APPENDIX I

WATER SOFTENING ALTERNATIVES

Water Softening Alternatives

According to District staff members who use treated water from Lopez WTP, most complaints from water customers are for problems caused by water hardness. Thus, water softening alternatives were developed and compared with the other alternatives. Water softening can be used to reduce hardness while simultaneously treating the water to meet pertinent drinking water regulations. The raw water from Lake Lopez is very hard, with an average total hardness of 350 mg/L as $CaCO_3$ (200 mg/L from calcium and 150 mg/L from magnesium). In 1968, the American Water Works Association (AWWA) established a water quality goal for total hardness of 80-100 mg/L as $CaCO_3$, but current AWWA water quality goals do not include hardness. In recent years, total hardness of 120 mg/L or less appears to be an acceptable design criterion for softening facilities in most applications.

Water softening can be accomplished by chemical precipitation, sodium zeolite (cation exchange), and nanofiltration (NF), which is a membrane filtration process.

The cation exchange process uses sodium in synthetic or natural ion exchange resin to replace calcium and magnesium from water when the water is passed through an ion exchange bed. This process adds a large amount of sodium to the water, and the disposal of a large quantity of brine from the regeneration process is problematic. In addition, this process is not economically competitive with the chemical precipitation process unless very low hardness is required in the treated water. Very low hardness is not desirable from both public health and corrosion control concerns. Therefore, cation exchange softening was eliminated from further consideration.

NF is a relatively new application for water softening. NF is similar to reverse osmosis (RO) except that the membrane pores are larger so that larger ions (divalent) such as calcium, magnesium, and sulfate are rejected while smaller ions (monovalent) such as sodium, potassium, chloride, and nitrate can pass through the NF membrane. As a result, NF systems are operated at lower pressures than RO systems. However, both NF and RO are expensive and generate large liquid reject streams (20 to 25 percent of influent) for disposal. In addition, pretreatment requirements for NF to treat surface water such as Lopez Lake water are elaborate; hence, NF is not economically competitive.

Chemical Softening

Softening by chemical precipitation is similar to conventional surface water treatment consisting of coagulation, flocculation, and sedimentation. The existing treatment facilities could be utilized, with modifications and upgrades to accomplish water softening prior to filtration. This evaluation assumed softening by chemical precipitation as the logical choice for consideration at the Lopez WTP. Alternative chemicals can be used for chemical softening, including lime ($CaOH_2$), lime with soda ash (Na_2CO_3), and caustic (NaOH), depending on the degree of softening desired, economics, and ease of operation and maintenance (O&M).

Detailed calculations by a computer-based model (SOFTEN) for each chemical alternative are shown at the end of this Appendix. The lowest total hardness concentration that can be achieved with lime alone is about 120 mg/L as $CaCO_3$, with a lime dosage of 350 mg/L. Use of soda ash (100 mg/L) in conjunction with lime can further reduce the total hardness to as low as 64 mg/L as $CaCO_3$. Use of caustic alone (200 mg/L) can reduce total hardness to 116 mg/L as $CaCO_3$. For Lopez WTP, it is recommended that a reduction of total hardness to 120 mg/L as $CaCO_3$ is adequate and thus soda ash addition is not necessary.

To achieve a total hardness of 120 mg/L, a lime dosage of 350 mg/L or a caustic dosage of 200 mg/L is required. The resultant sludge production for using lime and caustic is 681 and 261 mg/L, respectively, corresponding to 6,219 and 2,384 tons/yr of sludge (on a dry basis) for a 6mgd plant. Using lime would probably require a completely new treatment system specifically designed to handle lime. Because lime could present tremendous O&M problems using the existing facilities and the sludge production would be much higher, use of caustic for this evaluation is recommended. The softened water needs to be neutralized (stabilized) to a pH of 7.5 through either acid or carbon dioxide addition. Because acid is hazardous to handle and it adds significantly high total dissolved solids (TDS) to the treated water (sulfate from sulfuric acid), use of carbon dioxide is recommended.

The water treatment plant improvements for the softening alternative are similar to those of Alternative 2 (Pretreatment and Conventional Filters) with additional items. Additional new facilities would include:

1. A caustic storage and feed system.
2. A liquid carbon dioxide storage, feed and diffusing system.
3. A sludge scraping system in each sedimentation basin.
4. Two sludge recirculation or disposal pumps.
5. A filter press sludge dewatering system.

Modifications to the sludge blowdown system would also be required to provide backflushing of the pipes with clear water after each blowdown to reduce the possibility of lines clogging from settled residuals. In addition, the sedimentation basins would need to be modified to provide a chamber for carbon dioxide dissolution prior to filtration.

The main chemical costs for chemical softening are 200 mg/L of caustic (10,008 lb/d) for precipitation and 100 mg/L of carbon dioxide for stabilization. Other chemicals include approximately 10 mg/L of alum or ferric chloride for coagulation, and 0.25 to 1.0 mg/L of polyphosphate to control encrustation of the filter media, in addition to chlorine and ammonia for chloramination for disinfection. Chlorine dioxide for preoxidation would be unnecessary under this alternative, as iron and manganese and a significant portion of the TOC would be removed. The chemical softening plant would need to be staffed continuously (24 hours/7 days) with much higher O&M requirements than a conventional treatment plant (the 4-mgd Lompoc lime softening plant is staffed continuously). Addition of 4 full-time (40 hours/week) O&M positions is anticipated for this option due to the sludge handling and continuous operation requirements. The total construction cost of the chemical softening alternative is presented in Chapter 5 of this Audit Report.

The advantages of a chemical softening alternative include:

1. Reducing scale-forming tendencies and water quality complaints
2. Providing supplemental disinfection and reducing algal growth in basins
3. Reducing TOC and DBP formation
4. Reducing iron and manganese
5. Reducing turbidity in conventional filter effluent (likely to meet CAP goal of 0.1 NTU)
6. High likelihood of reduced solids deposition in pipes

The disadvantages of chemical softening include:

1. High chemical cost
2. High sludge disposal cost
3. High O&M cost
4. Increase in sodium concentration of treated water by 115 mg/L

Split Softening by NF

Split softening (67% of flow) by NF with subsequent blending of softened and un-softened water could achieve an equivalent degree of softening for this water (assuming 100% removal of hardness by NF). This option involves installing a new 5.0 mgd NF plant following full conventional treatment as in Alternative 2. Since the NF product water will be very low in turbidity and TOC concentrations, the total (blended) effluent water quality would be improved. However, because approximately 20% of the NF feed water would be rejected, the conventional treatment plant would need to treat 7 mgd in order to produce 6 mgd net treated water for distribution. Influent flow to the NF plant would be 5 mgd and the reject stream to be disposed of would be 1 mgd. The construction cost of the 5-mgd NF system is shown in Chapter 5. These costs do not include cost for NF reject disposal, which may include pipeline construction cost, sewer connection fee, and sewer discharge fee. The advantage of this option is that the total TDS of the plant effluent water will be reduced and there is no increase in sodium levels. The main disadvantage is the high cost of the NF system and the disposal of a large reject stream.

Major Chemical Cost and Sludge Disposal Cost (Calculations):

1. Caustic @ 200 mg/L x 8.34 x 6 mgd = 10,008 lb/d
   Cost = $0.16/lb (dry basis) delivered at 25% or 30% NaOH
   Annual cost = $0.16 x 10,008 x 365 = $584,500

2. Carbon dioxide @ 100 mg/L x 8.34 x 6 mgd = 5,004 lb/d
   Cost = $0.10/lb delivered as 100% liquid
   Annual cost = $0.10 x 5,004 x 365 = $182, 600

   (Carbon dioxide prices may fluctuate due to natural gas price changes. It used to cost about $0.04-0.05/lb; recent increases in natural gas prices have caused large increases in carbon dioxide prices.)

3. Sludge production at 271 mg/L x 8.34 x 6 mgd = 13,500 lb/d
   = 13.5 ton/d @ 50% solids
   Landfill disposal @ $50/ton = $50 x 13.5 x 365 = $246,000/year

   (The landfill disposal cost is based on is based on local landfill quotation: $22/ton for tipping fee, $340 for trucking of a 12-ton load, and miscellaneous charges such as liner and bin rental. A long-term disposal contract may reduce this cost considerably.)

Additional O&M Personnel Cost:

4. Additional full time O&M personnel @ $45,000/year including benefits, insurance, etc.

   $45,000 x 4 = $180,000 (The $45,000/year labor cost needs to be verified)

Table 1. Lopez WTP Softening Calculations--Lime Treatment with Sulfuric Acid Neutralization

Item	Lime dose, mg $Ca(OH)_2$/L					
	0	100	200	300	350	400
Raw water and final effluent						
Ca	80	45	27	20	34	53
Ca hardness, as $CaCO_3$	200	112	68	50	85	134
Mg	36.5	36	29	20	8	2
Mg hardness, as $CaCO_3$	150	148	118	82	34	7
Total hardness, as $CaCO_3$	350	260	186	132	119	141
M-Alkalinity, as $CaCO_3$	272	156	81	20	10	6
Ct, as CO_3	321	200	104	26	12	7
SiO_2	45	45	18	3	4	9
Na	29	29	29	29	29	29
SO_4	110	136	137	144	142	167
pH, units	8.18	7.5	7.5	7.5	7.5	7.5
Solids production, mg/L	0	217	440	625	681	707
Unneutralized effluent, mg/L						
M-Alkalinity, as $CaCO_3$	N/A	184	109	56	44	65
pH	N/A	8.81	9.34	10.64	10.82	11.16
Na	N/A	29	29	29	29	29
SO_4	N/A	110	110	110	109	110
Chemical feeds, mg/L						
H_2SO_4	0	27	27	35	33	58
$Ca(OH)_2$	0	100	200	300	350	400
Na_2CO_3						
NaOH						

Assumptions

1. Lime purity = 95%, % lime dissolved = 90%,
   effective lime dose = (0.95)(0.90) measured lime dose.
2. NaOH purity = 98%.
3. Na_2CO_3 purity = 95%.

Table 2. Lopez WTP Softening Calculations--Caustic Treatment with Sulfuric Acid Neutralization

Item	Caustic dose, mg NaOH/L			
	0	100	200	300
Raw water and final effluent				
Ca	80	20	5	4
Ca hardness, as $CaCO_3$	200	49	14	9
Mg	36.5	32	25	13
Mg hardness, as $CaCO_3$	150	131	105	55
Total hardness, as $CaCO_3$	350	180	118	64
M-Alkalinity, as $CaCO_3$	272	180	164	162
Ct, as CO_3	321	231	209	207
SiO_2	45	29	6	5
Na	29	85	141	198
SO_4	110	153	228	296
pH, units	8.18	7.5	7.5	7.5
Solids production, mg/L	0	181	261	296
Unneutralized effluent, mg/L				
M-Alkalinity, as $CaCO_3$	N/A	225	288	356
pH	N/A	9.16	10.18	10.92
Na	N/A	85	141	198
SO_4	N/A	110	110	110
Chemical feeds, mg/L				
H_2SO_4		44	120	190
$Ca(OH)_2$				
Na_2CO_3				
NaOH		100	200	300

Table 3. Lopez WTP Softening Calculations--Lime + Soda Ash with Sulfuric Acid Neutralization

Note: Lime dose 350 mg/L, as $Ca(OH)_2$

	Soda ash dose, mg Na_2CO_3/L		
Item	0	40	100
Final effluent			
Ca	34	23	12
Ca hardness, as $CaCO_3$	85	58	30
Mg	8	8	8
Mg hardness, as $CaCO_3$	34	34	34
Total hardness, as $CaCO_3$	119	92	64
M-Alkalinity, as $CaCO_3$	10	13	25
Ct, as CO_3	12	17	32
SiO_2	4	4	4
Na	29	45	70
SO_4	142	146	159
pH, units	7.5	7.5	7.5
Solids production, mg/L	681	711	741
Unneutralized effluent, mg/L			
M-Alkalinity, as $CaCO_3$	44	51	33
pH	10.82	10.83	10.86
Na	29	45	70
SO_4	109	110	110
Chemical feeds, mg/L			
H_2SO_4	33	38	51
$Ca(OH)_2$	350	350	350
Na_2CO_3	0	40	100
NaOH			

Lopez WTP Softening Calculations--Lime Treatment with Sulfuric Acid Neutralization

	Lime dose, mg $Ca(OH)_2$/L					
Item	0	100	200	300	350	400
Ca hardness, as $CaCO_3$	200	112	68	50	85	134
Mg hardness, as $CaCO_3$	150	148	118	82	34	7
Total hardness, as $CaCO_3$	350	260	186	132	119	141
$Ca(OH)_2$, mg/L	0	100	200	300	350	400
M-Alkalinity, as $CaCO_3$	272	156	81	20	10	6
SiO_2	45	45	18	3	4	9
SO_4	110	136	137	144	142	167
pH, units	8.18	7.5	7.5	7.5	7.5	7.5
$Ca(OH)_2$, mg/L	0	100	200	300	350	400
Solids production, mg/L	0	217	440	625	681	707
Unneutralized effluent, mg/L						
M-Alkalinity, as $CaCO_3$	N/A	184	109	56	44	65
pH	N/A	8.81	9.34	10.64	10.82	11.16
Na	N/A	29	29	29	29	29
SO_4	N/A	110	110	110	109	110
Chemical feeds, mg/L						
H_2SO_4		27	27	35	33	58
$Ca(OH)_2$		100	200	300	350	400
Na_2CO_3						
NaOH						

Fig. 1. Hardness Removal by Lime Treatment
Lopez WTP Softening Calculations

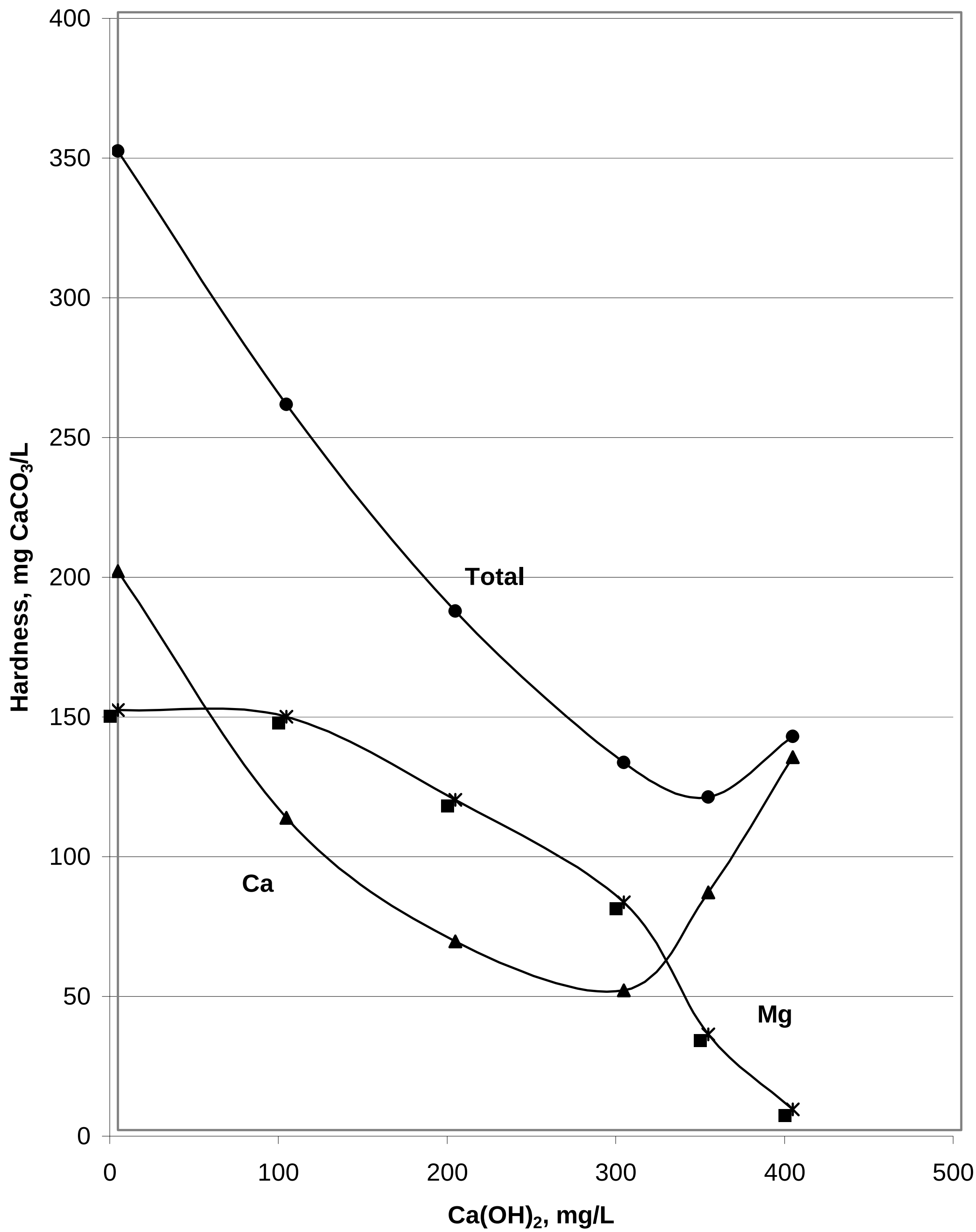


Fig. 2. Effect of Lime on Effluent Quality
Lopez WTP Softening Calculations

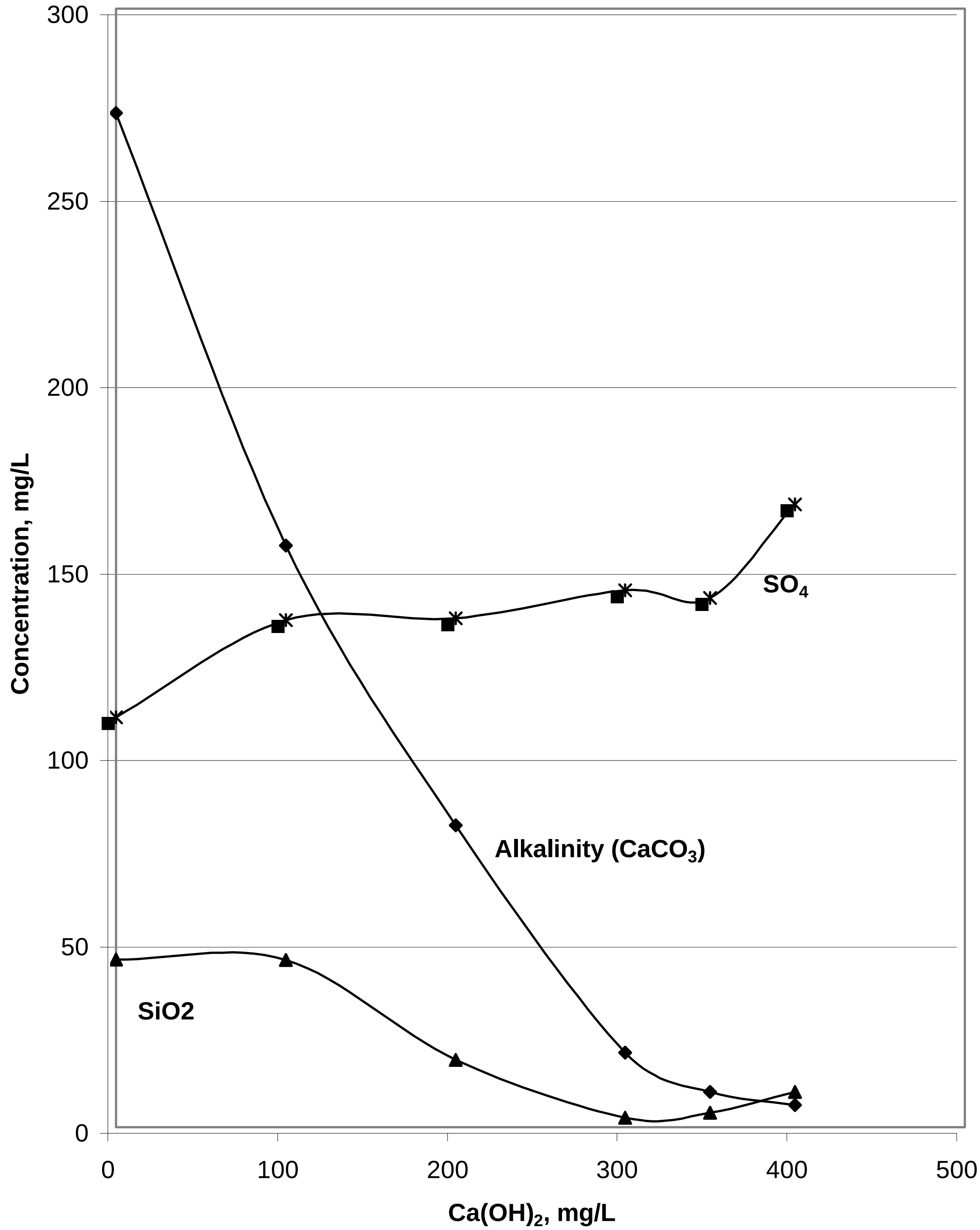
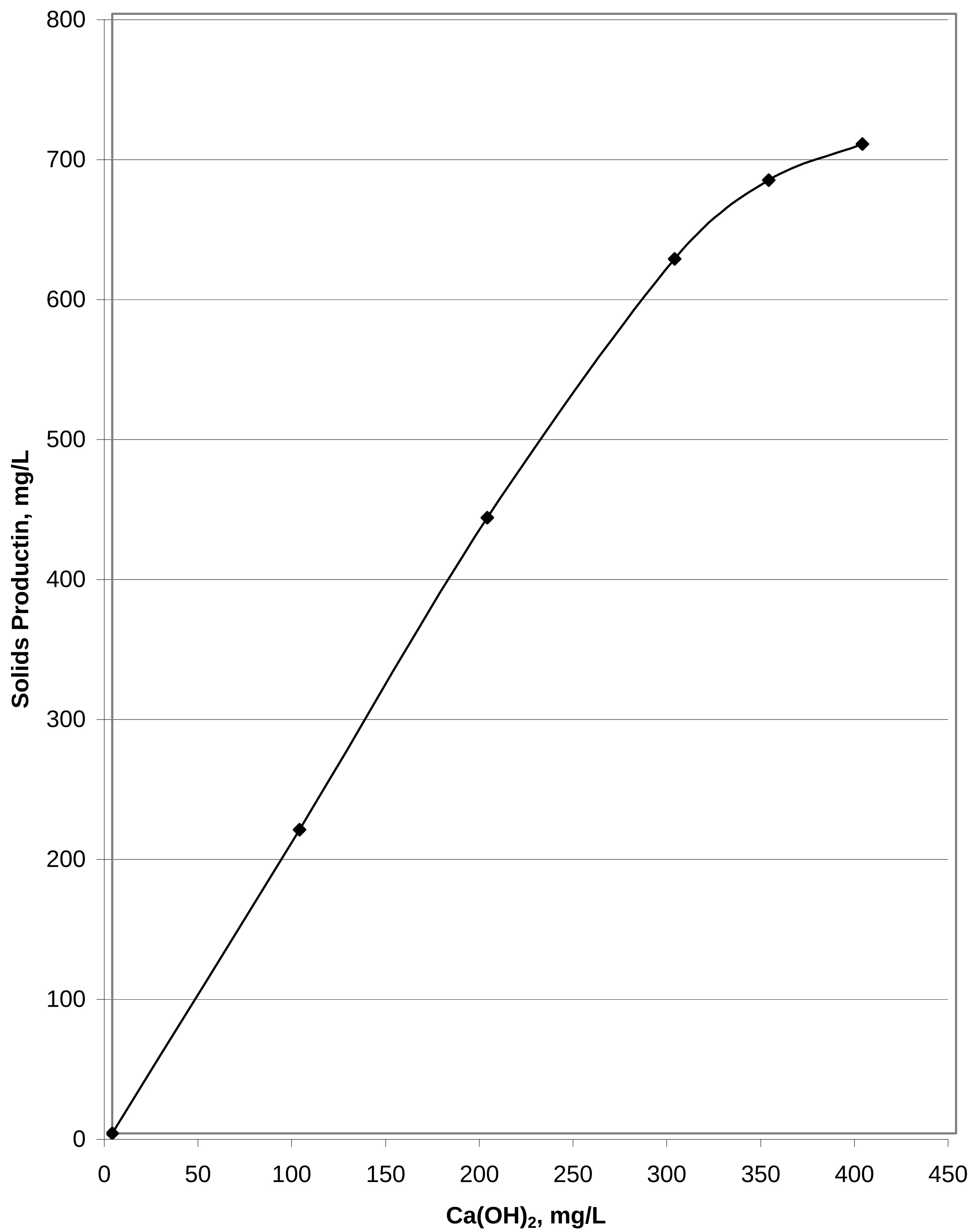


Fig. 3. Effect of Lime Dose on Solids Production
Lopez WTP Softening Calculations



Lopez WTP Softening Calculations--Caustic Treatment with Sulfuric Acid Neutralization

Item	Caustic dose, mg $Ca(OH)_2$/L			
	0	100	200	300
Ca hardness, as $CaCO_3$	200	49	14	9
Mg hardness, as $CaCO_3$	150	131	105	55
Total hardness, as $CaCO_3$	350	180	118	64
NaOH	0	100	200	300
M-Alkalinity, as $CaCO_3$	272	180	164	162
SiO_2	45	29	6	5
Na	29	85	141	198
SO_4	110	153	228	296
pH, units	8.18	7.5	7.5	7.5
NaOH	0	100	200	300
Solids production, mg/L	0	181	261	296
Unneutralized effluent, mg/L				
M-Alkalinity, as $CaCO_3$	N/A	225	288	356
pH	N/A	9.16	10.18	10.92
Na	N/A	85	141	198
SO_4	N/A	110	110	110
Chemical feeds, mg/L				
H_2SO_4		44	120	190
$Ca(OH)_2$				
Na_2CO_3				
NaOH		100	200	300
File		NaOH1	NaOH2	NaOH3

Fig. 4. Hardness Removal by Caustic Treatment
Lopez WTP Softening Calculations

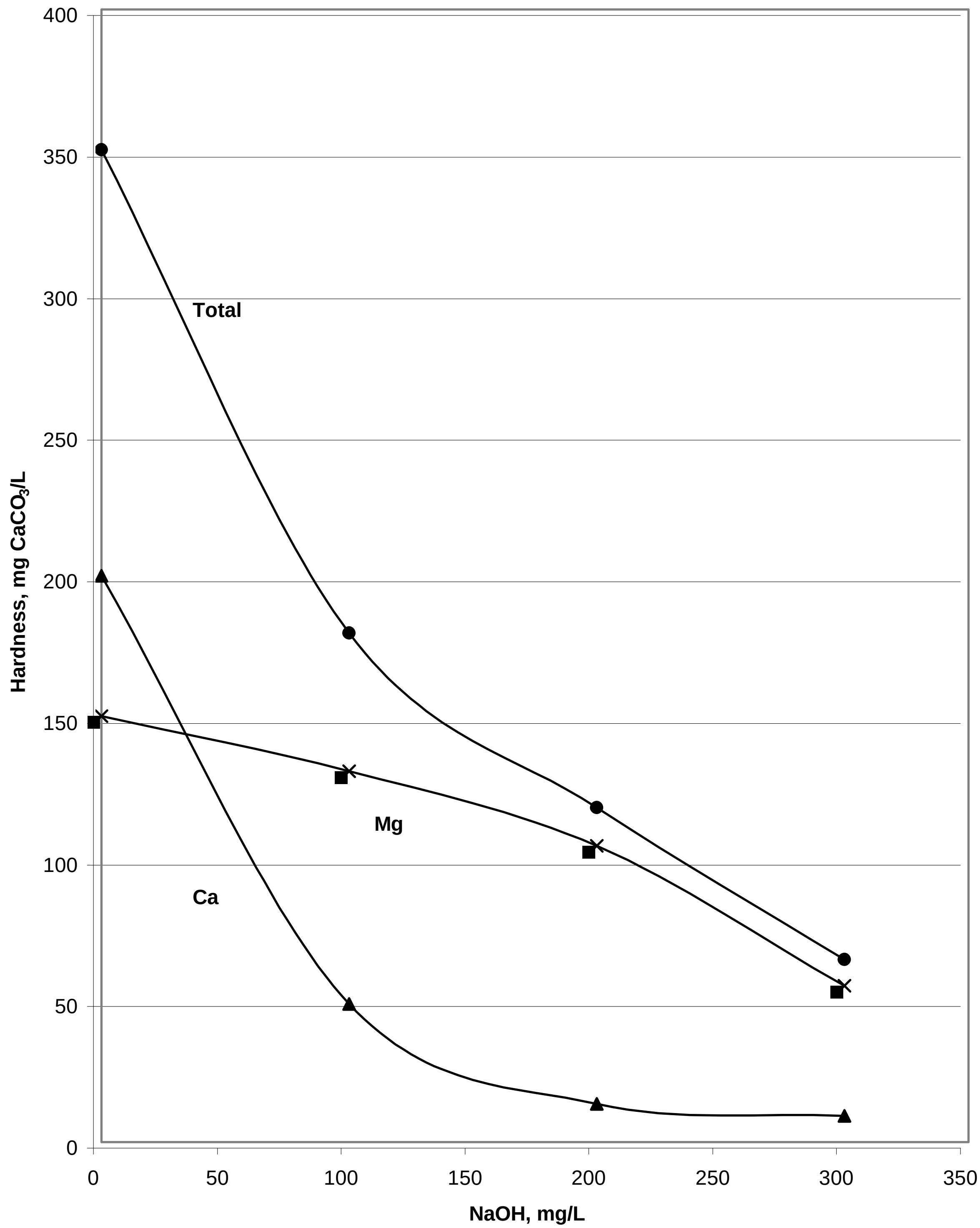


Fig. 5. Effect of Caustic on Effluent Quality
Lopez WTP Softening Calculations

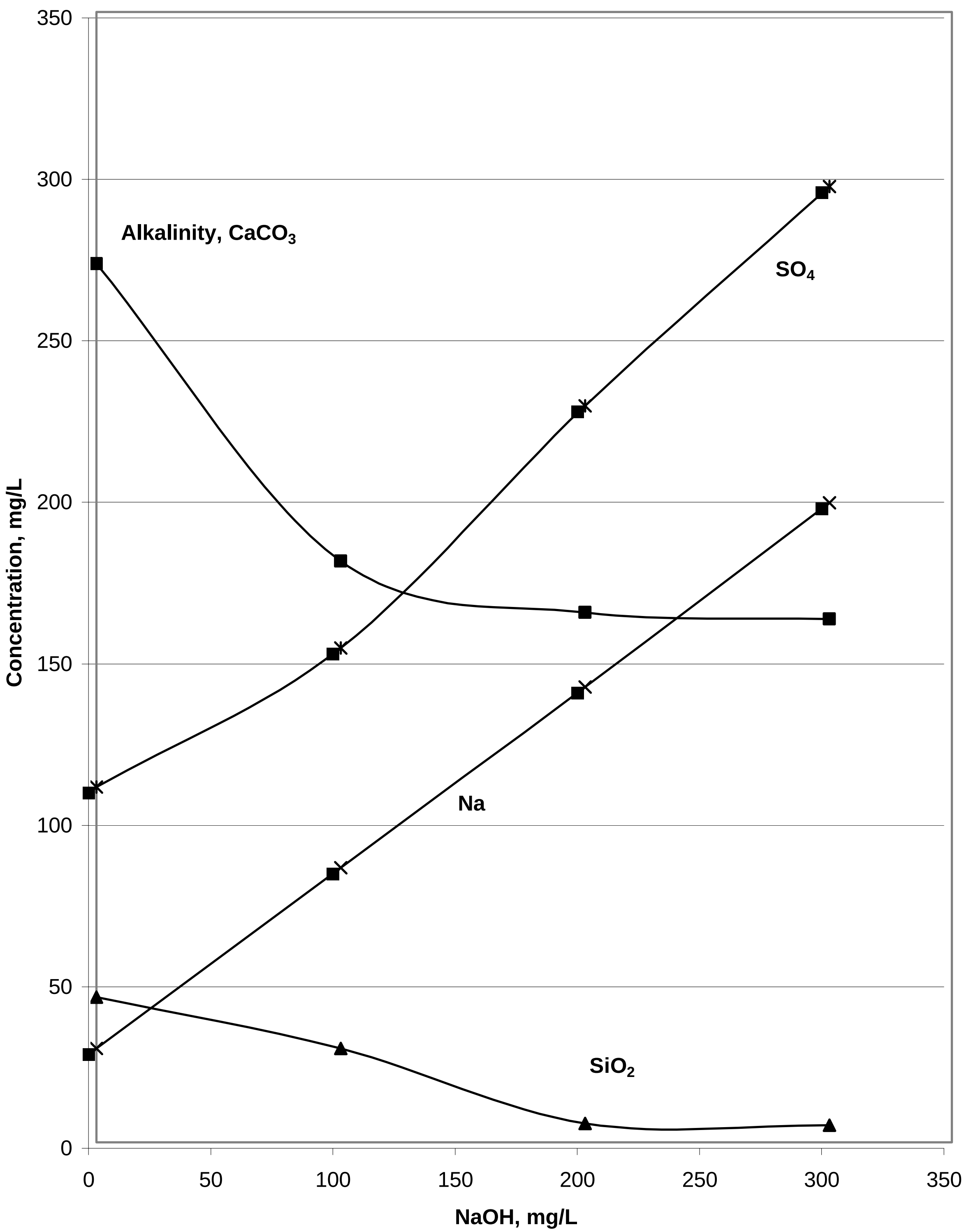
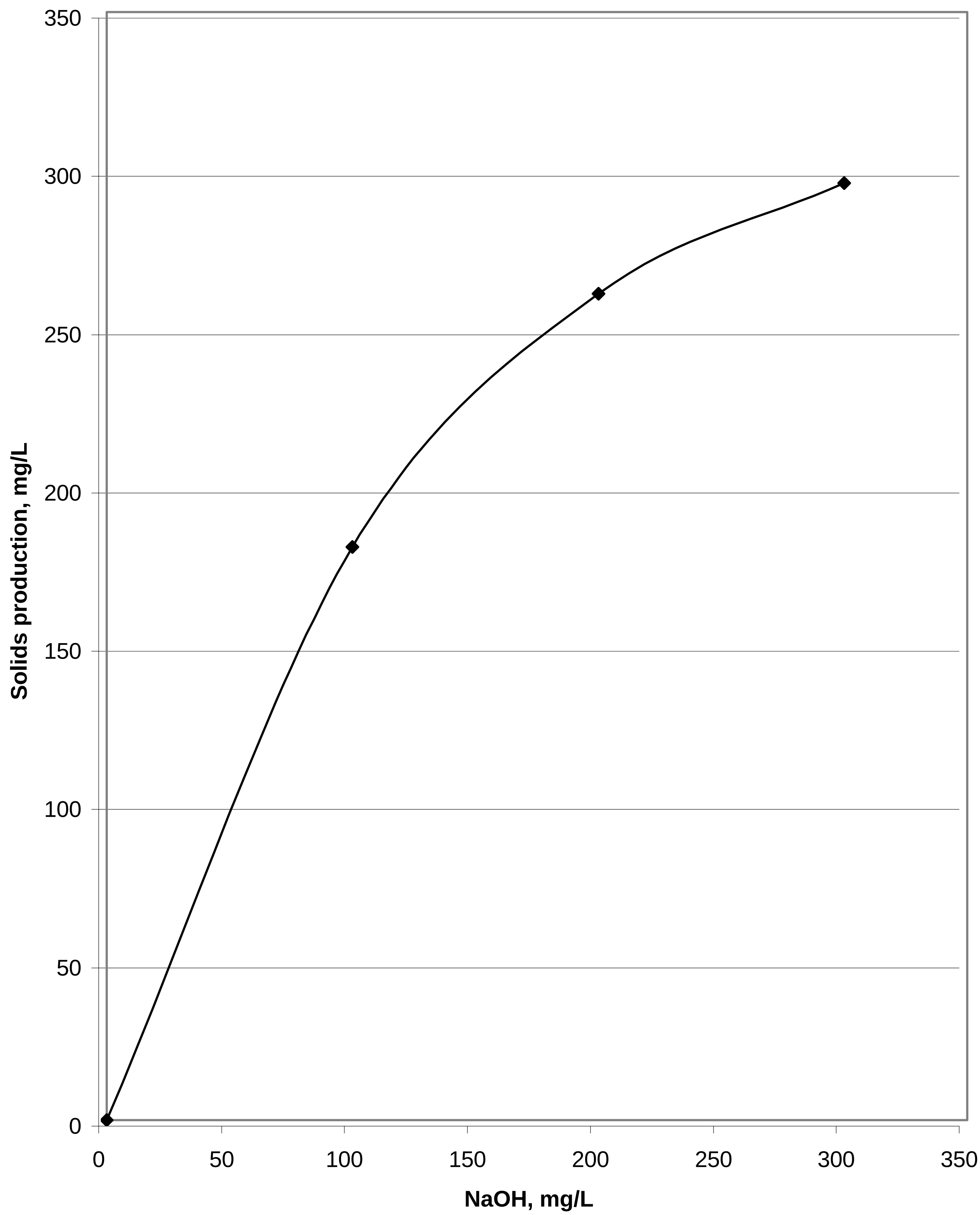


Fig. 6 Effect of Caustic Dose on Solids Production, Lopez WTP Softening Calculations



Lopez WTP Softening Calculations

Lime + Soda Ash Treatment with Sulfuric Acid Neutralization

Note: Lime dose 350 mg/L, as $Ca(OH)_2$

	Soda Ash dose, mg $Ca(OH)_2$/L		
Item	0	40	100
Final effluent			
Ca hardness, as $CaCO_3$	85	58	30
Mg hardness, as $CaCO_3$	34	34	34
Total hardness, as $CaCO_3$	119	92	64
Na_2CO_3	0	40	100
M-Alkalinity, as $CaCO_3$	10	13	25
Na	29	45	70
SO_4	142	146	159
pH, units	7.5	7.5	7.5
Na_2CO_3	0	40	100
Solids production, mg/L	681	711	741
Unneutralized effluent, mg/L			
M-Alkalinity, as $CaCO_3$	44	51	33
pH	10.82	10.83	10.86
Na	29	45	70
SO_4	109	110	110
Chemical feeds, mg/L			
H_2SO_4	33	38	51
$Ca(OH)_2$	350	350	350
Na_2CO_3	0	40	100
NaOH			
File	Lime5	lisoda2	lisoda1

Fig. 7. Hardness Removal by Lime + Soda Ash Treatment, Lopez WTP Softening Calculations

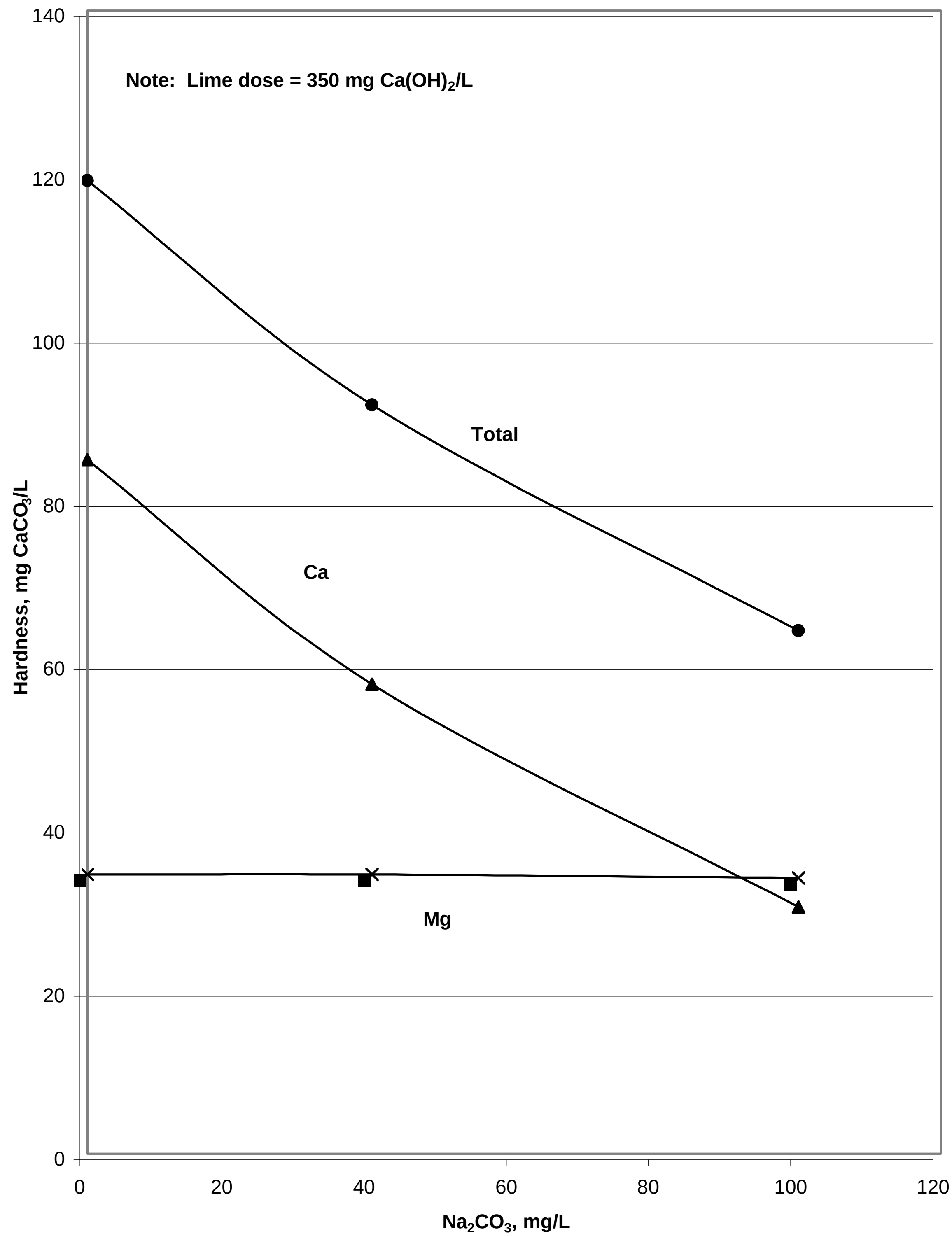


Fig. 8. Effect of Soda Ash on Effluent Quality, Lopez WTP Softening Calculations

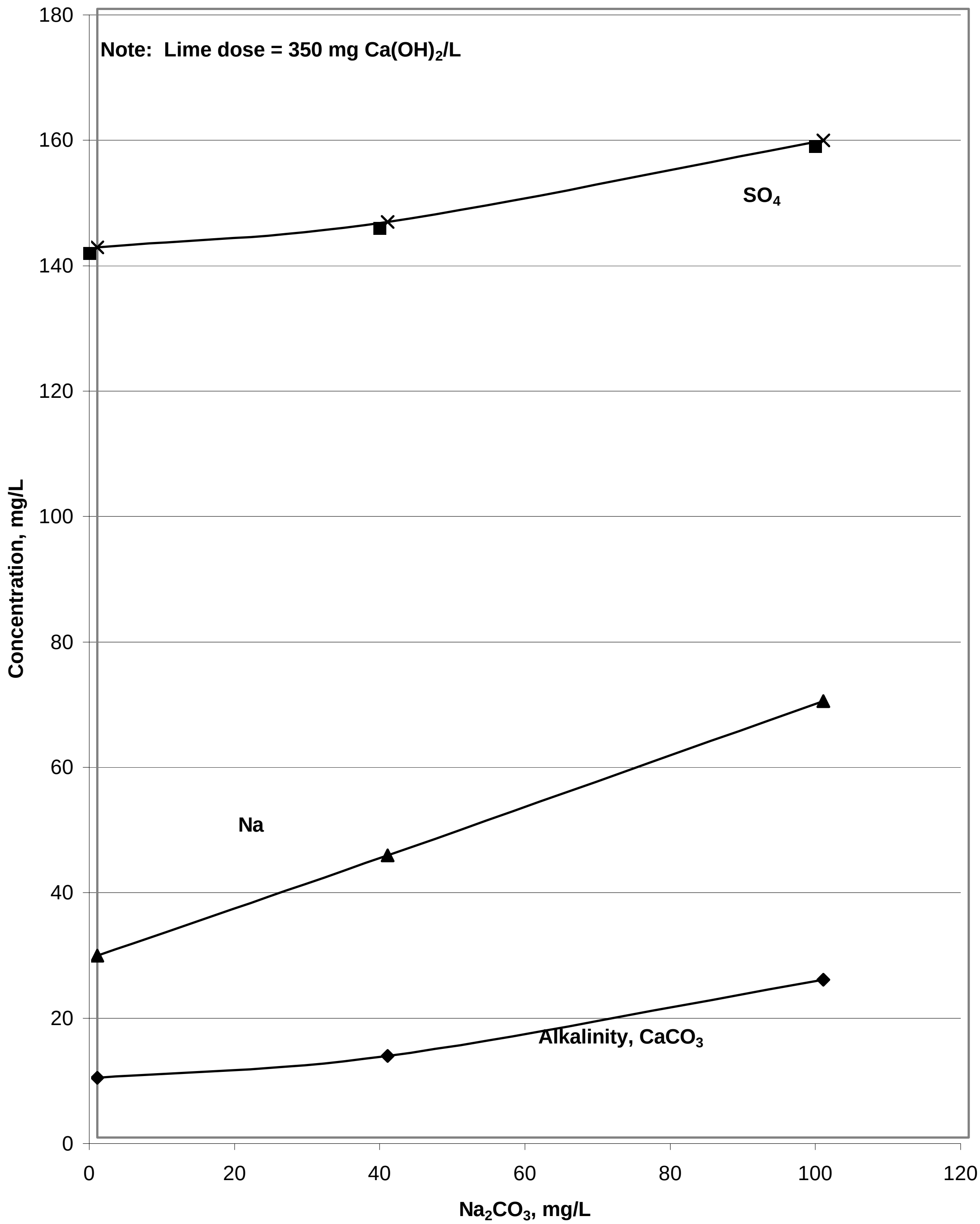


Fig. 9. Effect of Soda Ash Dose on Solids Production, Lopez WTP Softening Calculations