/12/14 0:00	7/13/14 0:00	1,265	318	947
7/13/14 0:00	7/14/14 0:00	1,307	339	968
7/14/14 0:00	7/15/14 0:00	1,371	415	956

Table A-2: Average GPM prior to project start (continued).

Data time start	Data time stop	Site GPM	PP GPM	Difference
7/15/14 0:00	7/16/14 0:00	1,426	478	949
7/16/14 0:00	7/17/14 0:00	1,403	457	946
7/17/14 0:00	7/18/14 0:00	1,381	434	947
7/18/14 0:00	7/19/14 0:00	1,400	441	958
7/19/14 0:00	7/20/14 0:00	1,368	406	961
7/20/14 0:00	7/21/14 0:00	1,349	394	955
7/21/14 0:00	7/22/14 0:00	1,386	438	948
7/22/14 0:00	7/23/14 0:00	1,344	387	957
7/23/14 0:00	7/24/14 0:00	1,408	463	945
7/24/14 0:00	7/25/14 0:00	1,367	433	933
7/25/14 0:00	7/26/14 0:00	1,376	418	958
7/26/14 0:00	7/27/14 0:00	1,395	442	952
7/27/14 0:00	7/28/14 0:00	1,376	435	941
7/28/14 0:00	7/29/14 0:00	1,370	436	934
7/29/14 0:00	7/30/14 0:00	1,322	381	941
7/30/14 0:00	7/31/14 0:00	1,428	472	956
7/31/14 0:00	8/1/14 0:00	1,452	478	974
8/1/14 0:00	8/2/14 0:00	1,446	483	963
8/2/14 0:00	8/3/14 0:00	1,412	449	963
8/3/14 0:00	8/4/14 0:00	1,347	371	976
8/4/14 0:00	8/5/14 0:00	1,358	403	956
8/5/14 0:00	8/6/14 0:00	1,321	371	950
8/6/14 0:00	8/7/14 0:00	1,397	434	962
8/7/14 0:00	8/8/14 0:00	1,358	410	948
8/8/14 0:00	8/9/14 0:00	1,415	463	952
8/9/14 0:00	8/10/14 0:00	1,370	410	960
8/10/14 0:00	8/11/14 0:00	1,347	410	937
8/11/14 0:00	8/12/14 0:00	1,393	433	960
8/12/14 0:00	8/13/14 0:00	1,308	363	945
8/13/14 0:00	8/14/14 0:00	1,290	363	927
8/14/14 0:00	8/15/14 0:00	1,446	536	910
8/15/14 0:00	8/16/14 0:00	1,414	468	945
8/16/14 0:00	8/17/14 0:00	1,416	473	943
8/17/14 0:00	8/18/14 0:00	1,383	424	959
8/18/14 0:00	8/19/14 0:00	1,460	510	950
8/19/14 0:00	8/20/14 0:00	1,354	387	967
8/20/14 0:00	8/21/14 0:00	1,395	435	960
8/21/14 0:00	8/22/14 0:00	1,364	435	929
8/22/14 0:00	8/23/14 0:00	1,343	422	921
8/23/14 0:00	8/24/14 0:00	1,318	370	948
8/24/14 0:00	8/25/14 0:00	1,423	466	958
8/25/14 0:00	8/26/14 0:00	1,424	487	937
8/26/14 0:00	8/27/14 0:00	1,435	430	1,005
8/27/14 0:00	8/28/14 0:00	1,313	337	975
8/28/14 0:00	8/29/14 0:00	1,442	492	950
8/29/14 0:00	8/30/14 0:00	1,433	505	928
8/30/14 0:00	8/31/14 0:00	1,451	505	946
8/31/14 0:00	9/1/14 0:00	1,439	487	952
9/1/14 0:00	9/2/14 0:00	1,458	495	963
9/2/14 0:00	9/3/14 0:00	1,463	532	931
9/3/14 0:00	9/4/14 0:00	1,467	526	941
9/4/14 0:00	9/5/14 0:00	1,478	531	947
9/5/14 0:00	9/6/14 0:00	1,465	497	968
9/6/14 0:00	9/7/14 0:00	1,436	484	953
9/7/14 0:00	9/8/14 0:00	1,422	479	943
9/8/14 0:00	9/9/14 0:00	1,367	432	935
9/9/14 0:00	9/10/14 0:00	1,353	403	951
9/10/14 0:00	9/11/14 0:00	1,399	462	938
9/11/14 0:00	9/12/14 0:00	1,413	460	953

Table A-2: Average GPM prior to project start (continued).

Data time start	Data time stop	Site GPM	PP GPM	Difference
9/12/14 0:00	9/13/14 0:00	1,464	530	935
9/13/14 0:00	9/14/14 0:00	1,448	489	959
9/14/14 0:00	9/15/14 0:00	1,434	483	951
9/15/14 0:00	9/16/14 0:00	1,415	494	921
9/16/14 0:00	9/17/14 0:00	1,385	451	933
9/17/14 0:00	9/18/14 0:00	1,495	549	946
9/18/14 0:00	9/19/14 0:00	1,491	553	938
9/19/14 0:00	9/20/14 0:00	1,506	549	957
9/20/14 0:00	9/21/14 0:00	1,460	511	948
9/21/14 0:00	9/22/14 0:00	1,446	498	947
9/22/14 0:00	9/23/14 0:00	1,479	536	944
9/23/14 0:00	9/24/14 0:00	1,381	430	951
9/24/14 0:00	9/25/14 0:00	1,447	502	946
9/25/14 0:00	9/26/14 0:00	1,514	612	903
9/26/14 0:00	9/27/14 0:00	1,486	563	923
9/27/14 0:00	9/28/14 0:00	1,481	546	935
9/28/14 0:00	9/29/14 0:00	1,430	495	935
9/29/14 0:00	9/30/14 0:00	1,510	580	931
9/30/14 0:00	10/1/14 0:00	1,421	480	941
10/1/14 0:00	10/2/14 0:00	1,318	369	949
10/2/14 0:00	10/3/14 0:00	1,279	319	960
10/3/14 0:00	10/4/14 0:00	1,456	522	934
10/4/14 0:00	10/5/14 0:00	1,474	532	942
10/5/14 0:00	10/6/14 0:00	1,434	489	945
10/6/14 0:00	10/7/14 0:00	1,447	534	913
10/7/14 0:00	10/8/14 0:00	1,453	507	946
10/8/14 0:00	10/9/14 0:00	1,364	428	936
10/9/14 0:00	10/10/14 0:00	1,426	490	935
10/10/14 0:00	10/11/14 0:00	1,438	495	942
10/11/14 0:00	10/12/14 0:00	1,426	491	935
10/12/14 0:00	10/13/14 0:00	1,434	490	944
10/13/14 0:00	10/14/14 0:00	1,481	549	932
10/14/14 0:00	10/15/14 0:00	1,452	527	925
10/15/14 0:00	10/16/14 0:00	1,373	393	980
10/16/14 0:00	10/17/14 0:00	1,453	486	967
10/17/14 0:00	10/18/14 0:00	1,442	497	945
10/18/14 0:00	10/19/14 0:00	1,403	463	940
10/19/14 0:00	10/20/14 0:00	1,414	478	937
10/20/14 0:00	10/21/14 0:00	1,340	404	936
10/21/14 0:00	10/22/14 0:00	1,331	373	958
10/22/14 0:00	10/23/14 0:00	1,428	491	937
10/23/14 0:00	10/24/14 0:00	1,446	504	942
10/24/14 0:00	10/25/14 0:00	1,361	405	956
10/25/14 0:00	10/26/14 0:00	1,437	490	947
10/26/14 0:00	10/27/14 0:00	1,262	313	949
10/27/14 0:00	10/28/14 0:00	1,243	279	964
10/28/14 0:00	10/29/14 0:00	1,408	460	947
10/29/14 0:00	10/30/14 0:00	1,401	475	927
10/30/14 0:00	10/31/14 0:00	1,295	355	940
10/31/14 0:00	11/1/14 0:00	1,272	332	940
11/9/14 0:00	11/10/14 0:00	1,226	302	925
11/10/14 0:00	11/11/14 0:00	1,270	325	945
11/11/14 0:00	11/12/14 0:00	1,331	415	916
11/12/14 0:00	11/13/14 0:00	1,336	444	892
11/13/14 0:00	11/14/14 0:00	1,369	468	901
11/14/14 0:00	11/15/14 0:00	1,377	456	921
11/15/14 0:00	11/16/14 0:00	1,397	480	917
11/16/14 0:00	11/17/14 0:00	1,375	466	909

Table A-2: Average GPM prior to project start (continued).

Data time start	Data time stop	Site GPM	PP GPM	Difference
11/17/14 0:00	11/18/14 0:00	1,313	400	912
11/18/14 0:00	11/19/14 0:00	1,283	363	921
11/19/14 0:00	11/20/14 0:00	1,386	480	906
11/20/14 0:00	11/21/14 0:00	1,320	434	886
11/21/14 0:00	11/22/14 0:00	1,307	402	905
11/22/14 0:00	11/23/14 0:00	1,359	458	901
11/23/14 0:00	11/24/14 0:00	1,412	520	892
11/24/14 0:00	11/25/14 0:00	1,408	507	901
11/25/14 0:00	11/26/14 0:00	1,303	396	907
11/26/14 0:00	11/27/14 0:00	1,409	515	894
11/27/14 0:00	11/28/14 0:00	1,369	471	899
11/28/14 0:00	11/29/14 0:00	1,341	455	886
11/29/14 0:00	11/30/14 0:00	1,394	510	884
11/30/14 0:00	12/1/14 0:00	1,362	479	883
12/1/14 0:00	12/2/14 0:00	1,304	416	888
12/2/14 0:00	12/3/14 0:00	1,340	436	903
12/3/14 0:00	12/4/14 0:00	1,345	446	899
12/4/14 0:00	12/5/14 0:00	1,352	439	913
12/5/14 0:00	12/6/14 0:00	1,388	481	907
12/6/14 0:00	12/7/14 0:00	1,389	487	901
12/7/14 0:00	12/8/14 0:00	1,363	456	907
12/8/14 0:00	12/9/14 0:00	1,355	444	910
12/9/14 0:00	12/10/14 0:00	1,329	422	907
12/10/14 0:00	12/11/14 0:00	1,436	530	906
12/13/14 0:00	12/14/14 0:00	1,345	457	888
12/14/14 0:00	12/15/14 0:00	1,379	483	896
12/15/14 0:00	12/16/14 0:00	1,434	529	906
12/16/14 0:00	12/17/14 0:00	1,426	544	882
12/18/14 0:00	12/19/14 0:00	1,459	559	900
12/19/14 0:00	12/20/14 0:00	1,417	518	900
12/20/14 0:00	12/21/14 0:00	1,440	534	905
12/21/14 0:00	12/22/14 0:00	1,400	504	896
12/22/14 0:00	12/23/14 0:00	1,437	528	909
12/23/14 0:00	12/24/14 0:00	1,380	482	898
12/24/14 0:00	12/25/14 0:00	1,270	367	903
12/25/14 0:00	12/26/14 0:00	1,303	406	896
12/26/14 0:00	12/27/14 0:00	1,363	456	907
12/27/14 0:00	12/28/14 0:00	1,359	451	908
12/28/14 0:00	12/29/14 0:00	1,287	373	914
12/29/14 0:00	12/30/14 0:00	1,327	419	909
12/30/14 0:00	12/31/14 0:00	1,257	329	928
12/31/14 0:00	1/1/15 0:00	1,283	379	904
1/1/15 0:00	1/2/15 0:00	1,221	312	909
1/2/15 0:00	1/3/15 0:00	1,273	356	917
1/3/15 0:00	1/4/15 0:00	1,270	339	932
1/4/15 0:00	1/5/15 0:00	1,193	281	912
1/5/15 0:00	1/6/15 0:00	1,226	290	936
		Average Difference		937 GPM

Table A-3: Average GPM since project inception.

Data time start	Data time stop	Site GPM	PP GPM	Difference
1/8/15 0:00	1/9/15 0:00	1,263	341	922
1/9/15 0:00	1/10/15 0:00	1,269	424	845
1/10/15 0:00	1/11/15 0:00	1,272	467	805
1/11/15 0:00	1/12/15 0:00	1,316	501	815
1/12/15 0:00	1/13/15 0:00	1,305	487	818
1/13/15 0:00	1/14/15 0:00	1,154	330	823
1/14/15 0:00	1/15/15 0:00	1,255	434	822
1/15/15 0:00	1/16/15 0:00	1,278	470	808
1/16/15 0:00	1/17/15 0:00	1,253	431	822
1/17/15 0:00	1/18/15 0:00	1,225	417	808
1/18/15 0:00	1/19/15 0:00	1,301	480	822
1/19/15 0:00	1/20/15 0:00	1,315	502	813
1/20/15 0:00	1/21/15 0:00	1,252	445	806
1/21/15 0:00	1/22/15 0:00	1,306	490	817
1/22/15 0:00	1/23/15 0:00	1,270	460	811
1/23/15 0:00	1/24/15 0:00	1,281	462	819
1/24/15 0:00	1/25/15 0:00	1,340	542	798
1/25/15 0:00	1/26/15 0:00	1,289	477	812
1/26/15 0:00	1/27/15 0:00	1,303	498	806
1/27/15 0:00	1/28/15 0:00	1,153	321	831
1/28/15 0:00	1/29/15 0:00	1,121	295	826
1/29/15 0:00	1/30/15 0:00	1,291	479	812
1/30/15 0:00	1/31/15 0:00	1,212	395	817
1/31/15 0:00	2/1/15 0:00	1,205	388	817
2/1/15 0:00	2/2/15 0:00	1,265	456	808
2/2/15 0:00	2/3/15 0:00	1,162	336	827
2/3/15 0:00	2/4/15 0:00	1,305	508	797
2/4/15 0:00	2/5/15 0:00	1,220	395	825
2/5/15 0:00	2/6/15 0:00	1,277	466	811
2/6/15 0:00	2/7/15 0:00	1,270	470	801
2/7/15 0:00	2/8/15 0:00	1,259	457	802
2/8/15 0:00	2/9/15 0:00	1,302	501	801
2/9/15 0:00	2/10/15 0:00	1,283	471	811
2/10/15 0:00	2/11/15 0:00	1,152	375	777
2/11/15 0:00	2/12/15 0:00	1,259	449	810
2/12/15 0:00	2/13/15 0:00	1,238	410	828
2/13/15 0:00	2/14/15 0:00	1,286	474	812
2/14/15 0:00	2/15/15 0:00	1,225	403	822
2/15/15 0:00	2/16/15 0:00	1,202	382	820
2/16/15 0:00	2/17/15 0:00	1,283	475	808
2/17/15 0:00	2/18/15 0:00	1,182	362	820
2/18/15 0:00	2/19/15 0:00	1,260	440	819
2/19/15 0:00	2/20/15 0:00	1,260	437	823
2/20/15 0:00	2/21/15 0:00	1,273	460	813
2/21/15 0:00	2/22/15 0:00	1,245	437	808
2/22/15 0:00	2/23/15 0:00	1,225	414	811
2/23/15 0:00	2/24/15 0:00	1,234	427	807
2/24/15 0:00	2/25/15 0:00	1,194	378	816
2/25/15 0:00	2/26/15 0:00	1,250	431	819
2/26/15 0:00	2/27/15 0:00	1,251	438	813
2/27/15 0:00	2/28/15 0:00	1,280	473	807
2/28/15 0:00	3/1/15 0:00	1,233	420	812
3/1/15 0:00	3/2/15 0:00	1,259	449	810
3/2/15 0:00	3/3/15 0:00	1,277	465	812
3/3/15 0:00	3/4/15 0:00	1,198	373	825
3/4/15 0:00	3/5/15 0:00	1,182	357	824
3/5/15 0:00	3/6/15 0:00	1,268	458	810
3/6/15 0:00	3/7/15 0:00	1,291	480	810
3/7/15 0:00	3/8/15 0:00	1,269	464	805

Table A-3: Average GPM since project inception (continued).

Data time start	Data time stop	Site GPM	PP GPM	Difference
3/8/15 0:00	3/9/15 0:00	1,257	452	805
3/9/15 0:00	3/10/15 0:00	1,279	467	812
3/10/15 0:00	3/11/15 0:00	1,194	377	817
3/11/15 0:00	3/12/15 0:00	1,261	438	824
3/12/15 0:00	3/13/15 0:00	1,323	483	840
3/13/15 0:00	3/14/15 0:00	1,212	367	845
3/14/15 0:00	3/15/15 0:00	1,224	414	809
3/15/15 0:00	3/16/15 0:00	1,246	429	817
3/16/15 0:00	3/17/15 0:00	1,279	467	812
3/17/15 0:00	3/18/15 0:00	1,255	437	818
3/18/15 0:00	3/19/15 0:00	1,230	417	813
3/19/15 0:00	3/20/15 0:00	1,270	456	814
3/20/15 0:00	3/21/15 0:00	1,267	452	815
3/21/15 0:00	3/22/15 0:00	1,216	402	814
3/22/15 0:00	3/23/15 0:00	1,126	301	824
3/23/15 0:00	3/24/15 0:00	1,128	291	837
3/24/15 0:00	3/25/15 0:00	1,193	367	826
3/25/15 0:00	3/26/15 0:00	1,063	215	847
3/26/15 0:00	3/27/15 0:00	1,020	182	837
3/27/15 0:00	3/28/15 0:00	1,082	254	828
3/28/15 0:00	3/29/15 0:00	1,180	360	820
3/29/15 0:00	3/30/15 0:00	1,253	440	813
3/30/15 0:00	3/31/15 0:00	1,233	405	828
3/31/15 0:00	4/1/15 0:00	1,223	403	820
4/1/15 0:00	4/2/15 0:00	1,218	380	838
4/2/15 0:00	4/3/15 0:00	1,191	366	825
4/3/15 0:00	4/4/15 0:00	1,238	409	829
4/4/15 0:00	4/5/15 0:00	1,292	481	811
4/5/15 0:00	4/6/15 0:00	1,327	508	819
4/6/15 0:00	4/7/15 0:00	1,234	414	820
4/7/15 0:00	4/8/15 0:00	1,101	264	837
4/8/15 0:00	4/9/15 0:00	1,217	396	821
4/9/15 0:00	4/10/15 0:00	1,258	438	819
4/10/15 0:00	4/11/15 0:00	1,254	436	818
4/11/15 0:00	4/12/15 0:00	1,257	442	815
4/12/15 0:00	4/13/15 0:00	1,240	424	816
4/13/15 0:00	4/14/15 0:00	1,279	456	823
4/14/15 0:00	4/15/15 0:00	1,191	362	828
4/15/15 0:00	4/16/15 0:00	1,308	490	818
4/16/15 0:00	4/17/15 0:00	1,178	353	826
4/17/15 0:00	4/18/15 0:00	1,248	425	823
4/18/15 0:00	4/19/15 0:00	1,272	445	828
4/19/15 0:00	4/20/15 0:00	1,268	459	809
4/20/15 0:00	4/21/15 0:00	1,247	430	817
4/21/15 0:00	4/22/15 0:00	1,254	436	818
4/22/15 0:00	4/23/15 0:00	1,242	417	825
4/23/15 0:00	4/24/15 0:00	1,179	348	831
5/9/15 0:00	5/10/15 0:00	1,240	399	841
5/10/15 0:00	5/11/15 0:00	1,281	437	844
5/11/15 0:00	5/12/15 0:00	1,277	440	837
5/12/15 0:00	5/13/15 0:00	1,198	348	850
5/13/15 0:00	5/14/15 0:00	1,270	428	842
5/14/15 0:00	5/15/15 0:00	1,272	437	835
5/15/15 0:00	5/16/15 0:00	1,220	372	848
5/16/15 0:00	5/17/15 0:00	1,101	249	852
5/17/15 0:00	5/18/15 0:00	1,240	396	844
5/18/15 0:00	5/19/15 0:00	1,247	398	849
5/19/15 0:00	5/20/15 0:00	1,178	330	848
5/20/15 0:00	5/21/15 0:00	1,276	433	843

Table A-3: Average GPM since project inception (continued).

Data time start	Data time stop	Site GPM	PP GPM	Difference
5/21/15 0:00	5/22/15 0:00	1,289	453	835
5/22/15 0:00	5/23/15 0:00	1,305	470	836
5/23/15 0:00	5/24/15 0:00	1,305	469	836
5/24/15 0:00	5/25/15 0:00	1,398	563	835
5/25/15 0:00	5/26/15 0:00	1,336	498	839
5/26/15 0:00	5/27/15 0:00	1,317	483	834
5/27/15 0:00	5/28/15 0:00	1,169	321	847
5/28/15 0:00	5/29/15 0:00	1,263	421	842
5/29/15 0:00	5/30/15 0:00	1,366	537	828
5/30/15 0:00	5/31/15 0:00	1,299	471	828
5/31/15 0:00	6/1/15 0:00	1,273	441	832
6/1/15 0:00	6/2/15 0:00	1,277	447	830
6/2/15 0:00	6/3/15 0:00	1,184	331	852
6/3/15 0:00	6/4/15 0:00	1,326	496	829
6/4/15 0:00	6/5/15 0:00	1,348	514	834
		Average Difference		823 GPM

Appendix B

Two Sample T-Tests and Box Plots Before and After Water Reduction Project Implementation

Below are a box plot and results of a two-sample T-test showing total site water usage. Information was used to show a significant change in total site water usage from before to after the water reduction project was initiated.

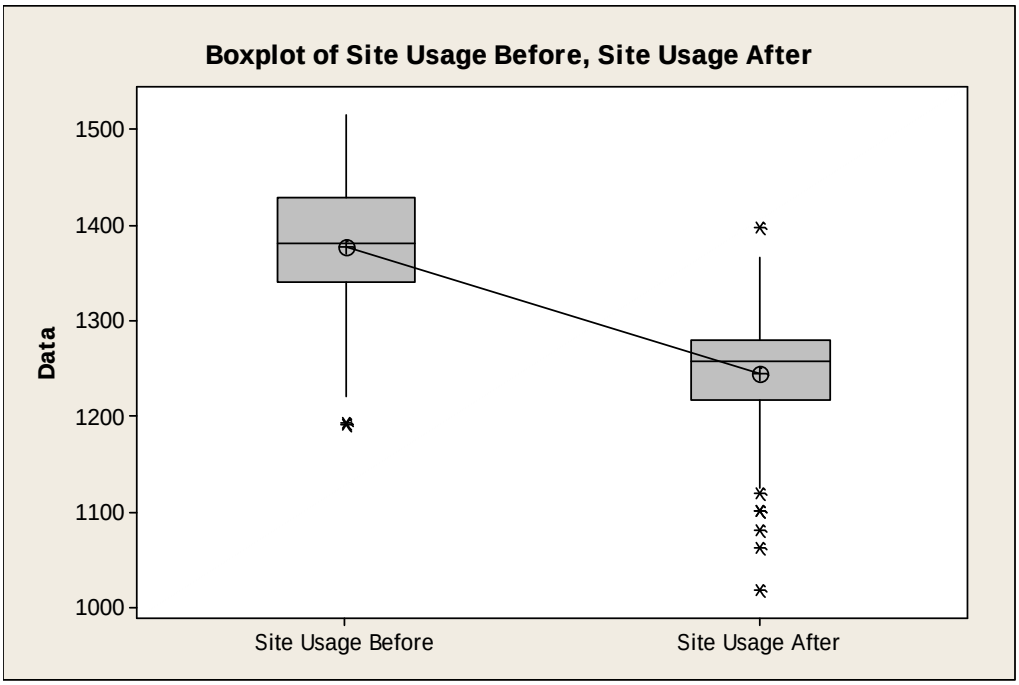

Figure B-1: Boxplot of total site water usage before and after project initiation.

Table B-1: Two-sample T-test results for total site water usage before and after project initiation.

	N	Mean	StDev	SE Mean
Site Usage Before	208	1,377.8	65.8	4.6
Site Usage After	133	1,245.2	59.6	5.2

Difference = mu (Site Usage Before) - mu (Site Usage After)
Estimate for difference: **132.65**
95% CI for difference: (119.08, 146.22)
T-Test of difference = 0 (vs not =): T-Value = 19.24 **P-Value = 0.000*** DF = 301

* P Value of 0.000 shows high significance. Difference is a value of 132 GPM (Gallon Per Minute).

Below are a box plot and results of a two-sample T-test showing PP (Pilot Plant) water usage. Information was used to show there was no significant change in total PP water usage from before to after the water reduction project was initiated. This was used to show that the PP had no impact on information gathered.

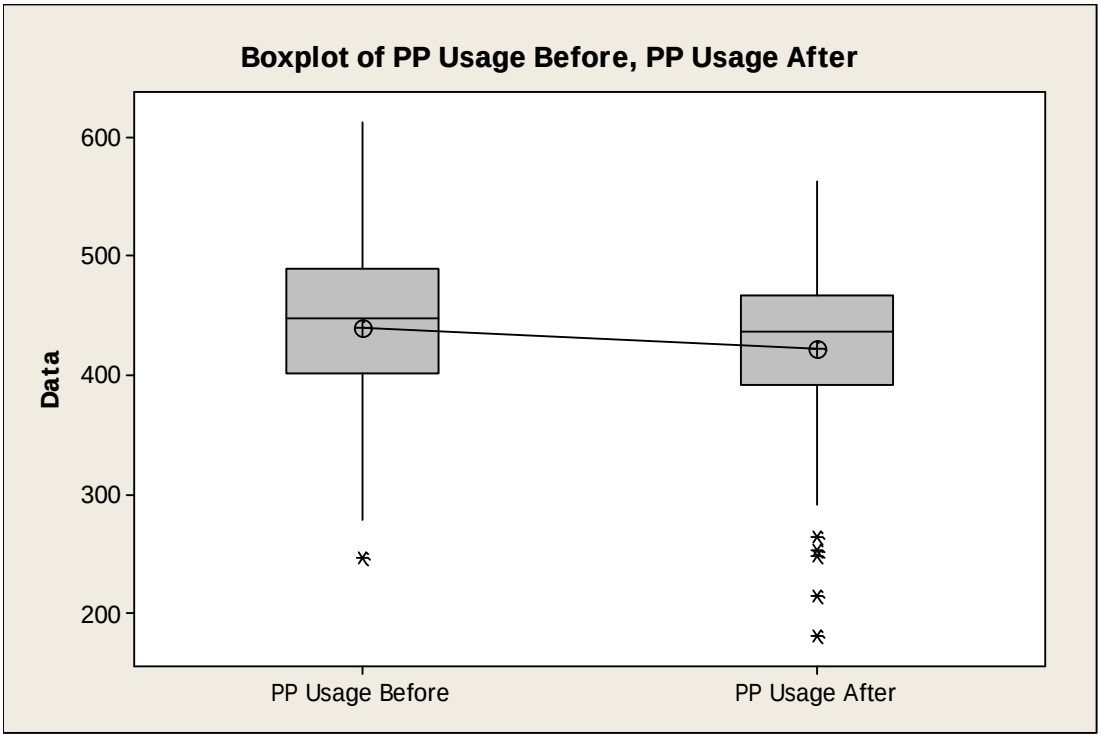

Figure B-2: Boxplot of pilot plant (PP) water usage before and after project initiation.

Table B-2: Two-sample T-test results for pilot plant (PP) water usage before and after project initiation.

	N	Mean	StDev	SE Mean
PP Usage Before	208	440.6	68	4.7
PP Usage After	133	422.3	64.7	5.6

Difference = mu (PP Usage Before) - mu (PP Usage After)
Estimate for difference: 18.29
95% CI for difference: (3.87, 32.71)
T-Test of difference = 0 (vs not =): T-Value = 2.50 **P-Value = 0.013*** DF = 291

* P Value of 0.013 shows a significant, but small, difference of 18 GPM.

Below are a box plot and results of a two-sample T-test showing CX (Cairox Plant) water usage. The flow Information was obtained by taking the total site flow and subtracting the flow for the pilot plant. This CX flow includes the water softener usage area that this project was directed to. The information below was used to show a significant change in CX water usage from before to after the water reduction project was initiated.

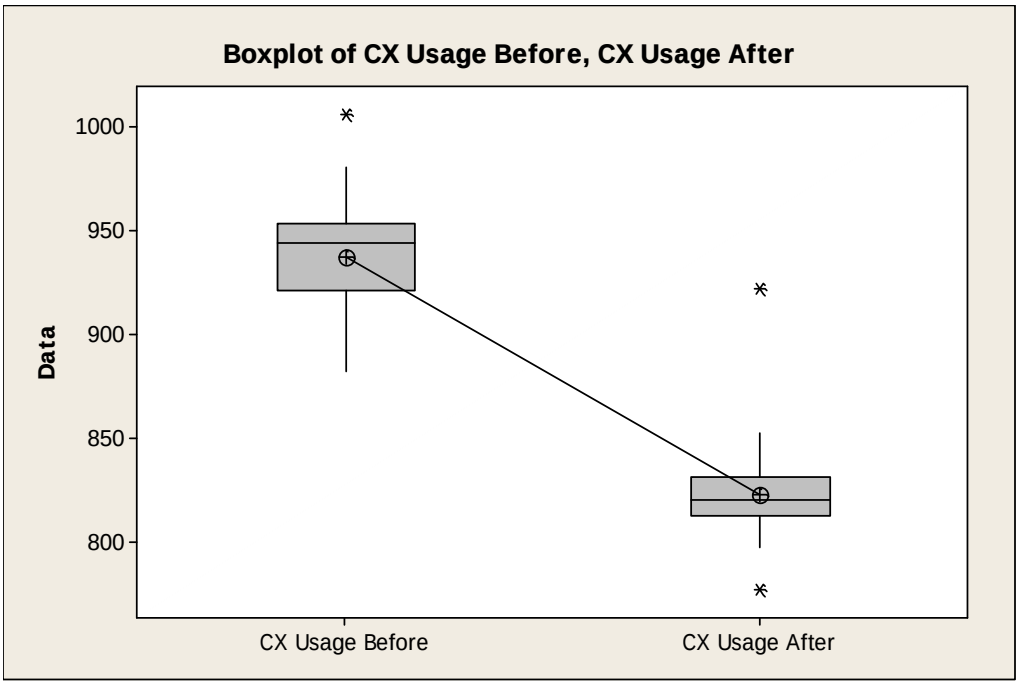

Figure B-3: Boxplot of Cairox plant (CX) water usage before and after project initiation.

Table B-3: Two-sample T-test for Cairox plant (CX) water usage before and after project initiation.

	N	Mean	StDev	SE Mean
CX Usage Before	208	937.2	23.5	1.6
CX Usage After	133	822.9	16	1.4

Difference = mu (CX Usage Before) - mu (CX Usage After)
Estimate for difference: **114.36**
95% CI for difference: (110.14, 118.58)
T-Test of difference = 0 (vs not =): T-Value = 53.35 **P-Value = 0.000*** DF = 337

*P Value of 0.000 shows high significance. Difference in use is 114 GPM (Gallons per minute).

Appendix C

PLC Screen Shots of System Change

Below are actual screen shots created for the work stations in the plant and control room showing the addition of the equipment and controls.

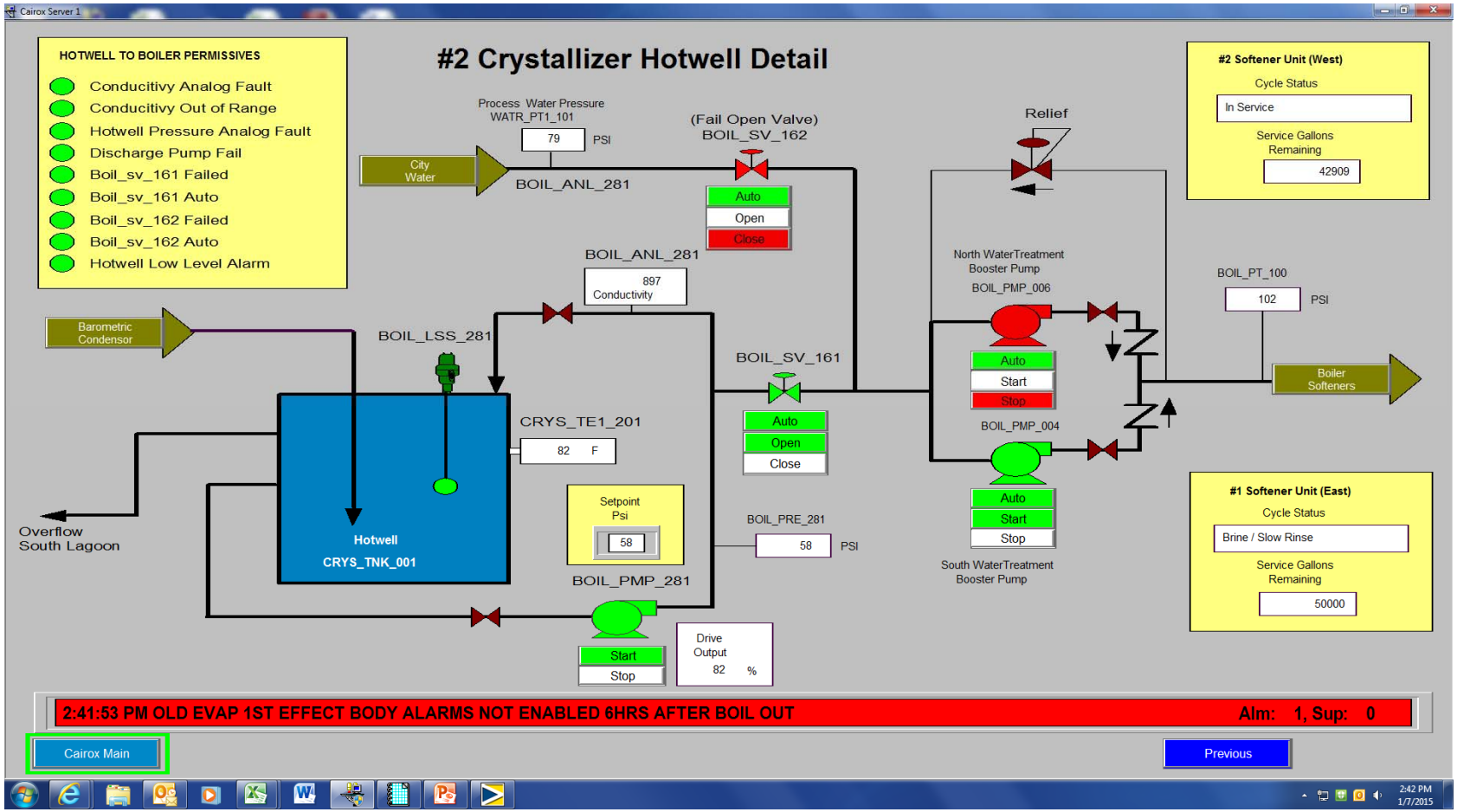

Figure C-1: Crystallizer hotwell detail.

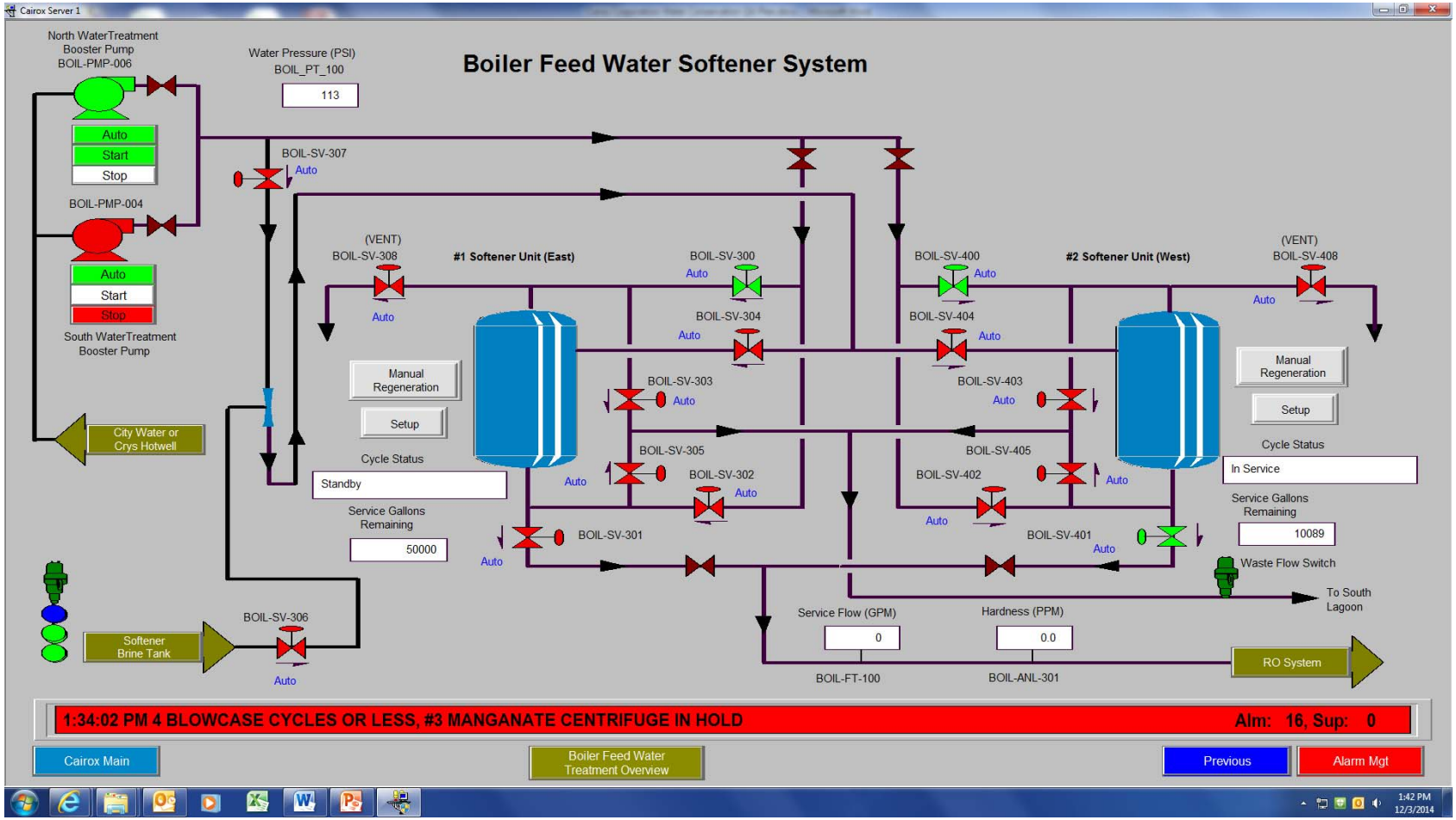

Figure C-2: Boiler feed water softener system.

Appendix D

Drawing of Flow Diagram

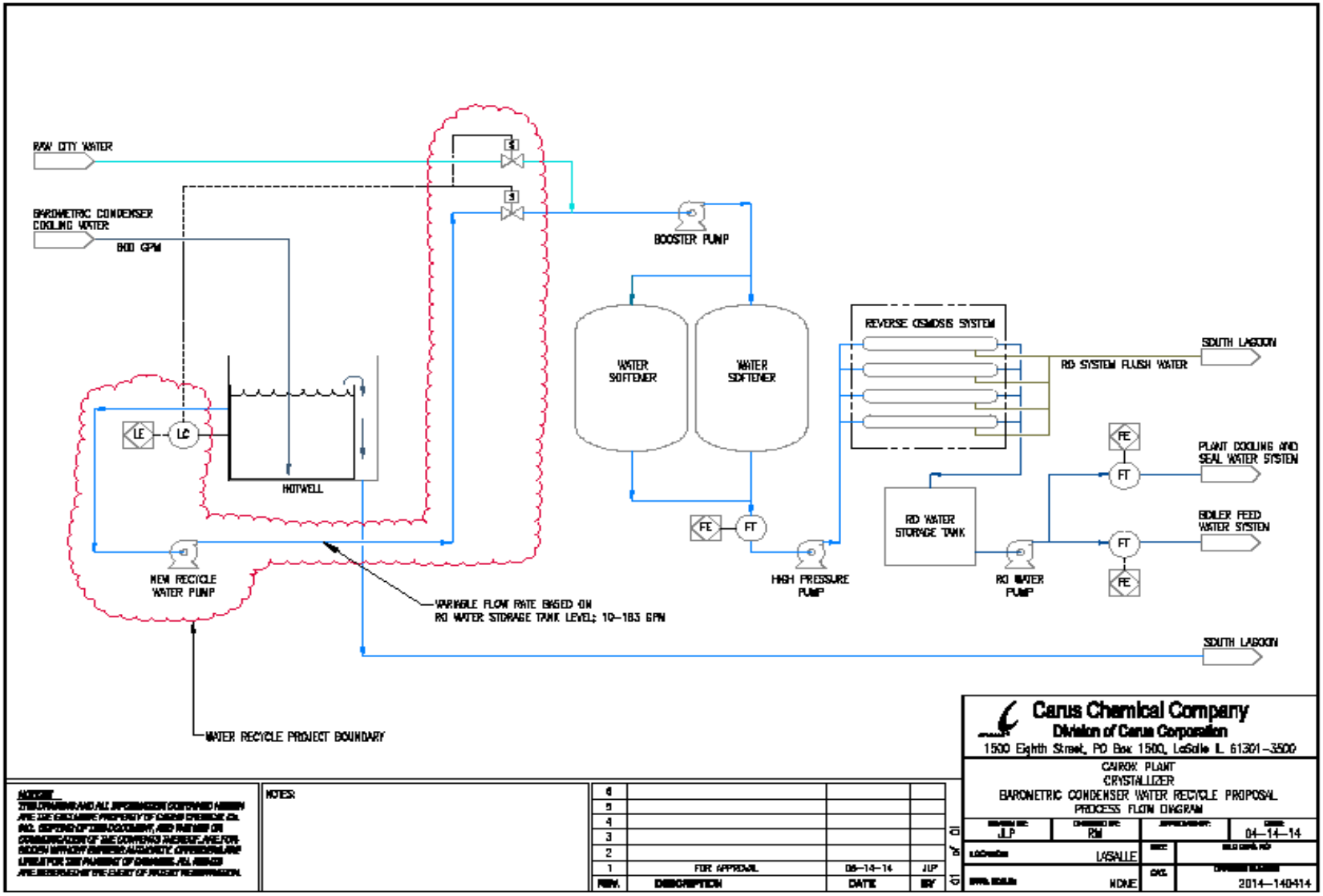

Figure D-1: Flow diagram.

Appendix E

High Level Process Flow Chart

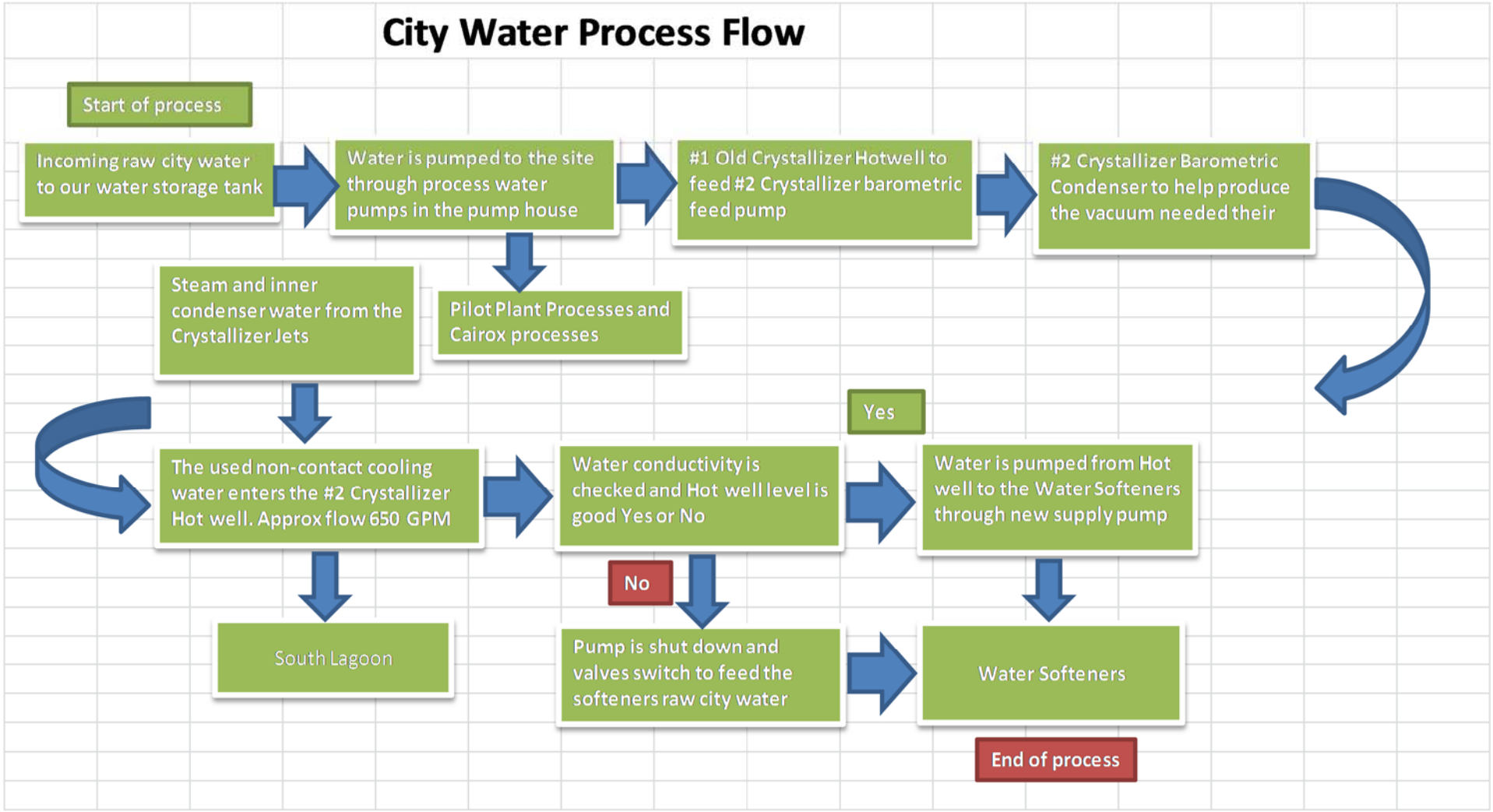

Figure E-1: High level process flow chart.