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LANSING BOARD OF WATER AND LIGHT

FEDERAL ASSISTANCE NUMBER: FF01-91-CE26615

VOLUME ONE:

OPTIMIZATION OF THE ENGINEERING DESIGN FOR
THE LANSING DISTRICT COOLING SYSTEM BY
COMPARATIVE ANALYSIS OF THE IMPACT OF
ADVANCED TECHNOLOGIES ON A CONVENTIONAL
DESIGN APPROACH.

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LANSING BOARD OF

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LBWL

VOLUME ONE

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1.0 Introduction & Background

The Lansing Board of Water and Light (LBWL) began investigating development of a cooling district in the Lansing Downtown in 1989 in order to retain and build summer load for its steam utility. A feasibility study was conducted in conjunction with SFT, Inc. and ZBA, Inc. which addressed many factors such as marketability of the product, impact on the summer steam load, distribution system development, system design, probable capital and operating costs, reliability and environmental and other regulatory impacts on a preliminary feasibility basis. The Phase I study completed in September of 1989 provided highly promising results for establishing a District Cooling System (DCS).

Subsequent to that study, the State of Michigan identified themselves as a potential base user for a first stage service district. In addition, an existing chilled water production facility owned by the State of Michigan was identified as a potential location for a DCS plant. With these changes a review of the feasibility with a new set of alternatives and sensitivities was evaluated in conjunction with the consulting firm of Lutz, Daily and Brain (LDB). This enhancement to the Phase I Study was nearing completion when the LBWL in conjunction with Energy, Mines and Resources Canada proposed to conduct the Phase II project in conjunction with DOE. The project was structured to proceed along a dual track to demonstrate the impact of the application of various innovative technologies on the selected standard engineering design approach identified in the Phase I enhancement.

2.0 Study Objective

The Primary objective of the Phase II Study is to select the best combination of innovative technologies to optimize the DCS for the LBWL considering operating and capital costs through the year 2012.

Secondary objectives include:

- > detail the impact of various innovative technologies on the capital and operating costs of a conventional DCS approach
- > demonstrate a strategy for determining the best combination of innovative technologies to obtain an optimized system at the lowest overall total cost.
- > document methodologies for impact assessments and selection of optimal strategies for general application.
- > detail methods for evaluating application of the innovative technologies to existing DCS systems.

Specific technologies and combinations of technologies were identified for evaluation: low temperature water supply, friction reducing additives (FRA's), FRA's and low temperature water, ice slurries, FRA's and ice slurries and distributed and central storage applications.

3.0 Reference Case

The results of Phase I Study enhancement were completed in November of 1990. The study results recommended a design concept using conventional chillers with redundancy to cover the largest unit out of service at peak load,. No storage facilities are included and chillers and main pumps are steam driven. The main distribution line would be a constant diameter of 30 inches and the system would operate with a supply temperature of 42^o and a return temperature of 57^o (delta T = 15^o F). Secondary line sizes were also specified as noted in figure 1b and Table 12 in Appendix 1. The CANMET report attached as Volume Two denotes the reference case as Case 1, operational alternative A1 (Case1/A1).

For the purposes of the study economic comparisons only, it was assumed that the State of Michigan (SOM) chilled water plant would be expanded to provide 13196 RT of installed capacity to the chilled water distribution system. An additional 5155 RT would serve the SOM distribution loop which is in place. The DCS peak load is estimated to be 90% of the connected load due to diversity in occurrence of customer peak requirements. While diversity does not impact the total energy requirement of the system, the production capacity required is reduced to 16516 RT.

Since location of the production facilities has not been finalized, flexibility to serve the DCS distribution partially or totally from either of two locations is essential. The limitation on distribution piping optimization was that either of two plant locations would have to be able to supply the peak cooling load of 16516 RT.

A load duration curve for the DCS was estimated based on steam system data reflecting cooling usage for customers with steam driven chillers. (Volume 2, figure 4) A cooling load profile was also developed based on data from July of 1989. (Volume 2, figure 8) This data was used to determine the equivalent load duration for the DCS (2390 hours), storage requirements, and annual system operating costs and revenues.

Detailed analysis of the reference case in the Phase I enhancement included economic evaluation of phased development of the DCS. A schedule through the year 2012 was developed specifying load additions which drives the requirement for distribution construction and plant equipment installation. Similar phasing plans were used for the comparative analysis of the alternatives recommended by CANMET for further consideration.

4.0 Analysis Summary

The primary effort made by CANMET and LDB (Volume Two) considered nine operating alternatives for distribution system piping and fourteen technology cases for production, storage and additives to determine the impact on system economics for combinations of the various alternatives.

The fourteen technology options are as follows:

Case 1: Conventional

Case 2: Conventional + FRA's

Case 3: Conventional + Central Storage

Case 4: Conventional + FRA's + Central Storage

Case 5: Low Temperature

Case 6: Low Temperature + FRA's

Case 7: Low Temperature + Central Storage

Case 8: Low Temperature + FRA's + Central Storage

Case 9: Low Temperature + Distributed Storage

Case 10: Low Temperature + Distributed Storage + FRA's

Case 11: Ice Slurry

Case 12: Ice Slurry + FRA's

Case 13: Ice Slurry + Central Storage

Case 14: Ice Slurry + FRA's + Central Storage

The operational alternatives are comprised of pipe sizing strategies and plant location alternatives. The operational alternatives assist in demonstrating a strategy for evaluating pipe sizing for optimizing operating and capital costs. The operational alternatives are detailed on pages 15 and 16 in Volume Two, the CANMET report.

In general, friction reducing additives did not offer strong benefits to the LBWL DCS due to the large diameters of pipes required to maintain flexibility for production plant location. This should not however be considered typical since cases analyzed with higher design velocities demonstrated short term paybacks. (see Volume 2, page 26)

CANMET discusses central vs distributed storage on pages 16 and 17 in Volume Two. Load management advantages were not totally realized since energy costs for the LBWL DCS do not include a significant demand ratchet. In addition, while distributed storage reduces distribution main sizes, BWL pipe costs are less than the industry average as a percentage of the total system capital. Based on capital and operating costs central storage provides the larger advantage to the LBWL DCS. With central storage, distribution costs are not impacted. Central storage does, however, reduce production capacity requirements from 16516 RT to 10405 RT. Reduced peak production also reduces the size of the steam service line required to serve the DCS plant from 16" to 14" which further reduces capital.

In CANMET's evaluation of ice slurry technology the uncertain cost of ice slurry chillers coupled with the lower than average piping costs for the LBWL DCS made any economic benefit minimal.

Due to the requirement for flexibility in plant location CANMET recommended the BWL limit consideration to two of the operational alternatives (E-1 & E-2) and consider both conventional and low temperature production technology. In addition, CANMET made a firm recommendation that central storage be included in any design selected. These recommendations resulted in four alternatives which were subjected to a more detailed analysis by the LBWL.

The CANMET approach levelized capital costs and utilized operating costs for the system as if all loads were in place. The LBWL additionally evaluated how staged system construction and load development would impact the four alternatives. Spreadsheets were constructed to model the operational and financial requirements of the four design alternatives as well as determine the impact on the cash flow for the system. Operating costs not accounted for in the CANMET

analysis have been added. These include operating labor, maintenance, waste water disposal, electric energy and debt service requirements. Spreadsheets detailing this part of the analysis are found in Volume 1 Appendix A.

Since the DCS is a new utility, capital for distribution and plant were bonded. Service line costs were excluded from the analysis since no determination of how costs for service lines will be assessed.

The following four cases were included in the detailed economic evaluation:

Case 1/A1 - Conventional Technology with 30 Inch Main Line Distribution
(Reference Case)

Case 3/E1 - Conventional Technology with tapered piping + central storage
(Optimized Reference Case)

Case 7/E1 - Low Temperature Technology with tapered piping + central storage

Case 7/E2 - Low Temperature Technology with tapered piping sized for all technologies + central storage.

The following table summarizes the analysis of the four recommended alternatives.

Summary Table : Economic Comparison of DCS Alternatives

CASE	O&M NPV \$1000	CAPITAL NPV \$1000	TOTAL NPV \$1000	UNIT REVENUE REQUIREMENT \$/TON HR *
CASE1/A1	24652	31919	56571	.138
CASE3/E1	25417	26048	51465	.125
CASE7/E1	25047	28253	53310	.129
CASE7/E2	24595	29385	53980	.131

* This unit revenue requirement is for a break-even analysis. Any rate of return requirement would be in addition. The LBWL analysis adds a 6% ROR to this revenue requirement.

All three of the alternatives provide marked improvement over the reference case. The most significant impact is due to the reduction of capital as a result of including storage and minimizing production equipment.

When evaluating the Case 7 alternatives the staging plan considers installation of the conventional chillers initially, the addition of storage when required to extend the capacity of the plant, and finally installation of the low temperature chillers when required to meet the load growth. This staging was suggested on page 25 of the CANMET report and provided the lowest overall NPV for the Case 7 alternatives.

The results of the BWL economic analysis confirm the preferred alternative as Case 3/E1 - the optimized reference case. This option provides a 9% reduction in total revenue requirements over the 20 year study period when compared to the reference case. While the overall operating costs are somewhat higher (3%) the debt service on capital requirements is reduced by 10%. Case 7/E1 which adds low temperature equipment when compared to the optimized reference Case 3/E1, increases the revenue requirements by 3% due to increased capital requirements. Case 7/E2, reduces the operating costs by optimizing the pipe sizing, but increases the capital costs resulting in a unit revenue requirement that is 1.5% higher than Case 7/E1.

Other costs and or benefits identified in previous LBWL evaluations relate to the multiple utility business operated by the LBWL and have not been included in these evaluations. These include costs/benefits attributable to deferred capacity requirements for the electric utility, lost steam and electric revenues for conversion of existing cooling customers, potential electric capacity sales with reduced summer peak requirements, deferred investment in electric distribution improvements and reduced production expenses for the electric utility.

5.0 Conclusions & Recommendations

Uncertainties in plant location, cost for ice slurry chillers and lower than average distribution piping costs result in the lowest cost alternative feasible for the Lansing DCS to be conventional technology optimized to include tapered piping and central storage. This optimization reduces the revenue requirements of the DCS by 9% when compared to the reference case. This will improve the marketability of the LBWL DCS.

In addition, construction of the piping system with tapered piping as outlined in operational alternative E-1 provides flexibility not only for plant location, but for additional load growth not anticipated at this time. Case 7/E1 demonstrates that installation of low temperature equipment is most economical at a later stage of system development. This allows for adjustment in the LBWL strategy in the event that the cost of that technology is reduced. In addition, low temperature technology can be utilized in the future as a way of supporting the addition of unanticipated loads without additional investment by extending the thermal carrying capacity of existing mains.

The approach used by CANMET documents the impact of various innovative technologies on the operating and capital costs of a conventional DCS approach. The LBWL approach follows a screening evaluation and adds staged construction and load development, investment and annual operating expenses, including debt service to permit analysis of the specific impact on revenue requirements and cash flow.

These methodologies for impact assessment and the strategy for determining the best combination of innovative technologies are adaptable to other DCS systems under evaluation.

In general, CANMET points out that when distribution expenses are high (30 to 40% of the production costs) due to higher unit piping costs or more extensive distribution systems, these systems would derive greater benefit from the use of advanced chiller technology. Additionally, FRA's should be considered when velocities are high since a short term payback can be demonstrated. Reduced costs for FRA's anticipated in the future will provide additional benefit from this technology.

For existing cooling systems, CANMET notes that low temperature water and ice slurry can increase the distribution capacity by as much as eight times for the

same pumping energy. Thus the use of advanced chillers may eliminate the need for distribution system upgrading or expansion.

CANMET notes that storage provides for load management or peak shaving to reduce energy demand and chiller capacity to the average demand from the peak demand. CANMET notes storage improves reliability since short term interruptions in production capacity can be accommodated from storage. This provides an opportunity to assess the need for chiller redundancy during the various stages of system development. CANMET also points out that low temperature and ice slurry technology reduce the storage volume required. If space is a premium, the value of reduced storage volume should be considered.

While individual DCS constraints and or circumstances may vary, this approach to evaluating the impact of innovative technologies on DCS design and operation can assist in optimizing system economics. For the LBWL that optimization provided an overall improvement of 9% which will make the utility more marketable and provide additional cost savings to its customers.

APPENDIX A

Lansing Board of Water and Light DCS Design Optimization

Conventional Technology w/o Central Storage-Reference Case 1														Reference Case				
30 inch piping sized for conventional technology- A1														Rate escalates @3.0%/Yr				
Installed chiller capacity required 16516 tons, 16" steam service to SOM														w/o ROR w/6% ROR w/ROR CUMUL				
SOM PLANT SOM				ENERGY COST		WASTE	MAINT	LABOR	ANNUAL	PROD	PIPING	DEBT	REVENUE	REVENUE	REVENUE	CASH	CUMUL	
LOAD	CAP	ELEC	STEAM	ELEC	STEAM	WATER	COST	COST	OP COST	EXPEND	COSTS	SERVICE	REQUIRED	@ 0.138	@ 0.146	FLOW	FLOW	
YEAR	tonhrs(1)	TONS(2)	MWH	Mlb(3)	\$1000(4)	\$1000(4)	\$1000(4)	\$1000(5)	\$1000(6)	\$1000	\$1000(7)	\$1000	\$1000(8)	\$1000	\$1000	\$1000	\$1000	
1994	15606700	10500	499	162268	24	639	55	182	194	1094	18164	3662	2097	3191	2154	2279	-912	
1995	16204200		507	168481	25	678	59	191	204	1157		289	2097	3254	2303	2437	-817	
1996	16443200		511	170966	26	704	61	200	214	1205		102	2097	3302	2407	2547	-755	
1997	20231350	13500	563	210352	30	885	78	259	225	1476	4179	515	2793	4268	3051	3228	-1041	
1998	23543890		608	244794	33	1052	93	272	236	1686		301	2793	4479	3657	3869	-610	
1999	23543890		608	244794	34	1075	96	285	248	1739		2374	2793	4531	3767	3985	-546	
2000	35967110	16500	780	373962	46	1679	151	363	260	2499	4768	384	3279	5778	5927	6270	492	
2001	35967110		780	373962	47	1716	156	381	273	2573			3279	5852	6104	6458	606	
2002	40857050	19500	847	424805	53	1992	182	477	287	2991	5207		3771	6762	7142	7556	795	
2003	40857050		847	424805	55	2036	188	501	301	3081			3771	6851	7357	7783	932	
2004	40857050		847	424805	57	2081	193	526	316	3173		88	3771	7032	7577	8017	985	
2005	40857050		847	424805	59	2126	199	553	332	3269			3771	7039	7805	8257	1218	
2006	40857050		847	424805	61	2173	205	580	348	3368			3771	7138	8039	8505	1367	
2007	40857050		847	424805	63	2221	211	609	366	3470			3771	7241	8280	8760	1519	
2008	40857050		847	424805	65	2270	217	640	384	3576			3771	7347	8528	9023	1676	
2009	40857050		847	424805	67	2320	224	672	403	3686			3771	7457	8784	9293	1837	
2010	43858890		888	456016	73	2545	248	705	424	3994		321	3801	7795	9713	10276	2480	
2011	43858890		888	456016	75	2601	255	741	445	4117			3801	7917	10004	10584	2666	
2012	43858890		888	456016	78	2658	263	778	467	4243			3801	8044	10304	10901	2857	
totals					969	33451	3133	8916	5926	52395	32318	8036	62794		totals	122903	130027	14750
NET PRESENT VALUES										24652				31919	NPV's	56865	3549	
total NPV													56571	-----MATCH-----				

NOTES:

1. Assumes 2390 equivalent full load hours.
2. Assumes chiller capacity to meet full system requirements of 16516 RT.
3. Includes steam requirements for both production and pumping.
4. Assumes electric rate escalates at 3.4%, steam escalates at 2.2%, waste water escalates at 3.0%.
5. Assumes maintenance at 1% of cumulative capital with 5% escalation.
6. Assumes manned operation of SOM DCP and 5 % labor cost escalation.
7. Includes capital costs associated with steam service to plant facilities and plant facility capital.
8. Assumes all capital requirements are financed with multiple 20 year bond issues at 7% (88K distribution expense in 2004 from cash flow)

NOTES:

ROR = Rate of Return
Assumes unit revenue increases
3% per year

Lansing Board of Water and Light DCS Design Optimization

Conventional Technology w/ Central Storage-Case 3 Tapered piping sized for conventional technology (E1) Installed chiller capacity reduced to 10405, 14" steam service to SOM														Case 3/E1 Optimized Reference Case Rate escalates @3.0%/Yr					
	SOM PLANT	SOM			ENERGY COST		WASTE	MAINT	LABOR	ANNUAL	PROD	PIPING	DEBT	REVENUE					
LOAD	CAP	ELEC	STEAM		ELEC	STEAM	WATER	COST	COST	OP COST	EXPEND	COSTS	SERVICE	REQUIRED					
YEAR	tonhrs(1)	TONS(2)	MWH	Mlb(3)	\$1000(4)	\$1000(4)	\$1000(4)	\$1000(5)	\$1000(6)	\$1000	\$1000(7)	\$1000	\$1000(8)	\$1000	\$1000	\$1000	\$1000	\$1000	
1994	15606700	8250	499	178614	24	704	60	161	194	1142	16073	3477	1882	3024		1951	2068	-956	-956.4
1995	16204200		507	185452	25	747	64	169	204	1208		289	1882	3090		2086	2211	-879	-1835
1996	16443200		511	188187	26	774	67	177	214	1258		102	1882	3141		2181	2311	-829	-2664
1997	20231350		563	231542	30	974	84	186	225	1499		415	1882	3381		2763	2929	-452	-3116
1998	23543890	2750	608	269453	33	1158	101	238	236	1767	3520	301	2507	4274		3312	3511	-763	-3879
1999	23543890		608	269453	34	1184	104	250	248	1820		2387	2507	4327		3412	3616	-711	-4590
2000	35967110	2750	780	411633	46	1848	164	314	260	2632	3844	384	2907	5538		5368	5690	152	-4438
2001	35967110		780	411633	47	1889	169	330	273	2707			2907	5614		5529	5861	247	-4191
2002	40857050		847	467596	53	2193	197	346	287	3076			2907	5983		6470	6858	875	-3315
2003	40857050		847	467596	55	2241	203	364	301	3164			2907	6070		6664	7063	993	-2322
2004	40857050		847	467596	57	2290	209	382	316	3254		88	2907	6161		6864	7275	1115	-1207
2005	40857050		847	467596	59	2341	216	401	332	3348			2907	6254		7069	7494	1239	32
2006	40857050		847	467596	61	2392	222	421	348	3444			2907	6351		7282	7718	1368	1400
2007	40857050		847	467596	63	2445	229	442	366	3544			2907	6451		7500	7950	1499	2899
2008	40857050		847	467596	65	2499	236	464	384	3647			2907	6554		7725	8188	1635	4534
2009	40857050		847	467596	67	2553	243	487	403	3754			2907	6660		7957	8434	1774	6308
2010	43858890		888	501952	73	2801	268	512	424	4078		321	2937	7014		8798	9325	2311	8619
2011	43858890		888	501952	75	2863	276	537	445	4197			2937	7133		9062	9605	2472	11091
2012	43858890		888	501952	78	2926	285	564	467	4319			2937	7256		9333	9893	2637	13728
totals					969	36821	3396	6744	5926	53857	23437	7764	50420			111325	118004	13728	
NET PRESENT VALUES										25417			26048		51508		3134		
total NPV													51465	-----MATCH	-----				

NOTES

1. Assumes 2390 equivalent full load hours.
2. System peak capacity requirement is reduced by 36.1% to 10405 RT due to storage.
3. Includes steam requirements for both production and pumping.
4. Assumes electric rate escalates at 3.4%, steam escalates at 2.2%, waste water escalates at 3.0%.
5. Assumes maintenance at 1% of cumulative capital with 5% escalation.
6. Assumes manned operation of SOM DCP and 5 % labor cost escalation.
7. Includes capital costs associated with steam service to plant facilities, plant facility capital and capital for storage.
8. Assumes all capital requirements are financed with multiple 20 year bond issues at 7% (88K distribution expense in 2004 from cash flow)

NOTES

ROR = Rate of Return
Assumes unit revenue increases
3% per year

Lansing Board of Water and Light DCS Design Optimization

Low Temperature Technology w Central Storage-Case 7 Tapered piping sized for conventional technology- E1 Installed chiller capacity required 10405 tons, 14" steam service to SOM														Case 7/E* Rate escalates @3.0%/Yr			
SOM PLANT SOM														w/o ROR w/6% ROR w/ROR CUMUL			
YEAR	LOAD	CAP	ELEC	STEAM	ENERGY COST	WASTE	MAINT	LABOR	ANNUAL	PROD	PIPING	DEBT	REVENUE	REVENUE	REVENUE	CASH	CASH
tonhrs(1)	TONS(2)	MWH	Mib(3)	\$1000(4)	\$1000(4)	\$1000(4)	\$1000(5)	\$1000(6)	\$1000	\$1000(7)	\$1000	\$1000(8)	\$1000	@ 0.129	@ 0.137	FLOW	FLOW
														\$1000	\$1000	\$1000	\$1000
1994	15606700	9390	499	178614	24	704	60	173	194	1154	17272	3477	1995	3149	2013	2138	-1011
1995	16204200		507	185452	25	747	64	181	204	1221		289	1995	3216	2153	2287	-930
1996	16443200		511	188187	26	774	67	190	214	1271		102	1995	3267	2250	2390	-877
1997	20231350		563	231542	30	974	84	239	225	1551	3338	415	1995	3547	2852	3029	-518
1998	23543890		608	269453	33	1158	101	251	236	1779		301	2603	4382	3418	3630	-752
1999	23543890		608	269453	34	1184	104	263	248	1833		2387	2603	4436	3521	3739	-697
2000	35967110	13510	780	389170	46	1747	156	357	260	2566	6041	384	3210	5776	5540	5884	108
2001	35967110		780	389170	47	1786	161	375	273	2642			3210	5852	5706	6060	209
2002	40857050		847	442079	53	2073	188	394	287	2995			3210	6205	6677	7091	886
2003	40857050		847	442079	55	2119	194	413	301	3082			3210	6292	6877	7303	1012
2004	40857050		847	442079	57	2165	200	434	316	3172		88	3210	6470	7083	7522	1053
2005	40857050		847	442079	59	2213	206	456	332	3265			3210	6475	7296	7748	1273
2006	40857050		847	442079	61	2262	212	479	348	3361			3210	6571	7515	7981	1410
2007	40857050		847	442079	63	2311	218	503	366	3461			3210	6670	7740	8220	1549
2008	40857050		847	442079	65	2362	225	528	384	3564			3210	6773	7972	8467	1693
2009	40857050		847	442079	67	2414	232	554	403	3670			3210	6880	8211	8721	1841
2010	43858890		888	474560	73	2649	256	582	424	3982		321	3240	7223	9079	9642	2420
2011	43858890		888	474560	75	2707	264	611	445	4101			3240	7341	9351	9931	2590
2012	43858890		888	474560	78	2766	272	641	467	4224			3240	7464	9632	10229	2765
totals				969	35114	3261	7623	5926	52893	26650	7764	55008			114887	122012	14023
NET PRESENT VALUES									25057			28253	NPV's		53157		3101
total NPV												53310	-----MATCH-----				

NOTES:

1. Assumes 2390 equivalent full load hours.
2. System peak capacity requirement is reduced by 36 1% to 10405 RT due to storage.
3. Includes steam requirements for both production and pumping.
4. Assumes electric rate escalates at 3.4%, steam escalates at 2.2%, waste water escalates at 3.0%.
5. Assumes maintenance at 1% of cumulative capital with 5% escalation.
6. Assumes manned operation of SOM DCP and 5 % labor cost escalation.
7. Includes capital costs associated with steam service to plant facilities, plant facility capital and capital for storage.
8. Assumes all capital requirements are financed with multiple 20 year bond issues at 7% (88K distribution expense in 2004 from cash flow)

NOTES:

ROR = Rate of Return
Assumes unit revenue increases
3% per year

Lansing Board of Water and Light DCS Design Optimization

Low Temperature Technology w Central Storage-Case 7

Tapered piping sized for conventional, low temperature or ice slurry technology- E2

Installed chiller capacity required 10405 tons, 14" steam service to SOM

Installed chiller capacity required 10405 tons, 14 steam service to SOM														Case 7/E2				
SOM PLANT SOM														Rate escalates @3.0%/Yr				
LOAD CAP ELEC STEAM ENERGY COST WASTE MAINT LABOR ANNUAL PROD PIPING DEBT														w/o ROR w/6% ROR w/ROR CUMUL				
TONS(2) MWH Mlb(3) ELEC STEAM WATER COST COST OP COST EXPEND COSTS SERVICE														REVENUE REVENUE REVENUE CASH CASH				
YEAR tonhrs(1)														@ 0.131 @ 0.139 FLOW FLOW				
TONS(2) MWH Mlb(3) \$1000(4) \$1000(4) \$1000(4) \$1000(5) \$1000(6) \$1000 \$1000(7) \$1000 \$1000(8)														\$1000 \$1000 \$1000 \$1000				
1994	15606700	8320	499	166631	24	657	56	190	194	1120	18960	3821	2196	3317	2044	2185	-1132	-1132
1995	16204200		507	173010	25	697	60	199	204	1185		375	2196	3381	2186	2337	-1044	-2176
1996	16443200		511	175562	26	722	63	209	214	1234		112	2196	3431	2285	2442	-988	-3164
1997	20231350		563	216008	30	908	80	219	225	1462		450	2196	3658	2896	3095	-563	-3728
1998	23543890	10380	608	251375	33	1080	95	264	236	1709	2766	320	2775	4484	3471	3710	-774	-4502
1999	23543890		608	251375	34	1104	98	277	248	1762		2596	2775	4537	3575	3821	-716	-5218
2000	35967110	13510	780	384016	46	1724	154	353	260	2537	4631	384	3249	5786	5626	6013	227	-4991
2001	35967110		780	384016	47	1762	159	371	273	2612			3249	5861	5795	6193	332	-4659
2002	40857050		847	436225	53	2046	186	389	287	2961			3249	6209	6780	7246	1037	-3622
2003	40857050		847	436225	55	2091	192	409	301	3047			3249	6296	6984	7463	1168	-2455
2004	40857050		847	436225	57	2137	197	429	316	3136		88	3249	6473	7193	7687	1215	-1240
2005	40857050		847	436225	59	2184	203	451	332	3228			3249	6477	7409	7918	1441	201
2006	40857050		847	436225	61	2232	210	473	348	3324			3249	6572	7631	8155	1583	1784
2007	40857050		847	436225	63	2281	216	497	366	3422			3249	6671	7860	8400	1729	3514
2008	40857050		847	436225	65	2331	222	522	384	3524			3249	6772	8096	8652	1880	5393
2009	40857050		847	436225	67	2382	229	548	403	3629			3249	6878	8339	8912	2034	7427
2010	43858890		888	468276	73	2613	253	575	424	3938		321	3279	7217	9220	9853	2636	10063
2011	43858890		888	468276	75	2671	261	604	445	4056			3279	7334	9496	10149	2814	12878
2012	43858890		888	468276	78	2730	269	634	467	4177			3279	7456	9781	10453	2997	15875
totals					969	34351	3203	7615	5926	52064	26357	8467	56657		totals	116668	124684	15875
NET PRESENT VALUES										24595					NPV's	53981	3667	
total NPV													53980	-----MATCH-----				

NOTES:

1. Assumes 2390 equivalent full load hours.
2. System peak capacity requirement is reduced by 36.1% to 10405 RT due to storage.
3. Includes steam requirements for both production and pumping.
4. Assumes electric rate escalates at 3.4%, steam escalates at 2.2%, waste water escalates at 3.0%.
5. Assumes maintenance at 1% of cumulative capital with 5% escalation.
6. Assumes manned operation of SOM DCP and 5% labor cost escalation.
7. Includes capital costs associated with steam service to plant facilities, plant facility capital and capital for storage.
8. Assumes all capital requirements are financed with multiple 20 year bond issues at 7% (88K distribution expense in 2004 from cash flow)

NOTES:

ROR = Rate of Return
Assumes unit revenue increases
3% per year

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VOLUME TWO:

**EVALUATION OF NEW TECHNOLOGIES FOR
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LANSING, MICHIGAN**

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**ENERGY SYSTEMS TECHNOLOGY
IMPLEMENTATION**

**COMBUSTION AND CARBONIZATION
RESEARCH LABORATORY**

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1. Introduction

While the demand for district cooling is growing, the cost is still very high given the large diameter pipelines required and the quantities of chilled water that must be pumped. In order to improve the cost effectiveness of district cooling, a number of technologies are being developed. They include: the generation of lower temperature water, the generation and transport of pumpable ice slurries, and of friction reducing additives (FRAs) that tend to suppress turbulence and reduce energy losses and thereby reduce pumping energy requirements.

This report explores the benefits of these new technologies as they would affect the proposed Lansing Board of Water and Light (LBWL) District Cooling System. Some of the technologies are commercialized while others may be approaching commercialization or not yet constructed in capacities envisaged for the LBWL system. However, the analyses take the best available estimates of how such systems would perform to allow an effective comparison. This report provides objective comment as to the state of commercial readiness of systems to assist LBWL in making a decision as to the most appropriate technology for implementation.

2.0 Background

The Board of Water and Light of Lansing, Michigan has received funding from the U.S. Department of Energy in support of an evaluation of a district cooling project for the city. As part of this project the Board has retained the consulting engineering firm of Lutz, Daily and Brain (LDB), Overland Park, Kansas to act as the principal consultants for the design team for the proposed system.

As a separate part of this study an evaluation of new district cooling technologies and their impact on the economics and operating strategies for the proposed system was performed. In collaboration with the Board and their lead consultants, the Canadian Federal Department of Natural Resource's research and development arm, the Canada Centre for Mineral and Energy Technology (CANMET), Ottawa, Ontario, along with its research partners carried out this evaluation.

3.0 Objective

The main objectives of this study were to optimize capital and operating cost benefits utilizing innovative technologies for LBWL's proposed district cooling system and to compare these reductions to any increased costs for new production technology. The report also explores how thermal storage can affect the feasibility of district cooling if new technologies are used.

4.0 New Technologies

4.1 Low Temperature Water Chillers

The mass flow required for a given cooling load varies inversely with the temperature difference in the supply and return water. In typical cooling systems water is normally sent out at about 42°F and returned at 55°F to 57°F. If the supply water temperature can be lowered to near 32°F then the mass flow can be reduced by about 40%.

The low temperature chiller developed by Sorenco Ltee, Ste. Foy, Quebec, Canada operates on the principle of supercooling of water. A stream of water, when cooled in a controlled manner can be cooled to 32°F without the formation of ice crystals at the liquid/wall interface. On further supercooling of the water to 29°F, ice crystals can be generated after the liquid leaves the evaporator. Ice is produced at about 0.7% (ice fraction) per pass for each degree F of cooling.

4.2 Ice Slurry Chillers

Ice slurry generation has been investigated for a number of years and although the main use has been in the food and beverage industry, several applications have been adopted to district cooling. Extensive research into the transport of ice slurries is currently taking place at the National Research Council in Ottawa, Canada. One ice slurry generator supplier, Sunwell Engineering of Canada, has many installations in Japan including a 1200 RT chiller in a 500 ft. (1.3 million square feet) high office tower in Osaka.

Sunwell manufactures ice slurry generators that produce ice in a glycol solution at approximately 23°F, depending on the glycol concentration. The freeze point depressant (glycol) prevents ice formation on the evaporator wall as well as the agglomeration of the ice in the distribution system. The generator accepts either water or ice slurry at the inlet.

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Due to the latent heat of the ice available for cooling and the low temperature of the water, further significant reductions in mass flows can be realized for a given cooling load. While it is possible to generate and pump ice slurry of up to 40% ice fraction, a more conservative value of 20% was used for this study. A 20% ice slurry mass enables a flow rate reduction of about 72% compared with flows based on 42°F supply water, when returned at a temperature of 57°F.

Extensive experiments¹ have shown that there are no problems associated with the pumping of ice slurries up to a certain ice fraction. This threshold ice fraction for pumpability is a function of ice particle size and geometry. For small spherical ice particles (diameters less than 0.04 inches), the pumpability of ice slurries should not be impaired at fractions below 30%.

4.3 Friction Reducing Additives

Friction Reducing Additives (FRAs) are surfactant-counterion mixtures which can be added to flowing fluid to reduce the loss in energy due to friction. The FRAs form rod-like micelles which act as 'flow straighteners' and reduce fluid turbulence. FRAs have been successfully demonstrated in Danish (Herning) and German (Dortmund) hot water district heating systems, reducing friction levels by about 90% in straight pipes and approximately 80% in overall systems where the effect of the FRA may be temporarily diminished when going through severe turbulent areas such as pumps and partially closed valves. FRAs quickly regain their effectiveness downstream of the high stress area. These hot water FRAs however are not suitable for chilled water systems.

FRAs for chilled water systems have been developed recently. In 1991, researchers at Saint Mary's University, Halifax, Nova Scotia, synthesized additives that remain soluble at temperatures lower than 32°F and achieved friction reduction in excess of 80%. FRAs have also been developed that are compatible with corrosion inhibitors.

In this analysis, friction reduction of 70% was assumed to result from the addition of FRAs. This value represents the lowest friction reduction typically observed experimentally. The actual pressure drop reduction can be as great as 90%.

¹ Experiments conducted at the National Research Council ice slurry test facilities, Ottawa, Canada.

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The same property which causes the reduction in friction can also result in diminished heat transfer. It is possible to offset this deleterious effect, however, by maintaining higher Reynolds numbers through the heat exchanger, thus eliminating the need for new heat exchangers during retrofit situations.

A complete review of the environmental impact of the use of FRAs is being carried out. The study will consider all possible points where FRAs can leak to the environment and the expected impact. The FRAs studied to date appear to be environmentally benign; they have low toxicities and are biodegradable.

Using a 5mM (milli mole) dosage of surfactant with a 50% molar excess of counterion, the estimated cost per 1000 U.S. gallons would be \$100 or 10 cents per gallon in system². Other types of FRAs are presently being looked into which may reduce the above cost by half.

5.0 Design Criteria and Assumptions

5.1 Proposed Cooling System

The proposed chilled water system is based on the Lansing Board of Water and Light assuming control of the State of Michigan (SOM) chilled water plant and then expanding the plant and creating a district cooling system in downtown Lansing, Michigan. Currently the total cooling load within the SOM chilled water system consists of 5155 RT which is served by two electrically driven centrifugal chillers located at the State of Michigan (SOM) building. The proposed new system would be expanded to serve 63 buildings, reaching a peak load (including the original 5155 RT) of 18351 RT by the year 2012. The individual cooling loads are identified in Fig. 1a and 1b and are summarized in Fig. 2.

If the entire load were to be met from the SOM plant then the proposed new main line distribution system would be sized for the additional load of 13196 RT, as the distribution system is already in place to serve the existing load at SOM complex.

² Details of FRA cost calculations are shown in Table 12.

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However, if the entire load were to be met from an alternative site, namely the Ottawa Street plant, then the proposed main line distribution system would be sized for 18351 RT.

The study took the position (LDB report) that the original production equipment would be replaced with new production capacity to meet all the load requirements. The existing distribution system would not be replaced and would therefore be oversized for many of the options suggested in this study.

5.2 Reference Case

The reference case, for purposes of this study, was that the State of Michigan chilled water plant would be expanded to include chillers and associated equipment in order to provide 13,196 tons of refrigeration (not firm capacity) to the chilled water distribution system. The cooling would be supplied by conventional chillers with no storage facilities and the chillers and main pumps would be stream driven. The main line would be a constant diameter of 30", ($\Delta T = 15^\circ F$).

5.3 Hydraulic Design Limits

Limiting fluid velocities and pressure gradients for the system were provided by LDB, and are summarized below:

Maximum Velocity:	10 ft/s
Maximum Pressure:	5 ft H ₂ O/100 ft
Pump Efficiency:	60%
Pressure drop through last heat exchanger:	0 ft H ₂ O

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Normally, it is desirable to select high peak design velocities and pressure gradients as suggested for this study by LBWL; that is maximum velocities of 10 ft/s and pressure gradients of 5%. However, after having conducted the original investigations using the above criteria, it was found that lower velocity limits yielded more cost effective results. An approach was taken to vary the velocities from 10 ft/s down to 2 ft/s to determine an optimum value which produced lowest overall costs. This approach was applied to main line pipes and branch line pipes concurrently. The rationale is that compared with other installations, the capital cost for piping is quite low and the energy costs are high due the use of low efficiency steam turbines to drive pumps. Thus the optimum distribution system design will compare larger pipes and lower pumping costs and therefore drastically reduce the effects of FRAs. To examine the impact of FRAs an additional analysis was carried out using the original criteria and may be seen in Tables 4a to 4e.

Analyses indicated that different optimum velocities occurred for tapered pipes and constant diameter pipes as well as different technologies. Below are the optimum velocities for the various operational alternatives (see Table 5.1) and production technologies that were used in the analyses. Alternatives A1, E1, F1 and F2 by definition were set at fixed diameters and therefore were not involved in this optimization.

TABLE 5.1 Optimum Velocities

Operational Alternative	Technology	Optimum Velocity
B, C, D and E2	Conventional	6 ft/s
B, C, D and E2	Low Temperature	4 ft/s
B, C, D and E2	Ice Slurry	4 ft/s
A2	Conventional	10 ft/s
A2	Low Temperature	8 ft/s
A2	Ice Slurry	8 ft/s
A1, E1, F1, F2	Conventional	10 ft/s
A1, E1, F1, F2	Low Temperature	10 ft/s
A1, E1, F1, F2	Ice Slurry	10 ft/s

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It is assumed that there will be a pressure difference of 0 psi between supply and return lines for the most remote building on the distribution line. Several customers furthest from the chilling plant will therefore have to pump the chilled water through their system. For other customers, however, the pressure differential may reduce or eliminate the internal building pumping requirement.

Ice slurry is considered to flow with the same frictional losses as water and require the same pumping energy³. While friction reducing additives can reduce the friction losses by about 80% in water, experimental data have shown that FRAs have a diminished benefit as ice slurry concentration increases. As a result, FRAs are considered to have an impact only in the return lines for ice slurry systems, where all the ice has melted.

5.4 Pipe Friction Factors

A Darcy-Weisbach friction factor of 0.015, the largest value which would be expected to result in any of the pipes in the main line distribution system, was used for all calculations. In larger pipes the friction factor would be expected to fall below this value and, as a result, values for pressure drop, pumping power and the associated costs, which are directly proportional to the friction factor, may be slightly overestimated.

The friction factor was reduced by 70% to a value of 0.0045 to illustrate the effect of FRA addition on the pressure drops and the corresponding decrease in pumping requirements.

5.5 Construction Costs

Material and installation costs for distribution pipes were obtained from LDB and have been inflated by 4.5%/a from 1990 to 1992 prices. Diameters were taken to be the internal pipe diameters.

³

Experiments at the National Research Council of Canada have demonstrated that slurry of concentrations up to 25% by mass experience frictional losses equivalent to water.

5.6 Cooling Load Profile - Design Day

A cooling load profile for the design day in Lansing has been developed based on estimated cooling loads provided by LBWL for Lansing for 1989. For a cooling system without storage, only the peak load for the design ambient temperature is required. However, for a system with storage, the cooling load profile is essential as peak cooling demand will be served from the storage tank that is provided during off peak hours. The cooling load profile has been developed from the average loads (provided by LBWL) for the period 7/4/89 to 07/6/89. (Fig. 3)

5.7 Diversity Factor

If the cooling demands for individual buildings were summed, a peak load of 18361 RT would result. However, this is unlikely to occur. By applying a diversity factor of 0.9, as recommended by LBWL, the peak load reduces to 16516 RT. The diversity factor quantifies the decrease possible in the installed chilling capacity in a district energy system because of the small likelihood of all buildings having peak demand simultaneously. While the peak load is reduced, the total energy requirement for the system remains the same.

The diversity factor is also considered to have an impact on the carrying capacity required in the main line distribution pipes. The main line distribution pipes are sized to carry 90% of the peak mass flow rate. The secondary lines, which serve a smaller group of users, are sized to provide 100% of the peak demand.

5.8 Load Duration Curve

The load duration curve, Figure 4, is based on estimates from Lansing LBWL and LDB and is essential for designing the system and for evaluating the annual system operating costs and revenues. The equivalent load duration hours is the annual energy divided by the peak load and will be 2390 hours for Lansing.

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5.9 Distribution Pumping Energy

There are a number of different ways of operating a district cooling system. Each alternative has a different impact on pumping energy and on chiller performance or COP. Normally, building owners depend on a maximum supply temperature of 42°F and thus the unit enthalpy difference (Btu/lb) between supply and return will be constant while the flow will vary. At lower temperatures, or with ice slurry, it is possible to vary the unit enthalpy while using a constant flow rate.

The following equivalent hours of pumping at peak have been calculated for the various supply alternatives based on the above load duration curve.

42°F Supply/57°F Return - Variable flow/constant enthalpy:	585
32°F Supply/57°F Return - Variable flow/constant enthalpy:	695
32°F Supply/57°F Return - Variable enthalpy/constant flow:	1875
20% Ice Slurry Supply/57°F return - constant flow/variable enthalpy:	2985

5.10 Energy Costs

A value of 10 lb/RT was used for the steam requirement to drive chillers with a COP of 5.5. Steam rates for other chillers with different COPs were proportioned accordingly. The steam usage to run the pumps was chosen at 50 lb/BHP (an average obtained from the LDB report). The cost of steam obtained from LBWL was 0.00394 \$/lb. These values were used in determining all pumping costs and impacted on the pipe sizes when optimum velocities (5.3) were used.

6.0 Production

As mentioned in section 5.1, this study was based on the fact that each selected plant location would have to meet a cooling load of 16516 RT including a diversity factor of 0.9 without storage. The cooling would be met by three modes, conventional 42°F water, 32°F water, and ice slurry with ice concentrations from 0% to 20%. The capacities of each of the production units were calculated from the unit enthalpy differences and mass flows required for each strategy.

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The capital cost of chillers is greater for low temperature chillers compared with conventional chillers and greater still for ice slurry chillers. The costs used in the preliminary analysis are \$1943, \$2043 and \$3143 per RT for conventional, low temperature and ice slurry chillers respectively. The system design strategy minimizes the use of the more expensive chillers.

6.1 42°F Supply - No storage

The supply of 42°F water would be entirely produced from conventional chillers using a constant return temperature of 57°F. The concept would use a variable flow rate to meet the design day cooling loads. Fig. 5a illustrates the configuration of the system and Fig. 5b graphically depicts the design day peak load (16516 RT) and the supply temperatures that would be required. Maximum mass flow rates were also calculated for design day conditions and are shown in Table 1.

6.2 32°F Supply - No Storage

The arrangement to supply 32°F water is shown in Fig. 6a. Water from the conventional chillers is passed through the low temperature chillers to reduce the temperature to 32°F. The proportion of capacities for the design day (16516 RT) of the two production plants are shown in Fig. 6b and are based on enthalpy differences at each unit. Sixty percent of the capacity is to be supplied by conventional chillers (9910 RT) and 40% with low temperature chillers (6606 RT). The load on the design day is met with constant flow and variable enthalpy (or variable temperature difference) when supply temperature is below 42° F. Maximum mass flow rates for design day loads are shown in Table 1. The low temperature (32°F) production plant may be bypassed to supply only 42°F water at variable flow rates to the load for low demand periods.

6.3 Ice Slurry Supply - No Storage

Fig. 7a illustrates the configuration to supply 20% ice slurry to meet the design day load (16516 RT) using variable mass flow rates. The return water temperature is cascaded downwards to 32°F through the conventional chillers and then the low temperature chillers to the inlet of the ice slurry generator. Capacity percentages (at design day conditions) of each technology using enthalpy differences are 53% for ice slurry generators (8753 RT), 19% for low temperature (3138 RT) and 28% for conventional chillers (4625 RT). This is illustrated in Fig. 7b. The load on the design day is met with variable enthalpy with constant flow rates. Maximum mass flow rates and capacities for each of the production units are shown in Table 1.

6.4 Production - With Storage

Thermal storage can be a great benefit in reducing production costs as chillers can be sized for average rather than peak loads. Demand charges can also be reduced, particularly when electric drive chillers are used. When storage is used, the diversity factor is not applied. Storage is more fully discussed in section 8.0.

The average load⁴ based on the design day load curve was found to be 63.1% of peak and is shown in Fig. 8. This reduces the peak load to 10422 RT. The configurations for the three supply options with storage are shown in Fig. 9a, 10a and 11a and relative capacities based on unit enthalpy differences of each of the technologies are shown in Table 1 and Fig. 9b, 10b and 11b.

6.5 42°F Supply - Storage

Fig. 9a and 9b illustrate a conventional system with storage. Conventional chillers meet the peak load of 10422 RT with variable flow, as well as supply the storage tank with 42°F water. The remaining load of 6095 RT is met with additional flow from the storage tank. Maximum flows through the chillers are shown in Table 1.

6.6 32°F Supply - Storage

Fig. 10a and 10b schematically illustrate conventional and low temperature technologies with storage. The conventional capacity using unit enthalpy differences is 6276 RT, 38% of peak (base load) and 4129 RT, 25% of peak, for low temperature chillers. The remaining 6111 RT (37% of peak) is supplied by storage. The load on the design day is met with constant temperature water at variable flow rates. As the demand increases from the base load, less 32°F water is supplied to storage and more is redirected to the load. At 63% of peak load all chillers are dedicated to the load and flow to and from storage is stopped. As the demand further increases, 32°F water is taken from storage to satisfy the load.

⁴ Details of average load calculations are given in Table 11a.

6.7 Ice Slurry Supply - Storage

Ice slurry supply with storage requires a more complex configuration, as shown in Fig. 11a. The ice slurry chillers and storage tank are separated so that they may function independently from the conventional and low temperature chillers. This was done as only ice slurry would be supplied to the storage tank. The base load requiring a temperature of 38.5°F on the design day (35% of peak) is met using conventional and low temperature chillers. In this arrangement, the use of conventional chillers is maximized to meet 28% of peak (4624 RT), and the remaining 7% is met with low temperature chillers (1156 RT). The remainder of the peak load (4624 RT) would be taken up by the ice slurry generators. The remaining 6111 RT (37% of peak) would be met by storage. As conventional and low temperature chillers meet the base load on the design day with 38.5°F water at constant flow, the ice slurry generator is supplying the storage tank with 20% ice slurry.

As the load increases above the capacity of the conventional and low temperature chillers, it is necessary to pass part of the water at 38.5°F into the ice slurry system and use chilled water to cool the supply water down to 32°F. With further increases in load demand, ice slurry ranging in concentrations from 1% to 20% will be supplied to the load. At peak demand, all water from the low temperature chillers will be directed to the ice slurry chillers and replaced with 20% ice slurry from the storage tank.

6.8 COPs AND COOLING PRODUCTION COST

In order to determine differences in production costs, the steam consumption for the various chiller combinations was calculated. The calculations were based on a steam rate of 10 lbs of steam per ton of refrigeration for a conventional steam driven chiller⁵. The steam rate for other chillers was assumed to be proportional to the change in chiller COP due to changes in evaporator temperatures. The steam turbine efficiency was kept constant.

The COPs for the chillers were calculated using the Carnot equation adjusted with a constant efficiency factor of 0.5 for all chillers and with a condenser temperature of 85°F.

$$\text{Carnot Equation } \text{COP} = \frac{T_{\text{evaporator}}}{T_{\text{condenser}} - T_{\text{evaporator}}}$$

⁵ Based on data given in LDB report for centrifugal chiller using 150 psig inlet steam pressure, 85°F inlet condenser temperature, and 40°F evaporator outlet temperature.

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Values for evaporator temperatures and calculated COPs and steam rates are shown in Table 2.

The change in COP due to lower ambient temperatures off peak, resulting in lower condenser temperatures, was not included in the calculation and will not affect the cost difference between the cases. Free cooling, using the cooling towers, was assumed for the cooling production outside the 3000-h cooling season.

For each case, the production cost was calculated using above steam rates and the annual cooling production from the different chillers. The production from the different chillers was based on load and temperature requirements using the load duration curve. Annual cooling production, steam consumption and steam rates are shown in Table 3.

6.9 Chiller Costs

The costs used in the calculations are \$1943/RT for conventional chillers, and \$2043/RT for low temperature chillers and \$3143/RT for ice slurry chillers. Each of the above costs includes a cost of \$1543/RT to account for costs associated with chiller installation such as overhead, steam piping inside the plant, controls, building costs, steam distribution system, contingencies and cooling tower costs. It is assumed that this cost would be largely independent of chiller type and could be added to the basic cost of low temperature and ice slurry chillers as well as conventional chillers.

A cost of \$1600/RT for ice slurry chillers represents one manufacturer's (Sunwell Engineering) current production costs for larger units. However, research in more cost effective large units suggests that costs can be lowered significantly. For this analysis, the \$1600/RT figure has been used although "break even" costs will be determined.

6.10 Plant Layouts

Schematic drawings of recommended technology options are shown in Fig. 12 to 16c were produced by LDB based on the findings of this report.

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7.0 Distribution

7.1 Central Chiller Location

Initially, loads up to the year 2012 will be provided from the State of Michigan (SOM) chilling plant. Thereafter LBWL would like the flexibility to provide further cooling requirements from a new station at the Ottawa Street power plant. It would also be desirable to be able to supply all of the cooling needs from the Ottawa Street plant if required.

While this flexibility is very desirable, there will be additional cost in the sizing of the main pipelines. To facilitate a thorough comparison of alternatives and clearly outline relative costs of alternatives, optimum designs were developed that show the minimum cost for supply of cooling from the SOM chiller or the future Ottawa Street chillers only, as well as a system design that permits supply from either chiller plant location.

7.2 Construction Costs

Costs for installed pipe were obtained from LDB and have been inflated by 4.5%/a from 1990 to 1992 prices. These values are listed in Table 10a.

7.3 Analytical Approach

For all analyses a spreadsheet model was developed using Quattro Pro, version 4.0. Using the Darcy-Weisbach formula and Darcy-Weisbach friction factor of 0.015 for cases with no FRAs and 0.0045 for cases using FRAs, theoretical pipe sizes were calculated and then progressively refined by applying specified velocity limits and a pressure gradient of 5 ft/100 ft. Nominal pipe sizes were selected that met the stated design constraints. For the selected pipe size, Reynolds Numbers were calculated so as to determine whether fully developed turbulent flow exists at the design condition. This was done because friction reducing additives (FRAs) are only effective in the turbulent flow regime. FRAs reduce friction by suppressing turbulence.

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7.4 Operational Alternatives: Main Line

In the district cooling system proposed by LDB, the main chilled water line was assumed to be of constant diameter so that chilled water could be supplied from either end of the system. Normally, if water were to be supplied from one end of the system, lines would become progressively smaller as flows diminished as distance from the chiller plant increased and as fewer buildings remained to be served.

To provide a full understanding of the system possibilities, the fourteen cases or **technology options** were evaluated for each of the following **operating alternatives**:

- A1. **A constant pipe diameter of 30 in** that was sized for a conventional system supplied from the SOM chiller. This is the reference case as outlined in specifications obtained from LDB.
- A2. **A constant pipe diameter** was sized for each of the conventional system, low temperature and ice-slurry technology alternatives with supply from the SOM chiller; 28in.for conventional, 26in.for low temperature, 18 in for ice slurry;
- B. **Supply from the State of Michigan chiller only with tapered piping** so as to minimize distribution system costs;
- C. **Supply from the proposed Ottawa Street chiller only with tapered piping** so as to minimize distribution system costs;
- D. A minimum pipe size option whereby **each chiller plant could supply a portion of the capacity** from each location such that pipe sizes are minimized. This alternative might not be realistic, but is included to demonstrate the extent to which pipe sizes and costs can be reduced;
- E1. A combination of B and C whereby pipes are **tapered but sized for a conventional system** such that chilling could be provided from either location while still respecting velocity and pressure drop gradient limits. This option is an optimization of the reference system outlined in the original report. The pipe sizes are not reduced for the novel technologies and only pumping costs are amended;

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- E2. Pipes are tapered and sized for conventional, low temperature and ice-slurry systems such that chilling can be provided from either location as in E1;
- F1. A case similar to A where constant 30in.diameters are maintained throughout the system but chilling is provided from the Ottawa Street plant. This case has been included to evaluate the adequacy of the reference design if chilling is provided from the Ottawa Street plant;
- F2. Main line pipe diameters are held constant at 34in.and chilling is supplied from the Ottawa Street plant. The design respects the original design philosophy of the constant diameter main line but increases the diameter so that velocity and pressure gradient limits are respected if only the Ottawa Street plant is used.

A summary of total distribution costs and pipe dimensions for these cases is shown in Appendix 3.

8.0 Storage

8.1 Central and Distributed

The purpose of all storage systems is to reduce the peak demand on production plants by averaging the cooling demand of the system (over a 24 h period) and sizing production plants to meet that average load. The average load for this system was 63.1% of peak or 11580 RT.

Central storage refers to storage tank(s) located near the production plants. One tank is usually sufficient; however, for very large systems several tanks may be required. Distributed storage has numerous storage tanks at or near each load. While both systems reduce the peak load, distributed storage has the added advantage of requiring smaller distribution piping to meet average load capacities rather than peak load capacities. However, the added cost of a distributed storage system over a central storage system may offset any savings in piping costs. Also, any space savings that a customer would gain by connecting to the system could be lost due to the space requirements of the storage tank.

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Central storage was investigated for all production plant arrangements while distributed storage was examined for low temperature chiller systems only. The variable enthalpy of the media generated by an ice slurry system would make distributed storage impractical as storage tanks would need to accommodate ice slurry as well as 42°F water during the same cooling day. The other main disadvantage of using distributed storage with ice slurry production is that during low load conditions there exists the possibility of return water reaching 32°F thus eliminating the advantage of smaller piping in the return system. Central storage systems appear to be less expensive than distributed systems.

The size of the larger central tanks is to include a 3.0 ft thermocline (mixing of supply and return water), a 1.5 ft space at the top, and a 2% increase due to energy losses. Storage tank manufacturers suggested a height of 48 ft for large tanks, that is, those in the range from 500,000 U.S. gal. to 10,000,000 U.S. gal. Thus, in this study, tanks were sized to meet the storage demand plus a percentage increase to accommodate the above criteria. Smaller distributed storage tanks were oversized by 12%.

8.2 Storage Tank Costs

The cost of large storage tanks, 500,000 to 10,000,000 U.S. gal., was based on data from CBI-Horton Industries and included the cost of material, foundation, paint, insulation and internal piping. Figure 17 shows the cost of such tanks. The cost of smaller tanks, 10,000 to 50,000 U.S. gal., were based on data from CANBAR, Waterloo, Ontario and are shown in Fig. 18. Smaller tank costs include material and labour to erect these tanks at a rate of \$25/h. The individual cost of tanks for the various operational scenarios is shown in Table 11b. Overall costs for central storage are shown in Figure 11c.

9.0 Sensitivity Analysis

A sensitivity analysis was carried out to look at the impact of larger piping costs on the various technology options and operational alternatives.

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10.0 Analysis

10.1 Cost Summaries

All costs using LDB's original design limits are summarized in Tables 4a to 4e (current piping costs) for all operational alternatives and production options. Tables 5a to 5e and 7a to 7e summarize all costs using the optimum velocities with Tables 7a to 7e using upper limit piping costs. Tables 6a to 6b and 8a to 8b (upper limit piping costs) summarize all costs using the same optimum velocities but with a break even cost for ice slurry chillers, that is, the cost of the ice slurry chillers when used in conjunction with central storage that would yield a total cost equal to the least cost option of operational alternative A1 (conventional with storage) for both current piping and upper limit piping costs respectively. The costs of the chillers are \$2003/RT and \$2061/RT respectively for these break even cases. Conventional and low temperature chiller option costs are not affected by these break even costs for ice chillers.

Cost analyses were graphically depicted for operational alternative E2 and are shown in Fig. 19a to 19b. These graphs illustrate the magnitude of each cost component and the effect of each technology for the selected alternative.

The upper limit piping costs are estimated from Figure 21 and are shown in Table 10b.

10.2 Principal Alternatives

A primary screening of all the various options using cost and system flexibility as criteria yielded four operational alternatives to be analyzed in more detail. These four alternatives are:

- A1 Reference alternative; a constant diameter main line of 30in. supplying 42°F water (reference case), low temperature water and ice slurry from the SOM plant;
- A2 A constant diameter main line sized for each of the three technologies from the SOM plant;
- B Tapered piping from the SOM plant sized for the various technologies;

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E2 Tapered piping for all three technologies with the provision that a plant can be located at the SOM plant or the Ottawa Street site.

A cost summary of these four alternatives is shown in Appendix 4 in order to make the following observations easier to visualize.

10.3 General Observations

An analysis of Fig. 19a to 19b clearly shows that the dominant costs are chiller capital costs and energy costs (chiller and pumping energy). Any savings in piping costs due to advanced technologies or optimized piping diameters are masked by small increases in any of these dominant factors. Although piping costs including installation are normally a significant portion of the overall costs, this particular system does not follow that trend.

Figure 21 illustrates relative costs in \$/ft. for distribution systems of different diameters in various cities. Factors that may vary these distribution costs are soil conditions, pipe location, local labour rates and the quantity of pipe purchased. The most cost effective option for each technology is combining that technology with central storage.

10.4 Analysis

A1: Conventional Technology - 30in.Pipe - Reference Case

This alternative yields an overall cost of \$4.20M, (reference case cost) 94% of which is production costs. The distribution costs are dominated by the main line piping cost (52% of distribution costs) due to the large diameter (30 in.) pipe used.

The use of FRAs reduces the pumping costs by \$17,253. However, as the initial pumping costs are already low due to the small pressure drops in the 30 in. line, the savings are negated by the cost of the FRA due to the amount needed for the volume in the 30 in. main line (\$36,658). In fact, the total cost is increased by about 0.5% using FRAs.

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The use of central storage reduces the production cost by about 28%, and overall costs by 22%. Distribution costs are not affected by the use of central storage. Addition of FRAs with central storage increases the overall cost to \$3.29M from \$3.27M due to the same reasons as stated above.

If the capital cost of the chillers increases relative to storage costs then central storage becomes more economically attractive.

This alternative would still permit operation from the Ottawa Street plant but with some violations on velocity and pressure drop limits.

A1: Low Temperature Technology - 30 in. Pipe

Overall costs increase by about 1.7% over the reference case cost due to the higher cost of the low temperature chillers. Only when central storage is used does the overall cost fall below the reference cost due to the lower production costs.

Distributed storage has no effect on piping costs in this case as a constant pipe diameter is used. Distributed storage overall costs are higher than central storage overall costs due to higher costs for storage.

A1: Ice Slurry Technology - 30 in. Pipe

Overall costs of \$5.34M using ice slurry technology are dominated by production costs of \$5.12M. Since there are no savings due to pipe reduction, this alternative with ice slurry is only cost effective when used in conjunction with storage. Using central storage, costs of \$3.8M are realized.

A2: Conventional Technology - Constant Diameter 28 in.

This alternative varied slightly from A1 in that the optimum constant diameter calculated was 28 in. as compared with the 30 in. diameter used for A1. The smaller diameter resulted in lower main line piping costs. Overall costs were marginally down from the A1 alternative.

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A2: Low Temperature Technology - Constant Diameter 26 in.

Overall costs for low temperature technology with constant diameter dropped slightly from A1 due to the lower distribution costs. Only when central storage is introduced does overall costs fall significantly below that of the reference case.

Addition of FRAs again increases the overall cost slightly due to the large volume associated with a constant diameter pipe system nullifying pumping cost reductions.

Overall costs using distributed storage surpass central storage overall costs due to the higher costs of individual storage tanks which counteracts the reduction in piping costs. This alternative could become more economically attractive if the cost of piping and civil work increases dramatically relative to the cost of storage.

A2: Ice Slurry Technology - Constant Diameter 18 in.

Similar trends are seen in this alternative using an ice slurry system. Overall distribution costs are minimized for this operational alternative with values 25% below that of reference case distribution cost. This technology option becomes more economically viable when used in conjunction with central storage with overall costs of \$3.77M.

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B: Tapered Piping - All Technologies

Optimizing piping diameters from the SOM plant reduced the cost of piping for all the technologies but increased pumping costs due to higher pressure drops along the system which counteract these savings. Using conventional technology, overall costs are below the reference case by \$13,200/a, however these savings do not reflect the loss of flexibility that a tapered pipe system would create in terms of future expansion and plant location. The cost-saving effect of FRAs is completely nullified due to the cost of the FRA in the system using optimized velocities (larger diameter piping). As indicated in the other operational alternatives, the use of central storage minimizes overall costs. In the case of low temperature chillers the use of central storage reduces the overall yearly cost from \$4.26M, some \$60,000 over the overall cost for the reference case, to \$3.3M, \$0.9M below overall costs for the reference case.

Ice slurry options without storage generate high overall costs and, as in A1, do not approach the reference case cost. Ice slurry technology with central storage and FRAs yield the lowest overall cost for this alternative at \$3.76M.

E2: Tapered Piping from both Plant Locations: Conventional Technology

This alternative yielded nearly the same overall cost as the reference operational alternative option, while providing maximum flexibility for plant location and future expansion. Pressure drop and velocity limits are also maintained using this operational alternative from an Ottawa Street plant location. Using central storage an overall cost reduction of \$927,046/a (from reference case) was realized.

E2: Tapered Piping from both Plant Locations: Low Temperature Technology

Low temperature technology with central storage yielded overall costs that approached 79% of that of the reference case cost due primarily to reduction in production costs and lower pumping costs. FRA addition actually increased the overall cost due to the volume of the system.

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The higher storage tank costs outweighed the savings in piping that a distributed storage system would provide. However, if piping costs rise dramatically, this option may seem more attractive.

E2: Tapered Piping from both Plant Locations: Ice Slurry Technology

Of all the ice slurry options, central storage yielded the lowest overall cost of \$3.77M, \$432,276/a less than the reference case. The high cost of chillers masked the savings that this option would generate in distribution costs with respect to the reference case.

10.5 Sensitivity Analysis

In order for ice slurry technology to become a realistic option for cooling systems, the cost of these units would have to be reduced from the current values used in this study. A sensitivity analysis was carried out equating the overall costs of the reference case with storage (lowest overall cost) to an ice slurry system with central storage, and solving for a cost of ice slurry chillers. This break even cost between the reference case and ice slurry with central storage yielded a cost of \$460/RT. This cost would be the target cost for ice slurry manufacturers in order for this technology to be viable given other current costs in this study. A summary of this break even cost exercise is shown in Fig. 6a and 6b and its effect on the overall costs can be seen in Fig. 20a to 20b.

Another sensitivity analysis was performed using the upper limit of piping costs obtained from actual cooling projects. The sensitivity analysis was carried out using higher piping costs to examine the impact on all technology options. The analysis was used to generate another break even cost for ice slurry chillers using the same methodology as that used in the previous break even analysis. The costs for piping were selected from the upper limit of district cooling distribution costs, Fig. 21.

This analysis yields a (conventional with storage) cost (A1) of \$3.38M, a percentage increase of overall costs of 3.3% which includes about a 50% increase in piping costs. The new break even cost/RT for the ice slurry chillers is \$518 (Tables 8a and 8b). The new costs for all scenarios are shown in Tables 7a to 7e. This higher cost of piping would benefit any option or alternative that supported reduced piping costs.

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11.0 Recommendations

Owing to the uncertainty of the cost of ice slurry chillers and the particular circumstances at LBWL, it is recommended that conventional and low temperature chiller technology be the two major technology option considerations.

It is recommended that operational alternative E2 or E1 be selected regardless of the technology used. These options give the best flexibility for plant locations and still do not violate any of the velocity and pressure criteria. Secondly, it is recommended that a central storage system be integrated with the selected alternative. This is advocated for economic reasons and should prove even more beneficial should demand charges become an issue in the future. Storage reduces the installed capacity and may impact on costs with regard to floor space. The cost of reduced floor space needed for the chillers in the plant was not accounted for in our economic analysis.

If a decision to proceed with the cooling project is made, but the final choice for a production plant location and types of chillers remains undecided, then alternative E1 would be the most suitable. This alternative's distribution system would permit any of the technologies to be used as it is sized for water at 42°F.

Using the cost data in this study, conventional technology with central storage would be the least expensive technology option for each of the operational alternatives. Low temperature technology, however, has much lower distribution costs and when used in conjunction with central storage approaches costs using conventional technology with storage. Low temperature chillers as well as ice slurry chillers also impact on costs not included in the study. These include costs associated with internal building piping and installation, storage tank land requirements and storage tank size restrictions. These costs should be considered in any final decision process relating to production selection.

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If the low temperature option is selected and operational alternative E1 is used it may also be possible to delay the purchase of the more expensive chillers until the load reaches a certain condition. During the initial accumulative load connections conventional chillers only could be used up to a total of 6276 RT. At this stage the storage tank, sized for low temperature water, could be brought on line. This would satisfy loads up to 9910 RT while still using 42°F water. Low temperature chillers could then start coming on line gradually decreasing water temperature until the final load is met.

12.0 Impact of New Technologies on Other Systems

Advanced chillers generating either ice slurry or low temperature water are more expensive than conventional chillers and can only be justified by savings in the distribution system. The energy absorbed by low temperature water or ice slurry is two to eight times higher than that of water in conventional cooling systems and thus smaller pipes can be used and the cost of the distribution system significantly reduced. In fact, for the main distribution piping, where constant design velocities are maintained yearly piping costs can be reduced by 26%.

The proposed LBWL District Cooling System has characteristics which mitigate or lessen some of the advantages offered by new chiller technologies. Such characteristics include the low cost of piping which was determined to be as little as 30% of that used by other utilities; the low cost of the distribution system in proportion to the cost of the central chilling plant which resulted in savings in distributions system costs having less impact than might otherwise be the case.

In Lansing the annual cost for distribution, including capital and operating was typically less than 10% of the total annual production cost. For other systems investigated, distribution costs were between 30 and 40 percent of production costs. These higher percentage costs were attributed to two main factors; a higher cost for piping, including installation, and lower density networks where cooling loads were distributed over a larger area. These systems with higher distribution costs would derive greater benefit (smaller pipes) from the use of new chiller technology.

Furthermore, the desire of LBWL to allow the flexibility of cooling plant location at either end of the system required that they maintain larger diameter main pipelines. This provision offset the potential benefits of both

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low temperature water and ice slurries as well as friction reducing additives.

It should be noted that normally, the reduction in piping cost through a progressively reduced diameter or "tapered" distribution system design yields substantial savings. Capital costs are reduced while pumping costs increase, yet, there is typically a net savings. Because of the high cost of pumping using steam pumps, which was estimated as much as 5.5 times the cost of operating electrical pumps, and the low cost of piping, the analyses showed that there was an insignificant savings available by attempting to reduce pipe diameters and optimize the system design.

Friction reducing additives did not offer strong economic benefits in the study. This was because the optimized designs selected minimized the pumping cost by increasing the size of the pipes. Accordingly, the friction reducing additives did not yield the same benefits as a more typical system with higher operating velocities. The case (operational alternative B) where design velocities of 10 feet per second were used, a payback period of about three months was calculated; a savings of nearly \$60 K for an additive cost of about \$17 K. For the future, it should be noted that costs may be reduced to about 55% of current study costs at which time the additives should be considered for many applications.

In summary, the use of new technologies may offer greater benefits for systems where unit pipe costs or more extensive distribution systems represent a more significant portion of overall costs than is the case in Lansing.

13.0 Additional Benefits

Low temperature water or ice slurry also provide savings for the customer's facilities. Pipe and heat exchanger or cooling coil sizes can be reduced. Furthermore, where cooling is provided by circulating air, duct sizes can be reduced by as much as 50% by distributing low temperature air. This can reduce the building volume for a given floor space requirement.

For existing cooling systems, low temperature water and ice slurry can increase the capacity by as much as eight times for the same pumping energy. Thus, the use of new chillers may eliminate the need for distribution system upgrading or expansion.

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Load management or peak shaving through the use of storage is clearly important for both electrical load management as well as for the reduction of chiller capacity to the average demand from the peak demand. Storage also provides greater reliability for the system as short interruptions can be accommodated from storage. In communities where space is at a premium, the value of a reduced storage volume by low temperature water or ice slurry could be considerable.

Figures

Figure 1a

Figure 1b

Building Index

Buildin Numbe (1)	Building Name (2)	Address - (3)	Demand Load Tons (4)
SOM Allegan Corridor			
1	SOM Chiller	615 W. Allegan	5
2	Ottawa Towers	600 Ottawa	1600
3	Library/Museum	717 W. Allegan	800
4	Law Building	575 W. Ottawa	704
5	Transportation	425 W. Ottawa	710
6	Treasury	480 W. Allegan	642
7	Mason	110 S. Pine	694
8	Cass	320 S. Walnut	846
9	Ramp/Maintenance	200-300 S. Pine	300
10	Kalamazoo Building	500 Kalamazoo	1386
12	Judicial Building	100 S. Capitol	100
13	Farnum	100 E. Allegan	810
14	Civic Center	515 W. Allegan	2400
15	Federal Building	300 W. Allegan	160
16	Michigan National Tower	124 W. Allegan	686
17	Bauch	115 W. Allegan	110
18	Olds Plaza	111 S. Capitol	405
19	City Hall	180 W. Michigan	405
20	B W & L Main Building	123 W. Ottawa	272
21	Commerce	300 S. Capitol	800
22	Washington Square Building	100 S. Washington	250
Subtotal			14085
LCC/Washington Corridor			
51	District Cooling Plant (alternate)	Cedar Boiler RM.	-
52	LCC Voc. Tech.	419 N. Washington	340
53	LCC Arts and Science	419 N. Washington	445
54	Michigan Bell	221 N. Washington	650
55	1 Michigan Avenue	120 N. Washington	360
56	First of America	101 S. Washington	185
57	Atrium	215 S. Washington	180
58	Knapps Center	300 S. Washington	380
60	Town center	333 S. Capitol	120
61	AT&T	-	256
62	Victor Building	201 N. Washington	350
63	New Load	Kalamazoo & Washington	1000
Subtotal			4266
Total			18351

Figure 2

Lansing District Cooling System Cooling Load for Design Day

Figure 3

Lansing District Cooling System Cooling Load Duration Curve

Figure 4

Figure 5a: No Storage, Conventional

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 5b: Design Day, No Storage, Conventional

Figure 6a: No Storage, Conventional & Low Temperature

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 6b: Design Day, No Storage, Conventional & Low Temperature

Figure 7a: No Storage, Conventional , Low Temperature & Ice Slurry

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 7b: Design Day, No Storage, Conventional, Low Temperature & Ice Slurry

Lansing District Cooling System Cooling Load for Design Day

Figure 8

Figure 9a: Storage, Conventional

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 9b: Design Day, Storage, Conventional

Figure 10a: Storage, Conventional & Low Temperature

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 10b: Design Day, Storage, Conventional & Low Temperature

Figure 11a: Storage, Conventional, Low Temperature & Ice Slurry

Lansing District Cooling System Cooling Load for Design Day

Supply Temperature

Figure 11b: Design Day, Storage, Conventional, Low Temperature & Ice Slurry

FIGURE 13b

FIGURE 14b

FIGURE 15a

FIGURE 16b

Cost of Large Tanks

Figure 17

Cost of Small Tanks

Labour @ \$25/hr
Wood Floor

Figure 18

Summary of the Economic Analysis

Cost of ice Slurry Chiller: \$3143/RT - NO STORAGE

Figure 19a

Summary of the Economic Analysis

Cost of ice Slurry Chiller: \$3143/RT - STORAGE

Figure 19b

Summary of the Economic Analysis

Cost of ice Slurry Chiller: \$2003/RT - NO STORAGE

Figure 20a

Summary of the Economic Analysis

Cost of ice Slurry Chiller: \$2003/RT - STORAGE

Figure 20b

Pipe Cost for District Cooling System

Figure 21

Tables

TECHNOLOGY OPTIONS

- Case 1: Conventional
- Case 2: Conventional + FRA
- Case 3: Conventional + Central Storage
- Case 4: Conventional + FRA + Central Storage
- Case 5: Low Temperature
- Case 6: Low Temperature + FRA
- Case 7: Low Temperature + Central Storage
- Case 8: Low Temperature + Central Storage + FRA
- Case 9: Low Temperature + Distributed Storage
- Case 10: Low Temperature + Distributed Storage + FRA
- Case 11: Ice Slurry
- Case 12: Ice Slurry + FRA
- Case 13: Ice Slurry + Central Storage
- Case 14: Ice Slurry + FRA + Central Storage

Production Requirements

Diversified Peak Capacity:

16516 RT

Estimated MFR
through chillers

			Power (RT)	(% Peak)	Temperature In Out		(lbm/sec) Max.
Case 1-2	Variable Flow Constant Enthalpy No Storage	Conventional	16516	100	57	42	3676
		Low Temperature	0	0	-	-	-
		Ice Slurry	0	0	-	-	-
Case 3-4	Variable Flow Constant Enthalpy Storage	Conventional	10405	63	57	42	2316
		Low Temperature	0	0	-	-	-
		Ice Slurry	0	0	-	-	-
Case 5-6	Constant Flow Variable Enthalpy No Storage	Conventional	9910	60	57	42	2205
		Low Temperature	6606	40	42	32	2205
		Ice Slurry	0	0	-	-	-
Case 7-10	Variable Flow Constant Enthalpy Storage	Conventional	6258	38	57	42	1393
		Low Temperature	4172	25	42	32	1393
		Ice Slurry	0	0	-	-	-
Case 11-12	Constant Flow Variable Enthalpy No Storage	Conventional	4600	28	57	42	1024
		Low Temperature	3067	19	42	32	1024
		Ice Slurry	8834	53	38	20%	1024
Case 13-14	Constant Flow Variable Enthalpy Storage	Conventional	4624	28	57	42	1029
		Low Temperature	1156	7	42	32	386
		Ice Slurry	4624	28	38	20%	536

Table 1

COPs and Cooling Production Steam Rates

	Evaporator Temperature (oF)	COP	Steam Rate (lbs/hr/RT)
Conventional Chiller	42	5.8	9.5
Conventional Chiller	40	5.5	10.0
Low Temperature Chiller	32	4.6	12.0
Ice Slurry Chiller	27	4.2	13.1

Carnot Equation:

$$\text{COP}_{\text{cooling}} = \frac{\text{Temp (evap)}}{\text{Temp(cond)} - \text{Temp(evap)}}$$

Table 2

Annual Cooling Production and Steam Consumption

Production Alternative	Chiller	Cooling Production RT-hr*1000	Annual Steam Consumption lbs*1000000	Peak Steam Consumption (lbs/hr)
Conventional w/o storage	Plant	25200 (39470 incl free cooling)	239 (9.5 lbs/RT-hr)	156900
	Conv.	25200	239	156900
Low Temperature w/o storage	Plant	25200	244 (9.7 lbs/RT-hr)	173400
	Conv.	23250	221	94100
	Low Temp.	1950	23	79300
Ice Slurry w/o storage	Plant	25200	274 (10.9 lbs/RT-hr)	196300
	Conv.	13390	127	43900
	Low Temp.	6790	81	36900
	Ice Slurry	5020	66	115500
Conventional with storage	Plant	25200	239 (9.5 lbs/RT-hr)	99000
	Conv.	25200	239	99000
Low Temperature with storage	Plant	25200	262 (10.4 lbs/RT-hr)	109400
	Conv.	16170	154	59400
	Low Temp.	9030	108	50000
Ice Slurry with storage	Plant	25200	279 (11.1 lbs/RT-hr)	118700
	Conv.	13430	127	43900
	Low Temp.	2640	32	12900
	Ice Slurry	9130	120	61900

Based on data given in the LDB report for a centrifugal chiller

Table 3

Summary of Costs for Lansing System - Max Velocity of 10 ft/sec

Peak Demand	18351 RT	Production Cost	COP	Period of Invest	20 years
Diversity Factor	0.9	Conv. Chiller:	1943 \$/ton	Interest Rate	7 %
Diversified Dem.	16516 RT	Low Temperature:	2043 \$/ton	Annuity	0.094
Perc. of Peak	0.631	Sunwell:	3143 \$/ton	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT			Steam Usage	10 lb/RT-hr

		Operational Alternatives									
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2	
Description	Categories										
1	Conventional	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
		Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
		Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
	Distributio	Piping-Main	123747	115554	78367	91586	62009	98322	98322	123747	140812
		Piping-Sec	90276	90276	90276	90276	90276	90276	90276	90276	90276
		Pumping	24644	24658	89057	96015	33799	53410	53410	43334	37102
		Total	238667	230488	257700	277877	186084	242008	242008	257357	268190
	Overall Total		4202428	4194249	4221461	4241638	4149845	4205769	4205769	4221118	4231951
2	Conventional+ FRA	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
		Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
		Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
	Distributio	Piping-Main	123747	115554	78367	91586	62009	98322	98322	123747	140812
		Piping-Sec	90276	90276	90276	90276	90276	90276	90276	90276	90276
		Pumping	7391	7396	26717	28805	10140	16017	16017	12993	11124
		Cost of FRA	36658	32395	16729	22709	10450	25753	25802	36658	46172
		Total	258072	245621	212089	233376	172875	230368	230417	263674	288384
Overall Total		4221833	4209382	4175850	4197137	4136635	4194129	4194177	4227435	4252145	
3	Conventional+ Central Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
		Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
		Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992
	Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660
	Distributio	Piping-Main	123747	115554	78367	91586	62009	98322	98322	123747	140812
		Piping-Sec	90276	90276	90276	90276	90276	90276	90276	90276	90276
		Pumping	24644	24658	89057	96015	33799	53410	53410	43334	37102
		Total	238667	230488	257700	277877	186084	242008	242008	257357	268190
Overall Total		3272318	3264140	3291352	3311529	3219736	3275660	3275660	3291008	3301841	

Table 4a

2 of 2

		Operational Alternatives												
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2				
Description	Categories													
4	Conventional + FRA + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0		
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516		
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337		
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	931655		
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992		
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660		
		Distributio	Piping-Main	123747	115554	78367	91586	62009	98322	98322	123747	140812		
			Piping-Sec	90276	90276	90276	90276	90276	90276	90276	90276	90276		
			Pumping	7391	7396	26717	28805	10140	16017	16017	12993	11124		
			Cost of FRA	36658	32395	16729	22709	10450	25753	25802	36658	46172		
			Total	258072	245621	212089	233376	172875	230368	230417	263674	288384		
			Overall Total	3291723	3279273	3245741	3267028	3206526	3264019	3264068	3297325	3322036		
5	Low Temperature	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0		
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516		
		Production	Capital	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466		
			Energy	953120	953120	953120	953120	953120	953120	953120	953120	953120		
			Total	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586		
		Distributio	Piping-Main	123747	92317	66589	74595	53781	98322	78951	123747	140812		
			Piping-Sec	90276	82793	82793	82793	82793	90276	82793	90276	90276		
			Pumping	17060	55924	167238	215379	68938	36978	110075	30002	25688		
			Total	231083	231034	316620	372767	205512	225576	271819	244025	256776		
			Overall Total	4275669	4275620	4361206	4417353	4250098	4270162	4316405	4288611	4301362		
		6	Low Temperature + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
					Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
Production	Capital			3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466		
	Energy			953120	953120	953120	953120	953120	953120	953120	953120	953120		
	Total			4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586		
Distributio	Piping-Main			123747	92317	66589	74595	53781	98322	78951	123747	140812		
	Piping-Sec			90276	82793	82793	82793	82793	90276	82793	90276	90276		
	Pumping			5106	16777	50171	64603	20677	11107	33014	9018	7724		
	Cost of FRA			36658	20452	11159	14243	7122	16678	25008	36658	46172		
	Total			255787	212339	210712	236234	164373	216383	219766	259699	284984		
	Overall Total			4300373	4256925	4255298	4280820	4208959	4260969	4264352	4304285	4329570		

Table 4b

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
7	Low Temperature + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio	Piping-Main	123747	92317	66589	74595	53781	98322	78951	123747	140812
			Piping-Sec	90276	82793	82793	82793	82793	90276	82793	90276	90276
			Pumping	6324	20729	61989	79834	25553	13706	40801	11121	9522
			Total	220347	195839	211371	237222	162127	202304	202545	225144	240610
	Overall Total	3320790	3296282	3311814	3337665	3262570	3302747	3302988	3325587	3341053		
8	Low Temperature + Central Storage + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio	Piping-Main	123747	92317	66589	74595	53781	98322	78951	123747	140812
			Piping-Sec	90276	82793	82793	82793	82793	90276	82793	90276	90276
			Pumping	1893	6219	18597	23946	7664	4117	12237	3343	2863
			Cost of FRA	36658	20452	11159	14243	7122	16678	25008	36658	46172
	Total	252573	201781	179137	195577	151361	209394	198989	254024	280123		
	Overall Total	3353017	3302224	3279581	3296020	3251804	3309837	3299433	3354467	3380567		
9	Low Temperature + Distributed Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847	236847	236847	236847	236847	236847
		Distributio	Piping-Main	123747	77951	58612	64766	49599	98322	68108	123747	140812
			Piping-Sec	90276	78987	78987	78987	78987	90276	78987	90276	90276
			Pumping	1585	14204	38536	49558	13509	3444	26642	2795	2393
			Total	215608	171142	176135	193311	142095	192042	173737	216818	233481
	Overall Total	3420919	3376453	3381446	3398622	3347406	3397353	3379048	3422129	3438792		

Table 4c

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
10 Low Temperature + Distributed Storage + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0	
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516	
	Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	
	Storage		236847	236847	236847	236847	236847	236847	236847	236847	236847	
	Distributio	Piping-Main	123747	77951	58612	64766	49599	98322	68108	123747	140812	
		Piping-Sec	90276	78987	78987	78987	78987	90276	78987	90276	90276	
		Pumping	478	4261	11561	14868	4053	1030	7991	834	714	
		Cost of FRA	36658	13956	7811	9889	5374	12309	15385	36658	46172	
		Total	251159	175155	156971	168510	138013	201937	170471	251515	277974	
		Overall Total	3456469	3380466	3362281	3373821	3343324	3407248	3375781	3456825	3483285	
11 Ice Slurry	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0	
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516	
	Production	Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	
	Distributio	Piping-Main	123747	71104	54196	58718	48147	98322	61215	123747	140812	
		Piping-Sec	90276	76678	76678	76678	76678	90276	76678	90276	90276	
		Pumping	2711	43899	125456	170648	29758	5908	84202	4795	4106	
		Total	216734	191681	256330	306044	154583	194506	222095	218818	235194	
		Overall Total	5339276	5314223	5378872	5428586	5277125	5317048	5344637	5341360	5357736	
	12 Ice Slurry + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
Production		Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	
Distributio		Piping-Main	123747	71104	54196	58718	48147	98322	61215	123747	140812	
		Piping-Sec	90276	76678	76678	76678	76678	90276	76678	90276	90276	
		Pumping	1777	28534	81547	110921	19342	3832	54731	3107	2659	
		Cost of FRA	19933	6502	4048	4735	3313	6589	15215	19933	24690	
		Total	235733	182818	216469	251052	147480	199019	207839	237063	258437	
		Overall Total	5358275	5305360	5339011	5373594	5270023	5321562	5330381	5359605	5380980	

Table 4d

		Operational Alternatives									
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2	
Description	Categories										
13 Ice Slurry + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
	Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
	Distributio	Piping-Main	123747	71104	54196	58718	48147	98322	61215	123747	140812
		Piping-Sec	90276	76678	76678	76678	76678	90276	76678	90276	90276
		Pumping	2711	43899	125456	170648	29758	5908	84202	4795	4106
		Total	216734	191681	256330	306044	154583	194506	222095	218818	235194
	Overall Total		3804898	3779845	3844494	3894208	3742747	3782670	3810259	3806982	3823358

14 Ice Slurry + FRA + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
	Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
	Distributio	Piping-Main	123747	71104	54196	58718	48147	98322	61215	123747	140812
		Piping-Sec	90276	76678	76678	76678	76678	90276	76678	90276	90276
		Pumping	1777	28534	81547	110921	19342	3832	54731	3107	2659
		Cost of FRA	19933	6502	4048	4735	3313	6589	15215	19933	24690
	Total	235733	182818	216469	251052	147480	199019	207839	237063	258437	
	Overall Total		3823897	3770981	3804632	3839215	3735644	3787183	3796002	3825227	3846601

Table 4e

Summary of Costs for Lansing System - Optimization of Velocity

Peak Demand	18351 RT	Production Cost	COP	Period of Invest	20 years
Diversity Factor	0.9	Conv. Chiller:	1943 \$/ton	Interest Rate	7 %
Diversified Dem.	16516 RT	Low Temperature:	2043 \$/ton	Annuity	0.094
Perc. of Peak	0.631	Sunwell:	3143 \$/ton	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT			Steam Usage	10 lb/RT-hr

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
1	Conventional	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	24644	24658	33132	40518	15356	53410	24227	43334	37102
			Total	238667	230488	225466	248341	181990	242008	241731	257357	268190
			Overall Total	4202428	4194249	4189227	4212102	4145751	4205769	4205492	4221118	4231951
2	Conventional + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	7391	7396	9939	12170	4606	16017	7267	12993	11124
			Cost of FRA	36658	32395	26611	34581	15065	25753	39817	36658	46172
			Total	258072	245621	228884	254574	186305	230368	264588	263674	288384
			Overall Total	4221833	4209382	4192645	4218335	4150066	4194129	4228349	4227435	4252145
3	Conventional + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	24644	24658	33132	40518	15356	53410	24227	43334	37102
			Total	238667	230488	225466	248341	181990	242008	241731	257357	268190
			Overall Total	3272318	3264140	3259118	3281992	3215642	3275660	3275382	3291008	3301841

Table 5a

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
4	Conventional + FRA + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa		0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	7391	7396	9939	12170	4606	16017	7267	12993	11124
			Cost of FRA	36658	32395	26611	34581	15065	25753	39817	36658	46172
			Total	258072	245621	228884	254574	186305	230368	264588	263674	288384
		Overall Total		3291723	3279273	3262536	3288225	3219957	3264019	3298240	3297325	3322036

5	Low Temperature	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa		0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466
			Energy	953120	953120	953120	953120	953120	953120	953120	953120	953120
			Total	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586
		Distributio	Piping-Main	123747	107584	92516	108586	67913	98322	117615	123747	140812
			Piping-Sec	90276	82793	90110	90110	90110	90276	90110	90276	90276
			Pumping	17060	39931	35358	39265	15970	36978	24371	30002	25688
			Total	231083	230308	217984	237961	173993	225576	232096	244025	256776
		Overall Total		4275669	4274894	4262570	4282547	4218579	4270162	4276682	4288611	4301362

6	Low Temperature + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa		0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466
			Energy	953120	953120	953120	953120	953120	953120	953120	953120	953120
			Total	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586
		Distributio	Piping-Main	123747	107584	92516	108586	67913	98322	117615	123747	140812
			Piping-Sec	90276	82793	90110	90110	90110	90276	90110	90276	90276
			Pumping	5106	11970	10598	11769	4787	11107	7302	9018	7724
			Cost of FRA	36658	27588	23919	31880	13376	16678	39299	36658	46172
			Total	255787	229935	217143	242345	176186	216383	254326	259699	284984
		Overall Total		4300373	4274521	4261729	4286931	4220772	4260969	4298912	4304285	4329570

Table 5b

System	Description	Cost Categories	Operational Alternatives								
			A1	A2	B	C	D	E1	E2	F1	F2
7	Low Temperature+ Central Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage	131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio Piping-Main	123747	107584	92516	108586	67913	98322	117615	123747	140812
		Piping-Sec	90276	82793	90110	90110	90110	90276	90110	90276	90276
		Pumping	6324	14801	13106	14554	5920	13706	9034	11121	9522
		Total	220347	205178	195732	213250	163943	202304	216759	225144	240610
		Overall Total	3320790	3305621	3296175	3313693	3264386	3302747	3317202	3325587	3341053
8	Low Temperature+ Central Storage+ FRA	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage	131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio Piping-Main	123747	107584	92516	108586	67913	98322	117615	123747	140812
		Piping-Sec	90276	82793	90110	90110	90110	90276	90110	90276	90276
		Pumping	1893	4437	3929	4362	1774	4117	2707	3343	2863
		Cost of FRA	36658	27588	23919	31880	13376	16678	39299	36658	46172
		Total	252573	222402	210474	234938	173173	209394	249731	254024	280123
		Overall Total	3353017	3322845	3310917	3335381	3273616	3309837	3350174	3354467	3380567
9	Low Temperature+ Distributed Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage	236847	236847	236847	236847	236847	236847	236847	236847	236847
		Distributio Piping-Main	123747	85024	76331	87537	57959	98322	94273	123747	140812
		Piping-Sec	90276	78987	83418	83418	83418	90276	83418	90276	90276
		Pumping	1585	10471	8767	10381	4154	3444	6240	2795	2393
		Total	215608	174482	168516	181336	145531	192042	183931	216818	233481
		Overall Total	3420919	3379793	3373827	3386647	3350842	3397353	3389242	3422129	3438792

Table 5c

System	Description	Cost Categories	Operational Alternatives								
			A1	A2	B	C	D	E1	E2	F1	F2
10	Low Temperature + Distributed Storage + FRA	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage	236847	236847	236847	236847	236847	236847	236847	236847	236847
		Distributio Piping-Main	123747	85024	76331	87537	57959	98322	94273	123747	140812
		Piping-Sec	90276	78987	83418	83418	83418	90276	83418	90276	90276
		Pumping	478	3138	2631	3115	1247	1030	1873	834	714
		Cost of FRA	36658	16781	15477	20303	8713	12309	35574	36658	46172
		Total	251159	183930	177857	194373	151337	201937	215138	251515	277974
		Overall Total	3456469	3389240	3383168	3399683	3356648	3407248	3420449	3456825	3483285
11	Ice Slurry	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542
		Distributio Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
		Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
		Pumping	2711	24361	30195	35294	11741	5908	20345	4795	4106
		Total	216734	178990	177429	191386	144899	194506	181988	218818	235194
		Overall Total	5339276	5301532	5299971	5313928	5267441	5317048	5304530	5341360	5357736
12	Ice Slurry + FRA	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542
		Distributio Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
		Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
		Pumping	1777	15835	20463	22931	7631	3832	13223	3107	2659
		Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
		Total	235733	178229	174607	187643	145311	199019	209952	237063	258437
		Overall Total	5358275	5300772	5297150	5310186	5267854	5321562	5332494	5359605	5380980

Table 5d

System	Description	Cost Categories	Operational Alternatives								
			A1	A2	B	C	D	E1	E2	F1	F2
13	Ice Slurry + Central Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
		Storage	52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
		Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
		Pumping	2711	24361	30195	35294	11741	5908	20345	4795	4106
		Total	216734	178990	177429	191386	144899	194506	181988	218818	235194
		Overall Total	3804898	3767154	3765593	3779550	3733063	3782670	3770152	3806982	3823358
14	Ice Slurry + FRA + Central Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
		Storage	52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
		Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
		Pumping	1777	15835	20463	22931	7631	3832	13223	3107	2659
		Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
		Total	235733	178229	174607	187643	145311	199019	209952	237063	258437
		Overall Total	3823897	3766393	3762771	3775807	3733475	3787183	3798116	3825227	3846601

Table 5e

Summary of Costs for Lansing System - Optimization of Velocity

Peak Demand	18351 RT	Production Cost	COP	Period of Invest	20 years
Diversity Factor	0.9	Conv. Chiller:	1943 \$/ton	Interest Rate	7 %
Diversified Dem.	16516 RT	Low Temperature	2043 \$/ton	Annuity	0.09439
Perc. of Peak	0.631	Sunwell:	2003 \$/ton	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT			Steam Usage	10 lb/RT-hr

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
1	Conventional	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	24644	24658	33132	40518	15356	53410	24227	43334	37102
			Total	238667	230488	225466	248341	181990	242008	241731	257357	268190
			Overall Total	4202428	4194249	4189227	4212102	4145751	4205769	4205492	4221118	4231951
3	Conventional + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660
		Distributio	Piping-Main	123747	115554	96985	112474	71285	98322	122155	123747	140812
			Piping-Sec	90276	90276	95349	95349	95349	90276	95349	90276	90276
			Pumping	24644	24658	33132	40518	15356	53410	24227	43334	37102
			Total	238667	230488	225466	248341	181990	242008	241731	257357	268190
			Overall Total	3272318	3264140	3259118	3281992	3215642	3275660	3275382	3291008	3301841
11	Ice Slurry	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3107913	3107913	3107913	3107913	3107913	3107913	3107913	3107913	3107913
			Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
			Total	4180215	4180215	4180215	4180215	4180215	4180215	4180215	4180215	4180215
		Distributio	Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
			Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
			Pumping	2711	24361	30195	35294	11741	5908	20345	4795	4106
			Total	216734	178990	177429	191386	144899	194506	181988	218818	235194
			Overall Total	4396949	4359205	4357644	4371601	4325114	4374721	4362203	4399033	4415409

Table 6a

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
12	Ice Slurry + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3107913	3107913	3107913	3107913	3107913	3107913	3107913	3107913	3107913
			Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
			Total	4180215	4180215	4180215	4180215	4180215	4180215	4180215	4180215	4180215
		Distributio	Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
			Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
			Pumping	1777	15835	20463	22931	7631	3832	13223	3107	2659
			Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
			Total	235733	178229	174607	187643	145311	199019	209952	237063	258437
		Overall Total		4415948	4358445	4354822	4367858	4325526	4379234	4390167	4417278	4438652
13	Ice Slurry + Central Storage		SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1945235	1945235	1945235	1945235	1945235	1945235	1945235	1945235	1945235
			Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
			Total	3037363	3037363	3037363	3037363	3037363	3037363	3037363	3037363	3037363
		Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio	Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
			Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
			Pumping	2711	24361	30195	35294	11741	5908	20345	4795	4106
			Total	216734	178990	177429	191386	144899	194506	181988	218818	235194
		Overall Total		3307064	3269320	3267759	3281716	3235229	3284836	3272318	3309148	3325524
14	Ice Slurry + FRA+ Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1945235	1945235	1945235	1945235	1945235	1945235	1945235	1945235	1945235
			Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
			Total	3037363	3037363	3037363	3037363	3037363	3037363	3037363	3037363	3037363
		Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio	Piping-Main	123747	77951	68488	77346	54412	98322	82897	123747	140812
			Piping-Sec	90276	76678	78746	78746	78746	90276	78746	90276	90276
			Pumping	1777	15835	20463	22931	7631	3832	13223	3107	2659
			Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
			Total	235733	178229	174607	187643	145311	199019	209952	237063	258437
Overall Total		3326063	3268560	3264938	3277974	3235642	3289350	3300282	3327393	3348768		

Table 6b

Summary of Costs for Lansing System-Upper Limit Piping Costs

Peak Demand	18351 RT	Production Cost	COP	Period of Invest	20 years
Diversity Factor	0.9	Conv.Chiller:	1943 \$/ton 5.84	Interest Rate	7 %
Diversified Dem.	16516 RT	Low Temperature:	2043 \$/ton 4.64	Annuity	0.094
Perc. of Peak	0.631	Sunwell:	3143 \$/ton 4.20	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT			Steam Usage	10 lb/RT-hr

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
1	Conventional	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
		Distributio	Piping-Main	184768	174355	145718	165683	109914	148519	177751	184768	205588
			Piping-Sec	139179	139179	147211	147211	147211	139179	147211	139179	139179
			Pumping	24644	24658	33132	40490	15356	53410	24227	43334	37102
			Total	348591	338192	326061	353384	272481	341108	349189	367281	381869
			Overall Total	4312352	4301953	4289822	4317145	4236242	4304869	4312950	4331042	4345630
2	Conventional + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761
		Distributio	Piping-Main	184768	174355	145718	165683	109914	148519	177751	184768	205588
			Piping-Sec	139179	139179	147211	147211	147211	139179	147211	139179	139179
			Pumping	7391	7396	9939	12146	4606	16017	7267	12993	11124
			Cost of FRA	36658	32395	26611	34581	15065	25753	39817	36658	46172
			Total	367996	353325	329479	359621	276796	329468	372046	373598	402063
	Overall Total	4331757	4317086	4293240	4323382	4240557	4293229	4335807	4337359	4365824		
3	Conventional + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660
		Distributio	Piping-Main	184768	174355	145718	165683	109914	148519	177751	184768	205588
			Piping-Sec	139179	139179	147211	147211	147211	139179	147211	139179	139179
			Pumping	24644	24658	33132	40490	15356	53410	24227	43334	37102
			Total	348591	338192	326061	353384	272481	341108	349189	367281	381869
	Overall Total	3382242	3371844	3359713	3387035	3306133	3374760	3382840	3400932	3415520		

Table 7a

		Operational Alternatives												
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2				
Description	Categories													
4	Conventional + FRA+ Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0		
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516		
		Production	Capital	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337		
			Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655		
			Total	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992		
		Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660		
		Distributio	Piping-Main	184768	174355	145718	165683	1099' 4	148519	177751	184768	205588		
			Piping-Sec	139179	139179	147211	147211	1472.1	139179	147211	139179	139179		
			Pumping	7391	7396	9939	12146	4606	16017	7267	12993	11124		
			Cost of FRA	36658	32395	26611	34581	15065	25753	39817	36658	46172		
			Total	367996	353325	329479	359621	276796	329468	372046	373598	402063		
		Overall Total		3401647	3386977	3363131	3393272	3310448	3363119	3405698	3407249	3435715		
5	Low Temperature	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0		
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516		
		Production	Capital	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466		
			Energy	953120	953120	953120	953120	953120	953120	953120	953120	953120		
			Total	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586		
		Distributio	Piping-Main	184768	163947	139753	160964	104669	148519	172414	184768	205588		
			Piping-Sec	139179	126220	138345	138345	138345	139179	138345	139179	139179		
			Pumping	17060	39931	35358	39265	15970	36978	24371	30002	25688		
			Total	341007	330098	313456	338574	258984	324676	335130	353949	370455		
		Overall Total		4385593	4374684	4358042	4383160	4303570	4369262	4379716	4398535	4415041		
		6	Low Temperature + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
					Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
Production	Capital			3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466	3091466		
	Energy			953120	953120	953120	953120	953120	953120	953120	953120	953120		
	Total			4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586	4044586		
Distributio	Piping-Main			184768	163947	139753	160964	104669	148519	172414	184768	205588		
	Piping-Sec			139179	126220	138345	138345	138345	139179	138345	139179	139179		
	Pumping			5106	11970	10598	11769	4787	11107	7302	9018	7724		
	Cost of FRA			36658	27588	23919	31880	13376	16678	39299	36658	46172		
	Total			365711	329725	312615	342958	261177	315483	357360	369623	398663		
Overall Total				4410297	4374311	4357201	4387544	4305763	4360069	4401946	4414209	4443249		

Table 7b

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
7	Low Temperature+ Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio	Piping-Main	184768	163947	139753	160964	104669	148519	172414	184768	205588
			Piping-Sec	139179	126220	138345	138345	138345	139179	138345	139179	139179
			Pumping	6324	14801	13106	14554	5920	13706	9034	11121	9522
			Total	330271	304968	291204	313863	248934	301404	319793	335068	354289
		Overall Total		3430714	3405411	3391647	3414306	3349377	3401847	3420236	3435511	3454732

8	Low Temperature+ Central Storage+ FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980	131980	131980	131980	131980	131980
		Distributio	Piping-Main	184768	163947	139753	160964	104669	148519	172414	184768	205588
			Piping-Sec	139179	126220	138345	138345	138345	139179	138345	139179	139179
			Pumping	1893	4437	3929	4362	1774	4117	2707	3343	2863
			Cost of FRA	36658	27588	23919	31880	13376	16678	39299	36658	46172
			Total	362497	322192	305946	335551	258164	308494	352765	363948	393802
Overall Total		3462941	3422635	3406389	3435994	3358607	3408937	3453208	3464391	3494246		

9	Low Temperature+ Distributed Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847	236847	236847	236847	236847	236847
		Distributio	Piping-Main	184768	132713	117376	133317	89398	148519	142598	184768	205588
			Piping-Sec	139179	119602	127088	127088	127088	139179	127088	139179	139179
			Pumping	1585	10471	8767	10381	4154	3444	6240	2795	2393
			Total	325532	262786	253231	270786	220640	291142	275926	326742	347160
		Overall Total		3530843	3468097	3458542	3476097	3425951	3496453	3481237	3532053	3552471

Table 7c

		Operational Alternatives									
System	Cost		A1	A2	B	C	D	E1	E2	F1	F2
Description	Categories										
10 Low Temperature + Distributed Storage + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311	1947311
		Energy	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152	1021152
		Total	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464	2968464
	Storage		236847	236847	236847	236847	236847	236847	236847	236847	236847
	Distributio	Piping-Main	184768	132713	117376	133317	89398	148519	142598	184768	205588
		Piping-Sec	139179	119602	127088	127088	127088	139179	127088	139179	139179
		Pumping	478	3138	2631	3115	1247	1030	1873	834	714
		Cost of FRA	36658	16781	15477	20303	8713	12309	35574	36658	46172
		Total	361083	272234	262572	283823	226446	301037	307133	361439	391653
	Overall Total		3566393	3477544	3467883	3489133	3431757	3506348	3512444	3566749	3596964
11 Ice Slurry	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	2711	24361	30195	34925	11741	5908	20345	4795	4106
		Total	326658	262011	254956	272921	214422	293606	266387	328742	348873
	Overall Total		5449200	5384553	5377498	5395463	5336964	5416148	5388929	5451284	5471415
12 Ice Slurry + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241	4050241
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
		Total	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542	5122542
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	1777	15835	19627	22700	7631	3832	13223	3107	2659
		Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
		Total	345657	261250	251298	269316	214834	298119	294351	346987	372116
	Overall Total		5468199	5383793	5373841	5391859	5337377	5420662	5416893	5469529	5494659

Table 7d

		Operational Alternatives										
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2		
Description	Categories											
13	Ice Slurry + Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
			Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
			Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
		Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
			Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
			Pumping	2711	24361	30195	34925	11741	5908	20345	4795	4106
			Total	326658	262011	254956	272921	214422	293606	266387	328742	348873
		Overall Total		3914822	3850175	3843120	3861085	3802586	3881770	3854551	3916906	3937037

14	Ice Slurry + FRA + Central Storage	Capacity	SOM	16516	16516	16516	J	9267	16516	16516	0	0
			Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production	Capital	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068	2443068
			Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
			Total	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196	3535196
		Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
		Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
			Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
			Pumping	1777	15835	19627	22700	7631	3832	13223	3107	2659
			Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
			Total	345657	261250	251298	269316	214834	298119	294351	346987	372116
Overall Total		3933821	3849414	3839462	3857480	3802998	3886283	3882515	3935151	3960280		

Table 7e

Summary of Costs for Lansing System-Upper Limit Piping Costs

Peak Demand	18351 RT		Production Cost	COP	Period of Invest	20 years
Diversity Factor	0.9	Conv. Chiller:	1943 \$/ton	5.84	Interest Rate	7 %
Diversified Dem.	16516 RT	Low Temperature:	2043 \$/ton	4.64	Annuity	0.09439
Perc. of Peak	0.631	Sunwell:	2061 \$/ton	4.20	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT				Steam Usage	10 lb/RT-hr

		Operational Alternatives									
System	Cost	A1	A2	B	C	D	E1	E2	F1	F2	
Description	Categories										
1	Conventional	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106	3029106
		Energy	934655	934655	934655	934655	934655	934655	934655	934655	934655
	Total	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	3963761	
	Distributio	Piping-Main	184768	174355	145718	165683	109914	148519	177751	184768	205588
		Piping-Sec	139179	139179	147211	147211	147211	139179	147211	139179	139179
		Pumping	24644	24658	33132	40490	15356	53410	24227	43334	37102
		Total	348591	338192	326061	353384	272481	341108	349189	367281	381869
	Overall Total	4312352	4301953	4289822	4317145	4236242	4304869	4312950	4331042	4345630	
	3	Conventional+ Central Storage	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0
Ottawa			0	0	0	16516	7249	16516	16516	16516	16516
Production Capital			1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337	1908337
Energy			934655	934655	934655	934655	934655	934655	934655	934655	934655
Total		2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	2842992	
Storage		190660	190660	190660	190660	190660	190660	190660	190660	190660	
Distributio		Piping-Main	184768	174355	145718	165683	109914	148519	177751	184768	205588
		Piping-Sec	139179	139179	147211	147211	147211	139179	147211	139179	139179
		Pumping	24644	24658	33132	40490	15356	53410	24227	43334	37102
		Total	348591	338192	326061	353384	272481	341108	349189	367281	381869
Overall Total		3382242	3371844	3359713	3387035	3306133	3374760	3382840	3400932	3415520	
11	Ice Slurry	Capacity SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
		Production Capital	3156229	3156229	3156229	3156229	3156229	3156229	3156229	3156229	3156229
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
	Total	4228530	4228530	4228530	4228530	4228530	4228530	4228530	4228530	4228530	
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	2711	24361	30195	34925	11741	5908	20345	4795	4106
		Total	326658	262011	254956	272921	214422	293606	266387	328742	348873
	Overall Total	4555188	4490541	4483486	4501451	4442952	4522136	4494917	4557272	4577403	

Table 8a

Operational Alternatives

System	Cost	A1	A2	B	C	D	E1	E2	F1	F2	
Description	Categories										
12 Ice Slurry + FRA	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	3156229	3156229	3156229	3156229	3156229	3156229	3156229	3156229	3156229
		Energy	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302	1072302
		Total	4228530	4228530	4228530	4228530	4228530	4228530	4228530	4228530	4228530
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	1777	15835	19627	22700	7631	3832	13223	3107	2659
		Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
		Total	345657	261250	251298	269316	214834	298119	294351	346987	372116
		Overall Total	4574187	4489781	4479829	4497846	4443364	4526650	4522881	4575517	4600647

13 Ice Slurry+ Central Storage		SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	1970760	1970760	1970760	1970760	1970760	1970760	1970760	1970760	1970760
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3062888	3062888	3062888	3062888	3062888	3062888	3062888	3062888	3062888
	Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	2711	24361	30195	34925	11741	5908	20345	4795	4106
		Total	326658	262011	254956	272921	214422	293606	266387	328742	348873
		Overall Total	3442513	3377866	3370811	3388776	3330277	3409461	3382242	3444597	3464728

14 Ice Slurry+ FRA+ Central Storage	Capacity	SOM	16516	16516	16516	0	9267	16516	16516	0	0
		Ottawa	0	0	0	16516	7249	16516	16516	16516	16516
	Production	Capital	1970760	1970760	1970760	1970760	1970760	1970760	1970760	1970760	1970760
		Energy	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127	1092127
		Total	3062888	3062888	3062888	3062888	3062888	3062888	3062888	3062888	3062888
	Storage		52968	52968	52968	52968	52968	52968	52968	52968	52968
	Distributio	Piping-Main	184768	122300	105890	119125	83810	148519	127171	184768	205588
		Piping-Sec	139179	115350	118871	118871	118871	139179	118871	139179	139179
		Pumping	1777	15835	19627	22700	7631	3832	13223	3107	2659
		Cost of FRA	19933	7765	6910	8620	4522	6589	35086	19933	24690
		Total	345657	261250	251298	269316	214834	298119	294351	346987	372116
		Overall Total	3461512	3377106	3367154	3385172	3330690	3413975	3410206	3462842	3487972

Table 8b

Appendix 1

Capital Cost

Peak Demand	18351	RT	Production Cost	
Diversity Factor	0.9		Conv. Chill:	1943 \$/ton
Diversified Dem.	16516	RT	Low Temp:	2043 \$/ton
Perc. of Peak	0.631		Sunwell:	3143 \$/ton
Average Demand	10422	RT		

		Power		Capital Cost	
		(RT)	(% Peak)	\$	
Case 1-2	Variable Flow Constant Enthalpy No Storage	Conventional	16516	100	32090394
		Low Temperature	0	0	0
		Ice Slurry	0	0	0
		Total			32090394
Case 3-4	Variable Flow Constant Enthalpy Storage	Conventional	10405	63	20216948
		Low Temperature	0	0	0
		Ice Slurry	0	0	0
		Total			20216948
Case 5-6	Variable Flow Constant Enthalpy No Storage	Conventional	9910	60	19254236
		Low Temperature	6606	40	13496793
		Ice Slurry	0	0	0
		Total			32751030
Case 7-10	Variable Flow Constant Enthalpy Storage	Conventional	6276	38	12194350
		Low Temperature	4129	25	8435496
		Ice Slurry	0	0	0
		Total			20629846
Case 11-12	Constant Flow Variable Enthalpy No Storage	Conventional	4624	28	8985310
		Low Temperature	3138	19	6410977
		Ice Slurry	8753	53	27512021
		Total			42908308
Case 13-14	Constant Flow Variable Enthalpy Storage	Conventional	4624	28	8985310
		Low Temperature	1156	7	2361939
		Ice Slurry	4624	28	14534653
		Total			25881902

Table 9

Pipe Cost - Based on data given by LDB

Costs are \$/ft (supply and return) and include all costs related to installation and burial.

Inflation Rate 4.5%/year

Diameter (in)	Cost (\$1990/ft)	Cost (\$1992/ft)
2	78	85
4	78	85
6	91	99
8	104	113
10	117	128
12	131	143
14	143	156
16	163	178
18	177	193
20	192	209
22	209	228
24	227	247
26	244	266
28	260	283
30	277	302
32	298	325
34	319	348
36	340	371
38	359	391
40	378	412

Formula used in the spreadsheets:

$$52.1617 + 5.2623 * \text{Diam} + 0.0600 * \text{Diam}^2 \quad (\$1990/\text{ft})$$

Table 10a

Pipe Cost - Based on upper limit costs

Costs are \$/ft (supply and return) and include all costs related to installation and burial.

Inflation Rate 4.5%/year

Diameter (in)	Cost (\$1990/ft)	Cost (\$1992/ft)
2	83	91
4	105	115
6	128	139
8	150	163
10	172	188
12	194	212
14	217	236
16	239	260
18	261	284
20	283	309
22	305	333
24	328	357
26	350	381
28	372	406
30	394	430
32	416	454
34	439	478
36	461	502
38	483	527
40	505	551

Formula used in the spreadsheets:

$11.10718 * \text{Diam} + 61.03322$	(\$1992/ft)
-------------------------------------	-------------

* the upper limit costs curve is shown on Figure 21

Table 10b

Load Duration Curve

Parameters:

Peak Demand	16516	RT.h
Average Chiller Capacity	10430	RT.h
Load Coefficient (% of peak load)	63.1	%
Total Production Capacity	250315	RT.h
Total Energy Demand	250315	RT.h
Excess Capacity	0.0	RT.h
Approximate Storage Demand	42896	RT.h
% Energy Storable	17.1	%

Hour	Load Coefficient (%)	Cooling Demand (RT.h)	to Storage (RT.h)	Charge of Storage Tank at End of Hour (RT.h)	(%)
1	42.0	6941	3488	7365	17.2
2	40.2	6645	3785	11149	26.0
3	38.8	6408	4022	15172	35.4
4	37.4	6170	4259	19431	45.3
5	36.5	6034	4395	23826	55.5
6	36.2	5983	4447	28273	65.9
7	34.5	5696	4734	33007	76.9
8	35.6	5874	4556	37563	87.6
9	41.4	6833	3597	41160	96.0
10	52.6	8694	1736	42896	100.0
11	65.0	10739	-310	42586	99.3
12	72.7	12011	-1581	41005	95.6
13	79.3	13091	-2662	38344	89.4
14	84.1	13888	-3458	34886	81.3
15	89.2	14728	-4298	30588	71.3
16	94.3	15577	-5147	25440	59.3
17	96.6	15953	-5523	19917	46.4
18	100.0	16516	-6086	13831	32.2
19	94.3	15577	-5147	8684	20.2
20	88.6	14639	-4209	4476	10.4
21	81.8	13512	-3082	1393	3.2
22	71.6	11823	-1393	0	0.0
23	55.1	9103	1327	1327	3.1
24	47.7	7880	2549	3876	9.0
Totals:		250315	0		
avg:	63.1				

Table 11a

Cost of Storage for tanks located at every building

Parameters:

Equivalent Peak Load Hrs	15.2 hours	Low Temperature Conditions:	
Storage Factor	17.1 %	Delta Temperature	25 oF
Safety Excess Volume	12 %	Tank Ice Content	0 %

No.	Peak Cooling Load (RT)	Energy Dem. (BTU/hr)	Energy Dem. (RT*hr)	Store (RT*hr)	Mass (lbm)	Volume Stor. (gal)	Tank Vol. (gal)	Tank Cost (\$)	Tank Cost (\$/year)
1	5	60000	76	13	6239	748	837	17288	1632
2	1600	19200000	24250	4156	1996461	239204	267909	169172	15969
3	800	9600000	12125	2078	998230	119602	133954	105857	9992
4	704	8448000	10670	1829	878443	105250	117880	96519	9111
5	710	8520000	10761	1844	885929	106147	118885	97114	9167
6	642	7704000	9730	1668	801080	95981	107498	90291	8523
7	694	8328000	10518	1803	865965	103755	116205	95525	9017
8	846	10152000	12822	2198	1055629	126479	141657	110199	10402
9	300	3600000	4547	779	374336	44851	50233	53137	5016
10	1386	16632000	21006	3600	1729434	207211	232076	154772	14609
12	100	1200000	1516	260	124779	14950	16744	29217	2758
13	810	9720000	12276	2104	1010708	121097	135629	106808	10082
14	2400	28800000	36374	6235	2994691	358806	401863	206593	19501
15	160	1920000	2425	416	199646	23920	26791	36563	3451
16	686	8232000	10397	1782	855982	102559	114866	94727	8942
17	110	1320000	1667	286	137257	16445	18419	30451	2874
18	405	4860000	6138	1052	505354	60549	67814	65047	6140
19	405	4860000	6138	1052	505354	60549	67814	65047	6140
20	272	3264000	4122	707	339398	40665	45545	49886	4709
21	800	9600000	12125	2078	998230	119602	133954	105857	9992
22	250	3000000	3789	649	311947	37376	41861	47309	4466
52	340	4080000	5153	883	424248	50831	56931	57727	5449
53	445	5340000	6744	1156	555266	66529	74512	69467	6557
54	650	7800000	9851	1689	811062	97177	108838	91103	8599
55	360	4320000	5456	935	449204	53821	60279	59997	5663
56	185	2220000	2804	481	230841	27658	30977	39581	3736
57	180	2160000	2728	468	224602	26910	30140	38979	3679
58	380	4560000	5759	987	474159	56811	63628	62252	5876
60	120	1440000	1819	312	149735	17940	20093	31682	2991
61	256	3072000	3880	665	319434	38273	42865	48013	4532
62	350	4200000	5305	909	436726	52326	58605	58864	5556
63	1000	12000000	15156	2598	1247788	149503	167443	124113	11715
Total:	18351	220212000	278128	47671	22898155	2743524	3072747	2509159	236847

Table 11b

Cost of Central Storage

Parameters:

Equivalent Peak		Case:	Delta Temp.	Ice Content
load hours:	15.2 hours	Conv.	15 oF	0 %
Storage Factor:	17.1 %	Low Temp.	25 oF	0 %
		Ice Slurry	25 oF	80 %

Excess Volume:

1. Tank Height	42.6 ft
2. Height allowable at top of the tank	1.5 ft
3. Height allowable for thermocline	3.0 ft
4. Height allowable for heat loss	0.9 ft (2%)
Typical Tank Height	48.0 ft

Case	Peak Cooling Load		Energy Dem.	Store	Mass	Vol. Stored	Tank Dia.	Tank Vol.	Tank Cost	Tank Cost
	(RT)	(BTU/hr)	(RT*hr)	(RT*hr)	(lbm)	(gal)	(ft)	(gal)	(\$)	(\$/year)
3-4	16516	198190800	250315	42904	34347233	4115286	128	4631825	2019855	190660
7-8	16516	198190800	250315	42904	20608340	2469172	99	2779095	1398193	131980
13-14	16516	198190800	250315	42904	4476004	536289	46	603602	561143	52968

Table 11c

Friction Reducing Additives Cost (for Reference Case)

FRA Cost: 100 \$/1000 gallons of water

Main Line

Section	Diam (in)	Length (ft)	Volume (cuft)	FRA Cost (\$)
---------	--------------	----------------	------------------	------------------

M16	30	360	1767	1322
M15	30	480	2356	1762
M14	30	100	491	367
M13	30	300	1473	1102
M12A	30	170	834	624
M12B	30	100	491	367
M11	30	300	1473	1102
M10	30	40	196	147
M9	30	540	2651	1983
M8	30	40	196	147
M7	30	55	270	202
M6	30	10	49	37
M5	30	420	2062	1542
M4	30	420	2062	1542
M3	30	680	3338	2497
M2	30	130	638	477
M1	30	410	2013	1505
Totals:		4555	22359	16725

Secondary Lines

Section	Diam (in)	Length (ft)	Volume (cuft)	FRA Cost (\$)
---------	--------------	----------------	------------------	------------------

S1	8	870	304	227
S2	14	150	160	120
S3	14	300	321	240
S4	14	200	214	160
S5	12	790	620	464
SS6	6	210	41	31
SS7	10	390	213	159
S8	6	400	79	59
S9	12	90	71	53
S10	10	135	74	55
S11	10	340	185	139
S12	8	210	73	55
SS13	10	80	44	33
SS14	8	130	45	34
SS15	8	110	38	29
S16	14	500	535	400
S17	12	20	16	12
S18	12	280	220	164
S19	12	140	110	82
S20	6	360	71	53
SS21	10	280	153	114
SS22	6	470	92	69
SS23	8	100	35	26
SS24	10	100	55	41
S25	10	70	38	29
S26	6	70	14	10
S27	6	150	29	22
S28	8	100	35	26
S29	8	150	52	39
S30	8	90	31	23
S31	10	110	60	45
S32	8	410	143	107
S33	8	340	119	89
Totals:		8145	4289	3208

Total Length	12700 ft
Total Volume:	26648 cuft
Overall Cost:	19933 \$

Table 12

Appendix 2

Distribution Cost Optimisation

Velocity	Conventional	B			Conventional	A2		
		Piping	Pumping	Total		Piping	Pumping	Total
2		294920	3019	297939		426595	1408	428003
4		219036	15043	234079		300088	6959	307047
6		192334	33132	225466		245030	11740	256770
8		177009	57533	234542		223517	24634	248151
10		168643	89057	257700		205830	24658	230488
Velocity	Low Temp	Main Line			Low Temp	Secondary Lines		
		Piping	Pumping	Total		Piping	Pumping	Total
2		234822	7350	242172		327057	3758	330815
4		182626	35358	217984		239791	13298	253089
6		161718	85493	247211		200489	30944	231433
8		153455	128085	281540		190377	39931	230308
10		149382	167238	316620		175110	55924	231034
Velocity	Ice Slurry	Main Line			Ice Slurry	Secondary Lines		
		Piping	Pumping	Total		Piping	Pumping	Total
2		175848	6526	182374		228237	2164	230401
4		147234	30195	177429		178582	13981	192563
6		137023	59837	196860		161702	17967	179669
8		133854	80957	214811		154629	24361	178990
10		130874	125456	256330		147782	43899	191681

Table 13

Distribution Cost Optimization

Conventional Technology-Alternative A2

Figure 22

Distribution Cost Optimization

Low Temp Technology-Alternative A2

Figure 23

Distribution Optimization Ice Slurry Technology-Alternative A2

Figure 24

Distribution Cost Optimization

Conventional Technology-Alternative B

Figure 25

Distribution Cost Optimization

Low Temp Technology-Alternative B

Figure 26

Distribution Cost Optimization

Ice Slurry Technology-Alternative B

Figure 27

Appendix 3

Summary of Main Line Mass Flow Rates and Pipe Diam - SOM Chiller

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor	0.015
Max Velocity-others	10 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
			Case 1-3		Case 2-4		Case 5-7		Case 6-8		
M16	445	5340000	360	320881	30	320881	30	192529	30	192529	30
M15	785	9420000	480	566049	30	566049	30	339629	30	339629	30
M14	1041	12492000	100	750646	30	750646	30	450388	30	450388	30
M13	1691	20292000	300	1219349	30	1219349	30	731609	30	731609	30
M12A	2041	24492000	170	1471728	30	1471728	30	883037	30	883037	30
M12B	2041	24492000	100	1471728	30	1471728	30	883037	30	883037	30
M11	2401	28812000	300	1731317	30	1731317	30	1038790	30	1038790	30
M10	2651	31812000	40	1911587	30	1911587	30	1146952	30	1146952	30
M9	2836	34032000	540	2044987	30	2044987	30	1226992	30	1226992	30
M8	2946	35352000	40	2124306	30	2124306	30	1274584	30	1274584	30
M7	3756	45072000	55	2708383	30	2708383	30	1625030	30	1625030	30
M6	6236	74832000	10	4496665	30	4496665	30	2697999	30	2697999	30
M5	8004	96048000	420	5771537	30	5771537	30	3462922	30	3462922	30
M4	8104	97248000	420	5843645	30	5843645	30	3506187	30	3506187	30
M3	10496	125952000	680	7568473	30	7568473	30	4541084	30	4541084	30
M2	12896	154752000	130	9299069	30	9299069	30	5579441	30	5579441	30
M1	13196	158352000	410	9515393	30	9515393	30	5709236	30	5709236	30
Total Main Line Pressure Drop:			18.55		5.56		6.68		2.00		

			Case 9		Case 10		Case 11-13		Case 12-14		
M16	445	5340000	360	121486	30	121486	30	89460	30	89460	30
M15	785	9420000	480	214306	30	214306	30	157811	30	157811	30
M14	1041	12492000	100	284195	30	284195	30	209275	30	209275	30
M13	1691	20292000	300	461646	30	461646	30	339947	30	339947	30
M12A	2041	24492000	170	557196	30	557196	30	410309	30	410309	30
M12B	2041	24492000	100	557196	30	557196	30	410309	30	410309	30
M11	2401	28812000	300	655477	30	655477	30	482680	30	482680	30
M10	2651	31812000	40	723727	30	723727	30	532939	30	532939	30
M9	2836	34032000	540	774232	30	774232	30	570130	30	570130	30
M8	2946	35352000	40	804262	30	804262	30	592243	30	592243	30
M7	3756	45072000	55	1025394	30	1025394	30	755080	30	755080	30
M6	6236	74832000	10	1702437	30	1702437	30	1253642	30	1253642	30
M5	8004	96048000	420	2185104	30	2185104	30	1609069	30	1609069	30
M4	8104	97248000	420	2212404	30	2212404	30	1629172	30	1629172	30
M3	10496	125952000	680	2865424	30	2865424	30	2110043	30	2110043	30
M2	12896	154752000	130	3520627	30	3520627	30	2592523	30	2592523	30
M1	13196	158352000	410	3602528	30	3602528	30	2652833	30	2652833	30
Total Main Line Pressure Drop:			2.66		0.80		1.44		0.94		

Ref Case 30"

Table A1.1

Summary of the Economical Analysis-SOM Chiller

Ref Case 30"

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O

	Case 1-3				Case 2-4		Case 5		Case 6		Case 7	
M16	445	360	9780	0.01	9780	0.00	9780	0.00	9780	0.00	9780	0.00
M15	785	480	13040	0.02	13040	0.01	13040	0.01	13040	0.00	13040	0.01
M14	1041	100	2717	0.01	2717	0.00	2717	0.00	2717	0.00	2717	0.00
M13	1691	300	8150	0.07	8150	0.02	8150	0.02	8150	0.01	8150	0.02
M12A	2041	170	4618	0.06	4618	0.02	4618	0.02	4618	0.01	4618	0.02
M12B	2041	100	2717	0.03	2717	0.01	2717	0.01	2717	0.00	2717	0.01
M11	2401	300	8150	0.14	8150	0.04	8150	0.05	8150	0.01	8150	0.05
M10	2651	40	1087	0.02	1087	0.01	1087	0.01	1087	0.00	1087	0.01
M9	2836	540	14670	0.35	14670	0.10	14670	0.12	14670	0.04	14670	0.12
M8	2946	40	1087	0.03	1087	0.01	1087	0.01	1087	0.00	1087	0.01
M7	3756	55	1494	0.06	1494	0.02	1494	0.02	1494	0.01	1494	0.02
M6	6236	10	272	0.03	272	0.01	272	0.01	272	0.00	272	0.01
M5	8004	420	11410	2.14	11410	0.64	11410	0.77	11410	0.23	11410	0.77
M4	8104	420	11410	2.20	11410	0.66	11410	0.79	11410	0.24	11410	0.79
M3	10496	680	18474	5.97	18474	1.79	18474	2.15	18474	0.64	18474	2.15
M2	12896	130	3532	1.72	3532	0.52	3532	0.62	3532	0.19	3532	0.62
M1	13196	410	11139	5.69	11139	1.71	11139	2.05	11139	0.61	11139	2.05
Main Line Delta P:			18.55		5.56		6.68		2.00		6.68	
Max Delta P:			26.68		8.00		9.60		2.87		9.60	
Subtotal:			123747	24644	123747	7391	123747	17060	123747	5106	123747	6324
Total Cost:			148391		131138		140807		128853		130071	

	Case 8				Case 9		Case 10		Case 11-13		Case 12-14	
M16	445	360	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00
M15	785	480	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00
M14	1041	100	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00
M13	1691	300	8150	0.01	8150	0.01	8150	0.00	8150	0.01	8150	0.00
M12A	2041	170	4618	0.01	4618	0.01	4618	0.00	4618	0.00	4618	0.00
M12B	2041	100	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00
M11	2401	300	8150	0.01	8150	0.02	8150	0.01	8150	0.01	8150	0.01
M10	2651	40	1087	0.00	1087	0.00	1087	0.00	1087	0.00	1087	0.00
M9	2836	540	14670	0.04	14670	0.05	14670	0.01	14670	0.03	14670	0.02
M8	2946	40	1087	0.00	1087	0.00	1087	0.00	1087	0.00	1087	0.00
M7	3756	55	1494	0.01	1494	0.01	1494	0.00	1494	0.00	1494	0.00
M6	6236	10	272	0.00	272	0.00	272	0.00	272	0.00	272	0.00
M5	8004	420	11410	0.23	11410	0.31	11410	0.09	11410	0.17	11410	0.11
M4	8104	420	11410	0.24	11410	0.32	11410	0.09	11410	0.17	11410	0.11
M3	10496	680	18474	0.64	18474	0.86	18474	0.26	18474	0.46	18474	0.30
M2	12896	130	3532	0.19	3532	0.25	3532	0.07	3532	0.13	3532	0.09
M1	13196	410	11139	0.61	11139	0.82	11139	0.24	11139	0.44	11139	0.29
Main Line Delta P:			2.00		2.66		0.80		1.44		0.94	
Max Delta P:			2.87		3.82		1.15		2.06		1.35	
Subtotal:			123747	1893	123747	1585	123747	478	123747	2711	123747	1777
Total Cost:			125640		125332		124225		126458		125524	

Ref Case 30"

Table A1.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Ottawa Chiller

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor	0.015
Max Velocity-others	3 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
			Case 1-3		Case 2-4		Case 5-7		Case 6-8		
M16	445	5340000	360	320881	28	320881	28	192529	26	192529	26
M15	785	9420000	480	566049	28	566049	28	339629	26	339629	26
M14	1041	12492000	100	750646	28	750646	28	450388	26	450388	26
M13	1691	20292000	300	1219349	28	1219349	28	731609	26	731609	26
M12A	2041	24492000	170	1471728	28	1471728	28	883037	26	883037	26
M12B	2041	24492000	100	1471728	28	1471728	28	883037	26	883037	26
M11	2401	28812000	300	1731317	28	1731317	28	1038790	26	1038790	26
M10	2651	31812000	40	1911587	28	1911587	28	1146952	26	1146952	26
M9	2836	34032000	540	2044987	28	2044987	28	1226992	26	1226992	26
M8	2946	35352000	40	2124306	28	2124306	28	1274584	26	1274584	26
M7	3756	45072000	55	2708383	28	2708383	28	1625030	26	1625030	26
M6	6236	74832000	10	4496665	28	4496665	28	2697999	26	2697999	26
M5	8004	96048000	420	5771537	28	5771537	28	3462922	26	3462922	26
M4	8104	97248000	420	5843645	28	5843645	28	3506187	26	3506187	26
M3	10496	125952000	680	7568473	28	7568473	28	4541084	26	4541084	26
M2	12896	154752000	130	9299069	28	9299069	28	5579441	26	5579441	26
M1	13196	158352000	410	9515393	28	9515393	28	5709236	26	5709236	26
Total Main Line Pressure Drop:				26.19		7.86		13.66		4.10	

			Case 9		Case 10		Case 11-13		Case 12-14		
M16	445	5340000	360	121486	20	121486	20	89460	18	89460	18
M15	785	9420000	480	214306	20	214306	20	157811	18	157811	18
M14	1041	12492000	100	284195	20	284195	20	209275	18	209275	18
M13	1691	20292000	300	461646	20	461646	20	339947	18	339947	18
M12A	2041	24492000	170	557196	20	557196	20	410309	18	410309	18
M12B	2041	24492000	100	557196	20	557196	20	410309	18	410309	18
M11	2401	28812000	300	655477	20	655477	20	482680	18	482680	18
M10	2651	31812000	40	723727	20	723727	20	532939	18	532939	18
M9	2836	34032000	540	774232	20	774232	20	570130	18	570130	18
M8	2946	35352000	40	804262	20	804262	20	592243	18	592243	18
M7	3756	45072000	55	1025394	20	1025394	20	755080	18	755080	18
M6	6236	74832000	10	1702437	20	1702437	20	1253642	18	1253642	18
M5	8004	96048000	420	2185104	20	2185104	20	1609069	18	1609069	18
M4	8104	97248000	420	2212404	20	2212404	20	1629172	18	1629172	18
M3	10496	125952000	680	2865424	20	2865424	20	2110043	18	2110043	18
M2	12896	154752000	130	3520627	20	3520627	20	2592523	18	2592523	18
M1	13196	158352000	410	3602528	20	3602528	20	2652833	18	2652833	18
Total Main Line Pressure Drop:				20.19		6.06		18.54		12.05	

Constant Dia/Tech

Table A2.1

Summary of the Economical Analysis - Ottawa Chiller

Cst Dia/ Tech

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

	Case 1-3				Case 2-4		Case 5		Case 6		Case 7	
M16	445	360	9133	0.01	9133	0.00	8503	0.00	8503	0.00	8503	0.00
M15	785	480	12177	0.03	12177	0.01	11337	0.02	11337	0.01	11337	0.02
M14	1041	100	2537	0.01	2537	0.00	2362	0.01	2362	0.00	2362	0.01
M13	1691	300	7610	0.10	7610	0.03	7086	0.05	7086	0.02	7086	0.05
M12A	2041	170	4313	0.08	4313	0.02	4015	0.04	4015	0.01	4015	0.04
M12B	2041	100	2537	0.05	2537	0.01	2362	0.02	2362	0.01	2362	0.02
M11	2401	300	7610	0.19	7610	0.06	7086	0.10	7086	0.03	7086	0.10
M10	2651	40	1015	0.03	1015	0.01	945	0.02	945	0.00	945	0.02
M9	2836	540	13699	0.49	13699	0.15	12754	0.25	12754	0.08	12754	0.25
M8	2946	40	1015	0.04	1015	0.01	945	0.02	945	0.01	945	0.02
M7	3756	55	1395	0.09	1395	0.03	1299	0.05	1299	0.01	1299	0.05
M6	6236	10	254	0.04	254	0.01	236	0.02	236	0.01	236	0.02
M5	8004	420	10655	3.03	10655	0.91	9920	1.58	9920	0.47	9920	1.58
M4	8104	420	10655	3.10	10655	0.93	9920	1.62	9920	0.49	9920	1.62
M3	10496	680	17250	8.43	17250	2.53	16060	4.40	16060	1.32	16060	4.40
M2	12896	130	3298	2.43	3298	0.73	3070	1.27	3070	0.38	3070	1.27
M1	13196	410	10401	8.03	10401	2.41	9684	4.19	9684	1.26	9684	4.19
Main Line Delta P:			26.19		7.86		13.66		4.10		13.66	
Max Delta P:			26.69		8.01		22.48		6.74		22.48	
Subtotal:			115554	24658	115554	7396	107584	39931	107584	11970	107584	14801
Total Cost:			140212		122950		147515		119554		122385	

	Case 8				Case 9		Case 10		Case 11-13		Case 12-14	
M16	445	360	8503	0.00	6720	0.01	6720	0.00	6161	0.01	6161	0.00
M15	785	480	11337	0.01	8959	0.03	8959	0.01	8214	0.02	8214	0.02
M14	1041	100	2362	0.00	1867	0.01	1867	0.00	1711	0.01	1711	0.01
M13	1691	300	7086	0.02	5600	0.07	5600	0.02	5134	0.07	5134	0.04
M12A	2041	170	4015	0.01	3173	0.06	3173	0.02	2909	0.06	2909	0.04
M12B	2041	100	2362	0.01	1867	0.04	1867	0.01	1711	0.03	1711	0.02
M11	2401	300	7086	0.03	5600	0.15	5600	0.05	5134	0.14	5134	0.09
M10	2651	40	945	0.00	747	0.02	747	0.01	685	0.02	685	0.01
M9	2836	540	12754	0.08	10079	0.38	10079	0.11	9241	0.35	9241	0.22
M8	2946	40	945	0.01	747	0.03	747	0.01	685	0.03	685	0.02
M7	3756	55	1299	0.01	1027	0.07	1027	0.02	941	0.06	941	0.04
M6	6236	10	236	0.01	187	0.03	187	0.01	171	0.03	171	0.02
M5	8004	420	9920	0.47	7839	2.33	7839	0.70	7188	2.14	7188	1.39
M4	8104	420	9920	0.49	7839	2.39	7839	0.72	7188	2.20	7188	1.43
M3	10496	680	16060	1.32	12693	6.50	12693	1.95	11637	5.97	11637	3.88
M2	12896	130	3070	0.38	2427	1.88	2427	0.56	2225	1.72	2225	1.12
M1	13196	410	9684	1.26	7653	6.19	7653	1.86	7016	5.69	7016	3.70
Main Line Delta P:			4.10		20.19		6.06		18.54		12.05	
Max Delta P:			6.74		25.20		7.55		18.54		12.05	
Subtotal:			107584	4437	85024	10471	85024	3138	77951	24361	77951	15835
Total Cost:			112021		95495		88162		102312		93786	

Constant Dia/Tech

Table A2.2

Summary of Main Line Mass Flow Rates and Pipe Diam - SOM Chiller

Parameters:			
Max Velocity-conv	6 ft/s	Friction Factor	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
Case 1-3Case 2-4Case 5-7Case 6-8											
M16	445	5340000	360	320881	8	320881	8	192529	8	192529	8
M15	785	9420000	480	566049	10	566049	10	339629	10	339629	10
M14	1041	12492000	100	750646	12	750646	12	450388	10	450388	10
M13	1691	20292000	300	1219349	14	1219349	14	731609	14	731609	14
M12B	2041	24492000	170	1471728	16	1471728	16	883037	14	883037	14
M12A	2041	24492000	100	1471728	16	1471728	16	883037	14	883037	14
M11	2401	28812000	300	1731317	16	1731317	16	1038790	16	1038790	16
M10	2651	31812000	40	1911587	18	1911587	18	1146952	16	1146952	16
M9	2836	34032000	540	2044987	18	2044987	18	1226992	16	1226992	16
M8	2946	35352000	40	2124306	18	2124306	18	1274584	18	1274584	18
M7	3756	45072000	55	2708383	20	2708383	20	1625030	20	1625030	20
M6	6236	74832000	10	4496665	26	4496665	26	2697999	24	2697999	24
M5	8004	96048000	420	5771537	30	5771537	30	3462922	28	3462922	28
M4	8104	97248000	420	5843645	30	5843645	30	3506187	28	3506187	28
M3	10496	125952000	680	7568473	34	7568473	34	4541084	32	4541084	32
M2	12896	154752000	130	9299069	36	9299069	36	5579441	34	5579441	34
M1	13196	158352000	410	9515393	36	9515393	36	5709236	36	5709236	36
Total Main Line Pressure Drop:				35.28		10.59		16.38		4.91	

				Case 9		Case 10		Case 11-13		Case 12-14	
M16	445	5340000	360	121486	6	121486	6	89460	6	89460	6
M15	785	9420000	480	214306	8	214306	8	157811	6	157811	6
M14	1041	12492000	100	284195	8	284195	8	209275	8	209275	8
M13	1691	20292000	300	461646	10	461646	10	339947	10	339947	10
M12B	2041	24492000	170	557196	12	557196	12	410309	10	410309	10
M12A	2041	24492000	100	557196	12	557196	12	410309	10	410309	10
M11	2401	28812000	300	655477	12	655477	12	482680	10	482680	10
M10	2651	31812000	40	723727	14	723727	14	532939	12	532939	12
M9	2836	34032000	540	774232	14	774232	14	570130	12	570130	12
M8	2946	35352000	40	804262	14	804262	14	592243	12	592243	12
M7	3756	45072000	55	1025394	16	1025394	16	755080	14	755080	14
M6	6236	74832000	10	1702437	20	1702437	20	1253642	16	1253642	16
M5	8004	96048000	420	2185104	22	2185104	22	1609069	20	1609069	20
M4	8104	97248000	420	2212404	22	2212404	22	1629172	20	1629172	20
M3	10496	125952000	680	2865424	26	2865424	26	2110043	22	2110043	22
M2	12896	154752000	130	3520627	28	3520627	28	2592523	24	2592523	24
M1	13196	158352000	410	3602528	28	3602528	28	2652833	24	2652833	24
Total Main Line Pressure Drop:				20.52		6.16		22.98		14.94	

Tapered

Table B.1

Summary of the Economical Analysis-SOM Chiller

Tapered

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P
RT	ft	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O

	Case 1-3				Case 2-4				Case 5				Case 6				Case 7			
M16	445	360	3634	4.21	3634	1.26	3634	1.52	3634	1.52	3634	0.45	3634	0.45	3634	1.52	3634	1.52	3634	1.52
M15	785	480	5471	5.73	5471	1.72	5471	2.06	5471	2.06	5471	0.62	5471	0.62	5471	2.06	5471	2.06	5471	2.06
M14	1041	100	1275	0.84	1275	0.25	1140	0.76	1140	0.76	1140	0.23	1140	0.23	1140	0.76	1140	0.76	1140	0.76
M13	1691	300	4247	3.09	4247	0.93	4247	1.11	4247	1.11	4247	0.33	4247	0.33	4247	1.11	4247	1.11	4247	1.11
M12B	2041	170	2654	1.31	2654	0.39	2407	0.92	2407	0.92	2407	0.28	2407	0.28	2407	0.92	2407	0.92	2407	0.92
M12A	2041	100	1561	0.77	1561	0.23	1416	0.54	1416	0.54	1416	0.16	1416	0.16	1416	0.54	1416	0.54	1416	0.54
M11	2401	300	4683	3.19	4683	0.96	4683	1.15	4683	1.15	4683	0.34	4683	0.34	4683	1.15	4683	1.15	4683	1.15
M10	2651	40	685	0.29	685	0.09	624	0.19	624	0.19	624	0.06	624	0.06	624	0.19	624	0.19	624	0.19
M9	2836	540	9241	4.45	9241	1.34	8430	2.89	8430	2.89	8430	0.87	8430	0.87	8430	2.89	8430	2.89	8430	2.89
M8	2946	40	685	0.36	685	0.11	685	0.13	685	0.13	685	0.04	685	0.04	685	0.13	685	0.13	685	0.13
M7	3756	55	1027	0.47	1027	0.14	1027	0.17	1027	0.17	1027	0.05	1027	0.05	1027	0.17	1027	0.17	1027	0.17
M6	6236	10	236	0.06	236	0.02	219	0.03	219	0.03	219	0.01	219	0.01	219	0.03	219	0.03	219	0.03
M5	8004	420	11410	2.14	11410	0.64	10655	1.09	10655	1.09	10655	0.33	10655	0.33	10655	1.09	10655	1.09	10655	1.09
M4	8104	420	11410	2.20	11410	0.66	10655	1.12	10655	1.12	10655	0.34	10655	0.34	10655	1.12	10655	1.12	10655	1.12
M3	10496	680	21021	3.19	21021	0.96	19731	1.56	19731	1.56	19731	0.47	19731	0.47	19731	1.56	19731	1.56	19731	1.56
M2	12896	130	4272	0.69	4272	0.21	4019	0.33	4019	0.33	4019	0.10	4019	0.10	4019	0.33	4019	0.33	4019	0.33
M1	13196	410	13473	2.29	13473	0.69	13473	0.82	13473	0.82	13473	0.25	13473	0.25	13473	0.82	13473	0.82	13473	0.82
Main Line Delta P:			35.28		10.59		16.38		4.91		16.38		5.97		19.90		19.90		19.90	
Max Delta P:			35.87		10.76		19.90		5.97		19.90		5.97		19.90		19.90		19.90	
Subtotal:			96985	33132	96985	9939	92516	35358	92516	10598	92516	13106	92516	10598	92516	13106	92516	13106	92516	13106
Total Cost:			130117		106924		127874		103114		105622		103114		105622		103114		105622	

	Case 8				Case 9				Case 10				Case 11-13				Case 12-14			
M16	445	360	3634	0.45	3182	2.54	3182	0.76	3182	0.76	3182	1.38	3182	1.38	3182	0.90	3182	0.90	3182	0.90
M15	785	480	5471	0.62	4845	2.51	4845	0.75	4845	0.75	4845	5.72	4242	5.72	4242	3.72	4242	3.72	4242	3.72
M14	1041	100	1140	0.23	1009	0.92	1009	0.28	1009	0.28	1009	0.50	1009	0.50	1009	0.32	1009	0.32	1009	0.32
M13	1691	300	4247	0.33	3420	2.38	3420	0.71	3420	0.71	3420	1.29	3420	1.29	3420	0.84	3420	0.84	3420	0.84
M12B	2041	170	2407	0.28	2168	0.79	2168	0.24	2168	0.24	2168	1.07	1938	1.07	1938	0.69	1938	0.69	1938	0.69
M12A	2041	100	1416	0.16	1275	0.46	1275	0.14	1275	0.14	1275	0.63	1140	0.63	1140	0.41	1140	0.41	1140	0.41
M11	2401	300	4683	0.34	3826	1.93	3826	0.58	3826	0.58	3826	2.60	3420	2.60	3420	1.69	3420	1.69	3420	1.69
M10	2651	40	624	0.06	566	0.15	566	0.04	566	0.04	566	0.17	510	0.17	510	0.11	510	0.11	510	0.11
M9	2836	540	8430	0.87	7645	2.24	7645	0.67	7645	0.67	7645	2.63	6887	2.63	6887	1.71	6887	1.71	6887	1.71
M8	2946	40	685	0.04	566	0.18	566	0.05	566	0.05	566	0.21	510	0.21	510	0.14	510	0.14	510	0.14
M7	3756	55	1027	0.05	859	0.21	859	0.06	859	0.06	859	0.22	779	0.22	779	0.14	779	0.14	779	0.14
M6	6236	10	219	0.01	187	0.03	187	0.01	187	0.01	187	0.06	156	0.06	156	0.04	156	0.04	156	0.04
M5	8004	420	10655	0.33	8512	1.45	8512	0.43	8512	0.43	8512	1.27	7839	1.27	7839	0.82	7839	0.82	7839	0.82
M4	8104	420	10655	0.34	8512	1.49	8512	0.45	8512	0.45	8512	1.30	7839	1.30	7839	0.84	7839	0.84	7839	0.84
M3	10496	680	19731	0.47	16060	1.75	16060	0.52	16060	0.52	16060	2.19	13782	2.19	13782	1.42	13782	1.42	13782	1.42
M2	12896	130	4019	0.10	3298	0.35	3298	0.10	3298	0.10	3298	0.41	2849	0.41	2849	0.27	2849	0.27	2849	0.27
M1	13196	410	13473	0.25	10401	1.15	10401	0.35	10401	0.35	10401	1.35	8986	1.35	8986	0.88	8986	0.88	8986	0.88
Main Line Delta P:			4.91		20.52		6.16		22.98		14.94		22.98		14.94		22.98		14.94	
Max Delta P:			5.97		21.10		6.33		22.98		14.94		22.98		14.94		22.98		14.94	
Subtotal:			92516	3929	76331	8767	76331	2631	68488	30195	68488	19627	68488	30195	68488	19627	68488	19627	68488	19627
Total Cost:			96445		85098		78962		98683		88115		98683		88115		98683		88115	

Tapered

Table B.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Ottawa Chiller

Parameters:			
Max Velocity-conv	6 ft/s	Friction Factor	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H ₂ O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in	
			Case 1-3		Case 2-4		Case 5-7		Case 6-8		
M1	5155	61860000	410	3717176	24	3717176	24	2230305	22	2230305	22
M2	5455	65460000	130	3933500	24	3933500	24	2360100	22	2360100	22
M3	7855	94260000	680	5664096	28	5664096	28	3398458	28	3398458	28
M4	10247	122964000	420	7388923	32	7388923	32	4433354	32	4433354	32
M5	10347	124164000	420	7461032	32	7461032	32	4476619	32	4476619	32
M6	12115	145380000	10	8735904	36	8735904	36	5241542	34	5241542	34
M7	14595	175140000	55	10524186	38	10524186	38	6314512	36	6314512	36
M8	15405	184860000	40	11108262	40	11108262	40	6664957	38	6664957	38
M9	15515	186180000	540	11187581	40	11187581	40	6712549	38	6712549	38
M10	15700	188400000	40	11320981	40	11320981	40	6792589	38	6792589	38
M11	15950	191400000	300	11501252	40	11501252	40	6900751	38	6900751	38
M12A	16310	195720000	170	11760841	42	11760841	42	7056505	38	7056505	38
M16	445	5340000	360	320881	8	320881	8	192529	8	192529	8
M15	785	9420000	480	566049	10	566049	10	339629	10	339629	10
M14	1041	12492000	100	750646	12	750646	12	450388	10	450388	10
M13	1691	20292000	300	1219349	14	1219349	14	731609	14	731609	14
M12B	2041	24492000	100	1471728	16	1471728	16	883037	14	883037	14
Total Main Line Pressure Drop:				33.36		10.01		14.07		4.22	

			Case 9			Case 10		Case 11-13		Case 12-14	
M1	5155	61860000	410	1407323	18	1407323	18	1036326	16	1036326	16
M2	5455	65460000	130	1489223	18	1489223	18	1096635	16	1096635	16
M3	7855	94260000	680	2144427	22	2144427	22	1579115	18	1579115	18
M4	10247	122964000	420	2797446	24	2797446	24	2059986	22	2059986	22
M5	10347	124164000	420	2824747	26	2824747	26	2080089	22	2080089	22
M6	12115	145380000	10	3307413	26	3307413	26	2435516	24	2435516	24
M7	14595	175140000	55	3984457	30	3984457	30	2934078	26	2934078	26
M8	15405	184860000	40	4205588	30	4205588	30	3096915	26	3096915	26
M9	15515	186180000	540	4235618	30	4235618	30	3119028	26	3119028	26
M10	15700	188400000	40	4286124	30	4286124	30	3156219	26	3156219	26
M11	15950	191400000	300	4354374	30	4354374	30	3206478	26	3206478	26
M12A	16310	195720000	170	4452655	32	4452655	32	3278850	26	3278850	26
M16	445	5340000	360	121486	6	121486	6	89460	6	89460	6
M15	785	9420000	480	214306	8	214306	8	157811	6	157811	6
M14	1041	12492000	100	284195	8	284195	8	209275	8	209275	8
M13	1691	20292000	300	461646	10	461646	10	339947	10	339947	10
M12B	2041	24492000	100	557196	12	557196	12	410309	10	410309	10
Total Main Line Pressure Drop:				18.95		5.68		21.19		13.77	

Tapered

Table C.1

Summary of the Economical Analysis-Ottawa Chiller

Tapered

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.742E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

Case 1-3			Case 2-4			Case 5		Case 6		Case 7		
M1	5155	410	8986	2.65	8986	0.79	8309	1.47	8309	0.44	8309	1.47
M2	5455	130	2849	0.94	2849	0.28	2635	0.52	2635	0.16	2635	0.52
M3	7855	680	17250	4.72	17250	1.42	17250	1.70	17250	0.51	17250	1.70
M4	10247	420	12187	2.54	12187	0.76	12187	0.92	12187	0.27	12187	0.92
M5	10347	420	12187	2.59	12187	0.78	12187	0.93	12187	0.28	12187	0.93
M6	12115	10	329	0.05	329	0.01	309	0.02	309	0.01	309	0.02
M7	14595	55	1917	0.29	1917	0.09	1807	0.14	1807	0.04	1807	0.14
M8	15405	40	1476	0.18	1476	0.05	1394	0.08	1394	0.03	1394	0.08
M9	15515	540	19928	2.46	19928	0.74	18823	1.14	18823	0.34	18823	1.14
M10	15700	40	1476	0.19	1476	0.06	1394	0.09	1394	0.03	1394	0.09
M11	15950	300	11071	1.44	11071	0.43	10457	0.67	10457	0.20	10457	0.67
M12A	16310	170	6630	0.67	6630	0.20	5926	0.40	5926	0.12	5926	0.40
M16	445	360	3634	4.21	3634	1.26	3634	1.52	3634	0.45	3634	1.52
M15	785	480	5471	5.73	5471	1.72	5471	2.06	5471	0.62	5471	2.06
M14	1041	100	1275	0.84	1275	0.25	1140	0.76	1140	0.23	1140	0.76
M13	1691	300	4247	3.09	4247	0.93	4247	1.11	4247	0.33	4247	1.11
M12B	2041	100	1561	0.77	1561	0.23	1416	0.54	1416	0.16	1416	0.54
Main Line Delta P:			33.36		10.01		14.07		4.22		14.07	
Max Delta P:			35.46		10.64		17.88		5.36		17.88	
Subtotal:			112474 40490		112474 12146		108586 39265		108586 11769		108586 14554	
Total Cost:			152964		124620		147851		120355		123140	

Case 8				Case 9		Case 10		Case 11-13		Case 12-14		
M1	5155	410	8309	0.44	7016	1.60	7016	0.48	6400	1.56	6400	1.02
M2	5455	130	2635	0.16	2225	0.57	2225	0.17	2029	0.56	2029	0.36
M3	7855	680	17250	0.51	13782	2.26	13782	0.68	11637	3.34	11637	2.17
M4	10247	420	12187	0.27	9206	1.54	9206	0.46	8512	1.29	8512	0.84
M5	10347	420	12187	0.28	9920	1.05	9920	0.32	8512	1.31	8512	0.85
M6	12115	10	309	0.01	236	0.03	236	0.01	219	0.03	219	0.02
M7	14595	55	1807	0.04	1494	0.13	1494	0.04	1299	0.15	1299	0.10
M8	15405	40	1394	0.03	1087	0.11	1087	0.03	945	0.12	945	0.08
M9	15515	540	18823	0.34	14670	1.48	14670	0.45	12754	1.65	12754	1.07
M10	15700	40	1394	0.03	1087	0.11	1087	0.03	945	0.12	945	0.08
M11	15950	300	10457	0.20	8150	0.87	8150	0.26	7086	0.97	7086	0.63
M12A	16310	170	5926	0.12	4933	0.37	4933	0.11	4015	0.57	4015	0.37
M16	445	360	3634	0.45	3182	2.54	3182	0.76	3182	1.38	3182	0.90
M15	785	480	5471	0.62	4845	2.51	4845	0.75	4242	5.72	4242	3.72
M14	1041	100	1140	0.23	1009	0.92	1009	0.28	1009	0.50	1009	0.32
M13	1691	300	4247	0.33	3420	2.38	3420	0.71	3420	1.29	3420	0.84
M12B	2041	100	1416	0.16	1275	0.46	1275	0.14	1140	0.63	1140	0.41
Main Line Delta P:			4.22		18.95		5.68		21.19		13.77	
Max Delta P:			5.36		20.21		6.07		21.50		13.98	
Subtotal:			108586	4362	87537	10381	87537	3115	77346	34925	77346	22700
Total Cost:			112948		97918		90652		112271		100046	

Tapered

Table C.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Combination

Parameters:			
Max Velocity-conv	6 ft/s	Friction Factor	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H ₂ O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
Case 1-3											
M4	50	600000	420	36054	6	36054	6	21632	4	21632	4
M3	2442	29304000	680	1760881	16	1760881	16	1056529	16	1056529	16
M2	4842	58104000	130	3491477	22	3491477	22	2094886	22	2094886	22
M1	5142	61704000	410	3707802	24	3707802	24	2224681	22	2224681	22
Case 2-4											
M5	50	600000	420	36054	6	36054	6	21632	4	21632	4
M6	1818	21816000	10	1310926	14	1310926	14	786556	14	786556	14
M7	4298	51576000	55	3099209	22	3099209	22	1859525	20	1859525	20
M8	5108	61296000	40	3683285	24	3683285	24	2209971	22	2209971	22
M9	5218	62616000	540	3762604	24	3762604	24	2257562	22	2257562	22
M10	5403	64836000	40	3896004	24	3896004	24	2337602	22	2337602	22
M11	5653	67836000	300	4076274	24	4076274	24	2445765	24	2445765	24
M12A	6013	72156000	170	4335864	26	4335864	26	2601518	24	2601518	24
Case 5-7											
M16	445	5340000	360	320881	8	320881	8	192529	8	192529	8
M15	785	9420000	480	566049	10	566049	10	339629	10	339629	10
M14	1041	12492000	100	750646	12	750646	12	450388	10	450388	10
M13	1691	20292000	300	1219349	14	1219349	14	731609	14	731609	14
M12B	2041	24492000	100	1471728	16	1471728	16	883037	14	883037	14
Case 6-8											
Total Main Line Pressure Drop:				34.38		10.31		15.92		4.78	

				Case 9		Case 10		Case 11-13		Case 12-14	
M4	50	600000	420	13650	4	13650	4	10052	4	10052	4
M3	2442	29304000	680	666670	12	666670	12	490923	12	490923	12
M2	4842	58104000	130	1321873	18	1321873	18	973402	16	973402	16
M1	5142	61704000	410	1403774	18	1403774	18	1033712	16	1033712	16
M5	50	600000	420	13650	4	13650	4	10052	4	10052	4
M6	1818	21816000	10	496317	12	496317	12	365478	10	365478	10
M7	4298	51576000	55	1173360	16	1173360	16	864040	14	864040	14
M8	5108	61296000	40	1394492	18	1394492	18	1026877	16	1026877	16
M9	5218	62616000	540	1424522	18	1424522	18	1048991	16	1048991	16
M10	5403	64836000	40	1475027	18	1475027	18	1086182	16	1086182	16
M11	5653	67836000	300	1543277	18	1543277	18	1136440	16	1136440	16
M12A	6013	72156000	170	1641558	20	1641558	20	1208812	16	1208812	16
M16	445	5340000	360	121486	6	121486	6	89460	6	89460	6
M15	785	9420000	480	214306	8	214306	8	157811	6	157811	6
M14	1041	12492000	100	284195	8	284195	8	209275	8	209275	8
M13	1691	20292000	300	461646	10	461646	10	339947	10	339947	10
M12B	2041	24492000	100	557196	12	557196	12	410309	10	410309	10
Total Main Line Pressure Drop:				20.68		6.20		19.30		12.54	

Tapered

Table D.1

Summary of the Economical Analysis - Combination

Tapered

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.742E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

Case 1-3			Case 2-4			Case 5			Case 6			Case 7		
M4	50	420	3712	0.26	3712	0.08	3205	0.71	3205	0.21	3205	0.71	3205	0.71
M3	2442	680	10615	7.49	10615	2.25	10615	2.70	10615	0.81	10615	2.70	10615	2.70
M2	4842	130	2635	1.15	2635	0.34	2635	0.41	2635	0.12	2635	0.41	2635	0.41
M1	5142	410	8986	2.64	8986	0.79	8309	1.47	8309	0.44	8309	1.47	8309	1.47
M5	50	420	3712	0.26	3712	0.08	3205	0.71	3205	0.21	3205	0.71	3205	0.71
M6	1818	10	142	0.12	142	0.04	142	0.04	142	0.01	142	0.04	142	0.04
M7	4298	55	1115	0.38	1115	0.11	1027	0.22	1027	0.07	1027	0.22	1027	0.22
M8	5108	40	877	0.25	877	0.08	811	0.14	811	0.04	811	0.14	811	0.14
M9	5218	540	11836	3.58	11836	1.07	10944	1.99	10944	0.60	10944	1.99	10944	1.99
M10	5403	40	877	0.28	877	0.09	811	0.16	811	0.05	811	0.16	811	0.16
M11	5653	300	6575	2.33	6575	0.70	6575	0.84	6575	0.25	6575	0.84	6575	0.84
M12A	6013	170	4015	1.00	4015	0.30	3726	0.54	3726	0.16	3726	0.54	3726	0.54
M16	445	360	3634	4.21	3634	1.26	3634	1.52	3634	0.45	3634	1.52	3634	1.52
M15	785	480	5471	5.73	5471	1.72	5471	2.06	5471	0.62	5471	2.06	5471	2.06
M14	1041	100	1275	0.84	1275	0.25	1140	0.76	1140	0.23	1140	0.76	1140	0.76
M13	1691	300	4247	3.09	4247	0.93	4247	1.11	4247	0.33	4247	1.11	4247	1.11
M12B	2041	100	1561	0.77	1561	0.23	1416	0.54	1416	0.16	1416	0.54	1416	0.54
Main Line Delta P:			34.38			10.31			15.92			4.78		
Max Delta P:			36.48			10.94			19.73			5.91		
Subtotal:			71285			15356			71285			4606		
Total Cost:			86641			75891			83883			72700		

Case 8			Case 9			Case 10			Case 11-13			Case 12-14		
M4	50	420	3205	0.21	3205	0.28	3205	0.09	3205	0.15	3205	0.10	3205	0.10
M3	2442	680	10615	0.81	8672	4.52	8672	1.36	8672	2.45	8672	1.59	8672	1.59
M2	4842	130	2635	0.12	2225	0.45	2225	0.13	2029	0.44	2029	0.28	2029	0.28
M1	5142	410	8309	0.44	7016	1.59	7016	0.48	6400	1.56	6400	1.01	6400	1.01
M5	50	420	3205	0.21	3205	0.28	3205	0.09	3205	0.15	3205	0.10	3205	0.10
M6	1818	10	142	0.01	128	0.04	128	0.01	114	0.05	114	0.03	114	0.03
M7	4298	55	1027	0.07	859	0.27	859	0.08	779	0.28	779	0.18	779	0.18
M8	5108	40	811	0.04	685	0.15	685	0.05	624	0.15	624	0.10	624	0.10
M9	5218	540	10944	0.60	9241	2.16	9241	0.65	8430	2.11	8430	1.37	8430	1.37
M10	5403	40	811	0.05	685	0.17	685	0.05	624	0.17	624	0.11	624	0.11
M11	5653	300	6575	0.25	5134	1.41	5134	0.42	4683	1.38	4683	0.89	4683	0.89
M12A	6013	170	3726	0.16	3173	0.53	3173	0.16	2654	0.88	2654	0.57	2654	0.57
M16	445	360	3634	0.45	3182	2.54	3182	0.76	3182	1.38	3182	0.90	3182	0.90
M15	785	480	5471	0.62	4845	2.51	4845	0.75	4242	5.72	4242	3.72	4242	3.72
M14	1041	100	1140	0.23	1009	0.92	1009	0.28	1009	0.50	1009	0.32	1009	0.32
M13	1691	300	4247	0.33	3420	2.38	3420	0.71	3420	1.29	3420	0.84	3420	0.84
M12B	2041	100	1416	0.16	1275	0.46	1275	0.14	1140	0.63	1140	0.41	1140	0.41
Main Line Delta P:			4.78			20.68			6.20			19.30		
Max Delta P:			5.91			21.94			6.58			19.61		
Subtotal:			67913			1774			57959			4154		
Total Cost:			69687			62113			59206			66153		

Tapered

Table D.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Combination

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor	0.015
Max Velocity-others	10 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H ₂ O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
Case 1-3											
M1	13196	158352000	410	9515393	28	9515393	28	5709236	28	5709236	28
M2	12896	154752000	130	9299069	28	9299069	28	5579441	28	5579441	28
M3	10496	125952000	680	7568473	26	7568473	26	4541084	26	4541084	26
M4	8104	97248000	420	5843645	26	5843645	26	3506187	26	3506187	26
M5	8004	96048000	420	5771537	26	5771537	26	3462922	26	3462922	26
M6	6236	74832000	10	4496665	28	4496665	28	2697999	28	2697999	28
M7	3756	45072000	55	2708383	30	2708383	30	1625030	30	1625030	30
M8	2946	35352000	40	2124306	32	2124306	32	1274584	32	1274584	32
M9	2836	34032000	540	2044987	32	2044987	32	1226992	32	1226992	32
M10	2651	31812000	40	1911587	32	1911587	32	1146952	32	1146952	32
M11	2401	28812000	300	1731317	32	1731317	32	1038790	32	1038790	32
M12A	2041	24492000	170	1471728	32	1471728	32	883037	32	883037	32
M16	445	5340000	360	320881	8	320881	8	192529	8	192529	8
M15	785	9420000	480	566049	10	566049	10	339629	10	339629	10
M14	1041	12492000	100	750646	10	750646	10	450388	10	450388	10
M13	1691	20292000	300	1219349	12	1219349	12	731609	12	731609	12
M12B	2041	24492000	100	1471728	12	1471728	12	883037	12	883037	12
Total Pressure Drop				54.04		16.21		19.46		5.84	

				Case 9		Case 10		Case 11-13		Case 12-14	
M1	13196	158352000	410	3602528	28	3602528	28	2652833	28	2652833	28
M2	12896	154752000	130	3520627	28	3520627	28	2592523	28	2592523	28
M3	10496	125952000	680	2865424	26	2865424	26	2110043	26	2110043	26
M4	8104	97248000	420	2212404	26	2212404	26	1629172	26	1629172	26
M5	8004	96048000	420	2185104	26	2185104	26	1609069	26	1609069	26
M6	6236	74832000	10	1702437	28	1702437	28	1253642	28	1253642	28
M7	3756	45072000	55	1025394	30	1025394	30	755080	30	755080	30
M8	2946	35352000	40	804262	32	804262	32	592243	32	592243	32
M9	2836	34032000	540	774232	32	774232	32	570130	32	570130	32
M10	2651	31812000	40	723727	32	723727	32	532939	32	532939	32
M11	2401	28812000	300	655477	32	655477	32	482680	32	482680	32
M12A	2041	24492000	170	557196	32	557196	32	410309	32	410309	32
M16	445	5340000	360	121486	8	121486	8	89460	8	89460	8
M15	785	9420000	480	214306	10	214306	10	157811	10	157811	10
M14	1041	12492000	100	284195	10	284195	10	209275	10	209275	10
M13	1691	20292000	300	461646	12	461646	12	339947	12	339947	12
M12B	2041	24492000	100	557196	12	557196	12	410309	12	410309	12
Total Pressure Drop				7.75		2.32		4.20		2.73	

Summary of the Economical Analysis-Combination

Conv Tech

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

	Case 1-3				Case 2-4				Case 5				Case 6				Case 7			
M1	13196	410	10401	8.03	10401	2.41	10401	2.89	10401	0.87	10401	2.89	10401	0.87	10401	2.89	10401	2.89		
M2	12896	130	3298	2.43	3298	0.73	3298	0.88	3298	0.26	3298	0.88	3298	0.26	3298	0.88	3298	0.88		
M3	10496	680	16060	12.21	16060	3.66	16060	4.40	16060	1.32	16060	4.40	16060	1.32	16060	4.40	16060	4.40		
M4	8104	420	9920	4.50	9920	1.35	9920	1.62	9920	0.49	9920	1.62	9920	0.49	9920	1.62	9920	1.62		
M5	8004	420	9920	4.39	9920	1.32	9920	1.58	9920	0.47	9920	1.58	9920	0.47	9920	1.58	9920	1.58		
M6	6236	10	254	0.04	254	0.01	254	0.02	254	0.00	254	0.02	254	0.00	254	0.02	254	0.02		
M7	3756	55	1494	0.06	1494	0.02	1494	0.02	1494	0.01	1494	0.02	1494	0.01	1494	0.02	1494	0.02		
M8	2946	40	1161	0.02	1161	0.01	1161	0.01	1161	0.00	1161	0.01	1161	0.00	1161	0.01	1161	0.01		
M9	2836	540	15669	0.25	15669	0.08	15669	0.09	15669	0.03	15669	0.09	15669	0.03	15669	0.09	15669	0.09		
M10	2651	40	1161	0.02	1161	0.00	1161	0.01	1161	0.00	1161	0.01	1161	0.00	1161	0.01	1161	0.01		
M11	2401	300	8705	0.10	8705	0.03	8705	0.04	8705	0.01	8705	0.04	8705	0.01	8705	0.04	8705	0.04		
M12A	2041	170	4933	0.04	4933	0.01	4933	0.01	4933	0.00	4933	0.01	4933	0.00	4933	0.01	4933	0.01		
M16	445	360	3634	4.21	3634	1.26	3634	1.52	3634	0.45	3634	1.52	3634	0.45	3634	1.52	3634	1.52		
M15	785	480	5471	5.73	5471	1.72	5471	2.06	5471	0.62	5471	2.06	5471	0.62	5471	2.06	5471	2.06		
M14	1041	100	1140	2.10	1140	0.63	1140	0.76	1140	0.23	1140	0.76	1140	0.23	1140	0.76	1140	0.76		
M13	1691	300	3826	6.68	3826	2.00	3826	2.40	3826	0.72	3826	2.40	3826	0.72	3826	2.40	3826	2.40		
M12B	2041	100	1275	3.24	1275	0.97	1275	1.17	1275	0.35	1275	1.17	1275	0.35	1275	1.17	1275	1.17		
Main Line Delta P:			54.04		16.21		19.46		5.84		19.46		5.84		19.46		5.84		19.46	
Max Delta P:			57.82		17.34		20.82		6.25		20.82		6.25		20.82		6.25		20.82	
Subtotal:			98322	53410	98322	16017	98322	36978	98322	11107	98322	36978	98322	11107	98322	36978	98322	11107	98322	13706
Total Cost:			151732		114339		135300		109429		109429		109429		109429		109429		112028	

	Case 8				Case 9				Case 10				Case 11-13				Case 12-14			
M1	13196	410	10401	0.87	10401	1.15	10401	0.35	10401	0.62	10401	0.41	10401	0.62	10401	0.41	10401	0.41		
M2	12896	130	3298	0.26	3298	0.35	3298	0.10	3298	0.19	3298	0.12	3298	0.19	3298	0.12	3298	0.12		
M3	10496	680	16060	1.32	16060	1.75	16060	0.52	16060	0.95	16060	0.62	16060	0.95	16060	0.62	16060	0.62		
M4	8104	420	9920	0.49	9920	0.64	9920	0.19	9920	0.35	9920	0.23	9920	0.35	9920	0.23	9920	0.23		
M5	8004	420	9920	0.47	9920	0.63	9920	0.19	9920	0.34	9920	0.22	9920	0.34	9920	0.22	9920	0.22		
M6	6236	10	254	0.00	254	0.01	254	0.00	254	0.00	254	0.00	254	0.00	254	0.00	254	0.00		
M7	3756	55	1494	0.01	1494	0.01	1494	0.00	1494	0.00	1494	0.00	1494	0.00	1494	0.00	1494	0.00		
M8	2946	40	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00		
M9	2836	540	15669	0.03	15669	0.04	15669	0.01	15669	0.02	15669	0.01	15669	0.02	15669	0.01	15669	0.01		
M10	2651	40	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00	1161	0.00		
M11	2401	300	8705	0.01	8705	0.01	8705	0.00	8705	0.01	8705	0.01	8705	0.01	8705	0.01	8705	0.01		
M12A	2041	170	4933	0.00	4933	0.01	4933	0.00	4933	0.00	4933	0.00	4933	0.00	4933	0.00	4933	0.00		
M16	445	360	3634	0.45	3634	0.60	3634	0.18	3634	0.33	3634	0.21	3634	0.33	3634	0.21	3634	0.21		
M15	785	480	5471	0.62	5471	0.82	5471	0.25	5471	0.45	5471	0.29	5471	0.45	5471	0.29	5471	0.29		
M14	1041	100	1140	0.23	1140	0.30	1140	0.09	1140	0.16	1140	0.11	1140	0.16	1140	0.11	1140	0.11		
M13	1691	300	3826	0.72	3826	0.96	3826	0.29	3826	0.52	3826	0.34	3826	0.52	3826	0.34	3826	0.34		
M12B	2041	100	1275	0.35	1275	0.46	1275	0.14	1275	0.25	1275	0.16	1275	0.25	1275	0.16	1275	0.16		
Main Line Delta P:			5.84		7.75		2.32		4.20		2.73		4.20		4.20		4.20		2.73	
Max Delta P:			6.25		8.29		2.48		4.50		2.92		4.50		4.50		4.50		2.92	
Subtotal:			98322	4117	98322	3444	98322	1030	98322	5908	98322	3832	98322	5908	98322	5908	98322	5908	98322	3832
Total Cost:			102439		101766		99352		104230		102154		104230		104230		104230		102154	

Conventional Tech

Table E1.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Combination

Parameters:			
Max Velocity-conv	6 ft/s	Friction Factor	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr		ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
			Case 1-3			Case 2-4		Case 5-7		Case 6-8	
M1	13196	158352000	410	9515393	36	9515393	36	5709236	36	5709236	36
M2	12896	154752000	130	9299069	36	9299069	36	5579441	34	5579441	34
M3	10496	125952000	680	7568473	34	7568473	34	4541084	32	4541084	32
M4	8104	97248000	420	5843645	32	5843645	32	3506187	32	3506187	32
M5	8004	96048000	420	5771537	32	5771537	32	3462922	32	3462922	32
M6	6236	74832000	10	4496665	36	4496665	36	2697999	34	2697999	34
M7	3756	45072000	55	2708383	38	2708383	38	1625030	36	1625030	36
M8	2946	35352000	40	2124306	40	2124306	40	1274584	38	1274584	38
M9	2836	34032000	540	2044987	40	2044987	40	1226992	38	1226992	38
M10	2651	31812000	40	1911587	40	1911587	40	1146952	38	1146952	38
M11	2401	28812000	300	1731317	40	1731317	40	1038790	38	1038790	38
M12A	2041	24492000	170	1471728	42	1471728	42	883037	38	883037	38
M16	445	5340000	360	320881	8	320881	8	192529	8	192529	8
M15	785	9420000	480	566049	10	566049	10	339629	10	339629	10
M14	1041	12492000	100	750646	12	750646	12	450388	10	450388	10
M13	1691	20292000	300	1219349	14	1219349	14	731609	14	731609	14
M12B	2041	24492000	100	1471728	16	1471728	16	883037	14	883037	14
Total Pressure Drop			24.13			7.24		9.91		2.97	

				Case 9		Case 10		Case 11-13		Case 12-14	
M1	13196	158352000	410	3602528	28	3602528	28	2652833	24	2652833	24
M2	12896	154752000	130	3520627	28	3520627	28	2592523	24	2592523	24
M3	10496	125952000	680	2865424	26	2865424	26	2110043	22	2110043	22
M4	8104	97248000	420	2212404	24	2212404	24	1629172	22	1629172	22
M5	8004	96048000	420	2185104	26	2185104	26	1609069	22	1609069	22
M6	6236	74832000	10	1702437	26	1702437	26	1253642	24	1253642	24
M7	3756	45072000	55	1025394	30	1025394	30	755080	26	755080	26
M8	2946	35352000	40	804262	30	804262	30	592243	26	592243	26
M9	2836	34032000	540	774232	30	774232	30	570130	26	570130	26
M10	2651	31812000	40	723727	30	723727	30	532939	26	532939	26
M11	2401	28812000	300	655477	30	655477	30	482680	26	482680	26
M12A	2041	24492000	170	557196	32	557196	32	410309	26	410309	26
M16	445	5340000	360	121486	6	121486	6	89460	6	89460	6
M15	785	9420000	480	214306	8	214306	8	157811	6	157811	6
M14	1041	12492000	100	284195	8	284195	8	209275	8	209275	8
M13	1691	20292000	300	461646	10	461646	10	339947	10	339947	10
M12B	2041	24492000	100	557196	12	557196	12	410309	10	410309	10
Total Pressure Drop				13.75		4.13		15.17		9.86	

Summary of the Economical Analysis-Combination

Best Tech

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

	Case 1-3				Case 2-4		Case 5		Case 6		Case 7	
M1	13196	410	13473	2.29	13473	0.69	13473	0.82	13473	0.25	13473	0.82
M2	12896	130	4272	0.69	4272	0.21	4019	0.33	4019	0.10	4019	0.33
M3	10496	680	21021	3.19	21021	0.96	19731	1.56	19731	0.47	19731	1.56
M4	8104	420	12187	1.59	12187	0.48	12187	0.57	12187	0.17	12187	0.57
M5	8004	420	12187	1.55	12187	0.47	12187	0.56	12187	0.17	12187	0.56
M6	6236	10	329	0.01	329	0.00	309	0.01	309	0.00	309	0.01
M7	3756	55	1917	0.02	1917	0.01	1807	0.01	1807	0.00	1807	0.01
M8	2946	40	1476	0.01	1476	0.00	1394	0.00	1394	0.00	1394	0.00
M9	2836	540	19928	0.08	19928	0.02	18823	0.04	18823	0.01	18823	0.04
M10	2651	40	1476	0.01	1476	0.00	1394	0.00	1394	0.00	1394	0.00
M11	2401	300	11071	0.03	11071	0.01	10457	0.02	10457	0.00	10457	0.02
M12A	2041	170	6630	0.01	6630	0.00	5926	0.01	5926	0.00	5926	0.01
M16	445	360	3634	4.21	3634	1.26	3634	1.52	3634	0.45	3634	1.52
M15	785	480	5471	5.73	5471	1.72	5471	2.06	5471	0.62	5471	2.06
M14	1041	100	1275	0.84	1275	0.25	1140	0.76	1140	0.23	1140	0.76
M13	1691	300	4247	3.09	4247	0.93	4247	1.11	4247	0.33	4247	1.11
M12B	2041	100	1561	0.77	1561	0.23	1416	0.54	1416	0.16	1416	0.54
Main Line Delta P:			24.13			7.24		9.91		2.97		9.91
Max Delta P:			26.23			7.87		13.72		4.11		13.72
Subtotal:			122155	24227		122155	7267	117615	24371	117615	7302	117615
Total Cost:			146382			129422		141986		124917		126649

	Case 8				Case 9		Case 10		Case 11-13		Case 12-14	
M1	13196	410	13473	0.25	10401	1.15	10401	0.35	8986	1.35	8986	0.88
M2	12896	130	4019	0.10	3298	0.35	3298	0.10	2849	0.41	2849	0.27
M3	10496	680	19731	0.47	16060	1.75	16060	0.52	13782	2.19	13782	1.42
M4	8104	420	12187	0.17	9206	0.96	9206	0.29	8512	0.81	8512	0.52
M5	8004	420	12187	0.17	9920	0.63	9920	0.19	8512	0.79	8512	0.51
M6	6236	10	309	0.00	236	0.01	236	0.00	219	0.01	219	0.00
M7	3756	55	1807	0.00	1494	0.01	1494	0.00	1299	0.01	1299	0.01
M8	2946	40	1394	0.00	1087	0.00	1087	0.00	945	0.00	945	0.00
M9	2836	540	18823	0.01	14670	0.05	14670	0.01	12754	0.06	12754	0.04
M10	2651	40	1394	0.00	1087	0.00	1087	0.00	945	0.00	945	0.00
M11	2401	300	10457	0.00	8150	0.02	8150	0.01	7086	0.02	7086	0.01
M12A	2041	170	5926	0.00	4933	0.01	4933	0.00	4015	0.01	4015	0.01
M16	445	360	3634	0.45	3182	2.54	3182	0.76	3182	1.38	3182	0.90
M15	785	480	5471	0.62	4845	2.51	4845	0.75	4242	5.72	4242	3.72
M14	1041	100	1140	0.23	1009	0.92	1009	0.28	1009	0.50	1009	0.32
M13	1691	300	4247	0.33	3420	2.38	3420	0.71	3420	1.29	3420	0.84
M12B	2041	100	1416	0.16	1275	0.46	1275	0.14	1140	0.63	1140	0.41
Main Line Delta P:			2.97			13.75		4.13		15.17		9.86
Max Delta P:			4.11			15.02		4.51		15.48		10.06
Subtotal:			117615	2707		94273	6240	94273	1873	82897	20345	82897
Total Cost:			120322			100513		96146		103242		96120

Best Tech

Table E2.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Ottawa Chiller

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor	0.015
Max Velocity-others	10 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len ft	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in
RT	BTU/hr										
Case 1-3											
M1	5155	61860000	410	3717176	30	3717176	30	2230305	30	2230305	30
M2	5455	65460000	130	3933500	30	3933500	30	2360100	30	2360100	30
M3	7855	94260000	680	5664096	30	5664096	30	3398458	30	3398458	30
M4	10247	122964000	420	7388923	30	7388923	30	4433354	30	4433354	30
M5	10347	124164000	420	7461032	30	7461032	30	4476619	30	4476619	30
M6	12115	145380000	10	8735904	30	8735904	30	5241542	30	5241542	30
M7	14595	175140000	55	10524186	30	10524186	30	6314512	30	6314512	30
M8	15405	184860000	40	11108262	30	11108262	30	6664957	30	6664957	30
M9	15515	186180000	540	11187581	30	11187581	30	6712549	30	6712549	30
M10	15700	188400000	40	11320981	30	11320981	30	6792589	30	6792589	30
M11	15950	191400000	300	11501252	30	11501252	30	6900751	30	6900751	30
M12A	16310	195720000	170	11760841	30	11760841	30	7056505	30	7056505	30
Case 2-4											
M16	445	5340000	360	320881	30	320881	30	192529	30	192529	30
M15	785	9420000	480	566049	30	566049	30	339629	30	339629	30
M14	1041	12492000	100	750646	30	750646	30	450388	30	450388	30
M13	1691	20292000	300	1219349	30	1219349	30	731609	30	731609	30
M12B	2041	24492000	100	1471728	30	1471728	30	883037	30	883037	30
Case 5-7											
Case 6-8											
Total Main Line Pressure Drop:				34.39		10.32		12.38		3.71	

			Case 9		Case 10		Case 11-13		Case 12-14		
M1	5155	61860000	410	1407323	30	1407323	30	1036326	30	1036326	30
M2	5455	65460000	130	1489223	30	1489223	30	1096635	30	1096635	30
M3	7855	94260000	680	2144427	30	2144427	30	1579115	30	1579115	30
M4	10247	122964000	420	2797446	30	2797446	30	2059986	30	2059986	30
M5	10347	124164000	420	2824747	30	2824747	30	2080089	30	2080089	30
M6	12115	145380000	10	3307413	30	3307413	30	2435516	30	2435516	30
M7	14595	175140000	55	3984457	30	3984457	30	2934078	30	2934078	30
M8	15405	184860000	40	4205588	30	4205588	30	3096915	30	3096915	30
M9	15515	186180000	540	4235618	30	4235618	30	3119028	30	3119028	30
M10	15700	188400000	40	4286124	30	4286124	30	3156219	30	3156219	30
M11	15950	191400000	300	4354374	30	4354374	30	3206478	30	3206478	30
M12A	16310	195720000	170	4452655	30	4452655	30	3278850	30	3278850	30
M16	445	5340000	360	121486	30	121486	30	89460	30	89460	30
M15	785	9420000	480	214306	30	214306	30	157811	30	157811	30
M14	1041	12492000	100	284195	30	284195	30	209275	30	209275	30
M13	1691	20292000	300	461646	30	461646	30	339947	30	339947	30
M12B	2041	24492000	100	557196	30	557196	30	410309	30	410309	30
Total Main Line Pressure Drop:				4.93		1.48		2.67		1.74	

30" dia

Table F1.1

Summary of the Economical Analysis - Ottawa Chiller

30" dia

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O	\$/year	ftH2O

	Case 1-3				Case 2-4				Case 5				Case 6				Case 7			
M1	5155	410	11139	0.87	11139	0.26	11139	0.31	11139	0.09	11139	0.31	11139	0.09	11139	0.31	11139	0.31	11139	0.31
M2	5455	130	3532	0.31	3532	0.09	3532	0.11	3532	0.03	3532	0.11	3532	0.03	3532	0.11	3532	0.11	3532	0.11
M3	7855	680	18474	3.34	18474	1.00	18474	1.20	18474	0.36	18474	1.20	18474	0.36	18474	1.20	18474	1.20	18474	1.20
M4	10247	420	11410	3.51	11410	1.05	11410	1.27	11410	0.38	11410	1.27	11410	0.38	11410	1.27	11410	1.27	11410	1.27
M5	10347	420	11410	3.58	11410	1.07	11410	1.29	11410	0.39	11410	1.29	11410	0.39	11410	1.29	11410	1.29	11410	1.29
M6	12115	10	272	0.12	272	0.04	272	0.04	272	0.01	272	0.04	272	0.01	272	0.04	272	0.04	272	0.04
M7	14595	55	1494	0.93	1494	0.28	1494	0.34	1494	0.10	1494	0.34	1494	0.10	1494	0.34	1494	0.34	1494	0.34
M8	15405	40	1087	0.76	1087	0.23	1087	0.27	1087	0.08	1087	0.27	1087	0.08	1087	0.27	1087	0.27	1087	0.27
M9	15515	540	14670	10.36	14670	3.11	14670	3.73	14670	1.12	14670	3.73	14670	1.12	14670	3.73	14670	3.73	14670	3.73
M10	15700	40	1087	0.79	1087	0.24	1087	0.28	1087	0.08	1087	0.28	1087	0.08	1087	0.28	1087	0.28	1087	0.28
M11	15950	300	8150	6.08	8150	1.82	8150	2.19	8150	0.66	8150	2.19	8150	0.66	8150	2.19	8150	2.19	8150	2.19
M12A	16310	170	4618	3.60	4618	1.08	4618	1.30	4618	0.39	4618	1.30	4618	0.39	4618	1.30	4618	1.30	4618	1.30
M16	445	360	9780	0.01	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00
M15	785	480	13040	0.02	13040	0.01	13040	0.01	13040	0.00	13040	0.01	13040	0.00	13040	0.01	13040	0.01	13040	0.01
M14	1041	100	2717	0.01	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00
M13	1691	300	8150	0.07	8150	0.02	8150	0.02	8150	0.01	8150	0.02	8150	0.01	8150	0.02	8150	0.02	8150	0.02
M12B	2041	100	2717	0.03	2717	0.01	2717	0.01	2717	0.00	2717	0.01	2717	0.00	2717	0.01	2717	0.01	2717	0.01
Main Line Delta P:			34.39		10.32		12.38		3.71		12.38		3.71		12.38		3.71		12.38	
Max Delta P:			37.95		11.38		13.66		4.11		13.66		4.11		13.66		4.11		13.66	
Subtotal:			123747	43334	123747	12993	123747	30002	123747	9018	123747	11121	123747	9018	123747	11121	123747	11121	123747	11121
Total Cost:			167081		136740		153749		132765		134868		132765		134868		132765		134868	

	Case 8				Case 9				Case 10				Case 11-13				Case 12-14			
M1	5155	410	11139	0.09	11139	0.12	11139	0.04	11139	0.07	11139	0.04	11139	0.07	11139	0.04	11139	0.04	11139	0.04
M2	5455	130	3532	0.03	3532	0.04	3532	0.01	3532	0.02	3532	0.01	3532	0.02	3532	0.01	3532	0.02	3532	0.02
M3	7855	680	18474	0.36	18474	0.48	18474	0.14	18474	0.26	18474	0.14	18474	0.26	18474	0.17	18474	0.17	18474	0.17
M4	10247	420	11410	0.38	11410	0.50	11410	0.15	11410	0.27	11410	0.15	11410	0.27	11410	0.18	11410	0.18	11410	0.18
M5	10347	420	11410	0.39	11410	0.51	11410	0.15	11410	0.28	11410	0.15	11410	0.28	11410	0.18	11410	0.18	11410	0.18
M6	12115	10	272	0.01	272	0.02	272	0.01	272	0.01	272	0.01	272	0.01	272	0.01	272	0.01	272	0.01
M7	14595	55	1494	0.10	1494	0.13	1494	0.04	1494	0.07	1494	0.04	1494	0.07	1494	0.05	1494	0.05	1494	0.05
M8	15405	40	1087	0.08	1087	0.11	1087	0.03	1087	0.06	1087	0.03	1087	0.06	1087	0.04	1087	0.04	1087	0.04
M9	15515	540	14670	1.12	14670	1.48	14670	0.45	14670	0.81	14670	0.45	14670	0.81	14670	0.52	14670	0.52	14670	0.52
M10	15700	40	1087	0.08	1087	0.11	1087	0.03	1087	0.06	1087	0.03	1087	0.06	1087	0.04	1087	0.04	1087	0.04
M11	15950	300	8150	0.66	8150	0.87	8150	0.26	8150	0.47	8150	0.26	8150	0.47	8150	0.31	8150	0.31	8150	0.31
M12A	16310	170	4618	0.39	4618	0.52	4618	0.15	4618	0.28	4618	0.15	4618	0.28	4618	0.18	4618	0.18	4618	0.18
M16	445	360	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00	9780	0.00
M15	785	480	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00	13040	0.00
M14	1041	100	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00
M13	1691	300	8150	0.01	8150	0.01	8150	0.00	8150	0.01	8150	0.00	8150	0.01	8150	0.00	8150	0.00	8150	0.00
M12B	2041	100	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00	2717	0.00
Main Line Delta P:			3.71		4.93		1.48		2.67		1.74		2.67		1.74		2.67		1.74	
Max Delta P:			4.11		5.44		1.62		2.95		1.91		2.95		1.91		2.95		1.91	
Subtotal:			123747	3343	123747	2795	123747	834	123747	4795	123747	3107	123747	4795	123747	3107	123747	3107	123747	3107
Total Cost:			127090		126542		124581		128542		126854		128542		126854		128542		126854	

30" dia

Table F1.2

Summary of Main Line Mass Flow Rates and Pipe Diam - Ottawa Chiller

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor	0.015
Max Velocity-others	10 ft/s	Friction Factor with FRA	0.0045
Max Pressure	5 ft H2O	Fraction of full load carried	0.631
Diversity Factor	0.9	when dist storage is involved	

Cooling Load			Len ft	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in	MFR lbm/hr	Dia. in
RT	BTU/hr										
			Case 1-3			Case 2-4		Case 5-7		Case 6-8	
M1	5155	61860000	410	3717176	34	3717176	34	2230305	34	2230305	34
M2	5455	65460000	130	3933500	34	3933500	34	2360100	34	2360100	34
M3	7855	94260000	680	5664096	34	5664096	34	3398458	34	3398458	34
M4	10247	122964000	420	7388923	34	7388923	34	4433354	34	4433354	34
M5	10347	124164000	420	7461032	34	7461032	34	4476619	34	4476619	34
M6	12115	145380000	10	8735904	34	8735904	34	5241542	34	5241542	34
M7	14595	175140000	55	10524186	34	10524186	34	6314512	34	6314512	34
M8	15405	184860000	40	11108262	34	11108262	34	6664957	34	6664957	34
M9	15515	186180000	540	11187581	34	11187581	34	6712549	34	6712549	34
M10	15700	188400000	40	11320981	34	11320981	34	6792589	34	6792589	34
M11	15950	191400000	300	11501252	34	11501252	34	6900751	34	6900751	34
M12A	16310	195720000	170	11760841	34	11760841	34	7056505	34	7056505	34
M16	445	5340000	360	320881	34	320881	34	192529	34	192529	34
M15	785	9420000	480	566049	34	566049	34	339629	34	339629	34
M14	1041	12492000	100	750646	34	750646	34	450388	34	450388	34
M13	1691	20292000	300	1219349	34	1219349	34	731609	34	731609	34
M12B	2041	24492000	100	1471728	34	1471728	34	883037	34	883037	34
Total Main Line Pressure Drop:				18.39		5.52		6.62		1.99	

			Case 9			Case 10		Case 11-13		Case 12-14	
M1	5155	61860000	410	1407323	34	1407323	34	1036326	34	1036326	34
M2	5455	65460000	130	1489223	34	1489223	34	1096635	34	1096635	34
M3	7855	94260000	680	2144427	34	2144427	34	1579115	34	1579115	34
M4	10247	122964000	420	2797446	34	2797446	34	2059986	34	2059986	34
M5	10347	124164000	420	2824747	34	2824747	34	2080089	34	2080089	34
M6	12115	145380000	10	3307413	34	3307413	34	2435516	34	2435516	34
M7	14595	175140000	55	3984457	34	3984457	34	2934078	34	2934078	34
M8	15405	184860000	40	4205588	34	4205588	34	3096915	34	3096915	34
M9	15515	186180000	540	4235618	34	4235618	34	3119028	34	3119028	34
M10	15700	188400000	40	4286124	34	4286124	34	3156219	34	3156219	34
M11	15950	191400000	300	4354374	34	4354374	34	3206478	34	3206478	34
M12A	16310	195720000	170	4452655	34	4452655	34	3278850	34	3278850	34
M16	445	5340000	360	121486	34	121486	34	89460	34	89460	34
M15	785	9420000	480	214306	34	214306	34	157811	34	157811	34
M14	1041	12492000	100	284195	34	284195	34	209275	34	209275	34
M13	1691	20292000	300	461646	34	461646	34	339947	34	339947	34
M12B	2041	24492000	100	557196	34	557196	34	410309	34	410309	34
Total Main Line Pressure Drop:				2.64		0.79		1.43		0.93	

34" dia

Table F2.1

Parameters:	Period of Investment	20 years	Period of Utilisation:	
	Interest Rate	7 %	Conventional	585 hours
	Annuity	0.0944	Low Temp	1875 hours
	Energy Cost	7.74E-05 \$/BTU	Low Temp(stor)	695 hours
	Pump Efficiency	0.6	Ice Slurry	2985 hours

Cooling Load	Len	Pipe	Delta	Pipe	Delta	Pipe	Delta P	Pipe	Delta	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O	\$/year	ftH ₂ O

Case 1-3			Case 2-4			Case 5			Case 6			Case 7		
M1	5155	410	12675	0.46	12675	0.14	12675	0.17	12675	0.05	12675	0.17	12675	0.17
M2	5455	130	4019	0.16	4019	0.05	4019	0.06	4019	0.02	4019	0.06	4019	0.06
M3	7855	680	21021	1.79	21021	0.54	21021	0.64	21021	0.19	21021	0.64	21021	0.64
M4	10247	420	12984	1.88	12984	0.56	12984	0.68	12984	0.20	12984	0.68	12984	0.68
M5	10347	420	12984	1.92	12984	0.57	12984	0.69	12984	0.21	12984	0.69	12984	0.69
M6	12115	10	309	0.06	309	0.02	309	0.02	309	0.01	309	0.02	309	0.02
M7	14595	55	1700	0.50	1700	0.15	1700	0.18	1700	0.05	1700	0.18	1700	0.18
M8	15405	40	1237	0.40	1237	0.12	1237	0.15	1237	0.04	1237	0.15	1237	0.15
M9	15515	540	16693	5.54	16693	1.66	16693	1.99	16693	0.60	16693	1.99	16693	1.99
M10	15700	40	1237	0.42	1237	0.13	1237	0.15	1237	0.05	1237	0.15	1237	0.15
M11	15950	300	9274	3.25	9274	0.98	9274	1.17	9274	0.35	9274	1.17	9274	1.17
M12A	16310	170	5255	1.93	5255	0.58	5255	0.69	5255	0.21	5255	0.69	5255	0.69
M16	445	360	11129	0.00	11129	0.00	11129	0.00	11129	0.00	11129	0.00	11129	0.00
M15	785	480	14839	0.01	14839	0.00	14839	0.00	14839	0.00	14839	0.00	14839	0.00
M14	1041	100	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00
M13	1691	300	9274	0.04	9274	0.01	9274	0.01	9274	0.00	9274	0.01	9274	0.01
M12B	2041	100	3091	0.02	3091	0.01	3091	0.01	3091	0.00	3091	0.01	3091	0.01
Main Line Delta P:			18.39		5.52		6.62		1.99		6.62			
Max Delta P:			32.50		9.74		11.70		3.52		11.70			
Subtotal:			140812	37102	140812	11124	140812	25688	140812	7724	140812	9522		
Total Cost:			177914		151936		166500		148536		150334			

Case 8			Case 9			Case 10			Case 11-13			Case 12-14		
M1	5155	410	12675	0.05	12675	0.07	12675	0.02	12675	0.04	12675	0.02	12675	0.02
M2	5455	130	4019	0.02	4019	0.02	4019	0.01	4019	0.01	4019	0.01	4019	0.01
M3	7855	680	21021	0.19	21021	0.26	21021	0.08	21021	0.14	21021	0.09	21021	0.09
M4	10247	420	12984	0.20	12984	0.27	12984	0.08	12984	0.15	12984	0.09	12984	0.09
M5	10347	420	12984	0.21	12984	0.27	12984	0.08	12984	0.15	12984	0.10	12984	0.10
M6	12115	10	309	0.01	309	0.01	309	0.00	309	0.00	309	0.00	309	0.00
M7	14595	55	1700	0.05	1700	0.07	1700	0.02	1700	0.04	1700	0.03	1700	0.03
M8	15405	40	1237	0.04	1237	0.06	1237	0.02	1237	0.03	1237	0.02	1237	0.02
M9	15515	540	16693	0.60	16693	0.79	16693	0.24	16693	0.43	16693	0.28	16693	0.28
M10	15700	40	1237	0.05	1237	0.06	1237	0.02	1237	0.03	1237	0.02	1237	0.02
M11	15950	300	9274	0.35	9274	0.47	9274	0.14	9274	0.25	9274	0.16	9274	0.16
M12A	16310	170	5255	0.21	5255	0.28	5255	0.08	5255	0.15	5255	0.10	5255	0.10
M16	445	360	11129	0.00	11129	0.00	11129	0.00	11129	0.00	11129	0.00	11129	0.00
M15	785	480	14839	0.00	14839	0.00	14839	0.00	14839	0.00	14839	0.00	14839	0.00
M14	1041	100	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00
M13	1691	300	9274	0.00	9274	0.01	9274	0.00	9274	0.00	9274	0.00	9274	0.00
M12B	2041	100	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00	3091	0.00
Main Line Delta P:			1.99		2.64		0.79		1.43		0.93			
Max Delta P:			3.52		4.66		1.39		2.53		1.64			
Subtotal			140812	2863	140812	2393	140812	714	140812	4106	140812	2659		
Total Cost:			143675		143205		141526		144918		143471			

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:

Max Velocity-conv:	10 ft/s	Friction Factor:	0.015
Max Velocity-others	8 ft/s	Friction Factor with FRA:	0.0045
Max Pressure:	5 ft H2O	Fraction of full load carried	
Diversity Factor:	1	when dist storage is involved:	0.631

Cooling Load	Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr

		Case 1-3		Case 2-4		Case 5-7		Case 6-8	
S1	300	3600000	870	240361	8	240361	8	144216	6
S2	2400	28800000	150	1922884	14	1922884	14	1153731	12
S3	2392	28704000	300	1916475	14	1916475	14	1149885	12
S4	2232	26784000	200	1788282	14	1788282	14	1072969	12
S5	1386	16632000	790	1110466	12	1110466	12	666279	10
SS6	160	1920000	210	128192	6	128192	6	76915	6
SS7	846	10152000	390	677817	10	677817	10	406690	8
S8	100	1200000	400	80120	6	80120	6	48072	6
S9	1768	21216000	90	1416525	12	1416525	12	849915	10
S10	1082	12984000	135	866900	10	866900	10	520140	10
S11	677	8124000	340	542414	10	542414	10	325448	8
S12	272	3264000	210	217927	8	217927	8	130756	6
SS13	686	8232000	80	549624	10	549624	10	329775	8
SS14	405	4860000	130	324487	8	324487	8	194692	8
SS15	405	4860000	110	324487	8	324487	8	194692	8
S16	2480	29760000	500	1986980	14	1986980	14	1192188	12
S17	1680	20160000	20	1346019	12	1346019	12	807611	10
S18	1560	18720000	280	1249875	12	1249875	12	749925	10
S19	1180	14160000	140	945418	12	945418	12	567251	10
S20	180	2160000	360	144216	6	144216	6	86530	6
SS21	800	9600000	280	640961	10	640961	10	384577	8
SS22	120	1440000	470	96144	6	96144	6	57687	6
SS23	380	4560000	100	304457	8	304457	8	182674	8
SS24	1000	12000000	100	801202	10	801202	10	480721	10
S25	810	9720000	70	648973	10	648973	10	389384	8
S26	110	1320000	70	88132	6	88132	6	52879	6
S27	185	2220000	150	148222	6	148222	6	88933	6
S28	250	3000000	100	200300	8	200300	8	120180	6
S29	360	4320000	150	288433	8	288433	8	173060	8
S30	350	4200000	90	280421	8	280421	8	168252	8
S31	650	7800000	110	520781	10	520781	10	312469	8
S32	256	3072000	410	205108	8	205108	8	123065	6
S33	340	4080000	340	272409	8	272409	8	163445	6

Case A2

Table SEC1.1

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:			
Max Velocity-corr:	10 ft/s	Friction Factor:	0.015
Max Velocity-others	8 ft/s	Friction Factor with FRA:	0.0045
Max Pressure:	5 ft H2O	Fraction of full load carried	
Diversity Factor:	1	when dist storage is involved:	0.631

Cooling Load	Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in

Case 9												Case 10		Case 11-13		Case 12-14	
S1	300	3600000	870	91001	6	91001	6	67011	6	67011	6						
S2	2400	28800000	150	728004	10	728004	10	536088	10	536088	10						
S3	2392	28704000	300	725577	10	725577	10	534301	10	534301	10						
S4	2232	26784000	200	677044	10	677044	10	498562	10	498562	10						
S5	1386	16632000	790	420422	8	420422	8	309591	8	309591	8						
SS6	160	1920000	210	48534	6	48534	6	35739	6	35739	6						
SS7	846	10152000	390	256621	8	256621	8	188971	8	188971	8						
S8	100	1200000	400	30334	6	30334	6	22337	4	22337	4						
S9	1768	21216000	90	536296	10	536296	10	394918	8	394918	8						
S10	1082	12984000	135	328208	8	328208	8	241686	8	241686	8						
S11	677	8124000	340	205358	8	205358	8	151222	6	151222	6						
S12	272	3264000	210	82507	6	82507	6	60757	6	60757	6						
SS13	686	8232000	80	208088	8	208088	8	153232	6	153232	6						
SS14	405	4860000	130	122851	6	122851	6	90465	6	90465	6						
SS15	405	4860000	110	122851	6	122851	6	90465	6	90465	6						
S16	2480	29760000	500	752271	10	752271	10	553958	10	553958	10						
S17	1680	20160000	20	509603	10	509603	10	375262	8	375262	8						
S18	1560	18720000	280	473203	10	473203	10	348457	8	348457	8						
S19	1180	14160000	140	357935	8	357935	8	263577	8	263577	8						
S20	180	2160000	360	54600	6	54600	6	40207	6	40207	6						
SS21	800	9600000	280	242668	8	242668	8	178696	8	178696	8						
SS22	120	1440000	470	36400	6	36400	6	26804	4	26804	4						
SS23	380	4560000	100	115267	6	115267	6	84881	6	84881	6						
SS24	1000	12000000	100	303335	8	303335	8	223370	8	223370	8						
S25	810	9720000	70	245701	8	245701	8	180930	8	180930	8						
S26	110	1320000	70	33367	6	33367	6	24571	4	24571	4						
S27	185	2220000	150	56117	6	56117	6	41323	6	41323	6						
S28	250	3000000	100	75834	6	75834	6	55843	6	55843	6						
S29	360	4320000	150	109201	6	109201	6	80413	6	80413	6						
S30	350	4200000	90	106167	6	106167	6	78180	6	78180	6						
S31	650	7800000	110	197168	8	197168	8	145191	6	145191	6						
S32	256	3072000	410	77654	6	77654	6	57183	6	57183	6						
S33	340	4080000	340	103134	6	103134	6	75946	6	75946	6						

Case A2

Table SEC1.2

Summary of the Secondary Line Economic Analysis

Parameters:		
Period of Investment:	20	years
Interest Rate:	7	%
Annuity:	0.0944	

Cooling Load	Len	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P
RT	ft	\$/year	ftH ₂ O	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year

			Case 1-3		Case 2-4		Case 5		Case 6		Case 7	
S1	300	870	8781	5.71	8781	1.71	7689	8.67	7689	2.60	7689	8.67
S2	2400	150	2124	3.84	2124	1.15	1913	2.99	1913	0.90	1913	2.99
S3	2392	300	4247	7.63	4247	2.29	3826	5.94	3826	1.78	3826	5.94
S4	2232	200	2831	4.43	2831	1.33	2551	3.45	2551	1.03	2551	3.45
S5	1386	790	10075	14.58	10075	4.37	9005	13.06	9005	3.92	9005	13.06
Branch Delta P:			26.64		7.99		22.44		6.73		22.44	
SS6	160	210	1856	1.65	1856	0.50	1856	0.59	1856	0.18	1856	0.59
SS7	846	390	4445	6.67	4445	2.00	3936	7.33	3936	2.20	3936	7.33
S8	100	400	3535	1.23	3535	0.37	3535	0.44	3535	0.13	3535	0.44
S9	1768	90	1148	2.70	1148	0.81	1026	2.42	1026	0.73	1026	2.42
S10	1082	135	1539	3.78	1539	1.13	1539	1.36	1539	0.41	1539	1.36
S11	677	340	3876	3.73	3876	1.12	3432	4.09	3432	1.23	3432	4.09
S12	272	210	2120	1.13	2120	0.34	1856	1.72	1856	0.52	1856	1.72
Branch Delta P:			11.34		3.40		9.59		2.88		9.59	
SS13	686	80	912	0.90	912	0.27	807	0.99	807	0.30	807	0.99
SS14	405	130	1312	1.56	1312	0.47	1312	0.56	1312	0.17	1312	0.56
SS15	405	110	1110	1.32	1110	0.39	1110	0.47	1110	0.14	1110	0.47
S16	2480	500	7079	13.67	7079	4.10	6377	10.64	6377	3.19	6377	10.64
S17	1680	20	255	0.54	255	0.16	228	0.49	228	0.15	228	0.49
S18	1560	280	3571	6.55	3571	1.96	3192	5.86	3192	1.76	3192	5.86
S19	1180	140	1785	1.87	1785	0.56	1596	1.68	1596	0.50	1596	1.68
S20	180	360	3182	3.59	3182	1.08	3182	1.29	3182	0.39	3182	1.29
Branch Delta P:			26.22		7.86		19.95		5.99		19.95	
SS21	800	280	3192	4.28	3192	1.29	2826	4.71	2826	1.41	2826	4.71
SS22	120	470	4154	2.08	4154	0.62	4154	0.75	4154	0.22	4154	0.75
SS23	380	100	1009	1.05	1009	0.32	1009	0.38	1009	0.11	1009	0.38
SS24	1000	100	1140	2.39	1140	0.72	1140	0.86	1140	0.26	1140	0.86
S25	810	70	798	1.10	798	0.33	707	1.21	707	0.36	707	1.21
S26	110	70	619	0.26	619	0.08	619	0.09	619	0.03	619	0.09
S27	185	150	1326	1.58	1326	0.47	1326	0.57	1326	0.17	1326	0.57
S28	250	100	1009	0.46	1009	0.14	884	0.69	884	0.21	884	0.69
S29	360	150	1514	1.42	1514	0.43	1514	0.51	1514	0.15	1514	0.51
S30	350	90	908	0.80	908	0.24	908	0.29	908	0.09	908	0.29
S31	650	110	1254	1.11	1254	0.33	1110	1.22	1110	0.37	1110	1.22
S32	256	410	4138	1.96	4138	0.59	3623	2.97	3623	0.89	3623	2.97
S33	340	340	3432	2.87	3432	0.86	3005	4.35	3005	1.30	3005	4.35
Total Pipe Cost:			90276		90276		82793		82793		82793	

Case A2

Table SEC1.3

Summary of the Secondary Line Economic Analysis

Parameters:

Period of Investment: 20 years
Interest Rate: 7 %
Annuity: 0.0944

Cooling Load Len Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P
RT ft \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year

			Case 8		Case 9		Case 10		Case 11-13		Case 12-14	
S1	300	870	7689	2.60	7689	3.45	7689	1.04	7689	1.87	7689	1.22
S2	2400	150	1913	0.90	1710	2.96	1710	0.89	1710	1.61	1710	1.04
S3	2392	300	3826	1.78	3420	5.88	3420	1.76	3420	3.19	3420	2.07
S4	2232	200	2551	1.03	2280	3.41	2280	1.02	2280	1.85	2280	1.20
S5	1386	790	9005	3.92	7974	15.87	7974	4.76	7974	8.61	7974	5.59
Branch Delta P:			6.73		25.17		7.55		13.65		8.87	
SS6	160	210	1856	0.18	1856	0.24	1856	0.07	1856	0.13	1856	0.08
SS7	846	390	3936	2.20	3936	2.92	3936	0.88	3936	1.58	3936	1.03
S8	100	400	3535	0.13	3535	0.18	3535	0.05	3053	0.73	3053	0.47
S9	1768	90	1026	0.73	1026	0.96	1026	0.29	908	1.60	908	1.04
S10	1082	135	1539	0.41	1363	1.65	1363	0.50	1363	0.90	1363	0.58
S11	677	340	3432	1.23	3432	1.63	3432	0.49	3005	3.72	3005	2.42
S12	272	210	1856	0.52	1856	0.68	1856	0.21	1856	0.37	1856	0.24
Branch Delta P:			2.88		4.93		1.48		6.59		4.28	
SS13	686	80	807	0.30	807	0.39	807	0.12	707	0.90	707	0.58
SS14	405	130	1312	0.17	1149	0.94	1149	0.28	1149	0.51	1149	0.33
SS15	405	110	1110	0.14	972	0.80	972	0.24	972	0.43	972	0.28
S16	2480	500	6377	3.19	5699	10.54	5699	3.16	5699	5.71	5699	3.71
S17	1680	20	228	0.15	228	0.19	228	0.06	202	0.32	202	0.21
S18	1560	280	3192	1.76	3192	2.33	3192	0.70	2826	3.86	2826	2.51
S19	1180	140	1596	0.50	1413	2.04	1413	0.61	1413	1.11	1413	0.72
S20	180	360	3182	0.39	3182	0.51	3182	0.15	3182	0.28	3182	0.18
Branch Delta P:			5.99		15.62		4.69		11.28		7.33	
SS21	800	280	2826	1.41	2826	1.87	2826	0.56	2826	1.02	2826	0.66
SS22	120	470	4154	0.22	4154	0.30	4154	0.09	3587	1.23	3587	0.80
SS23	380	100	1009	0.11	884	0.64	884	0.19	884	0.35	884	0.22
SS24	1000	100	1140	0.26	1009	1.05	1009	0.31	1009	0.57	1009	0.37
S25	810	70	707	0.36	707	0.48	707	0.14	707	0.26	707	0.17
S26	110	70	619	0.03	619	0.04	619	0.01	534	0.15	534	0.10
S27	185	150	1326	0.17	1326	0.23	1326	0.07	1326	0.12	1326	0.08
S28	250	100	884	0.21	884	0.28	884	0.08	884	0.15	884	0.10
S29	360	150	1514	0.15	1326	0.86	1326	0.26	1326	0.46	1326	0.30
S30	350	90	908	0.09	795	0.49	795	0.15	795	0.26	795	0.17
S31	650	110	1110	0.37	1110	0.49	1110	0.15	972	1.11	972	0.72
S32	256	410	3623	0.89	3623	1.18	3623	0.36	3623	0.64	3623	0.42
S33	340	340	3005	1.30	3005	1.73	3005	0.52	3005	0.94	3005	0.61
Total Pipe Cost:			82793		78987		78987		76678		76678	

Case A2

Table SEC1.4

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:			
Max Velocity-conv	10 ft/s	Friction Factor:	0.015
Max Velocity-others	10 ft/s	Friction Factor with FRA:	0.0045
Max Pressure:	5 ft H ₂ O	Fraction of full load carried	
Diversity Factor:	1	when dist storage is involved:	0.631

Cooling Load	Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT	BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr

	Case 1-3				Case 2-4				Case 5-7				Case 6-8			
S1	300	3600000	870	240361	8	240361	8	144216	8	144216	8	144216	8	144216	8	144216
S2	2400	28800000	150	1922884	14	1922884	14	1153731	14	1153731	14	1153731	14	1153731	14	1153731
S3	2392	28704000	300	1916475	14	1916475	14	1149885	14	1149885	14	1149885	14	1149885	14	1149885
S4	2232	26784000	200	1788282	14	1788282	14	1072969	14	1072969	14	1072969	14	1072969	14	1072969
S5	1386	16632000	790	1110466	12	1110466	12	666279	12	666279	12	666279	12	666279	12	666279
SS6	160	1920000	210	128192	6	128192	6	76915	6	76915	6	76915	6	76915	6	76915
SS7	846	10152000	390	677817	10	677817	10	406690	10	406690	10	406690	10	406690	10	406690
S8	100	1200000	400	80120	6	80120	6	48072	6	48072	6	48072	6	48072	6	48072
S9	1768	21216000	90	1416525	12	1416525	12	849915	12	849915	12	849915	12	849915	12	849915
S10	1082	12984000	135	866900	10	866900	10	520140	10	520140	10	520140	10	520140	10	520140
S11	677	8124000	340	542414	10	542414	10	325448	10	325448	10	325448	10	325448	10	325448
S12	272	3264000	210	217927	8	217927	8	130756	8	130756	8	130756	8	130756	8	130756
SS13	686	8232000	80	549624	10	549624	10	329775	10	329775	10	329775	10	329775	10	329775
SS14	405	4860000	130	324487	8	324487	8	194692	8	194692	8	194692	8	194692	8	194692
SS15	405	4860000	110	324487	8	324487	8	194692	8	194692	8	194692	8	194692	8	194692
S16	2480	29760000	500	1986980	14	1986980	14	1192188	14	1192188	14	1192188	14	1192188	14	1192188
S17	1680	20160000	20	1346019	12	1346019	12	807611	12	807611	12	807611	12	807611	12	807611
S18	1560	18720000	280	1249875	12	1249875	12	749925	12	749925	12	749925	12	749925	12	749925
S19	1180	14160000	140	945418	12	945418	12	567251	12	567251	12	567251	12	567251	12	567251
S20	180	2160000	360	144216	6	144216	6	86530	6	86530	6	86530	6	86530	6	86530
SS21	800	9600000	280	640961	10	640961	10	384577	10	384577	10	384577	10	384577	10	384577
SS22	120	1440000	470	96144	6	96144	6	57687	6	57687	6	57687	6	57687	6	57687
SS23	380	4560000	100	304457	8	304457	8	182674	8	182674	8	182674	8	182674	8	182674
SS24	1000	12000000	100	801202	10	801202	10	480721	10	480721	10	480721	10	480721	10	480721
S25	810	9720000	70	648973	10	648973	10	389384	10	389384	10	389384	10	389384	10	389384
S26	110	1320000	70	88132	6	88132	6	52879	6	52879	6	52879	6	52879	6	52879
S27	185	2220000	150	148222	6	148222	6	88933	6	88933	6	88933	6	88933	6	88933
S28	250	3000000	100	200300	8	200300	8	120180	8	120180	8	120180	8	120180	8	120180
S29	360	4320000	150	288433	8	288433	8	173060	8	173060	8	173060	8	173060	8	173060
S30	350	4200000	90	280421	8	280421	8	168252	8	168252	8	168252	8	168252	8	168252
S31	650	7800000	110	520781	10	520781	10	312469	10	312469	10	312469	10	312469	10	312469
S32	256	3072000	410	205108	8	205108	8	123065	8	123065	8	123065	8	123065	8	123065
S33	340	4080000	340	272409	8	272409	8	163445	8	163445	8	163445	8	163445	8	163445

Case A1-E1-F1-F2

Table SEC2.1

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:					
Max Velocity-conv	10	ft/s	Friction Factor:	0.015	
Max Velocity-others	10	ft/s	Friction Factor with FRA:	0.0045	
Max Pressure:	5	ft H ₂ O	Fraction of full load carried		
Diversity Factor:	1		when dist storage is involved:	0.631	

Cooling Load	Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
RT BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in

Case 9				Case 10		Case 11-13		Case 12-14			
S1	300	3600000	870	91001	8	91001	8	67011	8	67011	8
S2	2400	28800000	150	728004	14	728004	14	536088	14	536088	14
S3	2392	28704000	300	725577	14	725577	14	534301	14	534301	14
S4	2232	26784000	200	677044	14	677044	14	498562	14	498562	14
S5	1386	16632000	790	420422	12	420422	12	309591	12	309591	12
SS6	160	1920000	210	48534	6	48534	6	35739	6	35739	6
SS7	846	10152000	390	256621	10	256621	10	188971	10	188971	10
S8	100	1200000	400	30334	6	30334	6	22337	6	22337	6
S9	1768	21216000	90	536296	12	536296	12	394918	12	394918	12
S10	1082	12984000	135	328208	10	328208	10	241686	10	241686	10
S11	677	8124000	340	205358	10	205358	10	151222	10	151222	10
S12	272	3264000	210	82507	8	82507	8	60757	8	60757	8
SS13	686	8232000	80	208088	10	208088	10	153232	10	153232	10
SS14	405	4860000	130	122851	8	122851	8	90465	8	90465	8
SS15	405	4860000	110	122851	8	122851	8	90465	8	90465	8
S16	2480	29760000	500	752271	14	752271	14	553958	14	553958	14
S17	1680	20160000	20	509603	12	509603	12	375262	12	375262	12
S18	1560	18720000	280	473203	12	473203	12	348457	12	348457	12
S19	1180	14160000	140	357935	12	357935	12	263577	12	263577	12
S20	180	2160000	360	54600	6	54600	6	40207	6	40207	6
SS21	800	9600000	280	242668	10	242668	10	178696	10	178696	10
SS22	120	1440000	470	36400	6	36400	6	26804	6	26804	6
SS23	380	4560000	100	115267	8	115267	8	84881	8	84881	8
SS24	1000	12000000	100	303335	10	303335	10	223370	10	223370	10
S25	810	9720000	70	245701	10	245701	10	180930	10	180930	10
S26	110	1320000	70	33367	6	33367	6	24571	6	24571	6
S27	185	2220000	150	56117	6	56117	6	41323	6	41323	6
S28	250	3000000	100	75834	8	75834	8	55843	8	55843	8
S29	360	4320000	150	109201	8	109201	8	80413	8	80413	8
S30	350	4200000	90	106167	8	106167	8	78180	8	78180	8
S31	650	7800000	110	197168	10	197168	10	145191	10	145191	10
S32	256	3072000	410	77654	8	77654	8	57183	8	57183	8
S33	340	4080000	340	103134	8	103134	8	75946	8	75946	8

Case A1-E1-F1-F2

Table SEC2.2

Summary of the Secondary Line Economic Analysis

Parameters:

Period of Investment: 20 years
Interest Rate: 7 %
Annuity: 0.0944

Cooling Load Len Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P
RT ft \$/year ftH₂O \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year

			Case 1-3		Case 2-4		Case 5		Case 6		Case 7	
S1	300	870	8781	5.71	8781	1.71	8781	2.06	8781	0.62	8781	2.06
S2	2400	150	2124	3.84	2124	1.15	2124	1.38	2124	0.41	2124	1.38
S3	2392	300	4247	7.63	4247	2.29	4247	2.75	4247	0.82	4247	2.75
S4	2232	200	2831	4.43	2831	1.33	2831	1.59	2831	0.48	2831	1.59
S5	1386	790	10075	14.58	10075	4.37	10075	5.25	10075	1.57	10075	5.25
Branch Delta P:			26.64		7.99		9.59		2.88		9.59	
SS6	160	210	1856	1.65	1856	0.50	1856	0.59	1856	0.18	1856	0.59
SS7	846	390	4445	6.67	4445	2.00	4445	2.40	4445	0.72	4445	2.40
S8	100	400	3535	1.23	3535	0.37	3535	0.44	3535	0.13	3535	0.44
S9	1768	90	1148	2.70	1148	0.81	1148	0.97	1148	0.29	1148	0.97
S10	1082	135	1539	3.78	1539	1.13	1539	1.36	1539	0.41	1539	1.36
S11	677	340	3876	3.73	3876	1.12	3876	1.34	3876	0.40	3876	1.34
S12	272	210	2120	1.13	2120	0.34	2120	0.41	2120	0.12	2120	0.41
Branch Delta P:			11.34		3.40		4.08		1.22		4.08	
SS13	686	80	912	0.90	912	0.27	912	0.32	912	0.10	912	0.32
SS14	405	130	1312	1.56	1312	0.47	1312	0.56	1312	0.17	1312	0.56
SS15	405	110	1110	1.32	1110	0.39	1110	0.47	1110	0.14	1110	0.47
S16	2480	500	7079	13.67	7079	4.10	7079	4.92	7079	1.48	7079	4.92
S17	1680	20	255	0.54	255	0.16	255	0.20	255	0.06	255	0.20
S18	1560	280	3571	6.55	3571	1.96	3571	2.36	3571	0.71	3571	2.36
S19	1180	140	1785	1.87	1785	0.56	1785	0.67	1785	0.20	1785	0.67
S20	180	360	3182	3.59	3182	1.08	3182	1.29	3182	0.39	3182	1.29
Branch Delta P:			26.22		7.86		9.44		2.83		9.44	
SS21	800	280	3192	4.28	3192	1.29	3192	1.54	3192	0.46	3192	1.54
SS22	120	470	4154	2.08	4154	0.62	4154	0.75	4154	0.22	4154	0.75
SS23	380	100	1009	1.05	1009	0.32	1009	0.38	1009	0.11	1009	0.38
SS24	1000	100	1140	2.39	1140	0.72	1140	0.86	1140	0.26	1140	0.86
S25	810	70	798	1.10	798	0.33	798	0.40	798	0.12	798	0.40
S26	110	70	619	0.26	619	0.08	619	0.09	619	0.03	619	0.09
S27	185	150	1326	1.58	1326	0.47	1326	0.57	1326	0.17	1326	0.57
S28	250	100	1009	0.46	1009	0.14	1009	0.16	1009	0.05	1009	0.16
S29	360	150	1514	1.42	1514	0.43	1514	0.51	1514	0.15	1514	0.51
S30	350	90	908	0.80	908	0.24	908	0.29	908	0.09	908	0.29
S31	650	110	1254	1.11	1254	0.33	1254	0.40	1254	0.12	1254	0.40
S32	256	410	4138	1.96	4138	0.59	4138	0.71	4138	0.21	4138	0.71
S33	340	340	3432	2.87	3432	0.86	3432	1.03	3432	0.31	3432	1.03
Total Pipe Cost:			90276		90276		90276		90276		90276	

Case A1-E1-F1-F2

Table SEC2.3

Summary of the Secondary Line Economic Analysis

Parameters:

Period of Investment: 20 years
Interest Rate: 7 %
Annuity: 0.0944

Cooling Load Len Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P
RT ft \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year

		Case 8		Case 9		Case 10		Case 11-13		Case 12-14	
S1	300	870	8781 0.62	8781 0.82	8781 0.25	8781 0.44	8781 0.29				
S2	2400	150	2124 0.41	2124 0.55	2124 0.17	2124 0.30	2124 0.19				
S3	2392	300	4247 0.82	4247 1.09	4247 0.33	4247 0.59	4247 0.39				
S4	2232	200	2831 0.48	2831 0.63	2831 0.19	2831 0.34	2831 0.22				
S5	1386	790	10075 1.57	10075 2.09	10075 0.63	10075 1.13	10075 0.74				
Branch Delta P:			2.88	3.82	1.15	2.07	1.35				
SS6	160	210	1856 0.18	1856 0.24	1856 0.07	1856 0.13	1856 0.08				
SS7	846	390	4445 0.72	4445 0.96	4445 0.29	4445 0.52	4445 0.34				
S8	100	400	3535 0.13	3535 0.18	3535 0.05	3535 0.10	3535 0.06				
S9	1768	90	1148 0.29	1148 0.39	1148 0.12	1148 0.21	1148 0.14				
S10	1082	135	1539 0.41	1539 0.54	1539 0.16	1539 0.29	1539 0.19				
S11	677	340	3876 0.40	3876 0.53	3876 0.16	3876 0.29	3876 0.19				
S12	272	210	2120 0.12	2120 0.16	2120 0.05	2120 0.09	2120 0.06				
Branch Delta P:			1.22	1.63	0.49	0.88	0.57				
SS13	686	80	912 0.10	912 0.13	912 0.04	912 0.07	912 0.05				
SS14	405	130	1312 0.17	1312 0.22	1312 0.07	1312 0.12	1312 0.08				
SS15	405	110	1110 0.14	1110 0.19	1110 0.06	1110 0.10	1110 0.07				
S16	2480	500	7079 1.48	7079 1.96	7079 0.59	7079 1.06	7079 0.69				
S17	1680	20	255 0.06	255 0.08	255 0.02	255 0.04	255 0.03				
S18	1560	280	3571 0.71	3571 0.94	3571 0.28	3571 0.51	3571 0.33				
S19	1180	140	1785 0.20	1785 0.27	1785 0.08	1785 0.15	1785 0.09				
S20	180	360	3182 0.39	3182 0.51	3182 0.15	3182 0.28	3182 0.18				
Branch Delta P:			2.83	3.76	1.13	2.04	1.32				
SS21	800	280	3192 0.46	3192 0.61	3192 0.18	3192 0.33	3192 0.22				
SS22	120	470	4154 0.22	4154 0.30	4154 0.09	4154 0.16	4154 0.11				
SS23	380	100	1009 0.11	1009 0.15	1009 0.05	1009 0.08	1009 0.05				
SS24	1000	100	1140 0.26	1140 0.34	1140 0.10	1140 0.19	1140 0.12				
S25	810	70	798 0.12	798 0.16	798 0.05	798 0.09	798 0.06				
S26	110	70	619 0.03	619 0.04	619 0.01	619 0.02	619 0.01				
S27	185	150	1326 0.17	1326 0.23	1326 0.07	1326 0.12	1326 0.08				
S28	250	100	1009 0.05	1009 0.07	1009 0.02	1009 0.04	1009 0.02				
S29	360	150	1514 0.15	1514 0.20	1514 0.06	1514 0.11	1514 0.07				
S30	350	90	908 0.09	908 0.12	908 0.03	908 0.06	908 0.04				
S31	650	110	1254 0.12	1254 0.16	1254 0.05	1254 0.09	1254 0.06				
S32	256	410	4138 0.21	4138 0.28	4138 0.08	4138 0.15	4138 0.10				
S33	340	340	3432 0.31	3432 0.41	3432 0.12	3432 0.22	3432 0.14				
Total Pipe Cost:			90276	90276	90276	90276	90276				

Case A1-E1-F1-F2

Table SEC2.4

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:			
Max Velocity-conv:	6 ft/s	Friction Factor:	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA:	0.0045
Max Pressure:	5 ft H ₂ O	Fraction of full load carried	
Diversity Factor:	1	when dist storage is involved:	0.631

Cooling Load	Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.	
RT	BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in

		Case 1-3			Case 2-4			Case 5-7			Case 6-8		
S1	300	3600000	870	240361	8	240361	8	144216	6	144216	6		
S2	2400	28800000	150	1922884	18	1922884	18	1153731	16	1153731	16		
S3	2392	28704000	300	1916475	18	1916475	18	1149885	16	1149885	16		
S4	2232	26784000	200	1788282	16	1788282	16	1072969	16	1072969	16		
S5	1386	16632000	790	1110466	14	1110466	14	666279	12	666279	12		
SS6	160	1920000	210	128192	6	128192	6	76915	6	76915	6		
SS7	846	10152000	390	677817	10	677817	10	406690	10	406690	10		
S8	100	1200000	400	80120	6	80120	6	48072	6	48072	6		
S9	1768	21216000	90	1416525	14	1416525	14	849915	14	849915	14		
S10	1082	12984000	135	866900	12	866900	12	520140	12	520140	12		
S11	677	8124000	340	542414	10	542414	10	325448	10	325448	10		
S12	272	3264000	210	217927	8	217927	8	130756	6	130756	6		
SS13	686	8232000	80	549624	10	549624	10	329775	10	329775	10		
SS14	405	4860000	130	324487	8	324487	8	194692	8	194692	8		
SS15	405	4860000	110	324487	8	324487	8	194692	8	194692	8		
S16	2480	29760000	500	1986980	18	1986980	18	1192188	16	1192188	16		
S17	1680	20160000	20	1346019	14	1346019	14	807611	14	807611	14		
S18	1560	18720000	280	1249875	14	1249875	14	749925	14	749925	14		
S19	1180	14160000	140	945418	12	945418	12	567251	12	567251	12		
S20	180	2160000	360	144216	6	144216	6	86530	6	86530	6		
SS21	800	9600000	280	640961	10	640961	10	384577	10	384577	10		
SS22	120	1440000	470	96144	6	96144	6	57687	6	57687	6		
SS23	380	4560000	100	304457	8	304457	8	182674	8	182674	8		
SS24	1000	12000000	100	801202	12	801202	12	480721	10	480721	10		
S25	810	9720000	70	648973	10	648973	10	389384	10	389384	10		
S26	110	1320000	70	88132	6	88132	6	52879	6	52879	6		
S27	185	2220000	150	148222	6	148222	6	88933	6	88933	6		
S28	250	3000000	100	200300	8	200300	8	120180	6	120180	6		
S29	360	4320000	150	288433	8	288433	8	173060	8	173060	8		
S30	350	4200000	90	280421	8	280421	8	168252	8	168252	8		
S31	650	7800000	110	520781	10	520781	10	312469	8	312469	8		
S32	256	3072000	410	205108	8	205108	8	123065	6	123065	6		
S33	340	4080000	340	272409	8	272409	8	163445	6	163445	6		

Case B-C-D-E2

Table SEC3.1

Summary of Secondary Line Mass Flow Rates and Pipe Diameters

Parameters:			
Max Velocity-conv:	6 ft/s	Friction Factor:	0.015
Max Velocity-others	4 ft/s	Friction Factor with FRA:	0.0045
Max Pressure:	5 ft H ₂ O	Fraction of full load carried	
Diversity Factor:	1	when dist storage is involved:	0.631

	Cooling Load		Len	MFR	Dia.	MFR	Dia.	MFR	Dia.	MFR	Dia.
	RT	BTU/hr	ft	lbm/hr	in	lbm/hr	in	lbm/hr	in	lbm/hr	in
	Case 9		Case 10		Case 11-13		Case 12-14				
S1	300	3600000	870	91001	6	91001	6	67011	6	67011	6
S2	2400	28800000	150	728004	14	728004	14	536088	12	536088	12
S3	2392	28704000	300	725577	14	725577	14	534301	12	534301	12
S4	2232	26784000	200	677044	12	677044	12	498562	12	498562	12
S5	1386	16632000	790	420422	10	420422	10	309591	8	309591	8
SS6	160	1920000	210	48534	6	48534	6	35739	6	35739	6
SS7	846	10152000	390	256621	8	256621	8	188971	8	188971	8
S8	100	1200000	400	30334	6	30334	6	22337	4	22337	4
S9	1768	21216000	90	536296	12	536296	12	394918	10	394918	10
S10	1082	12984000	135	328208	10	328208	10	241686	8	241686	8
S11	677	8124000	340	205358	8	205358	8	151222	6	151222	6
S12	272	3264000	210	82507	6	82507	6	60757	6	60757	6
SS13	686	8232000	80	208088	8	208088	8	153232	6	153232	6
SS14	405	4860000	130	122851	6	122851	6	90465	6	90465	6
SS15	405	4860000	110	122851	6	122851	6	90465	6	90465	6
S16	2480	29760000	500	752271	14	752271	14	553958	12	553958	12
S17	1680	20160000	20	509603	12	509603	12	375262	10	375262	10
S18	1560	18720000	280	473203	10	473203	10	348457	10	348457	10
S19	1180	14160000	140	357935	10	357935	10	263577	8	263577	8
S20	180	2160000	360	54600	6	54600	6	40207	6	40207	6
SS21	800	9600000	280	242668	8	242668	8	178696	8	178696	8
SS22	120	1440000	470	36400	6	36400	6	26804	4	26804	4
SS23	380	4560000	100	115267	6	115267	6	84881	6	84881	6
SS24	1000	12000000	100	303335	8	303335	8	223370	8	223370	8
S25	810	9720000	70	245701	8	245701	8	180930	8	180930	8
S26	110	1320000	70	33367	6	33367	6	24571	4	24571	4
S27	185	2220000	150	56117	6	56117	6	41323	6	41323	6
S28	250	3000000	100	75834	6	75834	6	55843	6	55843	6
S29	360	4320000	150	109201	6	109201	6	80413	6	80413	6
S30	350	4200000	90	106167	6	106167	6	78180	6	78180	6
S31	650	7800000	110	197168	8	197168	8	145191	6	145191	6
S32	256	3072000	410	77654	6	77654	6	57183	6	57183	6
S33	340	4080000	340	103134	6	103134	6	75946	6	75946	6

Case B-C-D-E2

Table SEC3.2

Summary of the Secondary Line Economic Analysis

Parameters:

Period of Investment: 20 years
Interest Rate: 7 %
Annuity: 0.0944

Cooling Load Len Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P Pipe Delta P
RT ft \$/year ftH₂O \$/year \$/year \$/year \$/year \$/year \$/year \$/year \$/year

			Case 1-3		Case 2-4		Case 5		Case 6		Case 7	
S1	300	870	8781	5.71	8781	1.71	7689	8.67	7689	2.60	7689	8.67
S2	2400	150	2567	1.09	2567	0.33	2342	0.71	2342	0.21	2342	0.71
S3	2392	300	5134	2.17	5134	0.65	4683	1.41	4683	0.42	4683	1.41
S4	2232	200	3122	2.27	3122	0.68	3122	0.82	3122	0.25	3122	0.82
S5	1386	790	11184	6.75	11184	2.02	10075	5.25	10075	1.57	10075	5.25
Branch Delta P:			11.19		3.36		7.48		2.24		7.48	
SS6	160	210	1856	1.65	1856	0.50	1856	0.59	1856	0.18	1856	0.59
SS7	846	390	4445	6.67	4445	2.00	4445	2.40	4445	0.72	4445	2.40
S8	100	400	3535	1.23	3535	0.37	3535	0.44	3535	0.13	3535	0.44
S9	1768	90	1274	1.25	1274	0.38	1274	0.45	1274	0.14	1274	0.45
S10	1082	135	1722	1.52	1722	0.46	1722	0.55	1722	0.16	1722	0.55
S11	677	340	3876	3.73	3876	1.12	3876	1.34	3876	0.40	3876	1.34
S12	272	210	2120	1.13	2120	0.34	1856	1.72	1856	0.52	1856	1.72
Branch Delta P:			7.63		2.29		4.06		1.22		4.06	
SS13	686	80	912	0.90	912	0.27	912	0.32	912	0.10	912	0.32
SS14	405	130	1312	1.56	1312	0.47	1312	0.56	1312	0.17	1312	0.56
SS15	405	110	1110	1.32	1110	0.39	1110	0.47	1110	0.14	1110	0.47
S16	2480	500	8557	3.89	8557	1.17	7805	2.52	7805	0.76	7805	2.52
S17	1680	20	283	0.25	283	0.08	283	0.09	283	0.03	283	0.09
S18	1560	280	3964	3.03	3964	0.91	3964	1.09	3964	0.33	3964	1.09
S19	1180	140	1785	1.87	1785	0.56	1785	0.67	1785	0.20	1785	0.67
S20	180	360	3182	3.59	3182	1.08	3182	1.29	3182	0.39	3182	1.29
Branch Delta P:			12.63		3.79		5.67		1.70		5.67	
SS21	800	280	3192	4.28	3192	1.29	3192	1.54	3192	0.46	3192	1.54
SS22	120	470	4154	2.08	4154	0.62	4154	0.75	4154	0.22	4154	0.75
SS23	380	100	1009	1.05	1009	0.32	1009	0.38	1009	0.11	1009	0.38
SS24	1000	100	1275	0.96	1275	0.29	1140	0.86	1140	0.26	1140	0.86
S25	810	70	798	1.10	798	0.33	798	0.40	798	0.12	798	0.40
S26	110	70	619	0.26	619	0.08	619	0.09	619	0.03	619	0.09
S27	185	150	1326	1.58	1326	0.47	1326	0.57	1326	0.17	1326	0.57
S28	250	100	1009	0.46	1009	0.14	884	0.69	884	0.21	884	0.69
S29	360	150	1514	1.42	1514	0.43	1514	0.51	1514	0.15	1514	0.51
S30	350	90	908	0.80	908	0.24	908	0.29	908	0.09	908	0.29
S31	650	110	1254	1.11	1254	0.33	1110	1.22	1110	0.37	1110	1.22
S32	256	410	4138	1.96	4138	0.59	3623	2.97	3623	0.89	3623	2.97
S33	340	340	3432	2.87	3432	0.86	3005	4.35	3005	1.30	3005	4.35
Total Pipe Cost:			95349		95349		90110		90110		90110	

Summary of the Secondary Line Economic Analysis

Parameters:		Period of Investment:	20 years
		Interest Rate:	7 %
		Annuity:	0.0944

Cooling Load	Len	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P	Pipe	Delta P
RT	ft	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year	\$/year

			Case 8		Case 9		Case 10		Case 11-13		Case 12-14	
S1	300	870	7689	2.60	7689	3.45	7689	1.04	7689	1.87	7689	1.22
S2	2400	150	2342	0.21	2124	0.55	2124	0.17	1913	0.65	1913	0.42
S3	2392	300	4683	0.42	4247	1.09	4247	0.33	3826	1.28	3826	0.83
S4	2232	200	3122	0.25	2551	1.37	2551	0.41	2551	0.74	2551	0.48
S5	1386	790	10075	1.57	9005	5.20	9005	1.56	7974	8.61	7974	5.59
Branch Delta P:				2.24		7.67		2.30		10.63		6.91
SS6	160	210	1856	0.18	1856	0.24	1856	0.07	1856	0.13	1856	0.08
SS7	846	390	4445	0.72	3936	2.92	3936	0.88	3936	1.58	3936	1.03
S8	100	400	3535	0.13	3535	0.18	3535	0.05	3053	0.73	3053	0.47
S9	1768	90	1274	0.14	1148	0.39	1148	0.12	1026	0.52	1026	0.34
S10	1082	135	1722	0.16	1539	0.54	1539	0.16	1363	0.90	1363	0.58
S11	677	340	3876	0.40	3432	1.63	3432	0.49	3005	3.72	3005	2.42
S12	272	210	1856	0.52	1856	0.68	1856	0.21	1856	0.37	1856	0.24
Branch Delta P:				1.22		3.24		0.97		5.51		3.58
SS13	686	80	912	0.10	807	0.39	807	0.12	707	0.90	707	0.58
SS14	405	130	1312	0.17	1149	0.94	1149	0.28	1149	0.51	1149	0.33
SS15	405	110	1110	0.14	972	0.80	972	0.24	972	0.43	972	0.28
S16	2480	500	7805	0.76	7079	1.96	7079	0.59	6377	2.30	6377	1.49
S17	1680	20	283	0.03	255	0.08	255	0.02	228	0.10	228	0.07
S18	1560	280	3964	0.33	3192	2.33	3192	0.70	3192	1.27	3192	0.82
S19	1180	140	1785	0.20	1596	0.67	1596	0.20	1413	1.11	1413	0.72
S20	180	360	3182	0.39	3182	0.51	3182	0.15	3182	0.28	3182	0.18
Branch Delta P:				1.70		5.55		1.67		5.05		3.28
SS21	800	280	3192	0.46	2826	1.87	2826	0.56	2826	1.02	2826	0.66
SS22	120	470	4154	0.22	4154	0.30	4154	0.09	3587	1.23	3587	0.80
SS23	380	100	1009	0.11	884	0.64	884	0.19	884	0.35	884	0.22
SS24	1000	100	1140	0.26	1009	1.05	1009	0.31	1009	0.57	1009	0.37
S25	810	70	798	0.12	707	0.48	707	0.14	707	0.26	707	0.17
S26	110	70	619	0.03	619	0.04	619	0.01	534	0.15	534	0.10
S27	185	150	1326	0.17	1326	0.23	1326	0.07	1326	0.12	1326	0.08
S28	250	100	884	0.21	884	0.28	884	0.08	884	0.15	884	0.10
S29	360	150	1514	0.15	1326	0.86	1326	0.26	1326	0.46	1326	0.30
S30	350	90	908	0.09	795	0.49	795	0.15	795	0.26	795	0.17
S31	650	110	1110	0.37	1110	0.49	1110	0.15	972	1.11	972	0.72
S32	256	410	3623	0.89	3623	1.18	3623	0.36	3623	0.64	3623	0.42
S33	340	340	3005	1.30	3005	1.73	3005	0.52	3005	0.94	3005	0.61
Total Pipe Cost:			90110		83418		83418		78746		78746	

Case B-C-D-E2

Table SEC3.4

Appendix 4

Summary of Costs for Lansing System - Optimization of Velocity

Peak Demand	18351 RT	Period of Invest.	20 years
Diversity Factor	0.9	Interest Rate	7 %
Diversified Dem.	16516 RT	Annuity	0.094
Perc. of Peak	0.631	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT	Steam Usage	10 lb/RT-hr

	Production Cost	COP
Conv. Chiller:	1943 \$/ton	5.84
Supercap:	2043 \$/ton	4.64
Sunwell:	3143 \$/ton	4.20

Operational Alternatives

System	Cost		A1	A2	B	E2
Description	Categories					
1 Conventional	Capacity	SOM	16516	16516	16516	16516
		Ottawa	0	0	0	16516
	Production	Capital	3029106	3029106	3029106	3029106
		Energy	934655	934655	934655	934655
		Total	3963761	3963761	3963761	3963761
	Distribution	Piping-Main	123747	115554	96985	122155
		Piping-Sec	90276	90276	95349	95349
		Pumping	24644	24658	33132	24227
		Total	238667	230488	225466	241731
	Overall Total		4202428	4194249	4189227	4205492
2 Conventional+ FRA	Capacity	SOM	16516	16516	16516	16516
		Ottawa	0	0	0	16516
	Production	Capital	3029106	3029106	3029106	3029106
		Energy	934655	934655	934655	934655
		Total	3963761	3963761	3963761	3963761
	Distribution	Piping-Main	123747	115554	96985	122155
		Piping-Sec	90276	90276	95349	95349
		Pumping	7391	7396	9939	7267
		Cost of FRA	36658	32395	26611	39817
		Total	258072	245621	228884	264588
	Overall Total		4221833	4209382	4192645	4228349

Table 14a

Operational Alternatives

System	Cost	A1	A2	B	E2		
Description	Categories						
3	Conventional+ Central Storage	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660
		Distribution	Piping-Main	123747	115554	96985	122155
			Piping-Sec	90276	90276	95349	95349
			Pumping	24644	24658	33132	24227
			Total	238667	230488	225466	241731
Overall Total		3272318	3264140	3259118	3275382		
4	Conventional+ FRA+ Central Storage	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660
		Distribution	Piping-Main	123747	115554	96985	122155
			Piping-Sec	90276	90276	95349	95349
			Pumping	7391	7396	9939	7267
			Cost of FRA	36658	32395	26611	39817
Total	258072	245621	228884	264588			
Overall Total		3291723	3279273	3262536	3298240		
5	Low Temperature	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	3091466	3091466	3091466	3091466
			Energy	953120	953120	953120	953120
			Total	4044586	4044586	4044586	4044586
		Distribution	Piping-Main	123747	107584	92516	117615
			Piping-Sec	90276	82793	90110	90110
			Pumping	17060	39931	35358	39265
			Total	231083	230308	217984	232096
		Overall Total		4275669	4274894	4262570	4276682

Table 14b

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				
6 Low Temperature+ FRA	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	0
	Production	Capital	3091466	3091466	3091466
		Energy	953120	953120	953120
		Total	4044586	4044586	4044586
	Distribution	Piping-Main	123747	107584	92516
		Piping-Sec	90276	82793	90110
		Pumping	5106	11970	10598
		Cost of FRA	36658	27588	23919
		Total	255787	229935	217143
		Overall Total	4300373	4274521	4261729
7 Low Temperature+ Central Storage	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	0
	Production	Capital	1947311	1947311	1947311
		Energy	1021152	1021152	1021152
		Total	2968464	2968464	2968464
	Storage		131980	131980	131980
	Distribution	Piping-Main	123747	107584	92516
		Piping-Sec	90276	82793	90110
		Pumping	6324	14801	13106
		Total	220347	205178	195732
		Overall Total	3320790	3305621	3296175
8 Low Temperature+ Central Storage+ FRA	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	0
	Production	Capital	1947311	1947311	1947311
		Energy	1021152	1021152	1021152
		Total	2968464	2968464	2968464
	Storage		131980	131980	131980
	Distribution	Piping-Main	123747	107584	92516
		Piping-Sec	90276	82793	90110
		Pumping	1893	4437	3929
		Cost of FRA	36658	27588	23919
		Total	252573	222402	210474
	Overall Total	3353017	3322845	3310917	

Table 14c

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				

9	Low Temperature+ Distributed Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847
		Distribution	Piping-Main	123747	85024	76331	94273
			Piping-Sec	90276	78987	83418	83418
			Pumping	1585	10471	8767	6240
			Total	215608	174482	168516	183931
	Overall Total		3420919	3379793	3373827	3389242	

10	Low Temperature+ Distributed Storage FRA	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847
		Distribution	Piping-Main	123747	85024	76331	94273
			Piping-Sec	90276	78987	83418	83418
			Pumping	478	3138	2631	1873
			Cost of FRA	36658	16781	15477	35574
	Total	251159	183930	177857	215138		
	Overall Total		3456469	3389240	3383168	3420449	

11	Ice Slurry	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	4050241	4050241	4050241	4050241
			Energy	1072302	1072302	1072302	1072302
			Total	5122542	5122542	5122542	5122542
		Distribution	Piping-Main	123747	77951	68488	82897
			Piping-Sec	90276	76678	78746	78746
			Pumping	2711	24361	30195	20345
			Total	216734	178990	177429	181988
			Overall Total	5339276	5301532	5299971	5304530

Table 14d

Operational Alternatives

System Description	Cost Categories				
		A1	A2	B	E2
12 Ice Slurry + FRA	Capacity	16516	16516	16516	16516
	SOM Ottawa	0	0	0	16516
	Production Capital	4050241	4050241	4050241	4050241
	Energy	1072302	1072302	1072302	1072302
	Total	5122542	5122542	5122542	5122542
	Distribution Piping-Main	123747	77951	68488	82897
	Piping-Sec	90276	76678	78746	78746
	Pumping	1777	15835	20463	13223
	Cost of FRA	19933	7765	6910	35086
	Total	235733	178229	174607	209952
	Overall Total	5358275	5300772	5297150	5332494
13 Ice Slurry + Central Storage	Capacity	16516	16516	16516	16516
	SOM Ottawa	0	0	0	16516
	Production Capital	2443068	2443068	2443068	2443068
	Energy	1092127	1092127	1092127	1092127
	Total	3535196	3535196	3535196	3535196
	Storage	52968	52968	52968	52968
	Distribution Piping-Main	123747	77951	68488	82897
	Piping-Sec	90276	76678	78746	78746
	Pumping	2711	24361	30195	20345
	Total	216734	178990	177429	181988
	Overall Total	3804898	3767154	3765593	3770152
14 Ice Slurry + FRA + Central Storage	Capacity	16516	16516	16516	16516
	SOM Ottawa	0	0	0	16516
	Production Capital	2443068	2443068	2443068	2443068
	Energy	1092127	1092127	1092127	1092127
	Total	3535196	3535196	3535196	3535196
	Storage	52968	52968	52968	52968
	Distribution Piping-Main	123747	77951	68488	82897
	Piping-Sec	90276	76678	78746	78746
	Pumping	1777	15835	20463	13223
	Cost of FRA	19933	7765	6910	35086
	Total	235733	178229	174607	209952
	Overall Total	3823897	3766393	3762771	3798116

Table 14e

Summary of Costs for Lansing System - Optimization of Velocity

Peak Demand	18351 RT	Period of Invest.	20 years
Diversity Factor	0.9	Interest Rate	7 %
Diversified Dem.	16516 RT	Annuity	0.094
Perc. of Peak	0.631	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT	Steam Usage	10 lb/RT-hr

	Production Cost	COP
Conv. Chiller:	1943 \$/ton	5.84
Superpac:	2043 \$/ton	4.64
Sunwell:	2003 \$/ton	4.20

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				

1	Conventional	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	3029106	3029106	3029106	3029106
			Energy	934655	934655	934655	934655
			Total	3963761	3963761	3963761	3963761
		Distribution	Piping-Main	123747	115554	96985	122155
			Piping-Sec	90276	90276	95349	95349
			Pumping	24644	24658	33132	40518
			Total	238667	230488	225466	241731
		Overall Total		4202428	4194249	4189227	4205492

3	Conventional+ Central Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660
		Distribution	Piping-Main	123747	115554	96985	122155
			Piping-Sec	90276	90276	95349	95349
			Pumping	24644	24658	33132	24227
			Total	238667	230488	225466	241731
		Overall Total		3272318	3264140	3259118	3281992

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				

11	Ice Slurry	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	3107913	3107913	3107913	3107913
			Energy	1072302	1072302	1072302	1072302
			Total	4180215	4180215	4180215	4180215
		Distribution	Piping-Main	123747	77951	68488	82897
			Piping-Sec	90276	76678	78746	78746
			Pumping	2711	24361	30195	35294
			Total	216734	178990	177429	181988
		Overall Total		4396949	4359205	4357644	4362203

12	Ice Slurry + FRA	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	3107913	3107913	3107913	3107913
			Energy	1072302	1072302	1072302	1072302
			Total	4180215	4180215	4180215	4180215
		Distribution	Piping-Main	123747	77951	68488	82897
			Piping-Sec	90276	76678	78746	78746
			Pumping	1777	15835	20463	13223
			Cost of FRA	19933	7765	6910	35086
			Total	235733	178229	174607	209952
		Overall Total		4415948	4358445	4354822	4390167

13	Ice Slurry + Central Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1945235	1945235	1945235	1945235
			Energy	1092127	1092127	1092127	1092127
			Total	3037363	3037363	3037363	3037363
		Storage		52968	52968	52968	52968
		Distribution	Piping-Main	123747	77951	68488	82897
			Piping-Sec	90276	76678	78746	78746
			Pumping	2711	24361	30195	20345
			Total	216734	178990	177429	181988
		Overall Total		3307064	3269320	3267759	3272318

Table 15b

			Operational Alternatives			
System	Cost		A1	A2	B	E2
Description	Categories					

14	Ice Slurry+ FRA+ Central Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1945235	1945235	1945235	1945235
			Energy	1092127	1092127	1092127	1092127
			Total	3037363	3037363	3037363	3037363
		Storage		52968	52968	52968	52968
		Distribution	Piping-Main	123747	77951	68488	82897
			Piping-Sec	90276	76678	78746	78746
			Pumping	1777	15835	20463	13223
			Cost of FRA	19933	7765	6910	35086
			Total	235733	178229	174607	209952
		Overall Total		3326063	3268560	3264938	3300282

Table 15c

Summary of Costs for Lansing System-Upper Limit Piping Costs

Peak Demand	18351 RT	Period of Invest.	20 years
Diversity Factor	0.9	Interest Rate	7 %
Diversified Dem.	16516 RT	Annuity	0.094
Perc. of Peak	0.631	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT	Steam Usage	10 lb/RT-hr

	Production Cost	COP
Conv. Chiller:	1943 \$/ton	5.84
Superpac:	2043 \$/ton	4.64
Sunwell:	3143 \$/ton	4.20

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				
1 Conventional	Capacity SOM	16516	16516	16516	16516
	Ottawa	0	0	0	16516
	Production Capital	3029106	3029106	3029106	3029106
	Energy	934655	934655	934655	934655
	Total	3963761	3963761	3963761	3963761
	Distribution Piping-Main	184768	174355	145718	177751
	Piping-Sec	139179	139179	147211	147211
	Pumping	24644	24658	33132	24227
	Total	348591	338192	326061	349189
	Overall Total	4312352	4301953	4289822	4312950
2 Conventional+ FRA	Capacity SOM	16516	16516	16516	16516
	Ottawa	0	0	0	16516
	Production Capital	3029106	3029106	3029106	3029106
	Energy	934655	934655	934655	934655
	Total	3963761	3963761	3963761	3963761
	Distribution Piping-Main	184768	174355	145718	177751
	Piping-Sec	139179	139179	147211	147211
	Pumping	7391	7396	9939	7267
	Cost of FRA	36658	32395	26611	39817
	Total	367996	353325	329479	372046
	Overall Total	4331757	4317086	4293240	4335807

Table 16a

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				

3	Conventional+ Central Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660
		Distribution	Piping-Main	184768	174355	145718	177751
			Piping-Sec	139179	139179	147211	147211
			Pumping	24644	24658	33132	24227
			Total	348591	338192	326061	349189
	Overall Total		3382242	3371844	3359713	3382840	

4	Conventional+	Capacity	SOM	16516	16516	16516	16516
	FRA+		Ottawa	0	0	0	16516
	Central Storage	Production	Capital	1908337	1908337	1908337	1908337
			Energy	934655	934655	934655	934655
			Total	2842992	2842992	2842992	2842992
		Storage		190660	190660	190660	190660
		Distribution	Piping-Main	184768	174355	145718	177751
			Piping-Sec	139179	139179	147211	147211
			Pumping	7391	7396	9939	7267
			Cost of FRA	36658	32395	26611	39817
	Total	367996	353325	329479	372046		
	Overall Total		3401647	3386977	3363131	3405698	

5	Low Temperature	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	3091466	3091466	3091466	3091466
			Energy	953120	953120	953120	953120
			Total	4044586	4044586	4044586	4044586
		Distribution	Piping-Main	184768	163947	139753	172414
			Piping-Sec	139179	126220	138345	138345
			Pumping	17060	39931	35358	39265
			Total	341007	330098	313456	335130
			Overall Total	4385593	4374684	4358042	4379716

Table 16b

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				

6	Low Temperature+ FRA	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	3091466	3091466	3091466	3091466
			Energy	953120	953120	953120	953120
			Total	4044586	4044586	4044586	4044586
		Distribution	Piping-Main	184768	163947	139753	172414
			Piping-Sec	139179	126220	138345	138345
			Pumping	5106	11970	10598	7302
			Cost of FRA	36658	27588	23919	39299
			Total	365711	329725	312615	357360
		Overall Total		4410297	4374311	4357201	4401946

7	Low Temperature+ Central Storage	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980
		Distribution	Piping-Main	184768	163947	139753	172414
			Piping-Sec	139179	126220	138345	138345
			Pumping	6324	14801	13106	9034
			Total	330271	304968	291204	319793
		Overall Total		3430714	3405411	3391647	3420236

8	Low Temperature+ Central Storage+ FRA	Capacity	SOM	16516	16516	16516	16516
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		131980	131980	131980	131980
		Distribution	Piping-Main	184768	163947	139753	172414
			Piping-Sec	139179	126220	138345	138345
			Pumping	1893	4437	3929	2707
			Cost of FRA	36658	27588	23919	39299
			Total	362497	322192	305946	352765
		Overall Total		3462941	3422635	3406389	3453208

Table 16c

Operational Alternatives

System	Cost	A1	A2	B	E2		
Description	Categories						
9	Low Temperature+ Distributed Storage	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847
		Distribution	Piping-Main	184768	132713	117376	142598
			Piping-Sec	139179	119602	127088	127088
			Pumping	1585	10471	8767	6240
			Total	325532	262786	253231	275926
Overall Total		3530843	3468097	3458542	3481237		
10	Low Temperature+ Distributed Storage FRA	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	1947311	1947311	1947311	1947311
			Energy	1021152	1021152	1021152	1021152
			Total	2968464	2968464	2968464	2968464
		Storage		236847	236847	236847	236847
		Distribution	Piping-Main	184768	132713	117376	142598
			Piping-Sec	139179	119602	127088	127088
			Pumping	478	3138	2631	1873
			Cost of FRA	36658	16781	15477	35574
	Total	361083	272234	262572	307133		
Overall Total		3566393	3477544	3467883	3512444		
11	Ice Slurry	Capacity	SOM	16516	16516	16516	
			Ottawa	0	0	0	16516
		Production	Capital	4050241	4050241	4050241	4050241
			Energy	1072302	1072302	1072302	1072302
			Total	5122542	5122542	5122542	5122542
		Distribution	Piping-Main	184768	122300	105890	127171
			Piping-Sec	139179	115350	118871	118871
			Pumping	2711	24361	30195	20345
			Total	326658	262011	254956	266387
		Overall Total		5449200	5384553	5377498	5388929

Table 16d

Operational Alternatives

System Description	Cost Categories				
		A1	A2	B	E2
12 Ice Slurry + FRA	Capacity	16516	16516	16516	16516
	SOM				
	Ottawa	0	0	0	16516
	Production Capital	4050241	4050241	4050241	4050241
	Energy	1072302	1072302	1072302	1072302
	Total	5122542	5122542	5122542	5122542
	Distribution Piping-Main	184768	122300	105890	127171
	Piping-Sec	139179	115350	118871	118871
	Pumping	1777	15835	19627	13223
	Cost of FRA	19933	7765	6910	35086
	Total	345657	261250	251298	294351
	Overall Total	5468199	5383793	5373841	5416893
13 Ice Slurry + Central Storage	Capacity	16516	16516	16516	16516
	SOM				
	Ottawa	0	0	0	16516
	Production Capital	2443068	2443068	2443068	2443068
	Energy	1092127	1092127	1092127	1092127
	Total	3535196	3535196	3535196	3535196
	Storage	52968	52968	52968	52968
	Distribution Piping-Main	184768	122300	105890	127171
	Piping-Sec	139179	115350	118871	118871
	Pumping	2711	24361	30195	20345
	Total	326658	262011	254956	266387
	Overall Total	3914822	3850175	3843120	3854551
14 Ice Slurry + FRA + Central Storage	Capacity	16516	16516	16516	16516
	SOM				
	Ottawa	0	0	0	16516
	Production Capital	2443068	2443068	2443068	2443068
	Energy	1092127	1092127	1092127	1092127
	Total	3535196	3535196	3535196	3535196
	Storage	52968	52968	52968	52968
	Distribution Piping-Main	184768	122300	105890	127171
	Piping-Sec	139179	115350	118871	118871
	Pumping	1777	15835	19627	13223
	Cost of FRA	19933	7765	6910	35086
	Total	345657	261250	251298	294351
	Overall Total	3933821	3849414	3839462	3882515

Table 16e

Summary of Costs for Lansing System-Upper Limit Piping Costs

Peak Demand	18351 RT	Period of Invest.	20 years
Diversity Factor	0.9	Interest Rate	7 %
Diversified Dem.	16516 RT	Annuity	0.094
Perc. of Peak	0.631	Steam Cost	0.00394 \$/lb
Average Demand	10422 RT	Steam Usage	10 lb/RT-hr

	Production Cost	COP
Conv. Chiller:	1943 \$/ton	5.84
Superpac:	2043 \$/ton	4.64
Sunwell:	2061 \$/ton	4.20

Operational Alternatives

System	Cost	A1	A2	B	E2
Description	Categories				
1 Conventional	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	0
	Production	Capital	3029106	3029106	3029106
		Energy	934655	934655	934655
		Total	3963761	3963761	3963761
	Distribution	Piping-Main	184768	174355	145718
		Piping-Sec	139179	139179	147211
		Pumping	24644	24658	33132
		Total	348591	338192	326061
	Overall Total		4312352	4301953	4289822
3 Conventional+ Central Storage	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	0
	Production	Capital	1908337	1908337	1908337
		Energy	934655	934655	934655
		Total	2842992	2842992	2842992
	Storage		190660	190660	190660
	Distribution	Piping-Main	184768	174355	145718
		Piping-Sec	139179	139179	147211
		Pumping	24644	24658	33132
		Total	348591	338192	326061
	Overall Total		3382242	3371844	3359713

Table 17a

Operational Alternatives

System Description	Cost Categories				
		A1	A2	B	E2
11 Ice Slurry	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	16516
	Production	Capital	3156229	3156229	3156229
		Energy	1072302	1072302	1072302
		Total	4228530	4228530	4228530
	Distribution	Piping-Main	184768	122300	105890
		Piping-Sec	139179	115350	118871
		Pumping	2711	24361	30195
		Total	326658	262011	254956
					266387
	Overall Total		4555188	4490541	4483486
12 Ice Slurry + FRA	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	16516
	Production	Capital	3156229	3156229	3156229
		Energy	1072302	1072302	1072302
		Total	4228530	4228530	4228530
	Distribution	Piping-Main	184768	122300	105890
		Piping-Sec	139179	115350	118871
		Pumping	1777	15835	19627
		Cost of FRA	19933	7765	6910
		Total	345657	261250	251298
					294351
	Overall Total		4574187	4489781	4479829
13 Ice Slurry + Central Storage	Capacity	SOM	16516	16516	16516
		Ottawa	0	0	16516
	Production	Capital	1970760	1970760	1970760
		Energy	1092127	1092127	1092127
		Total	3062888	3062888	3062888
	Storage		52968	52968	52968
	Distribution	Piping-Main	184768	122300	105890
		Piping-Sec	139179	115350	118871
		Pumping	2711	24361	30195
		Total	326658	262011	254956
					266387
	Overall Total		3442513	3377866	3370811
					3382242

Table 17b

System Description	Cost Categories	Operational Alternatives				
		A1	A2	B	E2	
14 Ice Slurry + FRA + Central Storage	Capacity	SOM	16516	16516	16516	16516
		Ottawa	0	0	0	16516
	Production	Capital	1970760	1970760	1970760	1970760
		Energy	1092127	1092127	1092127	1092127
		Total	3062888	3062888	3062888	3062888
	Storage		52968	52968	52968	52968
	Distribution	Piping-Main	184768	122300	105890	127171
		Piping-Sec	139179	115350	118871	118871
		Pumping	1777	15835	19627	13223
		Cost of FRA	19933	7765	6910	35086
		Total	345657	261250	251298	294351
		Overall Total	3461512	3377106	3367154	3410206

Table 17c

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