

PROJECT COMPLETION REPORT

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EXTENDED USE OF TREATED MUNICIPAL
WASTEWATER BY THE BUCKEYE IRRIGATION
COMPANY: A DOCUMENTATION OF EFFECTS

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INTRODUCTION

The use of treated sewage effluent by the Buckeye Irrigation Company began with 800 acre-feet in 1962 and had increased to 40,000 a.f. by 1968. The effluent was diverted by the Buckeye Irrigation Company from the Gila River approximately seven miles below the City of Phoenix 91st Avenue treatment plant, as it became available at their diversion point. Natural streamflow, used in earlier years, had virtually stopped due to upstream development except in heavy runoff years such as 1941. The ground water in the district of the Buckeye Irrigation Company is relatively high in dissolved solids. The quality of the treated effluent is better. In 1971 the company signed a 40-year contract with Phoenix to assure its use of 30,000 a.f. of effluent per year. The effluent is mixed with native ground water to bring the total water applied on the 18,000-acre district up to approximately 90,000 a.f. (Halpenny, 1973).

The treated effluent use by the Buckeye Irrigation Company is the largest in the State of Arizona and one of the largest land applications of treated effluent in the United States. It is unique in that it is being utilized by an irrigation district. Most other uses have been by city operated farms or private farms under a single ownership.

In spite of its uniqueness the effects of effluent use by the Buckeye Irrigation District had not, prior to this research, been well documented. This documentation was made in order to improve the general knowledge needed to extend this type of use to other areas in the state and nation. "Widespread consideration and utilization of land application cannot be made until such time as adequate information concerning the technique involved is made available. The experience gained by those who have successfully utilized this wastewater management should be used... specific evaluation of established systems in the various climatic zones would appear to be more fruitful than new research installations for determining long term effects on soils, vegetation, ground water and the indigenous ecology..." (Sullivan, et al., 1973).

During the two year research period most of the initial objectives were achieved. The original specific objectives were:

1. To identify changes during an extended period of application of treated wastewater to irrigated fields in:
 - a. irrigation practices
 - b. cropping patterns
 - c. fertilization practices
 - d. crop yield response and quality
 - e. quality of irrigation water, and
 - f. soil properties.

2. To make a preliminary evaluation of the effects of the use of effluent on ground-water conditions.
3. To make a preliminary evaluation of changes in water costs and farm profits.

RESULTS

It was found during the course of the two year investigation that there had been little or no change in (1) irrigation practices, (2) cropping patterns, or (3) fertilization practices because of the pumped water - wastewater use.

The percentage of canal water that was effluent varied considerably during the course of the year. In the winter time, when the demand was low, the wastewater made up nearly 100 percent of the water delivered. In the summer the crop demand exceeded the rate of wastewater available by about 50 percent or more so the pumps were used to make up the difference.

There were one or two farmers that confided to us that they had gradually reduced fertilization rates. Most had not as late as 1975.

The crop yield response and quality, quality of irrigation water and study of soil properties on selected fields and crops are well documented in the Master's thesis by McFadyen (1976). Three papers have also been written as a result of this study. These are included in Appendix A. The additional papers on cotton, safflower and alfalfa are in various stages of completion at the present time.

Tables 1 and 2 indicate the crop and variety as well as the field soil type and type of water and commercial fertilizer used. The location of the fields can be seen in the map in Appendix B. Tables 3 through 7 give the results from the five crops tested in two different years. These tables include the fertilization rates which were not included in the thesis. The fertilization rates shown in Tables 3 through 7 include the amount contributed by the water. The amount of nutrients in the water is shown in Tables 8 and 9.

The data shows that each year more nitrate-nitrogen was deposited on fields irrigated with pump water alone than on fields irrigated with wastewater-pump water mixtures except on pump water irrigated fields G and I. These two fields were located north of the Buckeye Irrigation District (see Appendix B). Total nitrogen was higher in the wastewater-pump water mix than in the pump only. This was due to the organic nitrogen in the wastewater.

The total soluble salts was considerably less using pump-wastewater than the corresponding field irrigated with pump water except for field G.

There was no phosphorus in the pump water whereas the pump-wastewater blends contained approximately 4 ppm phosphorus.

All soils tested were alkaline with a pH over 7.0. No tendency to either higher or low pH was noted between irrigation treatments of the fields growing the same crop in 1974 and 1975.

Table 1. Crop, variety, irrigation treatment, fertilization, and soil type for each selected field location near Buckeye, Arizona in 1974.

Selected field identification	Crop	Variety	Irrigation treatment	Fertilization (kg/ha)	Soil type
A	Barley	Arivat	Pump water	N-448 P-98 K-372	Gilman loam
B	Barley	Arivat	Wastewater-pump water	N-45 P-24 K-0	Gilman loam
C	Wheat	Siete Cerros	Pump water	None	Gilman loam
D	Wheat	Siete Cerros	Wastewater-pump water	N-29 P-16 K-0	Gilman loam
E	Alfalfa	Hayden	Pump water	N-12 P-19 K-0	Avondale clay loam
F	Alfalfa	Mesa-Sirsa	Wastewater-pump water	none	Avondale clay loam
G	Safflower	Gila	Pump water	N-47 P-7 K-26	Gila sandy loam
H	Safflower	Gila	Wastewater-pump water	none	Gilman loam
I	Cotton	Deltapine 61	Pump water	N-67 P-0 K-0	Gilman loam
J	Cotton	Deltapine 61	Wastewater-pump water	none	Gilman loam

Table 2. Crop, variety, irrigation treatment, fertilization, and soil type for each selected field location near Buckeye, Arizona in 1975.

Selected field identification	Crop	Variety	Irrigation treatment	Fertilization (kg/ha)	Soil type
K	Barley	Arivat	Pump water	none	Glenbar clay loam
L	Barley	Arivat	Wastewater-pump water	N-54 P-29 K-0	Gilman loam
M	Wheat	Cajeme 71	Pump water	N-112 P-0 K-0	Laveen loam
N	Wheat	Cajeme 71	Wastewater-pump water	none	Avondale clay loam
O	Alfalfa	Hayden	Pump water	none	Glenbar clay loam
P	Alfalfa	Hayden	Wastewater-pump water	none	Gilman loam
Q	Safflower	AC-1	Pump water	N-23 P-13 K-0	Gilman loam
R	Safflower	AC-1	Wastewater-pump water	none	Gilman loam
S	Cotton	Deltapine 61	Pump water	N-7 P-10 K-0	Valencia
T	Cotton	Deltapine 61	Wastewater-pump water	none	Gilman loam

Table 3. Average plant height, seed weight, grain yield, and nitrogen and phosphorus fertilization⁺ for Arivat Barley grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height, (cm)	Seed weight (mg/seed)	Grain yield		Fertilization	
				(kg/ha)	% pump water	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Pump water	1974	86a*	43a	5,526a	100	526	98
	1975	114a	49a	5,846a	100	127	0
	1974-75	100a	46a	5,686a	100	327	49
	Average						
Wastewater-pump water	1974	86a	45a	6,732a	122**	239	48
	1975	109a	45a	7,327b	125	347	50
	1974-75	98a	45a	7,030b	124	293	49
	Average						

+Fertilization from grower applications and from nutrients present in irrigation water.

*Means in the same column of the same year followed by the same letter are not different at the 5% level of significance.

**Using the pump water grain yield as the 100% base, the following percentages express the increase in grain yield for wastewater-pump water irrigated fields.

Table 4. Average plant height, seed weight, grain yield, and nitrogen and phosphorus fertilization⁺ for Siete Cerros and Cajeme 71 Wheat grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height (cm)	Seed weight, (mg/seed)	Grain yield		Fertilization	
				(kg/ha)	% pump water	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Pump water	1974	79a*	35a	5,255a	100	83	0
	1975	74a	40a	5,329a	100	223	0
	1974-75	77a	38a	5,292a	100	153	0
	Average						
Wastewater-pump water	1974	102b	38b	8,363b	159**	183	38
	1975	76a	50b	7,056b	132	156	25
	1974-75	89b	44b	7,710b	146	169	32
	Average						

+Fertilization from grower applications and from nutrients present in irrigation water.

*Means in the same column of the same year followed by the same letter are not different at the 5% level of significance.

**Using the pump water grain yield as the 100% base, the following percentages express the increase in grain yield for wastewater-pump water irrigated fields.

Table 5. Average plant height, hay yield, and nitrogen and phosphorus fertilization⁺ from the third cutting for Hayden and Mesa-Sirsa Alfalfa grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height, (cm)	Hay yield adjusted to 10% moisture		Fertilization	
			(kg/ha)	% pump water	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Pump water	1974	53a	3,333a	100	80	19
	1975	94a	4,011a	100	303	0
	1974-75	74a	3,672a	100	192	10
	Average					
Wastewater-pump water	1974	64a	4,452b	134**	447	78
	1975	79a	5,104b	127	512	50
	1974-75	72a	4,778b	130	479	64
	Average					

+Fertilization from grower applications and from nutrients present in irrigation water.

*Means in the same column of the same year followed by the same letter are not different at the 5% level of significance.

**Using the pump water grain yield as the 100% base, the following percentages express the increase in grain yield for wastewater-pump water irrigated fields.

Table 6. Average plant height, bushel weight, seed yield, and nitrogen and phosphorus fertilization⁺ for AC - 1 Safflower grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height, (cm)	Bushel weight (kg/hl)	Grain yield		Fertilization	
				(kg/ha)	% pump water	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Pump water	1974	97a*	55b	2,710a	100	66	7
	1975	99a	53a	4,010a	100	238	13
	1974-75	98a	54a	3,360a	100	152	10
	Average						
Wastewater-pump water	1974	119b	49a	3,031a	112**	213	45
	1975	109b	55a	3,916a	98	522	37
	1974-75	114b	52a	3,474a	103	367	41
	Average						

+Fertilization from grower applications and from nutrients present in irrigation water.

*Means in the same column of the same year followed by the same letter are not different at the 5% level of significance.

**Using the pump water grain yield as the 100% base, the following percentages express the increase in grain yield for wastewater-pump water irrigated fields.

Table 7. Average plant height, lint cotton yield, and nitrogen and phosphorus fertilization⁺ for Deltapine 61 Cotton grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height, (cm)	Lint Cotton yield		Fertilization	
			(kg/ha)	% pump water	Nitrogen (kg/ha)	Phosphorus (kg/ha)
Pump water	1974	89a*	1,745a	100	216	0
	1975	91a	1,415a	100	291	10
	1974-75	90a	1,580a	100	254	5
	Average					
Wastewater-pump water	1974	119b	1,845a	106**	243	40
	1975	119b	1,505a	106	367	37
	1974-75	119b	1,675a	106	305	39
	Average					

⁺Fertilization from grower applications and from nutrients present in irrigation water.

*Means in the same column of the same year followed by the same letter are not different at the 5% level of significance.

**Using the pump water grain yield as the 100% base, the following percentages express the increase in grain yield for wastewater-pump water irrigated fields.

Table 8. Estimated depth of water, total soluble salts, nitrate-nitrogen, and phosphorus in and deposited by irrigation water from pump water alone or wastewater-pump water mixtures received by each selected field near Buckeye, Arizona, during the growing season in 1974.

Selected field identification	Irrigation treatment	Estimated depth of water applied (cm)	Total soluble salts		Nitrate-Nitrogen		Phosphorus		Total N	
			(ppm)	(kg/ha)	(ppm)	(kg/ha)	(ppm)	(kg/ha)	(ppm)	(kg/ha)
A	Pump water	64	3,994	25,434	12.2	78	0*	0	12.2	78
B	Wastewater-pump water	64	1,983	12,628	6.4	41	3.8	24	30.3	194
C	Pump water	58	4,325	25,159	14.2	83	0	0	14.2	83
D	Wastewater-pump water	58	1,598	9,296	5.6	33	3.8	22	26.5	154
E	Pump water	115	2,016	23,182	5.9	68	0	0	5.9	68
F	Wastewater-pump water	189	1,517	28,629	5.0	94	4.1	78	23.7	447
G	Pump water	114	913	10,419	1.7	19	0	0	1.7	19
H	Wastewater-pump water	115	1,689	19,478	3.9	45	3.9	45	18.5	213
I	Pump water	105	3,848	40,269	14.2	149	0	0	10.2	149
J	Wastewater-pump water	105	1,739	18,199	4.9	52	3.8	40	23.2	243

*Only traces of phosphorus were found in water samples from selected pumps in the Buckeye Irrigation District.

Table 9. Estimated depth of water, total soluble salts, nitrate-nitrogen, and phosphorus in and deposited by irrigation water from pump water alone or wastewater-pump water mixtures received by each selected field near Buckeye, Arizona, during the growing season in 1975.

Selected field identification	Irrigation treatment	Estimated depth of water applied (cm)	Total soluble salts		Nitrate-Nitrogen		Phosphorus		Estimated Total N	
			(ppm)	(kg/ha)	(ppm)	(kg/ha)	(ppm)	(kg/ha)	(ppm)	(kg/ha)
K	Pump water	64	3,315	21,302	19.8	127	0*	0	19.8	127
L	Wastewater-pump water	64	1,837	11,698	9.7	62	3.3	21	45.9	293
M	Pump water	58	3,708	21,569	19.0	111	0	0	19.0	111
N	Wastewater-pump water	58	1,358	7,899	5.7	33	4.4	25	27.0	156
O	Pump water	189	3,705	69,921	16.0	303	0	0	16.0	303
P	Wastewater-pump water	139	1,715	23,758	7.8	109	3.6	50	36.9	512
Q	Pump water	114	2,827	32,262	18.8	215	0	0	18.8	215
R	Wastewater-pump water	114	1,871	21,352	9.7	111	3.2	37	45.9	522
S	Pump water	105	5,380	56,302	27.1	284	0	0	27.1	284
T	Wastewater-pump water	105	1,664	17,414	7.4	77	3.5	37	35.0	367

*Only traces of phosphorus were found in water samples from selected pumps in the Buckeye Irrigation District.

There were also no consistent differences found in each of two types of fields in 1974 and 1975 in electrical conductivity, exchangeable sodium percentage and nitrate-nitrogen. There was more phosphorus found in both 1974 and 1975 in the fields where a pump-wastewater mixture was used than in the corresponding fields growing the same crop with only pump water. The complete analysis of these soil properties for five different zones are included in Tables 10-19.

The effect of wastewater irrigation on ground-water quality with time is shown in Figures 1 through 6. In almost all cases there is an increase in nitrate after 1962, about the time effluent was first used. Nitrate tends to accumulate in ground water with time exceeding the concentration of nitrate in the recharging water.

Wells 3M (Figure 1), 5M (Figure 2) and 27M (Figure 6) tended to increase in total dissolved solids, starting before the arrival of the municipal wastewater in 1960. Wells 9M (Figure 3), 15M (Figure 4) and 23M (Figure 5) tended to have reduced total dissolved solids after the beginning of using wastewater. Some of the fluctuations can be explained by intermittent flooding down the Salt-Gila River system and sampling and analyzing errors.

The location of the selected wells as well as a contour map of the nitrate concentration in the Buckeye Irrigation District is shown in the map in Appendix B. The map does show a concentration of the nitrates in the ground water in the Buckeye Irrigation District. Other nitrate data is given for other years next to each well on the map.

SUMMARY

The study showed there was an increase in crop production in areas where a municipal wastewater-pump water blend was used as compared to the use of only pump water. This expected result is due both to increased nutrients and lower dissolved solids in the wastewater-pump water blend as compared to pump water only.

The pump water did contain more nitrate than the wastewater-pump water blend, however the organic nitrogen plus phosphorus contained in the blended water made the total nutrient content higher in the mixture than the pumped water only. The data showed that in some cases the individual farmer fertilized where he was using wastewater-pump water blend but another farmer, in the case of 1975 barley crop using pump water only, did not fertilize. Even with fertilization in the pump water only crops and no fertilization in the blended water the latter generally produced higher yields. This indicated that the lowered total dissolved solids also had an influence on yields.

Soluble salts and nitrate-nitrogen were higher in soils treated with pump water than they were in soils irrigated with the wastewater-pump water mixture. Extractable phosphorus were in general higher in the soils irrigated with the mixture as compared to pump water only. Most of the nitrogen in the wastewater-pump water mixture was not in the nitrate form. In the process of irrigation there could be some losses. Further there might be a delay in the nitrogen

Table 10. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 0 to 1 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1974.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
A	Pump water	7.8-7.9	1.57	5.0	3.2	2.3
B	Wastewater	7.7-8.0	2.66	13.5	7.0	4.4
C	Pump water	7.9-8.0	2.82	11.5	5.7	1.5
D	Wastewater	7.7-8.0	1.51	7.5	1.4	4.1
E	Pump water	7.7-7.9	2.15	7.6	4.0	1.6
F	Wastewater	7.7-7.9	1.76	6.6	7.9	3.9
G	Pump water	7.8-8.1	1.84	10.3	5.2	7.1
H	Wastewater	7.9	2.63	9.7	10.4	8.9
I	Pump water	7.8	4.62	13.5	10.2	1.3
J	Wastewater	8.0-8.2	2.75	9.1	11.8	3.3

* From CO₂ extraction.

Table 11. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 1 to 2 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1974.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
A	Pump water	7.9-8.0	1.92	9.8	2.6	1.1
B	Wastewater	7.8-8.3	2.66	14.5	5.2	2.3
C	Pump water	7.8-8.0	4.12	7.6	4.1	1.3
D	Wastewater	7.7-8.0	1.69	7.8	1.4	1.3
E	Pump water	7.7-7.9	2.33	10.2	3.9	0.6
F	Wastewater	7.9-8.0	1.65	7.7	3.7	1.6
G	Pump water	7.8-8.1	2.03	8.0	2.5	2.0
H	Wastewater	7.9-8.0	2.85	8.8	7.5	4.1
I	Pump water	7.7-7.9	5.36	15.6	21.9	0.7
J	Wastewater	7.9-8.1	3.35	11.9	5.0	1.4

* From CO₂ extraction.

Table 12. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 2 to 3 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1974.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
A	Pump water	7.9-8.2	1.88	8.1	2.4	0.8
B	Wastewater	7.7-8.3	3.06	14.5	3.0	2.1
C	Pump water	7.9-8.1	4.36	6.1	5.6	0.9
D	Wastewater	7.7-8.1	1.93	10.0	1.0	0.8
E	Pump water	7.8-8.0	2.37	7.5	3.3	0.6
F	Wastewater	7.9-8.1	1.70	8.5	2.9	0.9
G	Pump water	7.9-8.2	1.84	8.4	6.5	0.9
H	Wastewater	7.9-8.0	2.17	12.8	6.0	2.9
I	Pump water	7.6-7.9	4.92	18.8	16.2	0.7
J	Wastewater	7.9-8.1	3.33	14.8	3.3	0.5

* From CO₂ extraction.

Table 13. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 3 to 4 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1974.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
A	Pump water	7.9-8.2	1.97	10.9	1.9	0.6
B	Wastewater	7.9-8.3	2.69	16.5	5.4	1.4
C	Pump water	7.9-8.1	4.28	5.7	4.4	0.6
D	Wastewater	7.8-8.1	2.36	10.4	1.2	0.6
E	Pump water	7.8-7.9	2.91	8.6	2.8	0.4
F	Wastewater	7.9-8.0	1.84	8.2	2.8	0.8
G	Pump water	8.0-8.3	1.60	16.1	4.3	1.0
H	Wastewater	7.9-8.1	1.78	10.2	3.6	1.7
I	Pump water	7.8-7.9	4.62	14.7	8.5	1.2
J	Wastewater	7.9-8.0	4.31	21.0	3.1	0.4

* From CO₂ extraction.

Table 14. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 4 to 5 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1974.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
A	Pump water	7.9-8.2	2.37	18.0	2.6	0.4
B	Wastewater	7.9-8.3	2.77	12.9	6.4	1.1
C	Pump water	7.9-8.1	2.97	6.4	4.3	0.7
D	Wastewater	8.0-8.2	1.91	9.9	1.5	0.5
E	Pump water	8.0	3.39	11.2	1.8	0.1
F	Wastewater	8.0-8.2	1.71	11.0	2.7	2.0
G	Pump water	8.0-8.3	1.95	11.1	5.4	0.5
H	Wastewater	7.9-8.1	1.93	9.5	3.8	1.4
I	Pump water	7.9-8.0	4.36	11.3	9.5	1.0
J	Wastewater	7.9-8.0	3.92	15.8	6.7	0.3

* From CO₂ extraction.

Table 15. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 0 to 1 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1975.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
K	Pump water	7.9-8.3	2.03	6.4	6.3	2.7
L	Wastewater	7.7-8.0	1.90	7.9	7.7	8.0
M	Pump water	8.1-8.3	2.59	5.8	4.6	1.9
N	Wastewater	8.1	2.00	9.0	4.8	6.6
O	Pump water	7.8-8.2	3.08	13.5	9.3	1.9
P	Wastewater	7.8-8.1	2.75	9.8	7.3	6.8
Q	Pump water	7.8-7.9	4.53	13.2	14.8	2.5
R	Wastewater	7.9-8.1	4.30	13.0	28.5	7.9
S	Pump water	8.0-8.1	1.77	3.8	8.0	3.0
T	Wastewater	7.7-8.1	2.59	8.1	12.6	9.8

* From CO₂ extraction.

Table 16. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 1 to 2 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1975.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
K	Pump water	8.0-8.2	2.59	7.1	4.8	1.8
L	Wastewater	7.5-8.2	1.86	5.6	3.3	3.4
M	Pump water	8.1-8.2	3.52	8.3	4.6	.9
N	Wastewater	8.0-8.3	1.75	6.3	3.3	1.6
O	Pump water	7.8-8.2	2.95	9.6	4.3	1.1
P	Wastewater	8.2-8.3	2.88	10.6	4.5	4.2
Q	Pump water	7.9-8.0	5.07	11.8	11.5	1.7
R	Wastewater	7.9-8.4	4.30	9.5	8.3	2.1
S	Pump water	8.1-8.3	1.29	5.1	17.6	4.4
T	Wastewater	7.9-8.1	2.70	8.3	35.0	6.8

* From CO₂ extraction.

Table 17. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 2 to 3 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1975.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
K	Pump water	8.0-8.2	2.94	9.8	3.3	3.7
L	Wastewater	7.5-8.1	2.10	7.3	3.2	2.2
M	Pump water	8.1-8.2	2.45	8.5	8.2	1.0
N	Wastewater	8.0-8.3	1.65	8.3	2.8	1.5
O	Pump water	8.0-8.1	3.08	13.3	4.0	1.0
P	Wastewater	8.0-8.2	3.68	10.8	3.1	1.0
Q	Pump water	7.9-8.0	5.00	13.0	11.2	3.3
R	Wastewater	7.8-8.2	4.60	10.0	5.0	0.7
S	Pump water	7.9-8.6	2.18	4.9	3.5	0.9
T	Wastewater	8.0-8.4	2.88	10.1	3.6	1.3

* From CO₂ extraction.

Table 18. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 3 to 4 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1975.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
K	Pump water	8.0-8.1	4.51	9.1	2.8	1.4
L	Wastewater	8.1-8.4	2.22	8.4	3.5	1.6
M	Pump water	8.0-8.2	2.45	7.9	10.6	0.7
N	Wastewater	8.0-8.2	1.78	8.3	2.3	2.5
O	Pump water	7.8-8.1	2.93	12.0	4.0	0.9
P	Wastewater	8.0	4.15	11.3	2.4	1.0
Q	Pump water	7.8-7.9	4.77	10.8	10.5	1.2
R	Wastewater	8.0-8.3	4.2	11.7	4.3	0.6
S	Pump water	8.0-8.2	2.71	5.4	8.4	0.9
T	Wastewater	8.3	2.29	9.1	2.9	1.1

* From CO₂ extraction.

Table 19. Average pH, electrical conductivity, exchangeable sodium percentage, nitrate-nitrogen, and extractable phosphorus in the 4 to 5 ft depth of soils from selected fields irrigated with two irrigation treatments near Buckeye, Arizona in 1975.

Selected field identification	Irrigation treatments	Paste pH	Electrical conductivity (EC x 10 ³)	Exchangeable sodium percentage (ESP)	Nitrate-nitrogen (ppm)	Extractable phosphorus* (ppm)
K	Pump water	8.1-8.2	4.97	9.8	2.5	1.0
L	Wastewater	7.9-8.3	2.26	6.9	5.3	1.8
M	Pump water	7.9-8.2	2.45	8.3	9.6	.7
N	Wastewater	8.1-8.2	2.10	11.8	2.2	1.3
O	Pump water	7.9-8.0	3.58	12.5	3.5	0.6
P	Wastewater	7.9-8.0	5.05	11.5	2.5	1.2
Q	Pump water	7.9-8.0	4.33	8.7	9.2	0.9
R	Wastewater	7.7-8.4	4.13	9.8	4.5	0.6
S	Pump water	8.0-8.4	2.84	6.4	12.0	0.8
T	Wastewater	8.1-8.5	2.64	10.5	6.2	1.5

* From CO₂ extraction.

Figure 1. Well 3M, Buckeye Irrigation District.

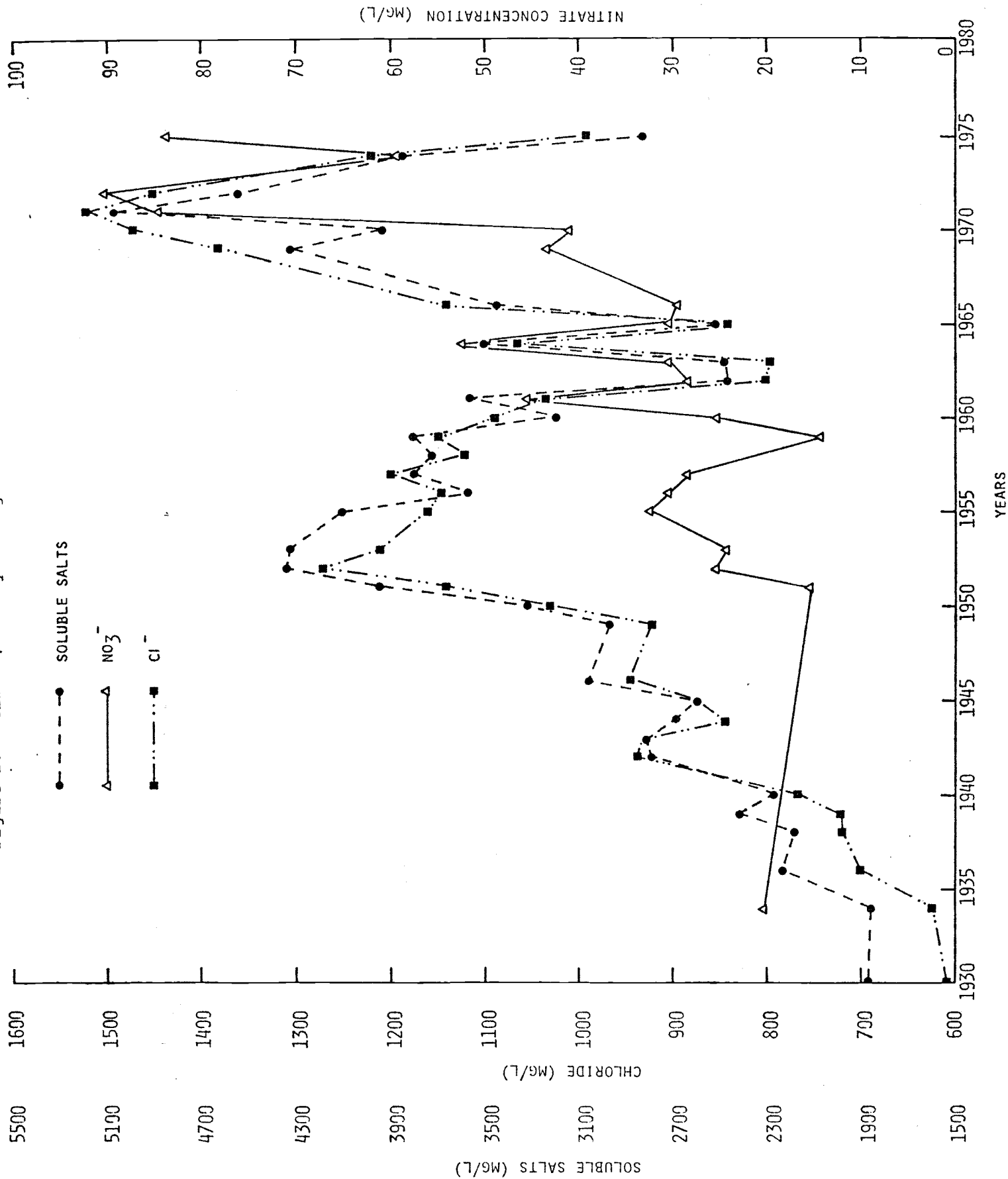
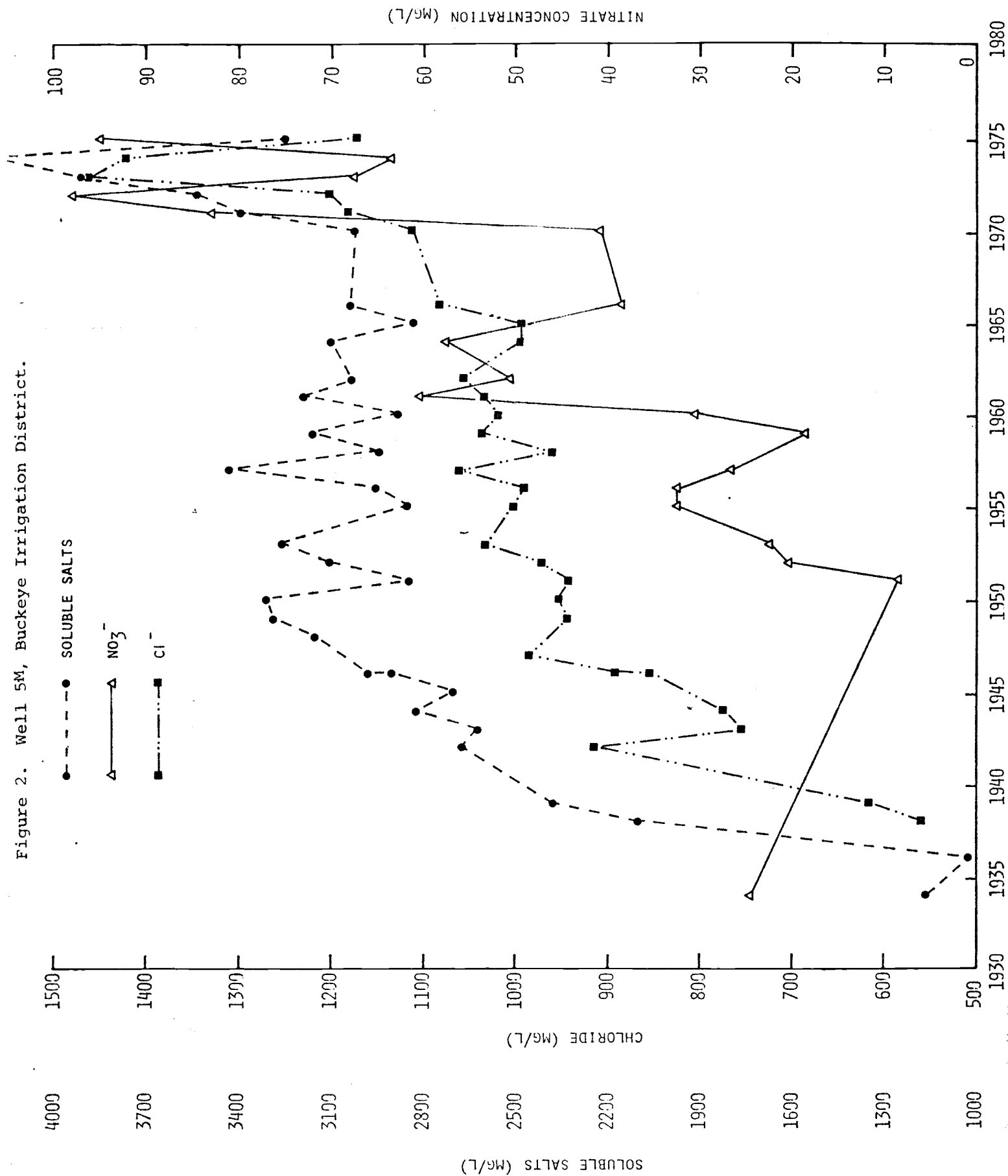
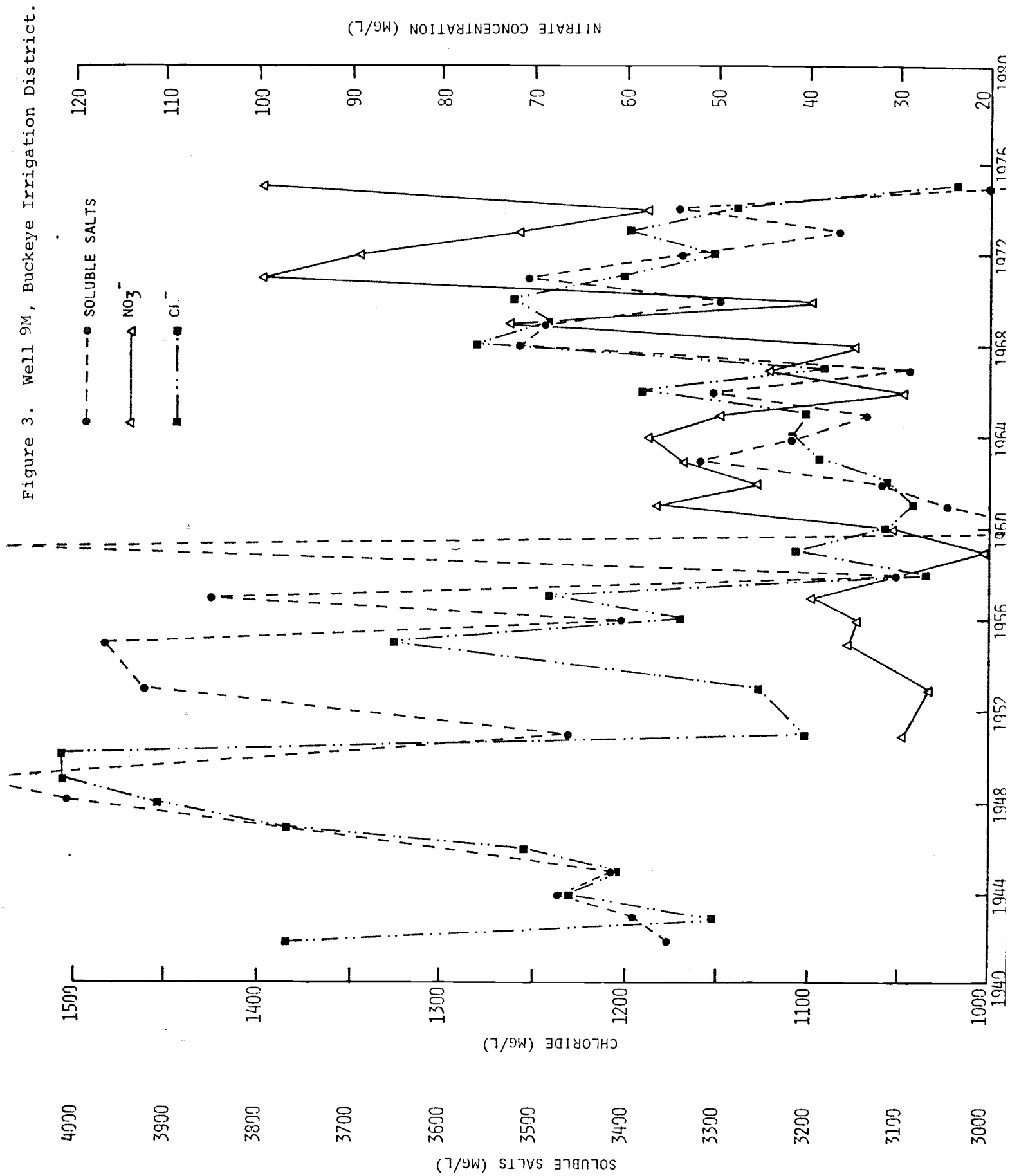
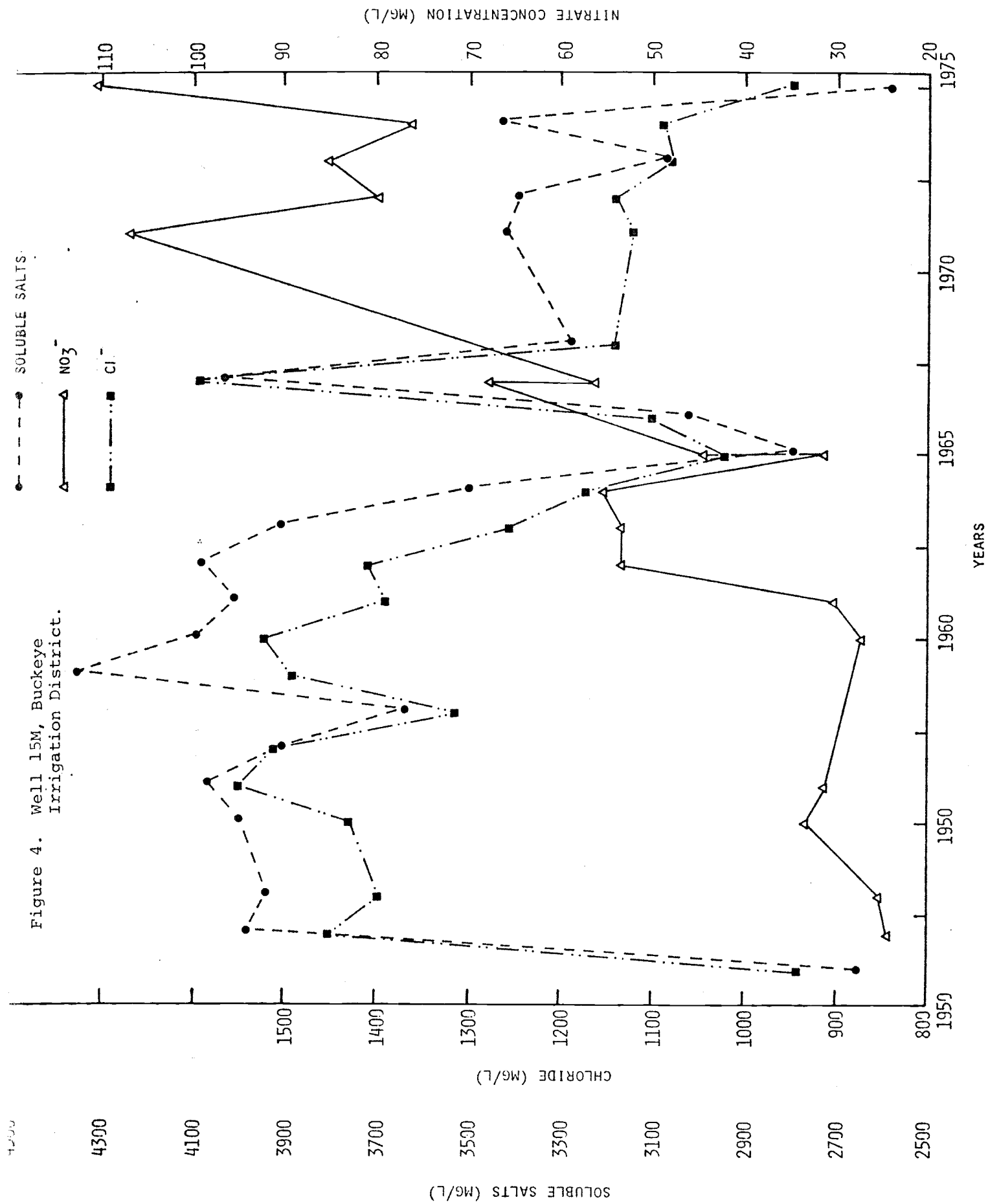
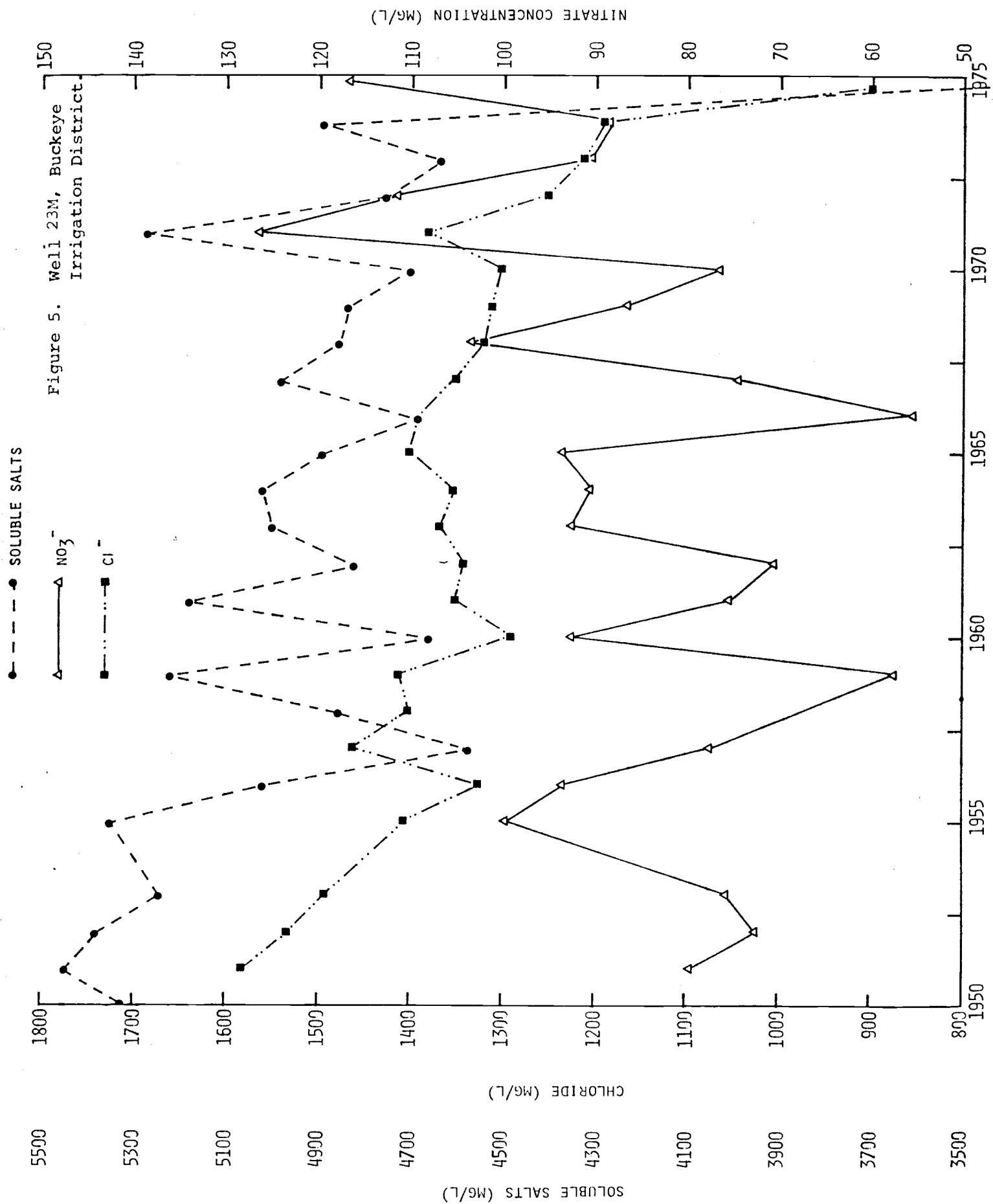


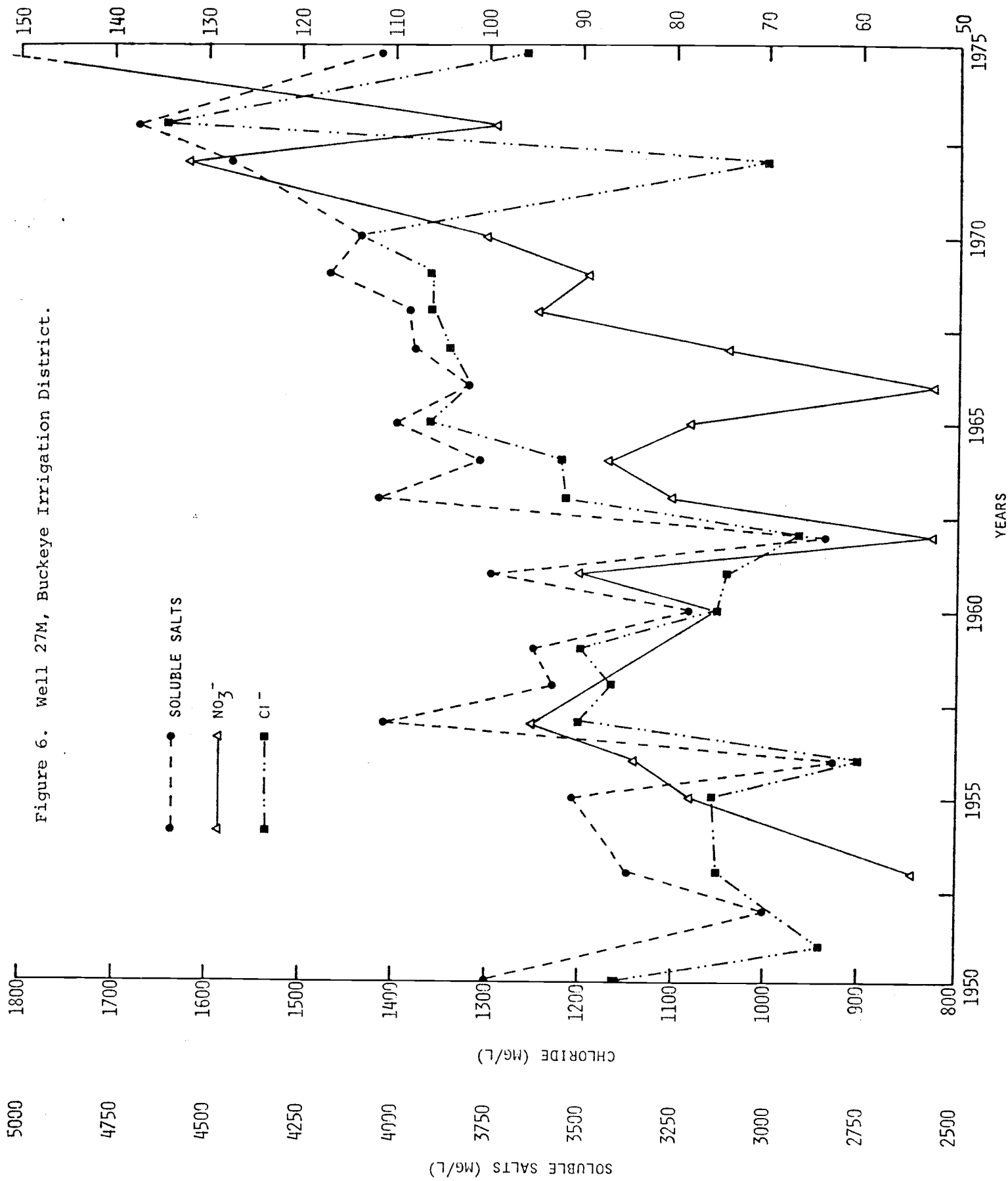
Figure 2. Well 5M, Buckeye Irrigation District.











transformation to nitrate that the soil testing did not measure. Further, the lower residual NO_3 in soils irrigated with pump water-wastewater mixture may be due to higher vegetative growth which indicated a higher nitrogen use efficiency.

The study did show there appeared to be no damage done to the soil after, in some cases, 12 years of using wastewater-pump water for irrigation.

The study showed an accelerating increase in nitrate concentration in ground water since the use of wastewater began. This increase may, in part, be due to the expanding use of fertilizer in the 1950 and 1960's and the practice of farmers to continue their fertilization practices even though they were using wastewater. Due to the high nitrate levels that are now in the ground water, the soil analyses show that the pumped water only irrigation may be causing a higher rate of buildup of nitrates than the wastewater-pumped water mixture.

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APPENDIX A

SPRING WHEAT GROWN WITH MUNICIPAL WASTEWATER¹

A. D. Day, J. A. McFadyen, T. C. Tucker, and C. B. Cluff²

Representative fields of wheat were carefully identified on similar soil types and under similar management practices for detailed studies in 1974 and 1975. The principal soil type was a Gilman loam. The Gilman series is a member of the coarse-loamy, mixed, (calcareous), hyperthermic family of Typic Torrifluvents. The response of wheat to two irrigation treatments: (1) pump water alone and (2) a 25/75 mixture of pump water and wastewater were compared by sampling the selected fields each year. A randomized complete block experimental design with four replications was used to compare the response of wheat to the two irrigation treatments. The cultivars evaluated were 'Siete Cerros' in 1974 and 'Cajeme 71' in 1975. In both 1974 and 1975, the wheat that was irrigated with pump water received 112 kg/ha of N prior to planting; however, the wheat that was irrigated with pump water and wastewater was not fertilized with commercial fertilizer. Approximately 82 cm (32 inches) of irrigation water were required to grow wheat to maturity, assuming 60% irrigation efficiency. All other cultural practices were similar for wheat grown under the two irrigation treatments.

In 1974, wheat irrigated with a mixture of pump water plus wastewater produced taller plants than did wheat grown with pump water alone; however, in 1975 wheat irrigated with the two types of water produced plants of similar height. The 2-year average indicated that wheat grown with pump water plus wastewater produced taller plants than did wheat produced with only pump water. Wheat irrigated with a mixture of pump water and wastewater produced more heads per unit area, heavier seeds, higher grain yields, and higher straw yields than did wheat grown with only pump water. Irrigation treatment had no significant effect on the number of seeds per head.

The plant height and straw yield data clearly indicated that wheat grown with a mixture of pump water plus wastewater produced more vegetative growth than did wheat produced with pump water. The increased vegetative growth from wheat grown with pump water plus wastewater was believed to be responsible for the increased lodging observed in that irrigation treatment. Although wheat grown with the pump water and wastewater mixture produced significantly higher

¹Contribution from the Department of Plant Sciences; Department of Soils, Water, and Engineering; and Water Resources Research Center; University of Arizona; Tucson, Arizona 85721. The research reported in this paper was supported by funds provided by the United States Department of Interior, Office of Water Research and Technology as authorized under the Water Resources Act of 1964 and by the State of Arizona.

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grain yields than did wheat grown with only pump water, the lower grain volume-weight of wheat produced with that irrigation treatment indicated that wastewater may lower the quality of wheat grain at the market place below the quality of wheat grain produced with pump water alone. Since wheat irrigated with the pump water plus wastewater mixture produced more straw than did wheat irrigated with pump water, a grower may expect to obtain higher yields of pasture forage, green chopped feed, and hay for livestock feed from wheat when wastewater is used as a portion of the irrigation water than may be obtained when only pump water is used for irrigation.

INFLUENCE OF MUNICIPAL WASTEWATER ON THE GROWTH AND YIELD OF COTTON¹

A. D. Day, J. A. McFadyen, T. C. Tucker, and C. B. Cluff²

Experiments were conducted in the field to study the influence of municipal wastewater on the growth and yield of cotton near Buckeye, Arizona, in 1974 and 1975. The soil type was a Gilman loam. Conventional culture for growing cotton on 38-inch beds was used. The crop was planted in April and harvested in November each year. Approximately 4 acre-feet of irrigation water were required to produce a cotton crop. Two sources of irrigation water were used: (1) pump water from local wells (control treatment) and (2) municipal wastewater plus pump water in a 50:50 mixture. The pump water contained approximately 4600, 21, and 0 ppm of total soluble salts, nitrate nitrogen, and elemental phosphorus, respectively. The wastewater plus pump water mixture contained about 2200, 6, and 37 ppm of total soluble salts, nitrate nitrogen, and elemental phosphorus, respectively. Fifty pounds per acre of nitrogen were applied before planting to the cotton that was irrigated with pump water. No nitrogen was applied to the cotton that was irrigated with the wastewater plus pump water mixture. The experimental design was a Modified Randomized Complete Block with four replications.

Plant growth and yield data for cotton grown with the two sources of irrigation water are presented in Table 1. Cotton irrigated with the wastewater plus pump water mixture produced taller plants that contained more vegetative growth than did cotton that was irrigated with pump water alone. When cotton was irrigated with the wastewater plus pump water mixture the yields of seed cotton and lint cotton were equal to or higher than the yields of seed cotton and lint cotton from plants irrigated with pump water.

Municipal wastewater can be used effectively as a source of irrigation water and plant nutrients in the commercial production of cotton in Arizona and, possibly, in similar environments throughout the world. When municipal wastewater is mixed with pump water that is high in total soluble salts, the salt content of the mixture is lowered and the quality of the irrigation water is improved.

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TABLE 1

Average plant height, seed cotton yields, and lint cotton yields for Deltapine 61 Cotton grown with two irrigation treatments near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height (inches)	Seed cotton yield		Lint cotton yield	
			Pounds per acre	% of pump water	Pounds per acre	% of pump water
Pump water (control)	1974	35	3,885	100	1,558	100
	1975	36	3,413	100	1,263	100
	1974-75 avg.	36	3,649	100	1,411	100
Wastewater & pump water	1974	47	4,463	115	1,647	106
	1975	47	3,632	106	1,344	106
	1974-75 avg.	47	4,048	111	1,496	106

Comments

1. Planted in April.
2. Harvested in November.
3. Soil type = Gilman loam.

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engineering**

Wastewater helps the barley grow!

By A. D. Day, J. A. McFadyen,
T. C. Tucker, and C. B. Cluff

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1979 issue of Water & Wastes Engineering.

Wastewater helps the barley grow!

Arizona barley irrigated with wastewater yields taller plants, more lodging, lower grain volume-weights, and higher grain yields.

By A. D. Day, J. A. McFadyen,
T. C. Tucker, and C. B. Cluff

SOUTHERN ARIZONA EXPERIMENTS indicate that barley irrigated with a 50:50 mixture of pump water and treated municipal wastewater was superior in growth, grain yield, and grain quality to barley irrigated with pump water alone.

In addition, soil irrigated with both types of irrigation water had similar pH at the end of the study.

An inadequate supply of water has always been a problem for inhabitants in the semi-arid southwestern United States. Since surface water is limited, ground water reserves have been pumped to supply the agricultural, municipal, and industrial needs.

Agricultural use of water combined with large increases in population have greatly increased the demand for ground water and have resulted in a lowering of the water table. Alternative sources of irrigation water must be used whenever possible by commercial agriculture to reduce the gap between the rates of pumping and recharge of ground water supply in the Southwest.

One alternative is the use of treated municipal wastewater for crop irriga-

tion. This would provide low-cost irrigation water that contains large quantities of plant nutrients.

Buckeye, Ariz., is an agricultural community located about 30 miles west of Phoenix in central Arizona. The Buckeye Irrigation Company provides irrigation water to about 18,000 acres of farmland, which is known as the Buckeye Irrigation District. Beginning in 1962, the Buckeye Irrigation Company began using treated municipal wastewater from the city of Phoenix for irrigation water. From the initial use of 800 acre-feet, the amount of wastewater used by the Buckeye Irrigation Company increased to 40,000 acre-feet by 1968. In 1971, a long-term contract with the city of Phoenix was signed to provide the Buckeye Irrigation Company with 30,000 acre-feet of treated municipal wastewater annually for 40 years. The need to investigate the effect of treated municipal wastewater upon the crops, soils, and irrigation water was recognized and two separate wastewater research studies were conducted from 1970 through 1977.

The objectives of this research were: (1) to compare the response of barley irrigated with a mixture of pump water and wastewater with the response of barley irrigated with pump water alone, (2) to compare the effects of pump water and pump water-wastewater irrigation on soil properties, and (3) to compare the quality of a pump water-wastewater mixture with the quality of pump water along as a source of irri-

gation water for barley production.

Representative 'Arivat' barley fields near Buckeye, Arizona, were selected on similar soil types and under similar management practices for investigation in 1974 and 1975. The dominant soil type in the fields studied was a coarse-loam.

The effects of two irrigation treatments was studied: (a) pumpwater (from deep wells) and (b) an approximate 50:50 mixture of pump water and treated municipal wastewater (pump water-wastewater) on barley fields each year. The experimental design was a modified randomized complete block with four replications.

Barley irrigated with pump water alone was fertilized with 112 kg/ha of N prior to planting; whereas barley irrigated with the pump water-wastewater mixture was not supplemented with commercial fertilizer. All other cultural practices in the two irrigation treatments were similar.

The barley crop was harvested by hand sickle, each year at maturity from four 0.405 m² plots in each selected field in 1974 and 1975. The selected fields ranged in size from 40 to 160 acres. Data collected from each plot for comparison of the irrigation treatments were: plant height, heads per unit area, seeds per head, seed weight, grain yield, and straw yield.

From 1970 to 1977, representative fields of barley in the Buckeye Irrigation District ranging from 40 to 160 acres were selected for the irrigation study.

Day is an agronomist and McFadyen a graduate assistant in the Department of Plant Sciences; Tucker is a soil scientist in the Department of Soils, Water, and Engineering; and Cluff is a hydrologist at the Water Research Center, University of Arizona, Tucson.

Twenty-five fields were irrigated with pump water alone. Another 25 fields were irrigated with the pump water-wastewater mixture. A total of 50 fields were studied during the eight-year period.

At maturity, the following data were obtained from each field: plant height, lodging, grain volume-weight, and grain yield. The barley was combine-harvested in May each year. Standard analysis of variance was applied to all data and the Student-Newman-Keuls' Test was used to compare treatment means.

At each harvest in 1974 and 1975, soil samples from the 0-30 cm depths were collected from each plot within each selected field. The soil samples were analyzed for paste pH, electrical conductivity ($EC \times 10^3$), exchangeable sodium percentage (ESP), nitrate-nitrogen (NO_3-N), and extractable Phosphorus (P).

The water quality of the pump water and wastewater used for irrigation of barley fields in 1974 and 1975 was monitored. Additional data from annual water quality reports from the Buckeye Irrigation Company and the Roosevelt Irrigation Company from 1970 through 1977 were studied. Based on the accumulated data, a composite water quality was formulated for the irrigation water used on each selected field in the large field studies from 1970 through 1977.

Comparing crop response

In 1974 and 1975, in small plot research, barley irrigated with a 50:50 mixture of pump water and wastewater produced taller plants, more heads per unit area, heavier seeds, higher grain yields, and higher straw yields than barley irrigated with pump water alone (Table 1). Number of seeds per head were not significantly affected by the irrigation treatments.

On large fields from 1970 through 1977, barley irrigated with the pump water-wastewater mixture had taller plants, more lodging, lower grain volume-weights and higher grain yields than barley irrigated with pump water alone (Table 2).

The vegetative growth of barley, as indicated by the plant height and straw yield data, was greater when it was irrigated with the pump water-wastewater mixture than when it was irrigated with pump water alone. Increased vegetative growth derived from the pump water-wastewater irrigation may be a partial explanation for the increased lodging.

Although barley irrigated with the pump water-wastewater mixture out-yielded barley irrigated with pump water alone, its lower grain volume-weight (seed weight and/or size) may be indicative of lower grain quality and marketability (Table 2). If a grower's

1—SMALL PLOT RESEARCH COMPARISON

Average plant height, heads per unit area, seeds per head, seed weight, grain yield, and straw yield from barley grown with pump water and pump water plus wastewater near Buckeye, Arizona in 1974 and 1975.

Irrigation treatment	Year	Plant height	Heads per m ²	Seeds per head	Seed weight	Grain yield	Straw yield (12% moisture)
		(cm)	(no.)	(no.)	(mg/seed)	(kg/ha)	(kg/ha)
Pump water	1974	86 b ⁺	509 b	25 a	43 b	5,526 b	5,835 b
	1975	84 b	533 b	27 a	41 b	5,846 b	6,094 b
	1974-75 average	85 b	521 b	26 a	42 b	5,686 b	5,965 b
Pump water plus wastewater	1974	96 a	562 a	28 a	46 a	6,732 a	7,702 a
	1975	92 a	581 a	26 a	48 a	7,327 a	7,893 a
	1974-75 average	94 a	572 a	27 a	47 a	7,030 a	7,798 a

⁺ Means in the same column for the same year or years followed by the same letter are not different at the 5% level of significance using the Student-Newman-Keuls' Test.

2—LARGE FIELD COMPARISON

Average plant height, lodging, grain volume-weight, and grain yield from 25 fields of barley grown with pump water and 25 fields of barley grown with pump water plus wastewater near Buckeye, Arizona from 1970 through 1977.

Irrigation treatment	Plant height	Lodging	Grain volume-weight	Grain yield
	(cm)	(%)	(kg/ha)	(kg/ha)
Pump water	86 b ⁺	60 b	62 a	4,102 b
Pump water plus wastewater	96 a	75 a	60 b	5,248 a

⁺ Means in the same column followed by the same letter are not different at the 5% level of significance using the Student-Newman-Keuls' Test.

3—SOIL ANALYSES

Average pH, electrical conductivity, exchangeable sodium, nitrate-nitrogen, and extractable phosphorus in the 0 to 30-cm depth of soils from fields irrigation with two irrigation treatments for the production of barley near Buckeye, Arizona in 1974 and 1975 (2-year average).

Irrigation treatment	Paste pH	Electrical conductivity	Exchangeable sodium percentage	Nitrate nitrogen	Extractable phosphorus (CO ₂ extraction)
	(pH)	($EC \times 10^3$)	(ESP)	(ppm)	(ppm)
Pump water	8.0 a ⁺	1.8 b	5.7 b	4.8 b	2.5 b
Pump water plus wastewater	7.9 a	2.3 a	10.7 a	7.4 a	6.2 a

⁺ Means in the same column followed by the same letter are not different at the 5% level of significance using the Student-Newman-Keuls' Test.

4—WATER QUALITY

Average depth of penetration, total soluble salts, nitrate-nitrogen, and phosphorus for pump water and pump water plus wastewater used to irrigate barley near Buckeye, Arizona in 1974 and 1975 (2-year average).

Irrigation treatment	Penetration of irrigation water	Total soluble salts	Nitrate nitrogen	Phosphorus
	(cm)	(ppm)	(ppm)	(ppm)
Pump water	64 a ⁺	3,655 a	16.0 a	0.0 b
Pump water plus wastewater	64 a	1,910 b	8.1 b	3.6 a

⁺ Means in the same column followed by the same letter are not different at the 5% level of significance using the Student-Newman-Keuls' Test.

objective is to produce barley for pasture forage, he may obtain higher vegetative yield by using wastewater as a partial source of irrigation water than by using pump water alone.

Results of soil analyses are shown on Table 3. In the 0–30 cm depth, all soil samples tested were slightly alkaline with a pH of about 8, indicating that irrigation treatments did not result in a significant pH change. Electrical conductivity, exchangeable sodium percentage, $\text{NO}_3\text{-N}$, and extractable P were significantly higher in soils irrigated with the pump water-wastewater mixture than in soils irrigated with pump water alone.

Average depths of water penetration were similar for the two irrigation treatments (Table 4). Pump water contained more total soluble salts and $\text{NO}_3\text{-N}$ than did the pump water-wastewater mixture. The pump water-wastewater mixture had a higher P content than pump water alone (Table 4).

Water quality for irrigation is influenced by salt concentrations. Excessive levels of salt in irrigation water may be detrimental to plant growth by inhibiting germination, limiting water uptake due to osmotic effects, and by the toxic effects on plants of specific ions present. The lower concentration of salt (Table 4) in the pump water-wastewater mixture was probably a major factor in its superiority to pump water alone for irrigation purposes in the Buckeye area.

The $\text{NO}_3\text{-N}$ content in the pump water-wastewater mixture was lower than the $\text{NO}_3\text{-N}$ content in the pump water alone (Table 4). This, however, does not account for the organic and ammonium forms of nitrogen that were present in wastewater and can be transformed to $\text{NO}_3\text{-N}$ over a period of time.

The amounts of total soluble salts, $\text{NO}_3\text{-N}$, and total P applied to each selected field from the pump water or pump water-wastewater irrigations

were estimated from the composite water quality data in conjunction with the amount of water applied. Barley consumptive water use data was used to estimate the amount of water applied.

The higher nitrate content of soils irrigated with the pump water-wastewater mixture (Table 3) probably resulted from the higher total nitrogen present in municipal wastewater. The higher nutrient content of wastewater was an additional factor that probably contributed to higher yields and larger plants.

From the experience in the Buckeye Irrigation District, it is evident that treated municipal wastewater can be used as a partial source of irrigation water and plant nutrients in the commercial production of barley in the irrigated areas of the Southwest and also in similar regions throughout the world.

□ □

APPENDIX B

BUCKEYE WATER CONSERVATION AND DRAINAGE DISTRICT
SERVICED BY BUCKEYE IRRIGATION COMPANY

SHOWING MAIN CANALS AND WELLS WITH NITRATE CONTOURS AND FIELDS USED IN MUNICIPAL WASTEWATER
CROP PRODUCTION STUDY, 1974-75

