THE HARDNESS OF ILLINOIS MUNICIPAL WATER SUPPLIES.

Edward Bartow.

It is not the purpose of this paper to show the advantages of a soft water. We are all agreed that a soft water is best. The large majority of the municipalities of Illinois have hard waters, and therefore what we wish to know is how to make them soft and when it is practicable to do so.

Whenever it is necessary to purify a water for drinking purposes an additional installation to soften the water is comparatively inexpensive. The same is true when it is found necessary to remove the iron from a water supply. To soften a hard but pure and clear water would mean a complete installation for softening purposes alone. In the latter case there will therefore be much hesitation on account of the expense before general softening plants are established. In all plants also there is a reluctance to treat all of the water supply when a soft water is not needed for all purposes.

Railroads are finding it profitable to soften the waters used in their locomotives, and plants for water treatment are in operation on all of the principal lines. The matter is of so much importance to them that an extended report has been made by the Committee on Water Service of the American Railway Engineering and Maintenance of Way Association*. The Committee discusses the matter from the standpoint of use in locomotives quite fully. What has been found practicable in locomotive practice may be extended to general boiler uses or even to domestic practice.

The whole supply of a municipality may be softened or, where this is impracticable, plants may be established by the

*Am. Ry. Eng. and Maintenance of Way Assn. Bull. No. 83, Jan. 1907.

TABLE SHOWING THE HARDNESS, AND THE AMOUNT OF LIME AND SODA ASH REQUIRED TO SOFTEN THE WATER FURNISHED TO NINETY-EIGHT ILLINOIS MUNICIPALITIES.

CITY	Class	Mineral Content—Parts per Million							Soda Ash			Lime			Chemicals Approximate Cost per 1000 Gallons	REMARKS
		Residue	Na_2CO_3	$MgCl_2$	$MgSO_4$	$MgCO_3$	$CaSO_4$	$CaCO_3$	Parts per Million	Grains per Gallon	Lbs. per 1000 Gals.	Parts per Million	Grains per Gallon	Lbs. per 1000 Gals.		
Amboy	I	389	14.1			125.2		212.6				285.	16.6	2.38	$.00714	
Atlanta	I	517	46.8			154.6		238.5				340.	19.8	2 83	.00849	
Aurora	II	458			35.4	35.1		165.0	31.	1.8	.26	156.	9.1	1.30	.00650	
Beardstown	II	373			65.0	56 4		189.2	57.	3.3	.48	211.	12.3	1.76	.01008	
Belleville	I	370	201.0			53.3		43.4								Deep wells.
	II	393			21.6	95.2		187.2	19.	1.1	.16	241.	14.1	2.01	.00763	Edgmont.
Belvidere	II	352			1.5	116.5		193.4	1.3	.1	.01	264.	15.4	2.20	.00670	
Berwyn	II	735			182.4	9.7		256.8	160.	9.3	1.33	242.	14.1	2.02	.01936	
Bloomington	II	810			436.2	130.2		156.3	384.	22 4	3.20	463.	27.0	3.86	.04358	
Bushnell	II	2038			228.0	16.4		279.8	201.	11 7	1.67	285.	16.6	2.38	.02384	
Byron	II	298			4.0	119.0		139.5	3.5	.2	.03	238.	13.9	1.99	.00627	
Cairo	II	235			7.3	21.4		47.4	6.4	.4	.05	58.	3.4	.48	.00194	Clay and silicious matter 103.5.
Cambridge	I	1052	49.0			68.6		104.9				177.	10.3	1.48	.00444	
Canton	II	1620			205.		119.3	157.8	283 0	16.5	2.36	184.	10.7	1.53	.02819	
Carbondale	I	1818	244 0			48.0		79.0				237.	13.8	1.98	.00594	Average of 3 analyses from different wells.
Carlyle (a)	II	248			20.0	55.4		117.3	17.6	1.0	.14	149.	8.7	1.24	.00512	Artesian well.
Carmi (a)	II	176			15.8	20.4		50.0	13.9	.8	.12	63.	3.7	.53	.00279	Spring.
Carrollton	II	3121			289 0		162.0	228.4	381.0	22.2	3.17	263.	15.3	2.20	.03830	
	II	348			4.8	92 1		195.0	4.2	.2	.03	234.	13.6	1.95	.00615	
Chadwick	I	429	35.4			148.6		212.4				335.	19.5	2.80	.00840	
Champaign	I	408	56.0			101.0		202.0				276.	16.1	2.30	.00690	
Charleston (a)	II	270			21.1	68.0		127.0	18.6	1.1	.16	171.	10.0	1.43	.00589	
Chatsworth	I	702	124.3			121 5		190.0				334.	19.5	2.78	.00834	
Chillicothe	III	420		16.9	94.4	41.1		202 9	102.	5.9	.85	222.	12.9	1.85	.01405	
Chrisman	I	2216	343.5			30.2		38.6								Well 140'—Suspended matter 83.9—
	III	571		22.1	194.		1.5	290.0	197.	11.5	1.64	266.	15.5	2.21	.02303	Well 17'
Clinton	I	310	18.6			118.		137.				243.	14.2	2.03	.00609	Wells.
	I	431	7.2			144.		236				327.	19.1	2.73	.00819	Springs.
Collinsville	II	392			41.	104.		184.	36.	2.1	.30	260.	15.2	2.17	.00951	
Danville (a)	II	281			38.0	60 0		135.	33.	1.9	.27	173.	10.1	1.44	.00702	
Decatur (a)	II	293			24.8	73.		137.	21.9	1.3	.18	185.	10.8	1.54	.00642	
DeKalb	I	301	60.			87.		132.				221.	12.9	1.84	.00552	
Dwight	II	1087			253.		101.	247.	222.	12.9	1.85	256.	14.9	2.14	.02492	
East Dubuque	I	361	48.3			109.5		113 3				234.	13.6	1.94	.00582	
East St. Louis	II	233			5.5	41 3		90 0	4.8	.3	.04	108.	6.3	.90	.00310	
Edwardsville	II	260			55.4	23.2		131 1	49.	2.9	.41	130.	7.6	1.08	.00734	
Effingham	II	257			38.4	42.9		69 2	33.8	2.0	.29	114.	6.6	.94	.00572	
Elgin (a)	II	290			30.0	83.0		127.0	26.4	1.5	.21	196.	11.4	1.63	.00699	(a) U. S. G. S.
Elgin	I	347	63.0			98.		150 0				248.	14.5	2.07	.00621	Deep wells.
Elmhurst	II	478			86.	78.0		255.0	76.	4.4	.63	287.	16.7	2.40	.01350	
Farmer City	I	719	255.1			85 0		146.4				330.	19.2	2.75	.00825	
Freeport	II	463			62.0	109.4		221.4	55.	3.2	.46	298.	17.4	2.48	.01204	
Galesburg	II	951			135.1	47.9		259.3	119.	6.9	.99	272.	15.9	2.27	.01661	Mixture of deep and shallow wells.
Geneseo	II	396			15.6	103.3		192.1	14.	.8	.12	252.	14.7	2.10	.00750	
Greenville	II	552			65.1	96.4		277.3	57.	3.3	.48	313.	18.3	2.61	.01263	
Harvey	II	1204			239.7		225.2	267.5	386.	22.5	3.21	261.	15.2	2.18	.03864	
Havana	II	196			15.5	35.9		96.1	14.	.8	.12	109.	6.4	.91	.00393	

CORRECTIONS IN TABLE,

Artesian well and spring are at Carrollton not Carlyle, and Carmi
Under Shelbyville, parts per million soda ash, reads 22.0 instead of 220,
Free acids and sulphates are in water at Staunton, not Springfield.

Henry	I	2497	259.1			60.3		94.1				269.	15.7	2.25	.00675	
Jacksonville	II	374			33.2	96.0		208.0	29.	1.7	.24	260.	15.2	2.17	.00891	New supply.
Jerseyville	II	2506			250.0		161.0	157.0	345.	20.1	2.87	204.	11.9	1.70	.03380	
Kankakee (a)	II	288			52.0	37.4		145.0	46.	2.7	.38	155.	9.0	1.28	.00764	
Kewanee	II	1265			87.0		40.0	175.0	108.	6.3	.90	138.	8.0	1.15	.01245	
Knoxville	II	1198			27.9	71.0		144.0	25.	1.5	.21	188.	11.0	1.57	.00681	
Lacon	III	446		6.4	47.0	97.0		218.0	49.	2.9	.41	277.	16.2	2.31	.01103	
LaGrange	II	571			58.0	111.0		288.0	51.	3.0	.43	336.	19.6	2.80	.01270	
LaSalle	II	432			80.0	56.0		216.0	70.	4.1	.59	233.	13.6	1.94	.01172	
Lewistown	II	293			48.8	50.0		153.0	43.	2.5	.36	175.	10.2	1.46	.00798	
Marshall	II	228			20.0	35.5		131.0	17.6	1.0	.14	130.	7.6	1.08	.00464	
Mascoutah	III	1060		10.2	299.0		119.0	453.0	368.0	21.5	3.06	399.	23.3	3.33	.04059	
Mattoon	I	611	16			185.		258.				399.	23.3	3.33	.00999	Mattoon Clear Well Water Co.
	II	222			42.	67.		96.	37.	2.2	.30	162.	9.4	1.34	.00702	Kickapoo Drain.
	II	298			66.	50.		144.	58.	3.4	.48	178.	10.4	1.48	.00924	Little Wabash Reservoir
Maywood	II	619			190.2	39.1		233.9	167.	9.7	1.38	272.	15.9	2.28	.02064	
Metropolis	III	233		2.7	20.0	17.7		163.0	17.6	1.0	.14	137.	8.0	1.14	.00482	
Minonk	I	2226	372.8			14.6		20.4								
Moline (a)	II	177.4			8.3	38.4		80.9	7.3	.4	.05	100.	5.8	.83	.00299	Suspended 108.
Morrison	I	314	6.6			110.8		153.9				237.	13.8	1.97	.00591	
Mound City	I	281	3.5			38.0		97.1				107.	6.2	.89	.00267	
Mount Morris	III	436		74.9	30.2	53.6		196.2	110.0	6.4	.91	240.	14.0	2.00	.01510	
Mt. Sterling	I	1542	88.			70.0		142.0				219.	12.8	1.83	.00549	Variable.
Newman	I	1221	76.			86.0		127.				226.	13.2	1.88	.00564	
Normal	I	410	153.			83.		131.				263.	15.3	2.20	.00660	
Oak Park	II	856			175.0		9.0	211.	154.	9.0	1.28	200.	11.7	1.67	.01781	Average of 2.
Onarga	II	1068			356.4		5.2	458.	314.0	18.3	2.61	418.	24.3	3.48	.03654	
Oregon	II	331			8.0	125.7		161.5	7.0	.4	.06	260.	15.2	2.16	.00708	
Ottawa	I	398	69.7			95.2		159.9				253.	14.8	2.12	.00636	
Palatine	II	701			269.4		62.1	118.8	237.0	13.8	1.97	192.	11.2	1.60	.02450	
Paris	II	443			58.4	102.1		188.2	51.4	3.0	.44	268.	15.6	2.23	.01109	
Pekin	III	416		41.7	82.1	46.4		187.5	119.0	6.9	1.00	229.	13.3	1.90	.01570	
Peoria	II	339			1.8	85.0		160.0	1.6	.1	.01	203.	11.8	1.70	.00520	
Peotone	II	604			126.0	35.0		302.8	111.0	6.5	.92	274.	16.0	2.28	.01604	
Plainfield	III	854		66.6	171.0	42.2		198.0	225.0	13.1	1.90	286.	16.7	2.38	.02614	
Polo	II	367			8.6	134.4		173.2	7.6	.4	.06	279.	16.3	2.33	.00759	
Prophetstown	II	339			60.8	35.7		195.9	53.6	3.1	.44	186.	10.8	1.54	.00902	
Quincy (a	II	203			12.3	47.0		90.0	10.8	.6	.09	119.	6.9	1.00	.00390	
Rantoul	I	357	38.0			112.4		167.9				263.	15.3	2.20	.00660	
Riverside	I	807	60.0			70.0		157.0				213.	12.4	1.78	.00534	Well No. 1.
	II	689			229.	56.0		295.0	202.	11.8	1.70	346.	20.2	2.88	.02564	Well No. 2.
Rochelle	II	337			1.1	85.2		203.7	.9	.1	.01	228.	13.3	1.90	.00580	
Rockford	I	351				120.0		187.0				264.	15.4	2.20	.00660	
Rock Island	I	82				6.5		10.7								March, 1902.
	II	191			11.0	40.0		87.0	9.7	.6	.08	107.	6.2	.89	.00347	February, 1906.
Roseville	II	2591			443.8		480.4	194.6	765.	44.6	6.38	314.	18.3	2.61	.07163	Use $BaOH_2$
Rushville	II	4121			380.4		339.7	189.0	599.	34.9	5.00	283.	16.5	2.36	.05708	Use $BaOH_2$
Ste. Anne	II	943			301.		105.	293.0	347	20.2	2.90	304.	17.7	2.53	.03659	
Shelbyville	II	408			98.0	53.0		210.0	86.	5.0	.72	234.	13.6	1.94	.01302	City supply.
Shelbyville (a)	II	279			25.0	73.0		132.0	220.	1.3	.18	183.	10.7	1.53	.00639	Auxiliary.
Sheldon	I	796	166.9			25.8		35.5								
Springfield	II	276			21.0	69.0		130.0	18.5	1.1	.16	174.	10.1	1.44	.00592	Free acid and sulphates.
Staunton	II	554			153.3		185.8		360.	20.9	3.00					
Sterling	II	332			25.5	107.2		160.6	22.4	1.3	.19	244.	14.2	2.03	.00799	
Streator (a)	II	325			61.0	59.0		137.0	54.0	3.1	.45	184.	10.7	1.53	.00909	
Taylorville	III	458.3		23.7	65.4	35.0		243.0	84.0	4.9	.70	227.	13.2	1.90	.01270	
Tolono	I	656	277.4			104.9		202.0				399.	23.3	3.33	.00999	
Urbana	I	408	56.0			101.0		202.				276.	16.1	2.30	.00690	
Warren	III	379		3.3	36.0	85.2		207.0	35.3	2.1	.30	248.	14.5	2.07	.00921	
West Chicago	II	381			22.0	109.1		151.1	19.4	1.1	.16	240.	14.0	2.00	.00760	
Wyoming	I	781	95.5			85.3		73.6				204.	11.9	1.70	.00510	
Lake Michig'n	II	140			7.3	29.4		81.4	6.4	.4	.05	89.	5.2	.43	.00179	Ave. for southern end.

larger consumers, or even household softening plants may be erected. In order to furnish the chemical data necessary for such treatment the accompanying table has been prepared.

The samples of water analyzed have been sent to the Water Survey from the various towns by the water-works men, the city officials, or by other citizens. The Water Survey has not been able to collect the samples itself, and thus can not be absolutely certain that the samples are authentic. The probability is that most of them are all right.

The analytical work reported has been done in the Laboratory of the State Water Survey at the University of Illinois during the past fifteen years. There is a possibility that some of the waters have changed in character, but most of the well supplies are very stable.

Ninety-seven of the 216 separate sources of supply within the State have been examined. The analytical data which is needed to determine the method of water softening is given. Most all of the analyses are reported in full in a Bulletin of the State Water Survey.*

The mineral content given in the table shows hypothetical combinations which have been calculated from the ionic content by calculating bases in the order, potassium, sodium, ammonium, magnesium, calcium, iron and aluminum, to the acid ions in the order, nitrate, chloride, sulphate and carbonate. By using this order the waters can be divided into several classes. To facilitate comparison we made three classes.

Class I. Includes those waters which contain more than enough sodium to unite with all of the nitrate, chloride and sulphate ions. These waters would, therefore, contain sodium carbonate, and possibly the carbonates of magnesium, calcium and iron. The waters of this class will form a sludge or soft scale when used in boilers. They may have a high soap-consuming power when used for laundry or in the lavatory. The hardness, which would necessarily consist of the carbonates of calcium and magnesium, will be almost entirely removed by boiling, or by treat-

*University of Illinois Bulletin, State Water Survey Series, No. 5.

ment with the necessary amount of lime. The relative cost of softening by boiling and by lime is given by Collett* as 50 to 1.

Class II. Includes those waters which have sufficient sodium to unite with all the nitrates and chlorides and with part of the sulphates present. These waters contain the sulphate of magnesium and sometimes the sulphate of calcium, iron and aluminium. The waters of this class will form a scale more or less hard, according to the proportion of sulphate present. Their soap-consuming power may be high, and boiling will not remove all of the hardness. Boiling will remove the carbonate hardness, but the sulphate hardness will remain. Lime will remove the carbonates, but soda ash or caustic soda must be used to change the sulphates to sulphates of sodium.

Class III. Includes those waters in which the sodium is not present in sufficient quantity to unite with all the nitrates and chlorides present. These waters will therefore contain magnesium chloride. The hardness may be due to chlorides, sulphates and carbonates of magnesium, calcium, etc. These waters will be corrosive, and will form a hard scale and pit when used in boilers. They will also consume a considerable quantity of soap, and the hardness will not all be removed by boiling. As in Class II lime will remove the carbonates, but soda ash or caustic soda must be used for the mineral acid hardness.

It is noted that the waters of the second class are most common, there being 64 waters in this class. The first class is next in order with 32 waters, and the third class numbers 10.

Most of these waters will yield to treatment, the exception being those containing a large residue. These may be softened, but because of the necessary addition of sodium salts in the softening process the foaming constituents will be increased so that they will be unsatisfactory for boiler uses. With the exception of the waters just mentioned, it is possible to so treat the Illinois waters that corrosion will be prevented and the scaling ingredients reduced to less than 85 parts per million (5 grains per gallon).

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*Water Softening and Purification, London, 1908, p. 3.

The amounts of sodium carbonate (soda ash, Na_2Co_3) and lime (CaO) needed to treat the waters were calculated, using factors as follows:

Magnesium chloride, $MgC1_2$ to Soda ash, Na_2CO_3..	1.1130
Magnesium sulphate, $MgSO_4$ to Soda ash, Na_2CO_3...	.8811
Calcium sulphate, $CaSO_4$ to Soda ash, Na_2CO_3.....	.7792
Sodium carbonate, Na_2CO_3 to Lime, CaO..........	.5287
Magnesium chloride, $MgC1_2$ to Lime, CaO..........	.5889
Magnesium sulphate, $MgSO_4$ to Lime, CaO.........	.4659
Magnesium carbonate, $MgCo_3$ to Lime, CaO.........	1.3300
Calcium carbonate, $CaCO_3$ to Lime, CaO............	.5600
Parts per million to grains per gallon..............	.05833
Parts per million to pounds per thousand gallons....	.008345

The amounts are calculated on the basis of pure soda ash and pure lime, and no account is taken of the residual carbonate of calcium and magnesium which can not be removed. Practice would probably show that the approximate cost is therefore a trifle high. The amount of soda ash present has been included in the calculation of the lime needed for the waters of Class I. This is according to the laboratory experiments of Bartow and Lindgren.*

The results are given in parts per million, grains per gallon and pounds per thousand gallons. This will make it convenient for treatment on a large or small scale. Those desiring to soften water for use in the household, where the whole supply is not softened, may soften from a few gallons up by adding the calculated amount. We have tried the experiment with the water at the University of Illinois on a laboratory scale, using 30 liters of water; and on a household scale, using 1,000 gallons of water. The Champaign and Urbana water supplies are in this way softened so that the soap-consuming capacity is very much decreased and so that the possibility of staining white goods from the iron present is entirely eliminated, and there is no danger of clogging the water-backs in the ranges.

Should plans be made to soften the water furnished from

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*Bartow and Lindgren, Proceedings of the Am. Water Works Assn. Vol. 27, page 505, (1907.)
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streams it is necessary to consider that the waters vary from day to day and that no specific rules can be laid down for the treatment. The results given are the averages. The analyses which are marked (a) are average analyses covering a period of one year, and were made by Mr. W. D. Collins, Assistant Hydrographer of the United States Geological Survey, and Mr. C. K. Calvert, Field Assistant of the United States Geological Survey, under the cooperative agreement with the State Water Survey, State Geological Survey, and the University of Illinois Engineering Experiment Station in a study of the streams of Illinois.

The cost of treatment has been calculated on the basis of lime at $6.00 per ton and soda at $1.00 per hundred. The cost at any place can be readily calculated by noting the relation between this estimated cost and the actual cost on the spot.

The above illustrates one of the lines of work planned for the survey. We wish to make analyses of all the supplies, and we wish also some day to have the privilege of collecting our own samples.

As an illustration of the possibility of success in water softening, I will mention an incident. My own cistern was dry, so I arranged to treat 1,000 gallons of water. When I was about to begin my wife expressed the wish that I experiment on some one else. The experiment was carried out, however. A few days later I was informed that the water I had treated was better. A few days later my attention was called to some curtains. "Don't they look nice? They were washed in the water you treated." I had thus one convert to water softening.