Publication No. 01-060-083

PROCEEDINGS OF THE THIRD INTERNATIONAL SYMPOSIUM ON PHOSPHOGYPSUM

VOLUME II

GREAT SEAL OF THE STATE OF FLORIDA
IN GOD WE TRUST

Organized by
The University of Miami
under a grant sponsored by the
Florida Institute of Phosphate Research
Bartow, Florida

December 1990

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH

The Florida Institute of Phosphate Research was created in 1978 by the Florida Legislature (Chapter 378.101, Florida Statutes) and empowered to conduct research supportive to the responsible development of the state's phosphate resources. The institute has targeted areas of research responsibility. These are: reclamation alternatives in mining and processing, including wetlands reclamation, phosphogypsum storage areas and phosphatic clay containment areas; methods for more efficient, economical and environmentally balanced phosphate recovery and processing; disposal and utilization of phosphatic clay; and environmental effects involving the health and welfare of the people, including those effects related to radiation and water consumption.

FIPR is located in Polk County, in the heart of the central Florida phosphate district. The institute seeks to serve as an information center on phosphate-related topics and welcomes information requests made in person, by mail, or by telephone.

Research Staff

Executive Director
Richard F. McFarlin

Research Directors

G. Michael Lloyd Jr.	-Chemical Processing
Gordon D. Nifong	-Environmental Services
Steven G. Richardson	-Reclamation
Hassan El-Shall	-Beneficiation
Robert S. Akins	-Mining

Florida Institute of Phosphate Research
1855 West Main Street
Bartow, Florida 33830

(863)534-7160

Proceedings
of the
Third International Symposium
on Phosphogypsum

Sponsored by

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH

Organized by

University of Miami

and *held at*

Radisson Plaza Hotel Orlando

Orlando, Florida

December, 1990

Editor: Wen F. Chang

Contract Manager: G. Michael Lloyd, Jr.

DISCLAIMER

Volume II

UTILIZATION

CONSTRUCTION

THE CURRENT STATE OF UTILIZATION OF PHOSPHOGYPSUM IN AUSTRALIA

J. Beretka
Principal Research Scientist
CSIRO Division of Building, Construction and Engineering (DBCE)
PO Box 56, Highett, Victoria 3190, Australia

ABSTRACT

This paper describes the present state of utilization of phosphogypsum in Australia. It covers the research and development work carried out for making plaster of Paris (stucco) and plaster products, the development of a new type of ettringite-based cement termed ‘Novel Cement’, and the application of phosphogypsum as a soil conditioner in agriculture. The potential radioactivity of phosphogypsum is also discussed.

INTRODUCTION

About 940 000 t of phosphogypsum is generated in Australia annually at five locations: Brisbane, Queensland; Newcastle, New South Wales; Melbourne and Geelong, Victoria; and Kwinana, Western Australia. At present, some 200 000 tpa is used mainly as a soil conditioner and low-grade fertiliser in agriculture, but the rest of the material is disposed of on land or into disused quarries, creating a stockpile of ~8 x 10^6 t. In comparison, a similar quantity of ~800 000 t was generated in 1980 (Beretka, 1980), of which about 70 000 to 100 000 t was used for making plaster products at two locations and as a soil conditioner in agriculture. The use of phosphogypsum for making plaster products was discontinued in about 1983, probably because (a) Australia is very rich in mineral resources including natural gypsum, (b) there were some problems associated with the extreme fineness and ‘lime sensitivity’ (Berry, 1972; Wirsching, 1978; Beretka, 1982; Beretka and Brown, 1983, 1986) of the materials during the production processes, and (c) there were concerns about the potential radioactivity of the materials used.

The bulk of phosphate rock used for making phosphoric acid originates from Nauru, Christmas Island, Florida and Jordan, and smaller quantities from Broken Hill South, NSW. The phosphoric acid producers and commercial enterprises are interested in using phosphogypsum for making plaster of Paris (stucco) and plaster products. However, economic and technological considerations, and an awareness of the potential radioactivity of phosphogypsum inhibits its application in building products at the present time. The author is not aware of the use of phosphogypsum as a retarder for Portland cement.

This paper describes the present use of and research on phosphogypsum in Australia. This includes research carried out at CSIRO DBCE for making plaster products and the development of a new type of ettringite-based cement/binder termed ‘Novel Cement’ (Santoro, *et al.*, 1984, 1986; Valenti, *et al.*, 1984, 1988; Beretka, Valenti, et *al.*, 1987; Beretka, Santoro, *et al.*, 1987) which incorporates a large percentage (2540%) of either natural gypsum or, preferably, phosphogypsum. Furthermore, its application in agriculture will be discussed, together with measurements carried out in establishing the radioactivity levels of the materials generated at the five Australian locations.

PROPERTIES OF PHOSPHOGYPSUM

The quantities of phosphogypsum generated at present in Australia are shown in Table I, and their chemical composition is presented in Table II. It can be seen that the materials have similar compositions to those generated at other plants which are employing two-stage crystallization, i.e. either Nissan or Fisons processes. Furthermore, it is evident that the materials contain relatively small percentages (0.1-0.9%) of residual phosphate. The phosphate content can also be expressed not only as total phosphate, but also as soluble, co-crystalline and unreacted phosphates. The presence of phosphate,

Table I
Production and utilization of phosphogypsum in Australia (1989)

Location	Plant type	Quantity (tpa)	Stockpile (t)	Method of disposal
Brisbane, Qld (Pinkeba)	Nissan	23 000	1.3 x 10^6	~70-90 000 tpa sold to farmers as soil conditioner; rest is held at disposal site.
Newcastle, NSW (Kooragang Island)	Nissan	260 000	1 x 10^6	~50 000 tpa sold as soil conditioner and as a calcium source in coal washing; rest disposed of as landfill under ovals and non-structural areas.
Melbourne, Vic. (Yarraville)	Nissan	100 000	4.5 x 10^6	~50 000 tpa sold as soil conditioner and as low-grade fertiliser; rest is held at disposal site (disused quarry). One company is experimenting with the use of material in the plaster industry.
Geelong, Vic.	Fisons	150 000	280 000	Stored at disposal site; some sold as soil conditioner.
Kwinana, WA	Fisons	200 000	1.05 x 10^6	Plant not operating since 1986. ~10 000 tpa sold as soil conditioner; rest held at disposal site.
Total		940 000	8.1 x 10^6	~200 000 sold as a soil conditioner

Table II
Chemical compositions of phosphogypsums (%)

	Sample				
	Brisbane	**Geelong**	**Melbourne**	**Newcastle**	**Kwinana**
Free water content (as received)	10.56	13.2	n.d.	13.7	20.53
Dried samples					
CaO	32.9	30.35	32.9	32.6	32.2
SO_3	45.1	43.0	44.8	44.5	45.2
SiO_2	0.11	5.0	0.11	<0.01	0.08
Al_2O_3	0.12	0.34	0.11 }	<0.01	0.34
Fe_2O_3	0.03	0.06	<0.01		0.03
MgO	0.04	0.02	0.03	n.d.	0.01
Na_2O	0.05	0.35	0.03	0.28	0.08
K_2O	0.02	0.013	0.05	n.d.	0.01
Total F^-	1.30	0.82	1.20	1.24	1.10
Total H_2O (H_2O^+)	20.6	18.85	19.9	20.9	20.5
Free water (H_2O^-)	<0.02	0.24	0.07	n.d.	0.02
Total P_2O_5	0.28	0.88	0.45	0.40	0.69
Organic C	0.10	0.08	0.14	n.d.	0.14
Total	100.55	100.00	99.8	99.94	100.22

n.d. not determined.

particularly the co-crystalline phosphate (Frochen and Becker, 1959), has a major influence on its potential application in the plaster industry due to the lime sensitivity of phosphogypsums (Berry, 1972; Wirsching, 1978; Beretka, 1982, 1988; Beretka and Brown, 1983, 1986). All the plants produce fine, acicular crystals. X-ray diffraction revealed that crystallographically all the materials are identical to natural gypsum. Only the sample from Geelong contained relatively high percentages (~5%) of silica (SiO_2), which was obviously added to the liquor in order to assist the crystallization process at that particular plant.

APPLICATION OF PHOSPHOGYPSUM IN THE PLASTER INDUSTRY

As previously mentioned, phosphogypsum has been used at two locations - Brisbane and Newcastle - for 10 and 2 years, respectively, for making plaster of Paris and plaster products, mainly plasterboard. Its use was discontinued in 1983 probably due to intermittent manufacturing and quality control problems associated with the variability of the materials, the variability of their impurity (mainly residual phosphate) content, and also to the general 'scare' about radioactivity. Another factor contributing to the discontinuation was probably due to the ready availability of relatively inexpensive natural gypsum in most Australian States.

Recently, at the request of a company in Victoria, investigations have been carried out at CSIRO DBCE on one of the large phosphogypsum stockpiles located near Melbourne and containing about 4 x 10^6 t of phosphogypsum. The disposal site is located next to a phosphoric acid plant. The company expressed interest in using this material for making plaster products, particularly plasterboard. The investigation was carried out (Brown and Varsamis, pers. comm.) on three types of samples: (a) six core samples taken at the site to a depth of 25 m, at 1 m intervals; (b) seven fresh samples from the phosphoric acid plant taken at monthly intervals for a six-month period; and (c) three large representative samples from the stockpile. The investigations carried out on the above will be presented at this Symposium (Brown and Beretka, 1990).

ETTRINGITE-BASED BINDER OR NOVEL CEMENT

It has been reported (Santoro, *et al.*, 1984, 1986; Valenti, et al., 1984, 1988; Beretka, Santoro, *et al.*, 1987) that hydraulic binders based on ettringite ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) and calcium silicate hydrate can be produced either from natural materials such as gypsum, alumina, lime and silica, or preferably from industrial wastes and by-products which contain CaO, Al_2O_3, SiO_2 and $CaSO_4.2H_2O$, such as phosphogypsum, fly ash, blast furnace slag, siliceous wastes, and Portland cement and/or lime. In fact, many other waste materials containing the above mentioned compounds can also be used for making this new type of binder/cement. In this system, the contribution to strength at very early ages arises from calcined phosphogypsum and (if present) Portland cement; later contributions to strength are due to the formation of ettringite and calcium silicate hydrate. The binder has great potential for application in the building industry and has been patented worldwide (Beretka, Valenti, et *al.*, 1987). Furthermore, since ettringite forms mainly by the reaction of gypsum with alumina and hydrated lime, the production of this binder may result in large-scale use of phosphogypsum, which proved to be more effective than natural gypsum in this system. The process of producing novel cement could also result in reduced exploitation of natural resources, protection of the environment, energy saving, reduction of CO_2 levels, and thus the greenhouse effect, and also reduced cost for building materials.

Novel cement can be produced by either blending the required ingredients such as calcined phosphogypsum, fly ash, ground blast furnace slag, Portland cement and/or lime, followed by curing at 100% r.h. preferably at elevated temperatures of 50-80°C for 16-24 h; and also by the addition of small quantities of calcium sulfoaluminate ($3CaO.Al_2O_3.CaSO_4$) 'seed' or clinker compound to the blended mix (Santoro, et al., 1987). This seed material can also be produced from waste materials incorporating phosphogypsum and synthetised at about 1100°C, (Valenti, et al., 1987) instead of >1470°C as for Portland cement. Examples of typical compositions and their strength properties are shown in Table III. It is seen that the pastes developed reasonable strength, particularly after curing at elevated temperatures. Furthermore, as compared with calcined natural gypsum, calcined phosphogypsum appears to enhance the reaction in all cases. A more detailed discussion of novel cement is presented at this Symposium (Beretka, *et al.*, 1990).

Table III

Composition (%) and modulus of rupture (MPa) of novel cements cured at 23 and 55°C; 100% R.H. w/s, 0.5, tested WET

Stock no.	A	AP	B	BP	C	CP
Composition						
Calcined pure gypsum	31		28.5		23	
Calcined phosphogypsum		31		28.5		23
Fly ash	31	31	43	43		
Pure lime	23	23	28.5	28.5	1	1
Portland Cement	15	15				
Blastfurnace slag					76	76
Days at 23°C, MPa, WET testing						
1	2.9	1.1				
7	4.7	3.6				
14	6.3	6.4				
28	9.6	11.2				
Days at 55°C, MPa, WET testing						
1	7.7	6.2	3.3	3.4	4.4	8.1
7	23.5	26.9	16.6	22.5	6.6	24.1
14	19.2	24.9	13.7	26.3	7.2	30.8
28	17.1	21.6	21.9	31.2	7.2	35.0

AGRICULTURAL INDUSTRY

Natural gypsum or phosphogypsum is widely used in Australia (Anon., 1981), mainly in arid areas, for the treatment of alkaline soils and for the treatment of saline soils in irrigated areas. During treatments, Ca^{2+} ions replace Na^{+} ions in the clay and as such improve drainage by flocculating colloidal particles. This area of application of phosphogypsum has shown large growth in Australia over the last 10 years. In particular, in 1980 only a small portion of the 73 000 t of phosphogypsum utilised was used in agriculture, but in 1989 about 200 000 t was used. The material is usually dispatched at about 10-12% moisture content, applied to the surface at the rate of 3-5 t per hectare, and then tilled to a suitable depth (15 cm) to ensure mixing. Gypsum is usually applied in early autumn to allow soil moisture to build up. One good rainfall is necessary after application before sowing, so that as much calcium as possible dissolves. Generally, re-application is necessary every 3-5 years. In Australia, the use of phosphogypsum on responsive soils is seen to have numerous benefits; it improves the surface structure of soils, improves water infiltration and penetration, allows cultivation of soil more easily and quickly, and results in less wear and tear on cultivation equipment.

RADIOACTIVITY

The natural radioactivity of phosphogypsum depends on the source of phosphate rock (apatite) used for making phosphoric acid. The concentration of radionuclide elements, viz. ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K, and other impurities varies with the geological origin of the phosphate rock, The sedimentary (marine) raw phosphates contain higher concentrations of radionuclide elements and other impurities than the phosphates of igneous or metamorphic origin. During the process of producing phosphoric acid, the radionuclide elements present in the phosphate rock are unevenly distributed between the product (orthosphosphoric acid) and the by-product (phosphogypsum). In particular, most of the thorium, uranium and potassium is concentrated in the orthophosphoric acid, and the radium in the phosphogypsum.

Samples of phosphogypsum were obtained from all the phosphoric acid manufacturers, their uranium content analysed by standard chemical methods (AMDEL, Adelaide); whilst their radium, thorium and potassium contents were determined by gamma-ray spectroscopy as previously described (Beretka and Mathew, 1985). The results are presented in Table IV. It can be observed that the gamma-ray activity of local phosphogypsums is attributed mainly to the presence of radium in the specimens. Furthermore, the level of radium at about 510 Bq/kg measured was about the same as in the materials available in other countries.

At present, there are neither standards nor guidelines in Australia for the proposed permissible levels of radioactivity of materials, including phosphogypsum.

Table IV
Mean specific activities and radium equivalent
activities of Australian phosphogypsums

Mean specific activity (Bq/kg)	
^{226}Ra	500
^{232}Th	10
^{40}K	20
^{238}U	510
Radium equivalent activity (Ra_{eq}) (Bq/kg)	
Range	**Mean**
280 – 1000	**510**

CONCLUSIONS

In Australia, about 940 000 t of phosphogypsum is generated annually, of which about 200 000 tpa is used as soil conditioner and low-grade fertiliser in agriculture. Phosphogypsum is not used at present for making plasterboard and plaster products. However, experiments have shown that phosphogypsum is suitable for such purposes. Another potential for application of large quantities of phosphogypsum is in the manufacture of novel cement consisting mainly of industrial wastes and by-products such as calcined phosphogypsum, fly ash, pelletised blast furnace slag, other siliceous materials, and lime and/or Portland cement. The materials generated at five locations have a mean radium equivalent activity (Ra_{eq} of 500 Bq/kg, which is considered to be moderate (Beretka and Mathew, 1985). However, some of the materials generated have activities twice this value, and there are obvious concerns about their application in the plaster industry.

REFERENCES

Anon. 1981. The utilisation of phosphogypsum in agriculture. *Phosphorus and Potassium,* No. 113: 23-26.

Beretka, J. 1980. Properties and utilisation of by-product gypsum in Australia. Proc. 1st Int. Symp. on Phosphogypsum, Florida, 5-7 Nov. 1980, 2: 615-634.

Beretka, J. 1982. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 1 - The kinetics of hydration. *J. Chem. Tech. Biotechnol.,* 32: 607-613.

Beretka, J. 1988. Studies on the lime sensitivity of phosphogypsum. Proc. 2nd Int. Symp. on Phosphogypsum, Florida Inst. Phosphate Res., Bartow, Florida, 2: 27l-276.

Beretka, J. and T. Brown. 1983. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 2 - Physical properties. *J. Chem. Tech. Biotechnol.,* 33A: 299-308.

Beretka, J. and T. Brown. 1986. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 3 - Phosphogypsum. *J. Chem. Tech. Biotechnol.,* 36: 512-518.

Beretka, J., R. Cioffi, L. Santoro and G.L. Valenti. 1990. The role of phosphogypsum during the formation of ettringite-based binders. 3rd Int. Symp. of Phosphogypsum, Orlando, Florida, 4-7 Dec.

Beretka, J. and P.J. Mathew. 1985. Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Physics,* 48: 87-94.

Beretka, J., L. Santoro and G.L. Valenti. 1987. New and durable building materials based on ettringite. Proc. 4th Int. Conf. Durability of Bldg Materials and Components, Singapore, 4-6 Nov., 1: 64-70.

Beretka, J. (CSIRO Australia), G.L. Valenti, L. Santoro and R. Cioffi (Universita di Napoli). 1987. Hydraulic builders and building elements formed of non-traditional materials. Australian Patent Appl. No. 10545/88. International Patent Appl. No. PCT/AU87/00419.

Berry, E.E. 1972. Some observations on the setting of calcium suphate hemihydrate plaster in the presence of phosphoric acid and hydrated lime. *J. Appl. Chem. Biotechnol.,* 22: 667-671.

Brown, T. and J. Beretka. 1990. Phosphogypsum as a raw material for the manufacture of plaster products. 3rd Int. Symp. on Phosphogypsum, Orlando, Florida, 4-7 Dec.

Frochen, J. and P Becker. 1959. Crystallisation and co-crystallisation in the manufacture of wet-process phosphoric acid. Tech. Meeting Int. Superphosphate Manufacturers Ass., Stockholm.

Santoro, L., I. Aletta and G.L. Valenti. 1986. Hydration of mixtures containing fly ash, lime and phosphogypsum. *Thermochimica Acta.,* 98: 71-88.

Santoro, L., R. Garofano and G.L. Valenti. 1987. Role of phosphogypsum in the hydration of calcium sulphoaluminate. *Thermochimica Acta,,* 116: 145-152.

Santoro, L., G.L. Valenti and G. Volpicelli. 1984. Application of differential scanning calorimetri to the study of the system phosphogypsum-lime-aluminium hydroxide-water. *Thermochimica Acta.,* 74: 35-44.

Valenti, G.L., L. Santoro and J. Beretka. 1988. Studies on the formation of cementitious compounds using phosphogypsum. Proc. 2nd Int. Symp. on Phosphogypsum, Florida Inst. Phosphate Res., Bartow, Florida, 2: 167-172.

Valenti, G.L., L. Santoro and R. Garofano. 1987. High-temperature synthesis of calcium sulpho-alumiuate from phosphogypsum. *Thermochimica Acta.,* 113: 269-275.

Valenti, G.L., L. Santoro and G. Volpicelli. 1984. Hydration of granulated blast-furnace slag in the presence of phosphogypsum. *Thermochimica Acta.,* 78: 101-112.

Wirsching, F. 1978. Lime sensitivity - a characteristic of the hydration of phosphoric acid by-product gypsum. *Materiaux et Constructions,* 11: 62-64;

UTILIZATIONS OF PHOSPHOGYPSUM IN IRAQ

Nabeel F. Khalil Assist. Professor Dept. of Basic Sci.
Nazar M. Alnuaimi Assist. Professor Dept. of Soil Sci.
College of Agriculture and Forestry. Mosul Univ.
Muath H. Mustafa Chem. Eng. Dept. College of Eng. Tikrit Univ.
IRAQ.

ABSTRACT

The increasing amounts of phosphogypsum resulting from phosphoric acid production represent a serious environmental problems, regardless of whether land filled in dumped as solid form or discharged into surface waters.

This research is in step with researches internationally and it can lead to greater usage of phosphogypsum in Iraq in the near future. The possibility of utilizing it in different ways but primarily in the building industry has been accomplished to reduce phosphogypsum amounts and pollution.

Different treatments has been made by mixing phosphogypsum with various ratios of lime, clay and pure silica sand to determine the chemical compositions of

the mixings and compressive strength. Using of lime to elevate the pH up to (12.4), mean-while using clay could be buffering to consume both SO_4 ion and lime; where lime could be react with silica, Al & Fe, occur in clay to produce a cementing material,

INTRODUCTION

A huge amount of phosphogypsum by-product material is generated in Iraq resulting from manufacturing the phosphate fertilizers. The bulk of this material is, however, dumped on land, into rivers. Due to the fact that Iraq has large resources of natural gypsum and rock phosphate, therefore dumping of phosphogypsum is a dangerous from environmental point of view due to the seepage ability of the dissolving substances from the phosphogypsum during raining season which could contaminate the ground water. Morever little interest has been shown previously in the utilization of phosphogypsum in Iraq.

By 1980, the annual production of phosphogypsum was 120-150 million metric ton. In 1981 a survey of companies producing phosphogypsum showed that 14% of all phosphogypsum was being reprocessed, 58% was stored, and 28% was being dumped.

The magnitude of wasted phosphogypsum means reprocessing options must be further explored. The evaluation potential uses of phosphogypsum in different sources as in the building industry (plaster, wall board, or sheetrock), or in the cement industry (a cement component or retarder), and in the fertilizer industry as source of minerals.

The objective of this paper is focus on relationship between mix proportions and strength characteristics with varying substances such as clay, sand, and lime with phosphogypsum in order to reduce the effect of phosphogypsum on environmental issues beside improving working conditions and setting of life.

MATERIALS AND METHODS

The chemical composition of Iraqi phosphogypsum has been determined as shown in table 1, according to the A. O. A. C. methods.

The materials used for the matrix preperation consisted of phosphogypsum, clay (bentonite), pure silica sand, and lime.

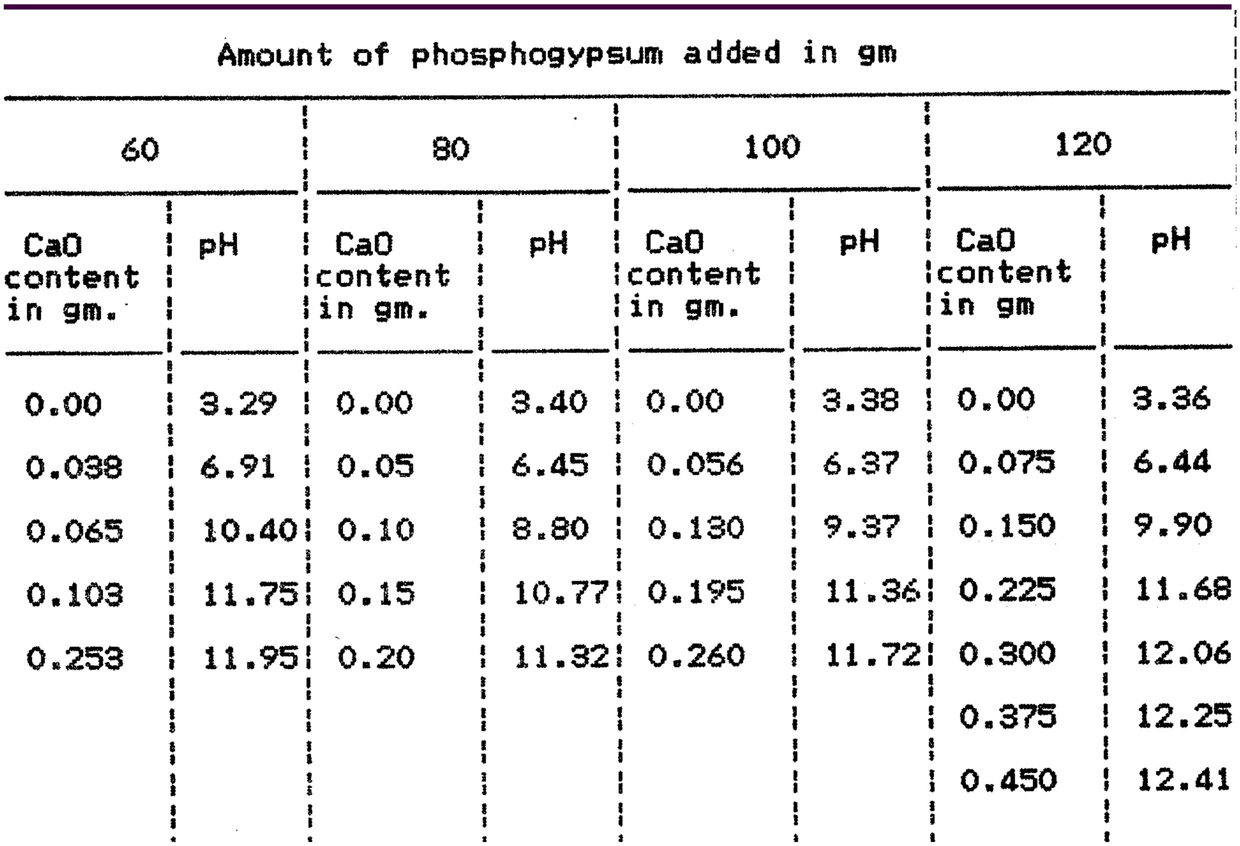
The different mixtures ordered as follows:-

1. Different amounts of phosphogypsum with varying amounts of lime were mixed in 200 ml distilled water in order to determine the pH as explained in table 2.
2. A 100 grams of phosphogypsum plus 100 grams of bentonite dissolved in 200 ml. distilled water, then different amounts of lime were added to this mixture.

Table I: Chemical Compositions of Iraqi Phosphogypsum.

Component	Percent
CaO	32.94
SO_3	44.94
P_2O_5	0.18
F	0.60
SiO_2	0.45
Fe_2O_3	0.40
Al_2O_3	1.05
MgO	0.46
Crystal-H_2O	19.18
$CaCO_3$	4.29
pH	3.6
Gypsum	80.0
Ec	2.40 ds/m.

Table II: Effect of Different Mixings of Phosphogypsum and Lime on pH.



Amount of phosphogypsum added in gm							
60		80		100		120	
CaO content in gm.	pH	CaO content in gm.	pH	CaO content in gm.	pH	CaO content in gm	pH
0.00	3.29	0.00	3.40	0.00	3.38	0.00	3.36
0.038	6.91	0.05	6.45	0.056	6.37	0.075	6.44
0.065	10.40	0.10	8.80	0.130	9.37	0.150	9.90
0.103	11.75	0.15	10.77	0.195	11.36	0.225	11.68
0.253	11.95	0.20	11.32	0.260	11.72	0.300	12.06
						0.375	12.25
						0.450	12.41

The pH and chemical composition were determined as shown in tables 3 and 4.

3. A 100 grams of bentonite, two rates of pure silica sand (0, and 100 grams), with different percents of phosphogypsum and lime. The mixtures were dissolved in to 200 ml. distilled water, the pH and chemical compositions were determined as shown in tables 5 and 6.

4. To measure the compressive strength of the matrix (phosphogypsum, sand, bentonite, and lime) which was one of the main objectives, Five different mixing treatments of the above materials in a duplicate were used to measure the compressive strength in moist air and soaked water at three different periods (24 hrs,3 days, and 7 days), as shown in table 7.

RESULTS AND DISCUSSION

The chemical analysis of Iraqi phosphogypsum indicated that it is likelyhood to the dihydrate phosphogypsum (DPG) as shown in table 1.

The dihydtrate phosphogypsum (DPG), a solid by-product of the phosphate industry plant, possesses good binding property under compaction and has good potential for use as a construction material. Asubstantial strengths are attainable for (DPG) alone and cement-DPG mixtures subjected to adequate composition (Lin and Chang, 1988).

Table III: Effect of Bentonite and Lime on pH of Phosphogypsum.

Ratios	100 gm Bentonite	
	CaO in gm.	pH
100 gm. Phosphogypsum	0.00	6.69
	0.05	7.66
	0.10	8.38
	0.15	8.87
	0.20	9.17
	0.25	9.39
	0.35*	9.62
	0.45	9.85
	0.65	10.09
	0.85	10.37
	1.25	11.07
	1.50	11.64
	2.00	12.06
	2.50	12.30
	3.00	12.43

Table IV : Chemical Compostion of the Mixture.

(Bentonite, Phosphogypsum and Lime)

Component	Bentonite	Phosphogypsum	Lime	Mixture
SiO_2	52.08	0.45	2.14	23.64
Al_2O_3	13.03	1.05	0.74	5.97
Fe_2O_3	2.57	0.40	0.12	1.18
CaO	6.88	32.94	92.80	25.10
MgO	5.85	0.46	0.19	3.05
SO_3	1.24	44.94	---	28.71
L.O.I.	15.26	19.20	4.29	10.83
Total	96.42	99.46	97.28	98.98
Carbonate		4.29	91.5	2.93

Table V: Effect of Bentonite, Sand and Lime on pH of Phosphogypsum.

Bentonite gm.	Sand gm.	Phosphogypsum %	Lime %	pH
100	0.0	0.0	0.0	7.80
100	100	0.0	0.0	7.90
100	100	5.0	5.0	12.650
100	100	10.0	5.0	12.646
100	100	15.0	5.0	12.640
100	100	20.0	5.0	12.634
100	100	25.0	5.0	12.625
100	100	30.0	5.0	12.618
100	100	35.0	5.0	12.610
100	100	40.0	5.0	12.605
100	100	45.0	5.0	12.600
100	100	50.0	5.0	12.585

Table VI: The Chemical Compositions of Final Mixture.

(Bentonite, Sand, Lime and Phosphogypsum)

Component	Percent
SiO_2	34.91
Al_2O_3	7.22
Fe_2O_3	2.28
CaO	17.10
MgO	2.68
SO_3	7.93
L.O.I	14.66
Na_2O	0.66
K_2O	0.52
Cl	0.04
Total CaO	36.08

Table VII: 7 days Compressive Strength on Five Different Treatments Using (soaked water and moist-air) Conditions.

No. of treatment	Lime gm	Phosphogypsum %	Sand gm	Bentonite gm	Strength Kg/Cm^2	
					Soaked water	Moist air
1	8	5	200	200	4	6
2	12	10	200	200	7	10
3	20	15	200	200	24	32
4	30	20	200	200	50	65
5	60	15	0.0	400	28	39

Concerning the effect of mixing various amounts of phosphogypsum with different proportions of lime as shown in table 2, it was found that the most successful and acceptable ratio was (120 grams of phosphogypsum + 0.450 grams of lime), to get pH value equal to 12.41. This mixture may be called as Gypsonat material depending on (Prandi, 1980), which may used as a catalyzer for road constraction. This material can be made by combining phosphogypsum with a strong base like lime, Prandi (1980) stated that pH of his material increases from 3 to 7 on average and indicated that the gypsonate is used in the making of light concrete and thermically insulation.

However addition of bentonite to phosphogypsum and lime was made, the best ratios was (100:100:3), to get pH value up to 12.44. This value may eliminate any source of life, such as micra-organisms and plants. The above mixture was analyzed chemically, it was noticed that the amounts of Al_2O_3,Fe_2O_3 and MgO were increased, meanwhile the amounts of SO_3 and Ca0 were decreased as shown in table 4.

Further investigation (data was not listed) indicated that the pH value raised up to 12.41 when the ratio of bentonite : phosphogypsum : lime was (100 : 20 : 13). Adding pure silica sand to the mixture above, it was found that maximum pH value raised up to 12.59 when the ratio of materials (bentonite : sand : phosphgypsum :

lime) was (100 : 100 : 50: 5) table 5. Analyzing of this mixture, it was noticed that the amounts of SiO_2, Al_2O_3, and Fe_2O_3 were increased, meanwhile CaO, MgO, and SO_3 were decreased, table 6. In order to get the calcilox process which involves treating the gypsum sludge with an unspecified silica sand waste and a small amount of hydrated lime (about 2% by weight). This converts the soft gypsum sludge which has no bearing strength into a firm, stable substance (Boynton, 1980), that is environmentaly acceptable as land-fill or for building embankments, however leacheates from this component are negligible, where lime reacts with the silica and sulphate radical to form a complex calcium-sulfosilicate -hydrate cementing compound that binds and hardens the gypsum sludge .

The effect of mixing proportions on the compressive strength was depended upon the ratios of the materials used in this study, however, not all compacted mixtures have shown a considerable compressive strength, considering the percentage levels of (bentonite, sand, phosphogypsum, and lime) in the mixture. However, the effect of sand content on the compressive strength under moist-air conditions is vital. It shows that, increasing the amount of sand content up to 25% increased the compressive strength, this results was in agreement with the results of Chang and Chang (1988), who stated that the effect of sand content on the compressive strength under moist-air conditions for a given sulfur content of 15%, by increasing the amount of sand content up to 60% increased the compressive strength.

The results in table 7 have shown that treatment number four reveal the highest compressive strength at 7-days period. The data also indicated that the compressive strength greatly depends on the mix proportions and to lime content and to some extent to phosphogypsum percent. From the results obtained it can be seen that. as the lime content increases the compressive strength increases. It is also noticed, that when sand is replaced by Bentonite, the compressive strength decreases to the half. This results contradicted with work done by (Ghafoori and Chang, 1988) where they used cement and di-hydrate materials instead of lime. Moreever, our results showed that the compressive strength was higher with moist-air than soaked conditions,

There is no any indications of compressive strength at the 24-hrs. and 3-days periods.

RECOMENDATIONS

1. Phosphogypsum in general indicates good binding strength fur road and precast building applications. The strength can be further enhanced by the addition of more amounts of lime and phosphogypsum.

2. The compressive strength greatly depends on the mix proportions and to the sand and lime contents in the mixtures.

ACKNOWLEDEMENT

Part of the analysis was done at Hammam Al-Alil and Singar cement factories in Ninavah Proviance-Iraq.

REFERENCES

A. O. A. C. 1980, Official Methods of Analysis. Association of Official Analytical Chemists. 11th Ed. WASHINGTON D.C. U.S.A.

Boynton, R. s. 1980. Chemistry and Technology of Lime and Limestone. Interscience Publishers, John Willy and Sons. New York.

Chang, W. C. and W. F. Chang. 1988. Stabilization of Phosphogypsum and Sand Mixtures with Sulfur. Proceeding of the Second International Symposium on Phosphogypsum. Florida Institute of Phosphate Research. Bartow, Florida. U.S.A.

Ghafoori, N. and W. F. Chang. 1988. Compaction Concrete Utilizing Dihydrate Phosphogypsum. Proceeding of the Second International Symposium an Phosphogypsum Florida Institute of Phosphate Research. Bartow, Florida. U.S.A.

Lin, K. T. and W. F. Chang. 1988. Strength Properties of Compacted Phosphogypsum - Based Mixtures. Proceeding of the Second International Symposium on Phosphogypsum. Florida Institute of Phosphate, Research. Bartow Florida. U.S.A.

Prandi. E. 1980. Use and Valorization of Phosphogypsum in Road Construction and Civil Engineering. Proceedings of the International Symposium on Phosphogypsum. Florida Institute of Phosphate Research, Bartow, Florida. U.S.A.

THE ROLE OF PHOSPHOGYPSUM DURING THE FORMATION OF ETTRINGITE-BASED BINDERS

J. Beretka
Principal Research Scientist, CSIRO Division of Building, Construction and Engineering
PO. Box 56, Highett, Victoria 3190, Australia

R. Cioffi
Engineers Dipartimento di Ingegneria dei Materiali e della Produzione
dell’Universita di Napoli, Italy

L. Santoro
Professor, Dipartimento di Chimica dell’Universita di Napoli
Italy

G.L. Valenti
Professor, Dipartimento di Ingegneria dei Materiali e della Produzione
dell’Universita di Napoli, Italy

ABSTRACT

This paper describes experiments on the development of a new type of hydraulic binder termed ‘Novel Cement’, which can be obtained from mixtures of calcined gypsum or phosphogypsum, alumina, silica-containing industrial wastes and by-products such as fly ash and blast furnace slag, Portland cement and/or lime. Particular emphasis has been placed on investigating the effect of phosphogypsum as compared with pure gypsum on the rate of formation and physical properties (mainly strength) of the binders. It was found that in most cases phosphogypsum enhanced the rate of hydration of the systems and generated higher mechanical strength in the cast specimens than did pure gypsum. This new type of cement could result in the large-scale utilisation of industrial wastes and by-products, reduced exploitation of natural resources, protection of the environment, energy saving and, by reduced production of carbon dioxide emission, it could contribute to a reduction in the greenhouse effect. This new binder has great potential for application in the building and construction industries.

INTRODUCTION

It has been established that new binders can be produced from mixtures of pure or natural gypsum, phosphogypsum and its calcined varieties, and alumina and silica-containing industrial wastes and by-products such as fly ash and blast furnace slag, Portland cement and/or lime (Azuma and Ichimaru, 1976; Azuma *et al,,* 1976; Santoro *et al.,* 1984, 1986; Valenti *et al.*, 1984, 1986; Beretka *et al.,* 1987a,b; Mehta, 1980). The chemical and mineralogical composition of this new type of binder when hydrated is distinctly different from that of hydrated Portland cement, and consists mainly of mixtures of ettringite $3CaO.Al_2O_3.3CaSO_4.32H_2O$ and calcium silicate hydrate. The use of phosphogypsum (Valenti *et al.,* 1986; Beretka et *al.,* 1987a) as the source of sulfate in mixtures of 'reactive' lime, alumina and silica derived from, for example, fly ash and blast furnace slag appears to be advantageous, since phosphogypsum enhances not only the rate of hydration but also the development of the strength of the system at an early age. Furthermore, in these systems the contribution to strength at very early ages is due to the setting of calcined gypsum and (if present) Portland cement. Later contributions to strength are due to the formation of ettringite and calcium silicate hydrate.

This paper presents experiments on the formation of three such typical hydraulic binders based on

(A) calcined gypsum-fly ash-Portland cement-lime,
(B) calcined gypsum-fly ash-lime, and
(C) calcined gypsum-blast furnace slag-lime (in this system lime is a slag activator).

Calcined gypsum was also replaced with calcined phosphogypsum and these systems are designated (AP), (BP) and (CP).

EXPERIMENTAL

RAW MATERIALS

The chemical composition of the materials used is shown in Table I. The calcined gypsum (hemihydrate, 'stucco') was prepared from gypsum dehydrated on a tray in a laboratory oven at 140-145°C for 16 h, followed by conditioning for 24 h in a room set at 67% r.h. and 21°C. The phosphogypsum was calcined in a kettle to the 'second boil' as in industry and conditioned as above.

COMPOSITION OF MIXES

The composition of the mixes investigated are shown in Table II. The materials were rendered uniform by mixing and sieving to pass a -150 µm sieve.

Table I
Major chemical constituents* (%) of the raw materials used for compositions (A), (B) and (C)

	Calcined phosphogypsum	Fly ash	Portland cement	Blast furnace slag (pelletised)
CaO	39.2	5.42	65.0	39.4
SiO_2	0.01	50.5	20.0	34.8
Al_2O_3	n.a.	27.8	4.66	18.1
TiO_2	n.a.	2.08	0.19	0.69
Fe_2O_3	n.a.	4.61	4.33	0.21
MgO	0.38	2.24	1.43	2.15
Na_2O	n.a.	3.81	n.a.	0.30
K_2O	n.a.	0.89	n.a.	0.53
CO_2	0.12	0.07	n.a.	n.a.
SO_3	53.7	0.26	2.56	0.78
P_2O_5 (total)	0.67	1.00	n.a.	0.04
F– (total)	1.23	n.a.	n.a.	n.a.
H_2O	5.15	0.76	n.a.	0.20

* The pure A.R. calcined gypsum (Merck) and pure A.R. lime (Univar) were not analysed.

n.a. Not analysed.

Table II
Composition (%) of the systems investigated (P denotes calcined phosphogypsum)

Composition	(A), (AP)	(B), (BP)	(C), (CP)
Calcined gypsum	31	28.5	23
Fly ash	31	43.0	
Portland cement	15		
Pure lime	23	28.5	1
Blast furnace slag			76

HYDRATION OF PASTES

Small samples (~2 g) were mixed with water (w/s, 0.5), sealed in plastic envelopes and cured at 21 and 55°C, 100% r.h. for 1 to 182 days as previously described (Santoro *et al.*, 1984). At the end of the curing period the specimens were removed, ground in acetone to stop the reaction, dried with ether and stored in a desiccator. The dried specimens were then analysed by thermal analysis (TGA/DTA) and by X-ray diffraction (XRD).

STRENGTH MEASUREMENTS

The required quantities of the stocks were mixed with water (w/s, 0.5) and the pastes were cast into 25 mm cube moulds, and cured at 23 and 55°C (or as specified) at 100% r.h. for 1-182 d. At the end of the curing period the specimens were tested in compression using an Instron machine (cross-head speed, 0.5 mm/min) either immediately (WET testing) or after drying them for at least 21 d at room temperature and 67% r.h. (DRY testing). The densities of the cast and air-dried specimens were determined by conventional methods. For the determination of expansion/shrinkage, 295 x 25 x 25 mm bars fitted with stainless steel studs were- used.

RESULTS AND DISCUSSION

COMPOSITIONS (A) AND (AP)

Figures 1 and 2 show the DTA traces for composition (A) and Figures 3 and 4 for composition (AP) (containing calcined phosphogypsum), hydrated at 21 and 55°C, respectively. One can clearly see the diminishing of the reactants, the gypsum (Figures 1 and 2), phosphogypsum (Figures 3 and 4) and lime; also the gradual formation of ettringite in the systems. At 21°C curing, residual gypsum or phosphogypsum was present in both (A) and (AP) to the end of the curing period studied. At this temperature the consumption of reactants is slightly faster at 55°C than 21°C (see Figures 2 and 4 *v*. 1 and 3). At 55°C curing, no residual lime was deteced in system (A) containing pure gypsum after 7 d, and in (AP) containing phosphogypsum after 4 d. The gypsum was almost completely consumed in sample (A) by 28 d, and in sample (AP) between 4 and 7 d It is evident from the above experiments that the system containing phosphogypsum reacted much faster than that containing pure gypsum. Furthermore, at 55°C curing there was no further evidence of ettringite formation after 7 d in system (AP), and after 14-28 d in system (A). In the above systems, calcium silicate hydrate also forms due to the hydration of Portland cement and the pozzolanic reaction involving fly ash. However, the detectability of calcium silicate hydrate by DTA, which occurs at ~70-80°C, is difficult due to the much larger overlapping peak due to ettringite at -100°C.

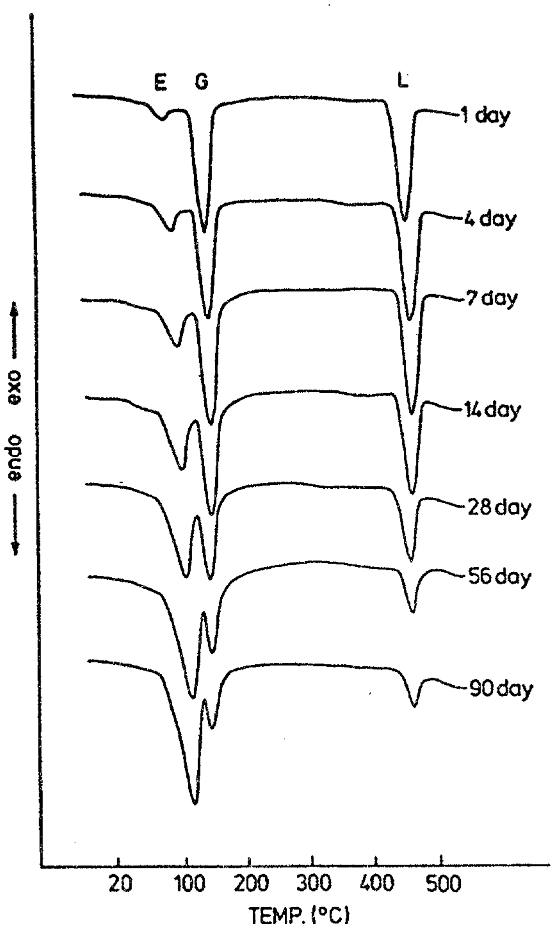


Figure 1 DTA traces for composition (A) cured at 21°C

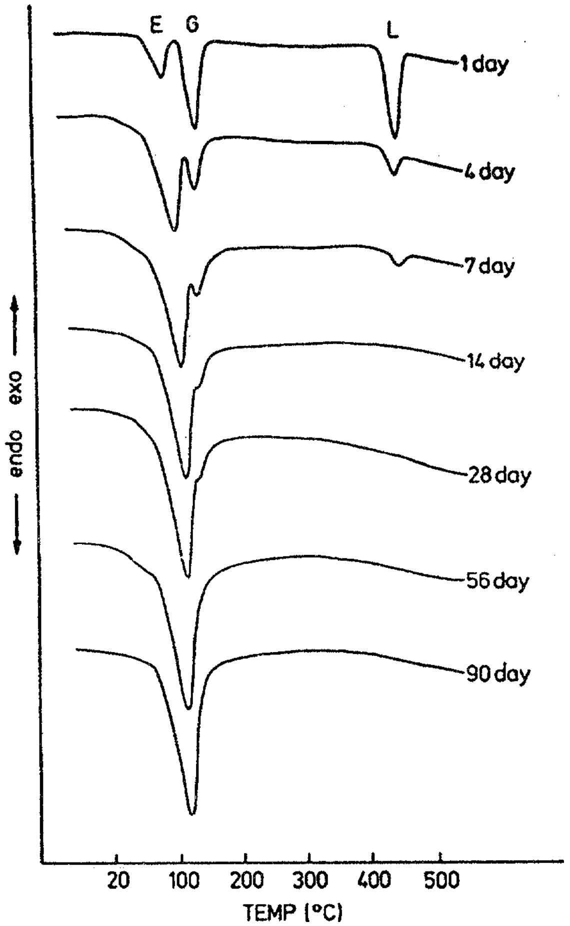


Figure 2 DTA traces for composition (A) cured at 55°C.

Note: in Figs 1,2,3,4, E = ettringite, G = gypsum, PG = phosphogypsum and L = lime).

The strength development in the above systems is shown in Figure 5. It is seen that at 55^{O}C curing, the pastes harden much faster than at 23°C, and they also develop higher early and ultimate strengths at 55°C. Figure 5 also shows that at 55°C, system (AP) containing phosphogypsum not only develops higher early strength but also higher ultimate strength as compared with sample (A) containing pure gypsum. The impurities present in phosphogypsum. (probably the phosphate), are likely to play an important role in the development of the mechanical strength of these binders as suggested previously (Valenti *et al.*, 1986).

The densities of the set and cured specimens gradually increased from 1320 to 1370 kg/m^3 (1 d) to 1350-1460 kg/m^3 (28 d). No significant shrinkage or expansion of the specimens was observed to the end of the curing period studied.

As pointed out previously, in this type of system the hydration and setting of calcined gypsum and Portland cement contributes to the strength development at early ages, later

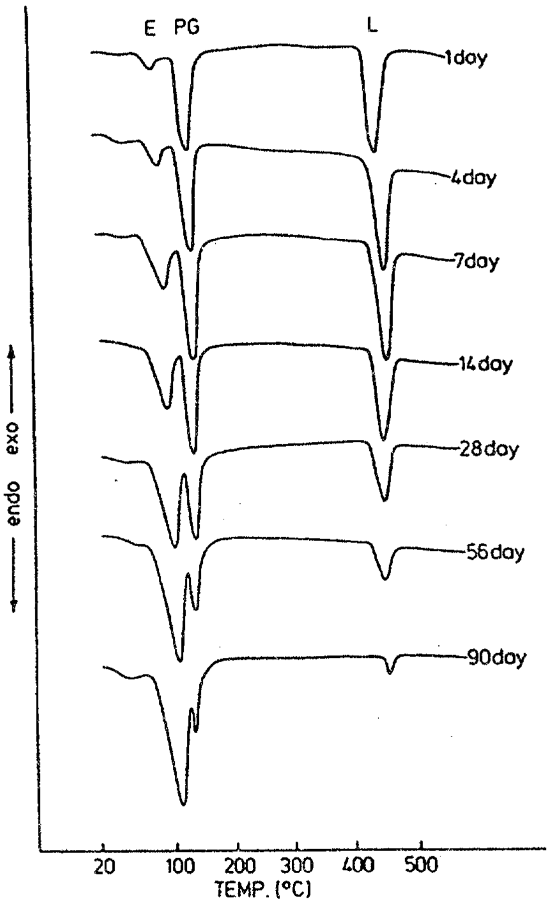


Figure 3 DTA traces for composition (AP) cured at 21°C.

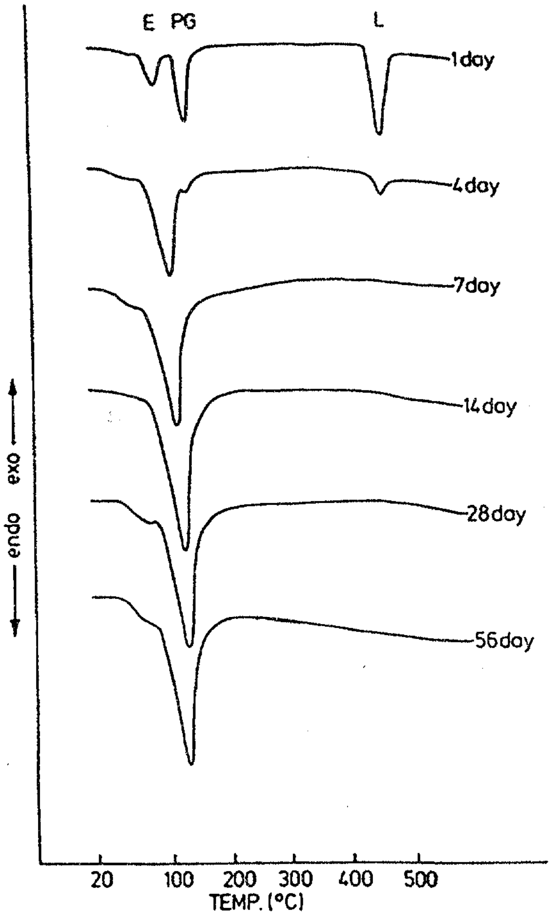


Figure 4 DTA traces for composition (AP) cured at 55°C.

contribution strength is due principally to the formation of ettringite and calcium silicate hydrate. At elevated temperatures the contribution of ettringite to strength levels off after ~7 d and beyond that time the further formation of calcium silicate hydrate contributes to the higher ultimate strength of the system. Calcium silicate hydrate is also expected to improve the durability of these ettringite-based binders.

COMPOSITIONS (B) AND (BP)

The experiments on compositions (B) and (BP) were carried out at 55°C. The thermograms (not shown) were similar to those for Compositions (A) and (AP). In particular, lime was consumed between 4 and 7 d for both (B) and (BP), and gypsum between 4 and 7 d for sample (B) and at 4 d for sample (BP). Ettringite was fully formed between 4 and 7 d in sample (B) and at 4 d for sample (BP).

The compressive strengths of samples (B) and (BP) are shown in Figure 6. Once again it can be observed that the system containing phosphogypsum (BP) develops higher early and higher ultimate strength than sample (B) containing pure gypsum. This finding

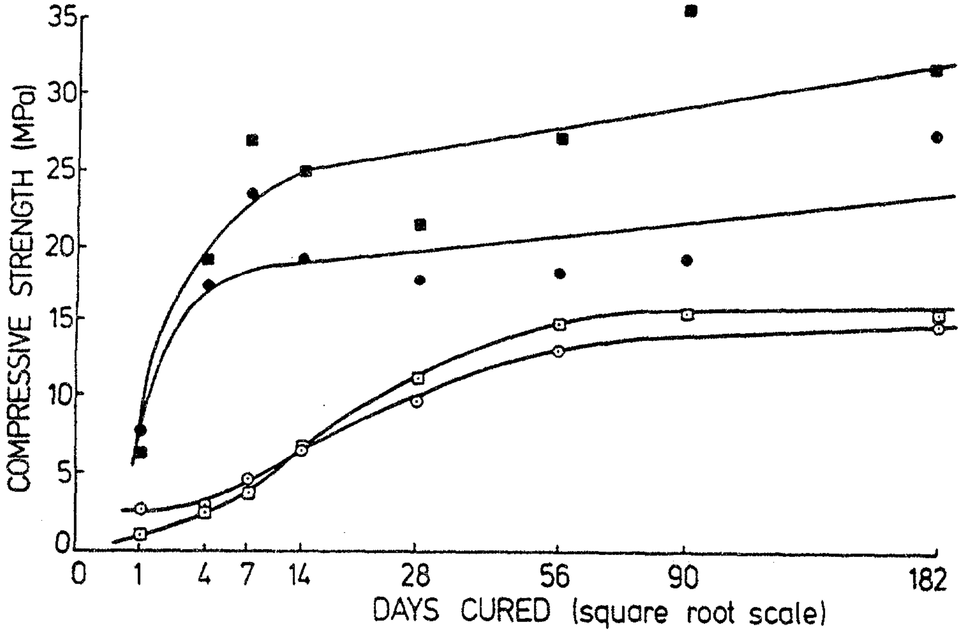


Figure 5 Compressive strength *v*. square root of time for compositions (A) [○,●] and (AP) [□,■] cured at 21 and 55°C, respectively.

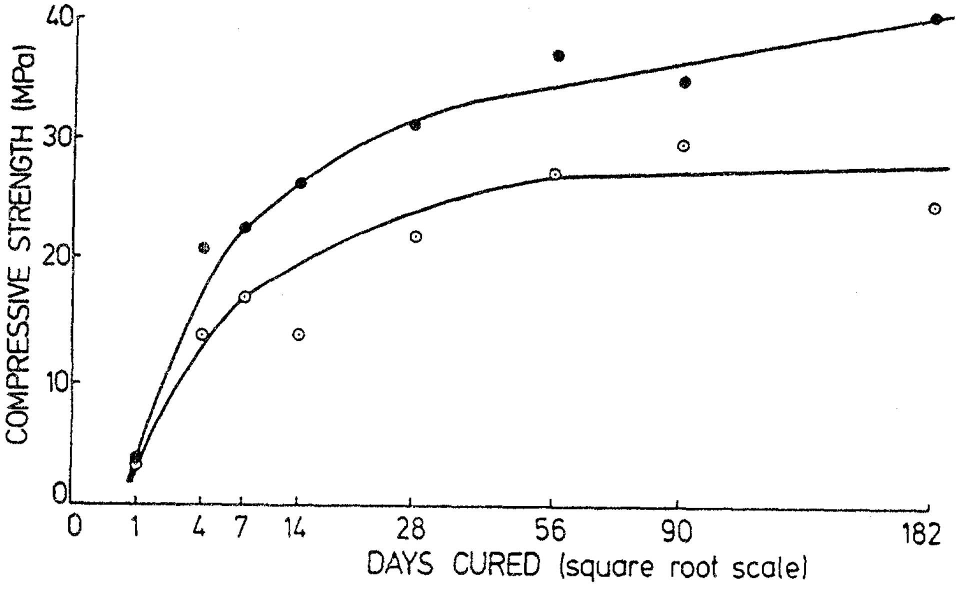


Figure 6 Compressive strength *v*. square root of time for compositions (B) [○] and (BP) [●] cured at 55°C.

was similar to systems (A) and (AP) discussed previously. It is interesting to observe that systems (B) and (BP) reach higher ultimate strength in respect to systems (A) and (AP), even if they do not contain Portland cement.

COMPOSITIONS (C) AND (CP)

The experiments on these compositions were also carried out at 55°C. The thermograms for compositions (C) and (CP) (not shown here) were different from those of the other two systems discussed previously. Even at 55°C hydration, no full reaction of the systems occurred to 90 d, and all the hydrated specimens contained large quantities of unreacted gypsum or phosphogypsum, respectively. However, in spite of the presence of unreacted material in the hydrated pastes, the cured specimens containing phosphogypsum developed very good strength, as shown in Figure 7. In particular, sample (CP) had ~35 MPa at 28 d, and 42-43 MPa at 90 d. The strength of the specimens containing pure gypsum (C) had much lower strength, as shown. In this case the effect of phosphogypsum impurities on the development of mechanical strength is much higher than in the previous ones. The densities of the cured specimens gradually increased for composition (C) from 1340 kg/m^3 (1 d) to 1390 kg/m^3 (28 d), and for composition (CP) from 1430 kg/m^3 (1 d) to 1545 kg/m^3 (28 d). No significant shrinkage or expansion of the specimens was observed.

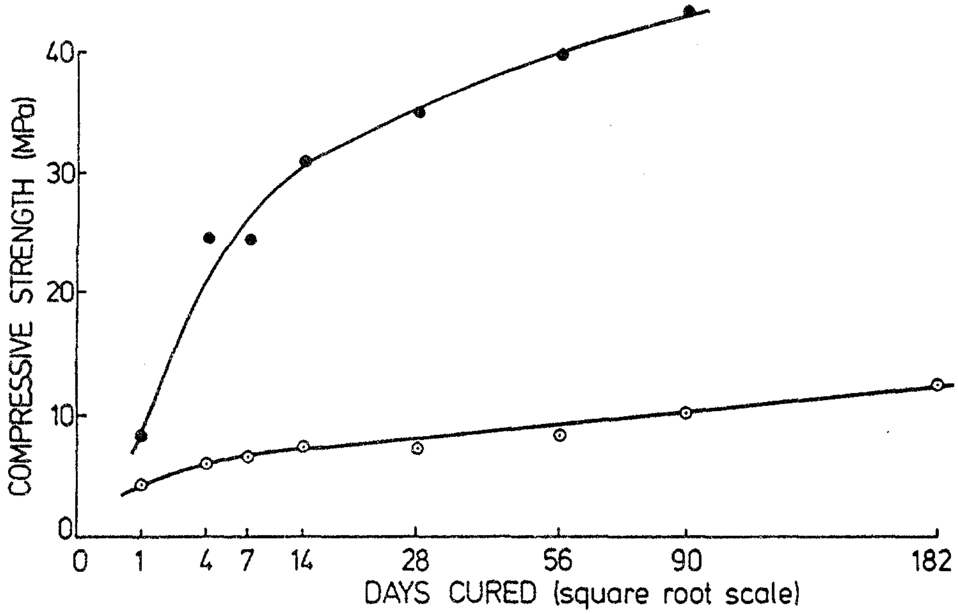


Figure 7 **Compressive strength *v.* square root of time for compositions (C) [○] and (CP) [●] cured at 55°C.**

CONCLUSIONS

It has been demonstrated that calcined phosphogypsum can be used in hydrating mixtures containing lime, alumina and reactive silica derived from fly ash or blast furnace slag, and Portland cement and/or time, to produce a new type of binder. In these mixtures, the gypsum reacts with alumina and lime to form ettringite, while the silica reacts with lime to form calcium silicate hydrate. Furthermore, in these systems phosphogypsum appears to be more reactive than pure gypsum and enhances the development of mechanical strength, especially in mixtures with blast furnace slag. The three systems investigated have developed reasonably good mechanical strengths of up to 24-27 MPa after 7 d, and up to 35 MPa at 28 d curing, particularly at 55°C. These mixtures can be effectively employed for the formulation of a new binder of interest for application in the building and construction industries.

ACKNOWLEDGMENTS

We wish to thank N. Sherman, A. Taylor and P. Westgate, CSIRO Division of Building, Construction and Engineering, for experimental assistance.

REFERENCES

Azuma, T. and K. Ichimaru. 1976. Calcium aluminate sulfate-based inorganic hardened product. Japan Kokai, 76, 62, 826.

Azuma, T., M. Ichimaru, T. Murakami and K. Tateno. 1976. Calcium aluminate monosulfate hydrate. Ger. Offen. 2,551,310.

Beretka, J., L. Santoro and G.L. Valenti. 1987a. New and durable building materials based on ettringite. Proc. 4th Int. Conf. on Durability of Building Materials and Components, Singapore, 4-6 November, 1987, 1: 64-70, Pergamon Press.

Beretka, J. (CSIRO Australia), G.L. Valenti, L. Santoro and R. Cioffi (Universita di Napoli). 1987b. Hydraulic binders and building elements formed from non-traditional materials. International Patent Application No. PCT/AU87/00Y19.

Mehta, P.K. 1980. Investigations of energy-saving cements. *World Cement Technology,* 11: 166-177.

Santoro, L., G.L. Valenti and G.L. Volpicelli. 1984. Application of differential scanning calorimetry to study the systems phosphogypsum-lime-aluminium hydroxide-water. *Themochimica Acta,* 74: 35-44.

Santoro, L., I. Aletta and G.L. Valenti. 1986. Hydration of mixtures containing fly ash, lime and phosphogypsum. *Thermochimica Acta*, 98: 71-80.

Valenti, G.L., L. Santoro and G. Volpicelli. 1984. Hydration of granulated blast furnace slag in the presence of phosphogypsum. *Thermochimica Acta,* 78: 101-112.

Valenti, G.L., L. Santoro and J. Beretka. 1986. Studies on the formation of cementitious compounds using phosphogypsum. Proc. 2nd Int. Symp. on Phosphogypsum, Florida Institute of Phosphate Research, Bartow, Florida, 1: 167-172.

THE MOISTUREPROOF BUILDING MATERIALS ON THE BASIS OF PHOSPHOGYPSUM. THEIR PRODUCTION AND USE IN THE USSR.

Ferronskaja A., Prof., Dr. Sc. (Eng.),
Volghensky A., prof,, Dr. Sc. (Eng.)

V.V.Kujbishev Civil Engineering Institute of
Moscow, USSR

The research results on the use of phosphogypsum waste for production of the moistureproof phosphogypsum binders, concretes and elements are presented in this paper.
The production of these binders on the basis of β-and α- modification of phosphogypsum binders with the help of different thermic technology methods, and the moistureproof phosphogypsum binders and elements which are obtained by nonthermic technology, is reported.

The strength and deformation properties of the concretes on the basis of moistureproof phosphogypsum binders, as well as their durability, including the corrosion resistance of steel armatures in these concretes are discussed.

Finally, the field of application of the moistureproof phosphogypsum binders, concretes including bearing elements in the USSR construction, is described.

INTRODUCTION

The utilization of one of the large-tonnage waste when manufacturing the mineral acids and complex fertilizers, i.e. phosphogypsum and borogypsum, phosphoric anhydride, acid fluoride, fluorogypsum, etc., is one of the biggest scientific-technical problems of the mineral-raw material rational use,

The presence of great potential users, i.e. gypsum and cement industries, and agriculture, the reduction of lands intended for waste placement, the economical and ecological factors determine the urgency of solving this problem.

In the USSR, the gypsiferous waste, and first of all, the phosphogypsum one is used in the cement industry as a mineralizer when calcinating the clinker and as an admixture when grinding it instead of the natural gypsum, as well as it is used for earth gypsuming in the agriculture.

The use of the phosphogypsum waste for manufacturing gypsum binders and elements is especially rational.

Developed in the USSR are different methods to produce the phosphogypsum binders in which composition either the β-or α- modification of calcium sulfate hemihydrate or the anhydrous calcium sulfate prevails depending on the dehydration conditions. In regard to their properties, these binders are similar to the usual, high-resistant or anhydrite ones on the basis of raw materials.

However, in view of their low-water resistance that results on considerable loss of strength (down to 35-40 % of strength in a dry state), lowered frost resistance and high creeping, the application of the elements made of these binders (as well as those on the basis of gypsum binders of raw materials) is limited in buildings with a maximum relative air humidity of 60 %, and in a less degree as small-sized stones for walls in the low-rise buildings.

There are different methods to improve the gypsum binder properties. It was found that the most effective one is combination of the gypsum binders with portlandcement and pozzolanic admixtures in order to produce the so-called gypsum-cement-pozzoulanic binders (GCP) and gypsum-slag-cement-pozzolanic binders (GSCP).

These binders, once developed by the Moscow Civil Engineering Institute in the fifties, have a capacity for hydraulic hardening in a humid and aqueous mediums, and they have the same hardening rate as the usual gypsum binders (Volghensky, 1950).

The investigation of many years of these binders, concretes and elements on their basis, as well as the practical experience of their production and application was generalized in (Volghensky, Ferronskaja, 1971, 1974; Ferronskaja, 1984).

The subsequent research demonstrated (approximately in the seventies and up) these binders are especially effective if they comprise those made of phosphogypsum waste instead of raw-material gypsum binders.

In this case, two directions for producing moistureproof phosphogypsum binders were determined, e.g.:

- The production of the moistureproof phosphogypsum binders making use of β-or α-modification of calcium sulfate hemihydrate: that are made of phosphogypsum waste with the help of different thermic technology methods,
- The production of the moistureproof phosphogypsum binders and elements making use of phosphogypsum waste with the help of non-thermic technology,

1. PRODUCTION OF THE MOISTUREPROOF PHOSPHOGYPSUM BINDERS MAKING USE OF β-OR α-MODIFICATION OF CALCIUM SULFATE HEMIHYDRATE, THAT ARE MADE OF PHOSPHOGYPSUM WASTE WITH THE HELP OF DIFFERENT THERMIC TECHNOLOGY METHODS

Two basic methods aimed to produce such binders may be mentioned, e,g,:

- The "traditional" method developed by the Moscow Civil Engineering Institute consists of a thorough mixing of β-or α-gypsum hemihydrate obtained in a liquid acid or alkaline medium, portland cement and an active mineral admixture in ratio according to the technique that was reported in (Specifications, 1989).

However the following should be noted: though the production of phosphogypsum-cement pozzoulanic binder on the basis of phosphogypsum binder obtained in an acid medium (Gordashevsky, 1961) is possible, it is not of practical value since the binder, if added with the portland cement and pozzoulanic admixture, loses its basic quality of fast setting and hardening, that is characteristic of the gypsum binder, because of impurities which are contained in the hemihydrate, (Ferronskaja et al. 1974; Volghensky et al,, 1977). The phosphogypsum-cement-poziolanic binders on the basis of β-or α-modification of gypsum hemihydrate, produced in an alkaline medium, is of practical interest (Ivanitzky et al., 1976, 1997; Ferronskaja et al. ,1974; Pechuro; Ferronskaja, 1977; Ferronskaja, Baranov, 1980; Stonis et al, 1980, 1982).

- The method, developed by the All-Union Scientific Research Institute of Building Materials and Constructions, consists of possible production of α-gypsum hemihydrate by treating the phosphogypsum suspension with portlandcement and active mineral admixture (the latter are added in order to improve the water resistance), that are introduced before the autoclave treatment; it is more effective to add previously-hydrated portlandcement with admixture to the suspension (Ivanitzky et al. ,1976, 1977; Ferronskaja et al., 1977; Ivanitzky et al., 1983.

Given below is approximate composition of the phosphogypsum-cement-pozzolanic binder that is produced by the first method:

β-or α-calcium sulfate hemihydrate made of phosphogypsum, %	50 to 80
Portlandcement and active mineral admixture, %	50 to 20

Making use of β-or α-calcium sulfate hemihydrate on the basis of phosphogypsum it is possible to produce the phosphogypsum-cement-pozzolanic binders of brands respectively 100 to 150 and 200 to 400 with a coefficient of softening of 0.65 to 0.75.

When producing the phosphogypsum-cement-pozzolanic binders *in* compliance with the second method, the amount of combination admixture should be within the limits of 25 to 35 %. In doing so, a binder of brand of up to 250 with a coefficient of softening of 0.60 to 0.69 is produced.

The period of setting: beginning - 13 and 30 minutes, finishing - 30 and 65 minutes, respectively for binders produced according to the first method and to the second one.

These binders are water resistant, durable during a long-term air or water hardening, during alternative water saturation and drying, as well as during freezing and defrosting.

In contrast to the phosphogypsum binders, the abovementioned ones have satisfactory elastic-plastic properties (Ref. Fig, 1). Really, the dry samples of phosphogypsum-cement-pozzolanic binder, as well as the samples of phosphogypsum binder, when carrying sustained load in a medium at relative air humidity of 0 %, practically are not distorted, The dry samples of phosphogypsum binder have the minimum creeping, As increasing the amount of complex admixture, the absolute values of dry sample plastic deformation are rising. And the creeping of the phosphogypsum-cement-pozzolanic binder samples, previously dried till obtaining constant mass and then absorbently moistened at different relative humidity of the medium, is directly related to the humidity, The research demonstrated also that the elastic-plastic properties of the phosphogypsum-cement-pozzolanic binder samples approximate to the portlandcement samples, and the more amount of portlandcement with pozzolanic admixture is contained in moisterproof binder, the more approximation is between them. In this case, the satisfactory deformation properties of the samples of these binders are obtained if they contains not less than 20 % of portland cement. It is explained by a radical transformation of the hardened phosphogypsum-cement-pozzolanic binder structure and it completely conforms to our early-performed research of gypsum-cement-pozzolanic binder (Ferronskaja et al, , 1973; Ferronskaja, Roghkova, 1974).

The phosphogypsum-cement-pozzolanic binders, that were produced according to the first method, demonstrated the best results on all the properties (Ferronskaja A.V. et al, , 1977; Pletnev V.P., 1978).

Developed in the USSR is also phosphogypsum binder OWC - oil-well cement intended for low-temperature wells (Specifications, 1985). It is a hydraulic binder that is produced by thorough mixing α - calcium sulfate hemihydrate made of phosphogypsum (70 to 80 %), portland cement (20 to 30 %) and hardening regulator (0.2 to 0.5 %). In comparison with the phosphogypsum binder, this binder has higher water resistance, rapid-gaining of strength, but slower-hardening period.

The technological parameters of the phosphogypsum binder production were developed by means of experimental commercial plants, The are assumed as a basis of the production of phosphogypsum-cement-pozzolanic binders on the basis of α - modification in the Uvarovo chemical splant (output of 180 thousand tones/year), and on the basis of β- modification of calcium sulfate made of phosphogypsum - in the Kedajnjay chemicals plant, Lithuanian SSR (output of 60 thousand tones/year), Actually, the binders OWC - - oil-well cement are produced by the Voskresensk mineral fertilizer factory "Minudobrenija".

The Moscow Civil Engineering Institute and other organizations performed numerous investigations related to possible production of different concretes on the basis of the phosphogypsum-cement-pozzolanic binders, i.e. heavy-weight concretes with coarse and fine aggregates, light-weight concretes with porous aggregates, heat-insulating concretes including dispersion reinforced concretes.

Characteristics of the concretes on the basis of phosphogypsum-cement-pozzolanic binders are shown in Table 1.

Table 1. Characteristics of concretes

Type of concrete	Mean density, kg/m^3, or brand acc to mean density	Class of compressive strength	Frost resistance brand	Organizations--developers
Heavy--weight concrete	2200 to 2400	B 7.5 to B 30	35 to 150	Moscow Civil Engineering Institute
Fine concrete	1800 to 2200	B 3.5 to B 20	35 to 100	
Light--weight concrete with porous aggregates	Д800; Д900	B2.5; B3.5	25 to 35	The same organization, All--Union Scientific Production Enterprise of Building Materials and Binders, Lithuania Scientific Research Institute of Civil Engineering
	Д100; Д1100	B2.5 to B7.5	25 to 50	
	Д1200; Д1300	B3.5 to B12.5	25 to 50	
	Д1400; Д1500	B3.5 to B15	35 to 75	
	Д1600; Д1800	B5 to B20	50 to 100	
Heat-insulating cellular concrete	Д400	B0.75 to B1	-	Moscow Civil Engineering Institute
	Д500	B1 to B1.5	15	

The concretes on the basis of phosphogypsum-cement-pozzolanic binders take precedence over the concretes on the basis of phosphogypsum binders, having a capacity for hardening under humid conditions and in water with time-unceasing growth of strength like analogous concretes on the basis of portlandcement . These concretes are characterized by intensive growth of strength (after 3 hours, approximately 20 to 30 % from R_{28} days) so dismantling forms and making elements of them are possible by means of nonthermic technology.

The research, performed by the Moscow Civil Engineering Institute and related to the strength of the heavy-weight concretes, fine concretes and light-weight concretes on the basis of phosphogypsum-cement-pozzolanic binders and to their capacity for deformation after having been loaded during short-term and long term with regard for concrete structure, permits to note that these concretes are characterized approximately by the same deformation properties as the concretes of equal strength on the basis of gypsum-cement-pozzolanic binders, and they approximate to the analogous properties of the concretes on the basis of portland cement (Volghensky, Ferronskaja, 1974; Ferronskaja, 1984; Recomendations, 1989, etc.). The same research demostrated the deformation and strength characteristics of the elements used for construction of experimental buildings and under natural observation, which were obtained as result of a center and eccentric compression test under short-term load and sustained load, not differ from those of the analogous elements on the basis of gypsum-cement-pozzolanic binders and portlandcement and they meet the requirements of strength-carrying capacity design with regard for the buckling according to (Construction Specifications and Regulations, 1984; Construction Specifications and Regulations, 1985),

The tests of floor slabs, beams under short-term and sustained bending loads resulted on satisfactory coincidence of design loads with actual ones, as well as correspondence with the design related to deformations, crack formation and opening in accordance with the same Construction Specifications and Regulations. The tests of the bended elements, made of different concretes on the basis of phosphogypsum-cement-pozzolanic binders, under short-term load, that were performed after having been loaded for 2 to 3 years under different humid conditions, demostrate that such sustained loading exerts positive influence upon their physical-mechanical properties (in contrast to the concretes on the basis of phosphogypsum binders). All this is indicative of these concretes durability and their reliability when in service.

The research demonstrated that the concretes *on* the basis of phosphogypsum-cement pozzoulanic binders differ from the concretes on the basis of gypsum-cement-pozzolanic binders by Power medium alkalinity thus provoking more aggresive corrosion of their steel armature. To protect the steel armature of the concretes on the basis of phosphogypsum-cement-pozzolanic binders, developed are different methods of protection (Ferronskaja et al. , 1981, 1984).

On the grounds of numerous laboratory and natural investigations related to the concretes and elements, they may be recommended to be used broadly in the construction not only in the fields traditional for gypsum binders but in wider fields proceeding from their possibilities'. On the whole, the fields of application of the elements made of phosphogypsum-cement-pozzolanic concretes are the same as in case of the concretes on the basis of gypsum-cement-pozzolanic binders and they are explained in (Recomendations, 1989).

The phosphogypsum-cement-pozzolanic concretes are especially effective for the production of spatial elements, i.e. utility cores, ventilating blocks, spatial blocks, etc,, as well as for laying of filled floors and in the solid construction.

The composite dispersion reinforced material on the basis of phosphogypsum-cement-pozzolanic binders may be used for the production of space enclosing structures of different application, i.e. counter ceilings, air ducts, ventilation system ducts and air-conditioning system ducts, heat-insulating elements, etc. (Ferronskaja, Andreev, 1982, 1984).

2. PRODUCTION OF THE MOISTUREPROOF PHOSPHOGYPSUM BINDERS AND ELEMENTS MADE OF PHOSPHOGYPSUM WASTE, WITH THE HELP OF NONTHERMIC TECHNOLOGY

Though the abovementioned methods of the production of moistureproof phosphogypsum binders provide for high quality of these binders, in same cases they may fail in competitive strength as regards the cost in comparison with the analogous binders made of raw materials, Besides, no high brand of binders is needed for many elements, the brands Г-3 to Г-7 are sufficient. Therefore, the investigation of more effective technology methods of the production of moisterproof phosphogypsum binders and elements is of great. practical interest,

Effective is the production of phosphogypsum binders made of phosphogypsum and quicklime not by simple mixing the components but by means of the phosphogypsum dihydrate "calcination" owing to heat of slaking of the milled quicklime (Volghensky, 1944). In this case the following exothermic reaction takes place, Eq. (1):

$$2(CaSO_4 \cdot 2H_2O) + 3CaO = 2(CaSO_4 \cdot 0{,}5H_2O) + 3Ca(OH)_2 + 156\ kj$$

The initial phosphogypsum and milled lime are mixed (i.e. by means of runners) in approximate relation of 1:0.8 to 1:1,5 depending on the lime activity and the phosphogypsum humidity, and then they are transferred fastly into a reservoir where the reaction takes place at a temperature of 140 to 160°C, Provision should be made for measures to prevent dust penetration into the room.

By adding milled pozzolanic mixture, i.e, tripoli, ashes, etc., a moisterproof binder may be produced.

These binders have a brand of Г-5 to Г-7 and may be used successfully for the production of building stones, blocks and other elements,

It is rational to organize the described production in those regions where phosphogypsum waste and lime-manufacturing plants are present.

The technology of producing elements for low-rise buildings making direct use of the phosphogypsum dihydrate without its previous thermal treatment, is also developed (Volghensky et al. , 1987). It is obtained via combination of the phosphogypsum waste with lime and pozzolanic admixtures, i.e. ashes, broken brick, tripoli, expanded-clay dust, etc. All components, water is included, are mixed by means of forced-action mixters, Molded of obtained mixtures are elements which are subjected to drying at a temperature of 70 to 120°C for 8 to 12 hours. Instead of lime with pozzolanic admixture, use of portland blastfurnace slag cement in amount of 10 to 15 % is possible.

The concretes, produced according to this technology, have a strength of 2.5 to 5.0 MPa and up with a mean density of 900 to 1400 kg/m3, being moistureproof and frostproof (15-35 Frst).

The building elements are 10-to-15 % more economical than walls with clay brick and expanded-clay Sight weight concrete panels (in terms of 1 m^2). Their production is 30-to-60 % less power--intensively. Organization of their production does not involve heavy outlay no heavy current expenses; their transportation and erection may be carried out without special equipment.

These mixtures are also used for the production of granules that may be employed as mixture instead of natural gypsum dihydrate when milling the portland cement clinker.

These mixture may be used for filling of mineral resources working in wells. This direction to use the phosphogypsum waste, harmful for ecology, is especially of perspective owing to economical efficiency and simplicity.

The method of producing moistureproof granules (Volghensky et al. , 1987), that consists in mixing the phosphogypsum dihydrate of up to 88 % with portland blastfurnace slag cement and pozzolanic portland cement is also developed. On completion of granulation, they are transferred to the drying drum where the drying takes place at a temperature of 70°C, maximum. The granule strength is of 1.5 to 3.5 MPa. Besides being used these granules when milling the portlandcement clinker, they also may be employed as aggregates for light-weight concretes and as thermal insulation bulk material. Finally, one cannot but emphasize the small-size elements , i,e. blocks and other ones for external walls of low-rise brildings, may be produced by means of simple technology making use of β- phosphogypsum hemihydrate (Volghenesky et al. , 1982). The technology provides for (Volghensky et al. 1982) milling of this binder together with sand till obtaining a specific surface of 2500 cm^2/g. The mixing is performed by means of runners. The compaction is carried out by means of vibration. The elements should be hardened under natural conditions.

By adding slag, i.e. electrophosphorus one activated by sodium carbonate (slag - 20 %, sodium carbonate - 0.4 to 0.9 % of slag mass), to this mixture, a moistureproof concrete may be produced.

CONSLUSIONS

Our research results have permitted to develop and use moistureproof phosphogypsum binders for the production of different elements.

As far as their properties (deformability and durability) are concerned they approximate to the elements made of cement concretes. Really these properties permit to expand the fields of their application in the construction, including bearing structures used in the buildings of relative air humidity exceeding 60 %.

The concretes on the basis of these binders are of special perspective of use in the spatial-block construction and in the solid construction.

The use of moistureproof building materials made of phosphogypsum favours not only expansion of utilization of the phosphogypsum waste but also setting free considerable earth areas, occupied with this waste, and ambient ecology improvement.

REFERENCE LIST

Volghensky A.V., Ivannikova R.V, 1950. Gypsum cement and gypsum slag binders, Building materials, elements and structures. 4.

Volghensky A.V., Stambulko V.I., Ferronakaja A.V. 1971. Gypsum--cement-pozzolanic binders, concretes and elements. Strojizdat.

Volghensky A.V.) Ferronskaja A.V. 1974. Gypsum binders and elements. Strojizdat,

Ferronakaja A.V. 1984. Durability of gypsum materials, elements and structures. Strojizdat.

Gypsum-cement-pozzolanic binder. Specifications. TY 21-31-62-89 (instead of OCT 21-29-77).

Gordashevaky P.F. 1961. Research of some properties of the building phosphogypsum, Scientific work collection of ROSNIIMS, 20:

Ferronskaja A.V., Stambulko V.I., Korovjakov V.F. 1974. Research of possible production of the moistureproof binders making use of phosphogypsum. Scientific work collection "Use of waste of phosphogypsum fertilizers production - phosphogypsum in the technology of portland cement, autoclave gypsum binders and building elements".

Volghensky A.V., Stambulko V.I., Korovjakov V.P. 1977. Gypsum-cement-pozzolanic binders on the basis of phosphogypsum. Scientific work collection "Actual gypsiferous materials and elements".

Ivanitzky V.V., Pletnjev V.P., Gordashevsky P.F. 1976. Method of binder production. A.S. No. 530004. B.I. No. 36.

Ivanitzky V.V., Pletnjev V.P. 1977. Raw material mixture on the basis of gypsum. A.S. No. 557072. B.I. No. 26.

Ferronskaja A.V., Gordashevaky P.F., Pletnjev V.P., Balkevitch L.V. 1977. Moistureproof binders on the basis of α- calcium sulfate hemihydrate. Scientific work collection of VNIIESM, series "Use of waste and by-product for producing the building materials". 4.

Pechuro S.S., Perronskaja A.V. 1979. Technical progress in gypsum elements production. VNIIESM.

Ferronskaja A.V,, Baranov I.M. 1980. Phosphogypsum-cement-pozzolanic binder, Specifications. TY 21-31-32-80.

Stonis S.N., Kaziljunas A.L. 1980. Particulars of production of building gypsum making use of phosphogypsum. Building materials. 2.

Stonis S.N., Kaziljunas A.L. 1983, Development of phosphogypsum--cement-pozzolanic binder on the basis of β - hemihydrate. Research of building materials. Mokslas.

Ivanitzky V.V., Gordashevsky P.F., Pletnjev V.P. 1977. Method of gypsum binder production. A.S, No. 565014. B.I. No. 37.

Ivanitzky V.V., Pletnjev V.P. 1983. Gypsum binders of high strength and water resistance on the basis of phosphogypsum. Building materials. 9:

Ferronskaja A.V., Volghensky A.V., Roghkova K.N. 1973. Influence of the gypsum-cement-pozzolanic block structure upon the deformation properties. Building materials. I:

Ferronskaja A.V., Roghkova K.N. 1974. Gypsum-cement-pozzolanic block structure. Building materials, II.

Pletnjev V.P. 1978. Research of properties of α- calcium sulfate hemihydrate made of phosphogypsum, and development of methods to improve its water resistance- Synopsis of thesis prepared by competitor for candidate's Sc, (Eng.) degree,

Oil-well cement used for the low-temperature wells. Specifications. TY 113-08-565-85.

Recomendation for design, production and application of the structures made of concretes on the basis of gypsum-cementpozzolanic binders. 1989.

Construction Specifications and Regulations СНиП 2.03.01 - 84. Concrete and reinforced concrete structures.

Construction Specifications and Regulations СНиП 2.01.07 - 85 /Cr СЭВ 384-76/. Loads and actions.

Ferronskaja A.V., Korolkova G.A., Tupikin E.I. 1981. Corrosion of concrete steel armature on the basis of phosphogypsum-cement-pozzolanic binder with admixtures PAV and their mixtures. Transactions of Higher Institutes of Learning, series "Chemistry and chemical technology", volume XXIV. 6th ed.

Ferronskaja A.V., Andreev E.I. 1982. Composite dispersion reinforced material on the basis of moistureproof gypsum binders. Building materials. 11:17-18.

Ferronskaja A.V., Andreev E.I., Baghenov Yu.M., Korovjakov V.F. 1984. Heat-insulating material on the basis of mineral wool and inorganic binder. Building materials. 9:24-25.

Volghensky A.V. 1944. Gypsum solusions of high water resistance. Construction Equipment Institute, Academy of Sciences of the USSR. 13.

Volghensky A.V., Karpova T.A., Chistov Yu,D., Gusarova G.A. 1987. Seminar supervised by the Economical Achivements Exibition of the USSR.

Volghensky A.V., Gusarova G.A., Chistov Yu.D., Largina O.I., Karpova T.A. 1987. Method of producing elements. A.S, No. 1328324. B.I. No. 29.

Volghensky A.V., Chistov Yu.D., Largina O.I., Karpova T.A. 1988. Granular phosphogypsum. A.S. No. 1446109. B.I. No. 47.

Volghensky A.V., Ferronskaja A.V., Sejketova B.B. 1982. Gypsum binder. A.S. No. 948937. B.I. No. 29.

Volghensky A.V., Sejketova B.B. 1982. Method of producing gypsum concrete. A.S. No. 962242. B.I. No. 36.

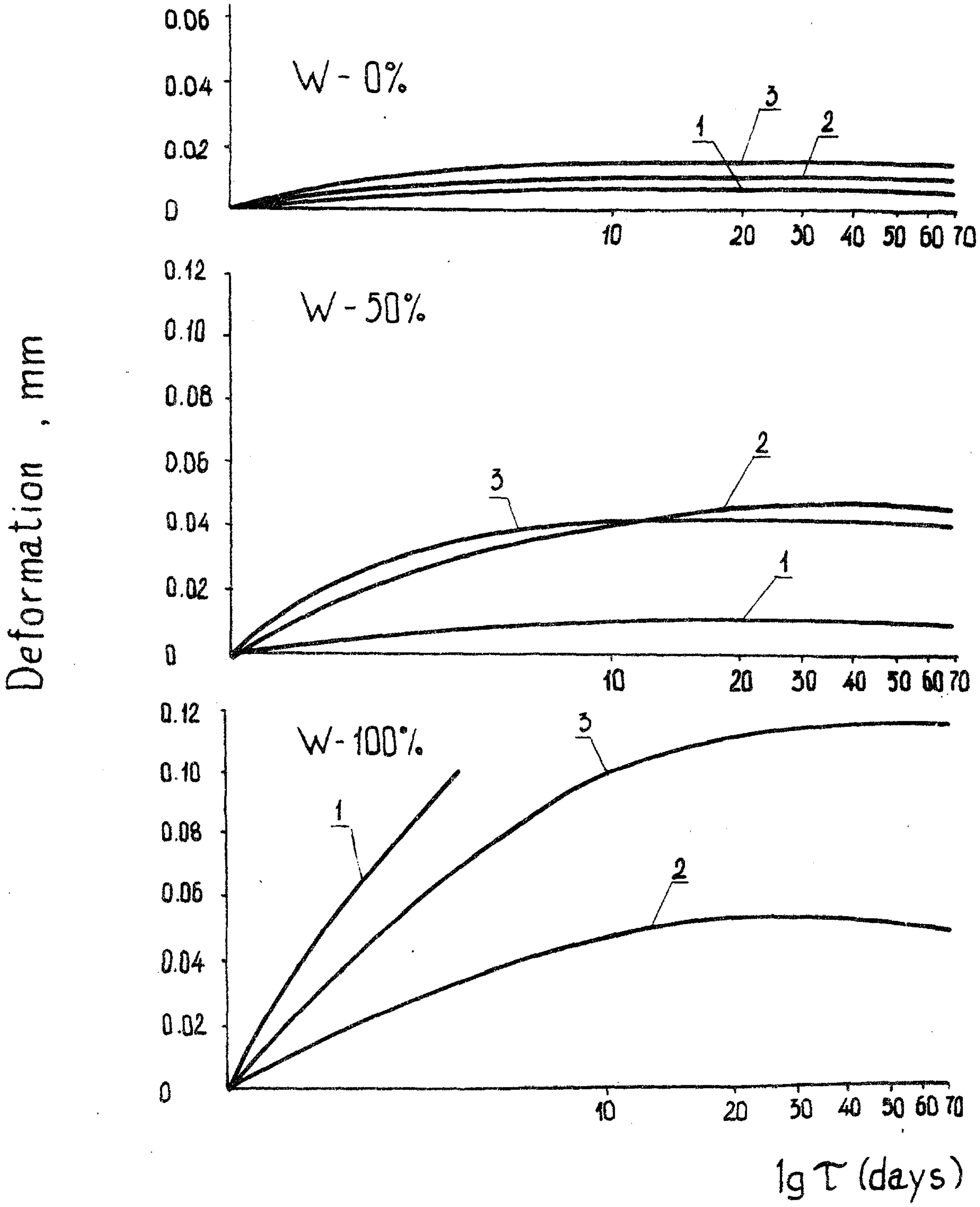


Figure 1. Relationship between the creeping of samples and relative air humidity:

100%-phosphogypsum binder (1);
50:30:20 (2) and 70:18:20 (3) - phosphogypsum-cement-pozzolanic binder (phosphogypsum binder : portlandcement : pozzolanic admixture)

PHOSPHOGYPSUM AS A RAW MATERIAL IN THE MANUFACTURING OF PLASTER PRODUCTS

T. Brown, Senior Technical Officer
J. Beretka, Principal Research Scientist
CSIRO Division of Building, Construction and Engineering
PO BOX 56, Highett, Victoria 3190, Australia

ABSTRACT

Phosphogypsum has previously been used at two locations in Australia for making plaster products, for about 2 and 10 years, respectively. However, its use was discontinued in 1983 probably due to intermittent manufacturing and quality control problems associated with the variability of the materials. Recently, at the request of a company in Victoria, investigations on the suitability of using phosphogypsum as a raw material for making plaster of Paris were carried out at the CSIRO Division of Building, Construction and Engineering (DBCE) on a large phosphogypsum stockpile containing about 4.5 x 10^6 t of phosphogypsum. The investigations were carried out on three types of samples, viz. core samples from the stockpile, fresh samples from the adjoining phosphoric acid plant, and on representative samples from the stockpile. It was found that plaster of Paris, plaster products and plasterboard with properties similar to those made from commercial casting plaster could be produced not only in the laboratory but also at pilot-plant scale. The company in question is considering the commercial production of plaster of Paris and plaster products from this material.

INTRODUCTION

Phosphogypsum is widely used throughout the world for the manufacture of plaster products, particularly plasterboard (Carmichael, 1988). For some 30 years the Nissan process has been one of the best established technologies that produce phosphogypsum containing low levels of impurities (Kouloheris, 1980; Goers, 1980). It is known that certain impurities, particularly phosphate and fluoride, affect the manufacturing process and the technological properties of plaster of Paris made from phosphogypsum (Wirsching, 1978; Berry, 1972; Beretka, 1982, 1988; Beretka and Brown, 1983a, 1986).

At present in Australia, three Nissan plants and two Fisons plants generate ~940 000 t of phosphogypsum. Phosphogypsum has been used in the past at two locations (Newcastle and Brisbane for 2 and 10 years, respectively) for making plaster of Paris and plasterboard. Its use was discontinued in 1983 possibly due to (a) Australia being very rich in mineral resources including high-purity natural gypsum, (b) some technological problems associated with the fineness and 'lime sensitivity' of the materials during the production processes, and (c) concerns about the potential radioactivity of the materials used for making plasterboard. The material is currently dumped at land sites.

This paper describes research and development work carried out at the CSIRO DBCE on the conversion of phosphogypsum (from Melbourne/Yarraville) to plaster of Paris and plasterboard. The experiments were carried out on three types of samples: core samples taken from the stockpile, fresh samples from the adjoining phosphoric acid plant collected at approximately monthly intervals, and large 'typical' representative samples from the stockpile. Some of the latter material is sold as soil conditioner in agriculture.

EXPERIMENTAL

MATERIALS

The following samples were received: (a) six cores from the stockpile taken to a depth of up to 21 m, sampled at 1 m intervals (111 samples); (b) seven fresh samples from the adjoining phosphoric acid plant collected at monthly intervals from June to December 1988; and (c) three "typical' representative samples from the stockpile. Furthermore, one large blended composite sample was received which was used for making the large plasterboard specimens. The chemical analyses of the three typical samples are shown in Table I. Due to the large number of samples (mainly the core samples), only core 1 was examined fully at 1 m intervals (20 samples) and the other five cores at 5 m intervals (25 samples). All the materials were dried at ~50°C, then sieved to pass a 1.4 mm sieve.

Table I
Chemical composition of phosphogypsums (%)*

Components	Sample		
	S1	S2	S3
CaO	33.6	32.9	32.9
SO_3	44.6	44.8	44.7
SiO_2	<0.01	0.11	0.03
Al_2O_3	0.20	0.11	0.13
Fe_2O_3	<0.01	<0.01	<0.01
MgO	0.05	0.03	0.04
Na_2O	0.07	0.03	0.05
K_2O	0.31	0.05	0.22
Total F	1.40	1.20	1.20
Total H_2O (H_2O+)	19.8	19.9	19.70
Free water (H_2O-)	0.07	0.07	0.1
Total P_2O_5	0.3	0.45	0.35
Organic C	0.06	0.14	0.09
Total	100.48	99.8	99.52
Water soluble F ppm	200	200	250
Soluble P_2O_5	0.24	0.24	0.30
Co-crystalised P_2O_5	0.16	0.34	0.24
Unreacted P_2O_5	0.06	0.21	0.05

* Analyses performed by AMDEL Limited.

PROPERTIES OF RAW MATERIALS

The following properties of the dried materials were determined: mineralogical composition by XRD, bulk volume, bulk density, specific surface area by air permeability

(Ridgen method), particle size distribution by sieving in alcohol, and pH of slurry (10 g solid in 100 ml water).

PROCEDURES

The three typical samples, identified with the symbols Sl, S2 and S3, were calcined in a small (capacity approximately 2 L) laboratory kettle, and the large blended composite sample, labelled SCC, in a large pilot-plant kettle (capacity approximately 50 L). The materials were calcined to the ‘second boil’ as in industry (Beretka and Brown, 1983b). The core samples and the fresh samples were calcined on a tray at 145-150°C for 16 h. All the samples were conditioned for 24 h in a room set at 21°C and 67% r.h. Comparisons were made between the physical properties of some of the materials calcined either on a tray or in a kettle. In general, higher mechanical strengths were obtained with the materials calcined on a tray. In addition, some of the samples were ground in a hammer mill either before or after calcination, and their properties examined.

PHYSICAL PROPERTIES OF PLASTERS AND PLASTERBOARDS

The calcined materials were tested for water requirement. Due to the thixotropic nature of the calcined phosphogypsum-water slurries, care needs to be taken in the interpretation of this property. Furthermore, the setting time (knife-edge test), mechanical strength and density were also determined. The latter properties were measured by casting 25 mm cube specimens with w/s ratios ranging from 0.6 to 1.0, drying them at room temperature to constant weight, then measuring their compressive strength on an Instron machine (rate of cross-head speed, 0.5 mm/min). The densities of the air-dried specimens were determined by conventional methods. Due to the relatively short (3-4 min) setting time of some of the materials, experiments were also carried out with commercial retarders, particularly hydrolysed keratin, in order to increase the setting times to more acceptable values of 25-30 min.

In addition, the pH of some of the slurries was adjusted with lime to between pH 6.5 and 8, in order to avoid lime sensitivity and the almost complete loss of strength associated with lime sensitivity. Neutralisation to pH 6.5-8 was also necessary for making the keratin retarder more effective, since it loses its effectiveness in acidic pH below ~6. Furthermore, 620 x 620 x mm plasterboards reinforced with a medium density chopped strand glass-fibre mat (270 g/m^2 Pilkington/ACI) were cast and tested for modulus of rupture according to the Australian Standard (AS 2590-1983). Finally, a few large (1.8 x 1.8 x 8 mm) plasterboards reinforced with glass-fibre mat were made for demonstration purposes. No keratin retarder was used for casting the small specimens, but for the large boards 0.015% of keratin was added to the gauging water.

RESULTS AND DISCUSSION

The chemical composition of samples S1, S2 and S3, as shown in Table I, indicate that the materials had relatively low levels of impurities, particularly P_2O_5 and F^- contents.

VARIABILITY OF THE STOCKPILE - EXAMINATION OF CORE SAMPLES

Forty-two dried core samples were examined from the stockpile. Their pH (slurry) varied considerably between 2.9 and 4.8 (mean 3.4), and their particle size, determined by the percentage of material passing a 45 pm sieve, varied from between 9.6 and 56.6% as shown in Figure 1.

The pH of the tray-calcined material varied between 2.8 and 4.7 (mean 3.2), its bulk volume between 80 and 108 ml/100 g, and the setting time between 3.5 and 21 min. The compressive strength of the individual core samples (calcined on a tray) *v.* depth at the w/s ratio of 0.6 is shown in Figure 2. The solid line represents the mean value for core 1, and the dashed line represents the mean value for compressive strength of that particular core sample. Although the means are generally consistent, the results indicate that the compressive strengths of the individual core samples varied between 8 and 16 MPa. However, all the core samples should be suitable for making plaster products and plasterboard provided the material is lightly ground either before or preferably after calcination (see below).

PROPERTIES OF FRESH SAMPLES FROM THE PHOSPHORIC ACID PLANT

The free moisture content of the seven samples collected between June and December was relatively uniform - between 18 and 22%. The pH was also relatively uniform - only between 2.1 and 3.0 - indicating that the materials were quite acidic. The pH of the tray-calcined materials (slurries) varied between 2 and 2.9; and their bulk

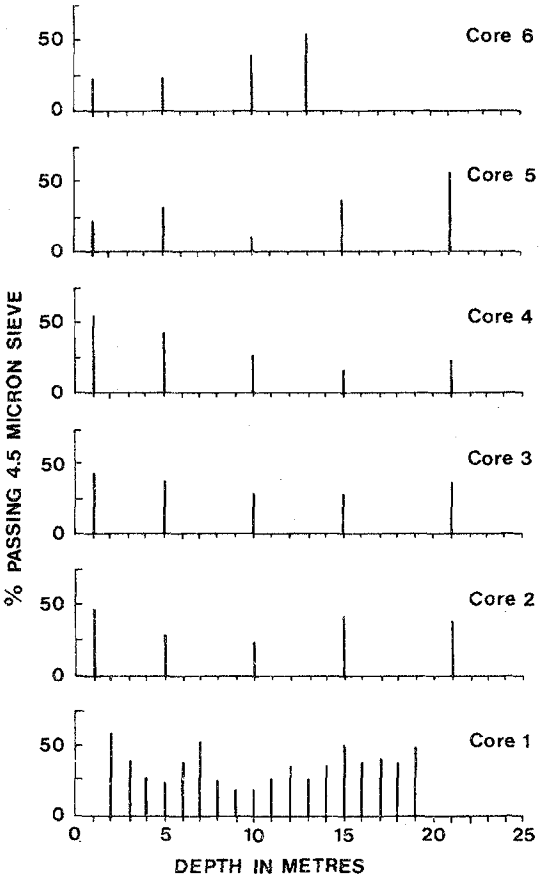


Figure 1 Uncalcined core samples passing a 45 μm sieve (%).

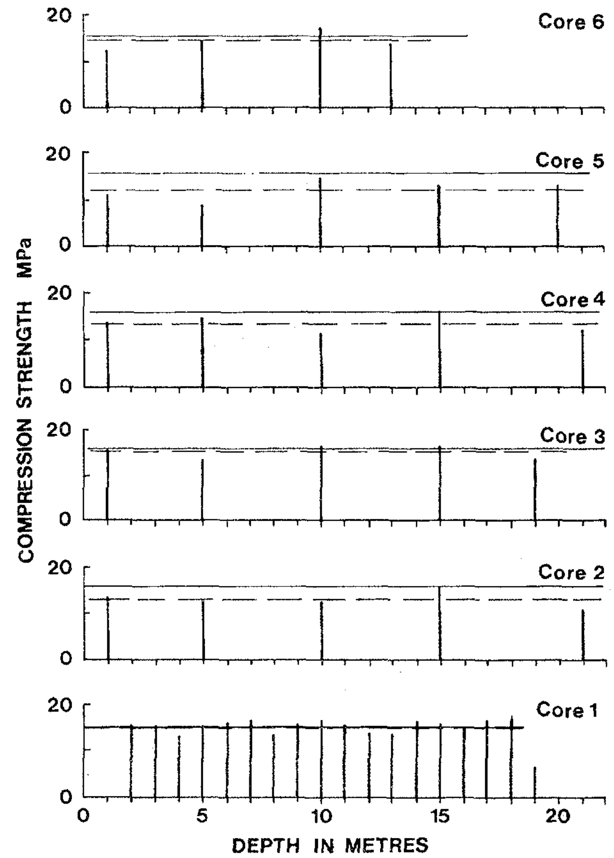


Figure 2 Compressive strength (MPa) of tray-calcined core samples collected at various depths (w/s ratio 0.6).

volume between 100 and 134 ml/100 g. The setting times, however, varied greatly between 7 and 43 min, as shown in Figure 3. The compressive strengths of the above samples (shown in Figure 4) varied considerably from month to month. In particular, the results indicate that at the w/s ratio of 0.6, the sample collected in December had very poor strength of <6 MPa. Those collected in July, August and November had reasonable strength, and the others collected in June, September and October had strengths suitable for making plaster products. Light grinding either before or after calcination should improve the strength properties of the above materials.

PLASTER PRODUCTS AND PLASTERBOARD

The experiments were carried out on the three typical samples from the phosphogypsum stockpile, identified with the symbols S1, S2 and S3, and on the large blended composite sample labelled SCC. Some of the calcined phosphogypsums were ground either before or after calcination in order to improve the properties of the water-plaster slurries and also the cast gypsum specimens and plasterboards made from them. Samples S1, S2 and S3 were calcined in a small (approximately 2 capacity) kettle, and the large sample SCC in the large (approximately 50 capacity) kettle. A commercial retarder, hydrolysed keratin (0.015%) was added to the gauging water to increase the setting time for casting the large plasterboard specimens. The physical properties of the dried and calcined materials used for the above experiments are shown in Table II.

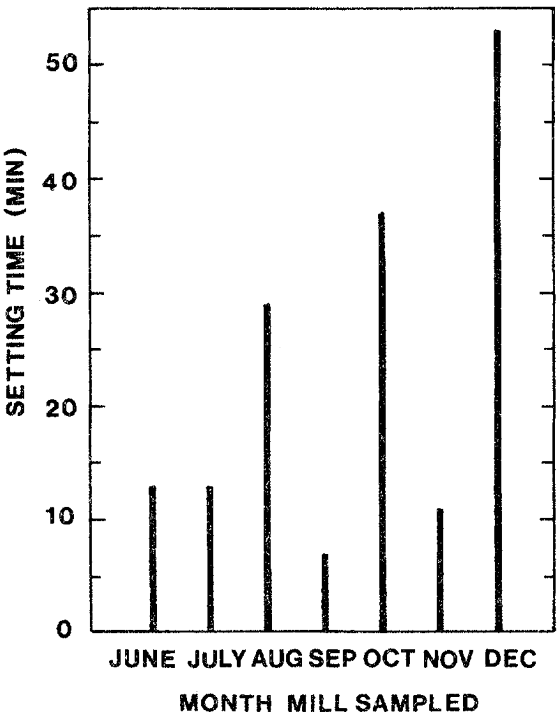


Figure 3 Setting time (min) of tray-calcined fresh samples collected from the phosphoric acid plant between June and December 1988.

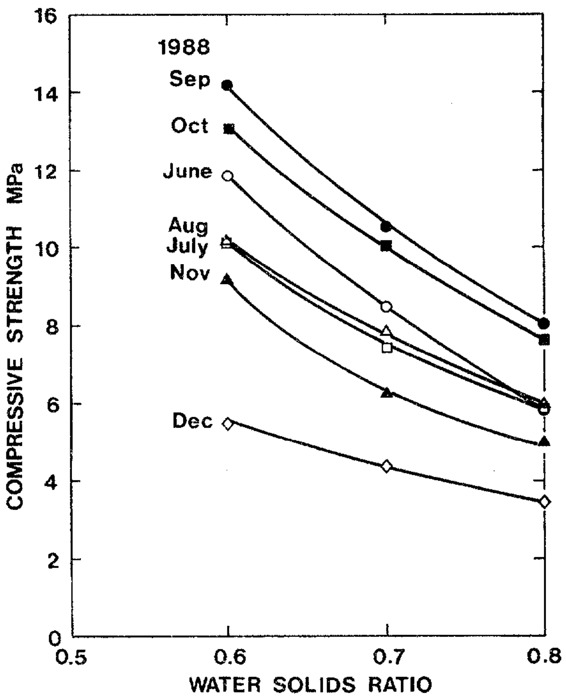


Figure 4 Relationship between compressive strength (MPa) and w/s ratio of tray-calcined samples collected from the phosphoric acid plant between June and December 1988.

Table II

Physical properties of dried and calcined materials

Sample	pH (slurry)	Specific surface area (m^2/g)	Bulk volume (ml/100 g)	Bulk density (kg/m^3)	Particle size <45 μm (%)	Water requirement (ml/100 g)	Setting time (min)	Setting time with 0.1% keratin retarder; no pH adjustment (min)
Dried materials								
S1	3.3	0.15	120	833	49			
S2	3.1	0.13	114	877	48			
S3	2.9	0.14	116	862	50			
Calcined materials								
S1	3.1	0.35	99	1010	81	95	7	29
S1/B*	3.0	0.40	97	1030	86	88	14	46
S1/A†	3.3	0.47	96	1040	92	84	6	28
S2	3.3	0.42	96	1040	66	86	8	11
S3	2.8	0.31	102	980	62	97	8	14
SSC							7	n.d.

* Ground before calcination.

† Ground after calcination

n.d. not determined

It can be seen that the properties of the dried samples were very similar. Their pH was between 2.9 and 3.3, surface area between 0.13 and 0.15 m^2/kg, their bulk volumes and bulk densities were similar, and 48-50% of their particles were ~45 µm in size.

Somewhat larger differences were observed in the properties of the calcined materials. In particular, 62-81% of their particles were <45 µm in size, and their water requirements varied between 86 and 95 ml/100 g.

Grinding the materials either before (S1/B) or after (S1/A) calcination, however, had a marked effect on the bulk properties of material S1. Its specific surface area increased, the particle size was reduced, and most importantly the water requirement was also reduced. There was little change in its relatively short setting times of 6-7 min. However, the setting time was increased from approximately 6 min to about 28 min after the addition of 0.015% keratin to the material ground after calcination (S1/A). No explanation can be given to the marked increase in setting time to 46 min for material S1/B (ground before calcination).

The physical properties of plaster slurries, cast gypsum specimens and plasterboards made from the calcined materials and commercial casting plaster (control) are shown in Table III. It can be seen that the cast phosphogypsums had comparable strengths to commercial casting plaster, and the plasterboards made from calcined phosphogypsum ground after calcination had similar strengths to the control. The setting times of the calcined phosphogypsums were shorter than the commercial casting plaster, about 10 min *v.* 30 to 35 min, but this could be adjusted further with commercial retarders, if required.

The colour of the plasterboards made from phosphogypsum was off-white as compared with the almost pure white control. However, it is evident from the above experiments that calcined phosphogypsum, after neutralisation with small percentages of lime to pH 6.5-8, is suitable for making plasterboard and plaster products.

CONCLUSIONS

Core samples from the stockpile available at Yarraville/Melbourne, in Victoria, fresh samples from the adjoining phosphoric acid plant and typical representative, and blended composite samples, from the stockpile were examined from the point of view of their suitability for making plaster of Paris and plasterboard. It was found that gypsum plasterboard reinforced with glass-fibre mat can be produced from the material available at the stockpile, provided it is neutralised with lime after calcination, and is also lightly ground after calcination. The resulting plasterboards have similar strength to those made from commercial casting plaster, and they also meet the requirements of the Australian Standard (AS 2590-1983).

The properties of the core samples representing the stockpile were variable, but most of them appeared to be suitable for making plaster products. The fresh samples from the phosphoric acid plant, however, were too acidic and variable to be considered for immediate application in the plaster industry. Most probably, weathering of the material during storage assists the uniformity of the stockpile, which in turn facilitates the further processing of the phosphogypsum prior to application in the plaster industry.

Table III
Physical properties of plaster slurries, cast gypsums and plasterboards reinforced with glass-fibre mat made from calcined phosphogypsum and commercial casting plaster (standard deviation in parentheses)

Slurry			Cast gypsum	Plasterboard	
pH (slurry)	Setting time (min)	w/s ratio	Compressive strength (MPa)	Modulus of rupture (MPa)	Density (kg/m^3)
Calcined phosphogypsum, unground					
7.4	9	0.7	9.3 (0.4)	1.9* (0.6)	1030
6.7	10	0.7	12.2 (0.5)	6.3 (1.0)	1130
7.0	10	0.75	10.3 (0.6)	3.4 (0.4)	1090
6.7	11	0.8	9.3 (0.3)	3.2 (0.6)	1060
Calcined phosphogypsum ground after calcination					
6.0	11	0.65	13.7 (0.7)	5.3 (0.4)	1020
6.5	10	0.7	13.4 (0.6)	6.1 (0.2)	1110
Large demonstration plasterboard (cast with 0.015% keratin retarder)					
7.3	20.5	0.78	9.1 (0.7)	n.d.	n.d.
Commercial casting plaster (control)					
7.5	nd	0.7	9.2 (0.4)	1.6*	1110
7.6	30	0.7	8.2 (0.6)	5.2	1060
7.8	35	0.65	14.1 (0.7)	6.0	1110

* Plasterboard without glass-fibre mat reinforcement
n.d. not determined

ACKNOWLEDGMENT

We wish to thank Mr J Varsamis, CSIRO DBCE, for experimental assistance.

REFERENCES

Beretka, J. 1982. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 1 - The kinetics of hydration. *J. Chem. Tech. Biotechnol.,* 32: 607-613.

Beretka, J. 1988. Studies on the lime sensitivity of phosphogypsum. Proc. 2nd Int. Symposium on Phosphogypsum, Florida Institute of Phosphate Research, Bartow, Florida, 2: 271-276.

Beretka, J. and Brown, T. 1983a. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 2 - Physical properties. *J. Chem. Tech. Biotechnol.,* 33A: 299-308.

Beretka, J. and Brown, T. 1983b. Studies on the reactivity and physical properties of calcined gypsum as a function of time and temperature. *J. Austral. Ceram. Soc.,* 19: 38-41.

Beretka, J. and Brown, T. 1986. Hydration of calcium sulphate hemihydrate in the presence of phosphoric acid and calcium oxide. Part 3 - Phosphogypsum. *J. Chem. Tech. Biotechnol.,* 36: 512-518.

Berry, E.E. 1972. Some observations on the setting of calcium sulphate hemihydrate plaster in the presence of phosphoric acid and hydrated lime. *J. App. Chem. Biotechnol.,* 22: 677-671.

Carmichael, J.B. 1988. Worldwide production and utilisation of phosphogypsum. Proc. 2nd Int. Symposium on Phosphogypsum, Florida Institute of Phosphate Research, Bartow, Florida, I: 105-110.

Goers, W.E. 1980. Nissan hemi phosphogypsum. Proc. 1st Int. Symposium on Phosphogypsum, Florida Institute of Phosphate Research, Bartow, Florida, I: 36-52.

Kouloheris, A.P. 1980. Chemical nature of phosphogypsum as produced by various wet process phosphoric acid plants. Proc. 1st Int. Symposium on Phosphogypsum, Florida Institute of Phosphate Research, Bartow, Florida, I: 8-35.

Wirsching, F. 1978. Lime sensitivity - a characteristic of the hydration of phosphoric acid by-product gypsum. *Materiaux et Constructions,* 11: 62-64.

GRANULATION OF GYPSUM, LIMESTONE OR GYPSUM-LIMESTONE MIX

By

Cecil P. Harrison
Chemical Engineer

Tennessee Valley Authority
National Fertilizer & Environmental Research Center
Chemical Development Department
Muscle Shoals, Alabama 35660-1010

ABSTRACT

An improved process has been developed for economically and effectively granulating solid, finely divided, particulate feedstock comprising phosphogypsum, limestone, or mixtures comprising 80 to 90% by weight sulfogypsum, natural or mineral gypsum, and limestone. Products produced by the process exhibit excellent physical and chemical properties relative to dustiness, storage, and handling. Also, when the granules come into contact with moist soil or water, they rapidly disintegrate to substantially their original ungranulated, fine particle size for realizing and effecting maximum crop response or other utilization. The granulation process involves introducing the finely divided feedstock, together with recycle material, into a rotary drum where granulation is effected with use of a relatively small amount of lignosulfonate solution as a granulation aid.

AGGLOMERATION OF GYPSUM, LIMESTONE, OR GYPSUM-LIMESTONE MIX

By

Cecil P. Harrison
Chemical Engineer

Tennessee Valley Authority
National Fertilizer & Environmental Research Center
Chemical Development Department
Mustle Shoals, Alabama 35660-1010

At TVA, we have developed what is believed to be a practical, economical process for granulating gypsum, agricultural limestone, or gypsum-limestone mix. The granular gypsum products contain 13 to 14% of water-soluble sulfur; moisture content is usually 0.1 to 0.3%. The limestone product contains 89 to 90% by weight of $CaCO_3$ equivalent and about 0.3% moisture.

As is well known, both calcium and sulfur are nutrients essential for most living plants and are generally classified by agronomists as secondary nutrients, with nitrogen, phosphorus, and potassium being the primary plant nutrients. It is also well known that calcium and sulfur are required for many major and economically important agricultural commodities including peanuts, most cereals, and most fiber-producing crops.

The mineral gypsum ($CaSO_4$) is found extensively in natural massive forms and also is produced in large quantities as a by-product ("sulfogypsum") when limestone and sulfuric acid are reacted to produce carbon dioxide or as a by-product ("phosphogypsum") when phosphate rock and sulfuric acid are reacted to produce wet-process phosphoric acid.

Gypsum is used in the manufacture of Portland cement to prevent the cement from setting too rapidly and in road construction as a soil stabilizer. In the agricultural industry, gypsum is used as a calcium or sulfur source and as an amendment to lower soil salinity. It is estimated that currently about one million short tons of gypsum is used annually in the Southeast in growing peanuts. The material is usually applied to the peanut crop at the blossom stage so that when the gynophore "peg" enters the soil, adequate calcium from the gypsum source is readily available for realization of maximum crop yield.

The mineral limestone, comprising mainly $CaCO_3$, is found in great abundance and when processed to fine particle size is used extensively as liming agent to aid in the adjustment of soil acidity to thereby effect maximum production of most agricultural food and fiber crops. It is estimated that, in the United States, some 20 to 25 million tons of agricultural limestone is used annually as a liming agent. Larger size (-6 +16 Tyler mesh) limestone is also used as a filler in the production of numerous bulk-blended fertilizers.

Agricultural gypsum and limestone are usually applied to the soil in a finely divided state because solubility of the materials is low. Such fine particle size is required for materials of relative low solubility to achieve the desired rate of reaction in the soil; therefore, products with low specific surface area may not be as effective as those applied as a fine powder. On the other hand, modern fertilizer application equipment is designed for broadcast or row placement of free-flowing granular-type solid fertilizer materials. Consequently, dustiness, bridging problems, and sometimes high-dollar cleanup costs are encountered when such equipment is used for field application of fine-size gypsum with particle size of 40% -325 mesh (U.S. Standard Sieve) or limestone that has been ground to meet USDA specifications that require that no less than 50% of the material passes a 60-mesh sieve.

The TVA granulation process comprises a method for converting fine-size gypsum or limestone to typical granular fertilizer size (-6 +16 mesh Tyler). The granular products exhibit good mechanical stability and are eminently suitable for direct application to soil, for addition to bulk-blend fertilizers, for use in road construction and other soil-stabilizing applications, and for use in the manufacture of Portland cement. The granules produced by the TVA process exhibit good physical properties so that dustiness is minimized during handling. Also, when the granules come into contact with moist soil or water, they rapidly disintegrate to substantially their original ungranulated, fine particle size for realizing and effecting maximum crop response or other utilization.

The agronomic quality of low-solubility granular products may be best evaluated by determining the rate at which the granules disintegrate to their original particle size when contacted with aqueous solution. To evaluate the dispersant characteristic, a laboratory test was devised to simulate subjecting granular products to a 1/2-inch rainfall. Results of the tests (Table I) showed that the granules disintegrated to essentially their original particle size. Consequently, crop response to granular gypsum or granular limestone should be essentially the same as the response to powder-type gypsum or limestone.

The granulation process involves feeding phosphogypsum, limestone, or mixtures of sulfogypsum or natural gypsum and limestone to a conventional rotary drum granulator or to a pan-type granulator and agglomerating the solids feedstock and recycle material with use of a dilute lignosulfonate solution. Granulation of sulfogypsum or natural gypsum alone was not satisfactory; however, granulation was very satisfactory when these gypsums were blended with about 10% by weight of limestone. For economic reasons, the preferred agglomerating solution is a 1:1 weight solution of water and 48% ammonium lignosulfonate; however, a 1:1 weight solution of water and 58% calcium lignosulfonate is as effective for the process as ammonium lignosulfonate solution. The agglomerating solution may be sprayed or sparged onto or into the granulation bed. The proportion of agglomerating solution required per ton of product was about 500 pounds when granulating phosphogypsum, about 400 pounds when granulating gypsum-limestone mix, and about 200 pounds when granulating limestone. These numbers will vary as moisture content of feedstock varies. Moisture contents of the granulator products were 5 to 8% and crushing strength of the -7 +8 mesh (Tyler) granules was about 1 pound. After the product was dried at a temperature of 200 to 225°F, moisture level was 0.2 to 0.3% and crushing strength of the -7 +8 mesh granules was about 7 pounds for gypsum and limestone and about 4 pounds for gypsum-limestone mix. Recycle ratios (pounds/pound of product) were about 2.5 for gypsum, 1.1 for gypsum-limestone mix, and 0.7 for limestone. In granulation of limestone, drying and screening may not be necessary if the product is intended for immediate use.

Figure 1 shows *a* flow diagram of the bench-scale equipment that was used for developing the granulation process. The drum granulator was a 12-inch-diameter rotary drum 22 inches in length and sloped about 1 inch/foot from the feed end to the discharge end. The drum was fitted with a 2-7/8-inch-high and a 2-inch-high retainer ring at the feed and discharge ends, respectively. Rotation of the drum for most of the tests was controlled at about 50 r/min (65% of critical speed). The solution phase for effecting binding and agglomeration was sprayed by means of an air-atomizing nozzle onto the surface of the granulation bed. Test results indicated no advantage in the operation by using more concentrated agglomerating solution and that optimum concentration of the agglomerating solution is in the range of 25 to 50% of lignosulfonate solution of 48 or 58% concentration and the remainder water.

The phosphogypsum raw material used in these tests was screened on a 4-mesh Tyler sieve to remove large, hard lumps prior to metering to the granulator. Other materials (sulfogypsum and limestone) were metered as received to the granulator.

Granular material containing about 5 to 8% moisture and having a particle crushing strength (-7 +8 mesh granules) of about 1 pound discharged from the granulator and was conveyed by a bucket elevator to a rotary drum-type dryer 12 inches in diameter and 36 inches long. The dryer unit was equipped with eight evenly spaced, 2-inch-high lifting flights and with 2-1/2- and 2-1/4-inch-high retainers at the feed and discharge ends, respectively. The dryer was sloped about 1 inch/foot from the feed end to the discharge end and was rotated at about 10 r/min. In operation, the flame from a propane burner and a jet of air equivalent to about 7,000 ft^3/min per ton of product were directed into the feed end of the dryer unit to induce drying. Residence time in dryer was about 8 minutes. Material discharged from the dryer at about 220°F and contained a free moisture content of about 0.1 to 0.3% by weight. In bench-scale operation, heat loss is excessive and a cooler is not normally used; consequently, material discharging from the dryer flowed by gravity directly to the screen deck.

The dryer product was sized on a 5- and 10-mesh screen deck. Granule (-7 +8 mesh) crushing strength of the products ranged from about 4 to 7 pounds.

In conducting the bench-scale tests, no substantial problems were observed in handling or transport of feed or product materials.

TABLE I

Particle-Size Distribution of Feedstock Materials and Granular Products After Simulated 0.5-Inch Rainfall

	Wt % in indicated size range (U.S. Standard Sieve)				
	+20	-20 +40	-40 +100	-100 +325	-325
Feedstock materials					
Gypsum	0.0	0.7	16.6	42.9	39.8
Limestone	21.2	17.8	23.9	15.1	22.0
Granular products					
Gypsum	1.3	1.8	15.6	41.5	39.8
Limestone	21.9	17.6	23.8	15.6	21.1
Gypsum-limestone	1.4	1.0	13.6	44.7	39.3

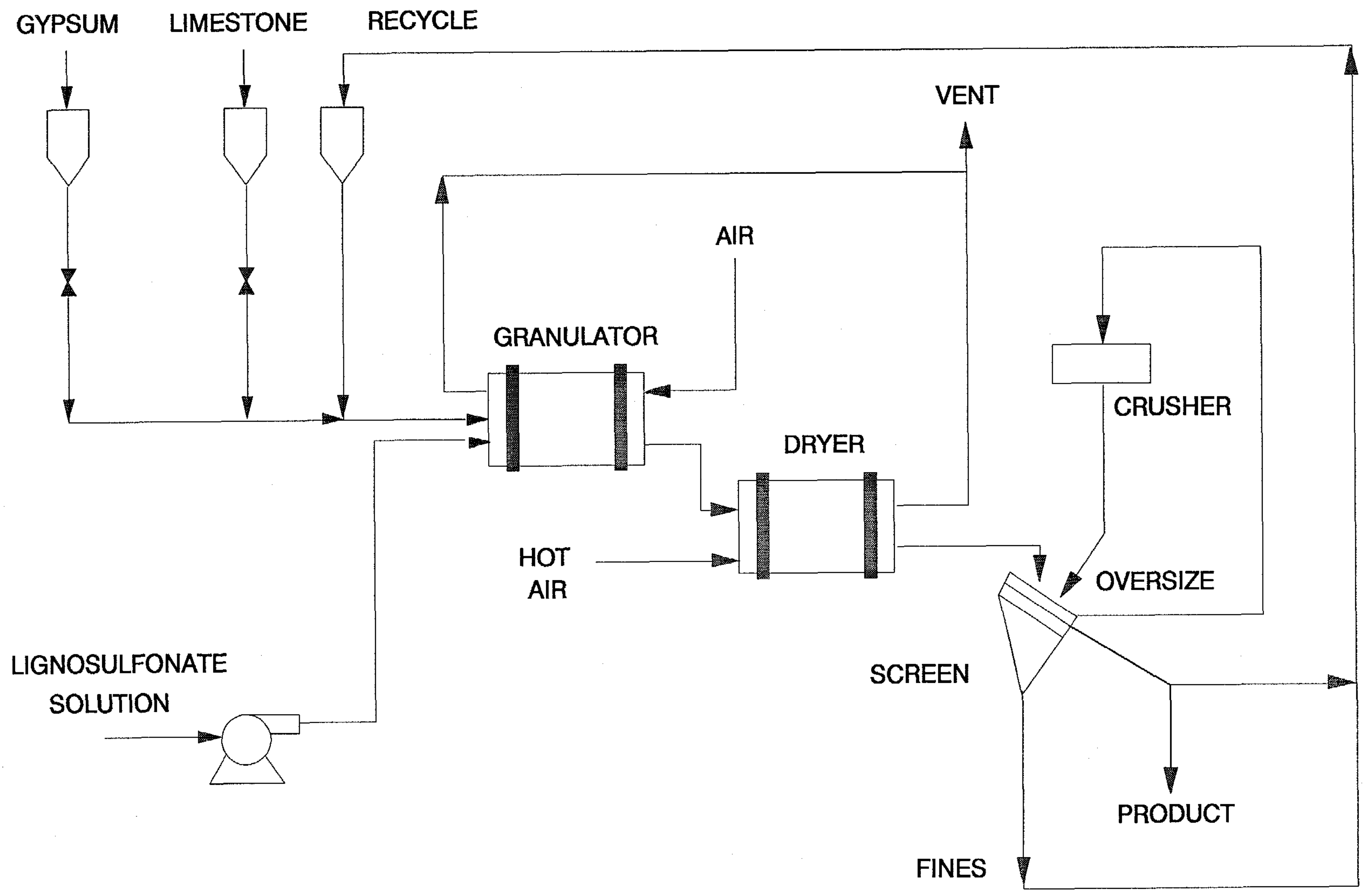


FIGURE 1

Flow Diagram for Gypsum, Limestone, or Gypsum-Limestone Mix Granulation

High-Strength Concrete Utilizing Industrial By-Product

By Lin, K.T., C.I. Lai, N. Ghafoori and W.F. Chang

Synopsis: An industrial by-product aggregate of excellent strength properties has been recently developed during the process of desulfurization of by-product gypsum (a waste material from the phosphate industry) for the production of sulfuric acid. In this study, the aggregate was used to produce high-strength concrete in the laboratory. Strength comparison was made between concretes utilizing as coarse aggregate, respectively, the by-product aggregate and conventional crushed limestone (ASTM C-33 No. 8 aggregate). The fine aggregate used, in both cases, was crushed limestone sand. The objective was to indicate the potential of this aggregate and its superiority to the conventional aggregate.!

The core of this study consists of strength properties of the high-strength concretes, consolidated by vibration at a constant slump of 2 in. (51 mm). Specimens were cured continuously at 100% R.H., and strength as a function of cement content and curing age was studied. Super-plasticizer (ASTM type F admixture) and silica fume of varying dosages were employed with a certain cement content to investigate their effect on increasing the compressive strength. Relationship between the splitting tensile and compressive strength was derived. Moreover, static modulus of elasticity under compression was obtained and correlation between the modulus and compressive strength developed. In addition, the effect of moisture conditions at the time of testing on the compressive strength was studied.

Generally, the high-strength concrete containing the by-product aggregate provides 30 to 40% higher compressive strength and around 20% higher density than the one using conventional limestone aggregate. By using superplasticizer and silica fume, the concrete, with 22.5% type I cement and 55% by-product aggregate, achieved a 28-day strength of over 14,000 psi (96.5 MPa). Preliminary durability study also demonstrated no deterioration of specimens when subjected to continuous soaking in plain water and ocean tidal and complete submergence conditions. This high strength indicates a good prospect that the by-product aggregate might not only give a solution to the phosphate waste problem, but also provide the construction industry with a new quality-aggregate, alleviating the ever escalating problems of good aggregate shortages.

Key words: by-product aggregate, high-strength concrete, modulus of elasticity, silica fume, strength, superplasticizer.

K.T. Lin is a Structural Engineer at Beiswenger, Hoch and Associates, N. Miami Beach, FL.

C.I. Lai received his Ph.D. (Civil Engineering) from the Univ. of Miami, Coral Gables, FL.

N. Ghafoori is an Assistant Professor at the Southern Illinois University, Carbondale, Illinois.

Wen F. Chang is Professor and Director of Phosphate Research Institute, College of Engineering, University of Miami.

INTRODUCTION

As a consequence of accumulation of solid wastes and depletion of natural resources, civil engineers have been urged to “convert” waste materials in general to useful building and construction materials. This approach, if successful, shall not only protect our environment from contamination but also conserve our natural resources.

In the phosphate industry, phosphate ore is processed with sulfuric acid to produce phosphoric acid, which is an important raw material for the production of fertilizers (88%), detergents (6%), and others [1]. World manufacturing consists of approximately 25 million tonnes per year of P_2O_5, and for each tonne of P_2O_5 there is the co-production of about, 5 tonnes of calcium sulfate (by-product gypsum). Currently, only 4% of the by-product gypsum is being utilized by gypsum and cement industries, while the bulk of the production has to be disposed of in an environmentally acceptable manner.

Due to the increasing environmental concern on accumulation of the by-product gypsum and local depletion of concrete aggregates in the state of Florida, a recent joint research by Davy McKee Corporation and Florida Institute of Phosphate Research has been successful in developing a practical process for the thermal decomposition of the by-product gypsum for the production of sulfuric acid and at the same time a high-quality by-product aggregate [2]. The process incorporates a mixture of the by-product gypsum, a solid carbon source, waste phosphatic clays, pyrites and other additives. The by-product aggregate, produced in a form of large sintered slabs, is essentially inert and can be crushed to desirable grading depending on its ultimate uses.

In recent years high-strength concrete (HSC) has gained its popularity from the construction industry. Production of HSC generally requires good quality aggregates. This experimental study, by using the by-product aggregate (BPA) for HSC, is to indicate its potential as quality concrete aggregate. In the experimental work, comparisons are first made between HSC using BPA and HSC using limestone aggregate (LSA), locally available in South Florida, to indicate the advantage of BPA over the conventional aggregate. Some factors affecting the strength of HSC using BPA, such as chemical and mineral admixtures, curing age, and cement content are then investigated. Finally, splitting tensile strength and modulus of elasticity of HSC using BPA are expressed in terms of the compressive strength, and some observations on the durability specimens in a preliminary study are reported.

RESEARCH SIGNIFICANCE

As most industrial by-products are limited to use as “marginal” aggregates, this research demonstrates as an example that conversion of some solid wastes could mean “quality” aggregates. Therefore, a solution to the escalating world-wide wastes problems and alleviation of aggregate shortages problems regionally developed could be achieved at the same time.

PREPARATION OF TEST SPECIMENS

Materials

The materials used were: 3/8 in. (9.5 mm) maximum size crushed BPA and LSA respectively as coarse aggregates, crushed limestone sand with fineness modulus of 2.6, ASTM type I portland cement, condensed silica fume, and a modified napthalene sulfonate superplasticizer (ASTM C494 type F). Table I shows the mineral composition of BPA [2]. Many studies [3,4] on HSC have shown that for optimum compressive strength the maximum size of coarse aggregate should be kept to a minimum, at 1/2 in. (12.7 mm) or 3/8 in. (9.5 mm). The latter was adopted in this study. Figure 1 shows the gradation of the coarse and fine aggregates, the water absorption and specific gravity of which are listed in Table II.

Casting curing and testing of specimens

Unless otherwise noted, all concrete mixes in this study had, by weight on a dry basis, 55% coarse aggregate, 22.5% cementitious material (i.e. cement or cement plus silica fume), and 22.5% sand. The superplasticizer (SP) content was varied from 0 to 2.1%, and silica fume (SF) of different dosages (0-18%), was used to replace cement, both in percentages of original cement weight. During the mixing, the air dry coarse and fine aggregates were first mixed with most of the mixing water for a period of 5 min., to let the aggregates absorb water during this period before mixing with cement. All the aggregates absorb water at about 80% of their 24-hour absorption capacity in 5 min., as can be computed from data shown in Table II. Afterwards, cement and admixtures (when used) were added in order and finally the adjusting mixing water was added to provide a constant slump of approximately 2 in. (51 mm).

High frequency external vibration was used to consolidate the concrete specimens, 3 in. (76mm) in diameter by 6 in. (152mm) in height. Curing was provided by 100% relative humidity and a temperature around 77 F (25 C) until testing. Before testing, the specimen testing surfaces were first smoothed using a masonry cutter to reduce irregularities. Test specimens were then capped using concrete capping compound whose compression strength, based on 2 in. (51 mm) cube, increases from 5,000 psi (34.5 MPa) at 1 hr. to 10,000 psi (68.9MPa) at 2 days. For 1- and 3-day strength, specimens were capped 1 hr. before the test and 2 days before the test for 7-, 28-, and 90-day strength. Except as otherwise noted, specimens were tested within 1 hr. after removal from the curing environment. Each representative strength value is the average of three tests.

TEST RESULTS

HSC using BPA and LSA respectively

Table III tabulates the compressive strength of all the concrete mixes tested in this program. Based on these values, a strength comparison is made between HSC using BPA and HSC using LSA, each with a cement content of 22.5%, as shown in Figures 2 & 3. In Figure 2, the 7- and 28-day compressive strengths are compared, with respect to 3 superplasticizer (SP) content : 0, 1.2, and 2.1% by weight of cement,. In this figure, the 28-day strength of the HSC using LSA without SP (0%) is expressed as unity, while all other strengths are expressed as ratios to that strength. As observable, the HSC (22.5% cement) using BPA generally provides 30-40% higher compressive strength than its counterpart for different SP contents. It is noted, even the 7-day strength of the HSC using BPA is 12 to 17% higher than the 28-day strength of the HSC using LSA. In Figure 3 a similar comparison is made for concretes with a fixed SP content of 1.2% and varying silica fume (SF) content of 0, 6, 12, and 18% by original weight of cement. For each case the cement plus SF content was kept constant at 22.5%, with SF replacing the indicated percentage of cement. Again, similar strength differences are observed. Thus, it is shown that BPA has a clear strength advantage over LSA for HSC.

One of the reasons explaining the strength advantage of BPA is that HSC using BPA requires lower water/cementitious (w/c) ratios than HSC using LSA. In this experimental work, the w/c ratio is defined as the weight of free water plus the weight of the superplasticizer (if used) plus the water in condensed silica fume (when used), divided by the weight of cement plus silica fume. The free water is meant by the total water in the mix minus the amount of water absorbed by both the coarse and fine aggregates having a saturated surface dry (SSD) condition. Table IV shows the w/c ratios for HSC series containing BPA and LSA, respectively, having a constant slump of approximately 2 in. (51mm). HSC using BPA requires w/c ratios 0.02 to 0.06 lower than its counterpart, as can be calculated from data shown in Table IV.

HSC using BPA has a 28-day dry density of around 163 pcf (2,612 Kg/m^3), about 20% higher than that of HSC using LSA (135 pcf = 2,163 Kg/m^3). Thus BPA has also the potential as aggregate for heavyweight concrete or shielding concrete.

Effect of superplasticizer and silica fume

The superplasticizer was added to study its effect on reducing w/c ratio and thereby strength increase of HSC using BPA. With reference to Table IV, as SP content of 1.2% and 2.1% respectively is used in the mix the corresponding drop of w/c ratio is 0.08 and 0.15, which compare well with those of HSC using LSA also shown in the table. As a result of the drop of w/c ratio, the strength increases greatly as can be seen in Figure 4. In this figure, the compressive strength is compared at specimen ages of 1, 3, 7, 28, and 90 days for the varying SP content, setting the strength as unity when no SP is included in the concrete. The strength enhancement is maximum at 7 and 28 days, which is above 30% with 1.2% SP content and 44% with 2.1% SP content. Though comparatively lower, use of SP still has a strong effect on increasing the strength at other days. As shown in Table III, 28-day strength above 13,000 psi (89.6 MPa) and 90-day strength above 14,000 psi (96.5 MPa) can be achieved for HSC using BPA with 22.5% cement and 2.1% SP.

The effect of another concrete admixture, silica fume (SF), which is getting more popular in HSC technology, was also investigated. Recent reports [5,6] have indicated that SF contents of 5-15% appears optimum for strength development of HSC. Due to the extreme fineness of SF, it is almost always used along with SP to maintain a suitable low w/c ratio, so that its contribution is not offset completely by the higher w/c ratio usually required by the use of SF. In this research, a constant SP content of 1.2% was added in the mixes while the SF dosages as percentage of cement replacement varied.. Plotted in Figure 5 is its effect on the compressive strength of HSC using BPA at different ages. It is seen the effect of SF varies slightly at different ages. At 7 days, 6% of SF appears adequate. At 28 and 90 days, 12% seems the optimum. Considering strength efficiency--strength increase vs SF replacement, however, addition of 6% SF is most effective. In general, use of SF replacing 6-18% of cement increases the compressive strength by 9-20%.

Effect of curing

As with normal strength concrete, the strength of HSC increases with curing age. Figure 6 presents the effect of curing, on the compressive strength of HSC using BPA. In this figure, the relative strength ratios at specimen ages of from 1 to 90 days, designating the 28-day strength as unity, are presented for three SP dosages. For all the three cases, it is seen that the strength increases continuously with the curing age. Like HSC using conventional aggregates, the HSC has high early to 28-day strength ratios as compared to normal strength concretes. As far as the strength ratio is concerned, use of SP produces lower strength ratios at 1, 3, and 90 days than when no SP is used, indicating that the strength gain as percentage of 28-day strength at very early or late days is lower when SP is used in the mixture. Nevertheless, the absolute strength values at any curing age increase with the SP content (up to 2.1%), as can be observed from the data tabulated in Table III.

A similar presentation is shown in Figure 7, where a fixed SP content of 1.2% and varying SF contents are used in the mixes. Again, high 7- to 28-day and low 90- to 28-day strength ratios are observed, compared to those of normal strength concretes using pozzolans. The high 7- to 28-day strength ratio can be attributed to the fineness of silica fume, which greatly accelerates the pozzolanic reaction. As the curing goes on; however, the extremely low permeability, associated with the use of silica fume and high cement content, plus subsequent self-desiccation of the specimens makes the curing much less effective, leading to a low 90- to 28-day strength ratio.

Cement factor

Increasing cement content and reducing water/cement ratio is one of the important keys to achieving high strength. For any given set of materials in a concrete mix, there may be an optimum cement content that produces maximum concrete strength. Figure 8 demonstrates the effect of cement percentage on the 28-day compressive strength of HSC using BPA without any chemical or mineral admixture. Strength was tested under two conditions--air-dry (7-day under lab conditions) and wet (immediately after removal from the moist room)--to also investigate the effect of testing conditions. As observed, the strength increases with cement content continuously of up to 32.5%. However, the increase is most from 17.5% to 22.5% of cement content, after 22.5% the strength efficiency--strength increase vs cement increase-- drops drastically. In a practical way, the optimum cement can be chosen as 22.5%, which has the highest strength efficiency. It should be noted at this cement content, 10,000 psi (68.9 MPa) strength can be achieved at 28 days without any admixtures. Also, as the curves in Figure 8 indicate, air-dry specimens produce higher compressive strength than wet ones; the difference becomes smaller, however, as the cement content increases.

Similar to the compressive strength, the splitting tensile strength also increases with the cement content, as shown in Figure 9. As the figure indicates, the strength efficiency is more uniform for tensile strength than for compressive strength.

Relationship between tensile and compressive strength

Figure 10 plots the relationship between the splitting tensile strength and the compressive strength of HSC using BPA having compressive strength of from 9,000 psi (62.0 MPa) to 14,000 psi (96.5 MPa) at 28 days. A regression analysis based on these data indicates the following equation for the prediction of the splitting tensile strength :

$$f_t' = 7.5 \sqrt{f_c'} \text{ psi},$$

$$\text{for } 9{,}000 \text{ psi } (62.0 \text{ MPa}) < f_c' < 14{,}000 \text{ psi } (96.5 \text{ MPa})$$

The equation compares well with results from other researchers using other aggregates [7].

Modulus of elasticity vs. compressive strength

ACI 318, section 8.5 expresses the modulus of elasticity for normal-strength concrete as $E_C = 33\, w^{3/2}\sqrt{f_c'}$. A comparison of experimental data in this investigation with the ACI expression indicates that the equation does not apply to HSC using BPA. Generally the ACI equation overestimates the modulus of elasticity for HSC [8]. Figure 11 plots the modulus of elasticity of HSC using BPA corresponding to the 28-day compressive strength ranging from 9,000 (62.0 MPa) to 14,000 psi (96.5 MPa). A least-square linear regression analysis generates the following equation for the prediction of the modulus for HSC using BPA.

$$E_c = (80{,}800\sqrt{f_c'} - 3.7 \times 10^6) \times (W/145)^{3/2} \text{psi}$$

$$\text{for } 9{,}000 \text{ psi } (62.0 \text{ MPa}) < f_c' < 14{,}000 \text{ psi } (96.5 \text{ MPa})$$

This equation is similar in format to that proposed by Martinez, et al. [8].

Durability of specimens

Preliminary study on the durability of HSC using BPA includes the following, based on a limited number of specimens

(1) Complete submersion of specimen in sea water and plain water
(2) Specimen subjected to sea tidal conditions
(3) Expansion measurement on 2 x 2 x 11 in. specimens soaked continuously in plain water

Observation on specimens under conditions (1) and (2) after a period of 9 months indicated no deterioration of the specimens nor strength decrease. Little expansion was observed, less than 0.002% in 4 months, for specimens under condition (3).

CONCLUSIONS

Experimental data presented in this study leads to the following conclusions:

1. The by-product aggragate shows good promise for use as aggregate for high-strength concrete. The HSC using the by-product aggregate indicates 30 to 40% higher compressive strength than HSC using the conventional limestone aggregate, locally available in South Florida.

2. The strength of HSC using the by-product aggregate can be further increased by using superplasticizer and silica fume. Using 22.5% cement and 2.1% superplasticizer by weight of cement, a compressive strength of 14,000 psi (96.5 MPa) can be achieved at 28 days.

3. For relationship between tensile and compressive strength and relationship between modulus of elasticity and compressive strength, HSC using BPA shows similar results to HSC using conventional aggregates.

4. Preliminary study suggests no durability problems associated with the use of BPA in concrete mix. A long-term, detailed investigation is necessary for further conclusions.

ACKNOWLEDGMENTS

This research was made possible by a grant from the Florida Institute of Phosphate Research, Bartow, Florida, to the University of Miami, College of Engineering, Coral Gables, Florida. The material supply of the by-product aggregate from the institute is also acknowledged.

REFERENCES

1. WIRSCHING, F., "Ruckstande Aus Der Phosphorsaure-produktion", Mull-und Abfallbeseitigung, 67.Lieferung, September 1982, Kennzahl 8581, (English translation of a section of Mull-und Abfallbeseitigung entitled "Residues From Phosphoric Acid Production," by F. Wirsching).

2. Kendron, T.J., and Lloyd, G.M., "Phosphogypsum to Sulfuric Acid with Cogeneration -- A Competitive Edge," Proceedings of the Second International Symposium on Phosphogypsum, Miami, Florida, 1988.

3. Walker, S., and Bloem, D.L., "Effects of Aggregate Size on Properties of Concrete," ACI Journal, Proceedings V. 57, No. 3, Sept. 1960, pp. 283-298.

4. Cordon, W.A., and Gillespie, H. A., "Variables in Concrete Aggregates and portland Cement Paste Which Influence the Strength of Concrete," ACI Journal, Proceedings V. 60, No. 8, Aug. 1963, pp. 1029-1052.

5. Yogenran, V., et al., "Silica Fume in High-Strength Concrete," ACI Journal, Jan.-Feb. 1988, pp. 124-129.

6. Carette, G.G., and Malhotra, V.M., "Silica Fume in Concrete--Prelimary Investigation," CANMET Report No. 82-1E, CANMEN, Energy, Mines and Resources, Ottawa, Feb. 1982, 15 pp.

7. Carrasquillo, R.L., et al., "Properties of High Strength Concrete Subjected to Short-Term Loads," ACI Journal, Proceedings V. 78, No. 3, May-June 1981, pp. 171-178, and Discussion, Proceedings V. 79, No.2, Mar.-Apr. 1982, pp. 162-163.

8. Martinez, S., et al., "Spirally Reinforced High-Strength Concrete Columns," Research Report No. 82-10, Department of Structural Engineering, Cornell University, Ithaca, Aug. 1982.

TABLE I: Mineral Composition of By-Product Aggregate

Major Phases: > 20%		
Melilite Group	Feldspathoid	$Ca_2Al(Al,Si)O_7$
Lime	Oxide	CaO
ematite/Magnetite	Oxide	Fe_2O_3/Fe_3O_4
Minor Phases: < 20%		
Fayalite (Calcian)	Olivene	$Fe_2^{2+}Si_4$
Orthoferrosilite	Pyroxene	$Fe_2^{2+}Si_2O_6$
Anhydrite	Sulfate	$CaSO_4$
Ellestadite	Sulfo-apatite	$Ca_5(Si,P,SO_4)_3(F,OH,Cl)$

TABLE II: Water Absorption and Specific Gravity of Aggregates

Aggregate Type	Water Absorption		Specific Gravity
	5 min. Soaking	24 hr. Soaking	
BPA	0.7%	0.9%	3.53
LSA	3.2%	3.8%	2.60
Sand	3.4%	3.8%	2.70

TABLE III: Compressive Strength Values

Aggregate Type	Mix Proportion C:SP:SF, %	Compressive Strength, psi				
		1-day	3-day	7-day	28-day	90-day
By-product aggregate	17.5: 0 : 0	-	-	-	4626	-
	27.5: 0 : 0	-	-	-	9856	-
	32.5: 0 : 0	-	-	-	10295	-
	22.5: 0 : 0	3575	5324	7510	9188	10968
	22.5:.27: 0	3971	5885	10329	11957	12466
	22.5:.47: 0	4232	6782	11334	13235	14123
	21.15:.27:1.35	-	-	11870	13753	13964
	19.8 :.27:2.7	-	-	11777	14298	14366
	18.45:.27:4.05	-	-	11263	14295	14177
Limestone aggregate	22.5 : 0 : 0	-	-	5354	6708	7823
	22.5 :.27: 0	-	-	7802	8832	9189
	22.5 :.47: 0	-	-	8317	9436	9450
	21.15:.27:1.35	-	-	8185	9968	9223
	19.8 :.27:2.7	-	-	8649	9977	9931
	18.45:.27:4.05	-	-	8524	9958	9434

Note: 1000 psi=6.89 MPa

TABLE IV: Water/Cement Ratio

Aggregate Type	Mix Proportion C:SP:SF	w/c	Δw/c
By-product aggregate	22.5: 0: 0	0.43	0
	22.5:.27:0	0.35	-.08
	22.5:.47:0	0.28	-.15
	22.5 :.27:0	0.35	0
	21.15:.27:1.35	0.33	-.02
	19.8 :.27:2.7	0.34	-.01
	18.45:.27:4.05	0.36	.01
	17.5 : 0: 0	0.60	.17
	22.5 : 0: 0	0.43	0
	27.5 : 0: 0	0.42	-.01
	32.5 : 0: 0	0.38	-.05
Limestone aggregate	22.5 : 0: 0	0.49	0
	22.5 :.27: 0	0.40	-.09
	22.5 :.47: 0	0.30	-.19
	22.5 :.27: 0	0.40	0
	21.15:.27:1.35	0.39	-.01
	19.9 :.27:2.7	0.40	0
	18.45:.27:4.05	0.43	.03

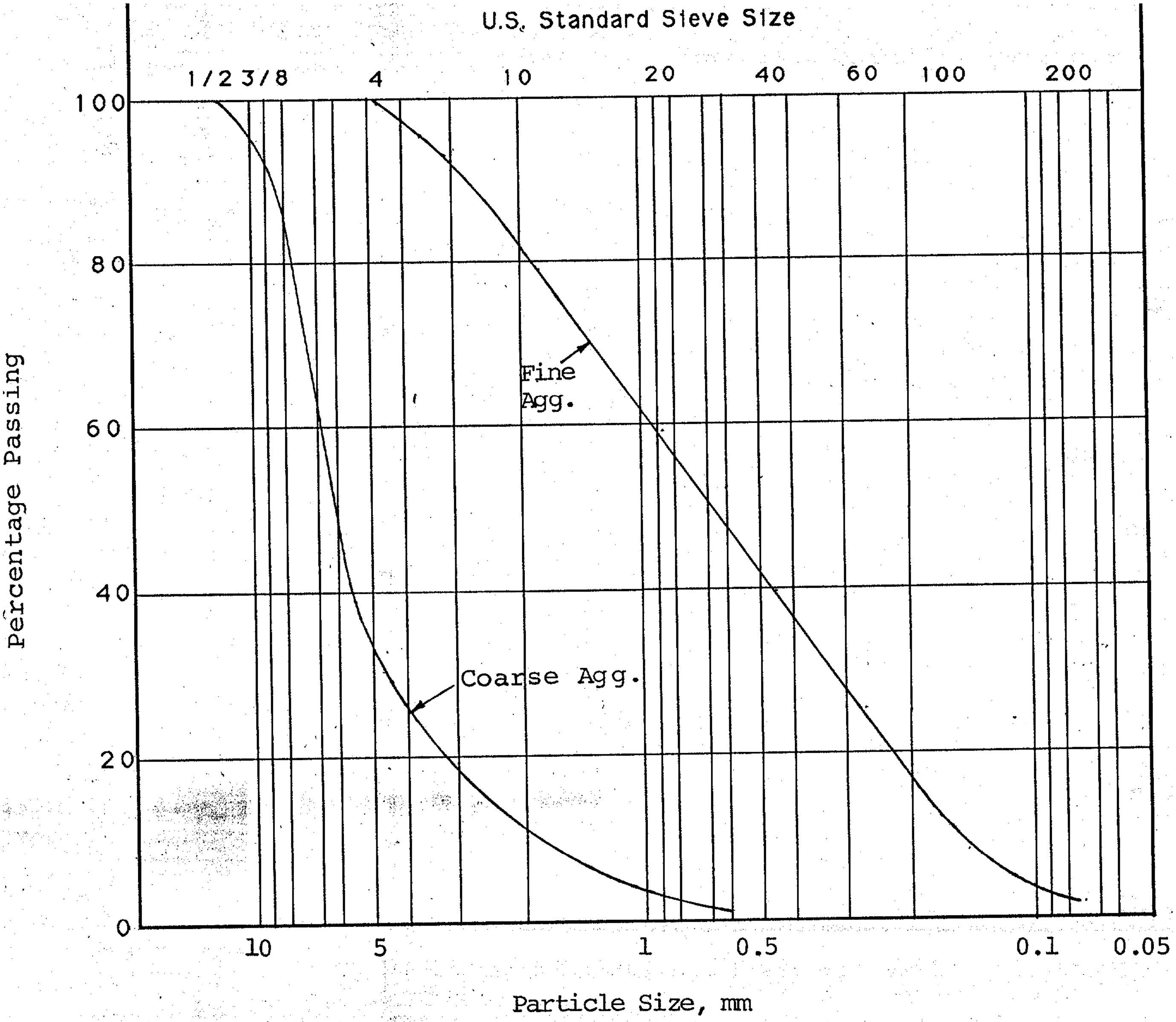


Fig.1 --Gradation of the coarse and fine aggregates

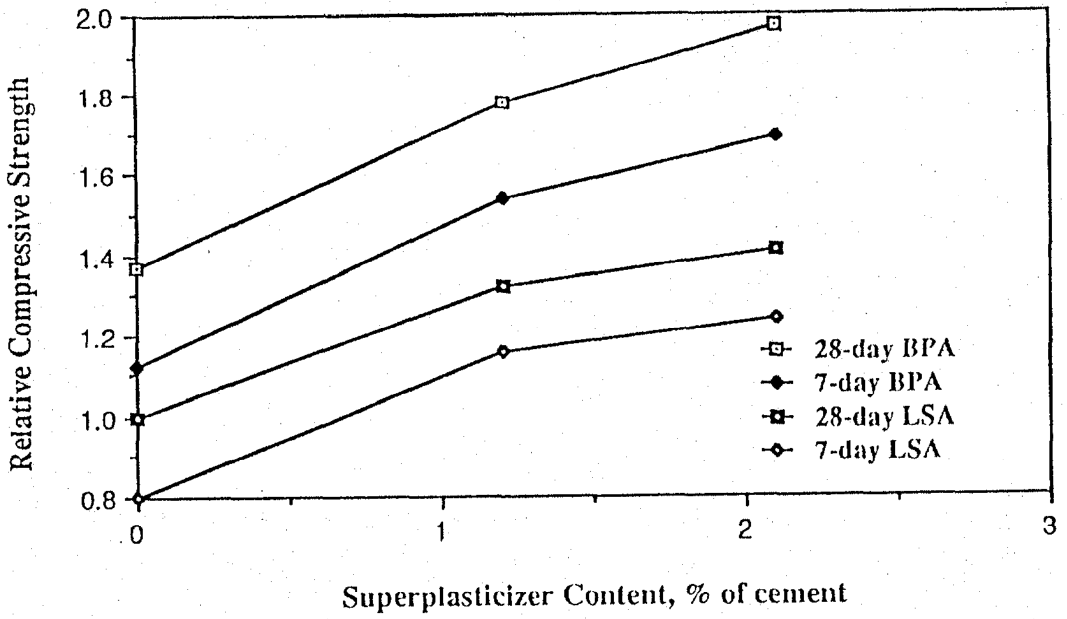


Fig. 2 -- Strength comparison between HSC using BPA (by-product aggregate) and HSC using LSA (limestone aggregate) with respect to superplasticizer content

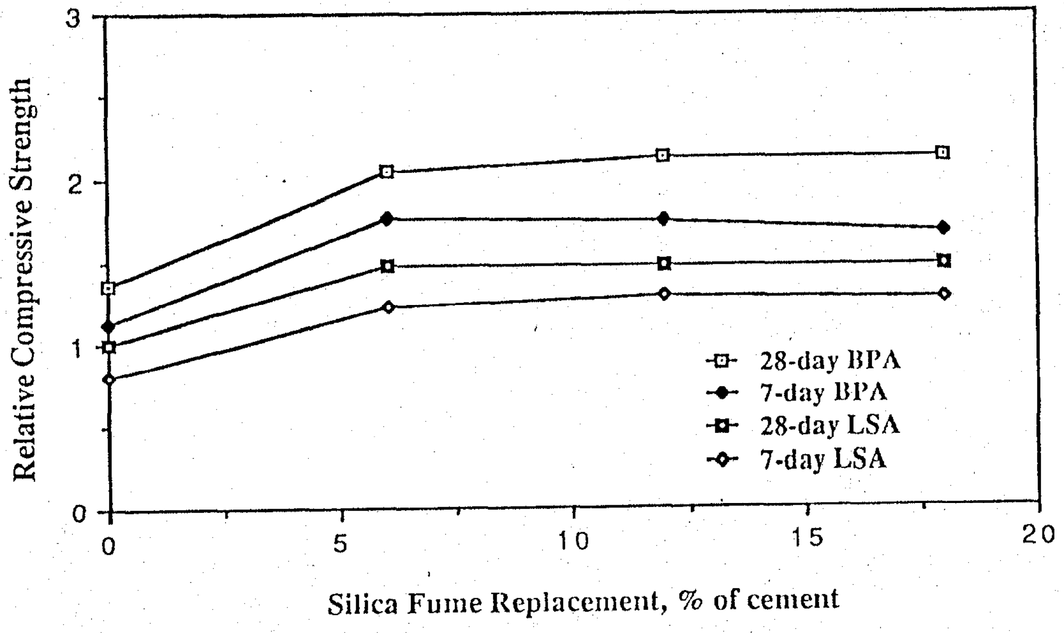


Fig. 3 -- Strength comparison between HSC using BPA (by-product aggregate) and HSC using LSA (limestone aggregate with respect to silica fume content

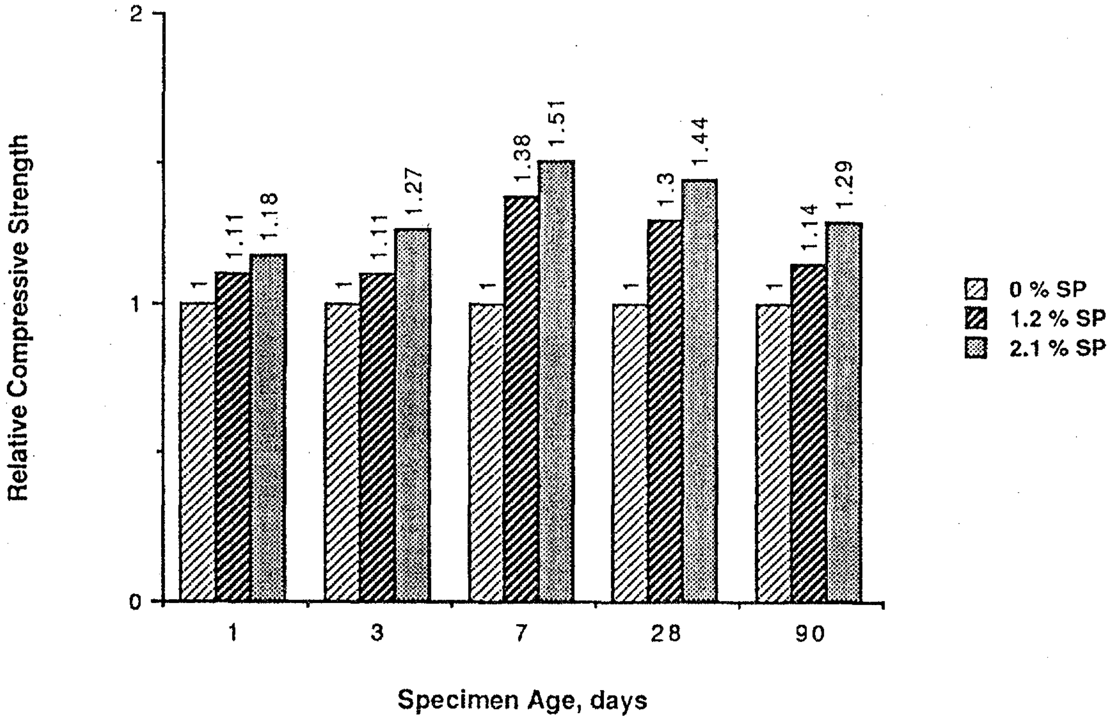


Fig. 4 --Effect of superplasticizer (SP) content on compressive strength of HSC using BPA at different ages

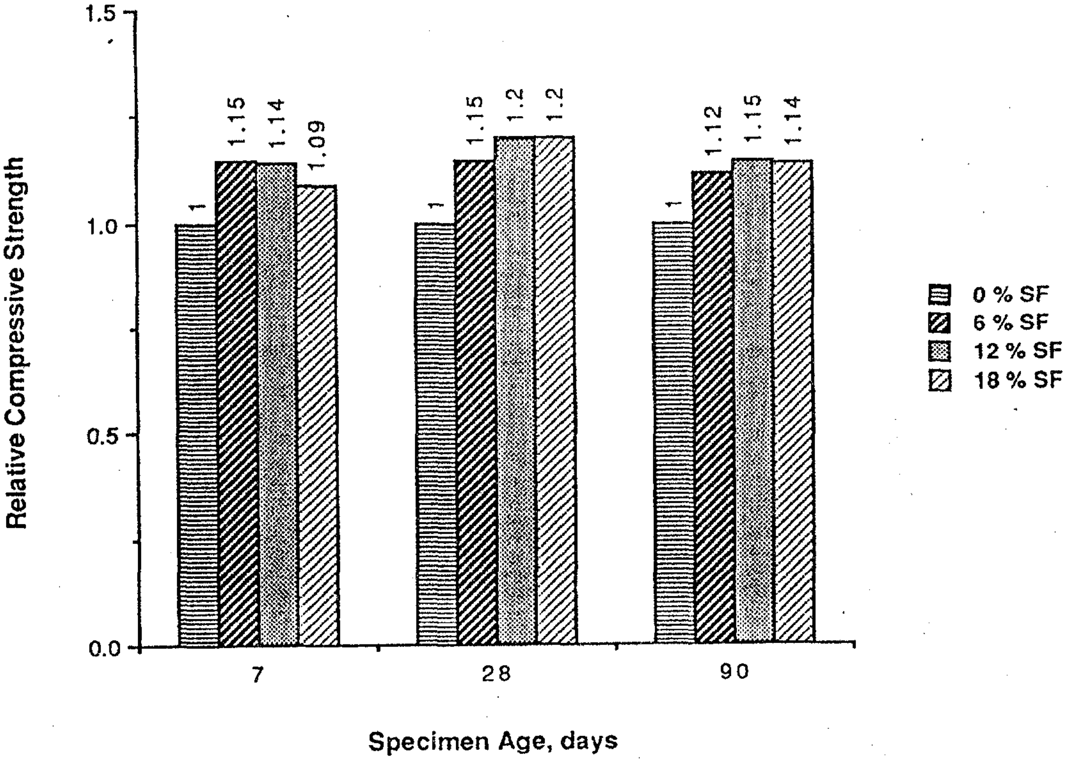


Fig. 5 -- Effect of silica fume (SF) content on compressive strength of HSC using BPA

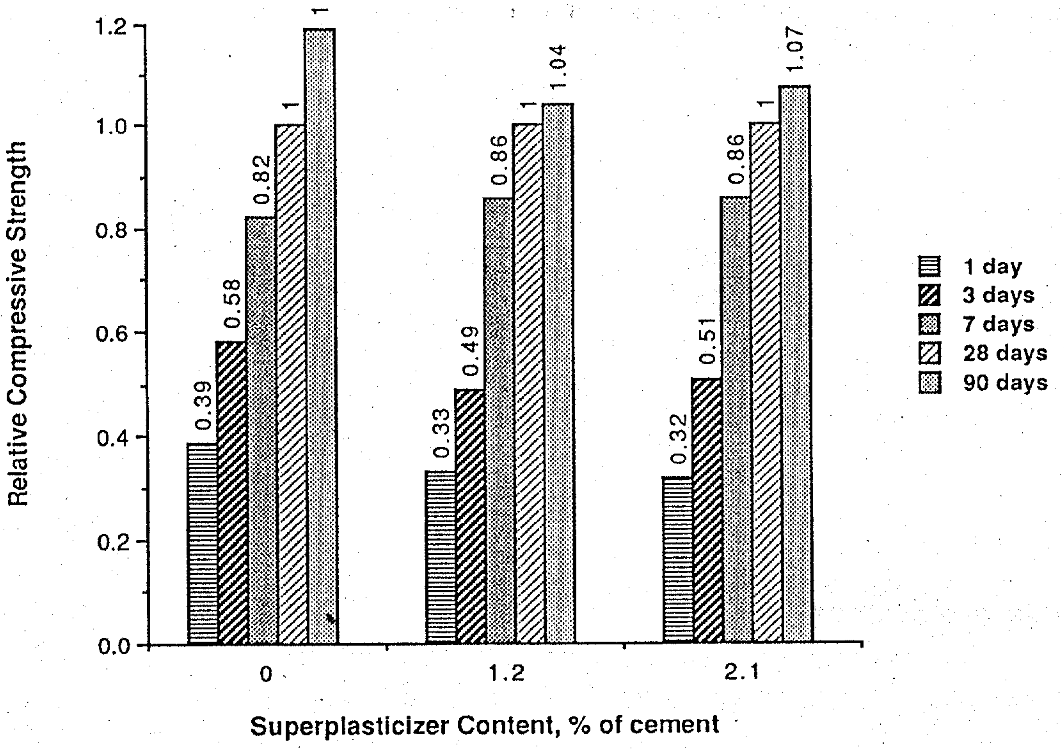


Fig. 6 --Effect of curing age on compressive strength of HSC using BPA at three superplasticizer content

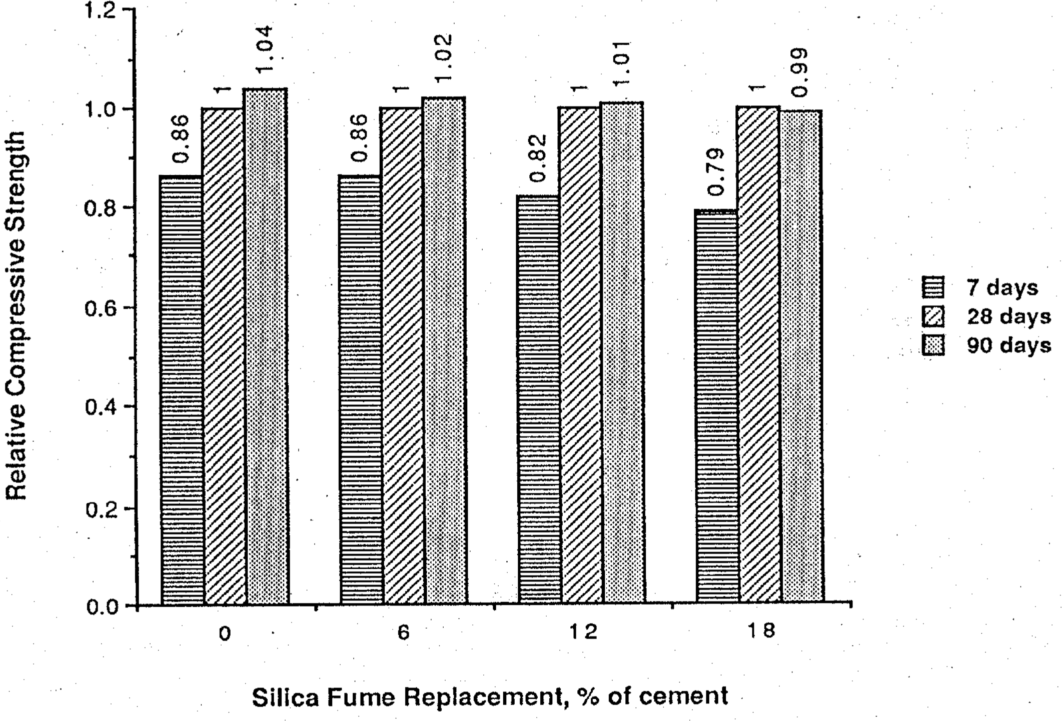


Fig. 7 --Effect of curing age on compressive strength of HSC using BPAat four silica fume content

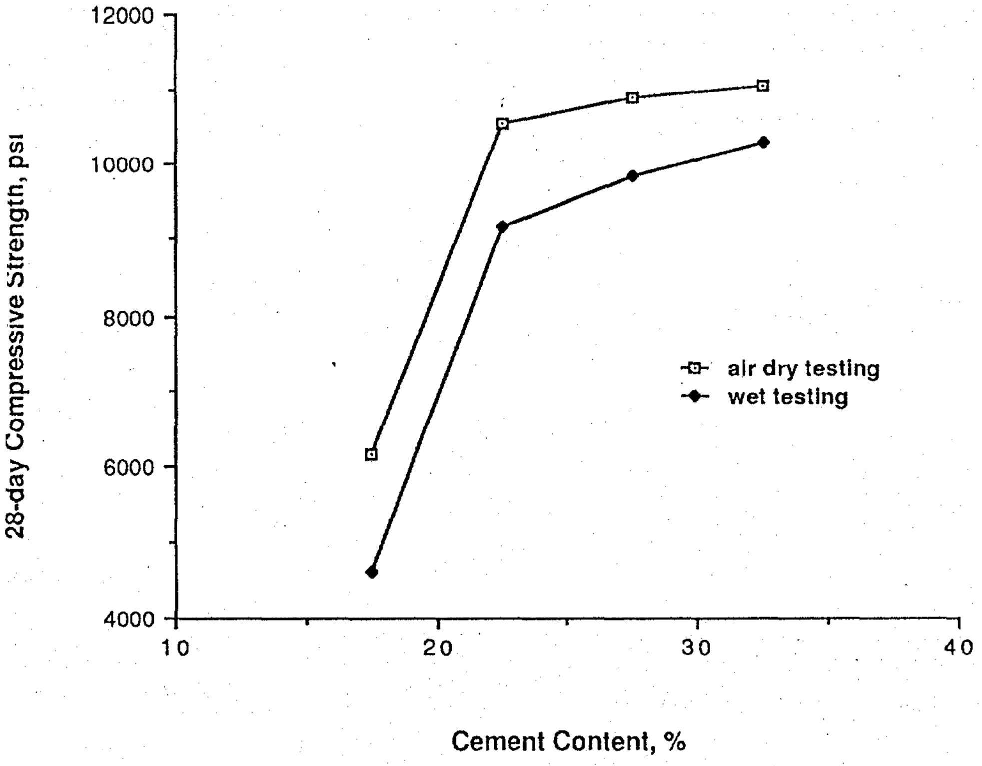


Fig. 8 -- Effect of cement content on compressive strength of HSC using BPA under two testing conditions (1000 psi=6.89 MPa)

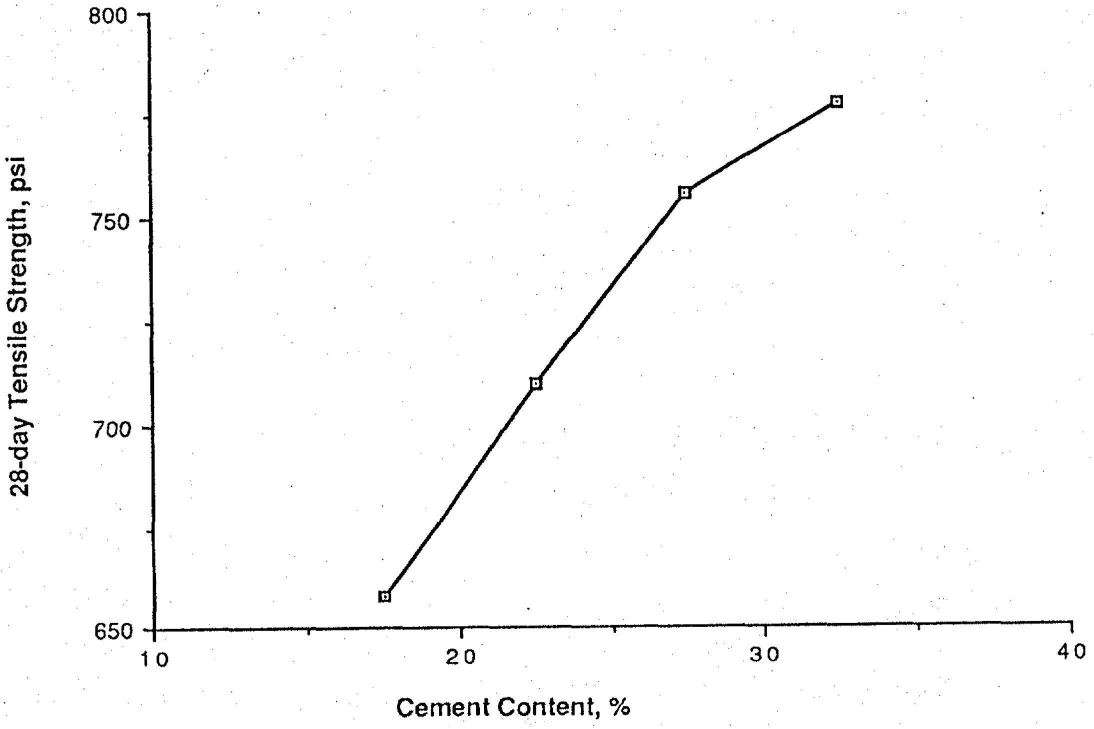


Fig. 9 --Effect of cement content on tensile strength of HSC using BPA (1000 psi=6.89 MPa)

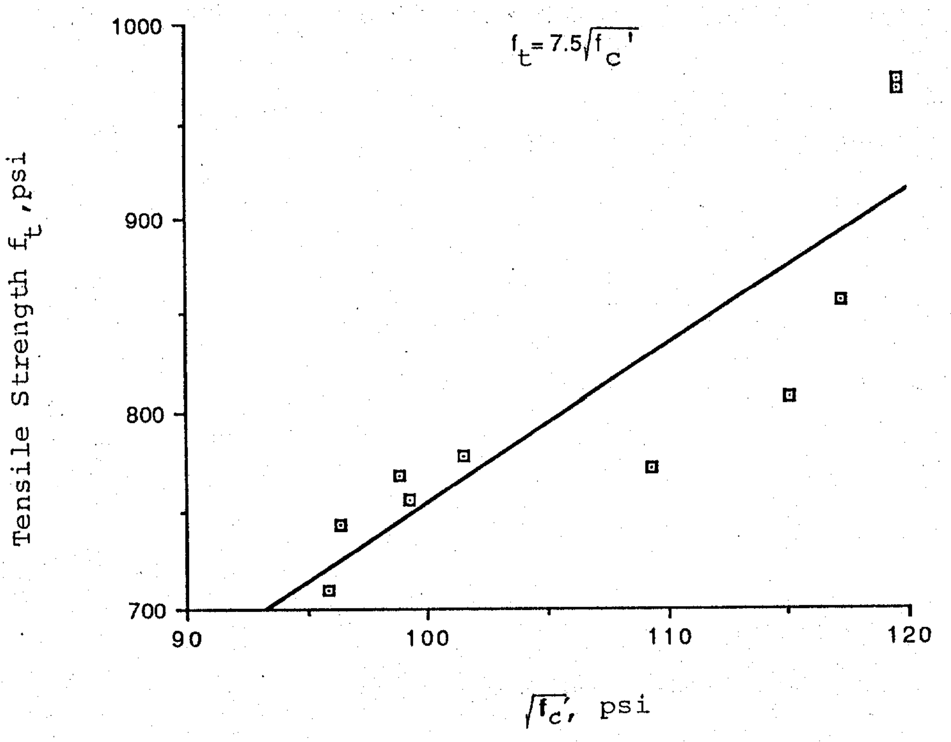


Fig. 10 -- Relationship between splitting tensile strength and compressive strength of HSC using BPA (1000 psi=6.89 MPa)

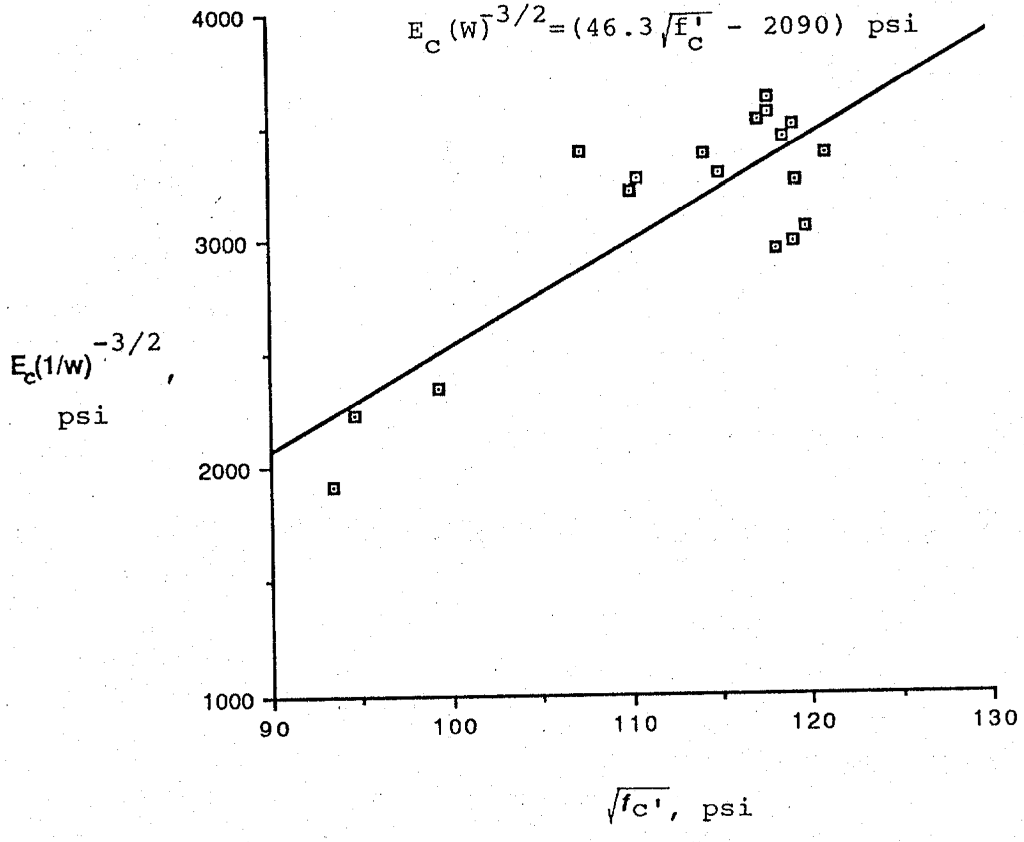


Fig. 11 --Relationship between modulus of elasticity and compressive strength of HSC using BPA (1000 psi=6.89 MPa)

HIGH STRENGTH BRICKS UTILIZING PHOSPHOGYPSUM

Bijan H. Ahmadi[1] and Wen F. Chang[2]

1. ABSTRACT

A new research aimed at producing high strength masonry bricks is introduced in this paper. This research features the utilization of a by-product of the phosphate industry, phosphogypsum, in combination with Portland Cement and sand (crushed lime stone) by the use of high-pressure static compaction. Bricks dimensioning 203x95x51 mm (8x3.75x2 in.) are manufactured merely by the use of a bench model brick press developed especially for this project, applying a pressure of 83 MPa (12,000 psi).

The experimental study consists of determining the fundamental characteristics of individual brick units such as compressive strength, modulus of rupture, density, water absorption, and abrasion resistance of different mixes of phosphogypsum, sand, and Portland Cement with various mixing water content. In addition to the mix proportions, the mixing water content plays an important role in affecting the physical properties. The final result of all the above tests shall provide engineering design charts; enabling the designer to choose the right mix for a specified purpose.

2. INTRODUCTION

Phosphogypsum is a by-product of the phosphoric acid industry. Phosphate rock is used to produce fertilizers which assist farmers. in providing food for the world, and in live stock feed supplements. Small portions of phosphoric acid are used in myriad of consumer products such as films, light bulbs, cleaning products, vitamins, bone china, soft drinks and others [l].

---

[1] P.E., Asst. Professor of Civil & Architectural Engineering, University of Bahrain. State of Bahrain.

[2] P.E., Professor and Director of Phosphate Research Institute, University of Miami, Coral Gables, FL. U.S.A.

Associated with the manufacture of phosphoric acid there is the production of phosphogypsum. Because of potential environmental, aesthetic appearance and economical factors, it is desirable to find a better solution than simple land or sea disposal.

The world wide production of phosphogypsum is approximately 120 million tonnes per year [1]. The typical composition of raw phosphogypsum is shown in Table 1:

Table 1: Typical Composition of Phosphogypsum [3]

Gypsum($CaSo_4/H_2o$)	%	85-93
P_2O_5	%	0.2-1.7
F	%	0.4-1.3
SiO_2	%	1.4-8.4
Soluble salts	%	0.1-5.3
PH		3.1-5.3
radium 226	pci/g	15-29

Application of high pressure compaction results in a molecular modification of the calcium sulfate particles binding into a rock-like body [2]. Increased pressure leads to increase strength properties of phosphogypsum [3]. Since 85 to 93 percent of phosphogypsum consists of calcium sulfate, test results [4] have shown that any industrial waste which contains similar or higher amounts of gypsum could be used for producing similar bricks.

3-MATERIALS

The following materials were used to produce the bricks:
- a) 60% and 40% Phosphogypsum.
- b) Sand (crushed limestone).
- c) Two to eight percent Portland Cement type I.
- d) Initial mixing water, 2 , 4, and 6 percent.

4-FABRICATION

All bricks were made on a bench model, semiautomatic press having a capacity of 1779.2 KN (400 kips) to produce bricks of 51x95x203 mm (1.75x3.75x8 in.) in size under a static compaction of 82.7 MPa (12,000 psi).

The following operations were performed for the production of one brick.

a) The material at the preset moisture content is fed into the mold.
b) The loose material fully occupies the space available in the mold. At this point a horizontal door forwards and trims the top surface and provide confinement to the upper side of the mold.
c) The ram is raised to compact the material in the mold (one cycle at predetermined maximum pressure) and immediately after, is slightly dropped to release any pressure from the confined material.
d) The horizontal door continues its forward motion to free the top surface of the newly formed brick while maintaining the supply of material shut. At this point the ram fully extends to extrude the brick.
e) The horizontal door slides then backwards to push and to resume the material feeding. The ram returns to its lower position.

5- CHARACTERISTICS AND BEHAVIOR OF THE BRICKS

Compressive strength, flexural strength, density, water absorption, abrasion resistance of bricks from different mixes of phosphogypsum, sand, and Portland Cement type I with various mixing water content were determined. Once the characteristics and behavior of the bricks were determined, the behavior of prisms constructed with several joint materials other than conventional cement mortar, could be studied for flexural, shear, and compressive strength.

5.1- Compressive Strength

Compressive strength of the units were determined according to ASTM C 67. Test bricks consist of a half brick with full height and width. Test results are presented in Figure 1 for bricks made of 60 percent phosphogypsum, two to eight percent Portland Cement type I, two to six percent initial moisture content and the rest sand. This figures shows the fact that compressive strength changes considerably as the initial moisture content and cement content vary. As shown in Figure 1 maximum compressive strength is reached when initial moisture content is between two and six percent depending on the cement content. Bricks produced with more than six percent initial moisture content showed cracks after fabrication due to excessive water. It can be observed that compressive strength of as high as 38.0 MPa (5500 psi) can be achieved by using a minimal four percent cement. Compressive strength for bricks submerged in water also has been improved by adding a minimal amount of portland cement and sand compared to the results obtained for only phosphogypsum mixes [4](Fig. 2).

5.2- Flexural Strength

For each different mix of phosphogypsum, sand, Portland Cement, and initial moisture content (same as in compressive strength tests), three flexural tests were performed according to ASTM C 67. Similar to compressive strength, the initial moisture content and cement content directly influence flexural strength. As shown in Figure 3, maximum flexural strength is reached when initial moisture content is between two and six percent depending on cement content. Flexural strength of bricks submerged in water also has been improved by adding a minimal amount of Portland Cement and sand. (Pig. 4).

5.3- Dry Density

Dry density remains approximately constant between 18.9 to 19.9 N/cu.m (121 to 127 pcf) for the bricks produced under 82.7 MPa (12,000 psi) static compaction when changing initial moisture content or cement content. Previous results [4] have shown the same characteristics for 100% phosphogypsum

5.4- Water Absorption

Water absorption tests were performed according to ASTM C 67 with half bricks submerged in water at 24 C (75 F) for 24 hours and also for submergence in boiling water for additional one hour. The test results in Table 2 show that as the cement content increases the water absorption decreases. Water absorption for seven days submergence is shown in Figure 9. Water absorption of the bricks is largely affected by the initial moisture content; as the initial moisture content increases the water absorption decreases as shown in Figure 5.

Table 3: Water Absorption
(60% phosphogypsum, sand, cement, and 4% initial water)

Cement content %	Water Absorp.after 24hr cold water	Water Absorp. after 24hr cold water + lhr boiling
2	7.4	7.6
4	7.0	7.4
6	6.4	7.3
8	6.0	7.2

5.5- Abrasion Resistance

In order to determine the abrasion resistance of by-product gypsum bricks, the standard test method for abrasion resistance of horizontal concrete surfaces ASTM C 779 was adopted. Test specimens were taken as a half a brick. Figure 6 shows time vs. depth of abrasion. It can be seen that as the cement content increases the abrasion resistance increases as well.

6- CONCLUSION

The results confirmed that phosphogypsum-based bricks produced under high static compaction pressure, possess not only a valuable compressive and flexural strength but a good appearance and tolerance. The influential elements affecting. the compressive, flexural strength, and water absorption of the units was found to be the initial mixing water content. The compressive, flexural strength of the bricks under soaked condition can easily be improved by adding a nominal two to four percent Portland Cement. Water absorption of phosphogypsum-based bricks, which is an important property, was found to be below the limits set by different building codes.

7- ACKNOWLEDGEMENT

The authors wish to thank the Florida Institute of Phosphate Research and the University of Bahrain for providing the financial support to the project.

8- REFERENCES

1. "Phosphate Fact sheet-1985", Florida Phosphate Council., Tallahassee, FL, 1986.
2. Wirching, F., "Drying and Agglomeration of Flue Gas Gypsum", Proceedings of the Symposium on the Technology of Gypsum and Gypsum Products, Kuntze, R. A., Editor, ASTM STP 861, Sept. 1984, pp160-172.
3. Lin, K. T., "Basic Engineering Properties of Phosphogypsum Subjected to Compaction", PH.D dissertation, U. of Miami, Coral Gables, Fl, May 1987.
4. Ahmadi, B. H., A. Nanni and W. F. Chang, "Characteristics and Behavior of By-product Gypsum Bricks", Proceedings of the Second International Seminar on Structural Masonry for Developing Countries, Malaysia, March 23-26, 1987.

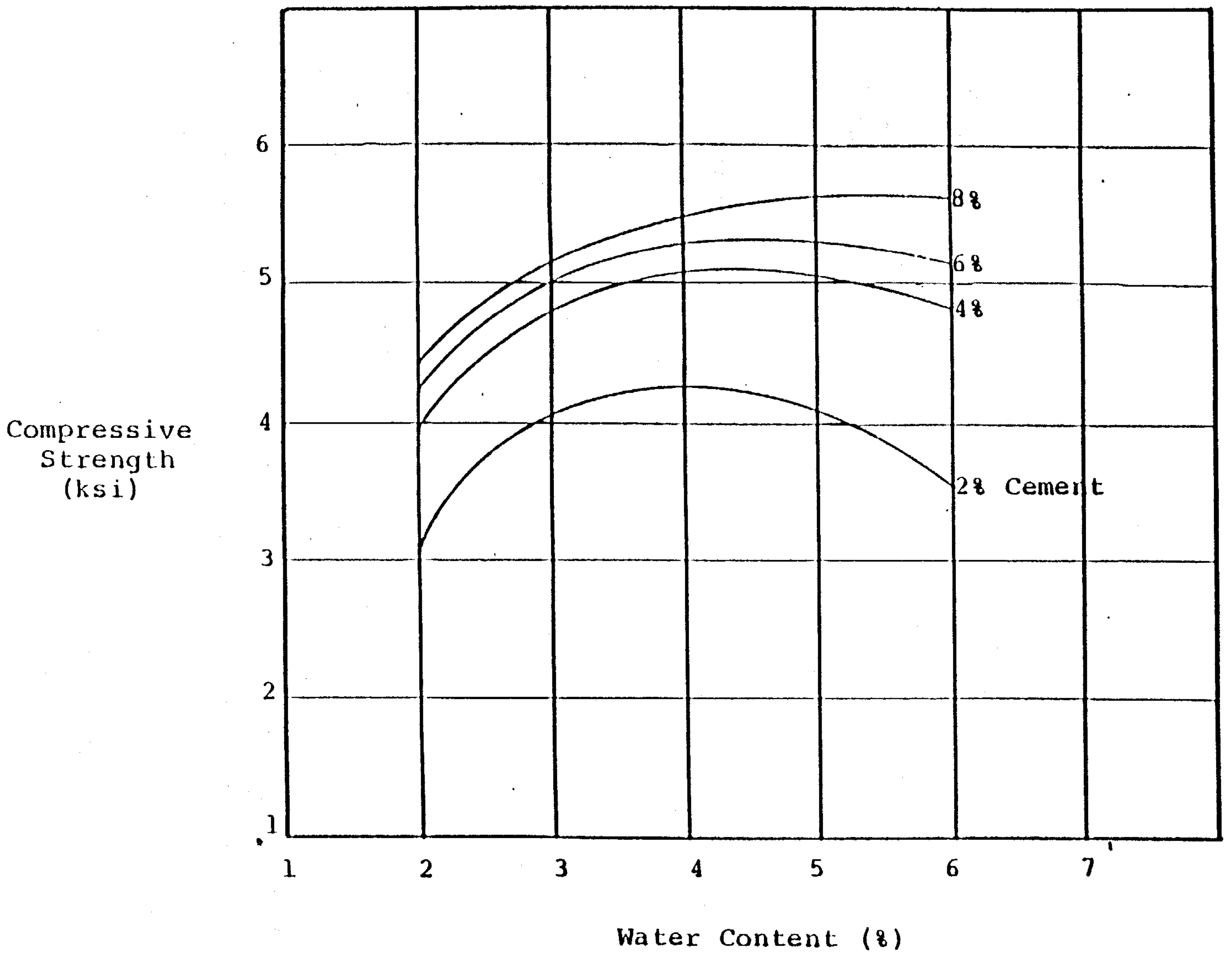


Figure 1. Compressive Strength vs Initial Mixing Water Content for Bricks produced with 60% Dihydrate Phosphogypsum 2 to 8% Portland Cement, and Sand After Removal of Curing Plastic Membrane.

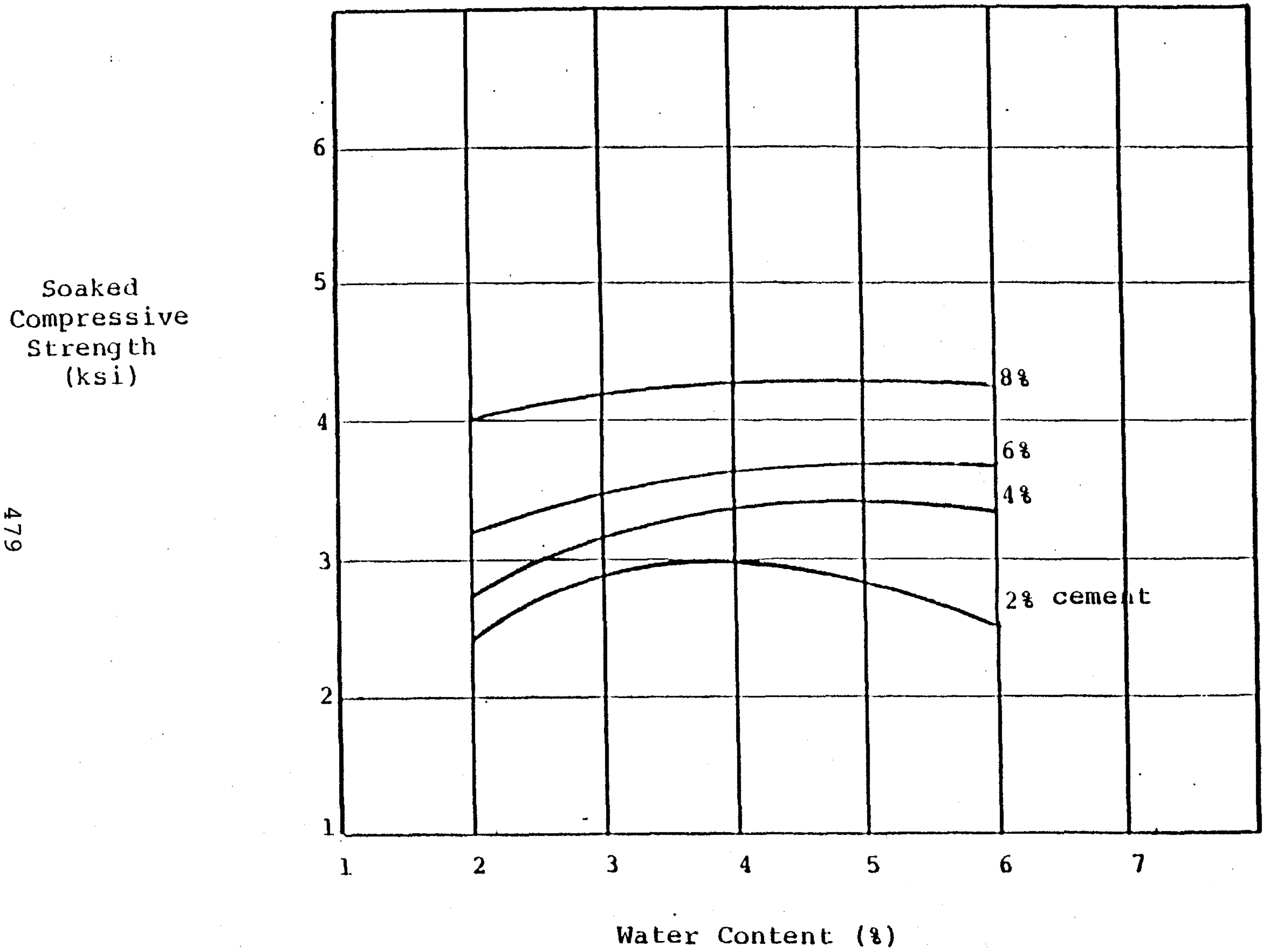


Figure 2. Compressive Strength vs. Initial Mixing Water Content, for Bricks Produced with 60% Dihydrate Phosphogypsum, 2 to 8% Portland Cement, and Sand, After Removal of Curing Plastic Membrane for 28 Days Followed by Seven Days Submergence in Water.

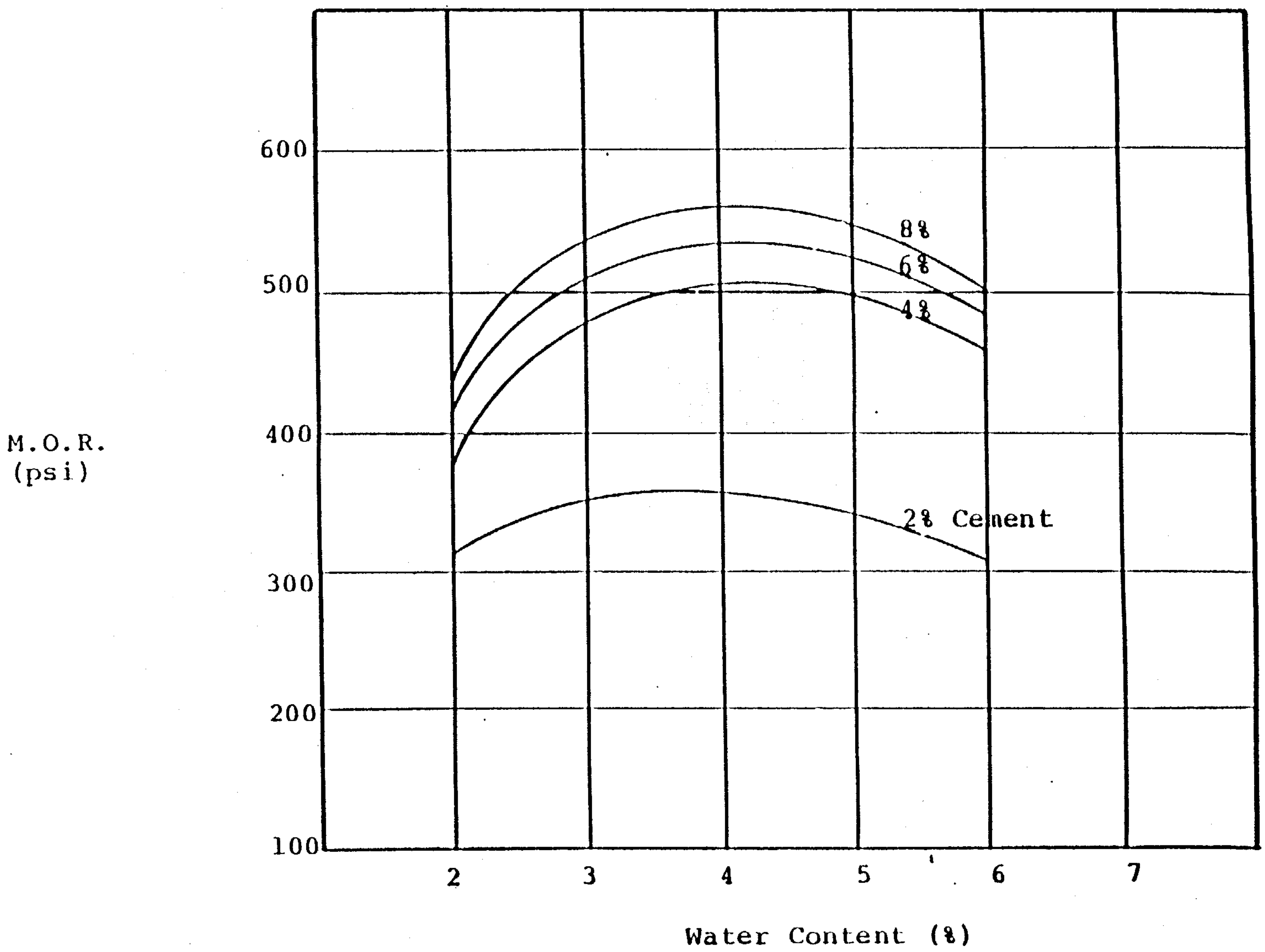


Figure 3. Modulus of Rupture vs. Initial Mixing Water Content, for Bricks Produced with 60% Dihydrate Phosphogypsum, 2 to 8% Portland Cement, and Sand After Removal of Curing Plastic Membrane.

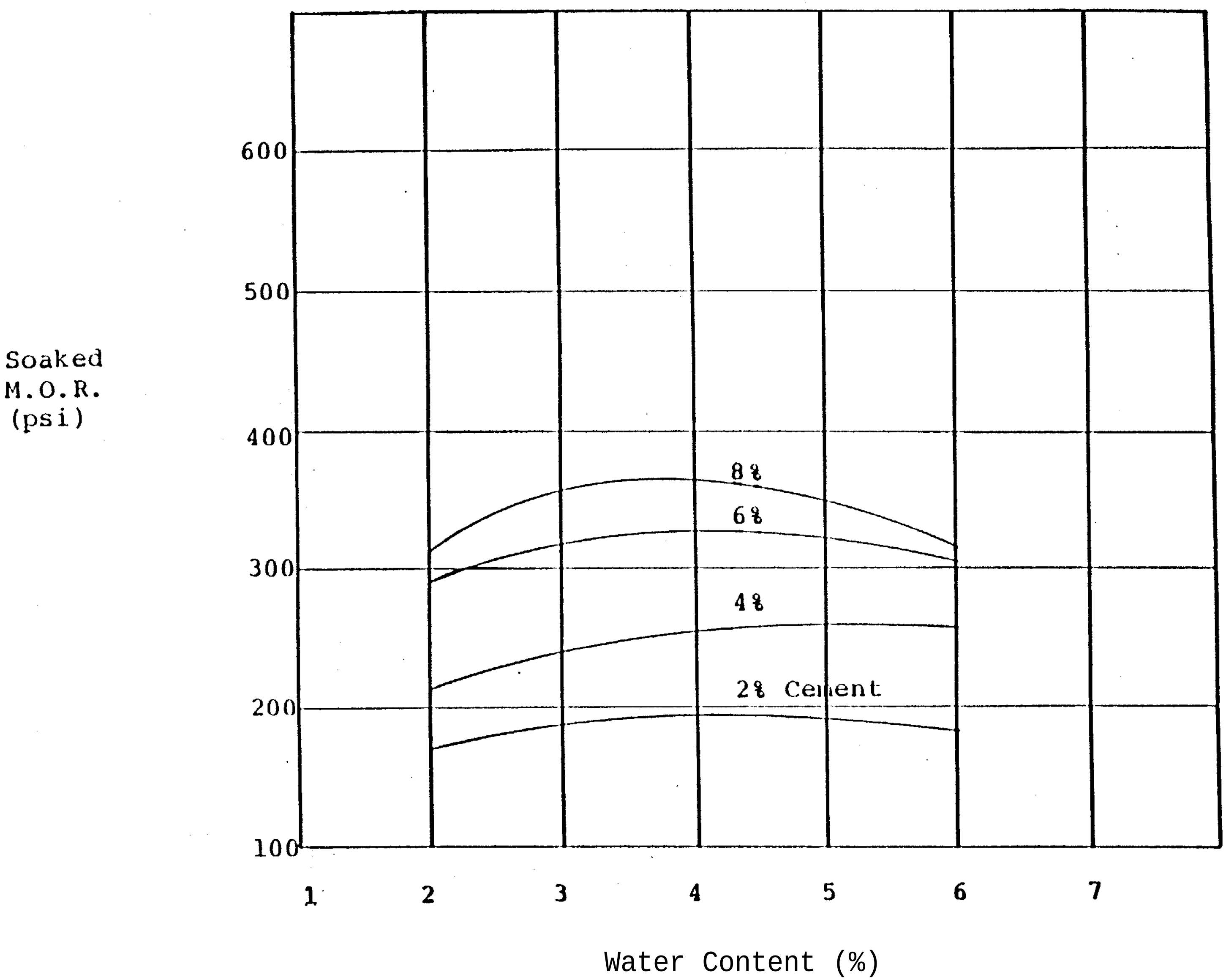


Figure 4. Soaked Modulus of Rupture vs. Initial Mixing Water Content for Bricks Produced with 60% Dihydrate Phosphogypsum, 2 to 8% Portland Cement, and Sand After Removal of Curing Plastic Membrane, followed by Seven Days Submergence in Water.

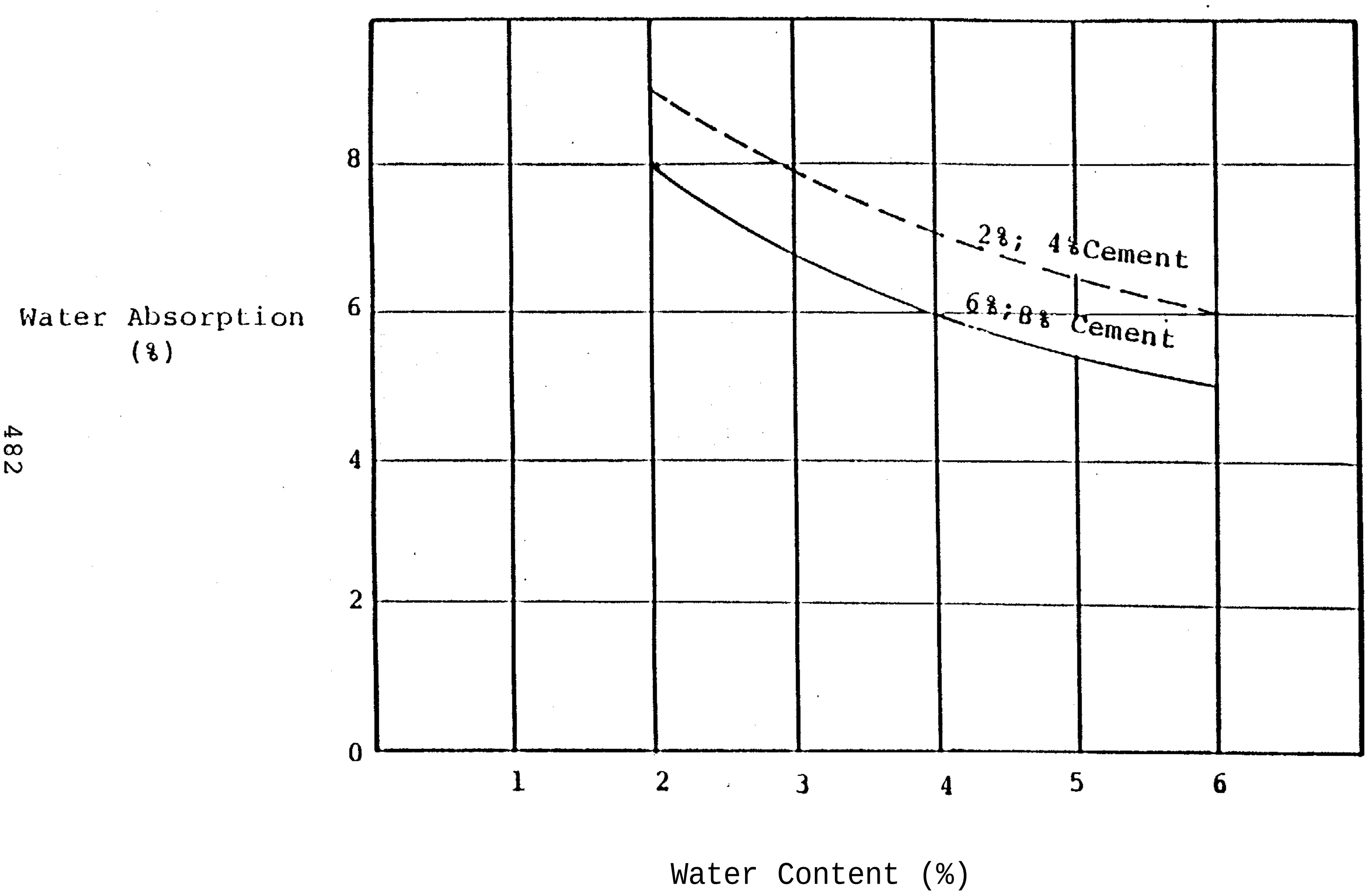


Figure 5. Seven Days Water Absorbtion vs. Initial Mixing Water Content for Mixtures Containing 60% Phosphogypsum, Sand and Cement.

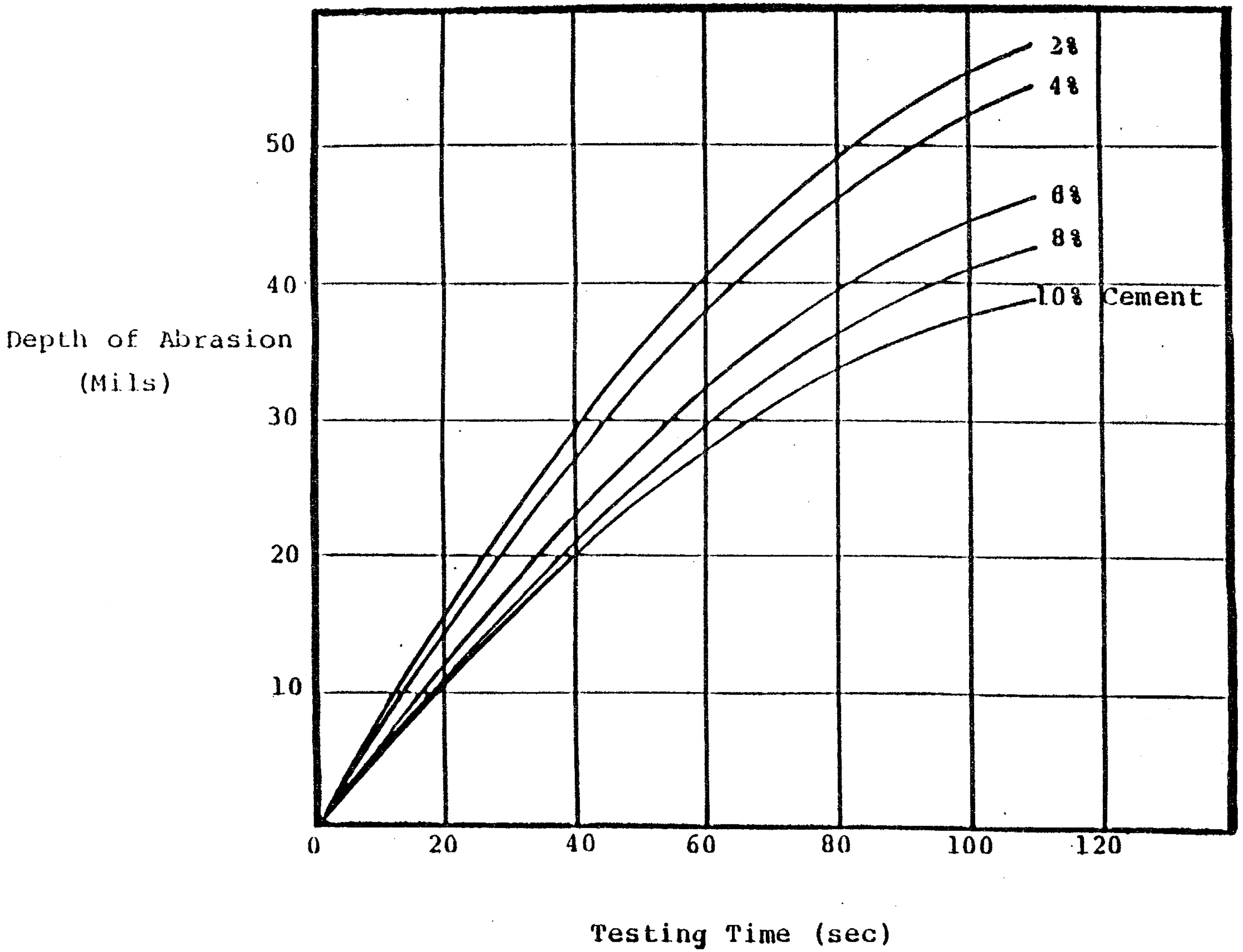


Figure 6. Depth of Abrasion vs. Testing Time for Bricks Containing 60% Phosphogypsum Sand, and Cement

STRUCTURAL BEHAVIOR OF MASONRY WALLS USING PHOSPHOGYPSUM-BASED BRICKS

Bijan H. Ahmadi[1] and Wen F. Chang[2]

1. ABSTRACT

This paper demonstrates an innovative technique to utilize by-product gypsum for masonry construction. The objective of this paper is to report on the satisfactory and promising results obtained on the structural behavior of by-product gypsum brick prisms and walls utilizing bonding compounds. The bricks used are manufactured merely by the use of high-pressure compaction on by-product gypsum, Portland Cement, and sand.

2. INTRODUCTION

Phosphogypsum is a by-product of the phosphoric acid industry. Phosphate rock is used to produce fertilizers which assist farmers in providing food for the world.

Associated with the manufacture of phosphoric acid is the co-production of phosphogypsum. Because of potential environmental, aesthetic appearance and economical factors, it is desirable to find a better solution than simple land or sea disposal. The world wide production of phosphogypsum is approximately 120 million tones per year [1]. The typical composition of raw phosphogypsum is shown in Table 1:

---

[1] P.E., Asst. Professor of Civil & Architectural Engineering, University of Bahrain, State of Bahrain.

[2] P.E., Professor and Director of Phosphate Research Institute, University of Miami, Coral Gables, FL. U.S.A.

Table 1: Typical Composition of Phosphogypsum[2]

Gypsum($CaSo_4/H_2o$)	%	85-93
P_2O_5	%	0.2-1.
F	%	0.4-1.3
SiO_2	%	1.4-8.4
Soluble salts	%	0.1-5.3
PH		3.1-5.3
radium 226	pci/g	15-29

The major composition of phosphogypsum is calcium sulfate. Application of high pressure compaction results in a molecular modification of the calcium sulfate particles binding into a rock-like body [3]. Test results [2] have shown that any industrial waste which contains similar or higher amounts of gypsum could be used for producing similar bricks.

2.1. Fabrication of the bricks

All bricks were made on a bench model, semiautomatic press having a capacity of 400 kips (1779.2 KN) to produce bricks of 1.75x3.75x8 in. (51x95x203 mm) in size under a static compaction of 12,000 psi (82.7 MPa).[2]

2.2. Materials

The following materials were used to produce the bricks:

a) 60% Phosphogypsum
b) Sand (crushed limestone).
c) Two to eight percent Portland Cement Type I.
d) Initial mixing water, 2 , 4, and 6 percent.
e) Bonding compounds: Concrete Repair Adhesive (CRA), Type M Black Magic (BMT), Ceramic Tile Cement (CTC)

3. CHARACTERISTICS AND BEHAVIOR OF THE PRISMS

Characteristics and behavior of the prisms were determined on prisms constructed with bricks made of 60% phosphogypsum, 36% sand, 4% Portland Cement, 4% initial mixing moisture content bonded with different bonding compound. This mixes for the brick was chosen based on good strength found in compressive and flexural tests of the bricks.

3.1. Flexural bond strength

Beam test method A of ASTM E518 third point loading and wrench flexural test according to ASTM C 1072 were used.

3.1.1- Beam test

Each specimen had a span to depth ratio of 5.3 (ten bricks stacked together). Test results are shown in Table 2.

Table 2: Flexural Bond Stress, psi (MPa) (from beam test)[4]

Beam No.	Joint Materials			
	BMT	CRA	CTC	cement mortar
1	80(0.55)	75(0.52)	49(0.34)	45(0.31)
2	62(0.43)	66(0.45)	46(0.32)	64(0.44)
3	54(0.37)	50(0.34)	76(0.52)	64(0.44)
4	65(0.45)	59(0.41)	83(0.57)	50(0.34)
5	70(0.48)	83(0.57)	63(0.43)	55(0.38)
Average	66.2(0.46)	66.6(0.46)	63.4(0.44)	55.6(0.38)

3.1.2- Wrench flexural test

This test was performed according to ASTM C 1072. Since the individual bond between the bricks could be tested one after another, more data could be achieved by this test. Test results are shown in Table 3.

Table 3: Flexural Bond Stress, psi (MPa). (from wrench test)[4]

Beam No.	Joint Materials			
	BMT	CRA	CTC	cement mortar
1	124(0.85)	103(0.71)	75(0.52)	136(0.94)
2	156(1.07)	91(0.63)	83(0.57)	140(0.96)
3	107(0.74)	103(0.71)	87(0.60)	120(0.83)
4	99(0.68)	103(0.71)	95(0.65)	136(0.94)
5	95(0.65)	144(0.99)	79(0.54)	140(0.96)
6	111(0.76)	91(0.63)	79(0.54)	128(0.88)
7	99(0.68)	95(0.65)	56(0.39)	138(0.95)
8	107(0.74)	91(0.63)	75(0.52)	140(0.96)
9	83(0.57)	95(0.65)	79(0.54)	120(0.83)
10	75(0.52)	103(0.71)	55(0.38)	125(0.86)
Average	105.6(0.73)	101.9(0.70)	76.3(0.53)	132(0.91)

3.1.3. Comparison on beam test and flexural wrench test

Test results shown in Table 2 and 3 for beam test and wrench test, respectively, show that the wrench flexural test results are approximately 60% higher that the beam test results for the same prism bonded with the same bonding compounds.

3.2. Shear Bond Strength

Shear strength of different joint materials were tested by subjecting three bricks to double shear loads. Shear strengths of the joint materials are shown in Table 4. Shear strength of as high as 176 psi (1.21 MPa) along with a high ductility was also observed during testing.

Table 4: Shear Strength of Joint Materials[4]

Joint Materials	Shear Strength psi (MPa)
CRA	175.9(1.21)
BTM	121.3(0.84)
CTC	83.00(0.57)

3.3. Compressive Strength of Prisms

Compressive strength of the prisms with different height to thickness ratios and different joint materials were tested in the direction of the depth of the bricks according to ASTM E447. Compressive stress vs. strain for two different joint materials are shown in Figures 1 and 2. Table 5 compares the ultimate compressive strength for different height to thickness ratios for two different joint materials.

Table 5: Comparison of Ultimate Compressive Strength[4]

Prism height to thickness ratio	Ultimate strength psi (MPa) BMT	CRA	Ratio BMT	CRA
1.6	3000 (20.7)	3167 (21.9)	0.71	0.80
2.13	2133 (14.7)	2533 (17.5)	1.00	1.00
4.27	1666 (11.5)	2400 (16.6)	1.28	1.06

4. CHARACTERISTICS AND BEHAVIOR OF STRUCTURAL MASONRY WALLS

Characteristics and behavior of structural masonry walls were determined on walls constructed with bricks made of 60% phosphogypsum, 36% sand, 4% Portland Cement, and 4% initial moisture content bonded with BMT bonding compound. The mixtures and bonding compound were chosen based on the comparative good strength found in brick testing and prism tests.

4.1. Diagonal Tension (shear) Test of Walls

Shear or diagonal tensile strength is of considerable concern to structural designers, especially in geographical areas where seismic design is required. The diagonal tension tests were performed using a procedure similar to ASTM E 519, but scaled down specimens.

This investigation used a 24 in. (610 mm) by 24 in. (610 mm) brick wallette, 3.75 in. (95 mm) thick. The specimen dimensions permitted twelve courses of brick with eleven full bed joints. All specimens in this investigation were laid in common bond. Half bricks were cut on a masonry saw. Three like specimens were constructed with the same size and type of by-product gypsum brick units, joint material, and workmanship.

Two steel loading shoes were used to apply the machine load to the specimen. The length of the shoe bearing was 6 in. (152 mm). The upper and lower loading shoes were positioned so as to be centered on the upper and lower bearing surfaces of the testing machine. The specimen was placed in a centered plumb position in a bed of gypsum capping material in the lower loading shoe. The upper corner of the specimen was capped similarly.

The shear stress was calculated on the basis of gross area. The shear stress of the specimen was calculated as follows:

$$S_s = 0.707 \times P / A$$

where:

S_s = shear stress on gross area, psi (MPa)
P = applied load lb (N),
A = average of the gross areas of the two contiguous upper sides of the specimen, in^2 (mm^2)

The shear strain was calculated as follows:

$$\text{shear strain} = \gamma = V + H/g$$

where:
γ = shear strain, in./in. (mm/mm),
V = vertical shortening; in. (mm)
H = horizontal extension, in. (mm),
g = vertical gage length, in. (mm)

H and V were based on the same gage length.
The modulus of rigidity (modulus of elasticity in shear) was calculated as follows:

$$G = S_s / \gamma$$

where:

G = modulus of rigidity, psi (MPa)

Figure 3 shows shear stress vs shear strain.

Modulus of rigidity of 1.8×10^4 psi (124 MPa) was determined. Ultimate shear strength of 87 psi (0.60 MPa) was found from the diagonal tension (shear) test.

4.2. Compressive Strength of Walls Under Eccentric Axial Loading

Sound engineering design of structures using new materials requires accurate technical data on the strength and rigidity of the basic elements employed in various construction systems. It is the purpose of these test methods to provide a systematic basis for obtaining engineering data.

Tests were made on three like specimens, each having a height equal to 4 ft. (1.22 m) and 2 ft. (0.61 m) in width with a thickness of a single brick 3.75 in. (95 mm). The specimen dimensions permitted twenty four courses of brick with twenty three full bed joints. All specimens in this investigation were laid in common bond. Half bricks were cut on a masonry saw.

This test was performed according to ASTM E 72, Standard Methods of Conducting Strength Tests of Panels for Building Construction. Two brackets were attached to the specimen near the upper end, supporting a metal rod. Two brackets also were attached to the specimen near its lower end, supporting two dial micrometers with the spindle up. Similarly, dial gages were attached at the mid depth to measure the deflection of the wall due to eccentric loading.

The specimen was tested as a column having a flat end at the bottom. Compressive load was applied to a steel plate with cross-section of 2-5/8 in. (67 mm) in width and 7 in. (178 mm) in depth. The steel plate was placed at the inside of the wall making 0.56 in. (14.2 mm) from center of the wall to the center of the steel plate. Loads, shortening of' the specimen, and lateral deflection were recorded.

Load vs. compressive deformation is shown in Figure 4. Since the failure in the wall a tensile failure in the transverse direction of the load rather than a compressive failure, failure is in the elastic range.

Load vs. lateral deflection is shown in Figure 5. This figure shows the nonlinear relation of load vs lateral defelection.

5. CONCLUSION

The past results [2] confirmed that by-product gypsum-based bricks produced under high static compaction pressure, possess valuable compressive and flexural strength. Laboratory brick specimens bonded with the bonding compounds as described, not only achieved high strength values in flexure, shear, and compression, for the prisms but also showed valuable strength in tension and compression plus bending for the walls. Based on the strength results from prisms as well as walls testings here, it can be concluded that high-pressure compacted bricks utilizing by-product gypsum have great potential for masonry construction. Due to the dimensional precision and surface flatness, use of bonding compounds other than the conventional cement mortar, shall facilitate the construction process. It is believed that utilization of by-product gypsum shall not only solve the environmental problems but also conserve the natural resources for construction.

6- ACKNOWLEDGEMENT

The authors wish to thank the University of Bahrain and Florida Institute of Phosphate Research for their financial support in this research.

7- REFERENCES

1. "Phosphate Fact sheet-1985", Florida Phosphate Council., Tallahassee, FL, 1986.

2. Ahmadi, B. H., A. Nanni, W. F. Chang, "Characteristics and Behavior of By-product Gypsum Bricks", Proceedings of the Second International Seminar on Structural Masonry for Developing Countries, Malaysia, March 23-26, 1987.

3. Wirching, F., "Drying and Agglomeration of Flue Gas Gypsum", Proceedings of the Symposium on the Technology of Gypsum and Gypsum Products, Kuntze, R. A., Editor, ASTM STP 861, Sept. 1984, pp160-172

4. Ahmadi, B. H., K. T. Lin, W. F. Chang, "Characteristics and Behavior of By-Product Gypsum Prisms and Structural Masonry Walls", Proceedings of the First Regional Conference in Civil Engineering, Bahrain, March 11-13, 1989.

5. Ahmadi, B. H., K. T. Lin, W. F. Chang, "Use of High Strength By-Product Gypsum Bricks in Masonry Construction", Proceedings of the 5th Canadian Masonry Symposium, Vancouver, British Columbia, Canada, June 5-7, 1989.

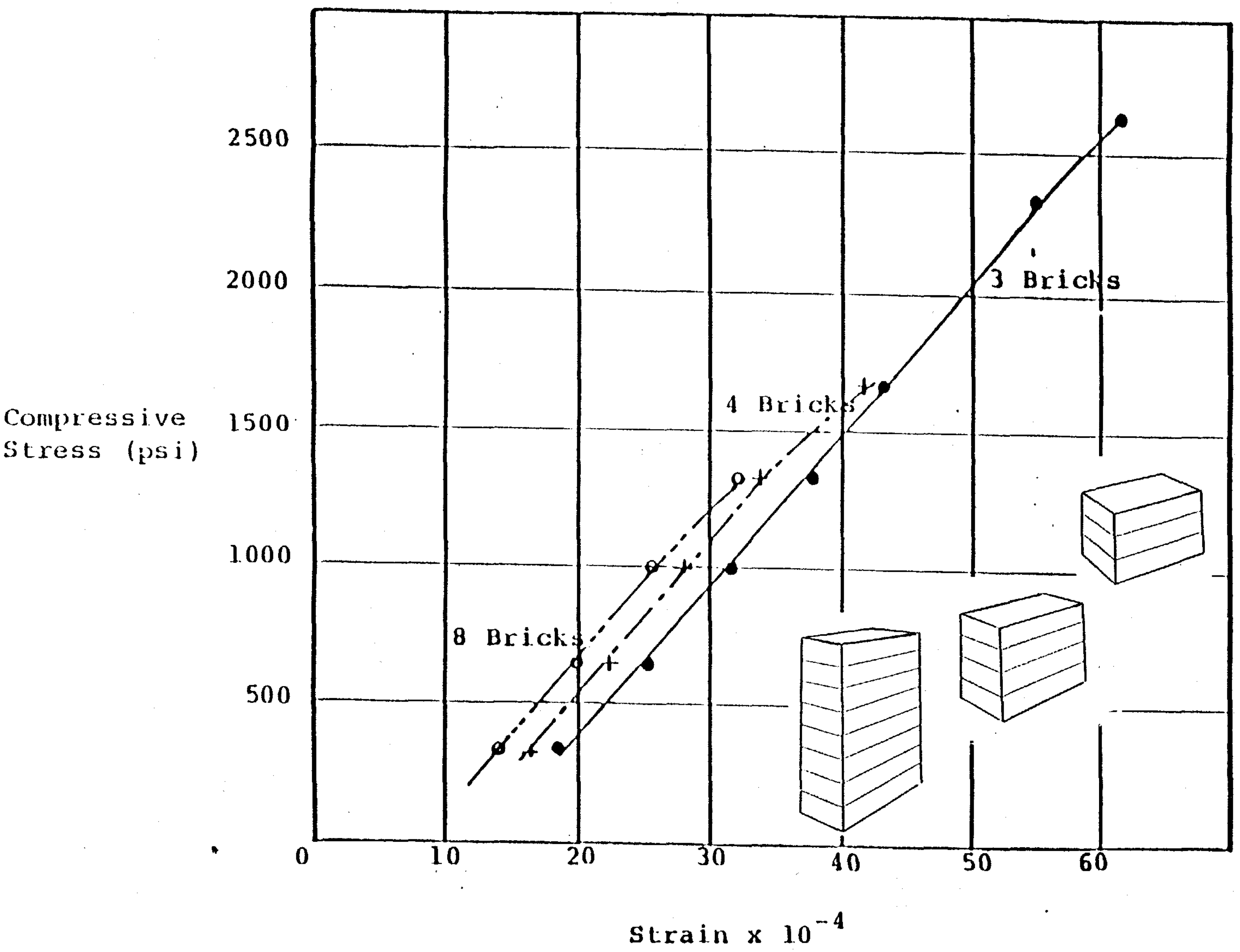
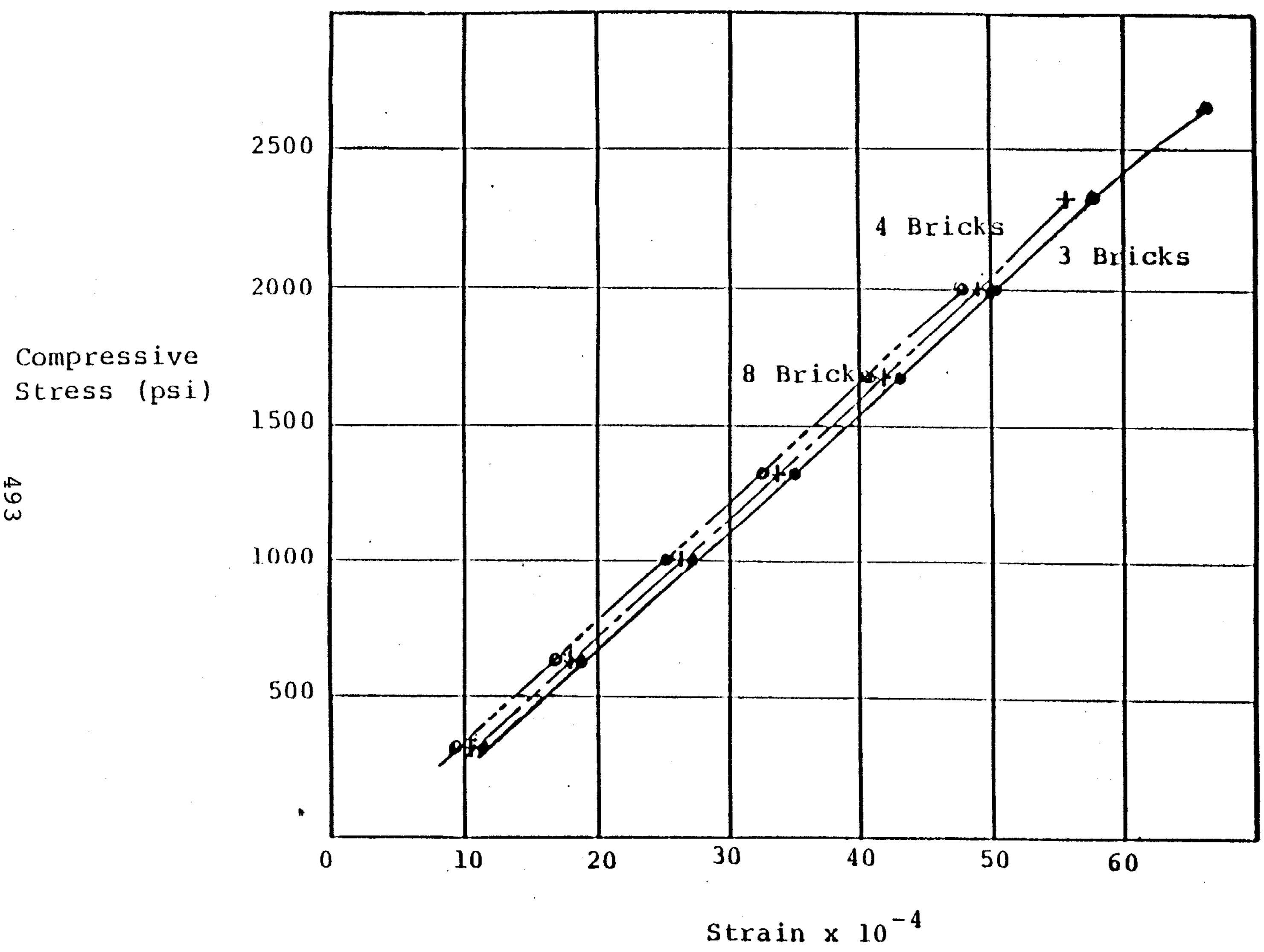


Figure 1. Compressive Stress vs. Strain for BMT Joint Material



$$E = \frac{1200-500}{(30-18)10^{-4}} = 0.6\text{x}10^{6} \text{ psi}$$

Figure 2. Compressive Stress vs. Strain For CRA Joint Material

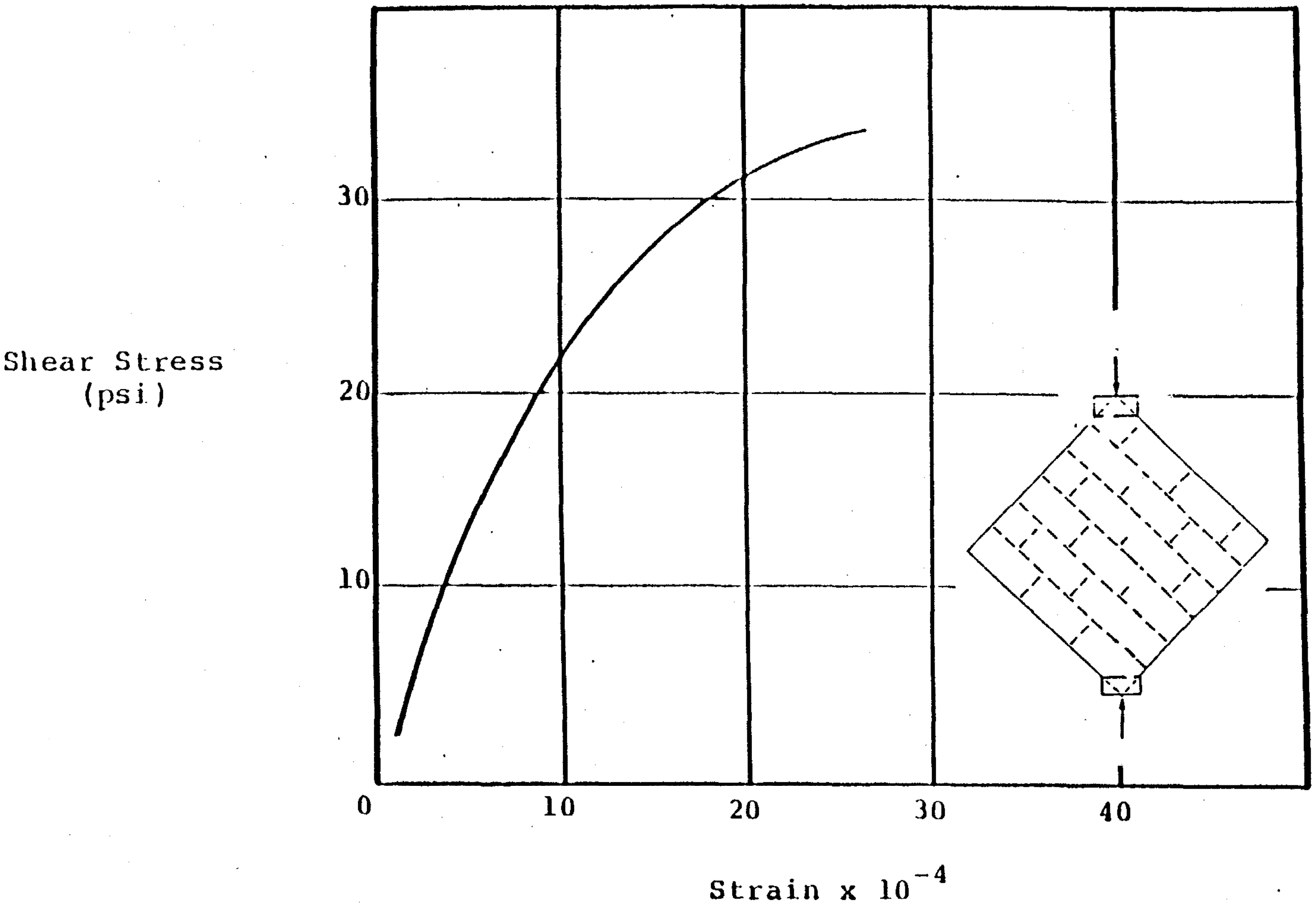


Figure 3. Shearing Stress vs. Shearing Strain

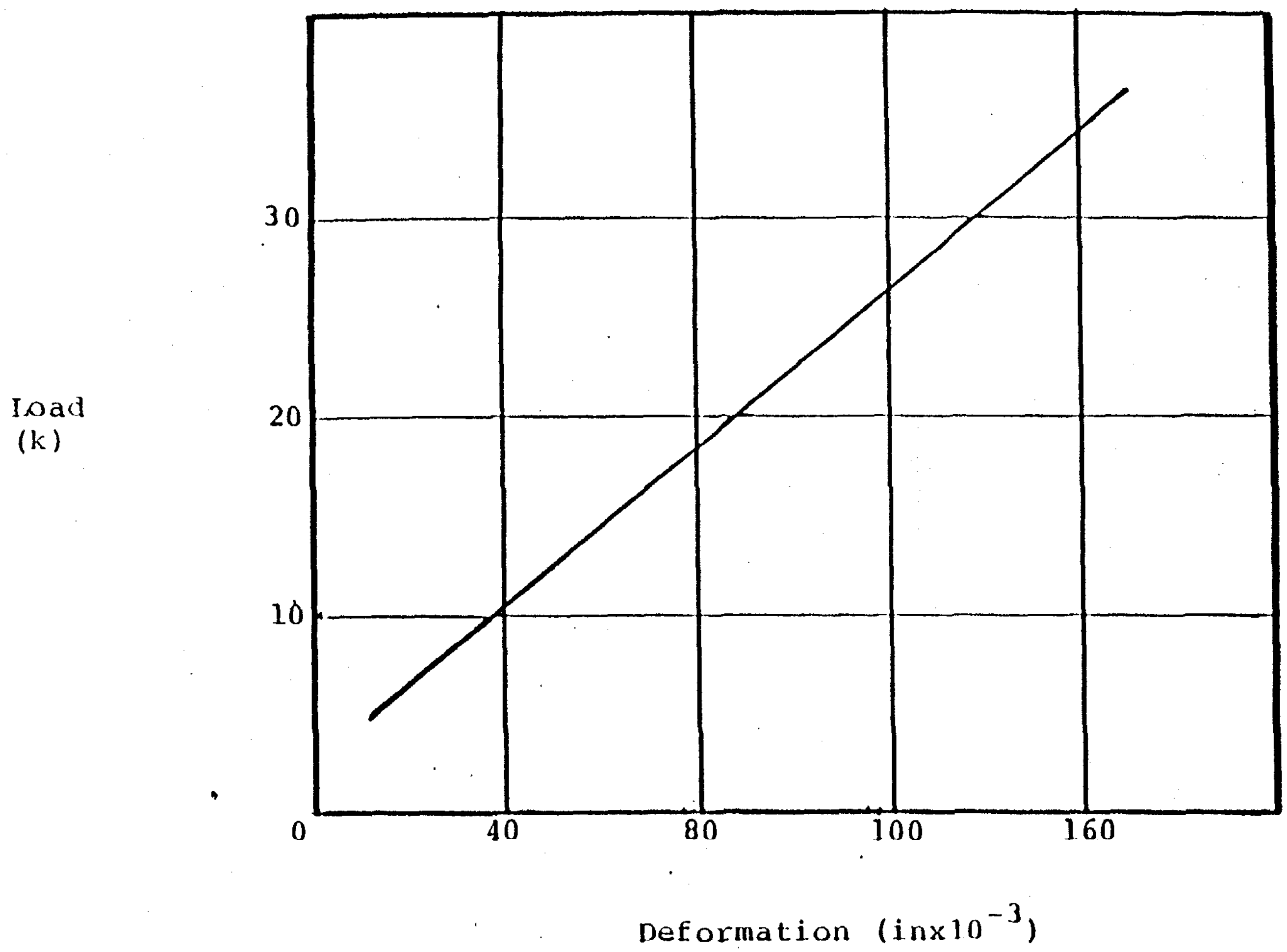


Figure 4. Load vs. Compressive Deformation

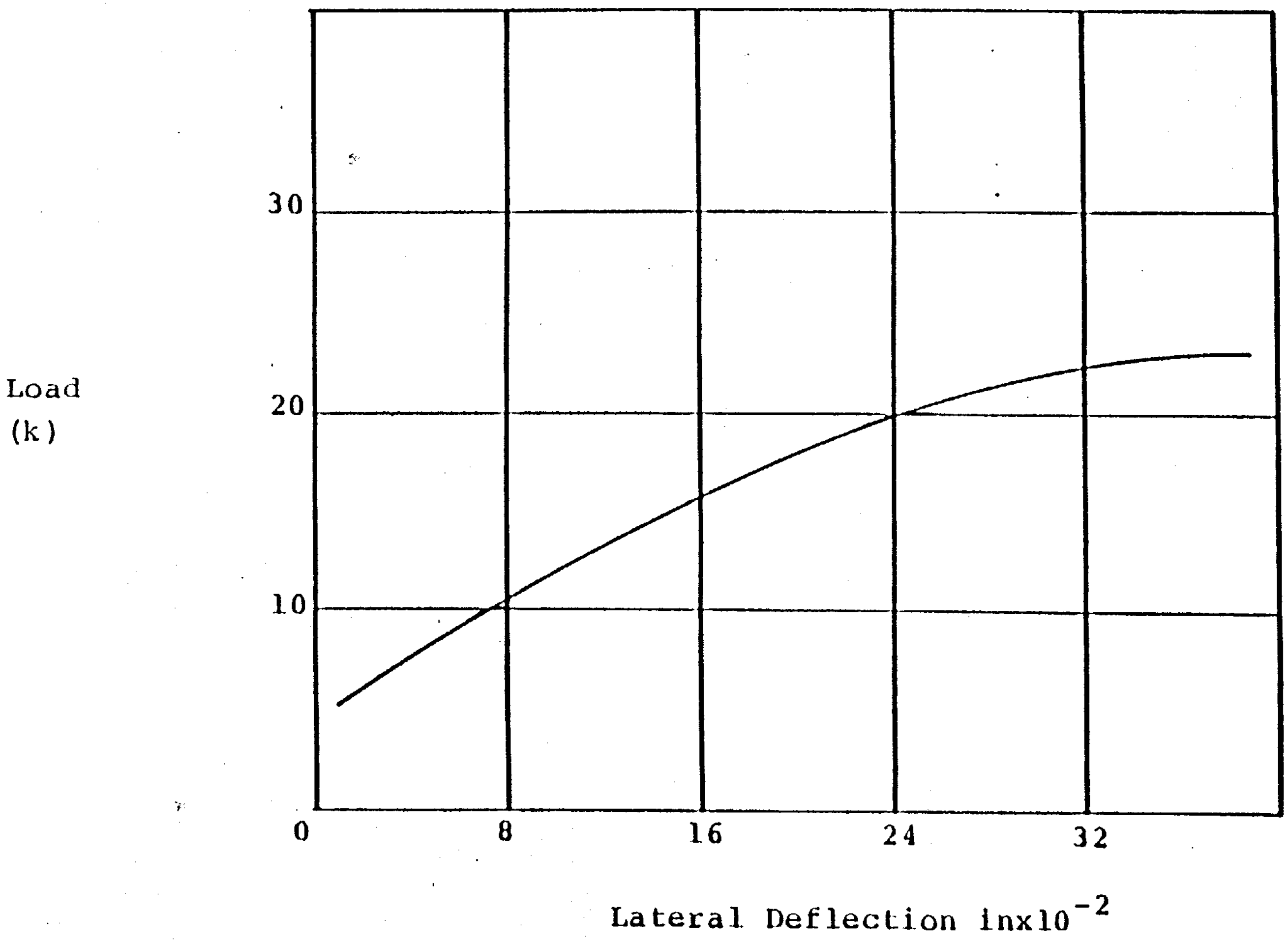


Figure 5. Load vs. Lateral Deflection

TECHNOLOGY OF MANUFACTURE OF BETA-MODIFICATION PHOSPHOGYPSUM BINDER AND WALL PRODUCTS MADE FROM IT

Krotkov V.V., licensed engineer,
Chief of General Department of the Ministry of Nuclear Power Industry of the USSR

Frikhodko V.A., Cd. Sc. (Engineering),
Chief of Department of “OrgtroiNIIproekt” Institute

Khimchenka V.I., licensed engineer,
Director of Production Association "Almaz"

USSR

ABSTRACT

Keywords: phosphogypsum, lime milk, pulping, neutralization filtering, drying, dehydration, milling, preparation of gypsum paste, casting of products, packaging , properties of gypsum binder and products.

This abstract introduces the results of scientific-research and experimental industrial work in the technology of production of beta-modification gypsum binder from phosphogypsum, which is an after-product of extraction phosphoric acid. It is shown. that the negative influence of water-soluble compounds of phosphorus and fluorine contained in phosphogypsum can be eliminated by neutralization of these compounds, for example, by lime milk. We show the relationships between the parameters of the phosphogypsum dehydration process and the phosphogypsum acid number. Settled are the requirements to the equipment for dehydration of phosphogypsum - the necessity of separation of the material and heat flows, adjustability of the time of material stay *at* preset temperatures.

We give the description of the design of a continuous-action heat-exchange and conveying apparatus, in which the processes of phosphogypsum drying and dehydration are combined. We present the binder property indiced, describe the process of fabrication of wall. products based on phosphogypsum binder. The abstract gives information on the property of the products, fields of their application.

INTRODUCTION

Continuous no-waste techonology of manufacture of a beta-modification gypsum binder from phosphogypsum and wall products based on this binder is worked out and realized on industrial scale.

The results of experimental work in determining the kinetics of neutralization of water-soluble compounds of phosphorus and fluorine by lime, data on possibility of reuse of filtrate in the technological cycle, research and development work in creation of special equipment for phosphogypsum drying and dehydration, moulding of wall products from a phosphogypsum binder served as the theoretical foundation of such a technology.

It is show that a gypsum binder of satisfactory characteristics can be obtained both from "acidic" and "alkaline" phosphogypsum. However, since in the first case the dehydration process is accompanied by liberation of aggressive compounds into the atmosphere, and in the second case it is associated with a high power consumption and formation of a slow binder, a conclusion is made thate industrial manufacture of phosphogypsum binder can be based on utilization of “neutral” phosphogypsum only.

We give information that water physically bound with phosphogypsum, at its content up to 18 to 20 % by mass, is a capillary film water, and it can be removed mainly by evaporation.

The conclusion on possibility of multiple reuse of filtrate for pulping the source materiale, or preparing the lime milk is grounded.

The content of water-soluble compounds in filtrate at its multiple reuse cannot exceed the content of water-soluble compounds in the moisture of the source material.

Principles are settled to be used in creation of equipment for dehydration of phosphogypsum. It is shown that gypsum-cooking boilers, drying drums, rotary-tube driers, fluidized-bed furnaces for thermal treatment of gypsum are acceptable but little.

The design of a continuous-action heat-exchange and conveying apparatus with a combination of the phosphogypsum drying and dehydration processes is worked out and realized. We give information on the main design approaches of this apparatus, parameters of the dehydration process, data on the binder properties as per USSR State Standard GOST 125-79, setting time (beginning- 5 to 7 min, end 12 to 15 min), strength brand: Г4-Г5, normal density -60 to 75 %.

Described is the design of the rotary machine for production of gypsum blocks by the casting method. 128 moulds are arranged around the edges of the rotary machine, with rotation of the machine, gypsum paste is cast in the moulds. During one revolution of the machine the gypsum paste is set, after which the product is ejected of compact. A special device orients the products in space and packages 96 pcs in a package.

In such a form the products are dispatched to the customer. The products are used for erection of low buildings of different purpose.

THEORETICAL PREMISES OF MANUFACTURE OF BETA-MODIFICATION PHOSPHOGYPSUM BINDER.

In the Soviet Union the by-product, formed in the process of sulfuric-acid decomposition of apatites and phosphorites in production of extraction phosphoric acid, was defined as phosphogypsum.

The average yearly yield of this material at the enterprises of the USSR is about 18 mln tons. Yearly used of this amount are only about 4 mln tons, mainly for soil development and in the cement industry.

In connection with worsening of the ecological situation in a number of regions of the USSR, exhaustion of the natural resources of gypsum stone in the areas of concentrated construction the urgency of utilization of phosphogypsum first of all instead of the natural gypsum raw sources has grown recently.

Without denying other ways of utilization of phosphogypsum, in the first stage we showed preference to the development and realization of the technology of manufacture of the beta-modification phosphogypsum binder.

Such a conclusion is founded not only on the comparative simplicity of technical solutions in manufacture of gypsum binders from phosphogypsum, but mainly on the estimation of the efficiency of use of various materials and products in construction.

The increase of the output of gypsum materials and products is one of the ways of intensification of construction engineering, reduction of the specific consumption of materials and power capacity, that is rarely used in this country for the time being.

The experience of construction in the Soviet Union testifies that the use of gypsum binders is rather effective not only for production of such traditional items as partition slabs and panels, decorative and acoustic stabs, but also for manufacture of wall products. According to estimation of Soviet specialists, in the conditions of low-building construction gypsum-concrete walls are more effective than walls made of clay-bric and claydite-concrete panels by 10 to 50 %, and less power-intensive by 30-60 %.

As the practice of construction in the USSR shows, the most expedient is the manufacture of gypsum-concrete wall products in the form of small blocks. Organization of manufacture of such products needs minimum specific capital investments and running expenditure, and their conveying to construction sites and erection of walls do not need any special facilities.

Just the efficiency of gypsum materials and products, a high labour and power-saving effect in their manufacture and use, as compared with similar cement- based materials and products, caused, first of all, The necessity of work in manufacture of gypsum binders and products on their base from phosphogypsum.

Since the service load on gypsum products, as a rule, does. not exceed 5 MPa, we gave preference to the development, first of all, of such a technology of manufacture of phosphogypsum binder that would provide manufacture of materials and products, having a strength higher than the specified one.

well-known are the difficulties of industrial production of gypsum binder from phosphogypsum conditioned mainly by dispersivity and dampness of the source material, presence of watersoluble compounds of phosphorus and fluorine in it, and variability of their content.

The data of our researches testify that the beta-modification gypsum binder satisfying the requirements of USSR State Standard GOST 125-79 can be obtained from phosphogypsum without a special preparation of it.

However, the industrial technology of production of phosphogypsum binder cannot be based on utilization of phosphogypsum binder cannot be based on utilization of phosphogypsum without a special preparation of it. Firstly, it is conditioned by the presence of aggressive compounds of fluorine, sulphur and phosphorus in the vapour-gas mixture formed at dehydration of phosphogypsum. This necessitates the manufacture of equipment f ram corrosion-resistant alloys, and use of volatile compound trapping arrangements in the line.

The above circumstances will result in the necessity of considerable capital investments and servise expenditure.

Secondly, variability of the content of water-soluble compounds of phosphorus and fluorine in phosphogypsum necessitates variation of the parameters of its heat treatment, which is rather difficult in industrial conditions.

The analysis of the data of our experimental researches (Table 1) shows that, with the increase of the content of acid water-soluble compounds in phosphogypsum (determined indirectly according to the pH value), the strength characteristics of the binder obtained from such a material in the same conditions of heat treatment essentially worsen, the setting time of such a material increases.

This pH value should be within 6.5 to 7.5.

In this case preparation of phosphogypsum to dehydration consists in pulping of the source material with water, neutralination of acid impurities (for instance, with lime milk) to pH value within 6.5 to 7.5, filtering of neutralized pulp.

Table 1

Properties of phosphogypsum binder with different content of water-soluble phosphorus

Sample No.	Content of water-soluble P_2O_5 in phosphogypsum, % by mass	pH value of source phosphogypsum	Binder properties					
			Setting time, min		Ultimate strength, MPa			
					compression		bending	
			begining	end	at 2-h age	in dry state	at 2-h age	in dry state
1	0.05	6.5	3	8	3.7	9.2	2.2	3.4
2	0.70	5.9	5	12	2.4	7.1	1.8	2.3
3	1.48	3.5	13	21	1.7	4.6	1.1	1.4
4	1.82	2.9	28	45	0.9	2.8	0.4	1.2
5	3.20	1.4	unspecified		0	0.8	0	0.4

According to our data, this is caused by an increase of the content of insoluble anhydrite in the binder (from 1.5 % in sample 1 to 97.9 % in sample 5) with the increase of phosphogypsum acidity.

The lower the pH value of phosphogypsum, the lower tempara-ture of dehydration and time of heat treatment of such a material are required for obtaining calcium sulfate hemihydrate from it (Table 2).

Table 2

Optimum parameters of phosphogypsum dehydration, depending on its acidity

Sample No.	pH value of phosphogypsum	Optimum temperature of dehydration, °C	Curing period at optimum temperature, min	Content of hydrate water in binder, % by mass
1	6.5	160	90	5.90
2	5.9	150	85	5.75
3	3.5	140	75	5.81
4	2.9	125	70	5.91
5	1.4	120	70	5.78

Note. The dehydration parameters given in Table 2 are determined at heat treatment of phosphogypsum in a muffle furnace.

The results of experimental researches given in Tables 1 and 2 testify that without stabilization of the content of water-soluble acid compounds in phosphogypsum the process of production of binder from it is uncontrollable.

The content of acid water-soluble compounds in phosphogypsum can be stabilized either by their washing, or by neutralization by known methods. We adopted the second way, since realization of the first way raises a new problem-utilization of aggressive waste water.

As it is testified by our experimental data, neutralization is possible both in the solid phase and in the agueous medium.

The first way seems to be more preferable due to the absence of wet processes, however, its realization will entail difficulties in the dosage of the stoichiometric amount of the neutralizing additive. An excess of the neutralizing additive is undesirable, since (for example, when calcium oxide is used) it necessitates an increase of the dehydration temperature and process period (Table 3)

Table 3

Optimum parameters of phosphogypsum dehydration with different amount of additive (calcium oxide)

Sample No.	Amount of additive (calcium oxide), % by mass	pH value of phosphogypsum	Optimum calcination temperature, °C	Curing period at optimum temperature, min	Content of hydrate water in binder, % by mass
3	0	3.5	140	75	5.81
6	0.5	5.2	150	80	5.73
7	1.0	6.3	160	90	5.69
8	2.0	7.4	160	95	5.96
9	3.0	9.1	180	100	5.84
10	4.0	11.3	200	110	5.76
11	5.0	12.6	210	120	6.02

An excess of the additive (calcium oxide) above the stoichiometric amount causes not only a necessity to increase the dehydration temperature and process period, but also results in production of a slow binder of a comparatively low strength (Table 4).

Table 4

Properties of phosphogypsum binder with different amount of additive (calcium oxide)

Sample No	Amount of additive (calcium oxide), % by mass	pH value of phosphogypsum	Binder properties					
			Setting time, min		Ultimate strength, MPa			
					compression		bending	
			beginning	end	at 2-h age	in dry state	at 2-h age	in dry state
3	0	3.5	4	9	2.1	5.2	2.4	7.9
6	0.5	5.2	4	11	2,5	6.1	2.9	8.9
7	1.0	6.3	5	12	2.4	5.4	2.9	8.7
8	2.0	7.4	7	15	1.7	5.9	3.2	9.8
9	3.0	9.1	21	34	0.6	2.1	1.3	3.5
10	4.0	11.3	39	47	0.1	0.9	0.7	2.9
11	5.0	12.6	67	92	0	0.7	0.2	2.4

Note. Heat treatment of phosphogypsum was carried out in a muffle furnace at a temperature of 140 C during 75 min.

Thus, neatralization of acid additives contained in phosphogypsum in agueous medium with an operative check and control of the process in pH value seems to be preferable.

The data of our researches testify that filtrate can be used many times (for example, for pulping of phosphogypsum) in a closed cycle of production of beta-modification gypsum from phosphogypsum. Naturally, in this case concentration of water-soluble compounds in the filtrate will rise, which may result in formation of salt cakes on products. However, the data of our theoretical and experimental researches indicate that the content of water-soluble compounds in the filtrate in case of its repeated use cannot exceed the content of these compounds in the source phosphogypsum.

Formation of salt cakes on products manufactured on the basis of phosphogypsum binder is associated mainly with the presence of sodium sulfate in it. The data of our experimental researches testify that when the content of sodium oxide is less than 0.3 % by mass, formation of salt cakes on products is impossible.

The actual content of sodium oxide in phosphogypsum of different enterprises of the USSR does not exceed 0.2 % by mass.

Thus, of all the considered variants of preparation of phosphogypsum to dehydration at production of beta-modification gypsum binder, we gave preference to neutralization of acid impurities contained in it to pH value within 6.5 to 7.5 with a subsequent filtering of the neutralized pulp.

EQUIPMENT REQUIRED FOR DRYING AND DEHYDRATION OF PHOSPHOGYPSUM.

The equipment for manufacture of gypsum binder from natural gypsum stone (drying drums, gypsum-cooking boilers) is acceptable but little, if phosphogypsum is used as raw material.

For heat treatment of phosphogypsum in gypsum-cooking boilers it is necessary to dry it to a moisture content not exceeding 10 % by mass.

Otherwise, phosphogypsum sticks to the boiler walls and bottom worsening the already low efficiency of heat transfer from the heat-transfer agent to the material being treated. Sticking is so intensive that can cause a seizure of the boiler agitator drive. Preliminary drying of phosphogypsum is connected with the necessity of installation of an additional thermal set, which results in an increase of already high power expenditure for production of phosphogypsum binder. Other methods of reduction of the content of physical water (except the thermal ones;) from 18-20 down to 10 % and below have no prospects, since free moisture within 0 to 18 (20) %, according to our data, is in a tough chemosorption bond with phosphogypsum.

Drying drums, in which material and heat flows are not separated, are acceptable but little for dehydration of phosphogypsum.

Our data testify that at a parallel flow of the heat-transfer agent and phosphogypsum practically the whole material being reated is carried away by waste gases. This circumstance conditions the necessity of installation of a branched dust-removing system.

In our opinion, the necessity of creation of special heat exchangers intended for heat treatment of phosphogypsum is beyond any doubt.

In such heat exchangers the material and heat flows should be separated so as to prevent carrying-away of the heat treatment products, and probable "plastering" of the apparatus cold end.

Due to a high sensitivity of phosphogypsum to variation of the process parameters of production of gypsum binder from it, the temperature and duration of stay of the material in different zones must be within a strictly preset range and subject to control.

To intensify the drying and dehydration processes (from the point of view of saving of power resources, these processes should be combined in the same apparatus), due to it, to reduce the heat rate, the heat exchanger must have a large active surface and provide a constant intensive agitation of the material.

Finally, for clear reasons, the heat exchanger should operate in a continuous duty.

The heat exchanger designed by us most of all satisfies the above requirements.

Equipped with such apparatus are the enterprises of the USSR manufacturing gypsum binder both from phosphogypsum (the production association "Almaz", scientific and production association “Fosfogips" Balakovo production association "Minudobreniya"), and from natural gypsum stone (the Ulyanovsk gypsum works).

Structurally, this heat exchanger, called by gypsum-cooking continuous-action plant, is a heat-insulated shell accommodating deviced for feeding and removing the heat-transfer agent. The shell accommodates a system of pipes interconnected by a sealed chamber on the material charging side, and by a collector - on the finished product uncharging side.

The sealed chamber is connected to the charging device passing through one of the thrust journals brought outside the zone of heat-transfer agent circulation. A tight seal is installed between the collector and the finished product uncharging side and shell. The device for removing the vapour-air mixture and the finished product uncharging device are installed behind the tight seal. The piping system is furnished with a common, drive.

The gypsum-cooking plant operates as follows.

Source phosphogypsum is supplied in a continuous flow to the sealed chamber with the aid of the charging device, and further - by scoops to each pipe. Due to the presence of an Archimedean spiral in each pipe, during rotation of the piping system phosphogypsum moves from the charging device to the discharging device within a time period determined by the helix lead and pipe rotational speed. The heat-transfer agent flows about the piping system and transfers heat to the material being treated through a highly developed surface of the pipes.

The arrangement of the sealed chamber in the place of supply of the heate-transfer agent provides for its heating up to the maximum temperature. Owing to it, a steam jacket is formed at the “chamber internal surface - source material" contact, which prevents sticking of wet raw material to the surface of the gypsum-cooking plant.

Horizontal installation of the heat exchanger on journals brought outside the zone of the heat-transfer agent makes it unnecessary to use thrust bearings, the bearing roller cooling system, cushions the operating conditions of loaded elements.

PROPERTIES OF PHOSPHOGYPSUM BINDER

For the averaged indices of the properties of beta-modification phosphogypsum binder manufactured according to the above technology refer to Table 5.

Table 5

Indices of properties of phosphogypsum binder

Description of indices	Unit of measurement	Index value	
		before milling	after 20-min milling
Specific surface	m^2/kg	500	650
Water requirements of paste of normal density	%	95	75
Setting time:	min		
beginning		7	6
end		15	13
Compression strength:	MPa		
in 2 h		2.6	3.8
in dry state		5.7	9.2
Bending strength:	MPa		
in 2 h		1.9	3.2
in dry state		2.6	3.7
Softening ratio		0.40	0.40

As is seen from Table 5, gypsum binder made from phosphogypsum satisfies the requirements of State Standard GOST 125-79. A short-time milling of beta-gypsum slightly accelerates its setting, decreases the water requirements for obtaining paste of normal density and considerably increases the strength characteristics.

Unlike the gypsum binder obtained from natural gypsum stone, phosphogypsum binder is characterized by some other influence of different additives on it.

For instance, a positive influence of an addition of sodium chloride on the strength characteristics of binder made from natural gypsum stone is well known. The data of our works testify that an addition of sodium chloride to phosphogypsum binder has a positive influence only at the beginning of the solidification period (the first 24 hours).

At the age of 28 days the strength of the specimens from phosphogypsum binder with an addition of sodium chloride is 1.5 to 2 times lower as compared with the strength without any addition, Such dependences can be also seen at introduction of an additive of magnesium sulfate. Citric acid and its salts, slowing down the setting of moulded gypsum based on natural gypsum stone, practically do not influence the setting period of phosphogypsum binder.

An addition of a dihydrate-phosphogypsum to phosphogypsum binder causes a sharp decrease of its strength indices (introduction of 1 % of phosphogypsum - by 22 %, 15 % - by 3.4 times). USSR Inventor's Certificate No.948937 has found out and protected the positive influence of a complex mineral additive, containing 2 to 4 % of sodium chloride and 1 to 4 % of magnesium sulfate, on the strength characteristics of phosphogypsum binder

A decrease of the water-to-gypsum ratio causes an increase of specimen strength both in a dry and water-saturated states, a decrease of the strain characteristics;

As it was mentioned above, milling of phosrhogypsum binder, as well as introduction of plasticizing additives, is an effective way of reduction of the water-to-gypsum ratio. The best effect is attained by the use of complex additives, containing both a plasticizer and a solidification activator.

WALL PRODUCTS MADE OF PHOSPHOGYPSUM BINDER.

As it was mentioned above, in the USSR gypsum binders have found the most effective use in manufacture of small-sized wall products. Taking this into account, a continuous line for production of wall blocks, measuring 390x190x188 mm, based on phosphogypsum binder is worked out and realized. Equipment for production of gypsum blocks and equipment for production of binder are arranged in the same building, which makes it possible to consider such a solution as a completed cycle of manufacture of wall products from the production waste - phosphogypsum.

The blocks are produced on a continuous-action rotary machine. From the hopper the binder is fed by the feeder to a continuous-action gypsum-concrete mixer, whereto mixing water is also proportioned. Water is proportioned visually proceeding from the mobility of gypsum paste.

The gypsum paste, coming out of the gypsum-concrete mixer (on the average, the water-to-gypsum ratio 0.8), is poured into cells-moulds of the rotary machine provided with 128 such cells-moulds. During rotation of the rotary machine the gypsum mass is smoothed out and levelled by the device installed above it.

Then the bottoms of each mould are opened by means of a special feeler mechanism, and the blocks are pushed out onto a turntable by a device synchronously operating with the drive of the rotary machine. Emptied moulds move to the automatic greasing station, after which they are closed by means of another feeler mechanism and delivered to the casting station. Thus, during one revolution of the rotary machine the moulds are filled in with gypsum paste, the mould bottoms are opened, the products are pushed out, the moulds are greased and their bottoms are closed.

From the turntable the products are pushed onto a belt conveyer by a leverage operating in step with the other mechanisms of the rotary machine. A summator is installed over the conveyer used to determine the quantity of moulded blocks. Besides, this device transmits command signals to another device, with the aid of which the position of the blocks on the conveyer belt periodically changes, depending on the adopted procedure of block packaging. The conveyer belt conveys the products to an automatic stacker, which forms a package of 96 blocks. The block package is reloaded onto a buggy, and further from the buggy it is delivered to the stock-room by means of a special grip.

The rotary machine capacity is 400 to 500 products per hour, depending on the binder setting period. The line is serviced by two operators.

For the averaged indices of the properties of gypsum blocks refer to Table 6.

Table 6

Averaged indices of properties of gypsum blocks

Property	Unit of measurement	Property indices at moisture content	
		10 % by mass	in dry state
Volume density	kg/m^3	1100	1000
Compression strength	MPa	5.3	8.3
Coefficient of heat passage	W/m °C	0.42	0.38
Frost resistance	number of cycles		25
Coefficient of softening			0.40

The blocks are used as a wall material in construction of single- and two- storey buildings of different purpose.

CONCLUSION AND RECOMMENDATIONS

A beta-modification gypsum binder within a wide range of variation of acidity and moisture content of the source material can be obtained from phosphogypsum. The minimum heat and power expenditures are required for obtaining beta-gypsum from acid phosphogypsum. The lower the pH value of phosphogypsum, the lower temperature is required for its dehydration. However, the necessity of manufacture in this case of the whole equipment of a corrosion-resistant version complicates the production of the binder and makes it more expensive.

The more acid water-soluble impurities are contained in phosphogypsum, the higher the probability of formation (with all other conditions being the same) of an insoluble anhydride from such a material, which considerably decreases the strength characteristics of the binder and increases its setting period.

Neutralization of acid water-soluble impurities in phosphogypsum by surplus calcium oxide causes a sharp increase of heat expenditure on dehydration of phosphogypsum and results in obtaining of a slow binder. The strength characteristics of such a binder are considerably lower than those obtained from acid or neutral phosphogypsum.

Taking into account the considerable dependence of the phosphogypsum dehydration parameters on its acidity index, as well as the unsteadiness of the contents of acid water-soluble impurities in phosphogypsum, the method of phosphogypsum heat treatment, with its preliminary neutralization to a pH value of 6.5 to 7.5, may be recommended for industrial conditions.

Water, physically bonded with phosphogypsum when its content is up to 18-20 % by mass, is in a tight chemisorption bond with the solid phase, due to which it can be removed mainly by heating.

Heat treatment of phosphogypsum in continuous-action plant is expedient from the technical and economical points of view, the main obligatory condition in these plants is the necessity of separation of the material and heat flows. The phosphogypsum heat treatment time in such plants, and the temperature of the process in its different stages should be checked and controlled.

The multi-pipe heat exchanger designed by us satisfies the specific character of phosphogypsum heat treatment most of all, each pipe of this heat exchanger is provided with guides installed on an Archimedean spiral.

An effective method of improvement of beta-gypsum from phosphogypsum is its short-time milling (up to 20 min), which results in the reduction of water requirements for obtaining paste of normal density and in the improvement of the strength characteristics of the binder.

For reducing the water requirements and thereby improving the strength characteristics use of organic plasticizers and complex additives containing a plasticizing substance and a crystallization process initiator is rather effective.

From the economical and technical points of view, the expedient trend of utilization of beta-modification gypsum binder in the USSR is the production of small-sized wall blocks on its base.

An automatic flow line is worked out and realized for production of gypsum blocks, measuring 390x190x188 mm. The blocks feature a sufficient carrying capacity, small density, satisfactory heat-insulating characteristics.

Such products are used with a high efficiency for construction of low buildings of different purpose.

The authors are very much obliged to Prof. A.V. Volzhensky, engineers V.I. Kornev, A.B. Levchenko, S.V. Pisarev for their active participation in the development and mastering of the technology of manufacture of phosphogypsum binder and wall products from it.

SHRINKAGE OF CEMENT-PHOSPHOGYPSUM MIXTURES SUBJECTED TO COMPACTION

By

C.X. Ling[1], K.T. Lin[2], and W.F. Chang[3]

SYNOPSIS

The huge quantity of phosphogypsum which has been stockpiled in Florida has caused increasing concerns with respect to its possible environmental impacts. Many research projects on utilization of phosphogypsum as construction materials have been sponsored by the Florida Institute of Phophate Research. It was found that phosphogypsum-based materials possess valuable strength sufficient for use in building and road construction after compaction.

The aim of the tests in this paper is to investigate the shrinkage properties of phosphogypsum-cement mixtures and the influence of the factors, such as moisture content (MC), cement content, curing conditions, the relation between shrinkage and moisture loss, comparison of shrinkages of the compacted and vibrated specimens and ambient humidity. The specimens covered 14% to 22% MC, 10:90 to 95:5 PG/C, 3 to 28 days curing and 50% to 70% ambient humidity. Effect of this factors on the development of drying shrinkage over time is described, and relationship between drying shrinkage and loss of water is given for each factor involved. The volume change of the specimen in the air is a swelling-shrinkage process with loss of moisture. Shrinkage of compacted specimen is much less than that of vibrated specimen. Curing conditions and ambient humidity are significant to the shrinkage. There is a maximum shrinkage at about 25:75 PG/C ratio and an empirical formula to predict effect of PG/C ratio is obtained, using a program which fit least-squares polinomials to bivariate data.

KEYWORDS: Shrinkage, Phosphogypsum, Cement, Compaction

[1] Ph.D. Candidate, Dept. of Civil Engineering, College of Engineering, University of Miami, Coral Gables, Florida.

[2] Ph.D., P.E., Structural Engineer, Beiswenger, Hoch and Associates, N, Miami Beach, Florida.

[3] Ph.D., P.E., Professor and Director of Phosphate Research Institute, College of engineering, University of Miami, Coral Gables, Florida.

l. INTRODUCTION

Recent laboratory research and field projects on phosphogypsum(Chang,l987,Lin,Nanni&Chang,l986) have shown that this material alone and when combined with portland cement, usually in low percentages, provides adequate strength, after compaction, for roadway bases and subbases construction. In addition to strength, one of the most important factors effecting the performance of roadway pavement, especially rigid pavement, is the shrinkage of the paving mixtures. Excessive shrinkage results in severe tensile stresses and cracks which may impair the structural integrity of the pavement. While shrinkage is a natural phenomenon of cement pastes, conventional aggregates usually have a restraining effect on shrinkage. Herein the shrinkage properties of cement-phosphogypsum pastes subjected to compaction are first studied.

Shrinkage generally is brought about by the loss of moisture from either fresh or hardened cement pastes. However, it is the "drying shrinkage", which undergoes after mixtures have hardened, that has more practical significance. In this study, some essential factors affecting the drying shrinkage of various cement-phosphogypsum mixtures are investigated. To represent the effect of roller compaction in the field , mixtures were compacted at a static pressure of 1,500 psi in the laboratory. The following factors affecting shrinkage of cement-phosphogypsum pastes are studied:

a) Moisture content at compaction (MC), from 14 to 22% where the desirable dry density as well as compressive strength of the mixtures can be obtained under the 1500psi of compaction pressure. (Lin,l987)
b) Phosphogypsum/cement ratio (P/C), 10/90 to 95/5
c) Curing conditions and ages,3-28 days versus sealed curing
d) Amount of moisture loss, and
e) Ambient relative humidity, 50% and 70% RH

In addition, for the purpose of comparison, shrinkage of some specimens prepared by conventional vibration method was studied.

In general, the shrinkage of cement-phosphogypsum mixtures can be expressed as a function of P/C ratio, age, and moisture loss. In this paper, mathematical equations, based on empirical results, are developed relating the shrinkage of certain ages to P/C ratio. Prediction of shrinkage of the cement-phosphogypsum mixtures, can be achieved by simply using these equations.

2. PREPARATION OF SPECIMEN

Portland cement type I was used in this study. For each mix proportion, three 1"x l"x 10" bar specimens for measurement of length change were prepared in a steel mold at a compaction pressure of 1,500 psi. After compaction, specimens were wrapped in plastic membrane for sealed curing for a period of three days unless otherwise noted. The temperature was maintained at 80F and relative humidity at 50% . Before measured, contact points were casted at the two ends by using CYLCAP. At the end of the curing, specimens *were* measured in length and allowed to dry under the same environment followed by measurement of specimen length changes at selected times. To investigate the influence of different curing environments and curing ages, some specimens were also subjected to wet curing (100% RH) and sealed curing of 14 days and of 28 days.

3. EXPERIMENTAL RESULTS

3.1 SHRINKAGE VERSUS SPECIMEN AGE

Figures 1 through 4 present the shrinkage as a function of drying age of a series of cement-phosphogypsum mixtures of varying phosphogypsum content and cement content (P/C ratio) , at compaction moisture content of 14,16,18,20 and 22 percent, respectively. From these curves, it is first observed that, except for some mixtures at a certain initial drying period, the shrinkage generally increases with the age as expected. Secondly , the cement content indicates to be an important factor affecting the shrinkage of these mixtures. The shrinkage is largely reduced when cement content is properly decreased. More precisely, with reference to Figure 5, there seems to be a certain cement content, at which the shrinkage is a maximum and by which the shrinkage decreases with lower cement content. Thus it is found that the shrinkage property of cement-phosphogypsum mixtures can be improved by adjusting cement content. As was noted above, for some mixtures, when the drying initially starts, the shrinkage does not increase but actually decreases with the time. This is because the specimens of these mixtures expand for a certain period before they start to shrink. In fact, these, mixtures are those with low cement content. The cause of this phenomenon is attributed to the fact that reaction between C A in portland cement and SO in phosphogypsum, with adequate moisture, results in formation of ettringite, which is accompanied with expansion. It is believed that during the initial drying, the moisture retained in the specimen remains adequate for the reaction. It is also believed the expansion is so large that it overcome the shrinkage due to the drying. As the result, the net effect is expansion rather the shrinkage. As the drying continues, it reaches to the point where the shrinkage prevails. To have a better view of this transition, Figure 6 is replotted in semi-log scale some of the curves shown previously in Figure 4. From these two figures , the followings can be seen:

1) The expansion-shrinkage phenomenon exists when P/C ratio is above 3.
2) The duration within which the expansion exceeds the shrinkage is approximately one day.

3.2 MOISTURE LOSS VERSUS AGE

The term "drying shrinkage" implies that the shrinkage of cement pastes exists as a result of drying or loss of moisture. During the period of experimentation, it was found the drying rate or rate of moisture loss (measured in gram) of cement- phosphogypsum mixtures depends on the cement content as shown in Figure 7. For mixtures of lower cement content, the moisture loss at any age is generally higher. This is due to the fact that mixtures with higher cement content, consume more moisture for hydration thus leaving less moisture available for drying. From the different point of view, this means that at the time of drying cement-phosphogypsum mixture with lower cement content retains more moisture in the mixture available for the formation of attringite. Also shown in the figure is that for low cement content mixture, the drying of specimens proceeds in a rather short period. As indicated in the figure, the drying curves for P/C ratio no less than 75:25 or 3:l reach their plateaus within 7-14 days. In contrast, mixtures with lower P/C ratios or higher cement content, dry gradually and continuously with the age up to 90 days, which is typical as for conventional cement pastes.

3.3 RELATION BETWEEN SHRINKAGE AND MOISTURE LOSS

Figure 8 presents the relationship between shrinkage and moisture loss for mixture of P/C ratio varying from 0/100 to 95/5. For 100% cement pastes, as shown in Figure 8, the relationship is quite linear. As the ratio goes higher , the relationship becomes more and more nonlinear. It is interesting to point out two aspects of the relationship for high P/C ratio (above 75/25) mixtures. First, at the time of initial moisture loss there is expansion due to the formation of ettrigite as explained earlier. For mixture. with extremely high P/C ratio (90/10 or 95/5), the expansion continues until very little moisture is left in the mixtures. And , the shrinkage is much off-set by the expansion, as seen in the figure. Second, the curves approach vertical at the end, meaning that the shrinkage continues without noticeable moisture loss. It is possible that at the final stage of shrinkage, moisture loss is not the only factor causing the shrinkage for high P/C ratio mixtures.

3.4 CORRELATION BETWEEN SHRINKAGE, INITIAL COMPACTION MOISTURE, AND P/C RATIO

Figure 9 presents the 28 days and 90 days shrinkage as a function of cement content, or P/C ratio, for different initial compaction moisture content. From these curves, it is seen that compaction moisture content within the range of this study has only a minor effect on the shrinkage as compared to the effect of cement content. The effect of the compaction moisture is significant only for high cement mixtures. On the other hand, the shrinkage changes drastically as the cement content varies from 5% to 90%. As seen, peaks of shrinkage values can be spotted at a cement content range of approximately 60% to 75%. Over the peak, the shrinkage decreases continuously as the cement content decreases. Similar results are shown that the shrinkage of cement-phosphogypsum mixtures can be greatly reduced by adjusting the cement content.

3.5 EFFECT OF CURING CONDITIONS ON SHRINKAGE

For the purpose of comparison, five types of curing conditions were used, as described as follows:

Type 1 : Specimens were cured under sealed conditions for 3 days then allowed to dry.

Type 2 : Specimens were cured under sealed conditions for 14 days

Type 3 : Specimens were under sealed curing for 28 days.

Type 4 : After sealed curing for 3 days, specimens were submerged in water immediately. The submersion continued for 11 days. Then the specimens were allowed to dry.

Type 5 : Same as type 4 except specimens were submerged in water for 25 days.

All of the five types of specimens were under the same temperature during the curing and the same temperature as well as relative humidity during the storing.

Figure 10 compares the shrinkage of the mixture subjected to type 1, 2 and 3 curing conditions. As observed, prolonged sealed curing merely delays the shrinkage of the mixture and produces the same shrinkage at longer ages as does the shorter sealed curing. During the prolonged sealed curing after the initial 3 days, as indicated by the curve for type 3 in the figure, the specimens first expand due to the formation of ettringite then shrink due to self-desiccation for hydration of cement and possible filtration of moisture from the specimens through the sealing membrane to the environment.

If after sealed curing, specimens were allowed to be soaked in water for a certain period, then the shrinkage can be reduced by the the expansion effect during the submersion period, as demonstrated in Figure 11. From this figure, it is seen that the longer the submersion period, the larger the expansion, and the smaller shrinkage.

In summary, longer sealed curing can only postpone the shrinkage while submersion after sealed curing reduces the shrinkage.

3.6 EFFECT OF RELATIVE HUMIDITY

For conventional cement paste, it is well known that the relative humidity(RH) affects the shrinkage. The lower the RH, the higher the shrinkage. For cement-phosphogypsum mixtures, Figure 12 shows the 90 day shrinkage for varying cement content at RX of 50% and 70%. Basically the cement-phosphogypsum mixtures indicate similar shrinkage characteristics to conventional pastes in this respect. However, the RH seems diminishing effective in affecting the shrinkage as the cement content decreases. This behavior of cement- phosphogypsum mixtures can be reasoned through the test data presented in Table 3.1, where the moisture loss at 90 days is compared, of mixtures with different cement content for RH of 50% and 70%. From this table, it is observed that at high P/C ratios, the moisture loss becomes practically the same for the two RH's. Since moisture loss is the main factor that shrinkage is affected by R.H., the characteristics shown in Figure 12 is well explained.

TABLE 3.1. WATER LOSS (GRAMS) WITH DIFFERENT RH

Cement Content(%)	100	90	75	50	25	10
P/C Ratio	0:100	10:90	25:75	50:50	75:25	90:10
RH = 50 %	15.0	15.4	17.8	21.2	26.3	34.7
RH = 70 %	7.1	9.7	13.2	14.7	23.6	34.7

3.7 SHRINKAGE OF SPECIMENS CONSOLIDATED BY VIBRATION

For the purpose of comparison, some specimens were also prepared by the conventional vibration method. Consolidation

by vibration generally, due to lower consolidation energy, requires more water than the compaction method to provide suitable workability. Excessive moisture increases the shrinkage of the specimens upon drying. As a consequence, shrinkage of vibration specimens is expected to be larger than that of compaction specimens.

Figure 13 plots the shrinkage of some vibration specimens with respect to the drying age. As seen, similar to the case when the compaction method was adopted, the shrinkage increases with the drying age. Also revealed in this figure and Figure 14 is the effect of cement content on the shrinkage . To better demonstrate this effect, Figure 15 plots the shrinkage at differant ages as a function of cement content. As shown, cement content remains an important factor in affecting the shrinkage , as is the case for the compaction method.

Figure 16 shows the relationship between shrinkage and moisture loss for vibration specimens. Due to the abundance of moisture in the specimens , expansion of specimens was observed for cement content ranging from low (20%) to high(80). In contrast, when the compaction method was used , only specimens with cement content lower than 50% shown the expansion characteristics.

As a comparison between shrinkage of vibration specimens and that of compaction specimens. The shrinkage is plotted as a function of cement content. As shown in Figure 15 , specimens consolidated by compaction have much less shrinkage than their counterparts due to less amounts of moisture in the mixtures. The difference in shrinkage does, however, depend on the cement content. As the cement content goes down lower, the difference becomes smaller, indicating that for low cement content the shrinkage is less affected by the moisture content in the mixtures. In other words, for high P/C ratios the compaction has less leverage on the shrinkage.

3.3.8 PREDICTION OF SHRINKAGE BY SIMPLY MATHEMATICAL EQUATIONS

From the previous paragraphs, it is known that shrinkage of cement-phosphogypsum mixtures under the static compaction is a function of age (t), cement content(C), initial compaction, moisture content(MC) relative humidity, and curing conditions. For the RH of 50% and curing conditions(sealed) mainly adopted in this program, a mathematical equation was developed to predict the shrinkage as function of t, C and MC. With reference to Figure 9, as presented earlier, the effect of MC can be eliminated by using the average of the shrinkage values as presented. A regression analysis using the least-square fitting method, based on the average shrinkage values at ages of 28 and 90 days, results in a second order polynomial. The derived equation as written below makes simple prediction of shrinkage of cement-phosphogypsum mixtures under the compaction:

$$Sm = At * (220 + 368 * (1-C) - 588 * (1-C)^2) * 10^{-5}$$

where Sm = shrinkage

At = coefficient depending on age; equals 0.9 for

age of 26 days and 1.1 for age of 50 days
C = cement content(%) by weight

Figure 17 demonstrates the perfect fitting of this equation to average experimental data.

4. CONCLUSIONS

Based on the experimental results as presented in this paper, the following conclusions on shrinkage of cement-phosphogypsum mixtures under the compaction can be drawn:

11 Cement content plays an important role in affecting the shrinkage of cement-phosphogypsum mixtures. By using low cement content, the shrinkage can be advantageously adjusted.

2) The relationship between the shrinkage and moisture loss is non-linear for cement-phosphogypsum mixtures, as opposed to that for conventional cement pastes.

3) Due to the formation of ettringite upon initial drying, the specimens with low cement content exhibit the expansion- shrinkage characteristics.

4) Prolonged sealed curing would not alter but only delay the long-term shrinkage. Proper duration of soaking the specimens after curing, however, helps reducing the shrinkage.

5) The shrinkage is also affected by the relative humidity of the enviroment. Lower RH increases the shrinkage, but the effect becomes negligible for low cement content in the mixtures.

6) For shrinkage, compaction has an edge on vibration. The edge becomes smaller as the cement content decreases.

7) The shrinkage of cement-phosphogypsum mixtures under static compaction can be assessed by using a simple mathematical expression.

5. ACKNOWLEDGEMENTS

This research was made possible by a grant from the Florida Institute of Phosphate Research, Bartow, Florida, to the University of Miami, College of Engineering, Coral Gables, Florida.

6. REFERENCES

[1] W.F. Chang, Reclamation, Reconstruction and Reuse of Phosphogypsum for Building Materials, 1987, Florida Institute of Phosphate Research, Publish No.0l-014-048.

[2] K.T. Lin, A.Nanni and W.F. Chang, Compressive Strength of Compacted Portland-Based Mixtures Using Phosphogypsum on Consolidation of Concrete, 1986, Symposium on Consolidation of Concrete, ACI Annual Convention, San Francisco, CA.

[3] K.T. Lin, Basic Engineering Properties of Phosphogypsum- Based Mixtures Subjected to Compaction, 1987, Ph.D. Thesis, University of Miami, Coral Gables, Florida.

FIG.1 SHRINKAGE VERSUS AGE(MC:14%)

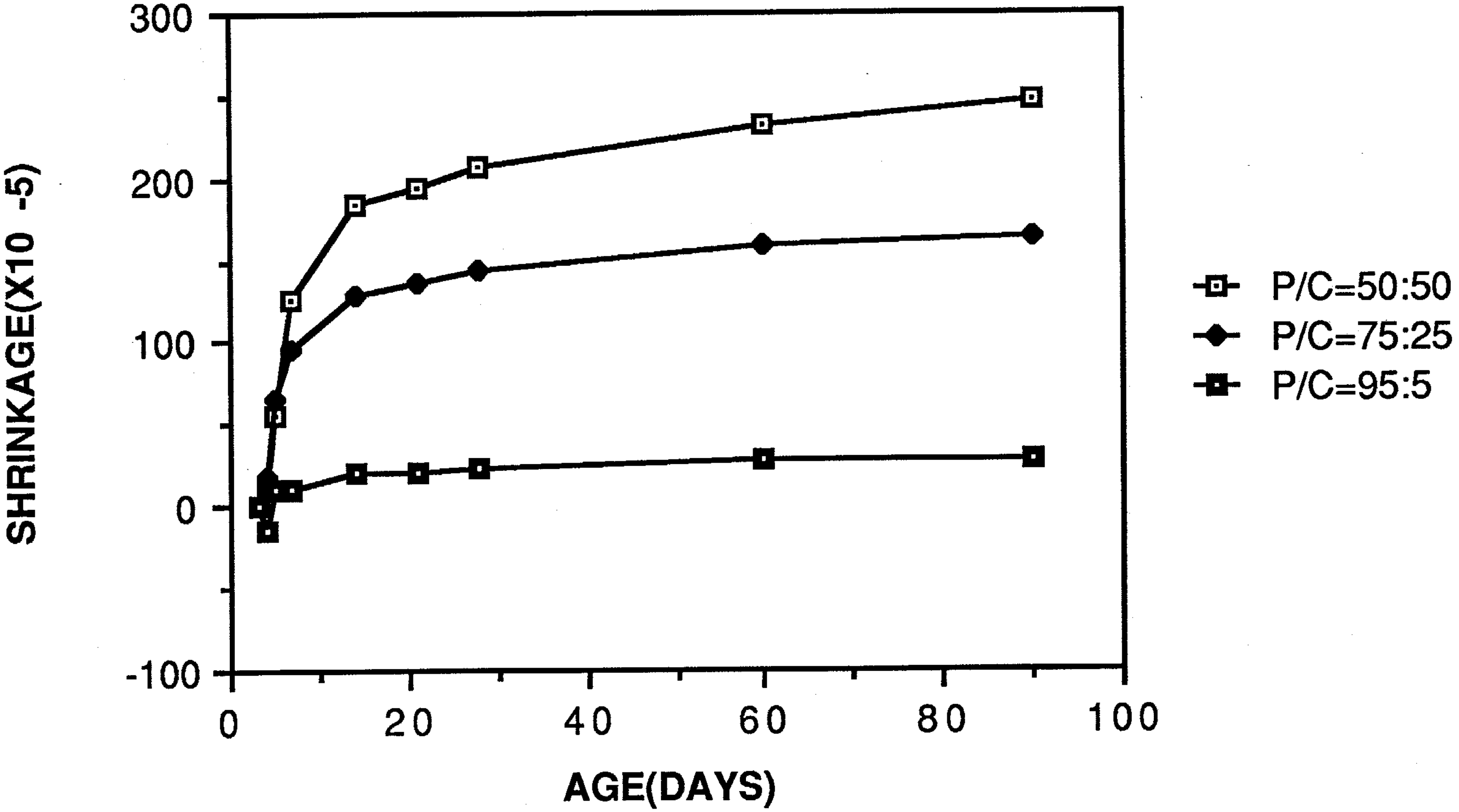


FIG.2 SHRINKAGE V.S. AGE(MC:16%)

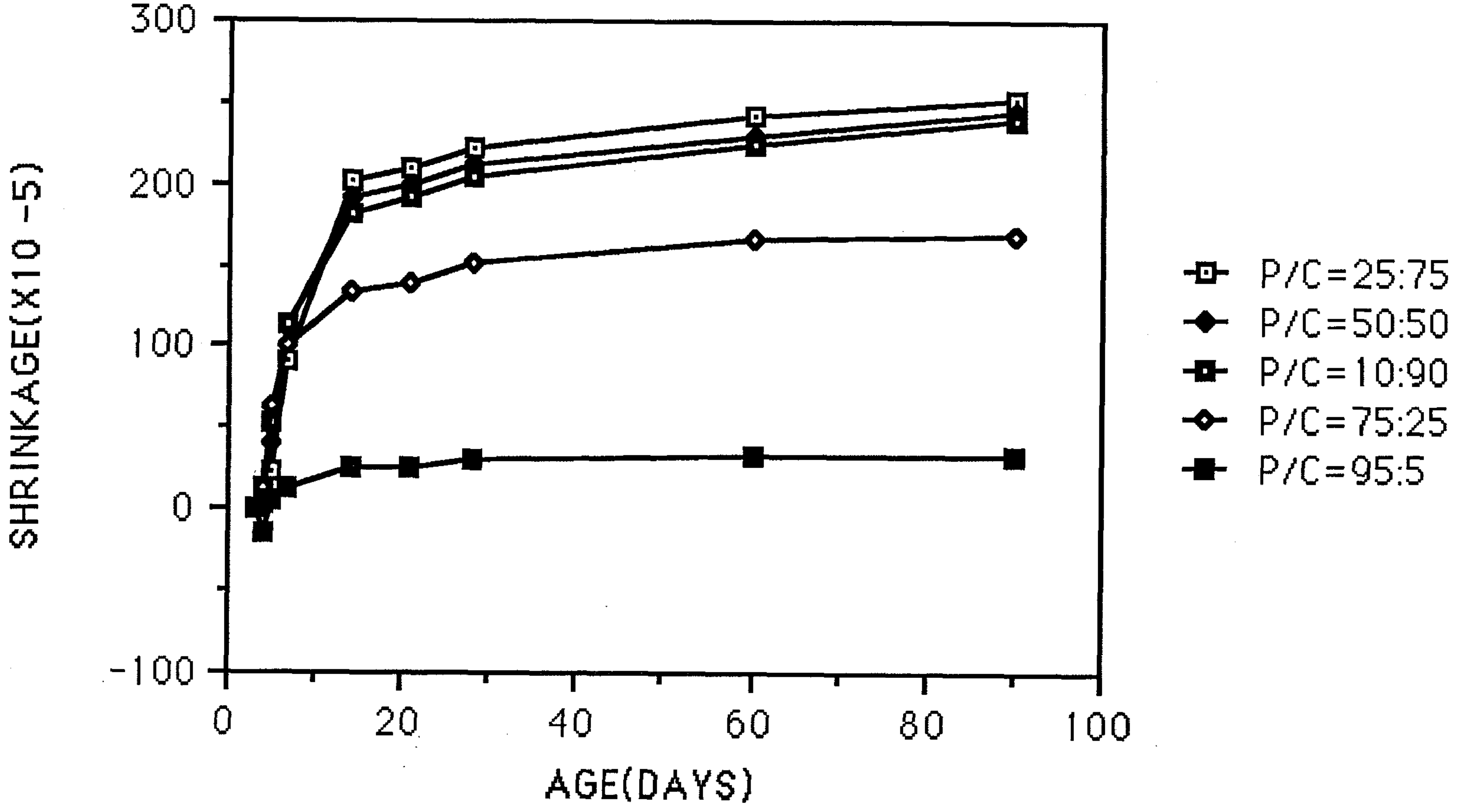


FIG.3 SHRINKAGE VERSUS AGE (MC:18%)

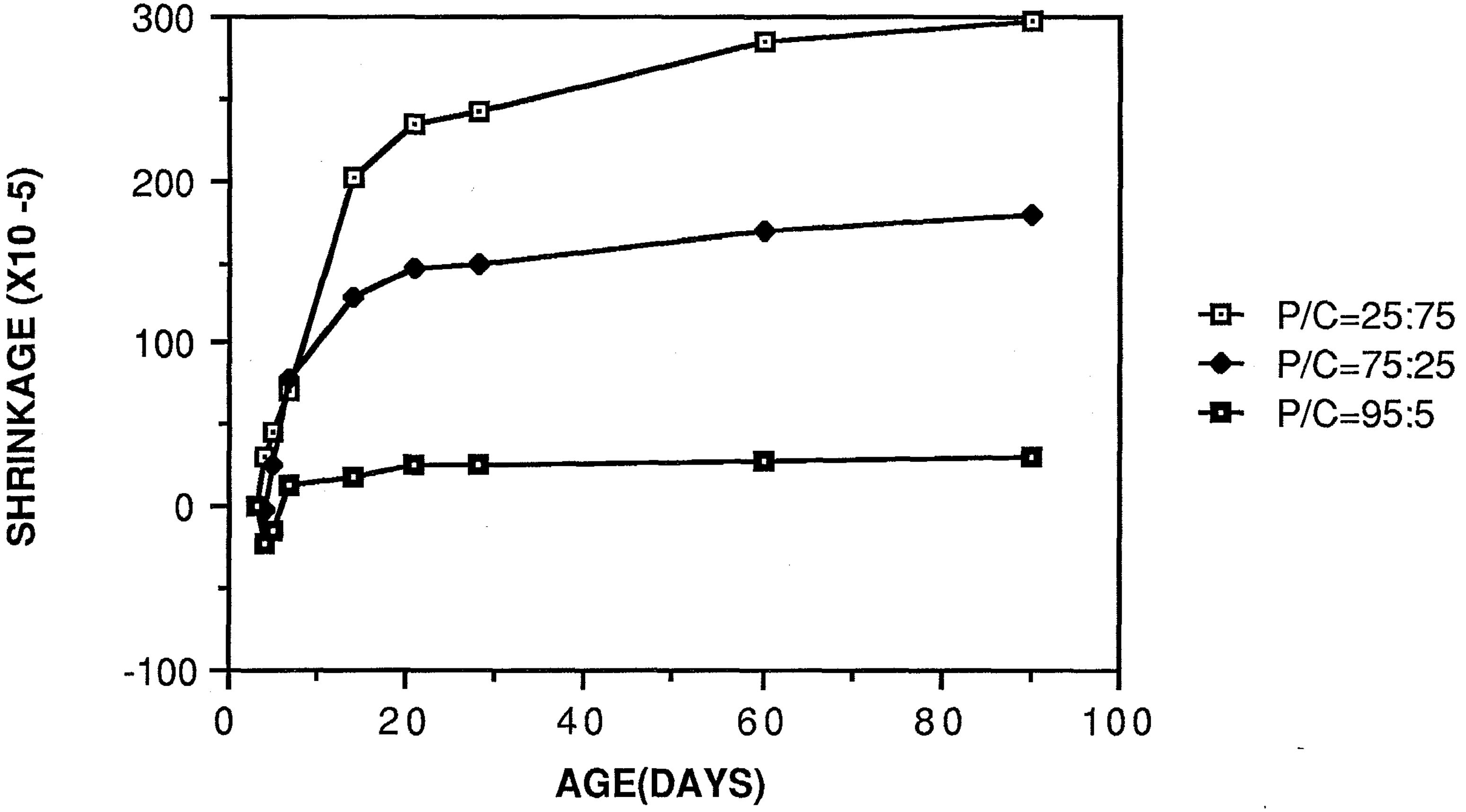


FIG.4 SHRINKAGE V.S. AGE(MC:20%)

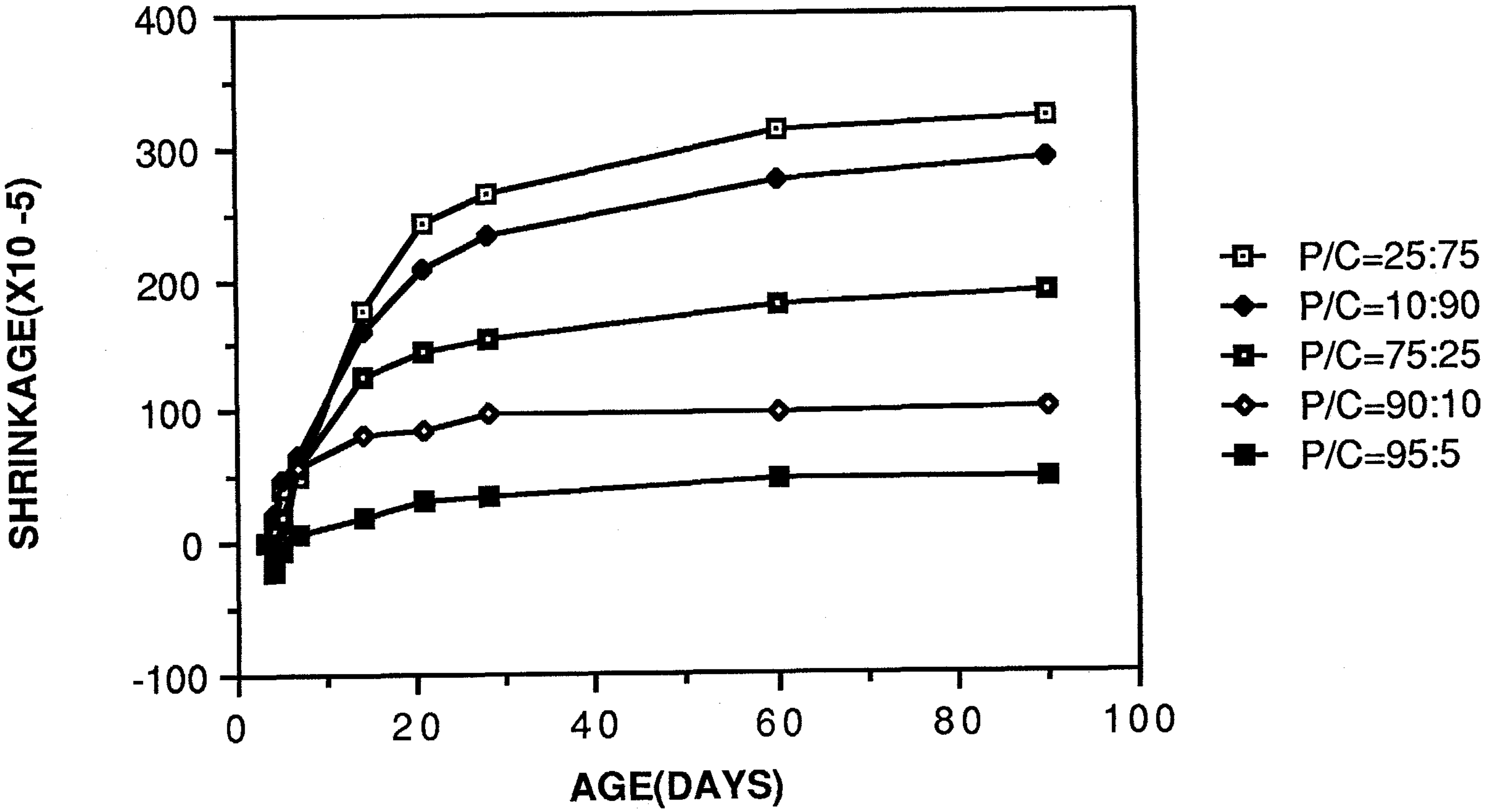


FIG.5 SHRINKAGE V.S. CEMENT CONTENT(MC:20%)

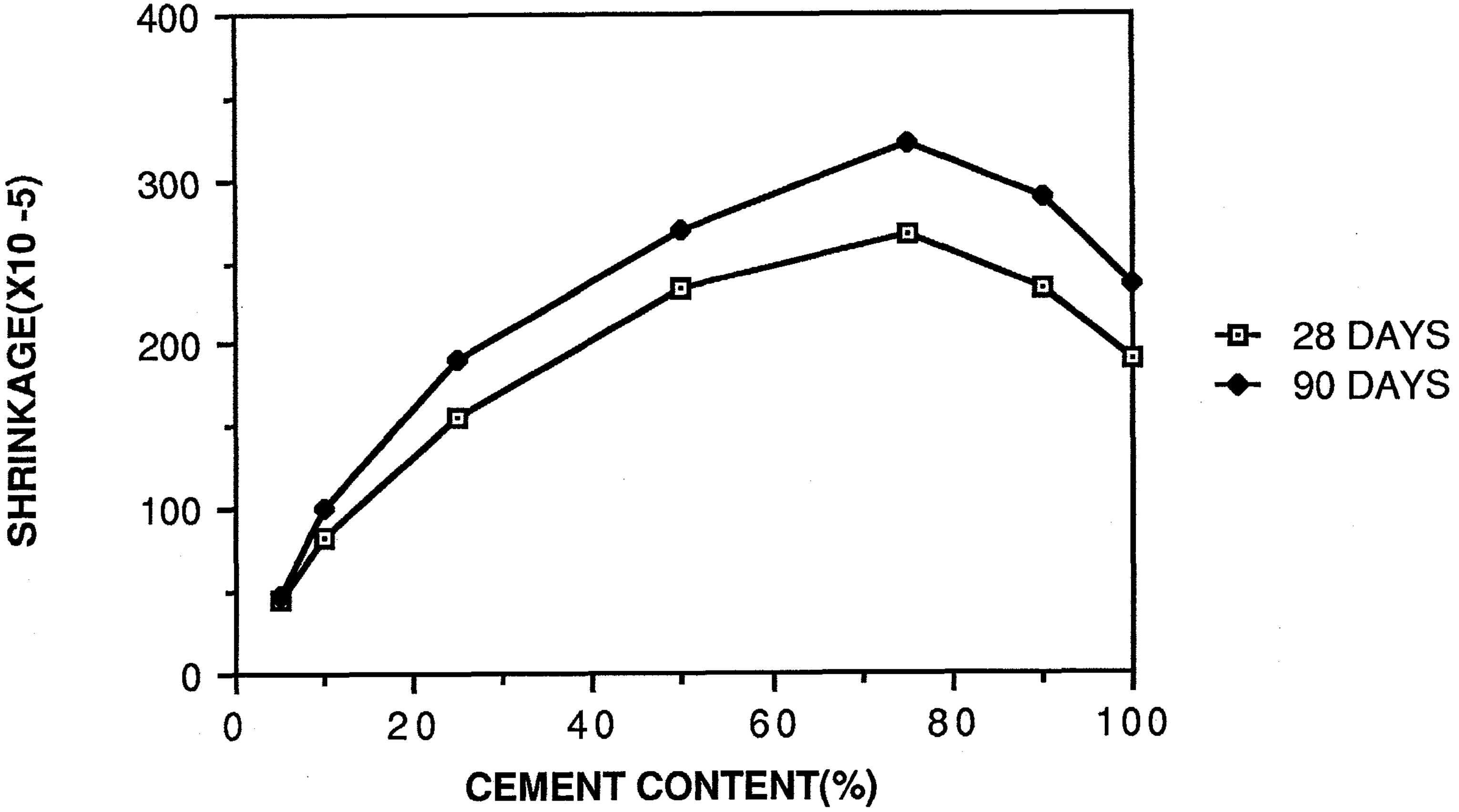


FIG.6 SHRINKAGE V.S. AGE(MC:20%)

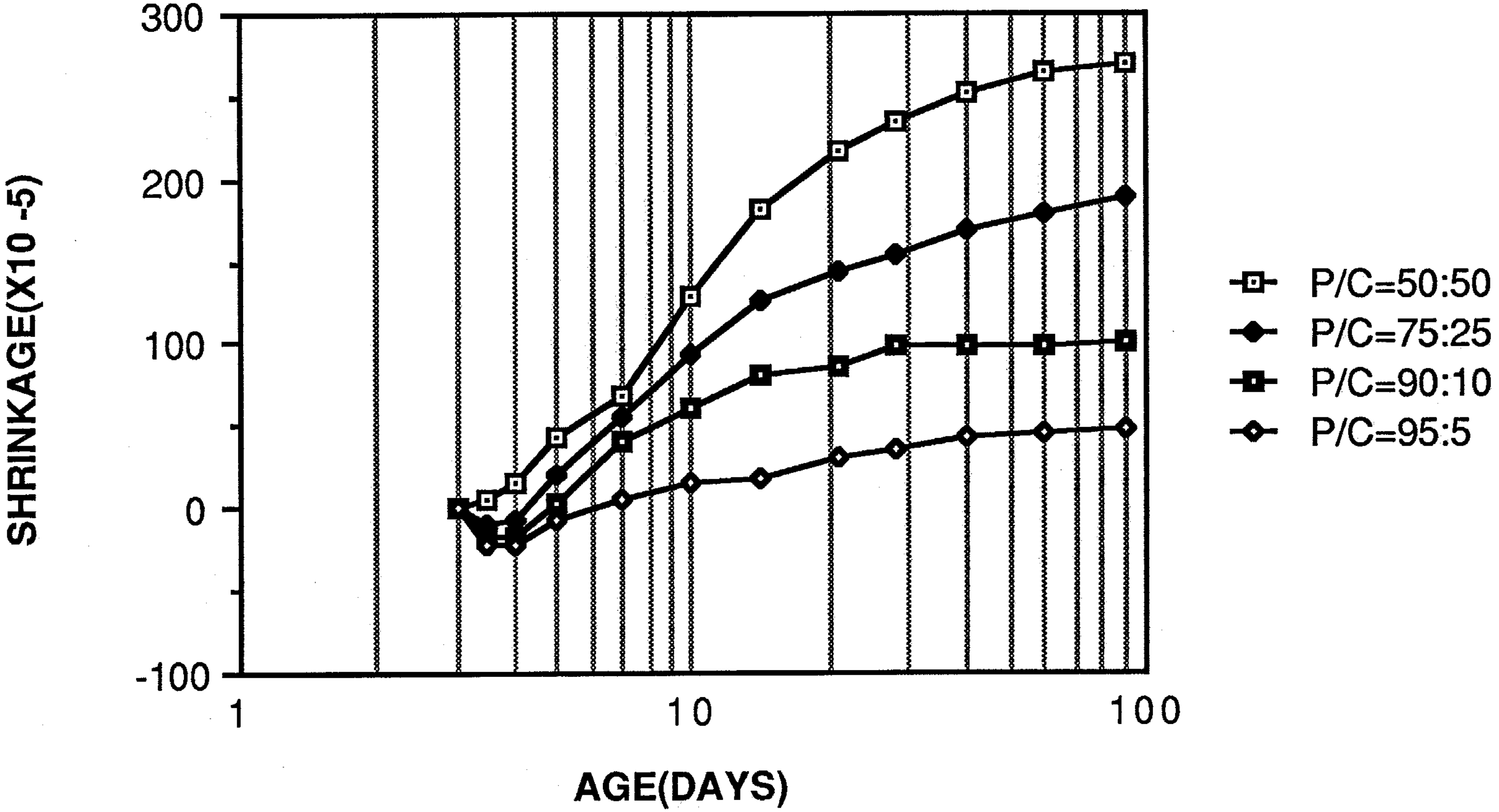


FIG.7 MCLOSS V.S. AGE(MC:20%)

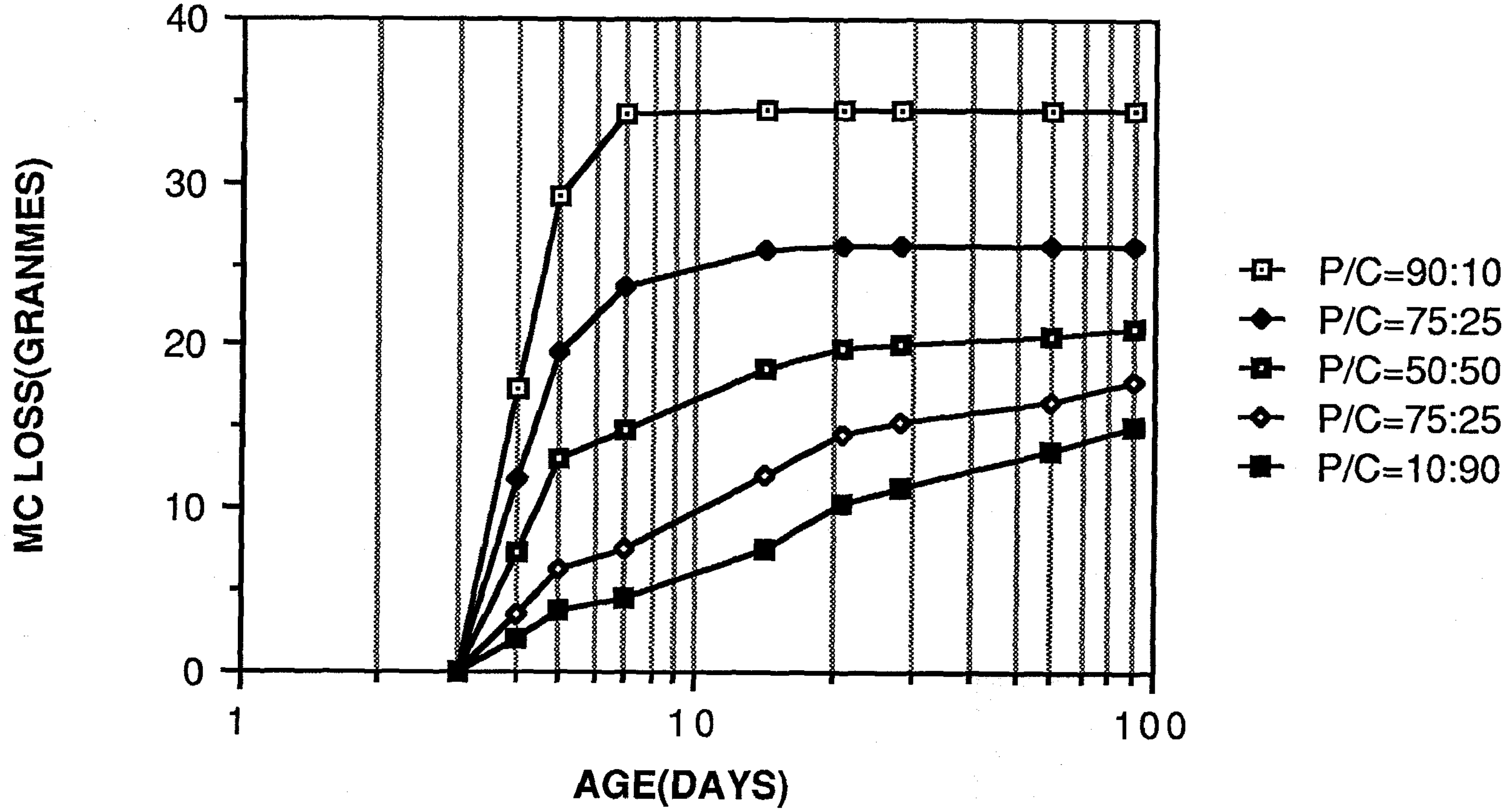


FIG.8 SHRINKAGE V.S. MC LOSS(20%MC)

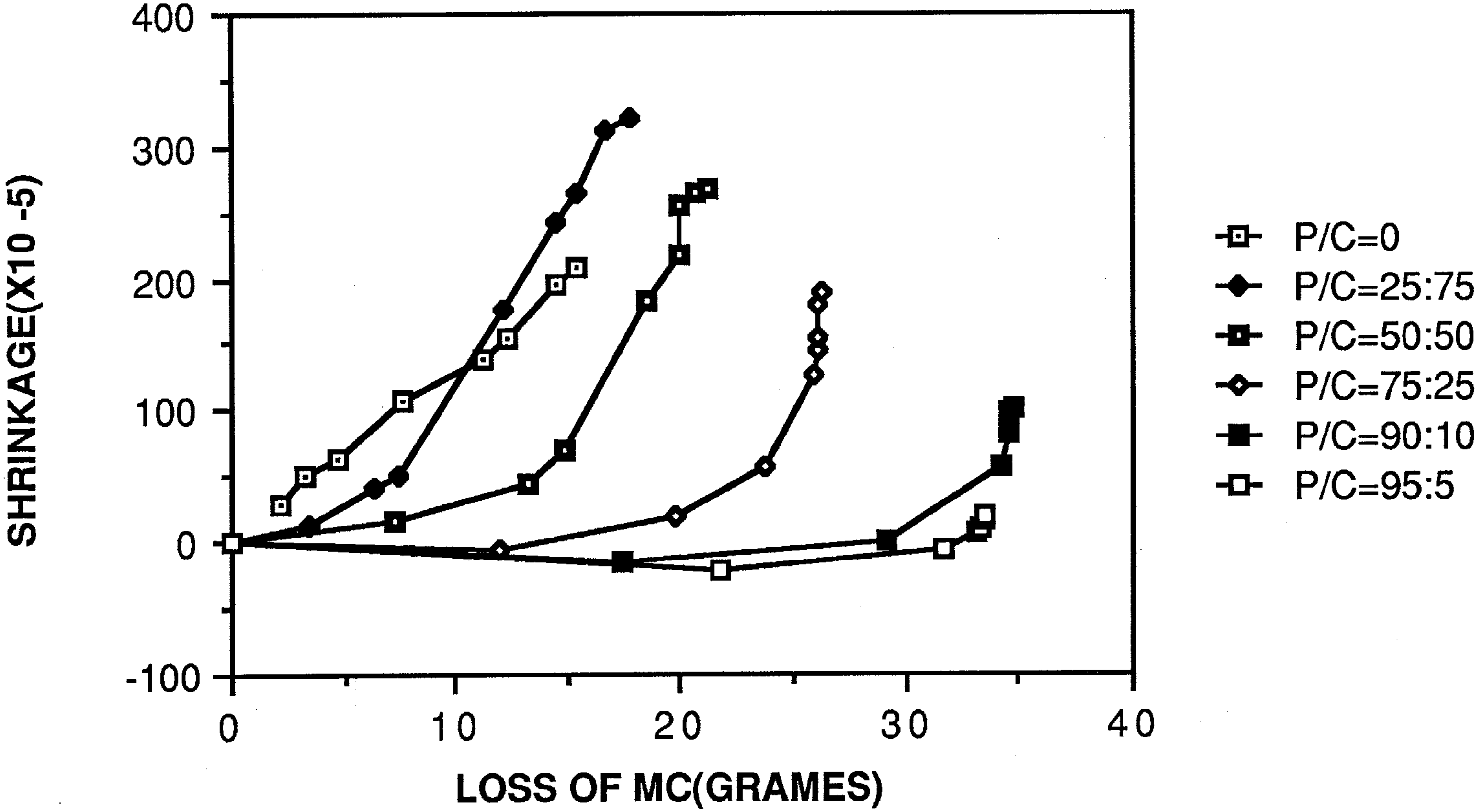


FIG.9 SHRINKAGE V.S. CEMENT CONTENT(90 DAYS)

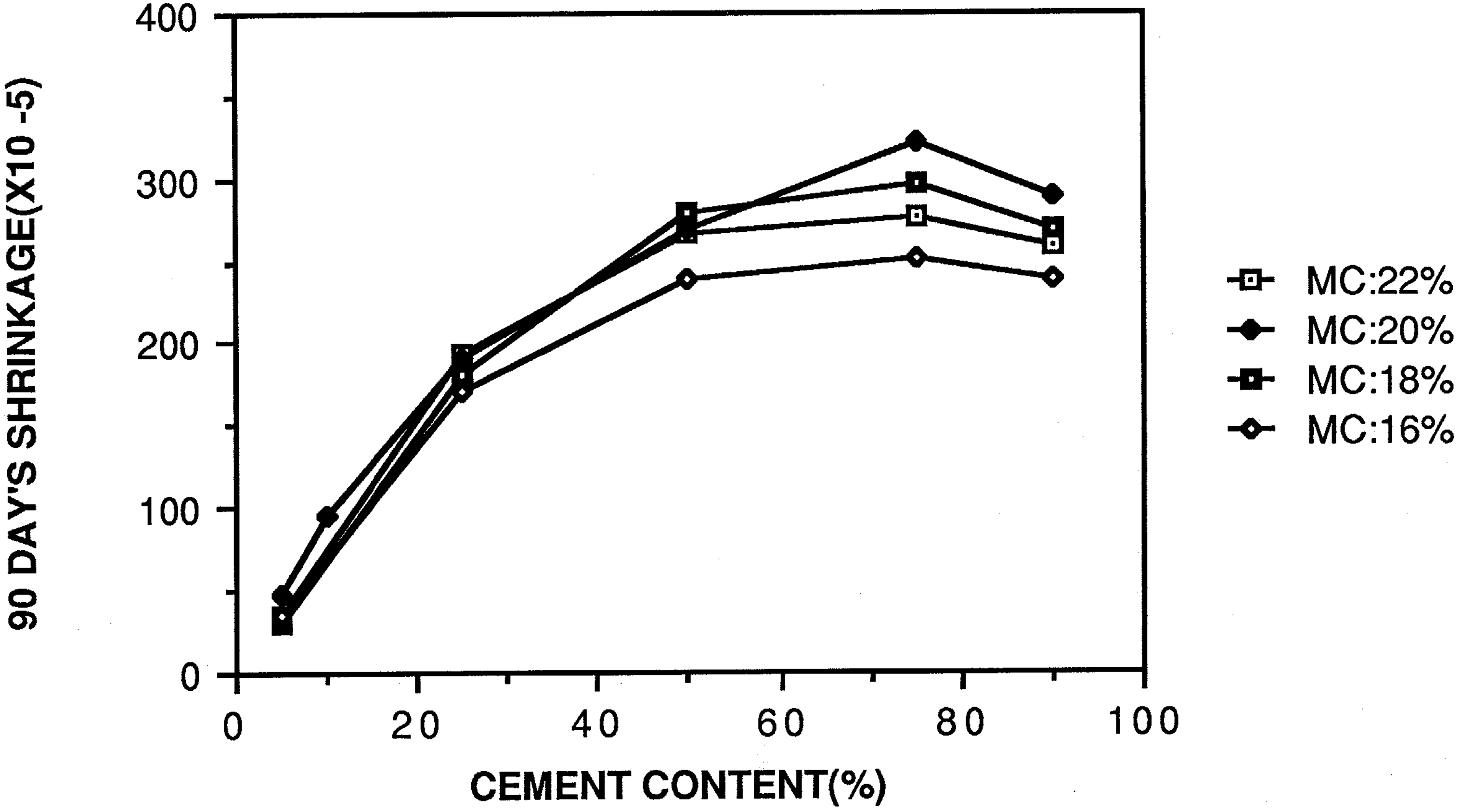


FIG.10 EFFECT OF CURING CONDITIONS(SEALED)

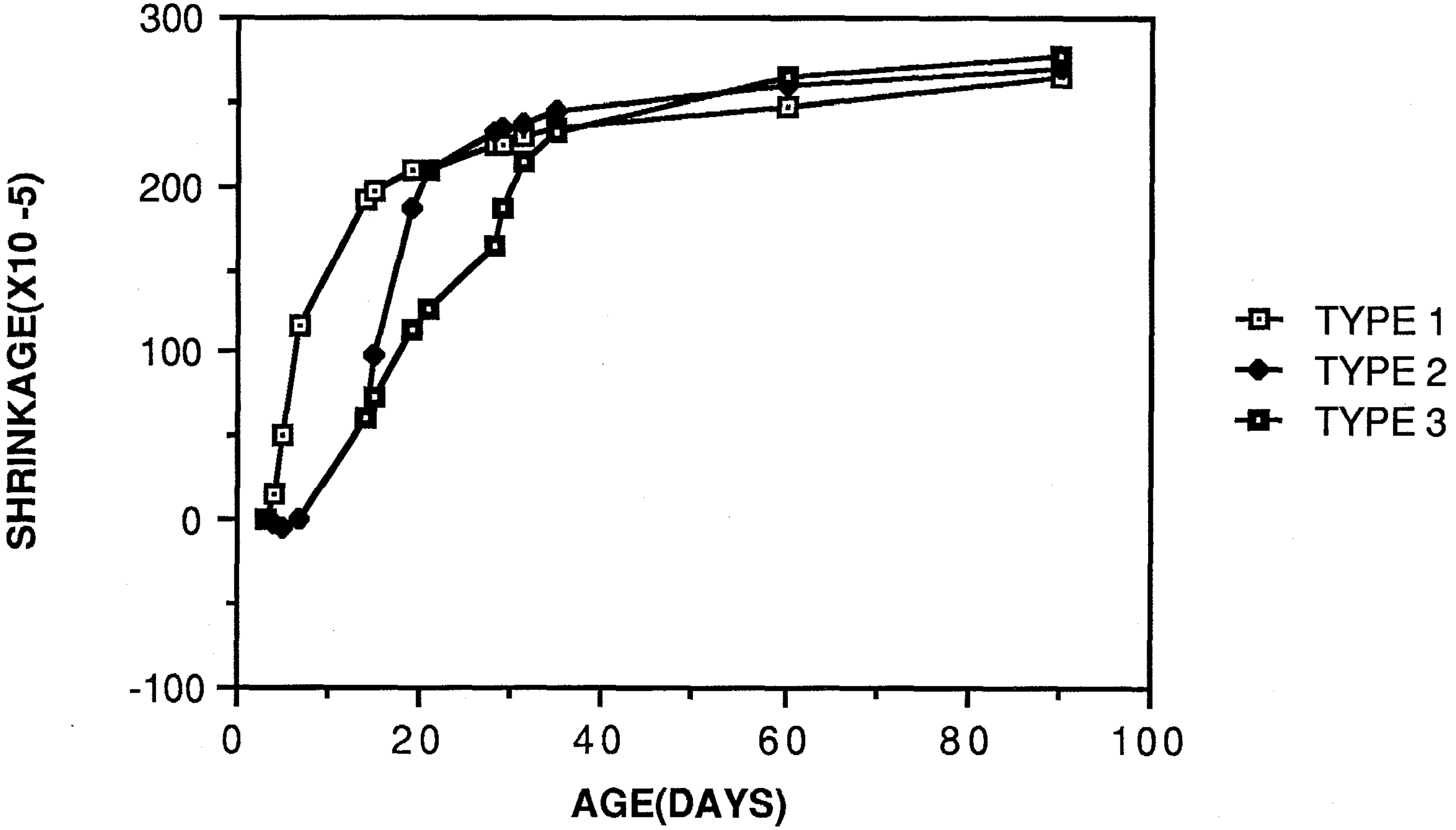


FIG.11 EFFECT OF CURING CONDITIONS(SOAKED)

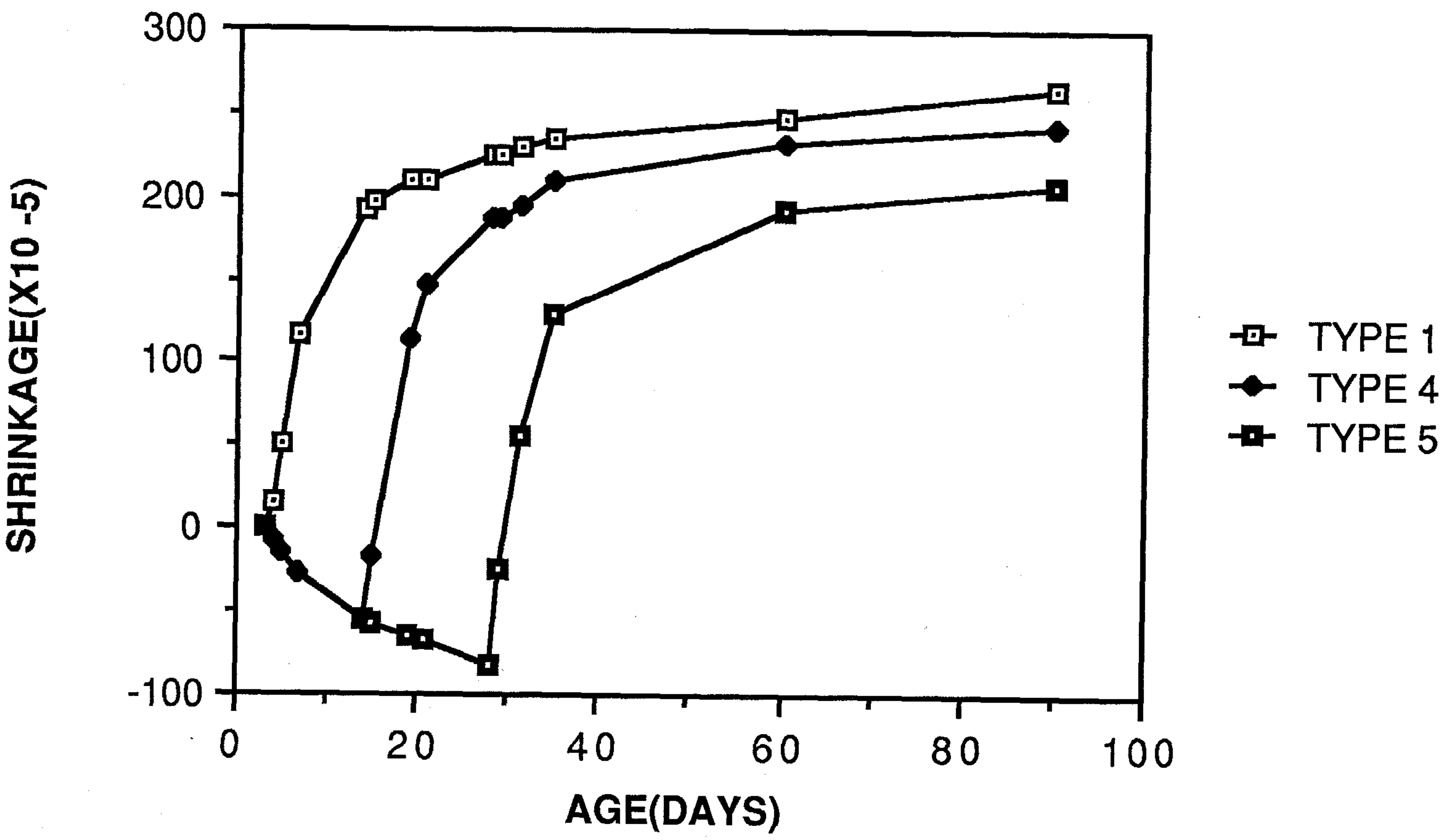


FIG.12 EFFECT OF R.H.(MC=16%)

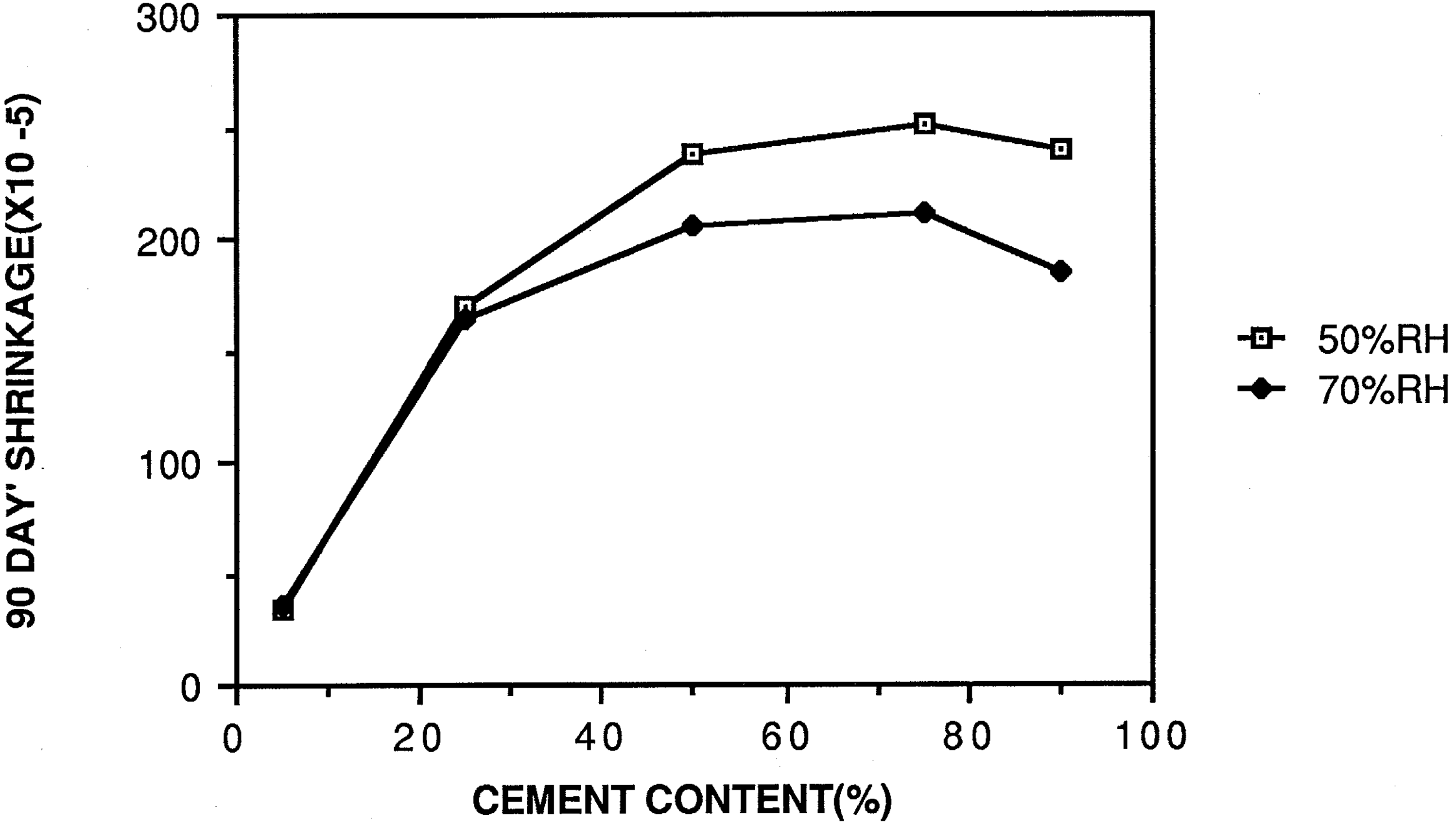


FIG.13 SHRINKAGE OF VIBRATION SPECIMENS

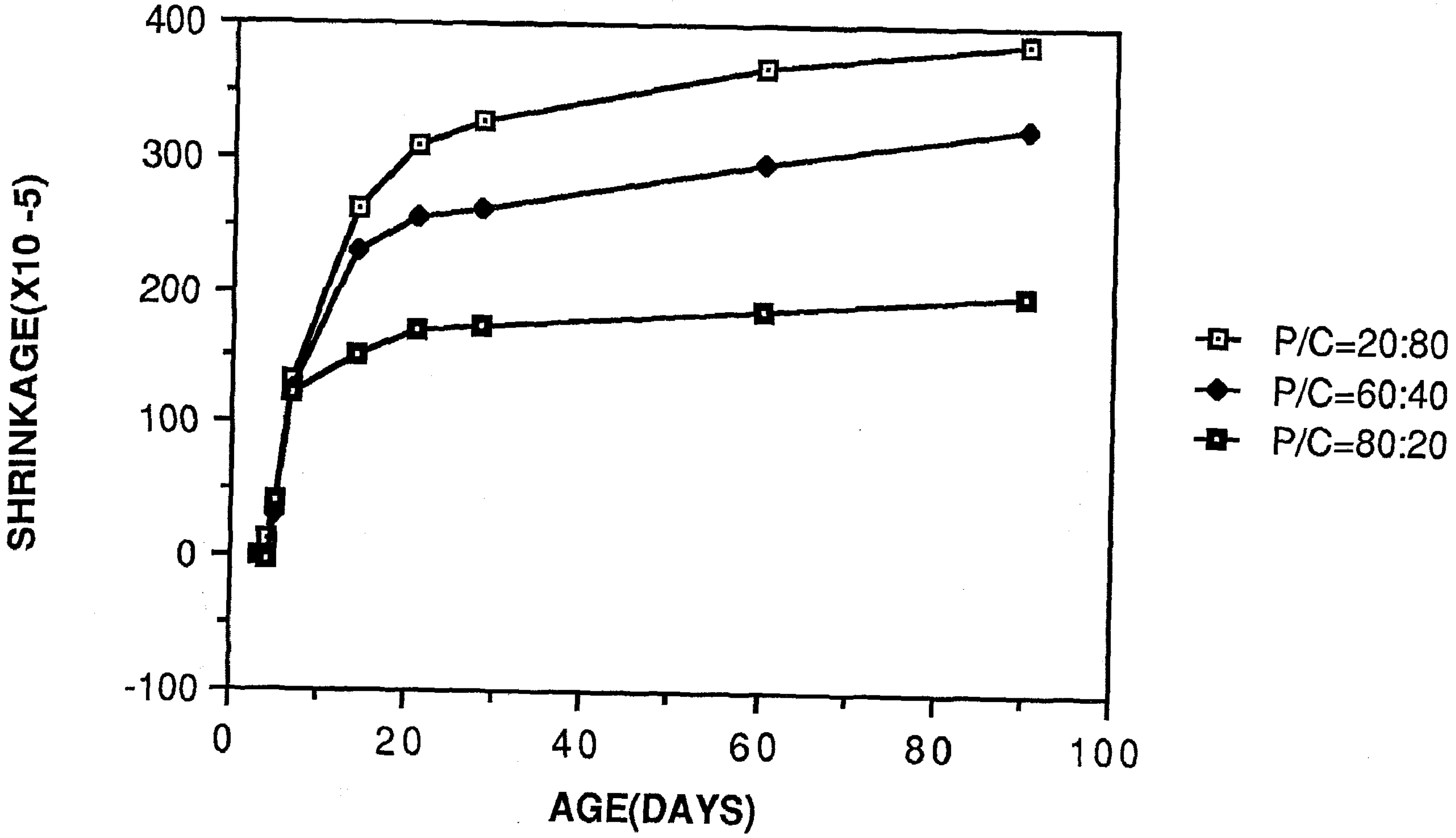


FIG.14 SHRINKAGE V.S. CEMENT FOR VIBRATION SPECIMENS

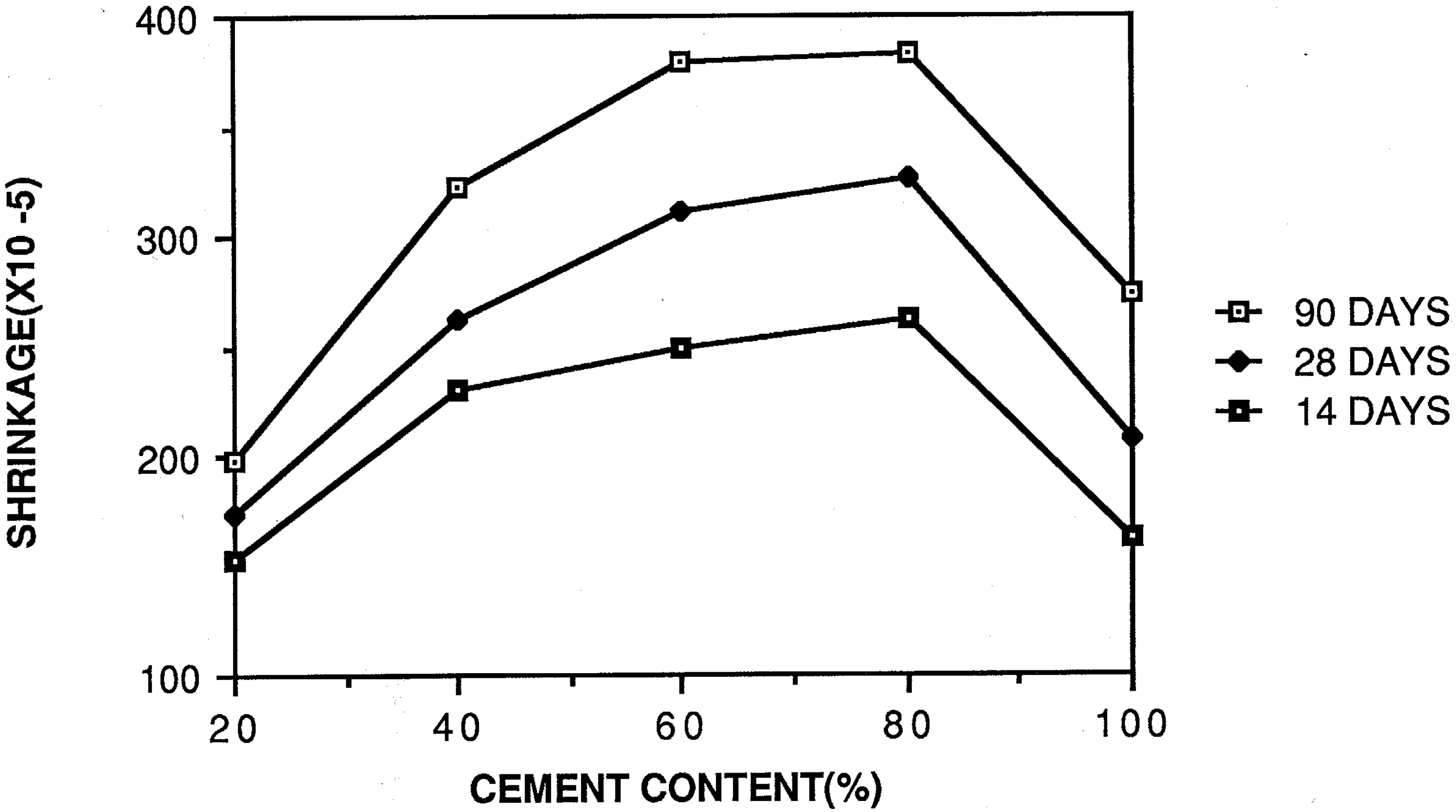


FIG.15 COMPARISON OF VIBRATION &COMPACTION

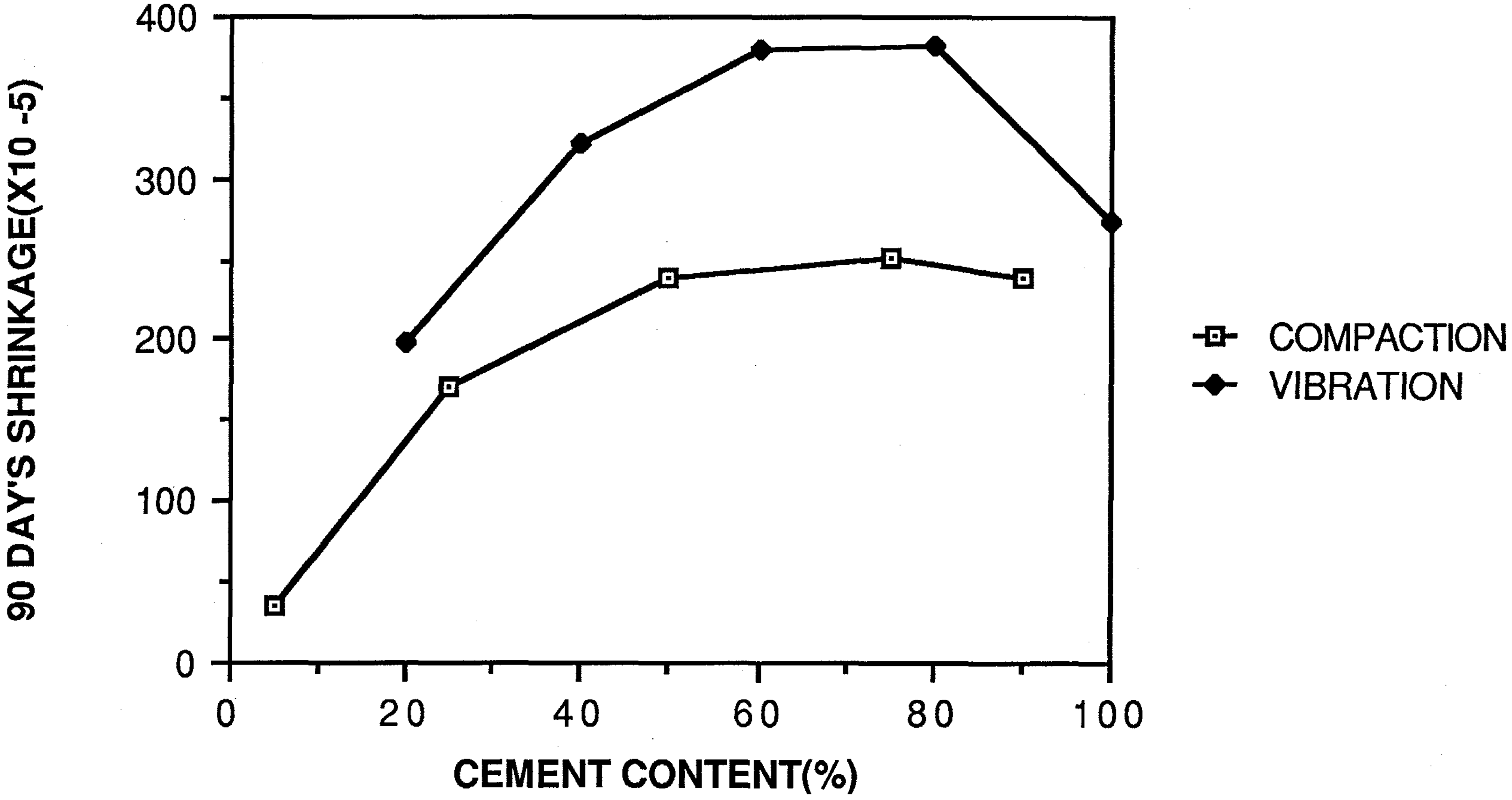


FIG.16 MC LOSS V.S. SHRINKAGE FOR VIBRATION

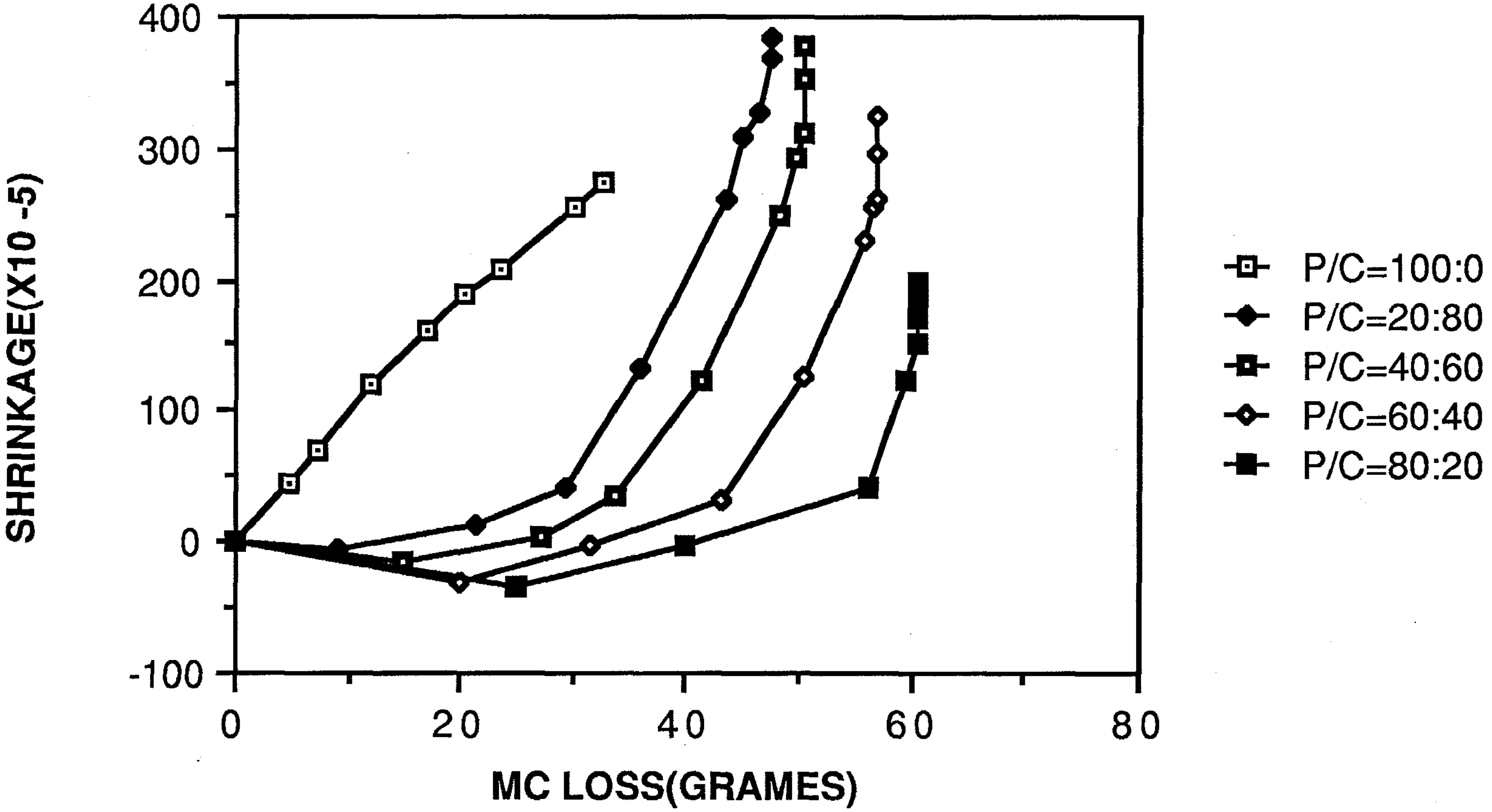
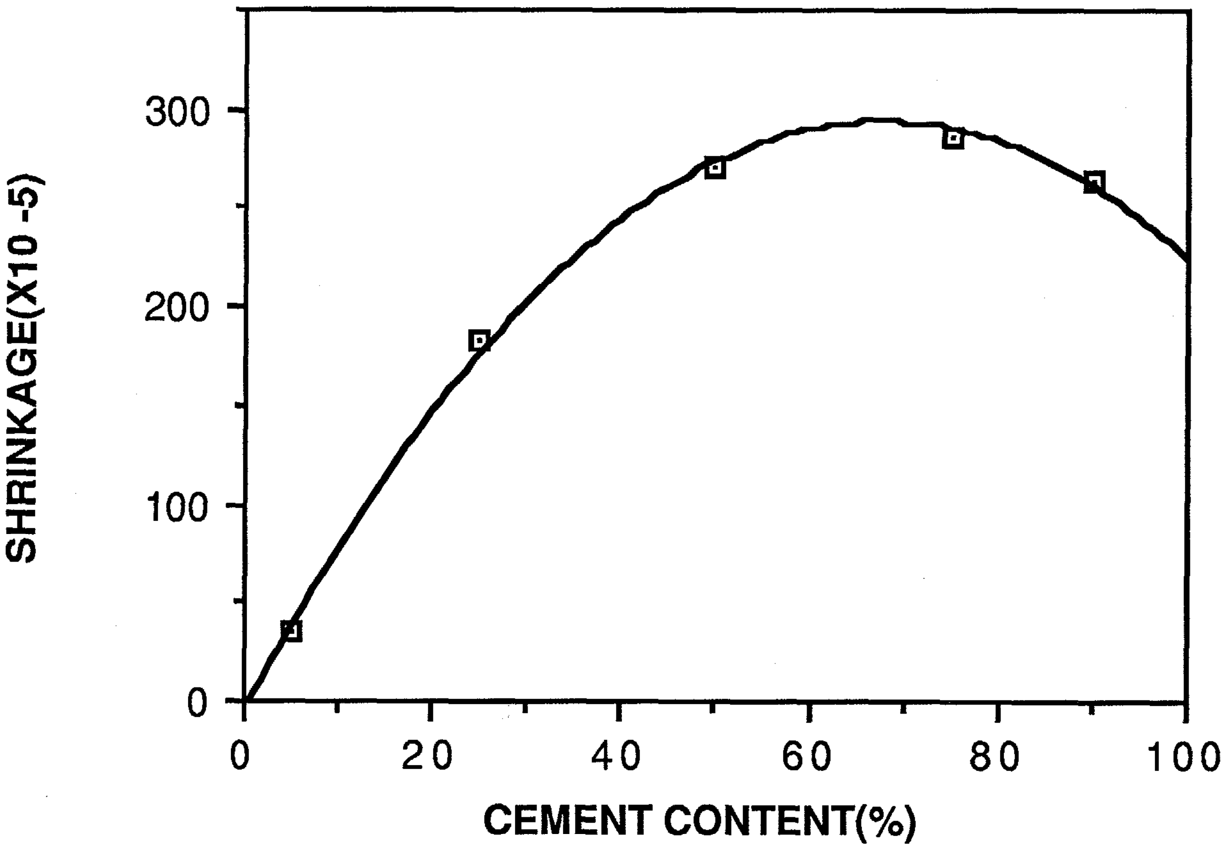


FIG.17 FITTING OF EMPIRICAL EQUATION



BASIC ENGINEERING PROPERTIES OF PHOSPHOGYPSUM-INCINERATOR FINE ASH BASED MIXTURES SUBJECTED TO COMPACTION

by
C.X. Ling[1] and W.F. Chang[2]

ABSTRACT

To develop further potentail applications of phosphogypsum in this paper, phosphogypsum is used as a binder to stablize incinerator fine ash, a solid waste prossessed poor binding properties. The basic engineering properties of phosphogypsum-ash-based materials were investigated, including water resistant, moisture-density-compaction pressure relationship, optimum moisture content and compression strength which is affected by some factors such as cement content, phosphogypsum /ash ratio, moisture content, compaction pressure and age. It is found that phosphogypsum possesses good binding properties under compaction and retains these properties when mixed with the fine ash, and phosphogypsum -ash-cement mixtures are of good water resistivity and compressive strength under static compaction.

KEYWORDS: phosphogypsum, incinerator fine ash, static compaction, engineering property.

---

[1] Ph.D. Candidate, Dept. of Civil Engineering, College of Engineering, University of Miami, Coral Gables, Florida.

[2] Ph.D., P.E., Professor and Director of Phosphate Research Institute, College of engineering, University of Miami, Coral Gables, Florida.

Introduction

Incinerator fine ash which may contain toxic materials comes from buring solid waste, i.e. municipal garbage. Virtually all of the incinerator fine ash is deposited in landfills. Such landfills should be specially designed to prevent groundwater and surface water contamination. The objective of this chapter is to stabilize and reuse the fine ash, combining with phosphogypsum, as a construction material.

The incinerator fine ash possesses poor binding property. It is difficult task to find useful applications. In this paper, phosphogypsum, which possesses good binding property after compacted, is combined with ash to form phosphogypsum-ash mixtures. The basic engineering properties of phosphogypsum-ash mixtures and phosphogypsum-ash-cement mixtures subjected compaction are Investigated. The significance of this effort is twofold: first, to find a potential applications for the two waste materials, second, to alleviate the pressure on the demand for aggregates in a region poor in this type of resource.

Two kind of mixtures, phosphogypsum-ash mixtures and phosphogypsum-ash-cement mixtures were studied in the course of experimentation. First, water resistant property of the mixtures with various proportions is investigated to establish the range of the material contents *for* the mixtures. Second, the relation among density, compaction pressure and moisture content is studied to obtain proper compaction energy and moisture content for the test of the mixtures. Then, the compressive strength properties are presented. The factors affecting the compressive strength of the mixtures, such as phosphogypsum/ash ratio, cement content, compaction pressure and test conditions, are studied.

1. Water Resistance of Phosphogypsum-Ash-Based Mixtures

Pure ash specimens possesses poor binding property, as shown *in* Table 1. The specimens were consolidated ranging from low compaction pressure of 1,500 psi to high compaction pressure of 24,000 psi with proper moisture contents and then sealed in plastic membrane for 28 days. There were visible cracks occurred on the surface of specimens of the pure ash specimens under compaction pressure of less than 6,000 psi after several days of sealed curing. No crack was observed on the surface of the specimens under compaction pressure of more than 12,000 psi. The signs "+" and "-" shown in Table 1 indicate these two situations.

No such binding problem occurs for phosphogypsum-ash mixture with 25 % phosphogypsum and 75 % ash and cement-ash mixture with 5 % cement and 95 % ash. The compaction pressure applied to both of the mixtures is as low as 1,500 psi. These facts illustate that both phosphogypsum and cement could improve the water resistance of the mixtures.

Water resistance of specimen is defined here as that there is no crack occured on the surface of the specimen after submerged in fresh water for more than two days (48 hours). To investigate water resistance of the phosphogypsum-ash-cement mixtures, specimens with cement content varying from 0% to 10% and phosphogypsum content varying from 0% to 75% were made. Two typical compaction pressure, 12,000 psi and 1,500 psi, were used to prepare the specimens. All of the specimens were sealed in plastic membranes for 7 or 28 days and then submerged in water for two days.

Table 2 through 4 present the results of the tests. The signs "+" or "-" mean that the specimen possesses positive or negative water resistance, respectively.

Table 2 gives the water resistance of phosphogypsum-ash mixtures (no cement). It can be seen that all of the pure ash specimens and the phosphogypsum-ash mixture at age of 7 days do not possess water resistant. All of the phosphogypsum-ash specimens at age of 28 days possess water resistance except those with phosphogypsum content of 25% and low compaction pressure, some of which cracked. It seems to indicate that the water resistivity of phosphogypsum-ash mixtures is improved with the age of the specimens.

Table 3 indicates the water resistance of phosphogypsum- ash -cement mixtures with cement content of 5%. Compared with Table 2, it is shown that the cement can improve water resistance of the mixtures with phosphogypsum/ ash ratio of 1/1 and 3/1 at the early age of 7 days.

If the cement content increases up to 10%, all of the ash-cement mixtures and phosphogypsum-ash-cement mixtures possess good water resistance property, as shown in Table 6.4.

To be summary, the effect of factors on water resistance can be repeated as follows:

(1) Cement and phosphogypsum contents are the most important factors improving the water resistance of the mixtures.
(2) Water resistance of phosphogypsum-ash based mixtures is improved with the age of specimens under sealed curing.

2. Relation Among Compaction Pressure, Density and Moisture Content of Phosphogypsum-Ash-Cement Mixtures

For specimens consolidated by static compaction, moisture content is an important factor affecting density, strength and other engineering properties. Under static compaction, moisture acts as a lubricant between particles of the materials in order to achieve adequate compaction density. If excessive water is provided, it will migrate within the specimens and accumulate on the specimen top and bottom surfaces. This surplus water and its migration may soften the already compaction solid material and have a harmful effect on the strength properties. Therefore, it is neccessary to find the relationship among compaction pressure, density and moisture content and to find the optimal moisture content for phosphogypsum-ash-cement mixtures with different proportions under varying compaction pressures.

The optimum moisture content is defined as the experimentally found maximum moisture content at which the moisture in mixture is not pressed out at the given compaction pressure. This definition was introduced by Skalny and Bajza (1970) in early work on cement paste. Under a certain static compaction, moisture in specimen acts as a lubricant between particals and helps obtaining higher density. If excessive moisture is provided, it will migrate within the specimens and accumulate at the specimen top and bottom surfaces. This surplus water and its migration may have a harmful effect on the strength properties.

2.1. Relation between Compaction Pressure and Density

Figure 1 shows the relation between compaction pressure and density of phosphogypsum-ash-cement mixtures. The mixtures consist of 10% cement, 45% phosphogypsum and 45% ash and moisture content varies from 10% to 25%. The density generally increases with pressure as expected. For a certain pressure, say 140psi and 430psi in Figure 2, the density of the specimens is increased with moisture content. This illustrates the lubricant action of the moisture content in the specimens. However, for specimen with a certain moisture content, there is a maximum compaction pressure over which moisture will be pressed out. As the compaction pressure is increased the optimum moisture is decreased.

It is observed from experimental data (Ling, l990) that phosphogypsum/ash ratio only has little effect on the relationship between compaction pressure and density within the range of 10% to 20% moisture contents. Therefore, the relation can be simplified by taking the average density of specimens with different phosphogypsum/ash ratio. Figure 3 has the regression curves for relation between compaction pressure and density with different moisture contents.

2.2. The Ralation among Compaction Pressure, Optimum Moisture Content and Density

From the data in (Ling, 1990), the relation between optimal moisture moisture content and compaction pressure and relation between optimum moisture content and maximum density can be expressed by the following simple equations.

$$\frac{1}{MC} = 0.0332+(1.268*Pr-0.0584*Pr^{2})*100 \qquad (1)$$

$$DS = 139-1.28*MC \quad (2)$$

where MC(%) = Optimum moisture content
Pr(ksi) = Compaction pressure
DS(lb/ft 3) = Maximum density

The two equations were plotted in Figure 4 and 5. As shown in the figures, the optimum moisture content decreases as the compaction pressure increases. For a certain compaction pressure, the optimum moisture content MC can be obtained from equation(l). The density of the specimen, under this compaction pressure Pr and with the optimum moisture content MC, can be calculated by using equation(2).

2.3. Effect of Cement Content on Optimum Moisture Content

Equation (2) for optimal moisture content is applies to the phosphogypsum-ash-cement mixtures containing 10% cement content. For the mixtures with different cement, content, experimental results indicate that the relation between cement content and optimum moisture content is linear, as shown in Figure 6. The relation can be expressed as follow :

$$Fc = 0.94 + 0.0062\ Ce \quad (3)$$

where Fc = cement effect factor
Ce(%) = cement content

This relation only applies to the phosphogypsum-ash-cement mixtures with cement content between 0% and 20% which was the range of the experiments in this chapter.

3. Compressive Strength of Phosphogypsum-Ash Mixtures

All of the specimens for compressive strength were sealed in the membrance for 28 days unless otherwise noted. The moisture content used was calculated by using equations (1) and (3).

3.1. Effect of Phosphogypsum/Ash Ratio on Compressive Strength

Figure 7 shows the effect of phosphogypsum /ash ratio on cornpressure strength of phosphogypsum-ash mixtures. The phosphogypsum/ash ratios used in this experiment are, 0/1, 1/3, 3/5, 1/1, 5/3 and 3/1 with respect to compaction pressure of 3 ksi. It is shown that there is a certain phosphogypsum ratio at which the strengths under the three testing conditions are maximum. These curves indicate the interaction between phosphogypsum and ash in these mixtures. Phosphogypsum content improves the binding ability of the mixtures in the range of phosphogypsum/ash ratio from 1/3 to 1/1 and the strength increases with the phosphogypsum /ash ratio. However, the strength decreases with phosphogypsum /ash ratio if the ratio is beyond 1/1.

3.2. Effect of Compaction Pressure on Compressive Strength of Phosphogypsum-Ash Mixtures

Figure 8 shows the effect of compaction pressure on compressive strength of phosphogypsum-ash mixtures. The figure indicates that compressive strength of phosphogypsum -ash mixtures depend on compaction pressure. As the compaction pressure increases, the resulting compressive strength also increases due to the increase of density. In the mixtures with higher compaction pressure, the phosphogypsum has a better binding ability which helps increasing the strength.

3.3. Effect of Testing Conditions on Compressive Strength of Phosphogypsum-Ash Mixtures

Three types of testing conditions were used in this experiment. They are air-dry testing condition , sealed testing condition and soaked testing condition. All of them are defined as follows:

Air-dry testing condition: specimens are sealed in plastic membrame for a period of 26 days. And then the specimens are allowed to dry quickly under a electric fan for 48 hour before tested.

sealed testing condition : specimens are sealed in plastic membrame for a period of 28 days.

soaked testing condition : specimens are sealed *in* plastic membrame for *a* period of 26 days. And then the specimens are submerged in water for 48 hours before tested.

From Figure 7, it can be seen that the compressive strength of the mixtures under air-dry condition is generally higher than those under sealed and soaked conditions. It seems that phosphogypsum/ash ratio affects the strength of the mixtures greater for air-dry condition than far soaked condition.

Figure 9 gives the relative strength with different testing conditions. The relative strength is defined as the ratio of strength under various testing conditions to the strength under air-dry testing condition. The relative strength for sealed testing condition varies from 0.67 to 0.84 and the relative strength for soaked testing condition varies from 0.42 to 0.68. The averages are respectivly 0.75 to 0.55.

3.4. Effect of Age on Compressive Strength of Phosphogypsum-Ash Mixtures

In all of previous cases, the tests were done only at the age of 28 days of specimens. In this section, the compressive strength of phosphogypsum-ash mixtures were tested at different ages. Figure 10 shows the effect of age on strength of phosphogypsum-ash mixtures. Similar to compressive strength of ordinary concrete, the strength of phosphogypsum-ash mixtures at age of 28 days is considerably different from those of at age of 7 days and 60 days.

Although the physical and Chemical reaction in phosphogypsum -ash mixtures is not well known, it is certain that the strength of phosphogypsum-ash mixtures increases with the age of specimens.

4. Compressive Strength of Phosphogypsum-Ash-Cement Mixtures

All of the specimens for compressive strength were sealed in the membrance for 28 days unless otherwise noted. The moisture content used were calculated by using equations (1) and (3).

4.1. Effect of Phosphogypsum/ash Ratio on Compressive Strength of Phosphogypsum-Ash-Cement Mixtures

It is expected that compressive strength of phosphogypsum -ash mixtures greatly increases as cement is added into the mixtures. Cement acts as a binder which increases the strength of the mixtures, particularly in soaked condition. Furthermore, cement gel itself is much stronger than hardened phosphogypsum -ash mixtures. To investigate the compressive strength of phosphogypsum-ash-cement mixtures, 10% cement content was used in this paper unless otherwise noted. Figure 11 shows the compressive strength of phosphogypsum-ash-cement mixtures subjected to compaction pressure of 1500psi. It seems that the binding action of phosphogypsum becomes less important due to the addition of cement. Compressive strength of phosphogypsum- ash-cement mixtures increases from phosphogypsum/ ash ratio of 1/3 to 3/5 and decreases from 3/5 to 3/1. For the mixtures subjected to high compaction pressure of 12ksi, the compressive strength increases with phosphogypsum/ash as shown in Figure 12. This means that phosphogypsum is of better behavior of compaction.

4.2. Effect of Compaction Pressure on Compressive Strength of Phosphogypsum-Ash-Cement mixtures

Static compaction pressure from 1.5 ksi to 12 ksi were applied for compaction of phosphogypsum-ash-cement mixtures. Specimens were compacted at optimal moisture content corresponding to each compaction pressure. Figure 13 shows the effect of compressive strength of phosphogypsum- ash-cement mixtures. As shown in the figure, the compressive strength of phosphogypsum-ash- cement mixtures greatly depends on the compaction pressure, especially under air-dry and sealed testing conditions. From this figure, it can be seen that the compressive strength of the mixtures increases almost linearly under air-dry and sealed testing conditions with the compaction pressure from 1.5 ksi to 12 ksi. This indicates that compaction pressure play a very important role in compressive strength of the mixtures.

4.3. Effect of Testing Conditions on Compressive Strength of Phosphogypsum-Ash-Cement Mixtures

Three types of testing conditions were used which have been defined in section 3.3. Figure 11 and 12 indicate that the compressive strength of phosphogypsum-ash- cement mixtures under air-dry condition is generally higher than those under sealed and soaked conditions.

4.4. Effect of Age on Compressive Strength of Phosphogypsum-Ash-Cement Mixtures

In this section, effect of age on compressive strength of phosphogypsum-ash-cement mixtures is investigated. Figure 14 shows the effect of age on the strength. Phosphogypsum/ash ratio of 1/1 and cement content of 10% were used to prepare the specimens. Compaction pressure was 1.5 ksi. Specimens were sealed in membrance for 7, 28, 60 days, respectively. Tests were performed under the three testing conditions. It is seen that the compressive strength of the mixtures under three testing conditions increases with the age of the specimens as expected.

4.5. Effect of Cement Content-on Compressive Strength of Phosphogypsum-Ash-Cement Mixtures

For all of phosphogypsum-ash-cement mixtures above, only 10% cement was used. To investigate the effect of cement content on compressive strength of phosphogypsum-ash-cement mixtures, several cement content were used in this section. The phosphogypsum/ash ratio of 1/l and the optimal moisture contents corresponding to the mixtures are used (see equations (1) and (3)). Compaction pressure was 1.5 ksi. Test were performed under three testing conditions.

Figure 15 gives the effect of cement content on the compressive strength. it is shown that the compressive strength of phosphogypsum-ash-cement mixtures greatly depends on cement content under all of the testing conditions as expected.

5. Conclusions

(1) Pure ash specimens possess very poor binding property. Pure ash can be stabilized by adding 25% phosphogypsum or 5% cement under the low compaction pressure of l.5ksi.

(2) Strength as well as water resistivity of the ash can be improved by adding a mimimum of 25% of phosphogypsum or 5% of cement under compaction pressure of not less than l.5ksi.

(3) Strength properties of phosphogypsum-ash mixtures as well as phosphogypsum-ash-cement mixtures improve with age.

(4) Compressive strength of phosphogypsum-ash mixture increases approximately in proportion to compaction pressure.

(5) The compressive strength of the phosphogypsum-ash mixtures under air-dry condition is generally higher than those under sealed and soaked conditions due to the reduction of internal friction of specimens.

(6) Compaction pressure has a marked effect on strength of phosphogypsum- ash-cement mixtures. The compressive strength of the mixtures increases linearly under air-dry and sealed testing conditions with the compaction pressure from 1.5ksi to 12ksi.

6. ACKNOWLEDGEMENTS

This research was made possible by a grant from the Florida Institute of Phosphate Research, Bartow, Florida, to the University of Miami, College of Engineering, Coral Gables, Florida.

7. REFERENCES

[1] C.X. Ling, Deformation and Strength of Phosphogypsum- based Mixtures Subjected to Static Compaction, 1990, Ph.D Thesis, University of Miami, Coral Gables, Florida.

[2] K.T. Lin, A. Manni and W.F. Chang, Compressive Strength of Compected Portland-Based Mixtures Using Phosphogypsum on Consolidation of Concrete, 1986, Symposium on Consolidation of Concrete, ACI Annual Convention, San Francisco. CA.

[3] K.T. Lin, Basic Engineering Properties of Phosphogypsum- Based Mixtures Subjected to Compaction, 1987, Ph.D. Thesis, University of Miami, Coral Gables, Florida.

Table 1. Condition of Ash Specimens under Sealed Curing

pressure (psi)	1,500	3,000	6,000	12,000	24,000
Specimen Condition	–	–	–	+	+

NOTE: – cracks on surface
+ no cracks on surface

Table 2. Water Resistance of Phosphogypsum-ash mixture (no cement)

Pressure	Age	Gypsum(%)/Ash(%)			
		0/100	25/75	50/50	75/25
High (12 ksi)	7 days	–	–	–	–
	28 days	–	+	+	+
Low (1.5ksi)	7 days	–	–	–	–
	28 days	–	+–	+	+

NOTE: – no water resistance
+ water resistant
+– unstable

Table 3. Water Resistance of Phosphogypsum-ash-cement mixtures(5% cement)

Pressure	Age	Gypsum(%)/Ash(%)			
		0/95	23/72	47/48	72/23
High (12 ksi)	7 days	–	–	+	+
	28 days	–	+	+	+
Low (1.5ksi)	7 days	–	–	+	+
	28 days	–	+–	+	+

NOTE:
– no water resistance
\+ water resistant
+– unstable

Table 4. Water Resistance of Phosphogypsum-ash-cement mixtures(10% cement)

Pressure	Age	Gypsum Content (%)			
		0/90	20/70	45/45	70/20
High (12 ksi)	7 days	+	+	+	+
	28 days	+	+	+	+
Low (1.5ksi)	7 days	+	+	+	+
	28 days	+	+	+	+

NOTE:
– no water resistance
\+ water resistant
+– unstable

FIG.1 PRESSURE V.S. DENSITY(P/A=1:1)

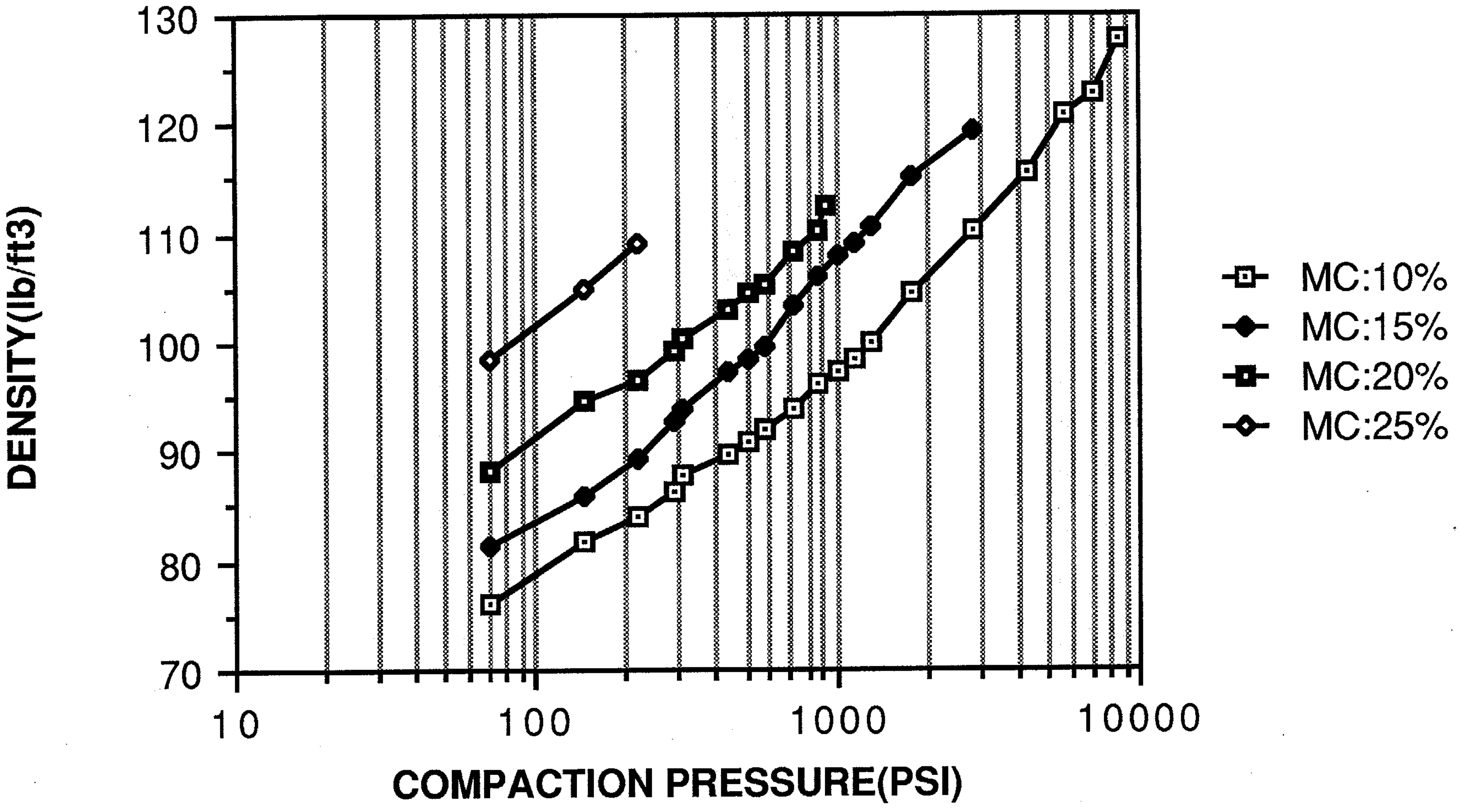


FIG.2 EFFECT OF MC ON DENSITY

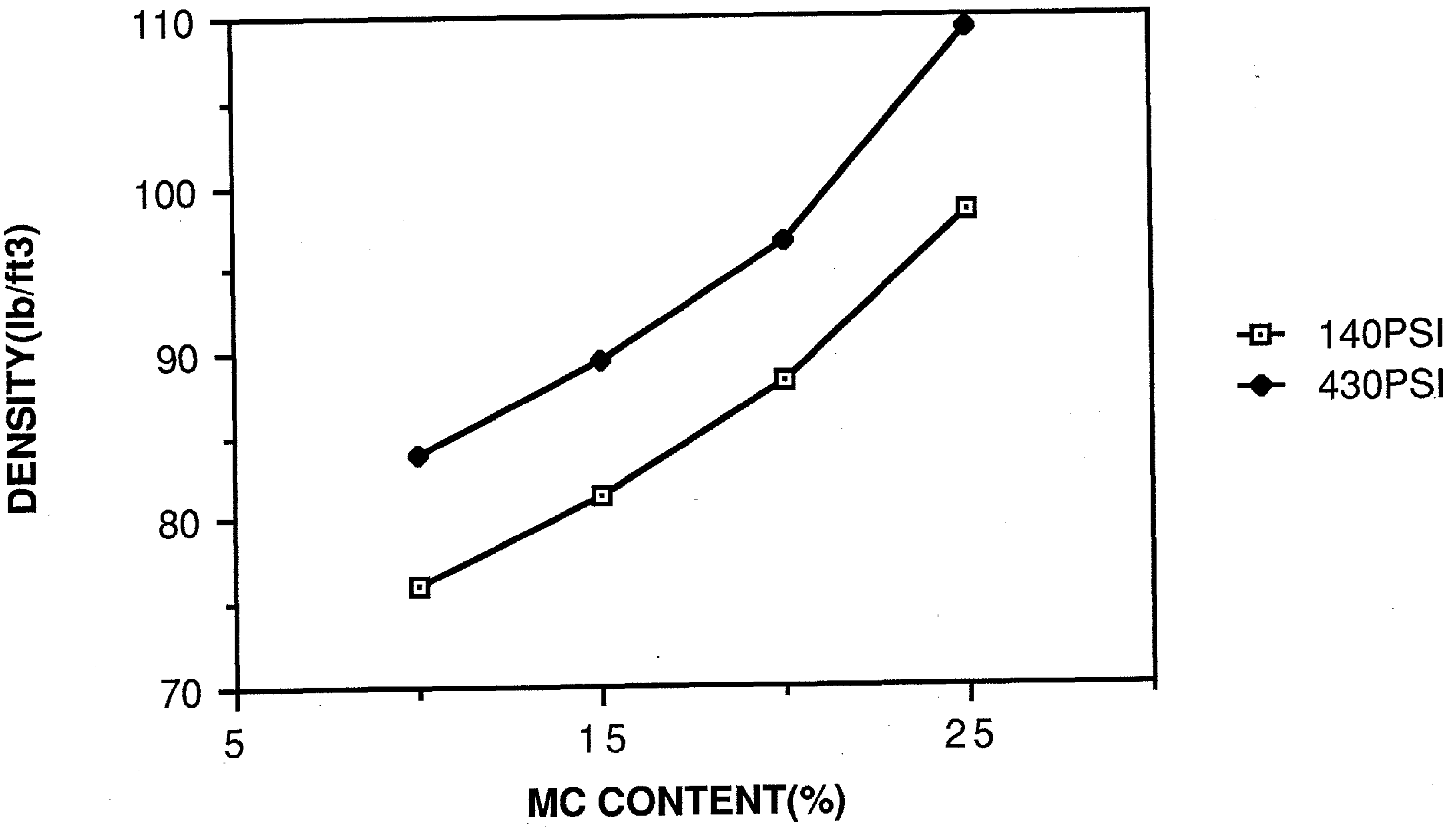


FIG.3 DENSITY V.S. PRESSURE BY REGRESSION(MC:10%)

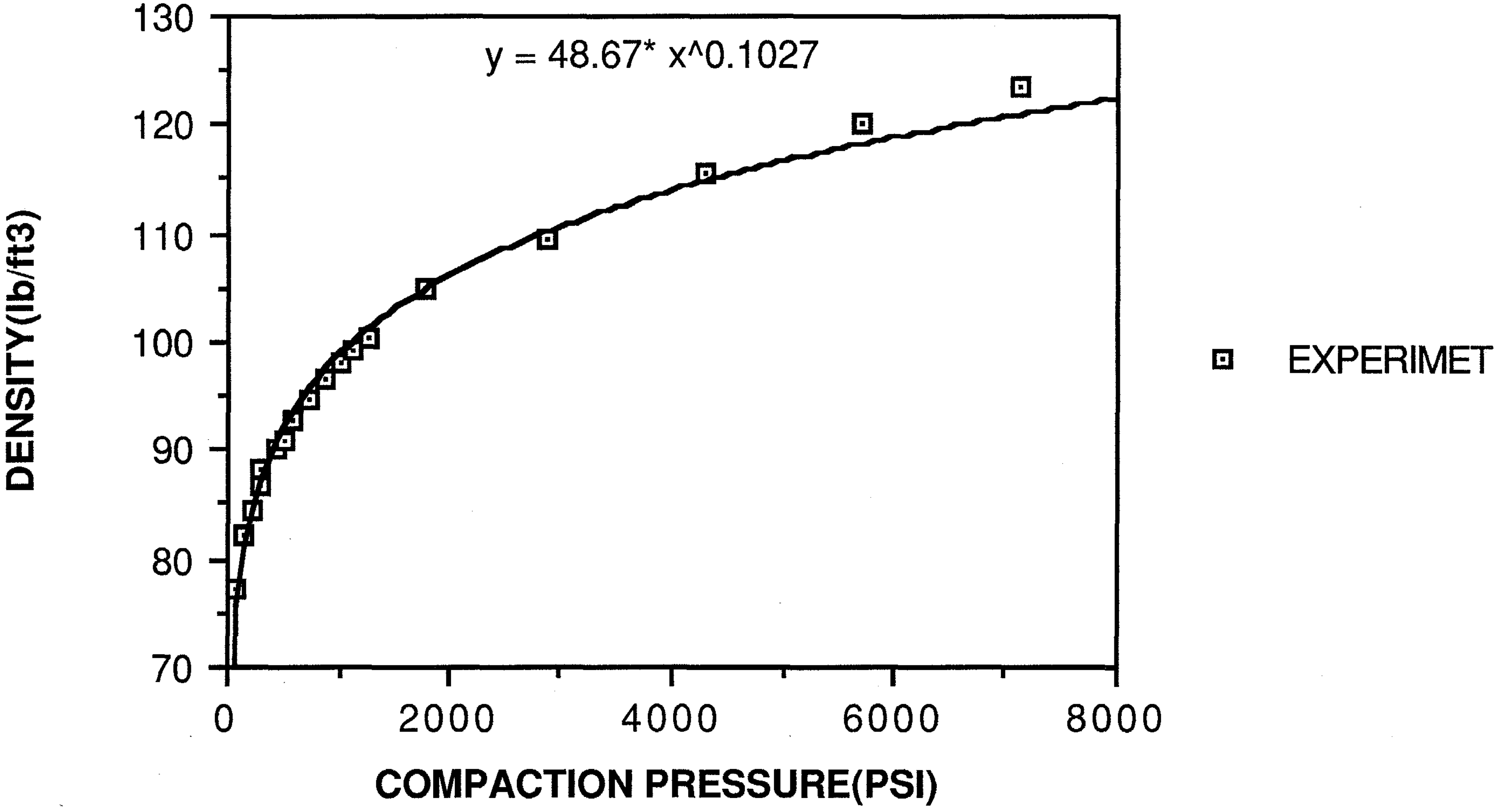


FIG.4 OPTIMAL MC CONTENT

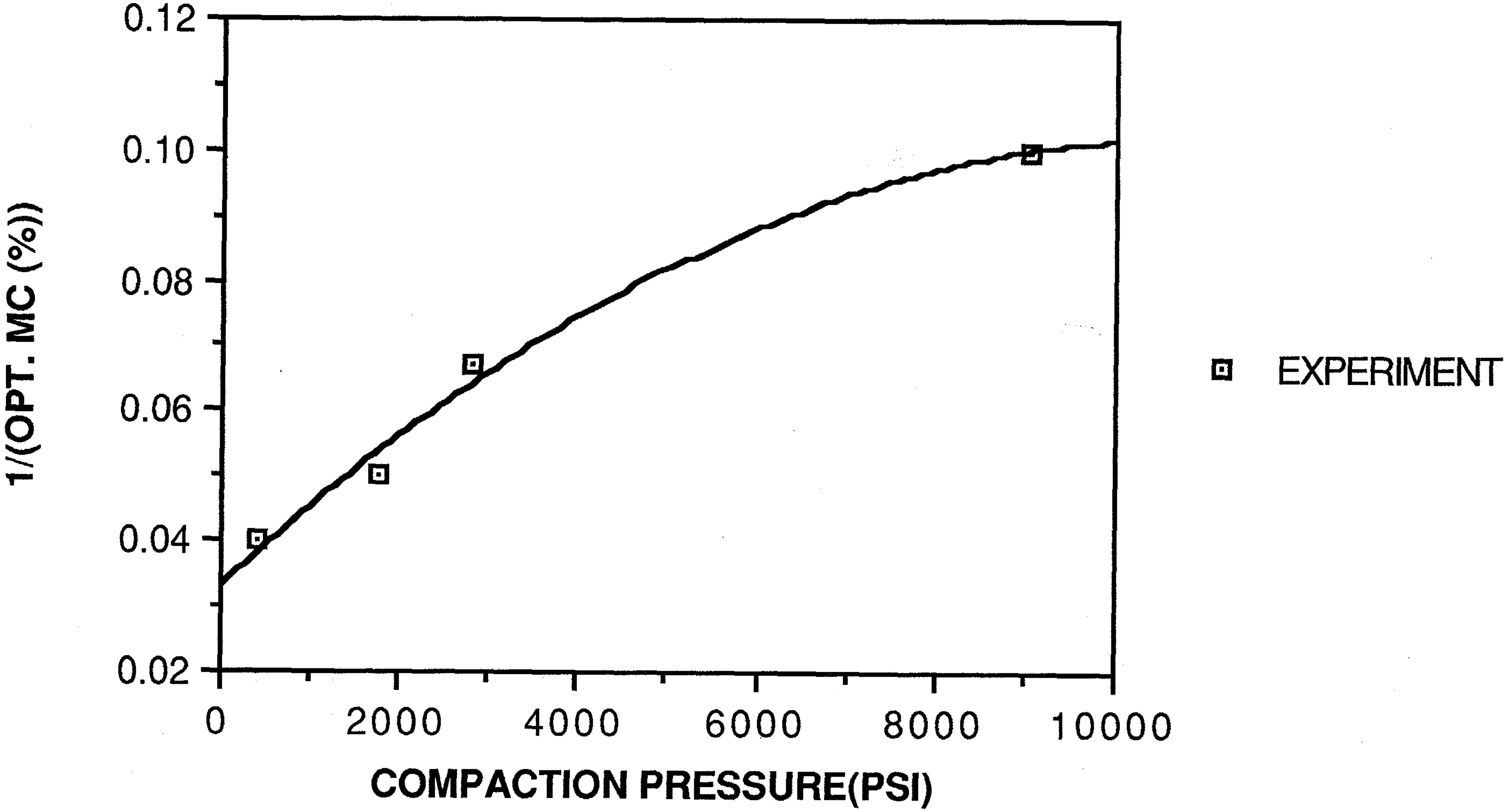


FIG.5 MAXIMUM DENSITY V.S. MC CONTENT

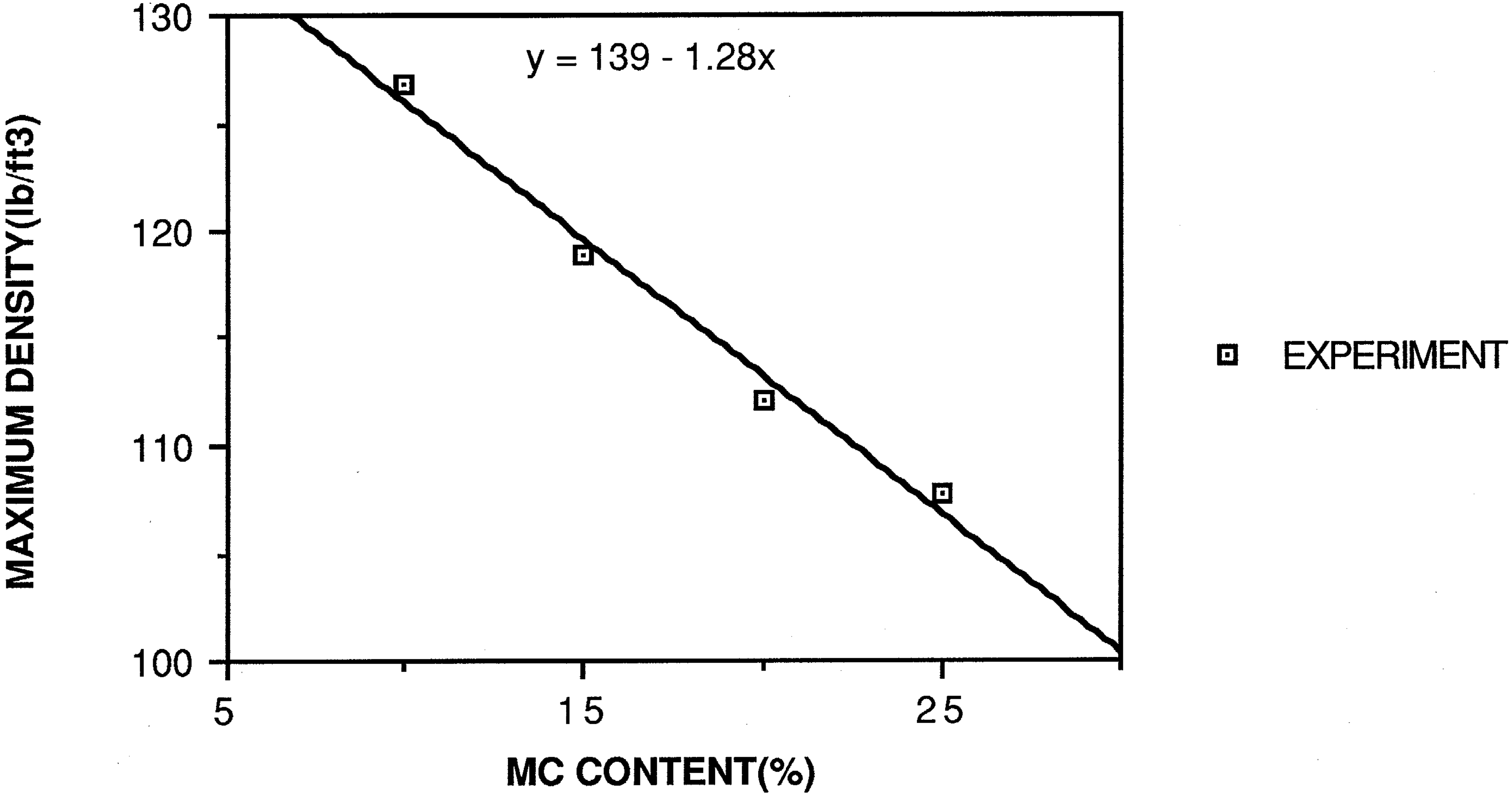
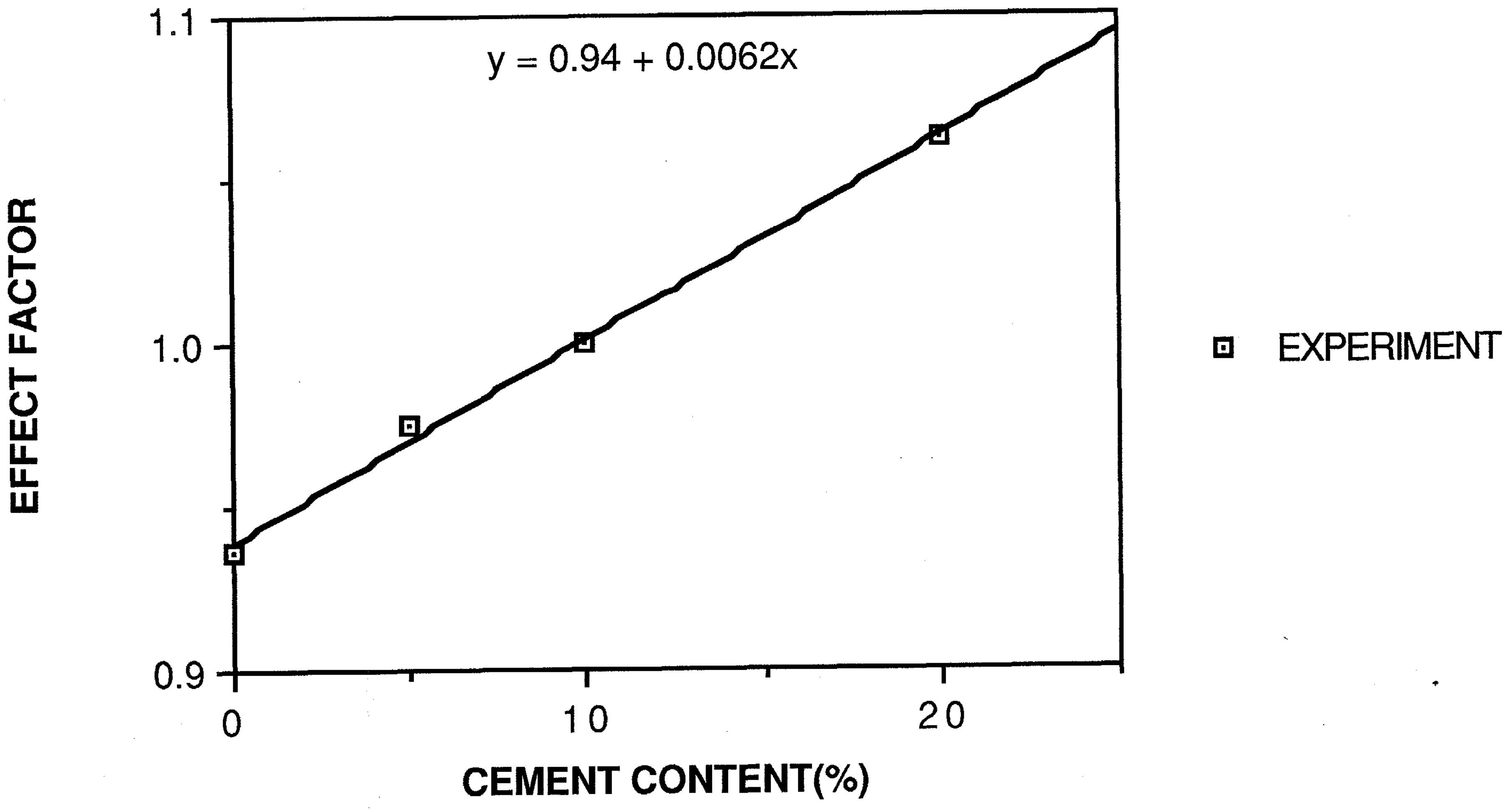


FIG.6 EFFECT FACTOR OF CEMENT CONTENT



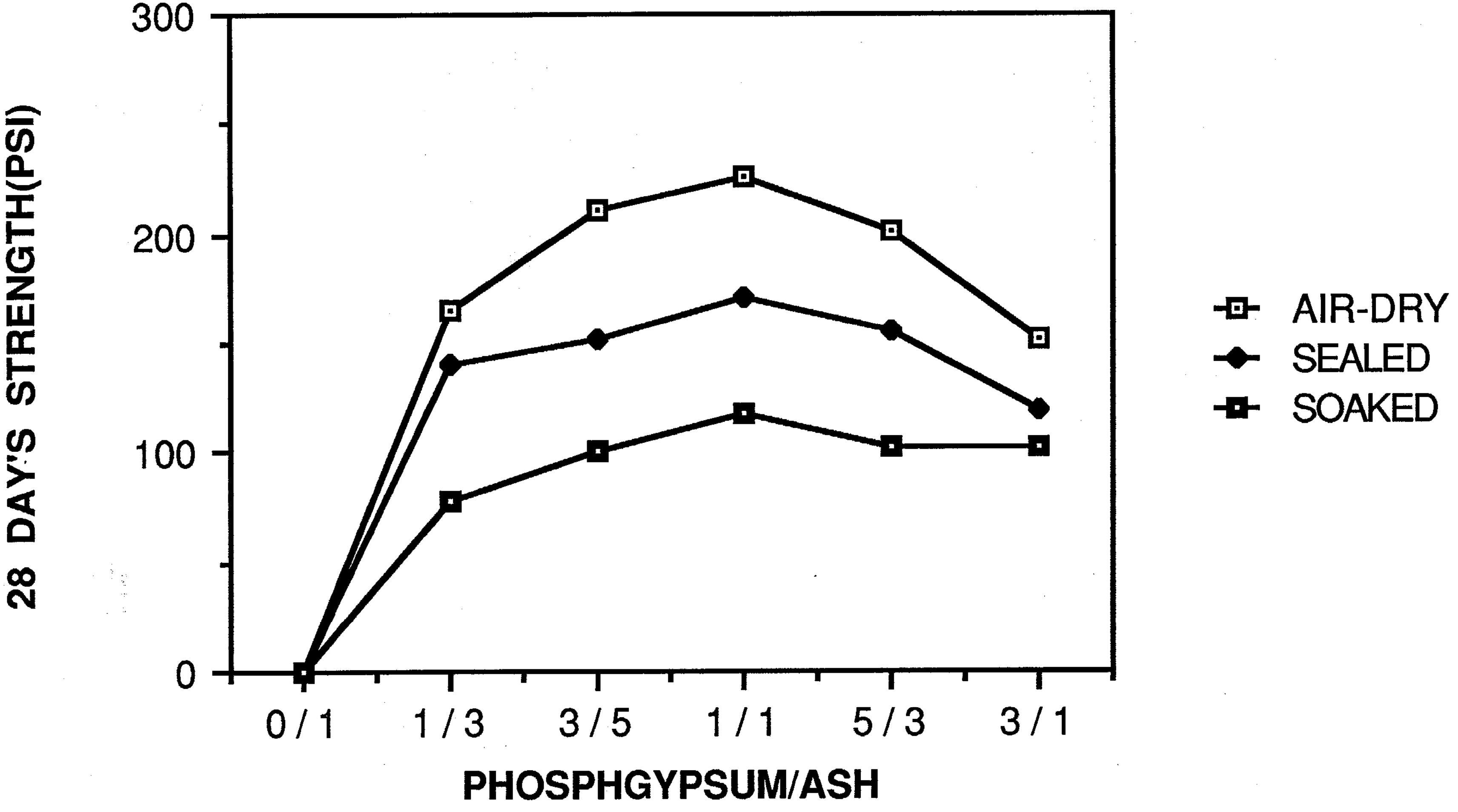


FIG.7 EFFECT OF P/A ON STRENGTH(Pr=3ksi)

FIG.8 EFFECT OF COMPACTION PRESSURE(P/A=1/1)

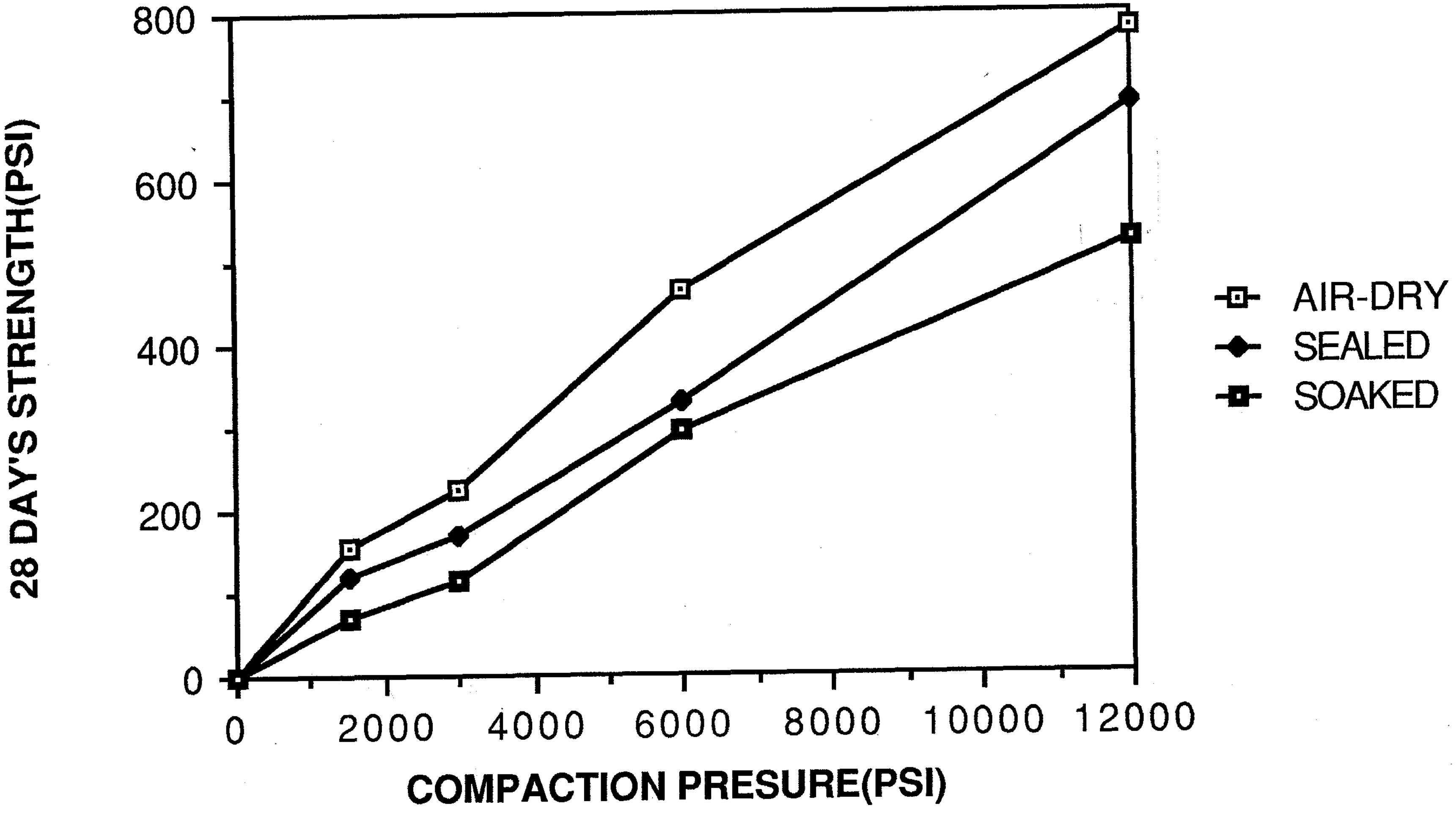


FIG.9 RELATIVE STRENGTH WITH TEST CONDITIONS(Pr=6ksi)

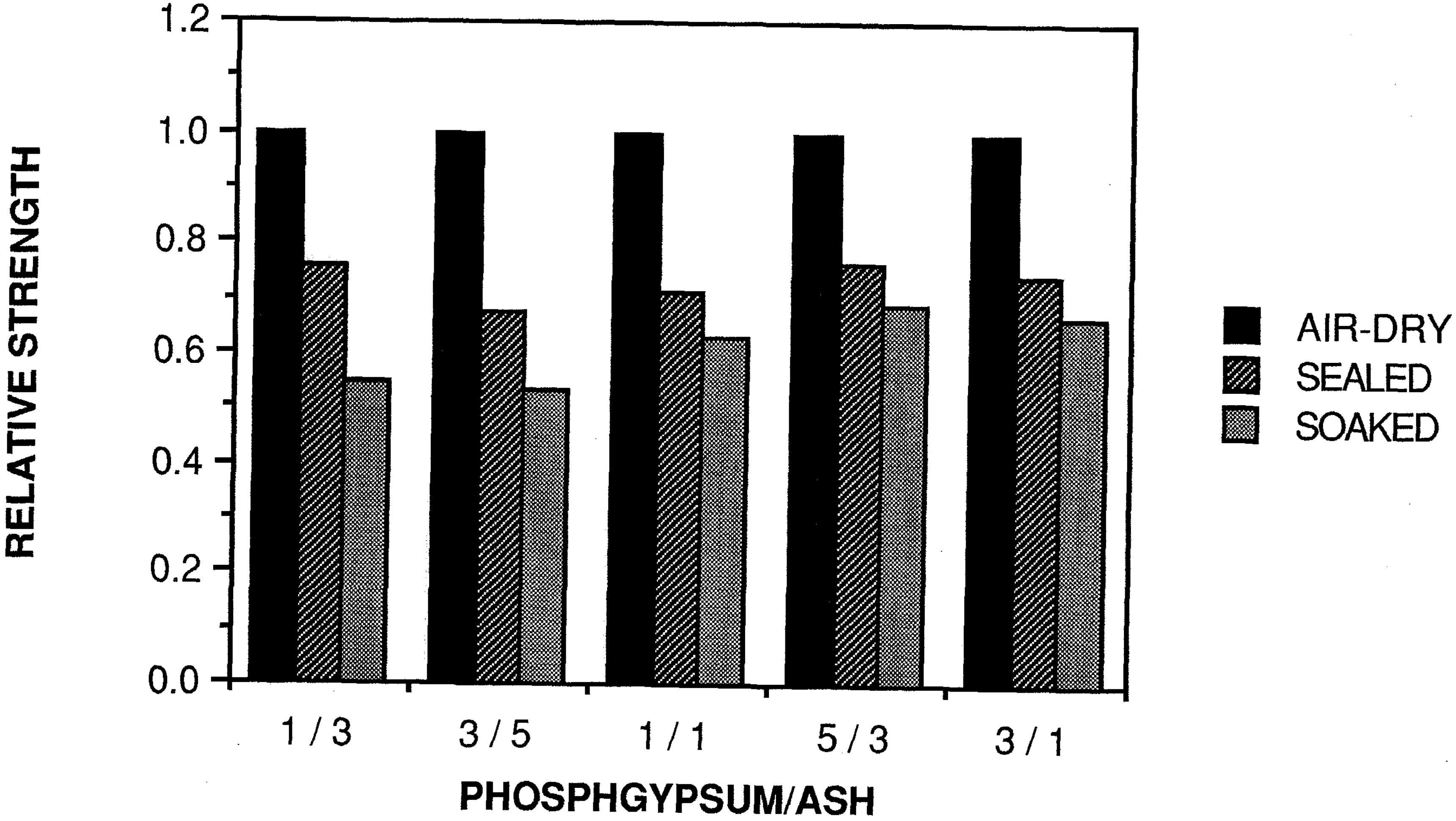


FIG.10 EFFECT OF AGE ON STRENGTH OF P-A MIXTURES

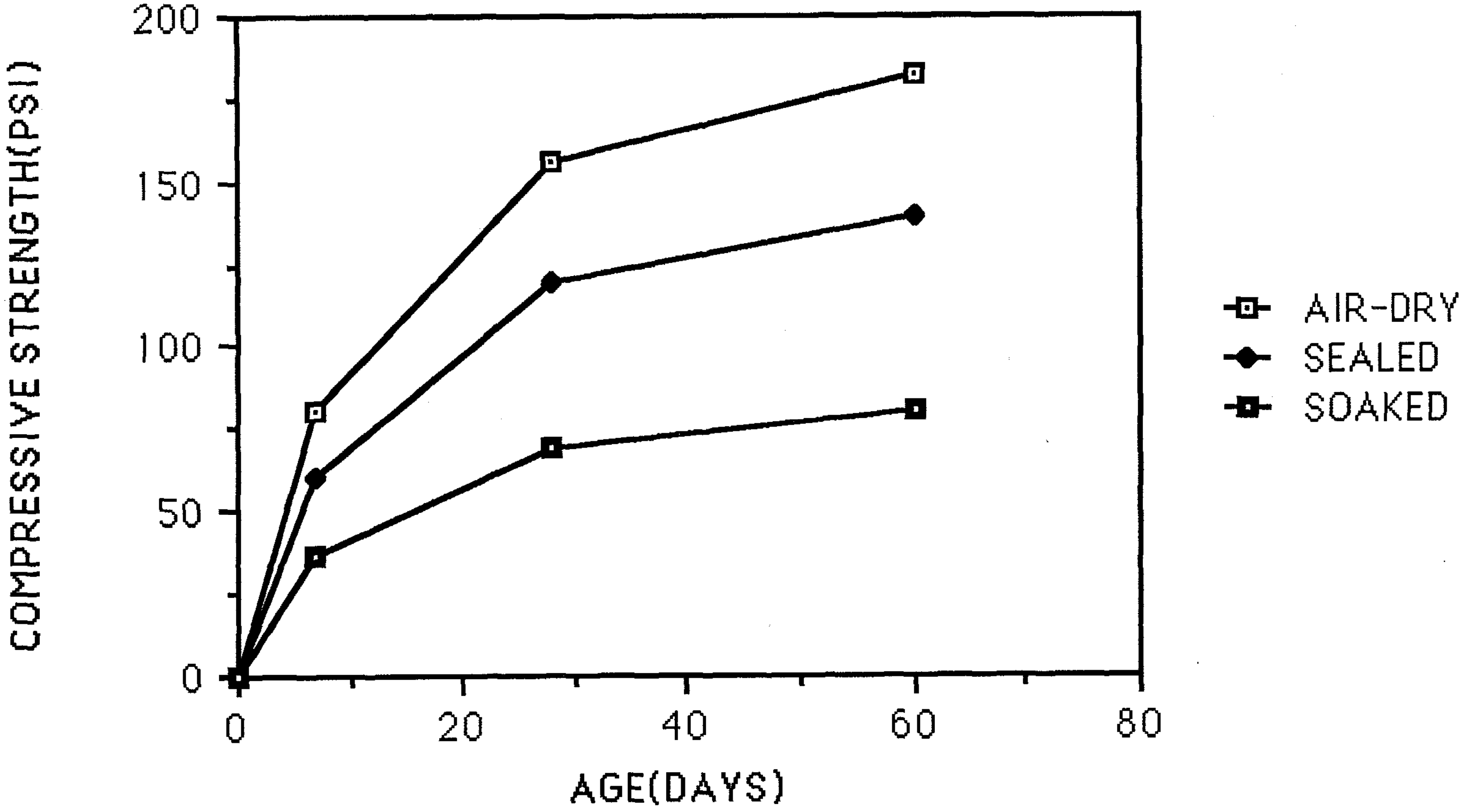


FIG.11 EFFECT OF P/A ON STRENGTH OF P-A-C MIXTURES(Pr=1.5ksi)

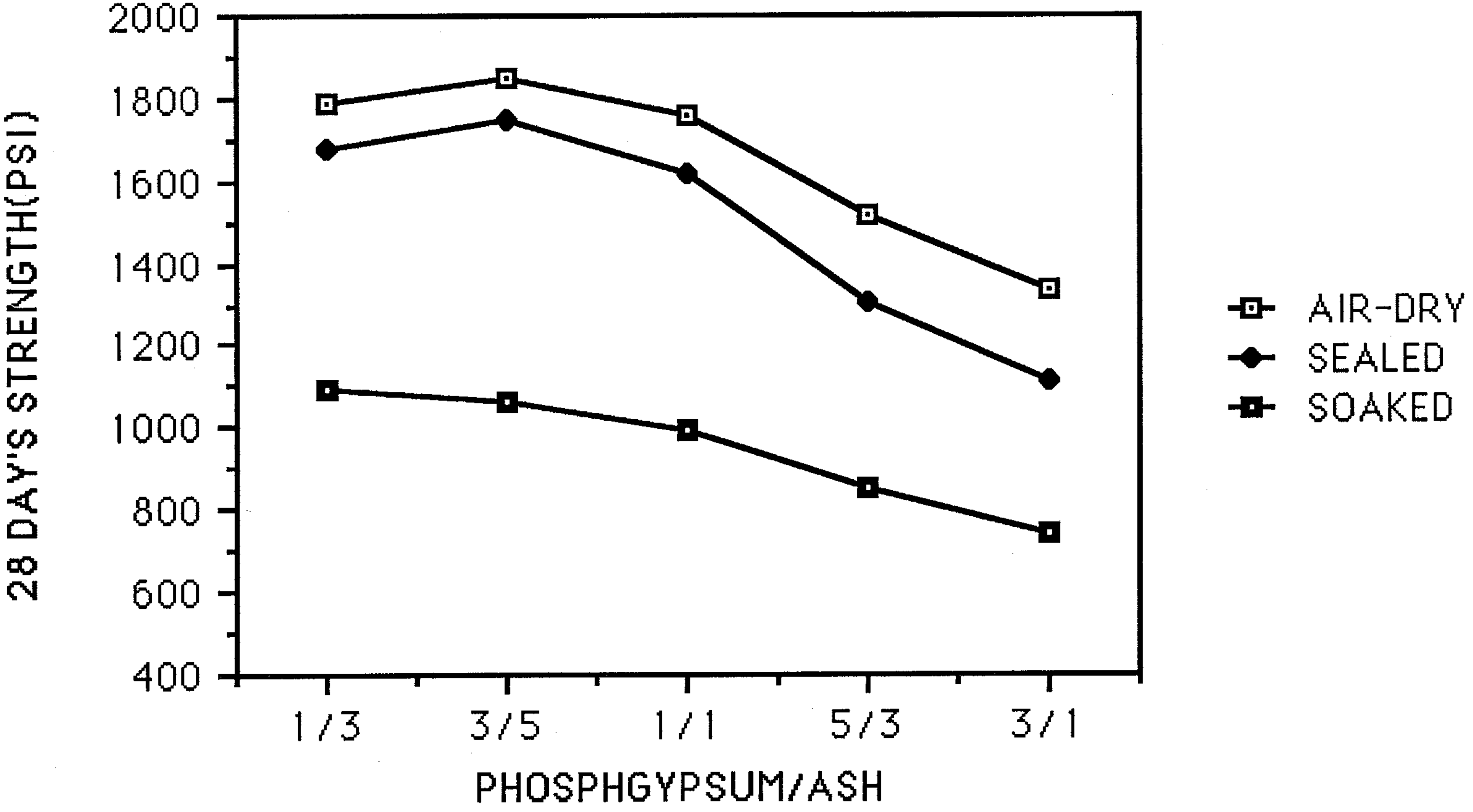


FIG.12 EFFECT OF P/A ON STRENGTH OF P-A-C MIXTURES(Pr=12ksi)

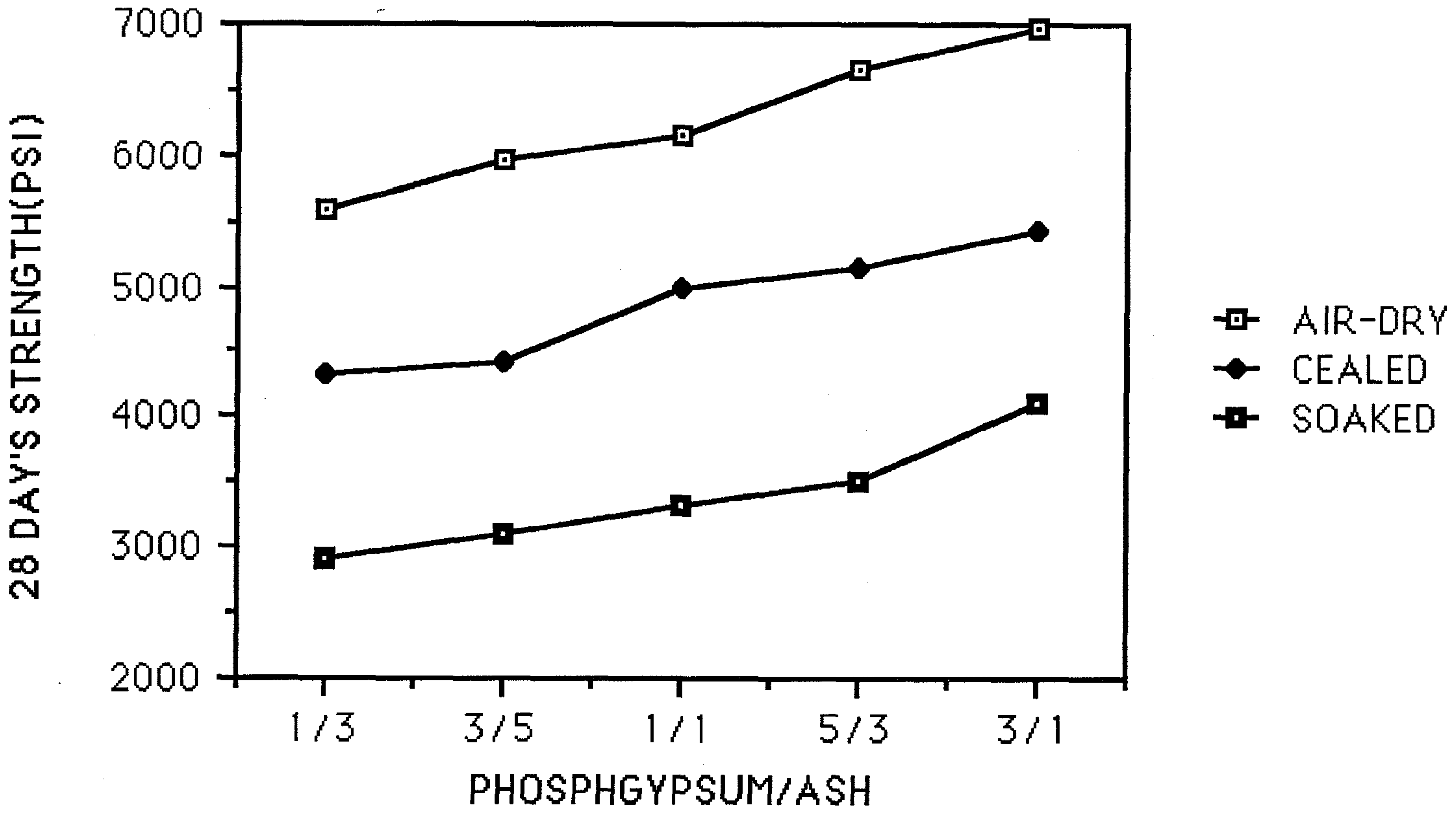


FIG.13 EFFECT OF COMPACTION PRESSURE(P/A=1/1)

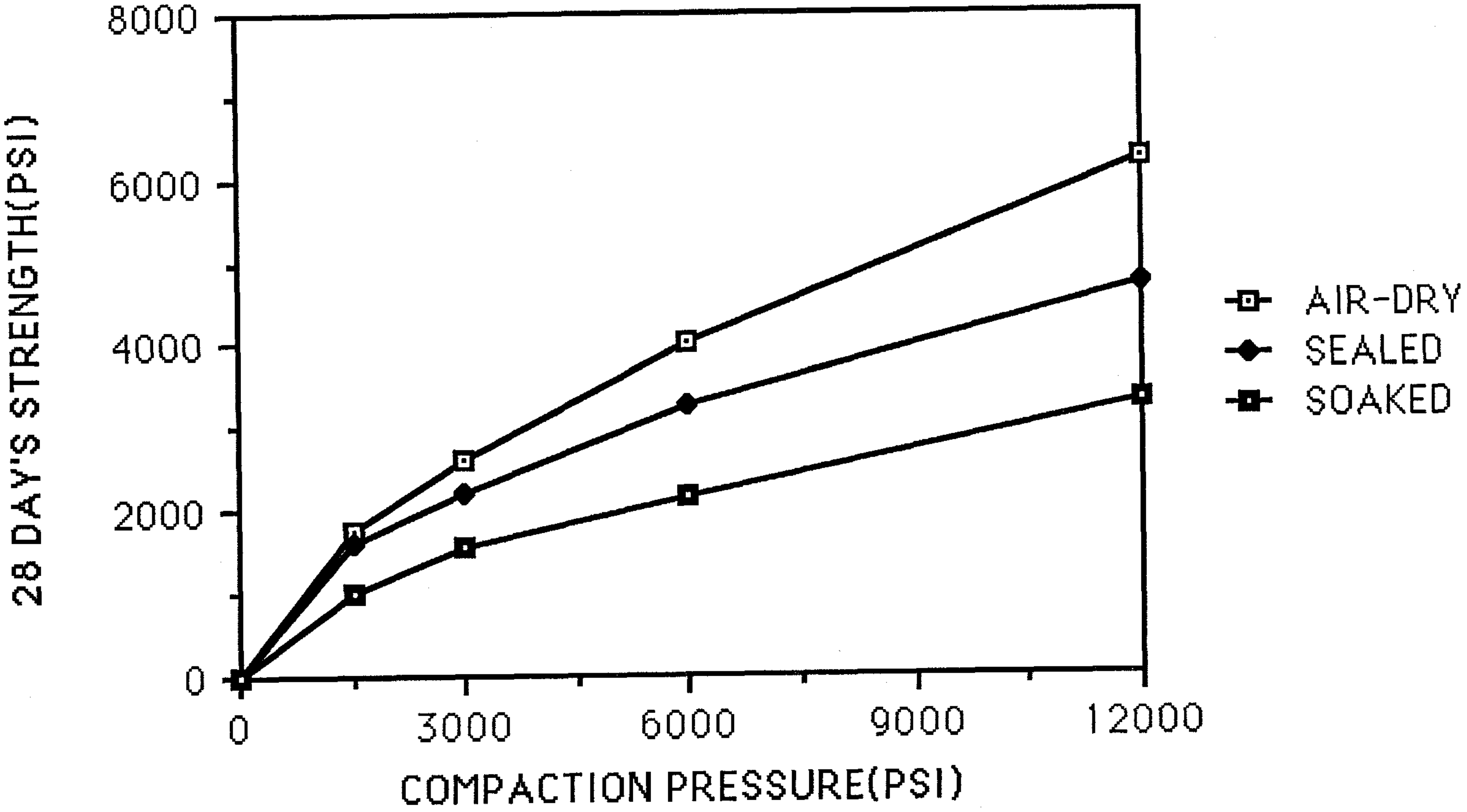


FIG.14 EFFECT OF AGE ON STRENGTH OF P-A-C MIXTURES

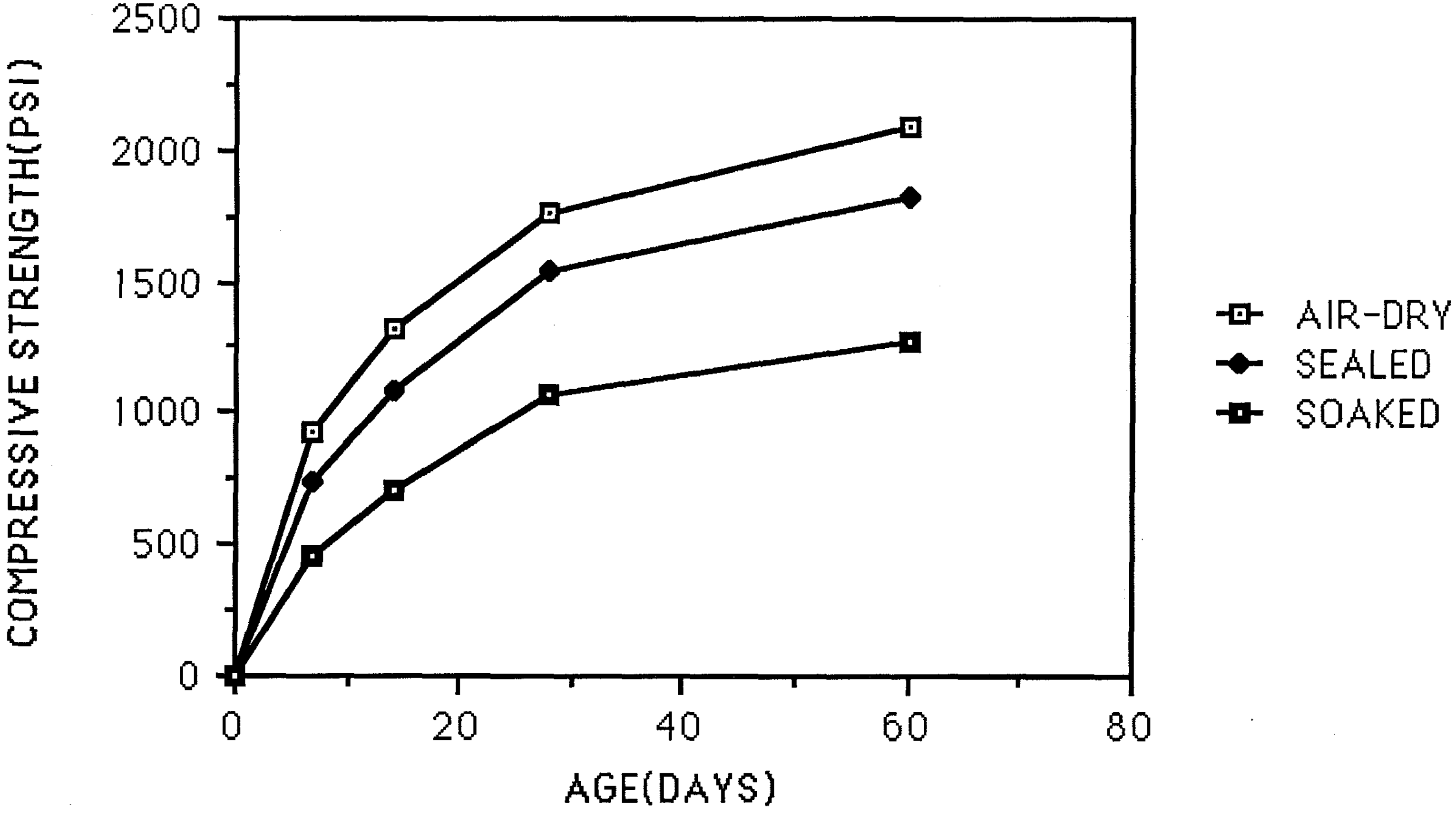
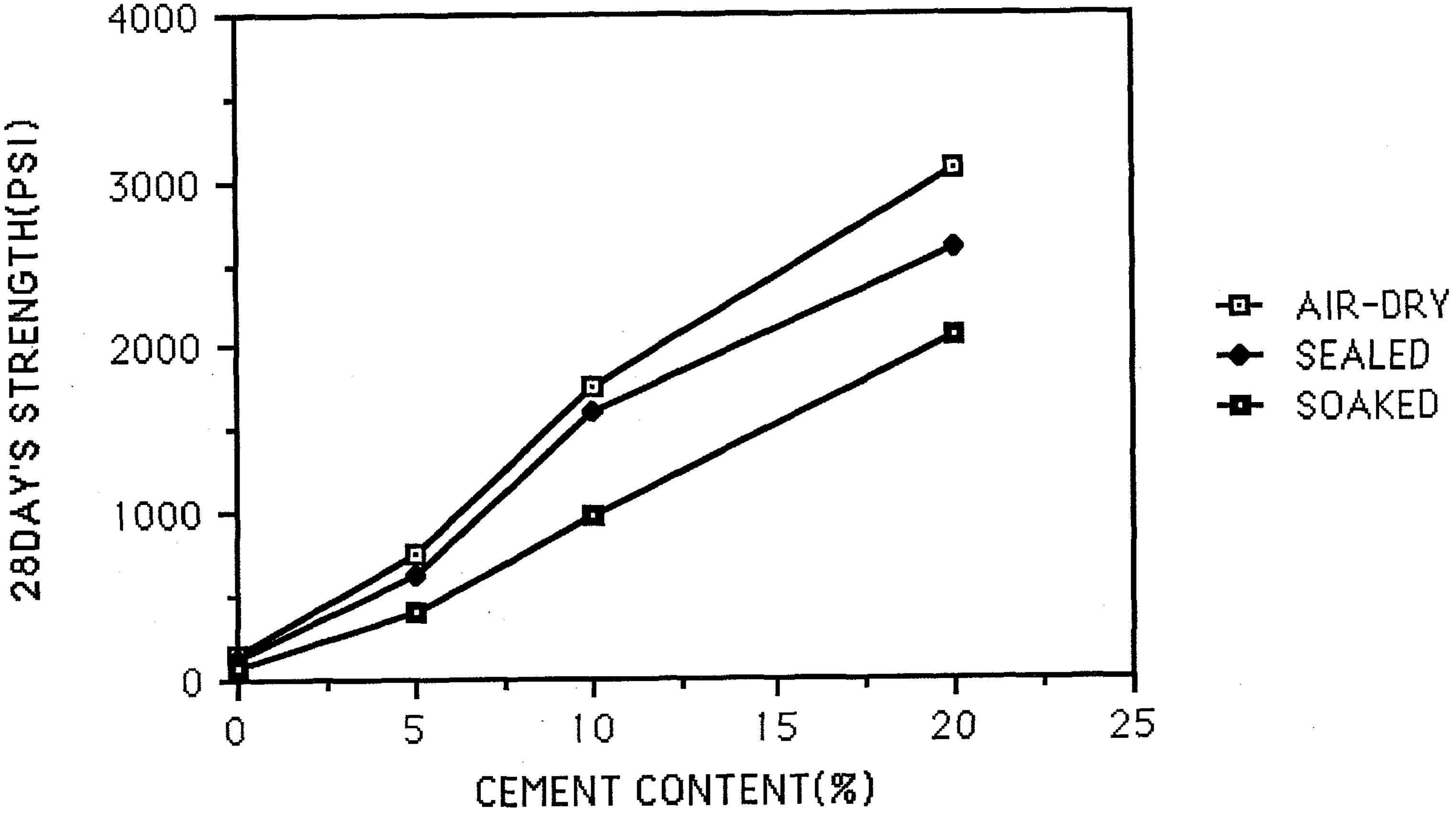


FIG.15 EFFECT OF CEMENT CONTENT



A Preliminary Assessment of Utilization Alternatives for Phosphogypsum

Ara Arman
Vice President, Woodward-Clyde Consultants
Baton Rouge, Louisiana

Roger K. Seals
Director, Institute for Recyclable Materials
College of Engineering
Louisiana State University
Baton Rouge, Louisiana

ABSTRACT

The results of a study that encompassed a comprehensive literature survey concerning the production, properties, and utilization of by-product gypsum are reported. A synthesis of the articles published in English was prepared in an attempt to reach some understanding of the current state-of-the-art in by-product gypsum (principally phosphogypsum) research and utilization. An abundance of information on chemical composition, environmental factors, leachates, and radon emissions related to by-product gypsum was found. However, little or no information appears to exist on the fundamental properties of mixtures of phosphogypsum and stabilizing additives. In spite of the extensive research efforts conducted to date, no generally accepted product has been produced or marketed in the United States. Even prior to the implementation of the recent EPA Regulations, phosphogypsum utilization was constrained by the presence of impurities (including radioactive minerals), and, perhaps, the comparatively low cost of competitive naturally-occurring materials. It is concluded that a well planned and coordinated interdisciplinary research effort is needed to find solutions to the problem.

INTRODUCTION

The purpose of this study was to: review, catalogue and annotate available literature on by-product gypsum; determine the state-of-the-art of reuse; and prepare the outline of a proposed approach for the solution of the phosphogypsum problem. Although the study encompassed the various types of by-product gypsum, its primary focus was directed towards phosphogypsum. Literature on fundamental properties, environmental characteristics, reuse, known engineering and other properties of phosphogypsum was collected, reviewed and analyzed. Interviews were conducted with users of by-product gypsum products and conferences were held with researchers working on the reuse aspects of by-product gypsum. A discussion of the study results and a plan of research for developing a viable solution to the phosphogypsum problem are presented herein.

An annotated bibliography (Arman and Seals, 1988) containing over 275 citations of both English and non-English articles was prepared. These articles encompass published and unpublished works. Copies of these articles have been placed in the library of the Institute for Recyclable Materials at Louisiana State University and are available for loan. This bibliography is now being incorporated into a computerized retrieval system that will allow specific searches to be conducted using key words.

DISCUSSION OF RESULTS OF LITERATURE REVIEW

A review of the literature and results of personal interviews indicate that much is known about the chemical properties and environmental characteristics of phosphogypsum, fluorogypsum and flue gas desulfurization (FGD) gypsum. As noted above however, the primary emphasis was given to phosphogypsum. Little remains to be done to determine the chemical composition, leachates or radionuclides present in unmodified forms of by-product gypsum. However, additional studies are needed to evaluate the effect of stabilizing agents on the environmental and structural properties of modified by-product gypsum.

Environmentally, the items of concern for outdoor use of phosphogypsum in its raw form appears to be the emission of low levels of radon and emission of low level gamma radiation. The literature indicates that radon emission from waste gypsum piles is at low levels (20 to 30 pCi/m^2-s) for thick sources. Gamma levels range from 30 to 70 microRem/hr including background. EPA has calculated risk estimates and numbers of cancers resulting from exposure to radium and radon associated with gypsum. Based on their assessment, EPA promulgated the National Emission Standards for Hazardous Air Pollutants; Regulation of Radionuclides (EPA, 1989) which, among other facilities, addresses phosphogypsum stacks. These regulations currently restrict the use of phosphogypsum for any purpose by requiring that all phosphogypsum be placed in a properly designed, operated and maintained disposal fill. This restriction applies to the use of phosphogypsum for research as well as for products for commercial purposes. Recently, the Nuclear Regulatory Commission (NRC) published a policy statement (NRC, 1990) that provides a mechanism to determine when radiation levels are so low that they do not warrant further regulatory control. This statement, termed “Below Regulatory Control,” can be utilized to assess the risk associated with various uses of phosphogypsum or any other material containing radioactive minerals. Such an assessment may reveal, according to the NRC policy, that certain uses of phosphogypsum may be “below regulatory control.” However, the response of EPA to such considerations is unknown.

Radiation and other potential contaminates result from impurities present in the original phosphate rock and are associated with the phosphoric acid production process. These impurities include the radioactive elements of uranium and radium, metals, lanthanide series elements, fluoride, and excess phosphate. Two of the more important and often discussed contaminants in phosphate ore and phosphogypsum are the radioactive elements uranium and radium. Altschuler, et al. (1958) discussed the association of uranium with sedimentary phosphates. They found that U^{4+} partially replaces Ca^{2+} in the apatite structure mainly because the ionic radii (0.97A and 0.99A, respectively) are comparable. This occurs through a complex coupled replacement in the apatite structure. When the apatite crystallizes in sea water it removes U^{4+}, produced in sea water by the reduction of $(UO_2)^{2+}$. This causes more U^{4+} to form which can then be incorporated into the apatite structure as it continues to crystallize. This results in the presence of high concentrations of uranium to be present in the apatite. In the Florida phosphate rocks, U^{4+} represents from 40 to 91 percent of the 10 to 200 ppm of uranium present in the phosphate, with the remainder being U^{6+}. The U^{6+} cation cannot be incorporated into the apatite structure and is absorbed on the surface of the crystal by chemisorption. The tetravalent form of uranium predominates when the apatite originally crystallizes, while the hexavalent form emerges later as a result of oxidation.

Where uranium remains undisturbed in nature, the members of the uranium decay series through radium-226 are approximately in radioactive equilibrium. In other words, all the members are present in nearly equal concentrations of radioactivity. Wet process phosphoric acid production disrupts the radioactive equilibrium which exists in the phosphate rock. Most of the uranium is removed in the phosphoric acid, while the radium-226 and a trace of uranium appear in the phosphogypsum. The radium-226 then breaks down into radon-222 which decays further into the radon daughters (Roessler, 1987)

Agricultural uses of phosphogypsum may have important implications on the exposure of humans to radioactivity caused by the breakdown of radium-226. First, radium could build up in the soil with repeated applications of phosphogypsum. This could affect the uptake of radium by plants although the presence of calcium in the phosphogypsum would probably reduce the uptake of the less soluble radium. Secondly and more importantly, land use changes from agricultural to residential may cause homes to be built on agricultural lands where phosphogypsum was applied (Lindeken, 1980). Other uses of phosphogypsum, especially as construction materials, will definitely be hampered by the lingering questions of radon buildup and gamma radiation exposure.

Other environmental considerations associated with phosphogypsum primarily deal with trace elements and heavy metals that may be found in the phosphogypsum and their potential mobility. Also of concern is the pH of any leachates produced by phosphogypsum stacks or facilities constructed using phosphogypsum. Several studies have been performed to evaluate phosphogypsum that has not been stabilized. These investigations have addressed fresh and aged phosphogypsum and active and inactive storage areas or stacks. Senes Ltd. (1987) studied leachate from fresh phosphogypsum, specifically addressing levels of calcium, sulfate, phosphorus, fluoride, potassium, aluminum, cadmium, chromium, iron, magnesium, nickel and vanadium. Results indicated elevated levels of cadmium, sulfate, phosphorus, fluoride and aluminum, with only fluoride and sulfate above allowable concentrations for drinking water.

Two studies conducted by May and Sweeney (1982, 1983) evaluated leachate from cored active and inactive phosphogypsum stacks. Leachates were generated using the EPA Extraction Procedure to address toxicity characteristics of a number of heavy metals including arsenic, barium, cadmium, chromium, lead, mercury selenium and silver. Results indicated that no constituents in the leachates were above allowable levels. Chromium, mercury and selenium were not detected while concentrations of other metals were detected at levels far below EPA requirements. The Mobil Chemical Company (Naff, 1984) studied leachate from fresh phosphogypsum stacks with the results indicating that all heavy metal concentrations were below leachate and drinking water standards.

A very limited amount of research has been performed on stabilized phosphogypsum with almost no results being presented in the scientific literature. Results from the Mobil study (Naff, 1984) have indicated that leachate constituents from stabilized phosphogypsum were at much lower levels than from raw phosphogypsum. In general, there is an identified need for additional research to be performed on various stabilized phosphogypsum products to evaluate possible environmental impacts.

Other characteristics of concern relative to phosphogypsum utilization are the presence of fluoride and phosphate and low pH. The quantities of phosphate and fluoride depend on the phosphoric acid process used, the efficiency of plant operation, and the quality of the phosphate rock. Phosphate and fluoride contents may greatly affect the performance of products made from phosphogypsum, especially in cement and plaster of Paris manufacturing. The pH of phosphogypsum is generally low and usually ranges from 2 to 5. The pH can be increased by further processing to remove excess acid contained in the phosphogypsum or by the addition of lime. The pH generally needs to be increased before the phosphogypsum can be used beneficially.

Industry and governmental agencies (e.g., Tennessee Valley Authority - TVA and Florida Institute for Phosphate Research - FIPR) have spent considerable effort and monies to find uses for phosphogypsum. TVA's work in agricultural applications are of particular significance. The results of agricultural applications (e.g., sugar cane, groundnuts, soybeans, etc.) have shown beneficial results. Additional agricultural research funded by FIPR is in progress at universities in Georgia.

Phosphogypsum has been tested and used in many types of soil applications. It has been used in soil conditioning for reclamation of saline and/or alkaline soils. In saline soils, the high salt content greatly restricts crop and vegetation growth. Alkaline soils suffer from poor drainage, surface crust formation, and runoff problems. Phosphogypsum can be used to disperse particles in the soil and thus improve drainage and crop yields. The Na^+ ions on cation exchange sites are replaced by Ca^{2+} ions. The soil can then be leached to remove Na_2SO_4 salt. In the United States, this application is used mainly in California. Gypsum and phosphogypsum have also been used to reduce soil pH.

In soil applications, phosphogypsum can also be used as a source of calcium and sulfate. Groundnuts in particular may suffer from a lack of calcium. In the southeastern U.S., peanut farmers have used minor applications of phosphogypsum as a source of calcium and to keep the soil slightly acidic. Both of these conditions are favorable to the growth of peanuts.

Agricultural applications have two drawbacks relative to having a major impact on the by-product gypsum problem besides the possibility of radionuclide accumulation discussed earlier. The most critical limitation in such applications is the necessity of transporting gypsum long distances from their sources to potential markets. The transportation cost quickly becomes prohibitive when the distance exceeds 50 miles. Other commercially available soil beneficiation products easily compete with gypsum in most farming markets. The second drawback is that the total tonnage needed for agricultural use is low relative to the tonnage of phosphogypsum stockpiled or produced annually (about 45 million tons in the USA). Thus, unless some unique agricultural needs and uses for phosphogypsum are identified, the market for this material in agriculture appears to be minimal and does not appear to have the potential of providing short term, massive usage markets.

The literature and the authors' interviews indicated great interest among producers and researchers in finding uses for this material in civil engineering works. The reason for this wide spread interest is that, if proven to be technically and economically useful in engineering works, the need for materials in this market is massive. The solution to the by-product gypsum usage problem lies in finding such massive markets which can use large amounts of this material.

There has been some scattered research and development work done by various private and public agencies in determining the engineering properties of waste gypsum in road embankments and road foundations. During the last five years several experimental and permanent roads have been constructed in Texas (Houston, Carthage, and Tatum) and Florida (Columbia and Polk County).

Monitoring of these structures (roads) has been conducted by gypsum producers, marketers or by agencies commissioned by producers and marketers. These studies have generally been limited in scope. There appear to be a few "success stories" reported in this area. Thorough environmental monitoring is in progress at the Florida road sites. However, most of the engineering monitoring and other studies performed have been low budget, short term and in some cases, in the opinion of the authors of this report, superficial ones. The cumulative results of these studies have not produced the type of engineering information needed by major users of aggregates and construction materials (e.g., U.S. Corps of Engineers, Federal

Highway Administration, Federal Aviation Agency, state highway departments, etc.) to determine the long term stability of facilities constructed using raw or stabilized phosphogypsum. Some of these applications have used Portland cement (4 to 6 percent), fly ash (5 to 25 percent} or a combination of cement and fly ash to improve the strength and stability of the product. Other applications made use of unstabilized mixtures of gypsum and natural aggregates (e.g., granite, crushed limestone, and sand) as road base materials. Several field installations have been in use for five or more years and appear to be successful. However, some have also exhibited problems attributed (but not clearly identified) to the formation of reaction products such as ettringite and traumsite.

Little discussion appears in the published and other literature on the use of phosphogypsum for coastal protection structures or other civil engineering applications. In the building industry, phosphogypsum has been used as a cement additive or setting retarder, and in the production of precast gypsum building blocks, plaster of Paris, and plasterboard. For example, in 1978 over 90 percent of the Japanese supply of gypsum came from phosphogypsum. Nearly all of it was used in building materials as a setting retarder for cement or in gypsumboard and plaster of Paris (Pena, 1985). May, et.al (1985) of the U.S. Bureau of Mines stated that using phosphogypsum with silica powder or calcium oxychlorides to make aggregates is not practical. The products obtained had low strengths or stability.

There are also processes developed to reclaim sulfur, sulfur dioxide and fused aggregates by incinerating phosphogypsum at high temperatures. There appears to be several viable processes developed or under development which produce results similar to each other. The reactions resulting from the heating of the gypsum at high temperatures are exothermic. Thus, they produce more BTUs than they consume.

Such processes appear to be ideal where cogeneration is also an economical alternative. The product of this process may be a fused aggregate, sulfuric acid and cogenerated power. Some of these processes appear to be economical, provided the aggregate produced has properties acceptable for use in construction and is economically competitive with other readily available construction materials. Furthermore, the question of the capital investment needed to build a plant to produce sufficient volumes of material (aggregate) to meet the requirements of the construction market remains to be studied. Initial bench top and pilot plant results indicate that these processes tend to “lock in” the radionuclides and will either completely eliminate or reduce the radon emission to negligible levels. At the time of the preparation of this report, no literature about or sample of this latter product was available to the authors for further evaluation.

There are other treatments that can be used to render phosphogypsum or phosphogypsum products more usable. For example, separating the finer fractions by hydrocycloning has been shown to reduce the radioactivity of the phosphogypsum by approximately 30 percent (Pena, 1985). Also, the Oak Ridge National Laboratory studied two processes that recover uranium from wet process phosphoric acid production. Of course, the implementation of these and other methods have to be considered in light of their impact on the cost of the end product and world market prices.

Habashi (1985) and Altschuler, et al. (1967) proposed several methods for the recovery of lanthanide (rare earth) elements from both the phosphate rock and the phosphogypsum. These include leaching with HNO_3 or HC1 (recovering more than 80 percent of the lanthanides), using less concentrated H_2SO_4 in the phosphoric acid making process, liquid-liquid extractions, selective precipitation, and extraction from caustic solutions.

One of the most widely studied treatments of phosphogypsum and gypsum is that of thermal decomposition. Several Soviet authors studied the kinetics of this reaction. Kouloheris (1981) did an excellent job evaluating the thermal decomposition processes that could be used for the production of various products from phosphogypsum. These products include sulfur dioxide, sulfides, lime, and sulfuric acid. Others have used microbial and bacterial sulfate degradation to breakdown gypsum or phosphogypsum into sulfur and sulfides.

Other possible uses of phosphogypsum have been discussed by Pena (1985), Nel (1981), and Kouloheris (1981). They include the following:

- Source of sulfur
- Fluorine recovery
- Source of elemental calcium
- Calcium carbide manufacture
- Ammonium sulfate manufacture
- Recovery of nickel from low grade ore
- Molding gypsum for ceramics industry
- Sodium sulfate manufacture

The recommendations made by Pena (1985) in a study for the United Nations Industrial Development Organization can be applied as well to the phosphogypsum studies in the Gulf Coast region. Two recommendations that seem appropriate to this region are:

1. In the construction of new plants, plant planning should include specifications for a process that produces phosphogypsum suitable for utilization. For example, the Japanese have developed the Nissan

Phosphoric Acid Process. This process produces a phosphogypsum of quality sufficient for direct use in wallboard and cement production.

2. In the case of existing plants, a feasibility study should be conducted on possible plant modifications (such as improved stirrers in the reactor) that would allow production of phosphogypsum that could be more readily utilized.

CONCLUSIONS AND RECOMMENDATIONS

A review of the literature and the results of interviews indicate that industry, industrial organizations and universities have performed a number of studies in identifying uses for by-product gypsum. It appears however that there has not been a major interdisciplinary research effort organized to determine the scientific, engineering, environmental, economic and marketing aspects of products that may be developed by such an effort. In spite of the fact that large amounts of funds have been expended by many parties, research efforts in reuse of this material have been somewhat narrowly focused.

To date, no generally accepted product has been produced or marketed in the USA. Lacking such outlets, the by-product gypsum problem is yet to be solved. FIPR and its member industries have done commendable work in the area of land reclamation and environmental protection of mined wetlands. They have also thoroughly studied the stability of by-product gypsum stacks and their environmental aspects such as leachates, radon emission from stacks, etc.

Based on project findings, the authors conclude -

- A well planned, well funded interdisciplinary effort must be initiated to find a solution to the problem. An outline of a study is presented herein. Such a study should be supported by both public and private entities.

- The combined talents and financial resources of public and private agencies are absolutely necessary to find uses for phosphogypsum.
- Use of phosphogypsum in massive amounts may be possible with proper research results and technology transfer programs.

ACKNOWLEDGMENTS

The study was supported by a grant from the Alternate Technology and Development Waste Reduction Program of the Louisiana Department of Environmental Quality. Their support of the study is gratefully acknowledge. The authors wish to acknowledge the significant contributions of Mr. Michael Strickler, Research Associate, Department of Civil Engineering, to the contents of this paper.

REFERENCES

Altschuler, Z. S., Berman, S. and Cuttitta, F., 1967. Rare earths in phosphorites--geochemistry and potential recovery. USGS Professional Paper 575-B, B1-B9.

Arman, A. and Seals, R. K., 1988. A preliminary assessments of utilization alternatives for waste gypsum. Volumes I, II, and Ill. Louisiana Transportation Research Center Report, Louisiana State University and Louisiana Department of Transportation and Development.

Habashi, F., 1985. The recovery of lanthanides from phosphate rock. Journal of Chemical Technology and Biotechnology. 35A, No. 1, 5-14.

Kouloheris, A. P., 1981. Evaluation of potential commercial processes for the production of sulfuric acid from phosphogypsum. Report No. FIPR/PUB-Ol-002-001, Florida Institute for Phosphate Research.

Lindeken, C. L., 1980. Radiological considerations of phosphogypsum utilization in agriculture. Proceedings, International Symposium on Phosphogypsum, Report No. CONF-801161-l.

May, A. and Sweeney, J. W., 1982. Assessment of the environmental impacts associated with phosphogypsum in Florida. U.S. Bureau of Mines Report of Investigation, RI 8639.

May, A. and Sweeney, J. W., 1983. Evaluation of radium and toxic element leaching characteristics of Florida phosphogypsum stockpiles. U.S Bureau of Mines Report of Investigation, RI 8776.

May, A., Cobble, J. R. and Sweeney, J. W., 1985. Assessment of Phosphogypsum as a constituent of aggregate material. U.A. Bureau of Mines Report of Investigation, RI 8939.

Naff, D. B., 1984. The classification of phosphogypsum for environmental purposes. Proceedings, Fertilizer Institute Environmental Symposium, 373-404.

Nel, P. R. C., 1981. Input-output study of by-product gypsum. Council for Scientific and Industrial Research Report, CSIR/INFO-110, Pretoria, South Africa.

Nuclear Regulatory Commission, 1990. Below regulatory concern; policy statement.

Pena, N., 1985. Utilization of phosphogypsum produced in the fertilizer industry. United Nations Industrial Development Organization Report, UNIDO/IS.533, V-85-26890.

Roessler, C. E., 1987. The radiological aspects of phosphogypsum. Proceedings, Second Workshop on By-Products of Phosphate Industries, Miami, FL.

U.S. Environmental Protection Agency, 1989. National emission standards for hazardous air pollutants; regulation of radionuclides - 40 CFR Part 61. Federal Register 54, No. 240, 51654-51715.

Appendix

PROPOSED RESEARCH PROGRAM

PROPOSED RESEARCH PROGRAM

Research Objective

The objective of this proposed research program is to identify and evaluate potential commercial utilization alternatives for phosphogypsum waste products. This program seeks to develop new products and applications for phosphogypsum and other waste gypsum products which will help maintain the economic viability of the affected manufacturing industries while assuring protection of the ecology and public health.

Approach

A multidisciplinary approach is proposed which will combine the technical expertise of chemists, environmental engineers, civil engineers, materials engineers, biologists, clay mineralogists, business, legal and agricultural experts. It is further recommended that a permanent pool of expertise be established involving the research, academic and industrial communities to provide for scientific management of the phosphogypsum problem on a continuing basis.

Outline of Research

Four major phases of research are proposed, with multiple tasks required for each phase. It is intended that formal research proposals detailing each of the required tasks will be generated once funding for the effort is secured.

In the interests of expediency, some elements of each phase should be initiated concurrently.

I. <u>State of the Art and Fundamental Property Assessment</u> - Although a considerable amount of previous work has been attempted in the area of phosphogypsum use, those studies have not included a detailed analysis of fundamental properties or a determination of long-term integrity of potential uses.

This phase of the proposed research will examine previous studies, supply and production factors, user experience and the fundamental properties of waste gypsum materials. This phase will provide a preliminary technical assessment of potential uses to be studied in subsequent phases, and will allow the research team to take a fresh approach towards resolution of the phosphogypsum problem.

A. Literature Review - Includes review, classification, cataloging and correlation of existing information. Theoretical, empirical and experimental data will be examined, including material properties, mixture properties and utilization of phosphogypsum, fluorogypsum and flue gas desulfurization (FGD) gypsum.

B. Engineering Study of Phosphogypsum/Fluorogypsum Flue Gas Desulfurization Gypsum Supply and Production Factors - Includes an analysis of the methods of production and disposal, quantities produced and stockpiled, variability and conditions of the stockpiled material, the locations of phosphogypsum, fluorogypsum and FGD gypsum stockpiles, and existing environmental constraints.

C. Survey of User Experience - Includes data acquisition and field surveys of those uses of phosphogypsum/fluorogypsum/FGD gypsum and their composite forms as determined in A. This task would yield existing information and observations as to design procedures, manufacturing, processing and construction methods, quality control and assurance, and specifications, as well as user experience with durability, cost effectiveness, and overall satisfaction with methods of utilization. Travel and on-site inspection will be required.

D. Determination of Fundamental Phosphogypsum/Fluorogypsum/ FGD Gypsum Properties -Includes an examination of the basic properties of phosphogypsum, describing the physical, chemical, mineralogical, biological, mechanical, radiological and environmental behavior of this material. This analysis will supplement and amplify existing information. It will take into account the variability within and between sources and the effect of time and elements on these properties.

E. Preliminary Technical Assessment of Potential Uses - A study will be done of current materials utilization by agency and function and a technical and economic assessment made of possible replacements for these materials with phosphogypsum/ fluorogypsum/FGD gypsum or their composite forms. Novel applications will also be considered. Priority rankings will be given to those applications offering the best combined technical and economic feasibilities and the largest potential markets.

F. Refinement and Development of Phase II Workplan - The detailed workplan for PHASE II research activities will be structured to reflect those composites and applications receiving the highest priorities as a result of PHASE I efforts.

II. Product Development - This phase of the research will identify and define new products and applications and provide in-depth studies of previously characterized applications. The engineering behavior of phosphogypsum, fluorogypsum, FGD gypsum and their composite forms will be determined. Environmental screening of selected applications combined with economic analysis will determine those deemed feasible for inclusion in the field application studies of PHASE III.

A. New Product Evolution and Development - Basic research will be conducted to evolve previously uncharacterized modifications of phosphogypsum, fluorogypsum, and FGD gypsum into new compounds with practical applications. This effort will include laboratory experimentation, followed by selection or design of processing technology.

B. Define the Engineering Behavior of Phosphogypsum, Fluorogypsum, FGD Gypsum and Their Composite Forms - Laboratory studies of raw and stabilized phosphogypsum will be performed to examine those properties pertinent to the uses determined in PHASE I. This will include the effects of organic compounds, salts, saturation, wave action, solubility, and compatibility with geosynthetics. These studies will also include more conventional engineering properties, such as the moisture-density relationships, wet/dry and freeze/thaw durability, vacuum saturation, unconfined compressive strength, bearing capacity and permeability, the effects of temperature and reactions with other materials such as asphalt cement, Portland cement or fly ash will be studied. In addition, fatigue characteristics, resilient modulus testing, pavement design analysis, autogenous healing and recrystallization of failure phases of compacted, stabilized gypsum will be studied. Design procedures for use in PHASE III applications will be generated.

C. Environmental Screening of Selected Mixtures (Uses) - An analysis will be made of the possible effects on the environment for each proposed product and use. An assessment based on this information will be employed to screen out environmentally unsound applications and to determine the extent and method of monitoring environmental considerations for Phase III application studies.

D. Development of an Economic Model - A data base and methodology will be developed for relating current and projected phosphogypsum/fluorogypsum/FGD gypsum uses and associated costs. An economic model will be devised to relate the variables describing costs (location, transportation, processing, quantities, etc.) to those describing uses (highway construction, marine and coastal protection, hazardous waste encapsulation, others) and users (La. DOTD, industry, commerce, municipal/parish bodies, Corps of Engineers, federal agencies, others). This model will provide guidance in the refinement of Phase III and IV tasks and be used in developing the marketing strategies resulting from application studies.

E. Refinement and Development of Phase III Workplan - The detailed workplan for PHASE III research activities will be structured to reflect the findings of PHASE II studies.

III. Field Application Research and Evaluation - The various gypsum composites and new products identified in previous phases of this research will be field evaluated, with emphasis given to applications of potentially large volume. Engineering effectiveness, environmental safety, and economic feasibility will be evaluated. In addition, marketing strategies will be developed for those products identified by field studies to have merit.

A. Product Field Application and Monitoring - Field application and/or prototype evaluation will be done for those uses of phosphogypsum, fluorogypsum, and FGD gypsum identified by the previous phase as feasible from an engineering/economics viewpoint. Each subtask will include design of the application, formulation of plans and specifications, construction, quality control and assurance, and monitoring long-term effectiveness and environmental impacts. Final results will be utilized to determine feasibility and adjust standards for use. Applications may include:

1. New products evolved in previous phases of research.
2. Use of gypsum and composite forms in marine and coastal protection structures (levees, riprap, etc.).
3. Use in hazardous waste encapsulation.

4. Use in transportation and other high-volume construction applications. Possible applications might include use as a soil stabilization agent in treatment of bases and subbases, as a mineral filler in a hot asphaltic-concrete mix or in concrete, embankments, buildings, parking lots or airport facilities.

5. Agricultural uses.

6. Aggregate manufacturing.

B. Develop Marketing Strategies - Factors affecting supply and demand should be examined to develop markets for those products proven effective in applications research. Strategies could include subsidies through tax structure revision or through bonus money incentives for using gypsum products. It is intended that this task employ and fine-tune the economic model developed in Phase I.

IV. Technology Transfer - Seminars and conferences should be held to facilitate interchange among the engineering, industrial and user communities. This phase may include the development of formal training materials for local and national distribution.

EFFECT OF PHOSPHOGYPSUM ON SOME PHYSICAL PROPERTIES OF A SILTY CLAY SOIL

Dougrameji , J.S. Ali, N.M. Al - Aubaidi, Z.H.

Soil sci. Dept. Agri. College Abu - Ghraib , Iraq.

Abstract

A completely randomized block design experiment with five treatments, 0, 0.5, 1, 2, 4 T / ha of phosphogypsum, and four replicates was conducted in the field of the soil science department at Abu Ghraib to study the effect of phosphogypsum on some physical properties of a silty clay soil. Phosphogypsum was mixed with the upper three centimeters of the soil.

Mean weight diameter, modulus of rupture , bulk density , soil penetration resistance and infiltration rate were measured as indicative parameter . The results of the study showed no significant effects of phosphogypsum on the studied properties under the prevailing conditions of the experiment.

INTRODUCTION

Soil crust is a common problem in the soils of alluvial plain in Iraq . The problem of crust ins which affects seedling emergence and crop yield as in other parts of the world is due to low organic matter , low degree of aggregation , high silt + clay content , high ESP value ..... etc (Awadhwal and Thierstain 1985 , Dougrameji 1988 , 1989) . Improving soil structure through enhancing the aggregate stability provides one of the means for reducing soil crusting by application of organic matter , synthetic polyelcetrolytes and polymers ..... etc . Gypsum has been widely used for this purpose on the basis of exchanging Ca for Na^+ ions on exchange complex and hence favouring flocculation of colloids and increasing aggregate stability , water infiltration, porosity , and hydraulic conductivity (Frenkel and Hadas 1981 , Agassi et al 1981 , Gal et al 1984 and Shainberg and singer 1985).

The aim of this study was to investigate the effectiveness of phosphogypsum (PG) in reducing soil crusting of a silty clay soil .

MATERIAL AND METHODS

A complete randomized block: design field experiment in four replicates was conducted during 1986 - 1988 in the research plots of soil department on a silty clay soil (Al - Aubaidi , 1988) . The soil properties is shown in table 1.

Table 1 . Some physical and chemical properties of the soil studied .

Soil class	vertic torrifluvents
Soil texture	silty clay
% Cilt	46.15
% Clay	42.67
% Carbonate	25.00
% Gypsum	0.03
% Organic matter	1.20
ECe dc / m	5.76
PH	7.69
CEC me / 100 g soil	22.31
ESP	4.70

The soil treatments were control , 0.5 ,1.0 ,2.0 and 4.0 t/ha- phosphogypsum (industrial byproduct of phosphate fertilizer , contains 96 % $CaSO_4$, 7 H_2O , 1 % P_2O_5 , 0.96 % F and some trace elements with a PH value 3.44 and EC 2.38 dc / m) . The phosphogypsum (PG) was added as surface broadcast . Corn and Barley were taken as crop sequence during the period of investigation .

The crops irrigated with basin irrigation method with class C_3S_1 water . The corn and Barley consumed 1070 and 600 mm water during their growing season . soil samples were taken after the crop harvest , mean weight dimmeter (MWD) , modulus of rupture (MR) , bulk density (BD) and particle size distribution (PZD) of the crust and subcrust were measured using. the procedures described by Youker and

MeGuinness 1956 , Richards 1953 and piper 1958 . Furthermore infiltration rate and accumulated infiltration were measured after harvest (Michael 1981) .

RESULTS AND DISCUSSION

The results of this investigation as shown in table 2 indicates no significant increase in mean weight diameter or a decrease in modulus of rupture and bulk density of soil with an increased addition of phosphogypsum . This was due to low ESP value and high electrohyte concentration of soil solution which was remained above flucculation threshold value (25.9 Me / L in our soil (Loveday 1976 , Haider 1986 , Sharma and Tunny 1981) . Also its Known that calcareous soils are generally well aggregated and do not response to gypsum applications as Ca ions will be dominant in soil solution . The poor structure of the soil studied probably was due to low organic matter and high silt and clay contents (Dougramrji et al 1976 , Hardan and Al - Ani 1976) .

Comparing the soil crust (C ,0 - 1 cm depth) with the cubcrust (SC , 1 - 3 cm) showed a decrease in mean weight diameter and an increase in modulus of rupture and bulk density values of the subcrust in all treatments .

This was due to the physical dispersion of soil aggregates caused by the impact of irrigation water on soil aggregates and deposition of dispersed fine particles of soil material on the soil surface as well as their move downwards with the percolating water and subsequently clogging the pores . Data in table 3 shows an increase in the clay contents of the

Table 2 . Mean weight diameter , modulus of rupture and bulk density of crust and sub . Crust of a silty clay soil treated with different dozes of phosphogypsum .

Treatments		M W D (m m)	M R (Kpa)	B D (kg / m^3
Control		0.555	261.07	1499
		0.392	324.45	1530
0.5 t / h	C	0.453	240.08	1486
	S C	0.350	360.08	1535
1.0 t / h	C	0.562	237.46	1471
	S C	0.320	336.92	1537
2.0 t / h	C	0.393	264.18	1500
	S C	0.340	348.41	1565
4.0 t / h	C	0.575	247.50	1469
	S C	0.313	319.12	1509
L S D 5 %	C	0.215	65.02	37.20
	S C	0.149	56.50	82.50

Table 3 . Particle size distribution (PZD) of the crust and subcrust of a silty clay soil after treatments with different dozes of phosphogypsum .

P Z D μm		Treatments Control	0.5	1	2	4 t / h
250 _ 500	C	0.395	0.476	0.220	0.201	0.284
	S C	0.222	0.171	0.219	0.257	0.263
100 _ 250	C	5.141	4.010	4.305	2.871	4.200
	S C	3.112	3.976	3.136	3.589	4.200
50 _ 100	C	9.560	6.719	6.319	7.201	7.907
	S C	7.487	7.416	7.006	7.677	8.050
20 _ 50	C	34.824	48.724	51.945	62.080	51.569
	S C	44.899	44.557	46.079	49.837	47.247
5 _ 20	C	8.600	2.523	1.642	1.767	0.548
	S C	1.926	3.309	3.741	2.487	1.786
2 _ 5	C	7.020	3.091	2.310	1.830	0.862
	S C	1.770	1.913	0 793	0.205	1.518
0 < 2 μm	C	34.460	34.466	34.208	34.323	34.630
	S C	40.584	38.608	39.026	35.948	36.936

subcrust which was amounted to 17.8 % in control and 14.08 with 1.0 t / h phosphogypsum . Also there was an increase in silt contents of the subcrust , therefore it is possible that some fine particles of the PG moved downward during mixing the surface soil (34 % of the phosphogypsum used was less than 0.1 mm in size) or was dissolved in the irrigation water and precipitated in the subcrust soil .

CONCLUSIONS

Based on the results of this and previous studies application of phosphogypsum for improvements of soil structure should be further studied in relation to carbonate content of the soil , size of phosphogypsum particles and method and dozes of application .

REFERENCES

Aggasi , M. , I. Shainberg and J. Morin . 1981 . Effect of electrolyte concentration and soil sodicity on the infiltration rate and crust fomation . Soil Sci. Soc. Am. J. 45 : 848 - 851 .

Al - Aubaidi , Z.H.H. 1988. Effect of phosphogypsum on some properties of a silty clay soil at Abu - Greaib and corn growth . M. Sc. thesis . Soil Sci. Dept. Agri. College , Iraq .

Daghistani , S.R. , J .S . Dougrameji and I.A. Ali . 1989 . Effect of some soil conditioners on some physical properties of soil . Fifth scientific Res. Cong. Baghdad , Iraq vol. 1 : 114 - 126 (in Arabic) .

Dougrameji , J.S. and R. Van Arat . 1976 . Improvement of poor structured basin depression soils at fudhaliya experimental field . Sumposium of water in heavy soils , Bratisalava , CSSR .

Dougrameji , J.S. , F.H. Ahmed and A.A. Jasim . 1988 . Soil crusting and its improvement : 1 . Penetration restance and seedling emergence of sugarbeet . J. Agric. Water Reso. Res 7 , 1. 1 - 14 . (in Arabic) .

Dougrameji , J.S. , H.F.S. Al - Azzawi and J.K. Kassim . 1989 . Effect of clay content and clay minerals on soil crust . Fifth scientific Res. Cong. Baghdad Iraq . Vol. 1 , 104 - 112 .

Frenkel , H. and A. Hadas . 1981 . Effect of tillage and gypsum incorporation on rain runoff and crust strength in field soils irrigated with saline sodic water . Soil Soc. Am. J. 48 : 156 - 167 .

Gal , M. , L. Arcan , I. Shainberg and R. Keren . 1984 . Effect of exchangeable sodium and phosphogypsum on crust structure - scanning electron microscope observations . Soil Sci. Soc. Am. J. 48 : 872 - 878 .

Haider , F.A. . 1986 . Effect of cations on hydraulic conductivity and clay dispersion in standard clays and arid soils . PH. D. Thesis . State University of Ghent .

Hardan , A. and A.N. Al - Ani . 1978 . Improvement of soil structure by using date and sugar beet waste products . In " modification of soil structure " . (Eds. W.W. Emerson et al) .

Loveday , J. . 1976 . Relative significance of electrolyte and cation exchange effects when gypsum is applied to a sodic clay soil . Aust. J. Soil Res. 14 , 361 - 371 .

Michael , A.M. . 1981 . Irrigation theory and practices . Vikas publishing house , New Delhi , India .

Piper , C.S. . 1950 . Soil and plant analysis . Academic press , New York .

Richards , L.A. . 1953 . Modulus of rupture as an index to crusting of soil . Soil Sci. Soc. Amer. Proc. 17 : 321 - 324 .

Shainberg , I. and M J. Singer . 1985 . Effect of electrolytic concentration on the hydraulic properties of depositional crust . Soil Sci. Soc. Am. J. 49 : 1260 - 1263 .

Sharma , M.L. and J. Tunny . 1978 . Interaction of gypsum with humotina and krilium on the structural stability and water flow properties of soils . In "modification of soil structure " (Eds. W.W. Emerson et al) . pp . 181 - 190 .

Youker , R.E. and J.L. McGuinness . 1956 . A short method of obtaining mean weight diameter values of aggregate analysis of soil . Soil Sci. 83 : 291 - 254 .

THE STATUS AND TRENDS OF PHOSPHOGYPSUM UTILIZATION IN THE USSR

Novikov A.A., Klassen P.V.
The Moscow Fertilizer and
Insecte-Fungicide Research Institute
(NIUIF)

Evenchik S.D.
The Moscow Institute for
Designing Basic Chemistry Plants
(GIPROKHIM)

I. Phosphogypsum Resources

Basically, only 39.0% P_2O_5 Kola apatite concentrate and 24.5% P_2O_5 straight Karatau phosphate rock are used in the USSR to produce wet-process phosphoric acid. In 1987 79.3% of wet-process phosphoric acid was produced from apatite concentrate, while 20.7% - from Karatau phosphate rock. The respective figures for 1990 are expected to be 72.7% and 25.3% (and 2% will be produced on the basis of imported phosphates).

The di- and hemihydrate processes are used in the USSR to produce wet-process phosphoric acid. Only the dihydrate route is used with Karatau phosphate rock.

In 1987 80.8% of wet-process phosphoric acid was produced using the dihydrate process, and 19.2% - using the hemihydrate process.

In 1988 23.5 mln t of phosphogypsum were produced at the Soviet wet-process phosphoric acid plants, including 3.5 mln t in the form of the hemihydrate (from here on - as dry dihydrate). Considering the amount of phosphate fertilizers to be produced, the amount of phosphogypsum will total 43.6 mln t in 2000.

On January 1, 1990 there were about 300 mln t of phosphogypsum (natural weight) in the disposal areas at the Soviet plants.

At certain wet-process phosphoric acid plants the amount of phosphogypsum produced has reached very high levels (between 1.3 and 3.8 mln t/a at full plant capacity).

II. Phosphogypsum Disposal and Storage

Phosphogypsum storage in disposals (dry or hydro-transportation).

In the USSR, like in other countries, phosphogypsum disposal and storage involve considerable one-time and operating costs. According to the plants' data, the one-time costs amount to 12% of the wet-process phosphoric acid plant installation cost and to approximately 18% of the operating cost.

Phosphogypsum disposals require big plots of land; sometimes it is necessary to allot even agricultural lands for them. Phosphogypsum storage in disposals has a detrimental effect on the environment, even if the storage conditions meet all the necessary requirements and the soluble impurities phosphogypsum contains are neutralized.

The negative effect of phosphogypsum disposals on the environment manifests itself in the contamination of ambient air, underground and surface waters, top-soil and vegetation with noxious substances infiltrating through the screen. This contamination can also occur because of weather erosion and dusting. Thus, during dry storage (without prior neutralization) the gas phase receives (on average) 0.1% of the fluorine contained in phosphogypsum; dust from the disposal area has, on average, 10 g F per 1 t of phosphogypsum (the radius of dust spread is up to 1.5 km); 10% F are washed out with precipitation (this figure refers to the plants where such observations were made).

Therefore, to solve the problems of phosphogypsum utilization in the USSR often means the possibility of building new phosphate fertilizer plants and expanding or even operating the existing ones.

At the same time it has been proved that phosphogypsum can be used as secondary raw materials replacing natural raw materials including natural gypsum, the requirement for which in the building materials industry and agriculture of the USSR reach 20,000,000 t/a.

In the USSR phosphogypsum is disposed only on land. In other countries (mainly in the USA) phosphogypsum is, as a rule, transported to disposal areas in the form of slurry, while in the USSR several ways of phosphogypsum transportation are employed now.

1. It can be transported by belt conveyors and rope-ways. Belt conveyors (usually two) are installed in the galleries that are heated. Phosphogypsum is transported by belt conveyors to the point of leading into charging cars of the rope-way at the battery limits.

2. Phosphogypsum can be transported by belt conveyors and dump trucks, disposals being formed later by bulldozers.

3. Phosphogypsum can be hydrotransported, with the slurry settling in gypsum ponds and the clarified liquor recycled for phosphogypsum repulping (after mixing with phosphoric acid a portion of it is sent into the wet-process phosphoric acid manufacture).

The fourth way of phosphogypsum transportation has also been used: phosphogypsum is taken by belt conveyors to the disposal area where it is stacked by the reversible tramways.

III. Main Trends of Phosphogypsum Utilization

The USSR has carried out and is still continuing research and development work on different ways and methods of direct phosphogypsum utilization or its processing into other products because research has proved the feasibility of phosphogypsum utilization in the national economy instead of traditional types of raw materials. Some of the results of this research and development work have been put into practice.

The main trends of phosphogypsum utilization are described below:

In Agriculture:

for chemical reclamation of solonetz soils instead of using ground raw natural gypsum;

for chemical reclamation of acid soils. Phosphogypsum is mixed with powdered lime materials (ground limestone, shale, ash, etc.);

for composting with organic fertilizers instead of ground phosphate rock.

In the Cement Industry:

as a means of mineralization: as an admixture in the raw materials (including the pyrite cinder);

as a cement retarder: phosphogypsum is added instead of natural gypsum to the cement clinker before it is ground.

In the Manufacture of Gypsum Plasters and Associate Products: instead of conventional methods:

a. Phosphogypsum is used in the production of strong composite autoclave gypsum plasters (the α -hemihydrate of calcium sulphate) of improved water resistance and anhydrite gypsum plasters which are used:

  - in the building industry: they are used directly (together with additions), or as plaster and filler materials, or for filled self-levelling bases of floors, or in the production of building materials (partition plates, acoustic and decorative boards, bricks and blocks for outer fencing of buildings, etc.);

  - in collieries and other types of pits for packing goafs and building guard belts during mining without establishing pillars (instead of cement);

  - in the production of oil-well cement which is used in low-temperature oil and gas wells and in geology (instead of cement);

b. calcined gypsum plasters (the β -hemihydrate of calcium sulfate) which are directly used in the building industry as plaster and coating materials, and in the production of building materials (partition plates and panels, gypsum-board sheets, gypsum fibre and gypsum-chip boards, sound-absorbing and decorative boards, etc.).

In the Sulphuric Acid Manufacture: (instead of conventional sulphur-containing raw materials - elemental sulphur and pyrite); a number of by-products are also produced:

- cement (including white cement): by using the thermal process;
- lime: by using the thermal process, with elemental sulphur obtained at the intermediate stage;
- silicate materials: by using the thermal and electro-thermal processes.

In the Manufacture of Building Materials (raw phosphogypsum is used):

- blocks and panels (phosphogypsum is mixed with flying ash and lime);
- bricks: by compacting a mixture of phosphogypsum and gypsum plaster produced from phosphogypsum;
- products made of phosphogypsum and organic binding agents (for example, urea resin).

As Asphalt Addition:

Research is under way to investigate the possibility of using phosphogypsum for foundation bases.

In the Production of Fertilizers and Salts:

Ammonium sulphate (without using sulphuric acid) and chalk, a mixture with carbamide, sodium sulphate.

As Filler

In the production of paper instead of kaoline, in the pain and varnish industry and in the production of plastics, glass, ammonium nitrate instead of conventional materials (heat-treated phosphogypsum - instead of microbarite, kaoline, chalk; phosphogypsum - instead of sodium sulphate, etc.)

In the Production of Heat-Insulating Materials.

In the Building of Motor Roads (some phosphohemihydrate can also be used directly.

IV. Practical Phosphogypsum Utilization

4.1 In Agriculture for Soil Chemical Reclamation

The USSR has about 66,000,000 ha of acid soils including 52,000,000 ha of agricultural lands, and over 100,000,000 ha of solonetz soils and solonetz-like complexes together with zonal soils (12.1% and 18.4% of the total agricultural land area, respectively) which require chemical reclamation.

In 1988 3.2 mln t of phosphogypsum were used instead of natural gypsum for chemical reclamation of solonetz soils.

In 1955 the phosphogypsum requirement for this purpose will reach 9.3 mln t, in 2000 - 19.2 mln t.
The problem of using phosphogypsum in mixtures with powdered limestone materials is still being studied.

This trend of phosphogypsum utilization is very promising because the requirement for limestone decreases by approximately 40%, and the sulphur requirement of soil is met.

4.2 In the Cement Industry

In 1988 only 0.63 mln t of phosphogypsum, including 0.25 mln t of non-granulated phosphogypsum, was used in the cement industry instead of natural gypsum.

In 1955 the cement industry will need 5.6 mln t of phosphogypsum, in 2000 - 5.9 mln t.

To increase rates of phosphogypsum utilization in the cement industry it is necessary to follow Japan's example and give up the practice of phosphogypsum granulation; this will considerably enhance the economic efficiency of its application.

4.3 In the Production of Gypsum Plasters

The USSR has one major plant producing 360,000 t/a of gypsum plaster (the α-hemihydrate of calcium sulphate); gypsum plaster is produced on the basis of the autoclave technology and is processed on site into products.

There are plans to build several more plants of this type to produce gypsum plaster of improved water resistance.

There are also several small 2.5 t/h plants where gypsum plaster (the β-hemihydrate of calcium sulphate) is produced out of phosphogypsum. This gypsum plaster is processed on site into wall stone.

A major plant to produce 400,000 t/a of anhydrite gypsum plaster is now under construction.

Possibilities of transferring the existing wet-process phosphoric acid units to the di-hemihydrate process are being considered to produce gypsum plaster of high strength directly at the phosphoric acid plant.

In 1980 0.4 mln t of phosphogypsum was used in the production of gypsum plasters. In 1955 the requirement for phosphogypsum in the production of gypsum plasters will total 11.4 mln t, in 2000 - 14.8 mln t.

4.4 In the Production of Sulphuric Acid and Cement/Lime

This trend of phosphogypsum utilization has long been studied.

Many reports have been published on the results of research work carried out in the USSR and other countries.

Nevertheless, there is no major commercial plant yet. At present tests are being conducted on phosphogypsum attack to produce SO_2 and CaO in the the fluidized bed.

Considering the amount of wet-process phosphoric acid to be produced in 2000, only a little more than one half of all the phosphogypsum and phosphohemihydrate produced could at the very best be utilized after meeting all the requirements for phosphogypsum in agriculture (for chemical reclamation of solonetz and acid soils), in the production of gypsum plasters, in the cement industry, after using it as a filler, in the production of heat-insulating materials, in highway engineering. But this is very unlikely.

The problem of phosphogypsum utilization can be solved radically only when ways will be found to process it on site into sulphuric acid which is recycled into the wet process phosphoric acid production with the simultaneous production of commercial-grade cement and lime.

We are studying the process of phosphogypsum treatment (cement being the by-product) with the aim of simplifying it considerably and minimizing heat consumption. We closely follow the respective joint research work done by Lurgi G.m.b.H. and Babcock-BSH and by FIPR and Davy McKee, Ltd.

We think it advisable to join the efforts of FIPR and the Scientific-and-Research Production Association "Minudobreniya" in solving the problem of phosphogypsum utilization in the sulphuric acid production.

4.5 Other Trends of Phosphogypsum Utilization

In 1988 other trends of phosphogypsum utilization used up 0.65 mln t, including 0.15 mln t of phosphohemihydrate (as phosphogypsum), in highway engineering.

The requirement for phosphohemihydrate (as phosphogypsum) will total 0.9 mln t in 1995 and 1.3 mln t in 2000.

X X X

Considering the current prices of products that can be manufactured on the basis of phosphogypsum, the processing of phosphogypsum into these products will, in most cases, cause the profits of phosphate fertilizer plants to fall. However, the necessity to do away with phosphogypsum disposals (due, first of all, to ecological requirements (and the desirability of replacing conventional natural raw materials (which have to be mined specifically) dictate the need for full phosphogypsum processing (except that part of it which can find direct us - in agriculture).

Phosphogypsum processing (as well as hydrofluosilicic acid treatment) should be considered as the final stage of wet-process phosphoric acid production.

References

"Phosphogypsum and Its Use". Moscow, Chemistry Publishing House (1990).

"Research on Phosphogypsum Utilization". NIUIF Proceedings, issue 256, Moscow (1989).

PAVEMENT EVALUATION OF TWO GYPSUM STABILIZED COUNTY ROADS

Robert K. H. Ho
Soils Materials Research Engineer
Florida Department of Transportation

Third International Symposium on Phosphogypsum
Orlando, Florida
December 4-7, 1990

PAVEMENT EVALUATION OF TWO GYPSUM STABILIZED COUNTY ROADS

Robert K. H. Ho
Soils Materials & Research Engineer
Florida Department of Transportation
Gainesville, Florida 32602

ABSTRACT

Two phosphogypsum stabilized experimental county roads were constructed in 1986 and 1987 in Polk and Columbia counties, Florida. Progress reports during the construction of these two projects were issued in 1986 and 1987.

This paper summarizes field test data not previously reported on the two completed projects. These test data include Clegg impact values (CIV), field densities and Dynaflect deflection readings and computed modulus values.

Comparison of Dynaflect deflection data and modulus values of the two roads with those from a primary highway gave some indication of the relative strength of the pavements.

Even though the Columbia County pavement surface was severely damaged by the hard freeze of December 1989, both experimental roads appear to be performing satisfactorily under present local traffic.

INTRODUCTION

During the latter part of 1986, two experimental county roads were constructed using phosphogypsum mixtures in Polk and Columbia Counties. The purpose of these two projects was to evaluate the construction and performance of phosphogypsum mixtures as base materials under traffic. Both these county roads are off the main highways and carry only local traffic.

An introductory paper (Ho, et al., 1986) was presented at the Second International Symposium on Phosphogypsum on December 10-12, 1986 at the start of constructionof White Springs Road in Columbia County. This was followed by a progress report (Ho, et al., 1987) on the construction of the first section of the Columbia County experimental road with approximate blends of 1 to 2 (phosphogypsum to sand). At about the same time, a report (Chang, 1987) was made on the construction of the other experimental road (Parrish Road) in Polk County. Both projects required environmental impact investigations which included preconstruction and post construction monitoring of air, soil and groundwater,

CONSTRUCTION OF EXPERIMENTAL ROADS

The general construction procedure for the two experimental roads had been reported (Chang, et al., 1989) previously. Briefly, the existing unpaved road surface was first graded with a motor grader. Truck loads of phosphogypsum hauled to the site were spread evenly over the prepared soil to a thickness required for the particular phosphogypsum to soil blend. The phosphogypsum and soil were then mixed thoroughly to a set depth with a rotomixer with several passes. The mixture was then compacted to 95% modified Proctor (AASHTO T-180) with a sheepsfoot roller followed by a steel wheeled roller and a pneumatic tire roller. The finished base was sealed with hot liquid asphalt and screenings or sand were placed and rolled. This was followed by about one inch of asphalt surface.

PARRISH ROAD, POLK COUNTY

Figure 1 shows the layout of Parrish Road experimental sections. This experimental road was completed in the fall of 1986. Dihydrate phosphogypsum used in this project was donated by USS-Agri-Chemicals. Three sections were constructed using slightly different blends of phosphogypsum and sand-clay as shown in Table 1. Note that Section 3 was built in two stages. Field inspection and density control were made by Polk County Public Works Department personnel and design specifications required the phosphogypsum mixture to be compacted to 95% modified Proctor. The road was opened to traffic in October 1986.

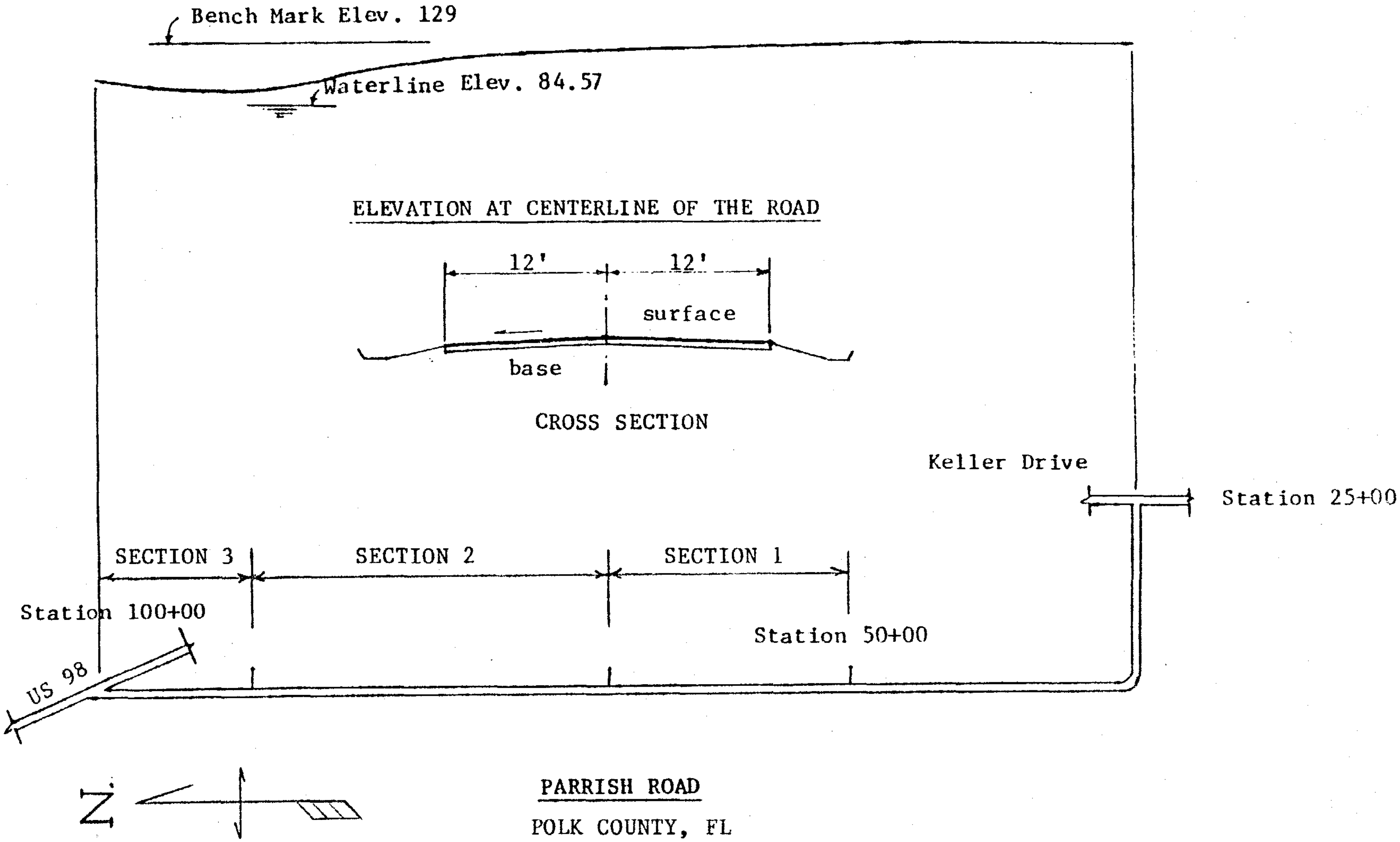
Table 1

Parrish Road, Polk County

Section	Stations	Max. Density pcf	Optimum Moisture %	Comments
1	50+00 - 66+00	124.1	7.1	6" dihydrate mixed to depth of 15" (base)
2	66+00 - 90+00	127.4	6.8	3" dihydrate mixed to depth of 15" (base)
3	90+00 - 100+00	122.5	8.2	First 3" dihydrate mixed to depth of 12" and compacted
3	90+00 - 100+00	116.2	9.1	Additional 3" dihydrate mixed to depth of 10" and compacted

WHITE SPRINGS ROAD, COLUMBIA COUNTY

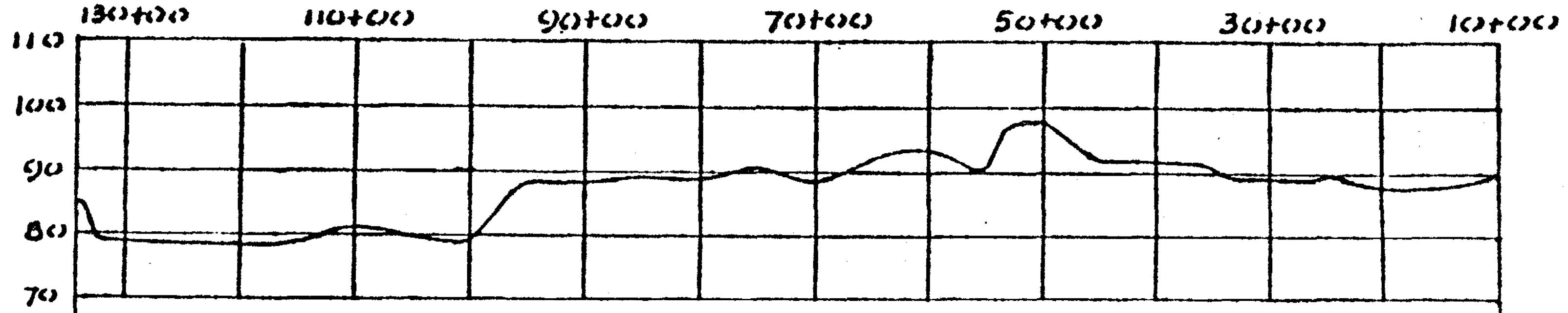
Construction of this test road by Columbia County Road Department started in November 1986 and was completed around May 1987. Phosphogypsum was supplied by Occidental Company. The base materials consisted of three different blends of phosphogypsum and sand of approximately 1:2, 1:1 and 2:1 as well as a 100% phosphogypsum section (Table 2) with lengths of about 5000, 2000, 1320 and 500 feet respectively. Figure 2 shows the layout of the test sections. Table 3 shows the actual blends of phosphogypsum and sand of samples taken from Sections 2, 3 and 4. It indicates that the individual sample blends were quite variable. Tables 4, 5 and 6 show CIVs taken during construction at Test Sections 2, 3 and 4, respectively, with field densities taken at random locations. Note that in all sections some areas did not obtain 95% of modified Proctor density, particularly in Section 2. Table 7 summarizes the average CIV for the four sections indicating also Section 2 yielded the lowest CIVs.



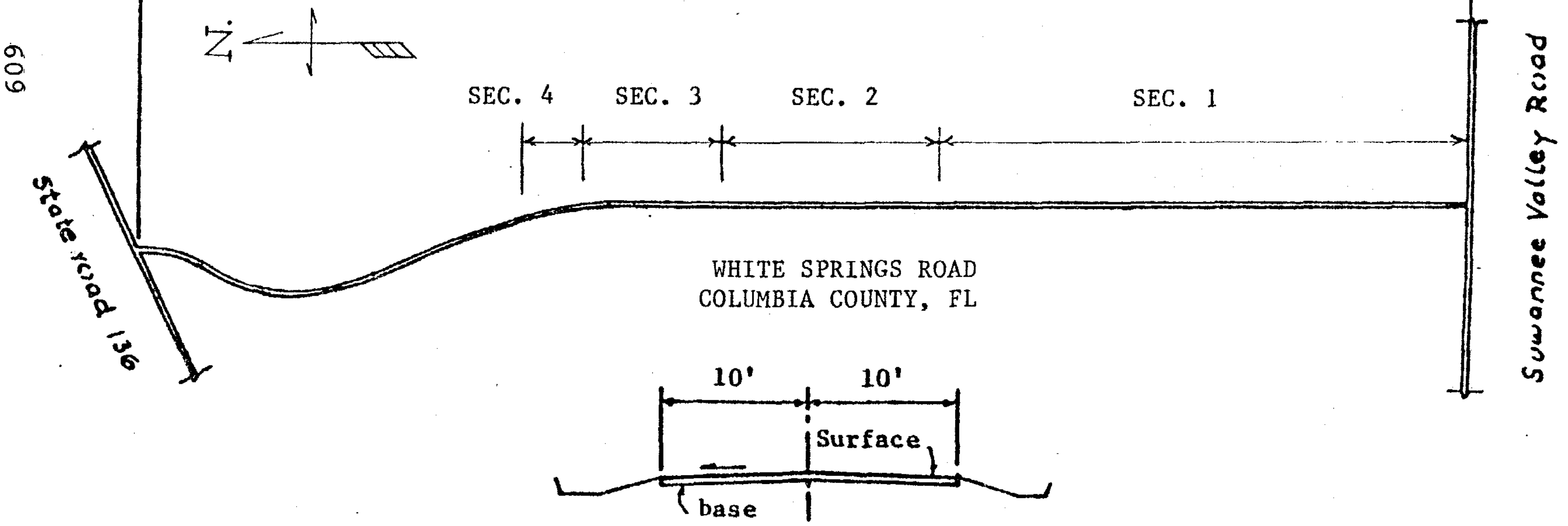
PARRISH ROAD

POLK COUNTY, FL

Figure 1



ELEVATION AT CENTERLINE OF THE ROAD



CROSS SECTION

Figure 2

Table 2

White Springs Road

Section	Station	Phosphogypsum: sand
1	10+00 - 60+55	1:2
2	60+55 - 80+56	1:1
3	80+56 - 93+77	2:1
4	93+77 - 98+86	100% phosphogypsum (dihydrate)

TABLE 3 - Laboratory Tests Summary

White Springs Rd

LOCATION	SAMPLE NO.	% GYPSUM	PH	ACTUAL* BLEND GYP/SAND	COMMENTS
STA 61+10 TO STA 80+56 (SECTION 2)	1-A	51.9	5.2	58/42	All samples contained a mixture of dihydrate and hemihydrate. (Blend Not Controlled)
	1-B	32.8	5.1	36/64	
	1-C	51.6	5.4	57/43	
	1-D	55.9	5.6	62/38	
	AVG	48.1	5.3	53/47	
STA 80+56 TO STA 93+77 (SECTION 3)	2-A	42.9	5.8	47/53	Sample 2-B contained a mixture of hemi and dihydrate gypsum. All other samples were dihydrate. (Blend Not Controlled)
	2-B	46.1	6.2	51/49	
	2-C	60.2	6.0	67/33	
	2-D	80.4	5.6	89/11	
	AVG	57.4	5.9	64/37	
STA 93+77 TO STA 98+86 (SECTION 4)	3-A	85.3	3.2	N/A	Sampled from roadway All samples contained dihydrate only. No hemihydrate.
	3-B	89.0	3.7	"	
	3-C	93.7	3.1	"	
	3-D	92.2	3.1	"	
	AVG	90.05	3.3	N/A	
MINE STOCKPILE	1	92.8	2.7	N/A	
	2	92.5	2.9	"	
	3	93.1	2.9	"	
	AVG	92.8	2.8	N/A	

*Blends computed on basis of percent gypsum in stockpile materials sampled from roadway.

TABLE 4 - Section 2

CLEGG IMPACT VALUES (CIV)

White Springs Rd

STATION	10' LT	5' LT	CL	5' RT	10' RT	γ_d	% PROCTOR
64+60	16	22	19	19	12*	111.3	95.7
65+30	18	24	17	22	19*	109.7	94.3
68+10	19	19	20*	23	14	105.4	90.6
69+50	19	20	18*	22	21	108.8	93.6
71+60	19*	20	16	19	18	108.3	93.0
73+70	17*	23	17	16	12	105.1	90.4
75+10	16	17	21	17	19*	107.9	92.8

PROCTOR: 116.3 pcf @ 10.1 %

* Denotes Location of density tests

TABLE 5 - Section 3

CLEGG IMPACT VALUES (CIV)

White Springs Rd

STATION	10' LT	5' LT	CL	5' RT	10' RT	γ_d	% PROCTOR
85+44	15	25	27*	28	16	107.6	95.1
86+80	17	21	20*	16	13	100.6	88.9
89+15	16	24	31*	22	14	106.5	94.2
91+50	23	25	29	25	22*	113.3	100.2

PROCTOR: 113.1 pcf @ 10.8 %
LBR: 21.5

TABLE 6 - Section 4

CLEGG IMPACT VALUES (CIV)

White Springs Rd

STATION	10' LT	5' LT	CL	5' RT	10' RT	γ_d	% PROCTOR
93+85	22	24	23*	26	25	113.2	117.8
94+89	19	25	35	23	18*	87.4	90.9
95+12	31*	31	37	27	19	102.9	107.1
96+46	21	32	34	31	20*	104.8	109.1

PROCTOR: 96.1 pcf @ 16.5 %
LBR: 14.0

* Denotes Location of density tests

Table 7

Average Clegg Impact Values
White Springs Road

Section	10'L	5'L	CL	5'R	10'R
1	21	28	28	25	20
2	18	21	18	20	16
3	19	24	28	22	18
4	23	28	32	27	20

NONDESTRUCTIVE TESTING

Nondestructive structural pavement evaluation consists of making nondestructive measurements on a pavement's surface and then inferring the in-situ characteristics of the various pavement layers from these measurements. Previously the only way to evaluate a pavement was the destructive method of cutting open trenches or test pit with field and laboratory tests. Today nondestructive testing of pavements has become routine in most State Highway Departments.

The three nondestructive techniques used by Florida Department of Transportation are

a) Benkelman beam - static deflection
b) Dynaflect - steady static (dynamic) deflection
c) Falling Weight Deflectometer - impact load response

Of these three methods, the method most often used is the Dynaflect because of its speed. It uses two counter rotating masses to apply a peak-to-peak load of 1000 lbs at a frequency of 8 hz through two steel wheels placed at 20 inch centers. The maximum deflections are measured by five geophones at one-foot intervals with the first one placed between the wheels. These readings yield the shape of the deflected pavement surface within 4 feet of the load wheels.

Godwin, et al, (1981) and Miley (1984) had correlated 12-inch field plate modulus values for base, subgrade and embankment of existing roadway sections with Dynaflect geophone Nos G2, G3, G4 respectively. These sections consisted of limerock bases, stabilized subgrade and embankment material varying from limerock to muck. Even though the two experimental roads were substantially different in pavement materials from the roadways used in the correlation, it was considered informative to compare the relative deflection as well as the computed modulus values for the selected primary roadway with those computed for the two experimental county roads.

DYNAFLECT DEFLECTION MEASUREMENTS

Florida Department of Transportation does not have any Dynaflect data on secondary roads. The nearest roadway with Dynaflect information is a section of US41 in southern part of Columbia County. This roadway cross section consists of a 3-inch asphaltic surface and 8 inches of limerock base. This is a stronger pavement section compared with the two experimental roads which consisted of about 1 inch of asphalt surface on a phosphogypsum and soil mix of about 10 inches. Therefore it is expected that the dynamic deflections for the two test roads will be greater than the US41 pavement section. This is confirmed by comparing the deflected surface of all the test sections with US 41 as shown in Figures 3 and 4. However, the pavement sections at White Springs Road yielded much high deflections than those at Parrish Road. On the other hand the deflections at Parrish Road were about the same or slightly greater than the US41 pavement section.

Figures 3 and 4 are plots of Dynaflect readings. taken at three and two years apart for White Springs Road and Parrish Road respectively. Both plots showed that the 1990 deflection readings were less than the corresponding readings taken several years before. This could be due to several factors such as the hardening of the asphaltic surface, changes in soil moisture conditions and/or possible consolidation of the pavement layers under cumulative traffic.

Figure 3 - White Springs Road

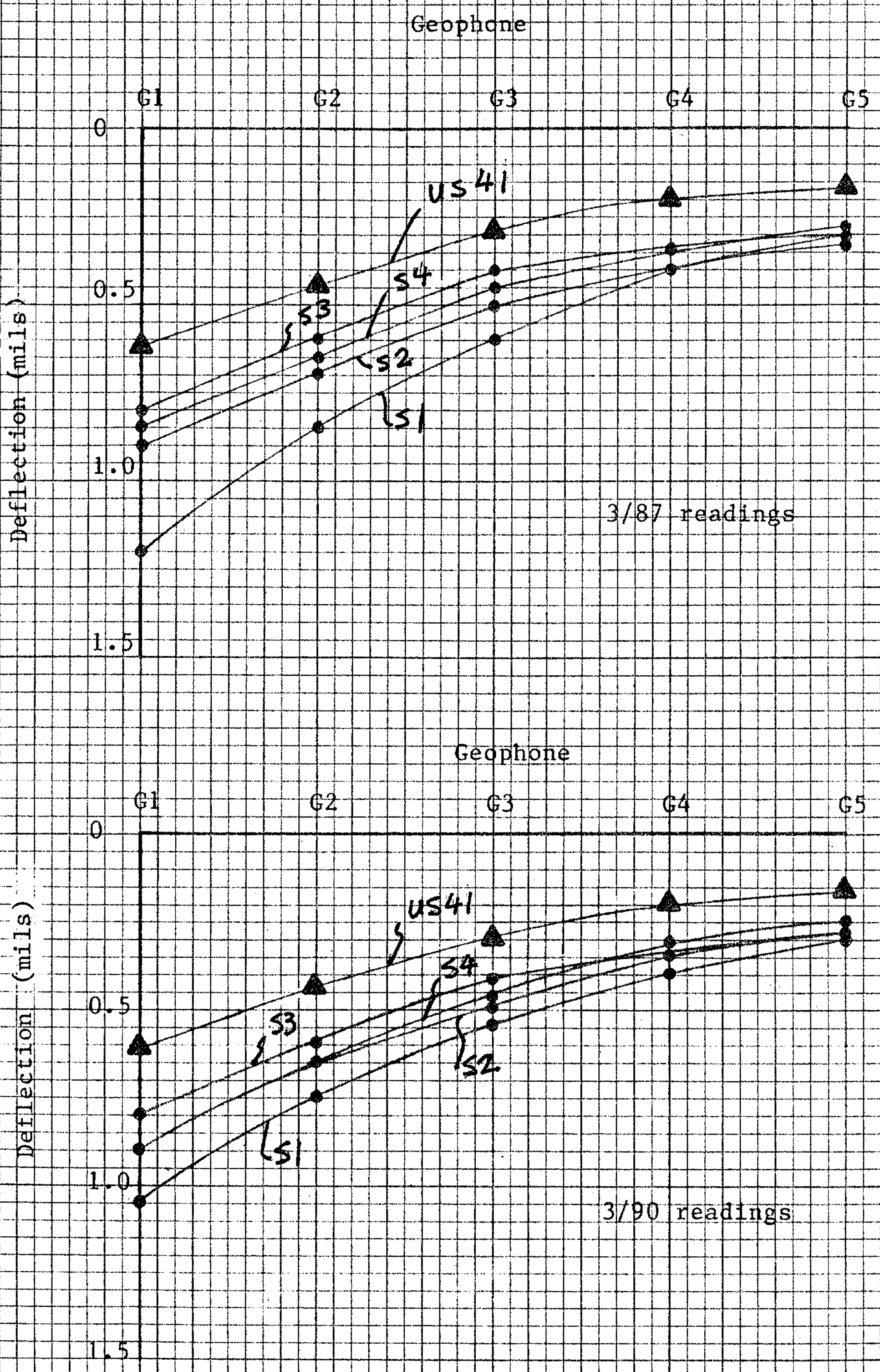
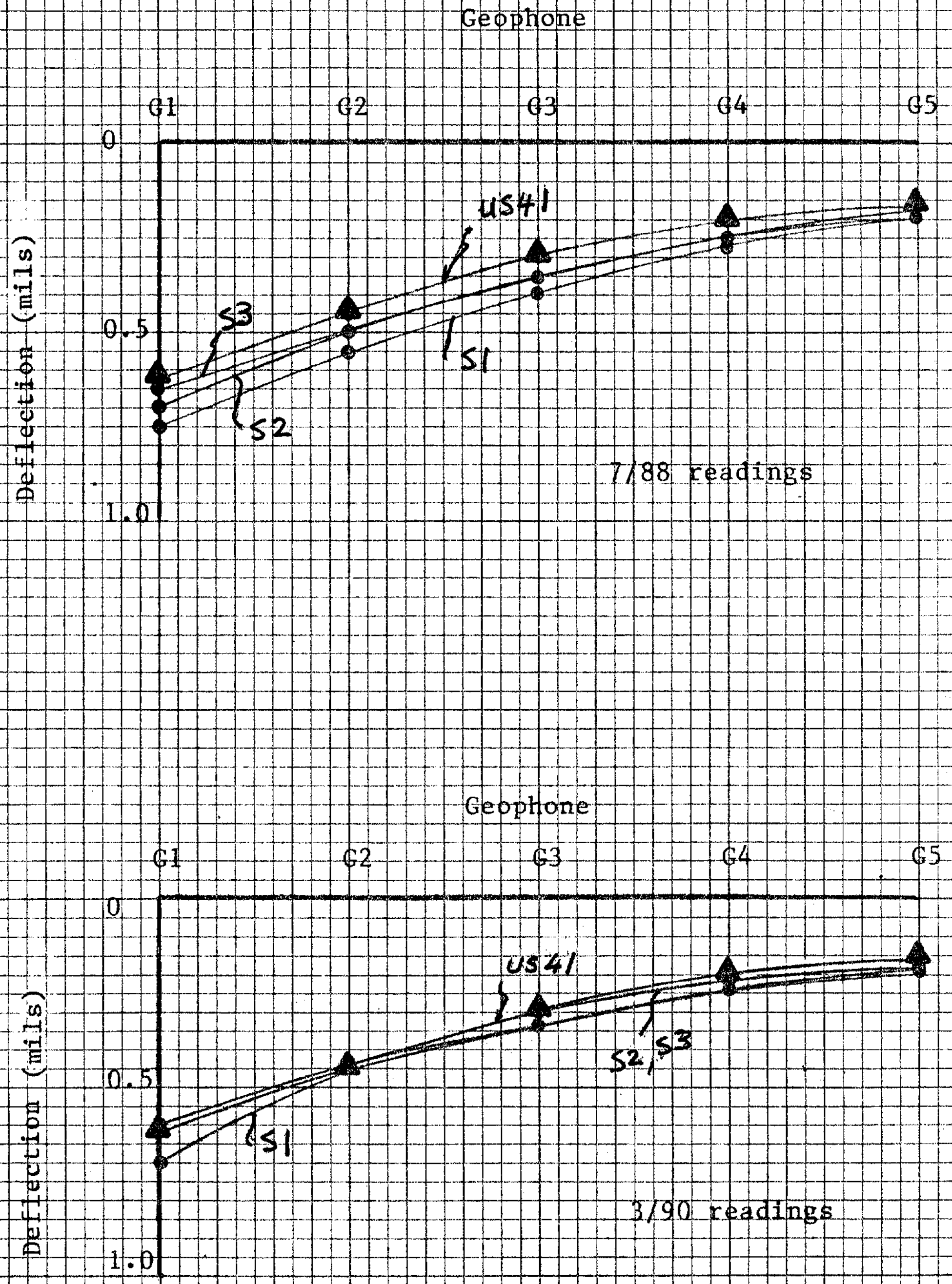


Figure 4 - Parrish Road



COMPUTED MODULUS VALUES

Using the regression equations developed by Godwin, et al., (1981) and Miley (1984), the estimated composite modulus values for base, subgrade and embankment were computed using average geophone readings taken in March 1990 on the northbound outer wheelpath.

The modulus values are tabulated below.

Table 8 - Computed Modulus Values

	White Springs Road Sections				Parrish Road Sections			US 41
	1	2	3	4	1	2	3	
Base	33.6	34.9	37.0	35.9	40.9	43.9	41.1	40.6
Subgrade	23.3	24.1	26.1	25.3	27.9	30.3	27.7	30.6
Embankment	18.9	19.4	21.5	21.2	23.3	25.5	22.8	25.1

All values are in 1000 psi

Comparison of corresponding modulus values gives the relative strengths of each pavement section though the numbers are not absolute values for that layer. The values seemed to indicate that Section 3 is the strongest at White Springs Road while Section 2 is the best at Parrish Road. Based on these readings, White Springs Road is a weaker pavement than Parrish Road which is comparable to the US 41 pavement section.

OBSERVATIONS AND RECOMMENDATIONS

Site visits were made to both roads before the Dynaflect tests were made in March 1990. The devastating cold spell on Christmas weekend in 1989 had caused extensive damage to food crops and highways in North Florida. The White Springs Road was no exception. During the visit in February 1990, numerous patches were noted on the pavement. Some failed areas revealed asphalt thickness between 1/2 to 3/4 inch. Some rutting was noted in Section 2.

Parrish Road being located further south in Polk County was not noticeably affected by the hard freeze of December 1989. Other than the freeze damage to the White Springs Road, both roads appear to be performing satisfactorily under local traffic as intended.

Experience with the two County Road Departments revealed that one county is better staffed than the other by providing density inspectors at the project site. Laboratory test data and construction records should be adequately documented particularly when evaluating new construction methods and/or material. Traffic counts should also be kept for long term evaluation of the performance of future pavements.

ACKNOWLEDGEMENT

The cooperation and assistance of the Pavement Evaluation Section of the Materials Office, Florida Department of Transportation are gratefully acknowledged.

REFERENCES

Chang, W. F. 1987. Rebuilding a Polk County Road Utilizing a Phosphogypsum Mixture. Phosphate Research Institute, University of Miami.

Chang, W.F., D. A. Chin, and R. Ho, 1989. Phosphogypsum For Secondary Road Construction. Florida Institute of Phosphate Research, Bartow, Florida. Publication No: 01-033-077 and 01-041-077.

Godwin, et al. 1981. Soil Support Values As Determined by The Dynaflect. Bureau of Materials and Research, Florida Department of Transportation, Gainesville, Florida.

Ho, et al. 1986. Columbia County Experimental Road. Second International Symposium on Phosphogypsum, Miami.

Ho, et al. 1987. Columbia County Experimental Road. Progress report. Materials Office, Florida Department of Transportation, Gainesville, Florida

Maji, A.K. 1984. Methods of Rebuilding Secondary Highways Using Phosphogypsum. Master Thesis, University of Miami.

Miley, W. G. 1984. Structural Layer Coefficient As Determined by The Dynaflect. Bureau of Materials and Research, Florida Department of Transportation, Gainesville, Florida.

Zhou, L. 1986. Engineering Properties of Phosphogypsum Mixtures for Secondary Roads. Master Thesis, University of Miami.

ROLLER COMPACTED CONCRETE UTILIZING PHOSPHOGYPSUM

Wen F. Chang
Director, Phosphate Research Institute
University of Miami

ABSTRACT

Phosphogypsum, a very fine material, possesses good binding property under compaction. The use of proper amounts of phosphogypsum in Roller Compacted Concrete lead to superior compaction and thus improve. strength properties. Phosphogypsum also provides retardation and workability to the cement based mixtures. Two demonstration projects consisted of parking area and/or driveway were successfully built.

INTRODUCTION

Roller compacted concrete (RCC) is a relatively new technology in which a zero slump portland cement concrete mixture is spread with concrete pavers and compacted with vibratory steel and rubber-tire rollers. Because of the ease and simplicity of this construction method, saving of one-third or more of the cost of conventional concrete pavement construction are possible for large projects.

Research conducted at the University of Miami has revealed that sufficient fines to fill the voids between aggregates is the key to the transformation of no slump concrete mix into a fully compacted mass. Phosphogypsum is a very fine material, which possesses good binding property under compaction. The use of proper amounts of phosphogypsum in RCC lead to superior compaction and thus improves strength properties. Phosphogypsum also provides retardation and workability to cement based mixtures. Two demonstration projects consisted of driveway and parking areas at the Florida Institute of Phosphate Research (FIPR) and a parking ramp at the University of Miami (UM), have successfully demonstrated the use of phosphogypsum in RCC pavement construction.

THE DEMONSTRATION PROJECTS

The demonstration projects consisted of a parking ramp built in 1985 at UM (Chang, 1986) and a driveway and parking areas built in 1988 at FIPR (Chang, 1988). Economic considerations led to the use of locally mined limestone aggregates from South and Central Florida respectively for the projects.

Mix proportions of the material constituents consisted of cement, phosphogypsum, aggregate and moisture content of the mixtures are given below:

CONSTITUENTS	PERCENTAGE BY WEIGHT UM PROJECT	PERCENTAGE BY WEIGHT FIPR PROJECT
Type II Cement	10	14
Phosphogypsum	20	13
Fine and Coarse Aggregate	70	73
Moisture Content	12	8.5

No water was added to the mix ingredients during mixing. The reported moisture contents of 12 and 8.5 percent dry weight resulted entirely from natural moisture of both phosphogypsum and aggregates.

It is very important to have proper combination of cement, phosphogypsum and aggregate grading to be suitable for RCC construction. A trial strip of the combined grading as shown by the dashed line of Figure 1 was laid, but it was found unstable at the free standing edges and excessive large shear cracks occurred on the pavement. The correction was made and the final gradation is shown by the solid line.

RCC CONSTRUCTION PROCEDURE

Phosphogypsum was fed through power screen to break up phosphogypsum lumps and subsequently mixed with fine and coarse aggregate in a pug mill as shown in Figure 2 to avoid re-lumping of phosphogypsum. The combined aggregate was stockpiled at the site of mixing plant until the time of mixing with cement. Natural moisture in the combined aggregate usually provides sufficient moisture content during the final stage of mixing with cement.

ENGINEERING PROPERTIES

Laboratory study on engineering properties of phosphogypsum-based compacted concrete was conducted at the University of Miami (Gafoori, 1987). Figure 3 shows 28-day compressive strength as a function of sand percentage for mixtures of 40% gravel content. Samples were prepared in accordance-with Modified Proctor Method, cured under sealed conditions and tested immediately after removal of the plastic covering membrance. It is noticed, that when phosphogypsum is replaced by sand, the compressive strength continusly increases for the mixtures having cement content of 15%, whereas a peak value is reached for the cement content of 10% and 5%. These peak curves reflect the strength contribution of dihydrate phosphogypsum to low cement content mixtures.

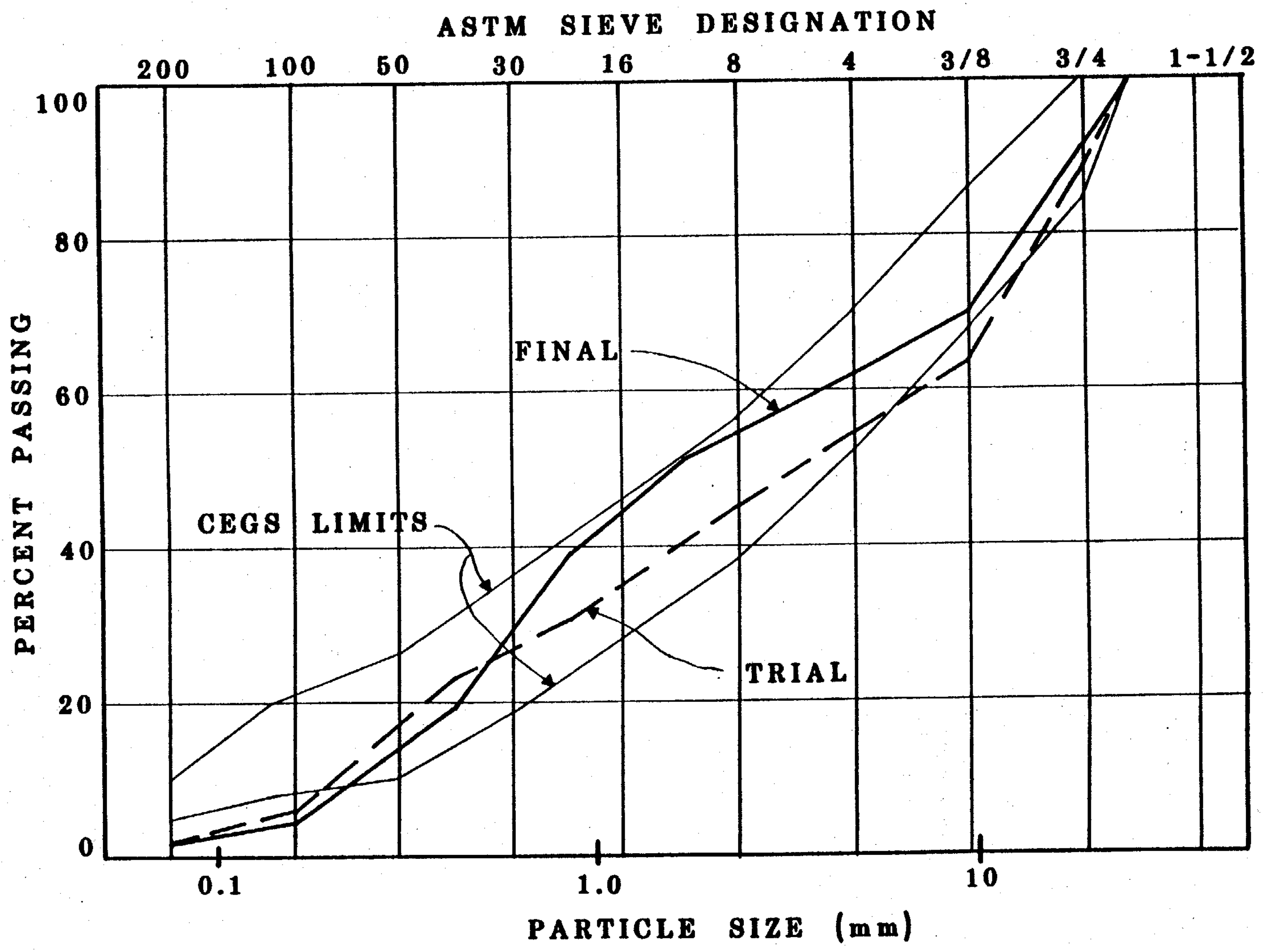


Figure 1 Combined Phosphogypsum and Aggregate Grading

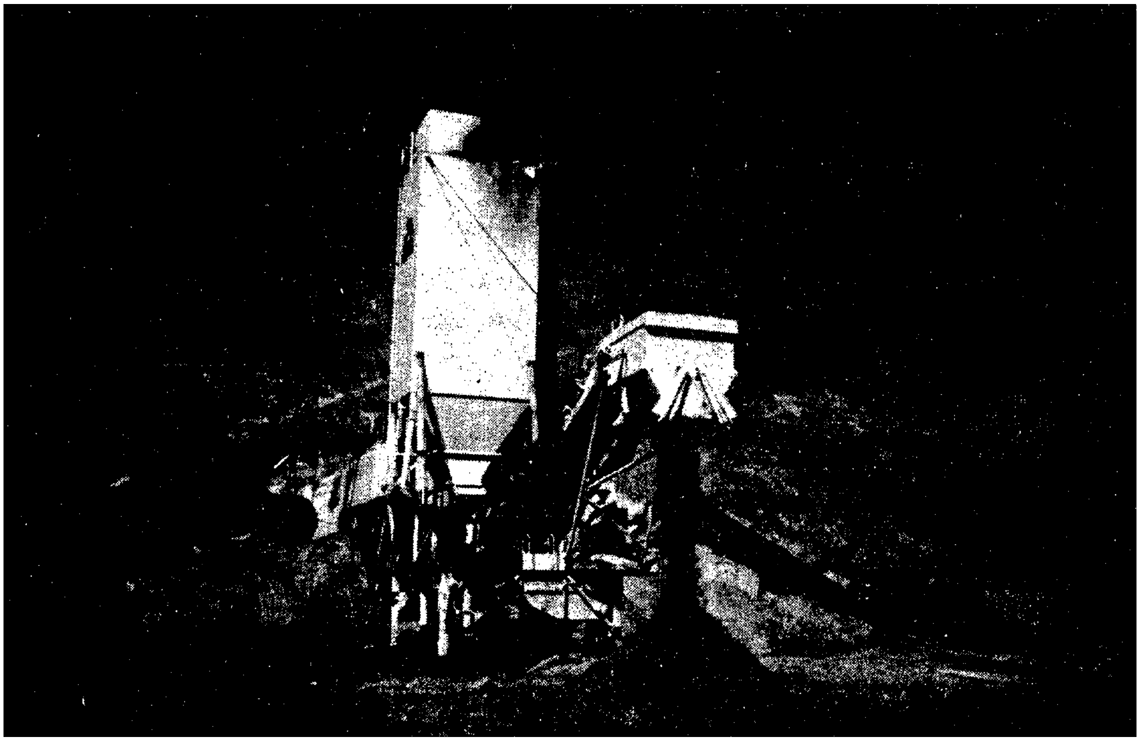


Figure 2 Pug Mill Mixer

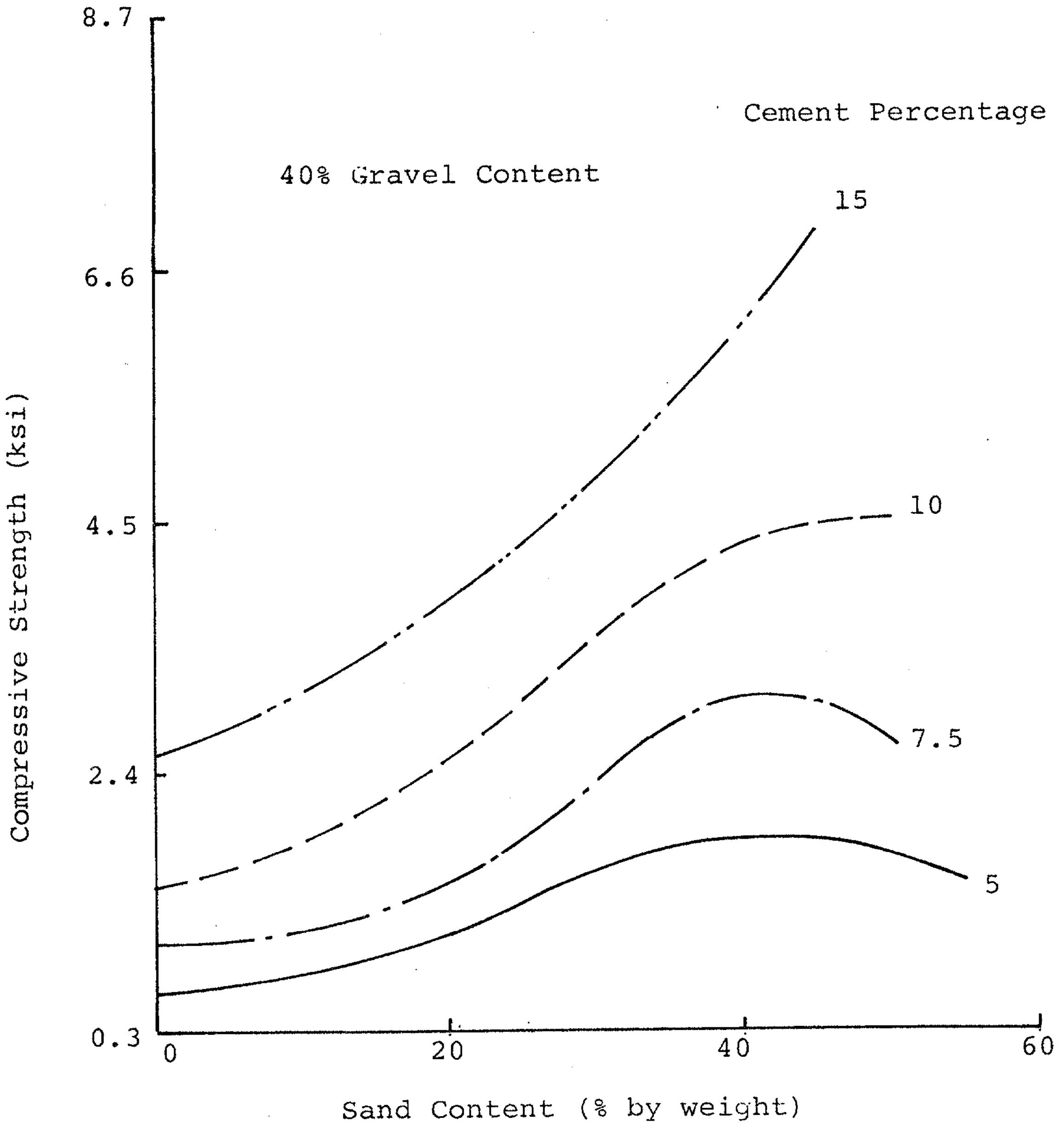


Figure 3 28-Day Compressive Strength vs. Sand Content (Sealed Curing, Sealed at Testing)

Core samples of 2.75" by 5.5" and 4" by 4.5" cylinders were taken from the UM and Fipr projects. Compressive strength of the core samples are as follows:

	COMPRESSIVE STRENGTH (psi)		
	28-day	90-day	2-year
UM Project	3,800*		3,530*
FIPR Project	2,176* 3,174**	2,430*	

* 2.7" by 5.4" Cylinder ** 4.0" by 4.5" Cylinder

Higher strength results from the UM project a consequence of the use of good quality limestone aggregate produced in South Florida. Observation of the compression failure mode of core samples collected from FIPR project, showed crushing of the limestone aggregates. The low quality of the limestone aggregate produced in Central Florida, contributed to the low compressive strength as well as large discrepancy on the strength of the core samples. Although the compressive strength of the core samples at 2-year taken at the UM project is about 7% lower than that of 28-day strength, the difference may be attributed to the different location of core samples and the error from testing technique.

Laboratory study on shringkage compensation of cement based mixtures containing phosphogypsum conducted at the University of Miami (Ouyang, 1988), indicated that the addition of phosphogypsum in the mixtures may reduce the dry shrinkage of mortar as shown in Figure 4.

RADIATION MONITORING

A gamma radiation survey on the RCC pavement at the FIPR project was conducted (Chang, 1988). A summary of the survey is described as follows:

LOCATION	GAMMA READINGS (micro-R/hr.)
RCC Pavement	11.4
Asphalt Pavement	24.1
Non-Paved Surfaces	15.0
Laboratories (indoor)	7.9

The external gamma radiation over the new RCC pavement is about 50% lower than that over the old asphalt pavement. The level over the new lot is also less than that over the original ground cover. As a point of reference, the HRS guide fur indoor residential gamma is 20 micro-R/hr..

CONCLUSION

The demonstration projects indicate that phosphogypsum based RCC is suitable for the construction of parking fac-

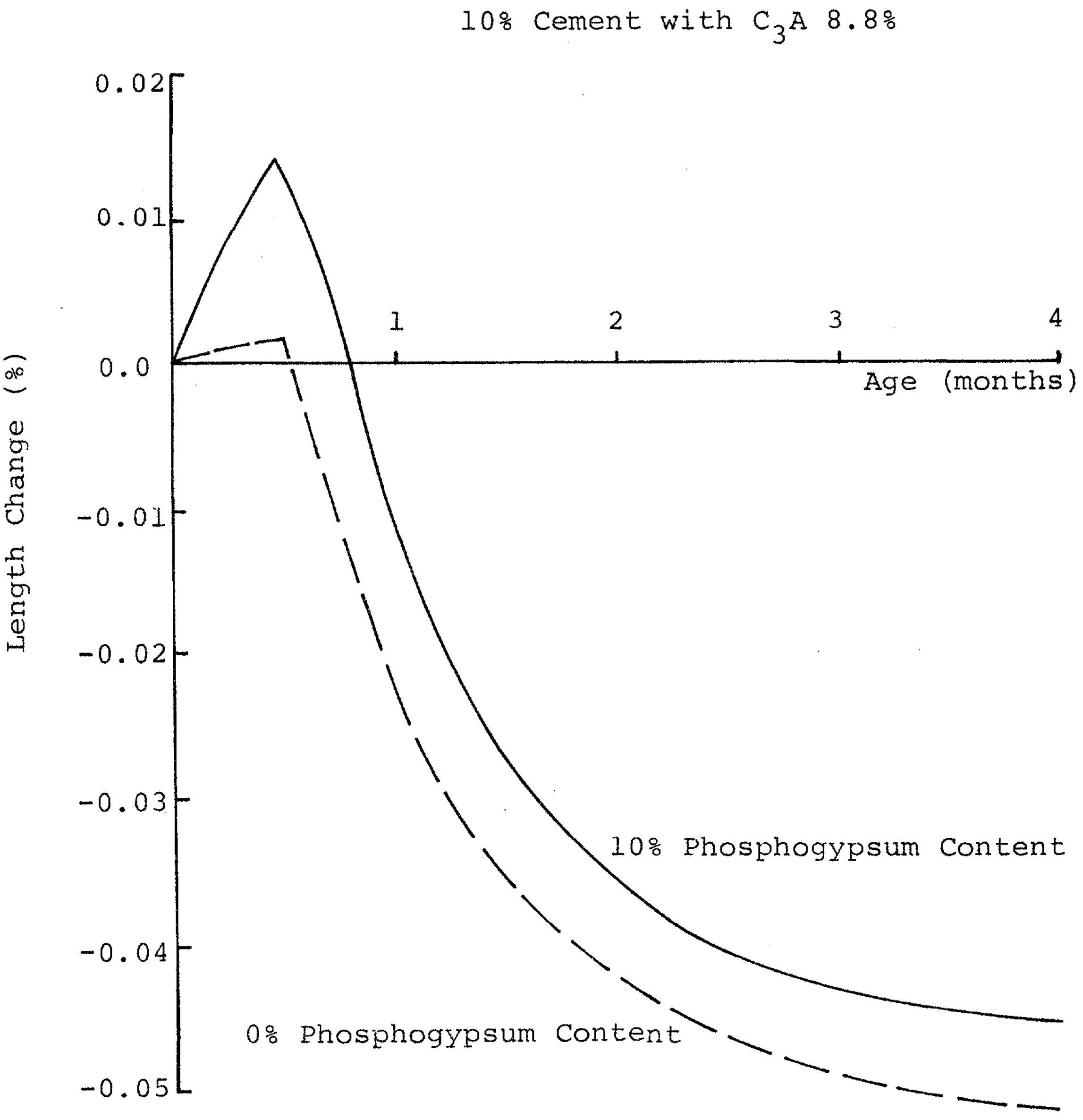


Figure 4 Effect of Phosphogypsum Content on Length Change for Mortar Specimens

ilities. The advantages of using phosphogypsumin RCC pavement are described as follows:

1. Phosphogypsum provides additional fines for better compactibility and surface finish without impairing long term durability.

2. Addition of proper amount of phosphogypsum in the cement based mixtures may compensate for some of the dry shrinkage to limit the extent of cracking.

3. Phosphogypsum in the mixtures retards setting time so that continuity at the cold joints is assured.

4. Quality of aggregates play an important role on strength properties of RCC and concrete in general. Limestone produced in Central Florida may not be suitable for projects where strength in excess of 2500 psi is needed,

5. Proper combined grading of the mixtures consisting of fine and coarse aggregate, cement and phosphogypsum, is highly important in the paving operation in order to prevent large shear cracks occurred on the pavement and instability of the free standing edges.

6. Moisture content in the mixtures is very critical in the paving operation. High moisture content in the mixtures will result in water flowing up to the top surface, therefore, hindering the compactive effort,

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to the Florida Institute of Phosphate Research, Bartow, Florida, for funding the projects.

REFERENCES

Chang, Wen F. 1986. Phosphogypsum-Based Concrete Ramp, Proceedings of the Third Workshop on By-products of Phosphate Industries, Florida Institute of Phosphate Research.

Chang, Wen F. 1988. A Demonstration Project: Roller Compacted Concrete Utilizing Phosphogypsum, Florida Institute of Phosphate Research.

Gafoori, Nader. 1987. Phosphogypsum-Based Concrete: Engineering Characteristics and Road Construction Application, A Ph. D. Dissertation, University of Miami.

Owang, Chengsheng. 1988. Sulfate Attack of Portland Cement-Based Mixtures Containing Phosphogypsum, A Ph. D. Dissertation, University of Miami.

THE MECHANISM OF STABLIZED PHOSPHOGYPSUM BASE

Zhao Qian , Zhang Chao
Zhang Dong-Liang
(Xian Institute of Highway)

PEOPLE'S REPUBLIC OF CHINA

Phosphogypsum is a kind of waste material that results from the production of fertilizer industry. Its major composition is calcium sulfate ($CaSO_4$), which estimates over 90% in dihydrate ($CaSO_4 \cdot 2H_2O$) in total amount. At present, however, although the use of phosphogypsum on highway engineering has been reported, the mechanism of phosphogypsum as a road material still is a new subject. This paper studies the engineering properties of phosphogypsum as a semirigid base material and further researches its mechanism of strength forming.

RESULTS OF EXPERIMENTS

Through a lot of experiments and analyses, a total of four mixtures were selected as preparation of test speciments. Under the condition of maximum dry unit weight and optimum moisture content, the speciments were prepared in φ5x5cm cylinders and 5 x 5 x 24cm joists, testing their unconfined compression and other engineering properties. The speciments were allowed to cure at room temperature (20 ^{o} C ± 5) to 7, 14, 28, 90 days and soaked in water for 24 hours before tested under unconfined compression. The results arc shown in table 1 (Seen from next page). As shown in table 1, phosphogypsum is a capable new material in road. The speciments containing phosphogypsum had significant engineering properties, especially higher compressive strength values at later stage. Compaired with lime-fly ash-soil and lime-soil mixtures, all of the test results of phosphogypsum mixtures were much better. The fact definitely showed the possibility of use phosphogypsum as a semirigid base material. And further, the mixtures had lower coefficient of temperature contraction and higher index of crack-resistance than others. The fact indicated phosphogypsum had the function of reducing the contraction of semirigid base materials and improving the anticrack of pavement.

Table 1

Specimens / Experiment items		No.1 Lime. flyash. gypsum	No.2 lime.flyash.gypsum.1% base	No.3 Lime.flyash.soil	No.4 Lime.soil
Curing time (days) and Saturated unconfiend compression values (MPa)	7	1.102	1.330	0.870	0.652
	14	2.535	2.721	1.176	0.974
	28	3.638	4.313	2.086	1.618
	90	4.788	6.275	3.121	2.493
90 days bending stress (MPa)		0.8652	0.9224	0.6325	0.4536
Bending resilience strain (10^{-4})		2.69	3.20	2.32	1.56
Antibending modulus of resilience		3217	2886	2729	2913
Mean value of temperature contraction coefficient (10^{-6})		14.56	12.56	14.73	14.87
Index of crack-resistance		18.50	25.50	15.75	10.47
Freezing of test (MPa) / Times of test		0.47 / 2	1.10 / 5	0.62 / 5	broken / 1

PERFORMANCE MECHANISM

According to the reaction mechnism of stabilization soil, volcanic ash reaction is one of the mainly factors to form stability structure. When lime and soil (or lime-fly ash- soil) were blended and compacted under optimum conditions, a series of reactions took place in the mixtures, in which lime ($Ca(OH)_2$) reacted with activated silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) in fly ash or soil, producing hydrated calcium silicate ($CaO \cdot SiO_2 \cdot nH_2O$) and hydrated calcium aluminate ($Ca0 \cdot Al_2O_3 \cdot nH_2O$). The equations of the chemical reaction are,

$$Ca(OH)_2+SiO_2+(n-1)H_2O = CaO \cdot SiO_2 \cdot nH_2O$$

$$Ca(OH)_2+SiO_2+Al_2O_3+(n-1)H_2O = CaO \cdot A1_2O_3 \cdot nH_2O$$

The reaction products possess good water stability and frost-resisiting stablity, which is a mainly fact to yield early stage strength of stabilizing lime soil. Through electron-microscope observation, the products were a jel-like substance, covering on the surface of various grains, especially on the fly ash grains which contained more actived substance. Seeing from the fig. 1.

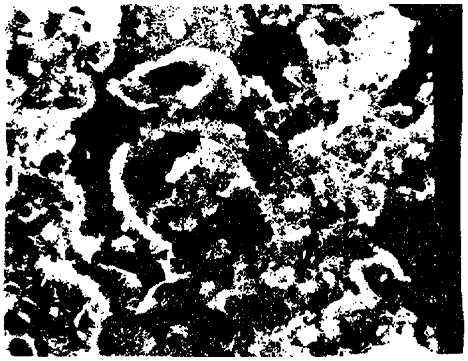


Fig.1. Specimen. No. 1
28 days curing, x 1100

In the middle of the picture there are two fly ash balls covered thick gel substance of reaction products. The gel had such adhesive strength that it could not be breaked but stripped from the balls during preparing samples for microscope examination. This adhesive, however, ‘was only bonded nearby grains. There was no direct effect among distance grains.

After phosphogypsum was mixed with lime-fly ash , the products $SiO_2 \cdot Al_2O_3 \cdot nH_2O$ might further react with dihydrate calcium sulfate which was a major composition of phosphogypsum ($CaSO_4 \cdot 2H_2O$), producing hydated calcium aluminium sulfate ($CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 32H_2O$). The chemical reaction equation may be represented as

$$CaO \cdot Al_2O_3 \cdot nH_2O+3CaSO_4 \cdot 2H_2O+(32-6H_2O) = Ca0 \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$$

This product which was a needle-shape crystal with hexagonsection formed and filled in around cracks where distributed one of the other volcanic reaction products $CaO \cdot SiO_2 \cdot nH_2O$. A lot of grains were joined together with needle crystals. This is shown in fig. 2.

It can be seen in fig.2 that there were plentiful needle crystals growning at surface of grains. The new crystals growned towards every-where and joined near or distance grains together. Dependent on the structure of crystal as well as jel to join grains, that was the explain why phosphogypsum mixtures showed significant increase in their soaked unconfined compressive strength values with time . In this case the mixtures were progressively stabilized to become as a whole. This can be seen in fig.3.

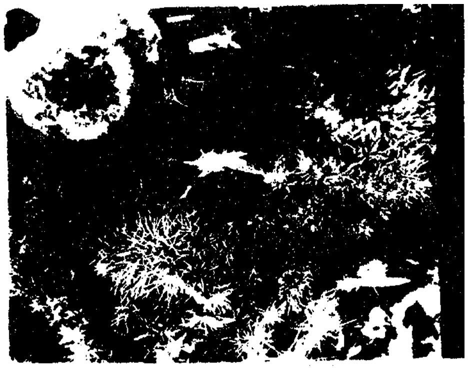


Fig.2. Specimen. №.2
3 days curing, × 1300

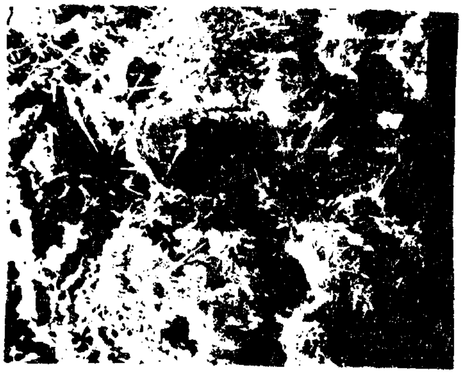


Fig.3. Specimen. No.2
28 days curing, x 1100

The sample showed in fig. 2 and 3 were same specimen and had similiar in magnifying multiple. The difference between two pictures was only curing time, 3 days the former, 23 days the latter. There was, however, great difference between these pictures in appearance under electron microscope. The needle crystals were disappeared and the cracks in the mixture were filled entirely with new product during 28 days curing. This result was much helpful to later strength. Because the formation of hydrate calcium aluminum sulfate founded on the volcanic ash resection, phosphogypsum used in lime soil mixture had lower strength than no phosphogypsum specimen, as shown in table 2. The reason of this result was that there was a little activate substance in the lime soil mixture, i.e. most of SiO_2 and Al_2O_3 in the mixture were not activate substances, so that the jel formed by volcanic ash reaction was very little. But a little $CaO \cdot Al_2O_3 \cdot nH_2O$ product could continue in reaction with $CaSO_4 \cdot 2H_2O$ to form calcium sulphoaluminate crystals, which brought about volume expansion because of the crystals increase and accumulation. In this case, the jel structure would be destroyed by crystals growning, and the strength be came lower. This fact was much similar to the phenomenon of cement bacillus in cement structure.

Table 2

Specimens	Saturated unconfined conpression values after 6 days curing (MPa)
lime:soil	0.813
lime:soil:3%gypsum	0.618
lime:soil:3%gypsum :1% base [1]	1.922
lime:soil:3%gysum :1% base [2]	1.868

It is common knowledge that only under base condition can the volcanic reaction take place. Because it was no enough basicity provided from lime to exite more oxide substances to join the reaction, the reaction capacity was much lower in lime-soil mixture. This problem can be improved after a small amount basic reagent was added to the mixture, and the strength values were greatly increased, as shown in the table 2, the latter two rows. According to this fact, when a small amount base was blended with lime -fly ash and phosphogypsum mixture, better results were generally obtained not only in mechanics properties but also in microcosmic structure. It can be seen in table 1, pictures 4 and 5.

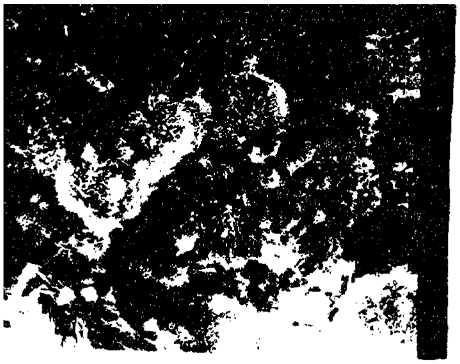


Fig. 4. The specimen №.2
3 days curing, × 2000

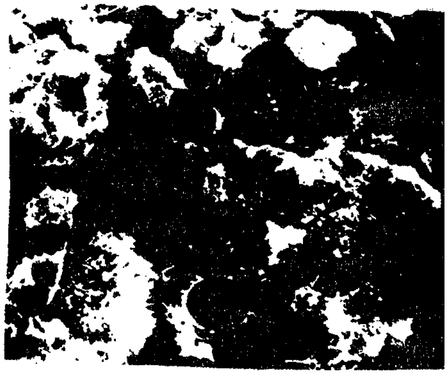


Fig. 5. The specimen №.1
3 days curing, × 2000

Based on the above discussion, we can say, the effect of calcium sulphoaluminate formed in the mixtures was double to formation of structure. if volcanic reaction was sufficient, it could promote to increase mechanics strength. Otherwise, the structure would be damaged by it. Because calcium sulphoaluminale crystals ($CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$) possessed characteristics of expansion, the mixtures contained phosphogypsum had lowcr coefficient of thermal contraction and higher crack-resistance index (Seen table 1). In this case the contraction of road base caused by temperature change would be decreased if some phosphogypsum was blend in road materials, and problem of pavement cracks would probably be overcome.

CONCLUSION

Here we may braw the following conclusions

1. Phosphogypsum is a kind road material with advantadge engineering properties.
2. The mechanism of stabilization semirigid base with phosphgypsum is distinctive in some degree. The reaction product calcium sulphoaluminate crystals arc benificial or harmful to the mixture engineering properties according to volcanic reaction degree.
3. The mixtures contained phosphogpsum have a property to reduce cracks of semirigid base.
4. The mixture properties can be successfully improved when added small amount basic reagent.

REFERENCES

1. J. Ludwig Figueroa, Ling Zhou, Wang F. Chang, 4th International Conference on Low-volume Roade Vol. 1.
2. Foreign Highway, 4, 1984 and 3, 1985.
3. Wang Zhen Cheng, «Using and Handling of Solid Wastes» Publishing House of JiaoTong University.

RADIATION MONITORING OF POLK AND COLUMBIA COUNTIES EXPERIMENTAL ROADS

Gordon D. Nifong, Ph. D.
Associate Director
Florida Institute of Phosphate Research

ABSTRACT

Phosphogypsum, a by-product in the manufacture of phosphoric acid, currently is stockpiled in Florida in an amount exceeding 600 million tons, A major research goal of the phosphate industry is to find viable, safe, high-volume uses for the product, One avenue may be its use in the construction of roads. In 1986-87, under the supervision of the University of Miami, two county roads were built in Florida using phosphogypsum in their base courses. Special attention was given to assessing any impact of the material upon the local environment, Measurements were made of potential contaminants in air, soil, and especially groundwater, before construction and for some three to four years after construction, Earlier monitoring was done by the University, and later work done by the Institute of Phosphate Research. Goals were to detect any changes to the environment shortly after construction, and any long term trends in pollution levels. Since phosphogypsum is known to contain elevated levels of radionuclides, including radium, as compared with typical Florida soils and rocks, special attention was given to radium in soil and groundwater, radon in air and soil, and external gamma radiation, This paper outlines the study design and the preliminary findings of the radiological portion of the study, Except for a modest increase in gamma radiation over the two roads following their construction, use of the phosphogypsum has had no significant or long-term impact on environmental quality in either area.

INTRODUCTION

Phosphogypsum is the name given to gypsum formed as a by-product during the manufacture of phosphoric acid by the phosphate fertilizer industry, Consisting mostly of calcium sulfate, about five tons of the material are formed for every ton of acid produced, Florida leads the nation by far in the mining and production of phosphate materials, but as a result of this activity some six hundred million tons of phosphogypsum are currently stockpiled on the ground in central and north Florida. Another thirty million tons are added annually. A major research emphasis of the Florida Institute of Phosphate Research, in cooperation with the industry and with several universities and public and private agencies, has been to try and develop practical, economic, and environmentally sound uses for the material. One of the more promising concepts has been use of the gypsum in road construction, where it might serve as an ingredient in the base course material as a substitute for aggregate, or even in embankment or paving materials, An overriding consideration, however, is that it must not adversely affect the immediate environment. Because phosphate ore is enriched in naturally occurring uranium and its decay series isotopes, relative to typical Florida soils and rocks, phosphogypsum is elevated in content of several radionuclides, mainly radium, lead and polonium. For example, central Florida gypsum contains about 25 picocuries of radium per gram of material (pCi/g), while background soil levels of radium would be about 1 to 2 pCi/g, In October of 1986 a test road [Parrish Road] was built in Polk County, and in April of 1987 a second test road [White Springs Road] was built in Columbia County, both in Florida and both utilizing phosphogypsum in their bases. Work was done under the supervision of the University of Miami. Two issues were addressed -- the engineering soundness of the use of this material in a roadbed, and any effects on local environmental quality occurring as a result of such use.

STUDY PLAN

For the project, the university installed monitoring wells along both sides of both roads to determine groundwater quality before and after construction. Ten wells were placed in Polk County and eight in Columbia County, spaced alternately 30 or 80 feet (“inner” or “outer”) from the road centerline, and 150 feet apart, as measured along that centerline, Wells were dug to the shallow water table, about 10 to 20 feet in Polk and about 20 to 25 feet in Columbia. Additionally, along each road one existing residential drinking water well tapping the surficial aquifer was included in the study. A limited amount of sampling was done of pre-construction conditions, After construction of each road, sampling was done every four months at both sites until August of 1988, then every two or three months until late in 1990. Numerous chemical parameters, including radium, were determined in the water from each well. Since environmental radiation was of particular concern, additional measurements were made along each road of airborne radon, soil radon, soil radium, and above ground [three feet] gamma radiation over the pavement and also adjacent to it. For radium in water, well water was pumped for several minutes to purge the collection equipment and to insure fresh water in the well, then a 2-liter sample was collected and placed into polyethylene containers, acidified, and later analyzed by radon emanation. On each field trip to either road, one well in rotation was always sampled in duplicate. Air and soil radon was measured by use of alpha track detectors. Soil was collected in bulk and analyzed for radium by gamma spectroscopy. Field gamma levels were measured with a scintillation meter.

RESULTS

The University of Miami completed its phase of environmental sampling in August of 1988. Results from both roads were published the following year by the Institute in “Phosphogypsum for Secondary Road Construction” (Chang, et al., 1989). Since the data have been published, only a summary of their work will be given here. This presentation will focus on the preliminary results of further work done by the Institute from August, 1988, through August, 1989.

GROUNDWATER RADIUM

Radium levels in groundwater at Parrish Road as measured by Miami were highly variable in space and time. Means for the ten test wells ranged from 1.9 to 18.7 picocuries per liter (pCi/l), an order of magnitude, Individual levels ranged from 1 pCi/l to nearly 50 pCi/l, and a 20-fold difference from low to high was seen at each of several wells, Radium levels at all wells peaked generally in May of 1987, then dropped off to levels at or below values found at the beginning of the study. Though magnitudes were different, time charts of radium at all wells were very similar, showing high correlation among all wells at any one point in time, and indicating rainfall or water level effects. In all Parrish Road waters radium was highly correlated with turbidity, showing that most radium was present in suspension. Even though results were highly variable, the general presence of higher radium levels at "inner" wells versus “outer” wells may indicate some leaching of radium from the roadbed.

Prior to August of 1988 mean radium levels in groundwater at eight test wells at White Springs Road in North Florida ranged from 1 to 10 pCi/l, Individual results were generally below 5 pCi/l, but at well #2 two values above 10 were found. Interestingly, the highest value, 28 pCi/l, was obtained before the test road was constructed, No general trends were noted, and it was the opinion of the University that no significant leaching of radium into the groundwater had occurred, No particular correlation of radium with turbidity was noted.

Seven sampling trips to each road were made by the Institute from August of 1988 through August of 1989. Groundwater radium at Parrish Road in Polk County is presented in Figure #l for the "inner“ wells and in Figure #2 for the “outer” wells. No trends are evident and no significant difference is noted due to “inner” or “outer” well location. Indeed, all samples except one (well #10, December, 1988) show radium levels below the drinking water standard of 5 pCi/l, No leaching appears evident.

Figures #3 and #4 depict groundwater radium for “inner” and “outer” wells at White Springs Road. With two exceptions, all values are below the drinking water standard of 5 pCi/l. No trend over time is noted, No significant difference is noted based on well location, and hence no leaching is evident, One anomoly, so far unexplained, in the data is that groundwater radium in Columbia County generally is higher than levels found in Polk County, even though no leaching is evident, and despite the fact that soil radium levels in Polk are higher than those in Columbia.

SOIL RADIUM

Soil radium at Parrish Road typically was found to be 2 to 3 picocuries per gram (pCi/g), whereas at White Springs levels of 0.5 to 1 pCi/g were common. No difference was noted between the University and Institute portions of the study. In summary, no differences were noted in soil radium averages before and after construction at either road, and no differences were noted at either road as a result of sampling locations,

AMBIENT RADON

Radon in outdoor air was monitored at two locations at each road by the use of nuclear track detectors placed some eight feet above ground on trees or utility poles adjacent to the roads. During one trip to Parrish Road sampling was duplicated with the use of electret monitors. Results are shown in Figures #5 and #6 for Parrish and White Springs Roads, respectively, Results are variable, but tend to be about 1 picoCurie per liter [pCi/l] at either site at both roads. This is the same value as found in the earlier work by the university. No trends were noted over time, and the university data showed no significant difference in airborne radon before versus after construction. A value of 1 pCi/l is a little higher than would be expected in the ambient air, but seems to hold true over a relatively large number of samples collected for sampling times ranging from two to six months.

SOIL RADON

A difference for soil radon content was noted between the two roads. Results are shown in Figures #7 and #8 for Parrish and White Springs Roads, respectively, Measurements were made at two locations at each road, on the same sample frequency as air radon. Results at Parrish Road ranged from less than 100 pCi/l to about 800 pCi/l, with a mean of about 500. At White Springs the mean was about 100 pCi/l (range 50 to 200 pCi/l). In general terms it seems that soil radium and soil radon correlate fairly well, but that airborne radon is rather independent of soil conditions.

GAMMA RADIATION

Measurements of gamma radiation were made during each field trip at six sites in Columbia County and five sites in Polk County. At each site measurements were made three feet over the road centerline, and three feet over the road shoulder some three feet distant from the pavement edge. In the Institute work, gamma levels at Parrish Road characteristically were about 13 microRoentgens per hour (uR/hr) above the pavement, and at White Springs Road about 5 uR/hr, also above the pavement. Over the road shoulder, readings generally were 2 uR/hr lower than over-pavement at both roads. Only the over-pavement results are presently graphically in this paper, as Figures #9 and #lO for Parrish and White Springs roads respectively. It might be noted that these values all are below the indoor residential guideline for gamma set several years ago by the Florida Department of Health.

Gamma levels found by the Institute exhibit no trend with time, and agree quite well with post-construction gamma levels found earlier by the University of Miami. But, it must be pointed out that the university work showed a significant increase of 2 to 3 uR/hr over the pavement after construction as compared with pre-construction levels. This was true at both sites. However, at neither site was there an increase after construction in levels found adjacent to the pavement.

SUMMARY AND CONCLUSIONS

This paper reports the findings of just over a year’s study by the Institute of the local radiological environment at the sites of two experimental phosphogypsum roads. It also summarizes previous work done at the same sites by the University of Miami. The mission of the University was to compare pre- and post-construction environmental radiation levels, and to investigate any near-term trends; the mission of the Institute was to study long-term trends. A moderate increase in gamma radiation over the pavement of both roads has been noted as a result of construction, but no significant trend has emerged. A possibility exists that some radium leached into surficial groundwater at several wells in Polk County several months after construction, but no upward trends have been noted. No effect of radium on the groundwater was noted in Columbia County. At both roads radium is highly variable over time and space, and appears more to be influenced by rainfall and geology than by the roads. The roads apparently have had no effect on air or soil radon or on soil radium, and no trends in any of these parameters have been noted at either site.

Data contained in this report are preliminary. The study by the Institute will not be complete until early 1991. Only then will statistical treatment of the data be made. At this time only the nature and magnitude of the Institute's results can be given. The University study, cited earlier, does include statistical data, including trend analysis, covering their portion of the study.

ACKNOWLEDGEMENTS

Special thanks are due to Jon Harris and Jim Woodrich of the Florida Institute of Phosphate Research for performing the field studies described in this report, and to the Office of Radiation Control of the Florida Department of Health and Rehabilitative Services for analysis of radium in soil and water.

REFERENCES

Chang, W. F., et al. 1989. Phosphogypsum for Secondary Road Construction. Florida Institute of Phosphate Research Publication #01-033-077/01-041-077.

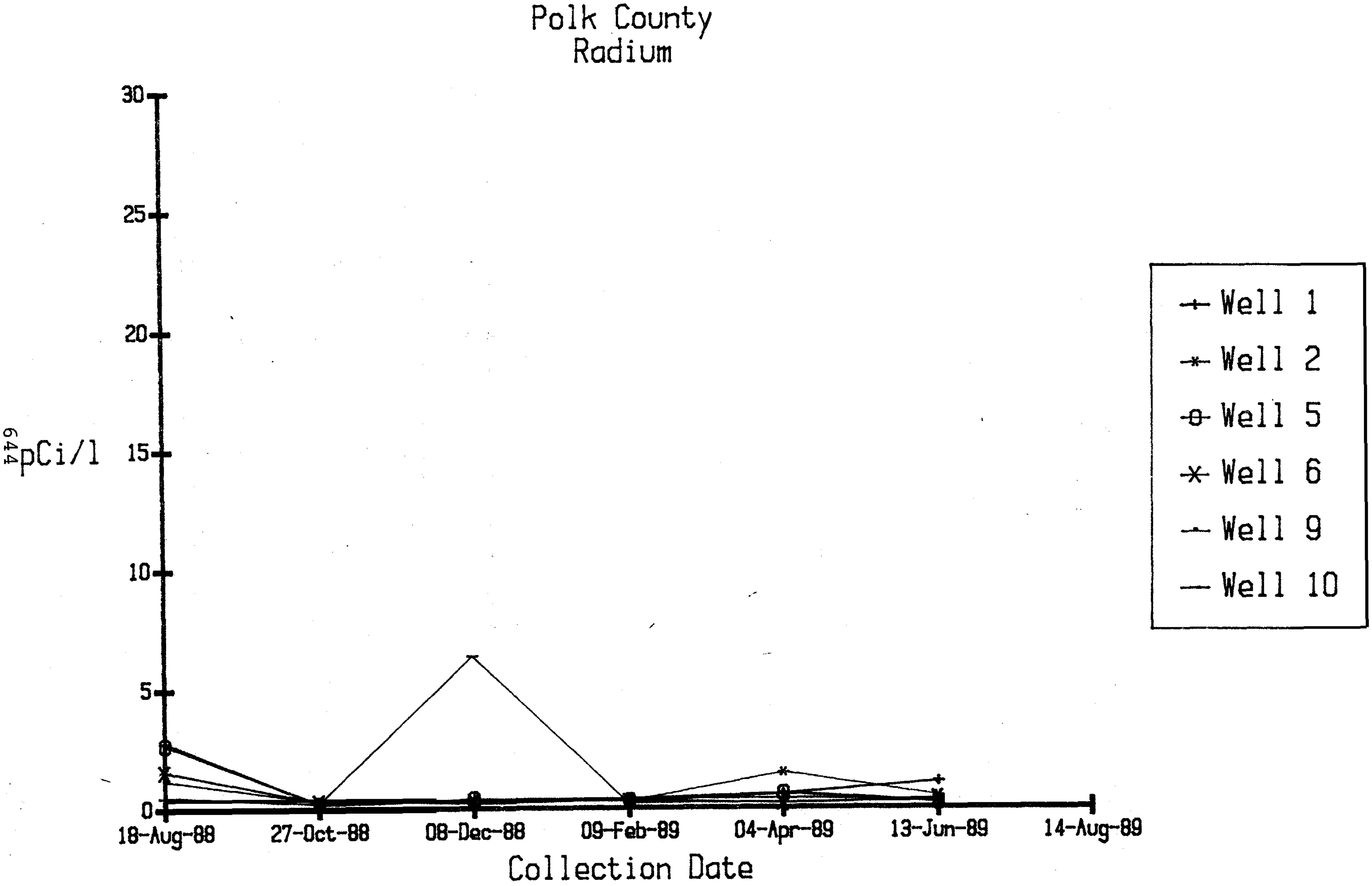

Polk County
Radium
30
25
20
15
10
5
0
pCi/l
18-Aug-88
27-Oct-88
08-Dec-88
09-Feb-89
04-Apr-89
13-Jun-89
14-Aug-89
Collection Date
Well 1
Well 2
Well 5
Well 6
Well 9
Well 10

Figure 1

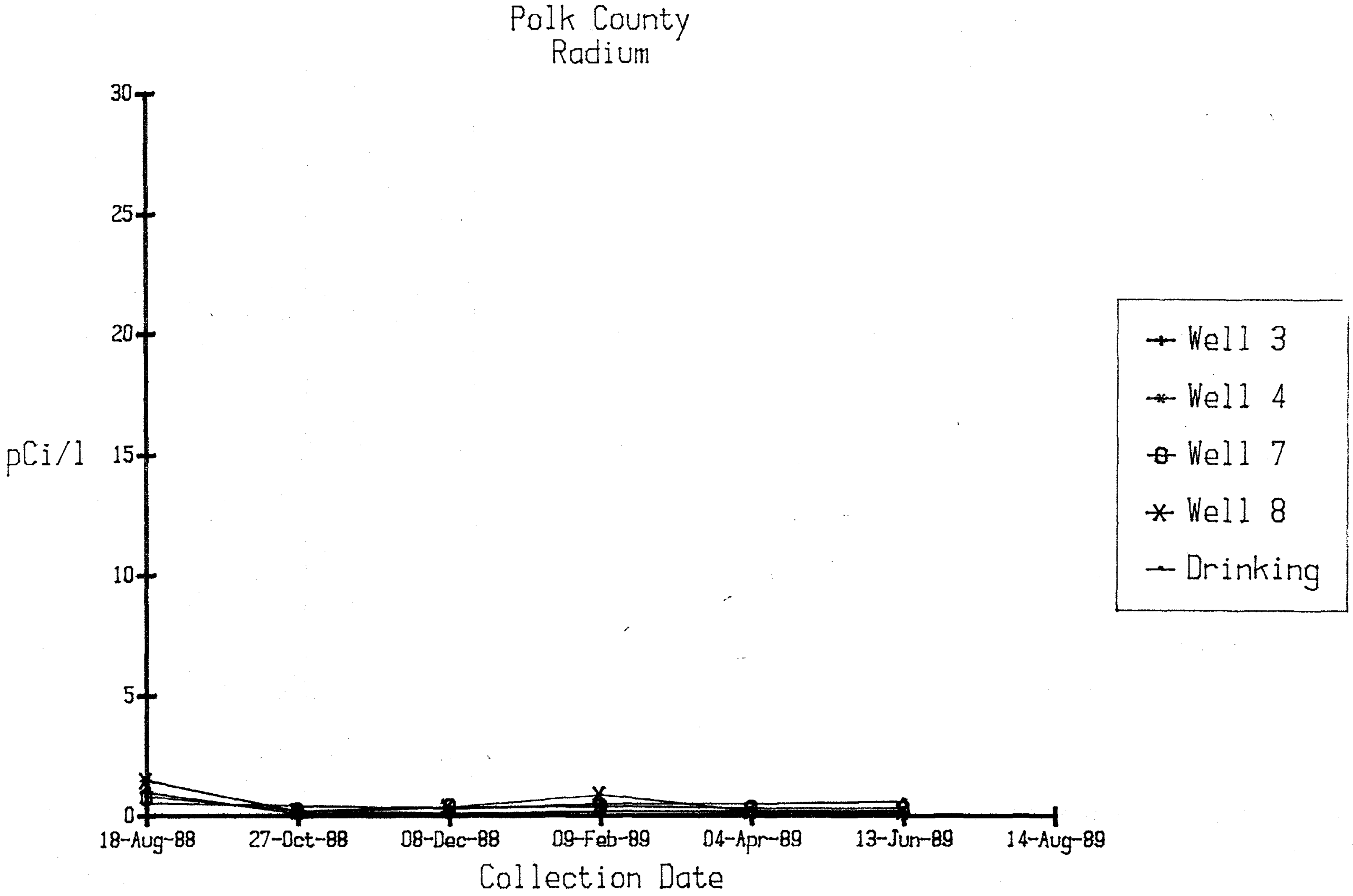

Polk County
Radium
pCi/l
30
25
20
15
10
5
0
18-Aug-88
27-Oct-88
08-Dec-88
09-Feb-89
04-Apr-89
13-Jun-89
14-Aug-89
Collection Date
Well 3
Well 4
Well 7
Well 8
Drinking

Figure 2

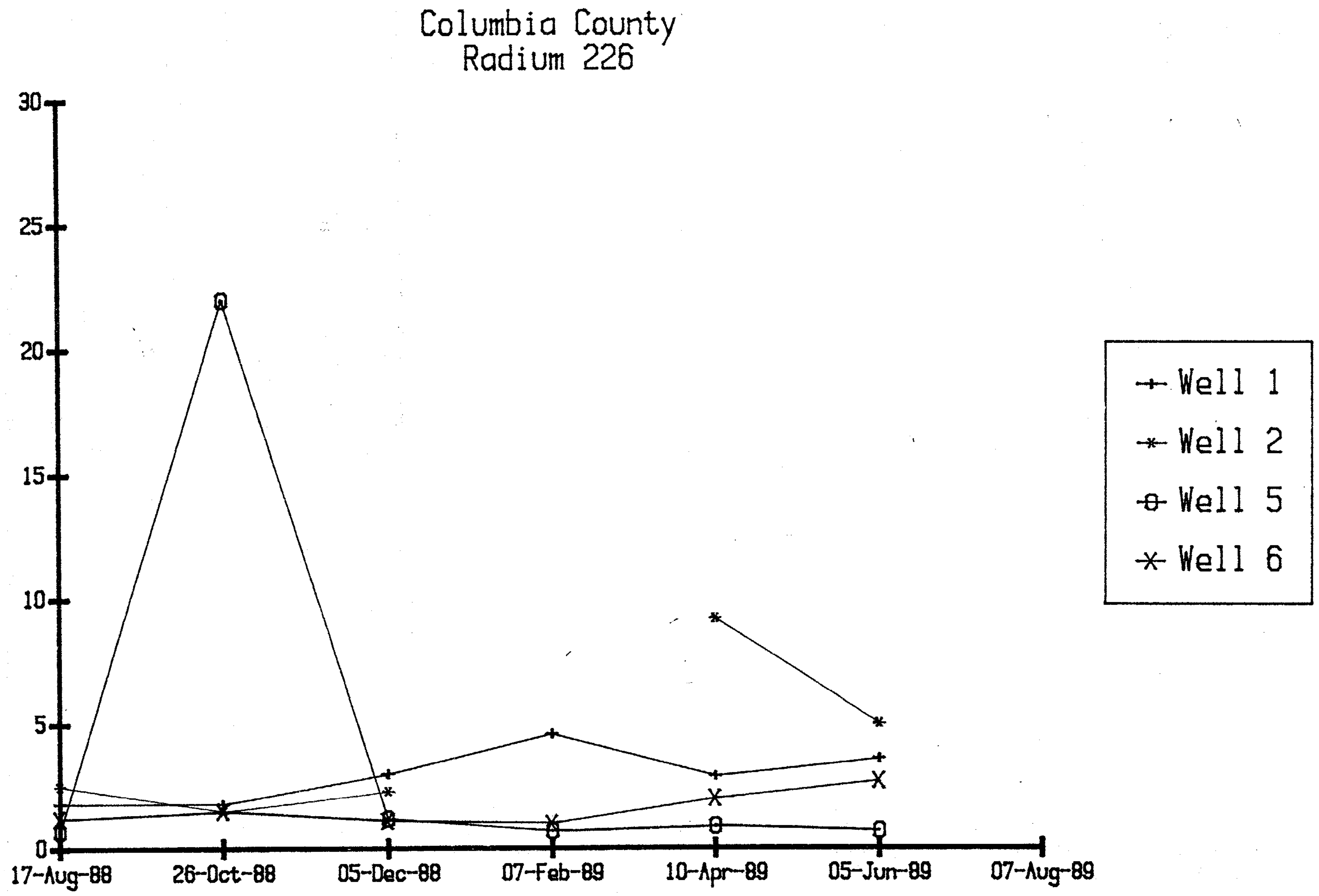

Columbia County
Radium 226
pCi/l
30
25
20
15
10
5
0
17-Aug-88
26-Oct-88
05-Dec-88
07-Feb-89
10-Apr-89
05-Jun-89
07-Aug-89
Collection Date
Well 1
Well 2
Well 5
Well 6

Figure 3

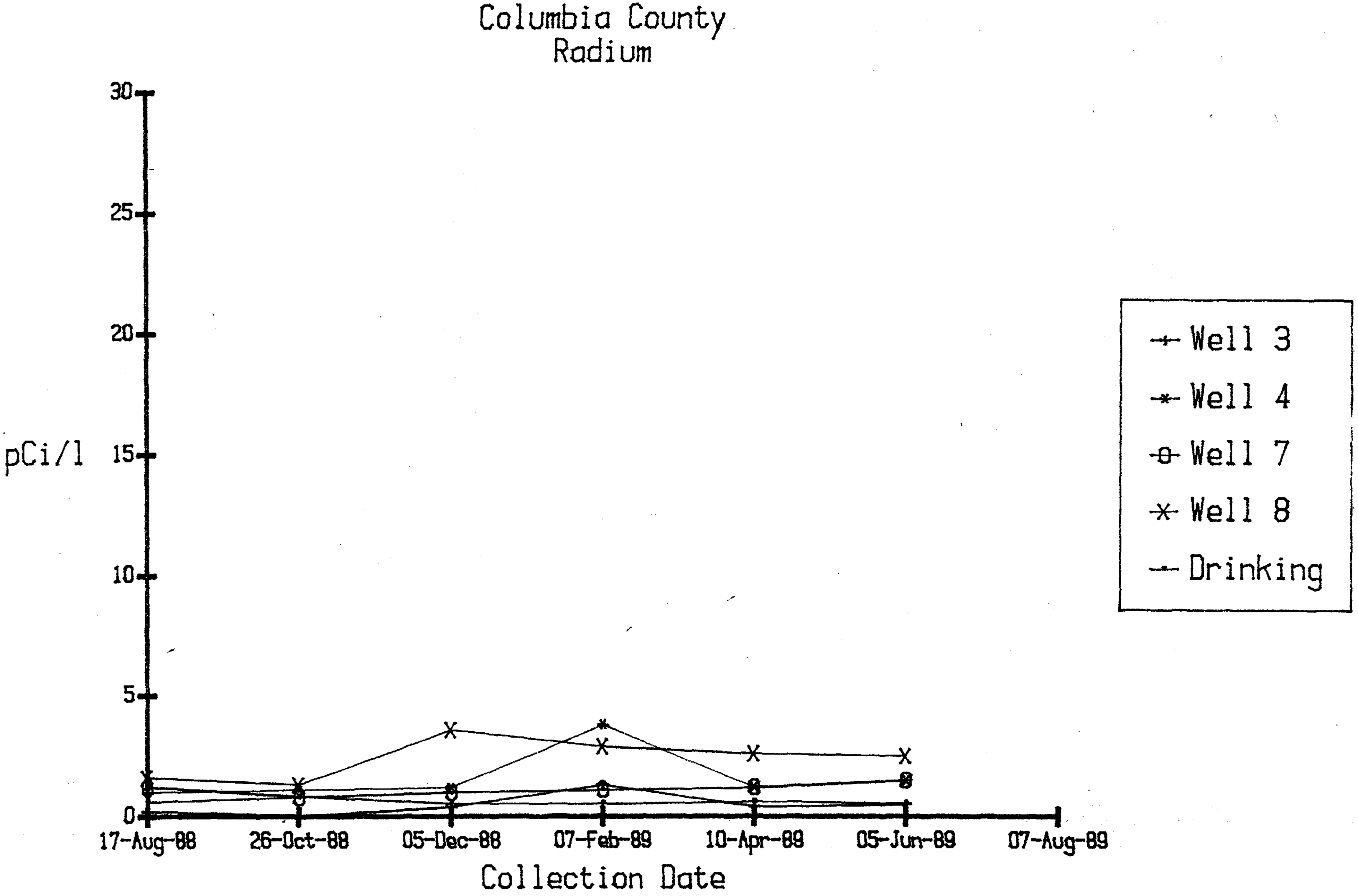

Columbia County
Radium
pCi/l
30
25
20
15
10
5
0
17-Aug-88
26-Oct-88
05-Dec-88
07-Feb-89
10-Apr-89
05-Jun-89
07-Aug-89
Collection Date
Well 3
Well 4
Well 7
Well 8
Drinking

Figure 4

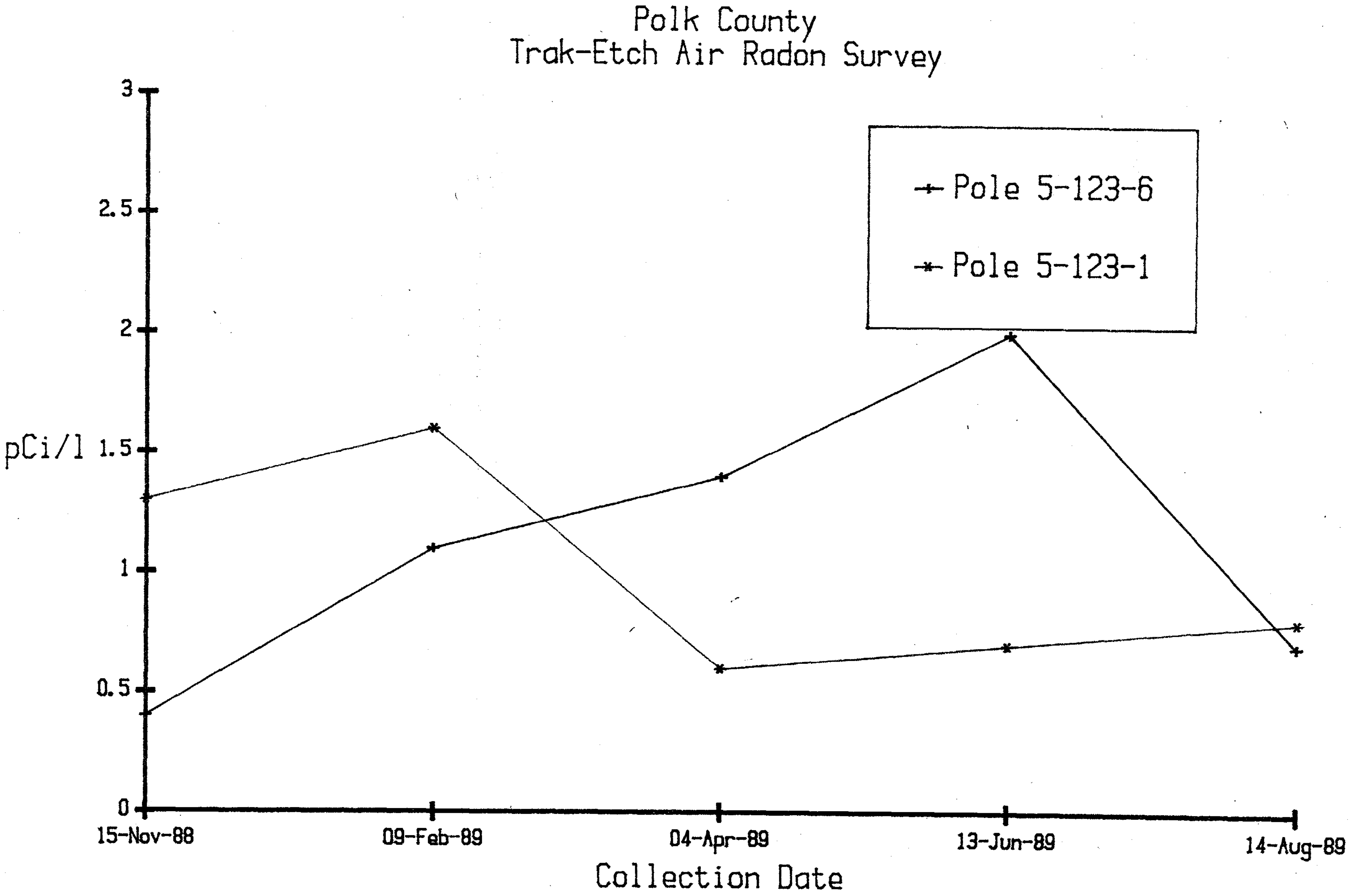

Polk County
Trak-Etch Air Radon Survey
pCi/l
3
2.5
2
1.5
1
0.5
0
Pole 5-123-6
Pole 5-123-1
15-Nov-88
09-Feb-89
04-Apr-89
13-Jun-89
14-Aug-89
Collection Date

Figure 5

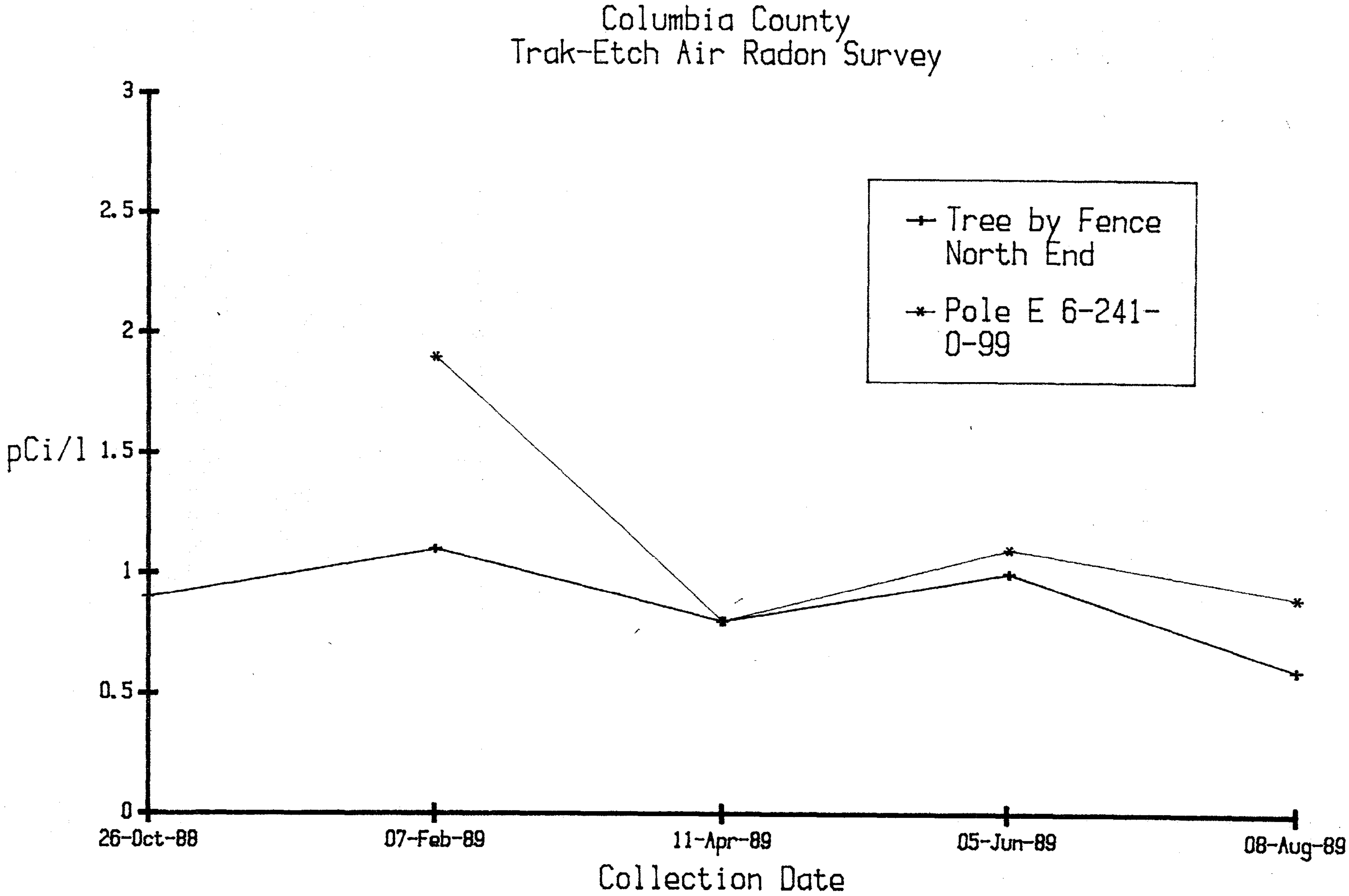

Columbia County
Trak-Etch Air Radon Survey
pCi/l
3
2.5
2
1.5
1
0.5
0
Tree by Fence North End
Pole E 6-241-0-99
26-Oct-88
07-Feb-89
11-Apr-89
05-Jun-89
08-Aug-89
Collection Date

Figure 6

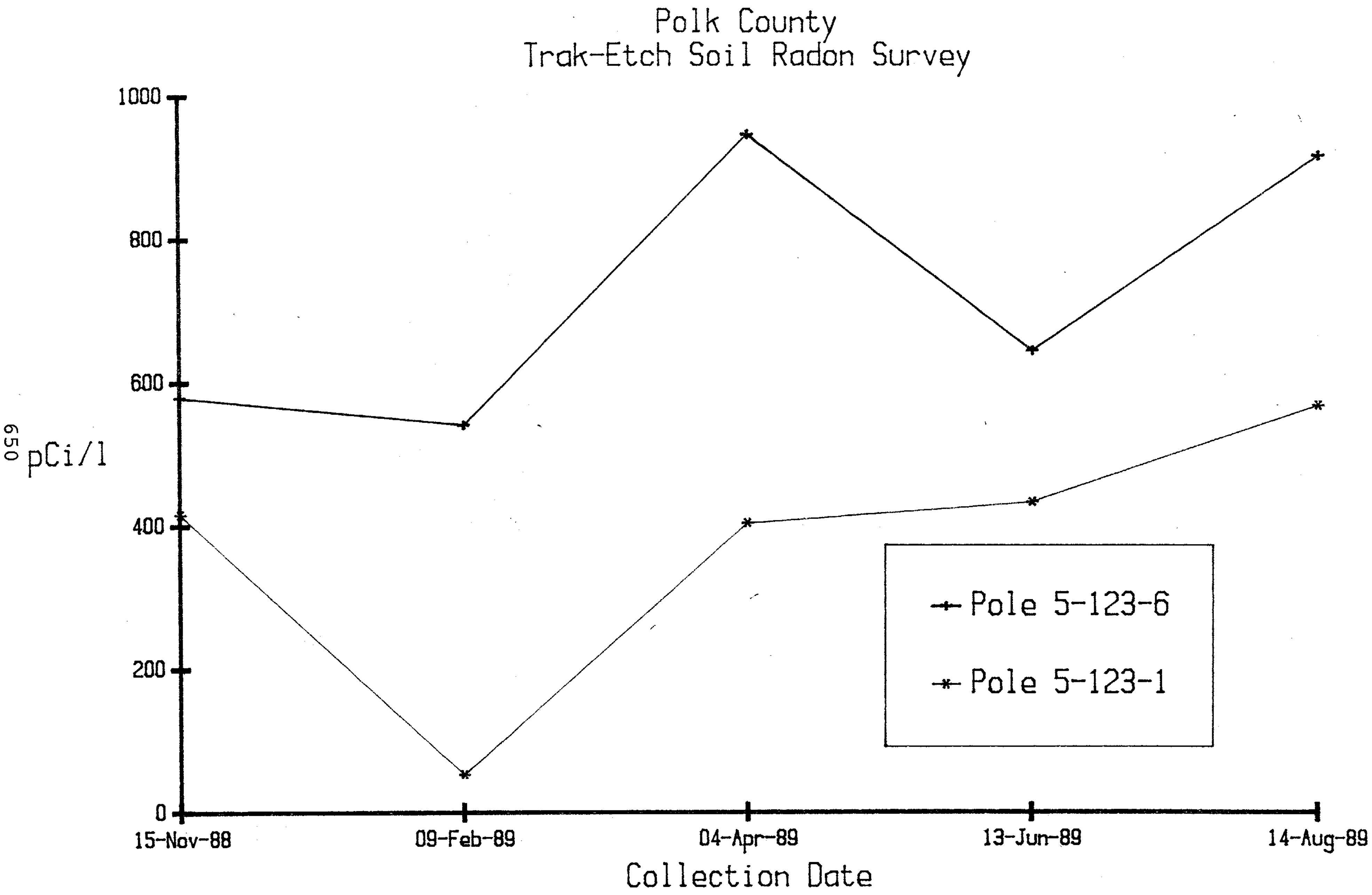

Polk County
Trak-Etch Soil Radon Survey
1000
800
600
400
200
0
650
pCi/l
15-Nov-88
09-Feb-89
04-Apr-89
13-Jun-89
14-Aug-89
Collection Date
Pole 5-123-6
Pole 5-123-1

Figure 7

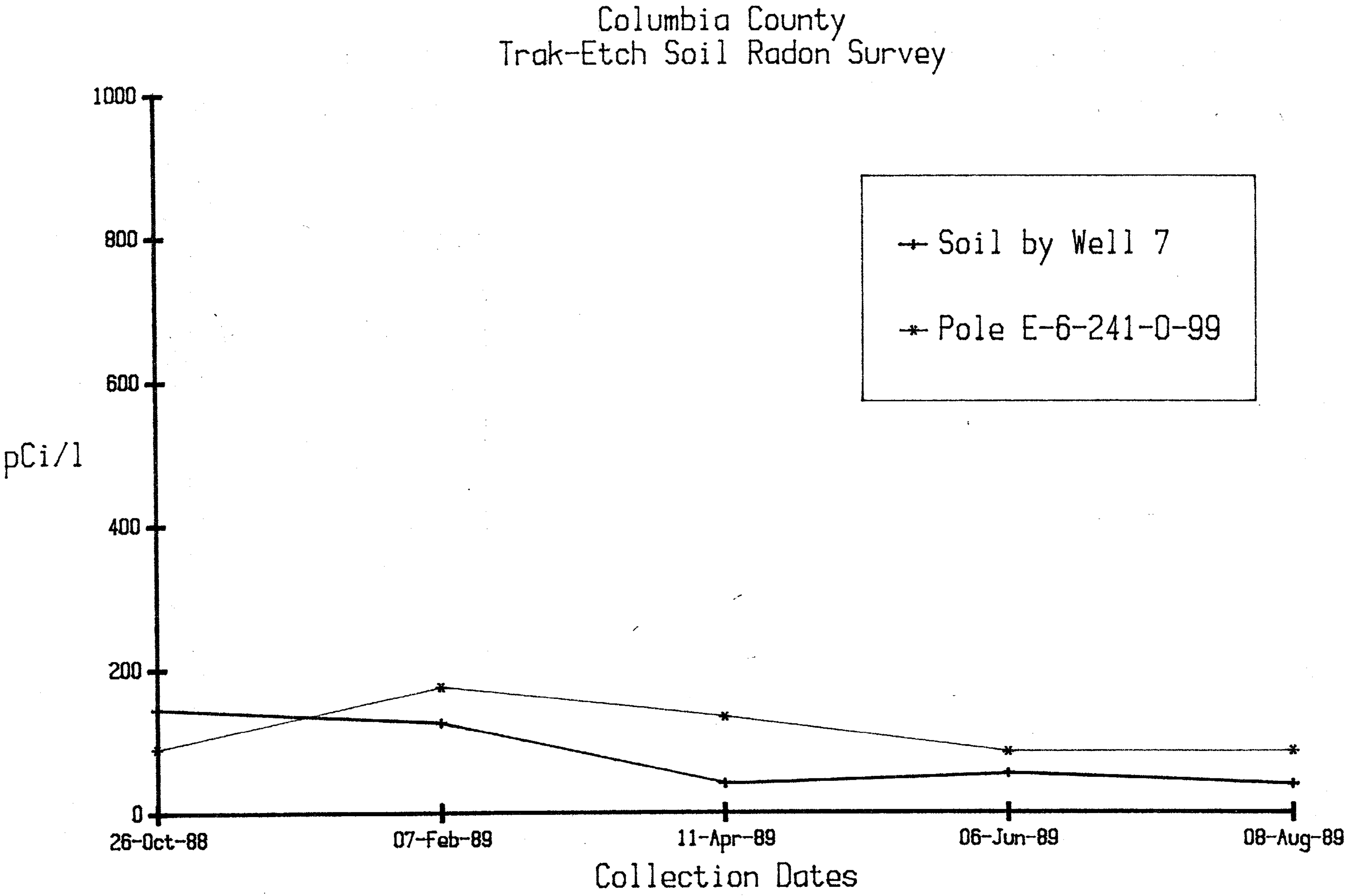

Columbia County
Trak-Etch Soil Radon Survey
1000
800
600
400
200
0
pCi/l
Soil by Well 7
Pole E-6-241-0-99
26-Oct-88
07-Feb-89
11-Apr-89
06-Jun-89
08-Aug-89
Collection Dates

Figure 8

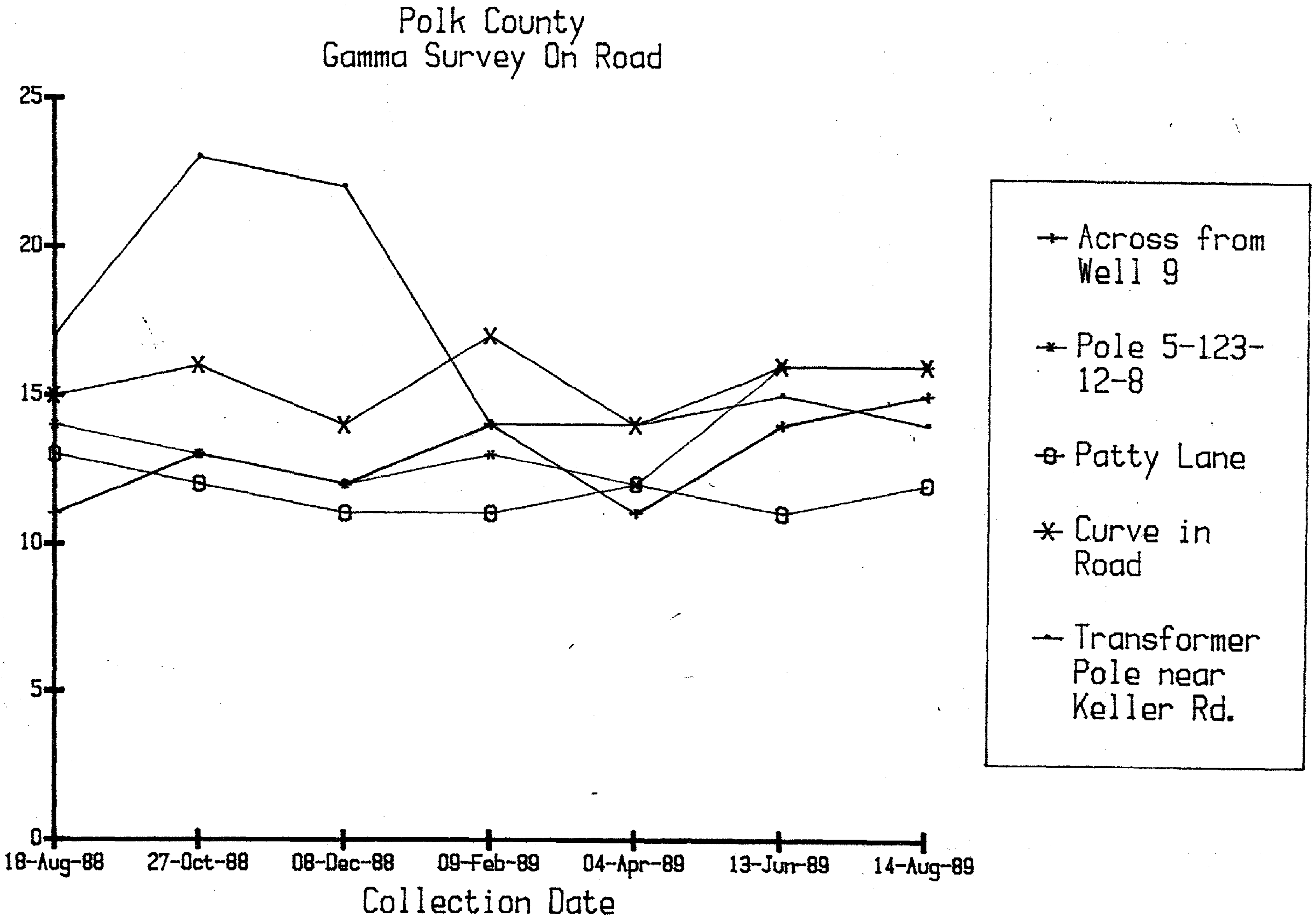

Polk County
Gamma Survey On Road
25
20
15
10
5
0
uR/h
18-Aug-88
27-Oct-88
08-Dec-88
09-Feb-89
04-Apr-89
13-Jun-89
14-Aug-89
Collection Date
Across from Well 9
Pole 5-123-12-8
Patty Lane
Curve in Road
Transformer Pole near Keller Rd.

Figure 9

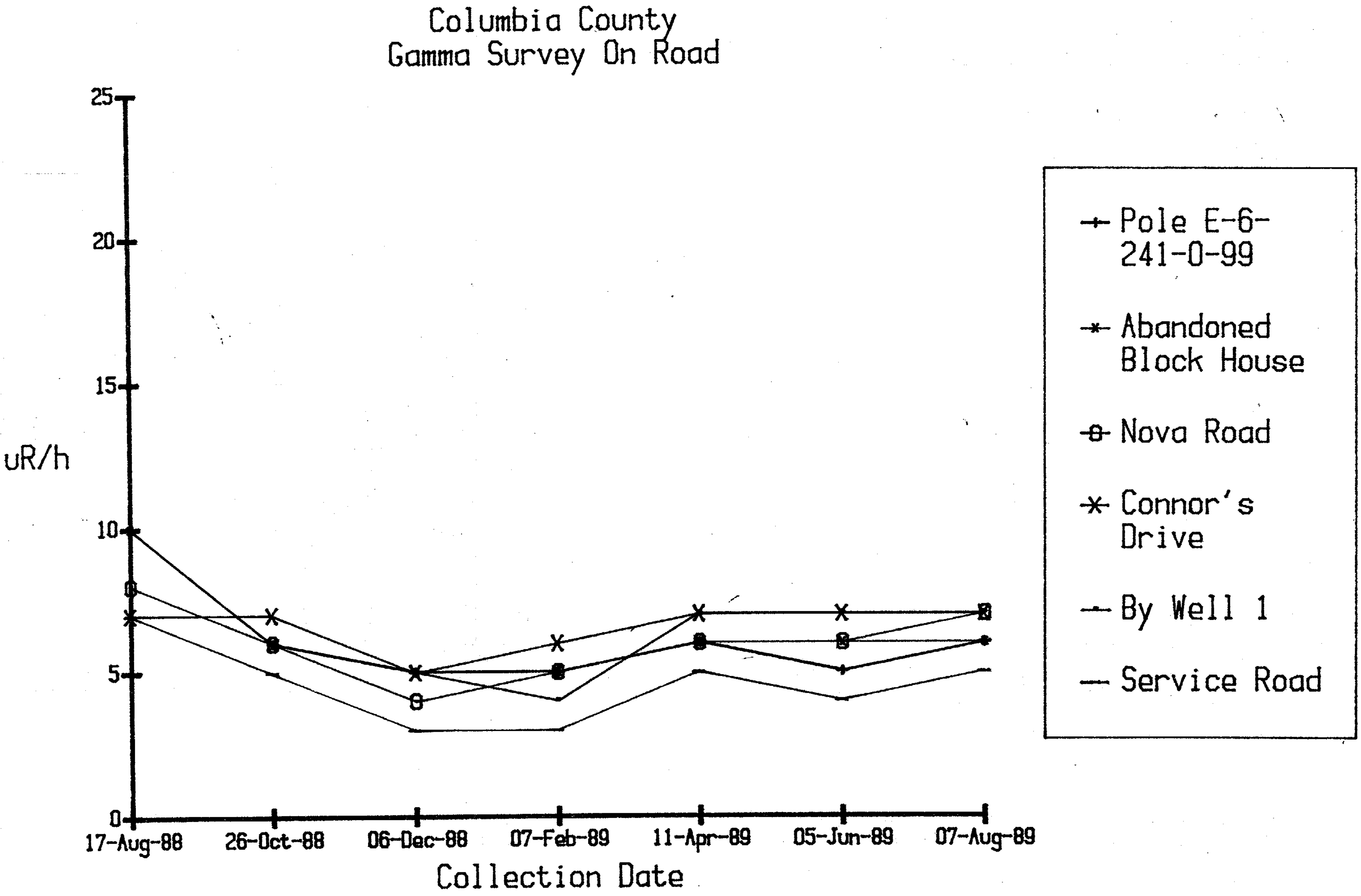

Columbia County
Gamma Survey On Road
25
20
15
10
5
0
uR/h
17-Aug-88
26-Oct-88
06-Dec-88
07-Feb-89
11-Apr-89
05-Jun-89
07-Aug-89
Collection Date
Pole E-6-241-0-99
Abandoned Block House
Nova Road
Connor's Drive
By Well 1
Service Road

Figure 10

THE EFFECTS OF POLK AND COLUMBIA COUNTY EXPERIMENTAL ROAD CONSTRUCTIONS UTILIZING PHOSPHOGYPSUM ON GROUND WATER QUALITY

by

Bhaskar Bandyopadhyay, Ph.D.
Technical Director
Occidental Chemical Corporation, White Springs, Florida

Gordon D. Nifong, Ph.D.
Research Director - Environmental Services
Florida Institute of Phosphate Research, Bartow, Florida

and

David A. Chin, Ph.D.
Associate Professor
University of Miami, Coral Gables, Florida

ABSTRACT

The ground water quality adjacent to the experimental phosphogypsum roads constructed at Polk and Columbia County was monitored to evaluate the environmental impact of the use of phosphogypsum in road construction. In the Polk County experiment, the monitoring period extended from over seven months prior to through over three years following the road construction. In Columbia County, the monitoring period extended from nearly nine months prior to through just under three years following the road construction. Numerous chemical parameters were measured including those most likely to have been affected by the phosphogypsum. Additionally, many of the chemical parameters covered by the National Primary and Secondary Drinking Water Standards were determined.

The results of the monitoring program did not show any consistent or significant adverse impact of the phosphogypsum on the ground water quality. No general trend in the chemical analysis of ground water was noted for any of the most probable contaminants from phosphogypsum. Results of numerous elements in the ground water from the sampling wells appeared to correlate well with each other at any given point in time. Several of the analytical parameters exceeded their corresponding drinking water standards, but once again no trend was observed to suggest any adverse impact from phosphogypsum.

INTRODUCTION

Phosphogypsum, a by-product in the sulfuric acid based wet process production of phosphoric acid, is being produced at a rate of 25-30 million tons per year by the Florida Phosphate industry and to date over 500 million tons have been accumulated in stockpiles in Florida due to the lack of any large volume use of the material. Although some 150,000 - 200,000 tons of the material are used as a soil ameliorant, primarily in the peanut farming industry, and continuing agronomic research looks promising for extending its use, large volume applications of phosphogypsum must be found if the accumulation of this by-product were to be curbed.

Recent research by the University of Miami has suggested a high volume outlet for this material. Extensive research into the engineering properties of phosphogypsum as well as mixtures of phosphogypsum and cement, flyash, lime and sand (Chang and Mantell, 1990) has shown that phosphogypsum may be used as a very effective binder in stabilizing on-site soil and this can replace shell and clay in secondary roads and parking lot constructions. However, phosphogypsum whose main constituent is gypsum or calcium sulfate dihydrate, also contains numerous other chemicals including radium, and therefore, the environmental impact of such use must be addressed before its routine use can be recommended.

To further evaluate any effects of such roads on the environment, and to prove the engineering soundness of the use of phosphogypsum in the reconstruction of secondary roads, the University of Miami undertook two test road projects under separate grants from the Florida Institute of Phosphate Research, Bartow, Florida. The two test road sites, one on Parrish Road, Polk County, Central Florida and the other on White Springs Road, Columbia County, North Florida represented significant hydrogeological and geochemical differences and thus allowed broader interpretation of results than would otherwise have been possible. The phosphogypsum source and its constituents, especially radium level, were sufficiently different in the two test roads increasing the value of the projects further.

The Parrish Road in Polk County, Florida was constructed in October of 1986 using phosphogypsum from U.S. Agrichemicals and the construction of White Springs Road in Columbia County, Florida using phosphogypsum from Occidental Chemical Corporation was completed in April of 1987 by a collective effort of the University of Miami and the Florida Department of Transporation. Environmental monitoring including pre- and post-construction sampling of air, soil and ground water was conducted by the University of Miami in cooperation with the Florida Department of Environmental Regulation and the Florida Department of Health and Rehabilative Services through August of 1988, and reported (Chang, et al, 1989). Subsequent long term monitoring through the January 1990 was conducted by the Florida Institute of Phosphate Research.

This paper is intended to provide a comprehensive summary of the results of the groundwater monitoring program completed through January, 1990 including any significant differences found due to the hydrogeological differences between the two sites and/or the differences in the phosphogypsum used in the two test roads.

EXPERIMENTAL ROAD CONSTRUCTION

GENERAL PROCEDURE

The road surface was leveled with a motor grader and compacted with a steel drum roller. Phosphogypsum at its natural moisture content was then evenly spread with bulldozers and motor graders to the designed thickness. The phosphogypsum was then mixed with the subgrade to the designed depth using pulverizers or rotomixers. Moisture content of the mixture was adjusted to the designed level by spraying water or scarifying the surface for drying under the sun. The surface was then sloped to conform to the designed cross-section profile, compacted in order with sheepfoot rollers, steel rollers and pneumatic tire compacters.

ROAD DESIGN AND CONSTRUCTION

Parrish Road

The Parrish Road is located in Polk County, Florida and stretches about 1 1/2 miles from US 98 to Keller Drive as shown in Figure 1. Construction of the road surface began September 12, 1986 using phosphogypsum supplied by U.S.S. Agri-Chemicals.

Referring to Figure 1, the first section of the road, between stations 90+00 to 100+00, was constructed with 3" layer of phosphogypsum mixed with a pulverizer to a depth of approximately 12" of loose mixture, compacted and left open to traffic for several days. This was followed with a laying of a second 3" of phosphogypsum, mixed to a depth of 10" and compacted.

The second section, between stations 66+00 to 90+00 was constructed with a single application of 3" layer of phosphogypsum mixed to a depth of 15" and compacted. The third section between stations 25+00 and 66+00 was constructed with a single 6" layer of phosphogypsum mixed to a depth of 15" and compacted.

Following compaction, cutback asphalt RC-70 was applied at a rate of 0.2 gal/sq.yd. to the entire road to seal the finished base surface. The section between 50+00 and 100+00 was subsequently covered with a tack coat and a 1" asphalt surface. The section between stations 25+00 and 50+00 was spread with a layer of fine sand over the cutback asphalt seal.

White Springs Road

The White Springs Road is located in Columbia County adjacent to Suwannee River and stretches nearly 2 1/2 mile between State Road 136 and Suwannee Valley Road as shown in Figure 2. The construction of this road was completed in two phases employing four different mixtures of phosphogypsum and the then-existing road base. The phosphogypsum was supplied by Occidental Chemical Corporation in White Springs, Florida.

The first section between station 10+00 and 60+00 was constructed by spreading 5" of phosphogypsum and, mixing to a depth of 14" to achieve a 1:2 mixture of phosphogypsum and sand. The compaction was completed after a two month delay due to rainfall and wet weather. The next two sections between

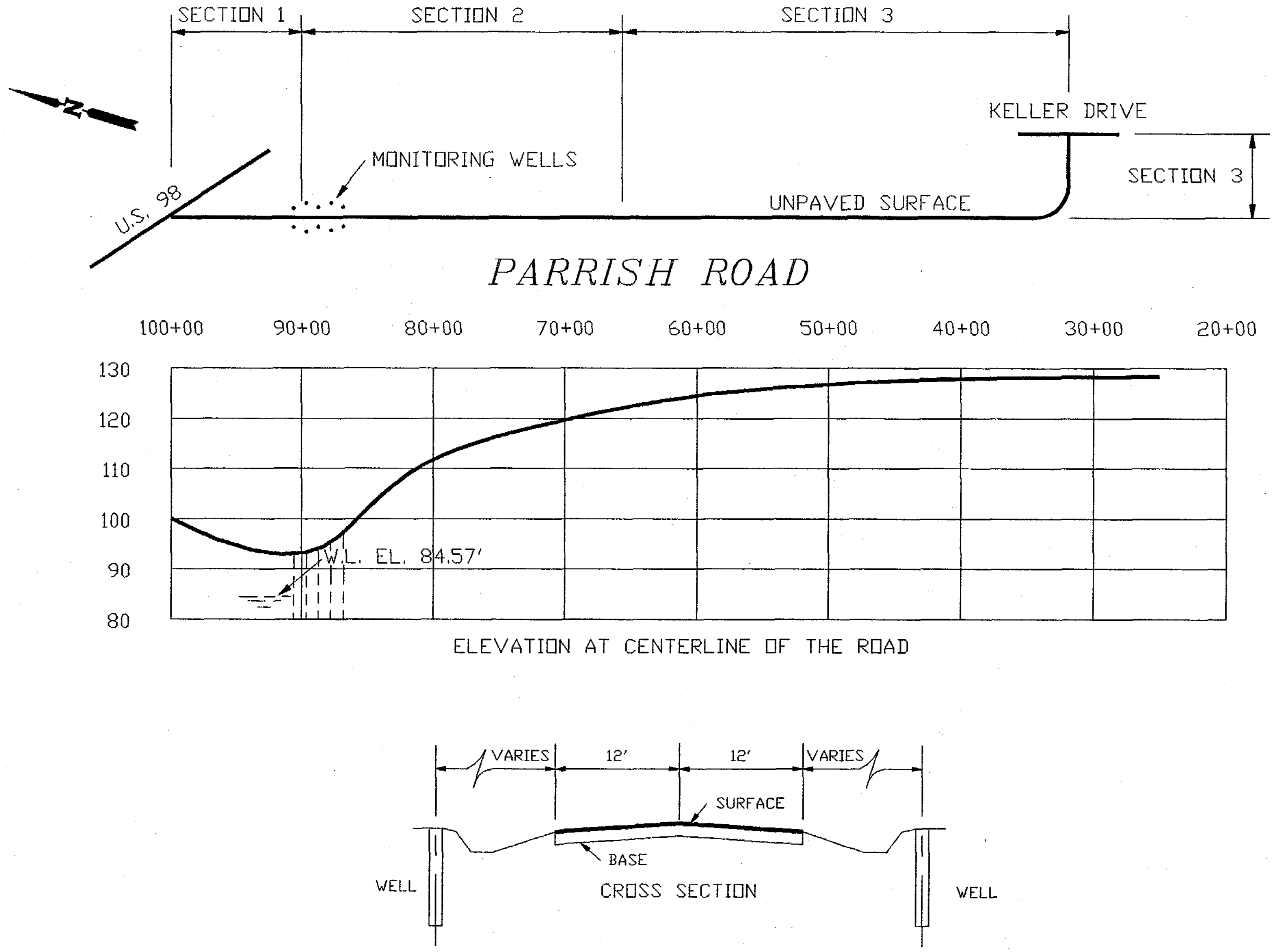


Figure 1. Parrish Road - Polk County, Florida

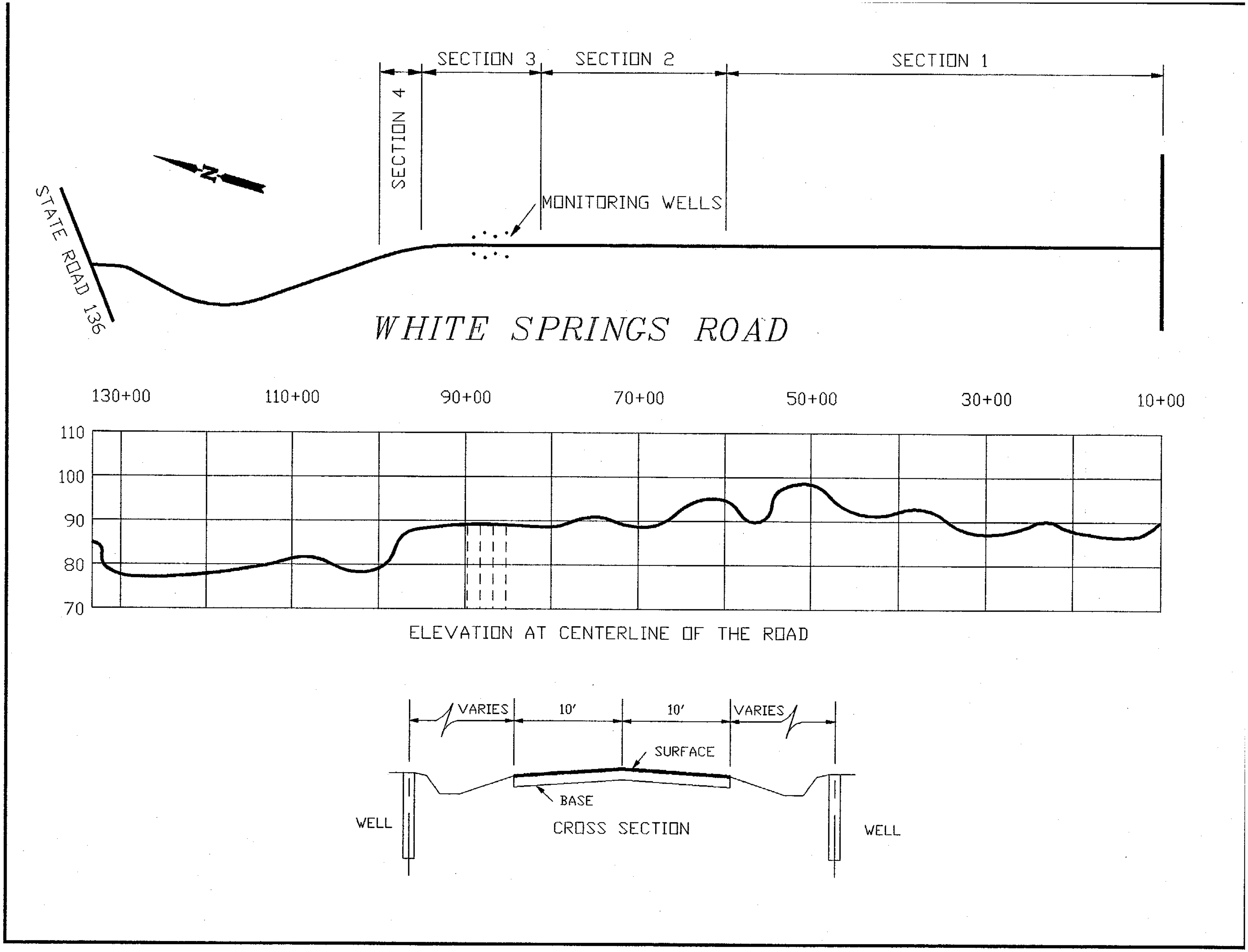


Figure 2. White Springs Road - Columbia County, Florida

stations 60+00 and 81+00, and between 81+00 and 95+00 were constructed with 1:1 and 2:1 mixtures of phosphogypsum and sand, respectively. The last section between stations 95+00 and l00+00 was built with 100% phosphogypsum by spreading 12" of the material and compacting.

The entire road surface was sealed with cutback RC-30 immediately after compaction. The surface was later covered with 1" asphalt concrete following coating the road surface with a prime coat of hot tar.

HYDROGEOLOGY OF THE EXPERIMENTAL ROAD SITES

PARRISH ROAD

Parrish Road is located in central Polk County and is oriented as shown in Figure 1. Both sides had been mined and reclaimed using sand tailings from the mining operation. The land immediately below had not been mined. The road is bounded by large lakes with relatively larger surface on the east side of the roadway indicating that rainfall will induce a flow of groundwater from west to east.

The surface elevation increases in the southerly direction with about 100 ft. MSL at the north end and about 130 ft. MSL at the south, also shown in Figure 1. The average groundwater level is at 84.6 ft. MSL.

The rainfall data obtained from the city of Pembroke, the closest data available, are shown in Figure 3. The amount of rainfall vary considerable through the year and between years with highest rainfall in the summer.

WHITE SPRINGS ROAD

The White Springs Road runs in a north-south direction in northern Columbia County, as shown in Figure 2. Its southern end is very close to the historic Suwannee River which is designated as outstanding Florida waters. The geology and hydrology of this area has been well documented by Ceryak et al, 1983. The soil profiles obtained during the study show that geology consists predominantly of clay with scattered amounts of sand and limestone.

The elevation of the experimental section of the roadway is around 90 ft. MSL with a low of about 87 ft. to a high of 97 ft, also shown in Figure 1. The Florida aquifer, which is unconfined and is under atmospheric pressure, in the only aquifer beneath the cite. The water table normally fluctuates between elevation of 50 ft. to elevation of 65 ft. The water flows generally in the southernly direction.

The rainfall data collected from the Suwannee River Water Management District are shown in Figure 4. Rainfall varies with high peaks during the summer months.

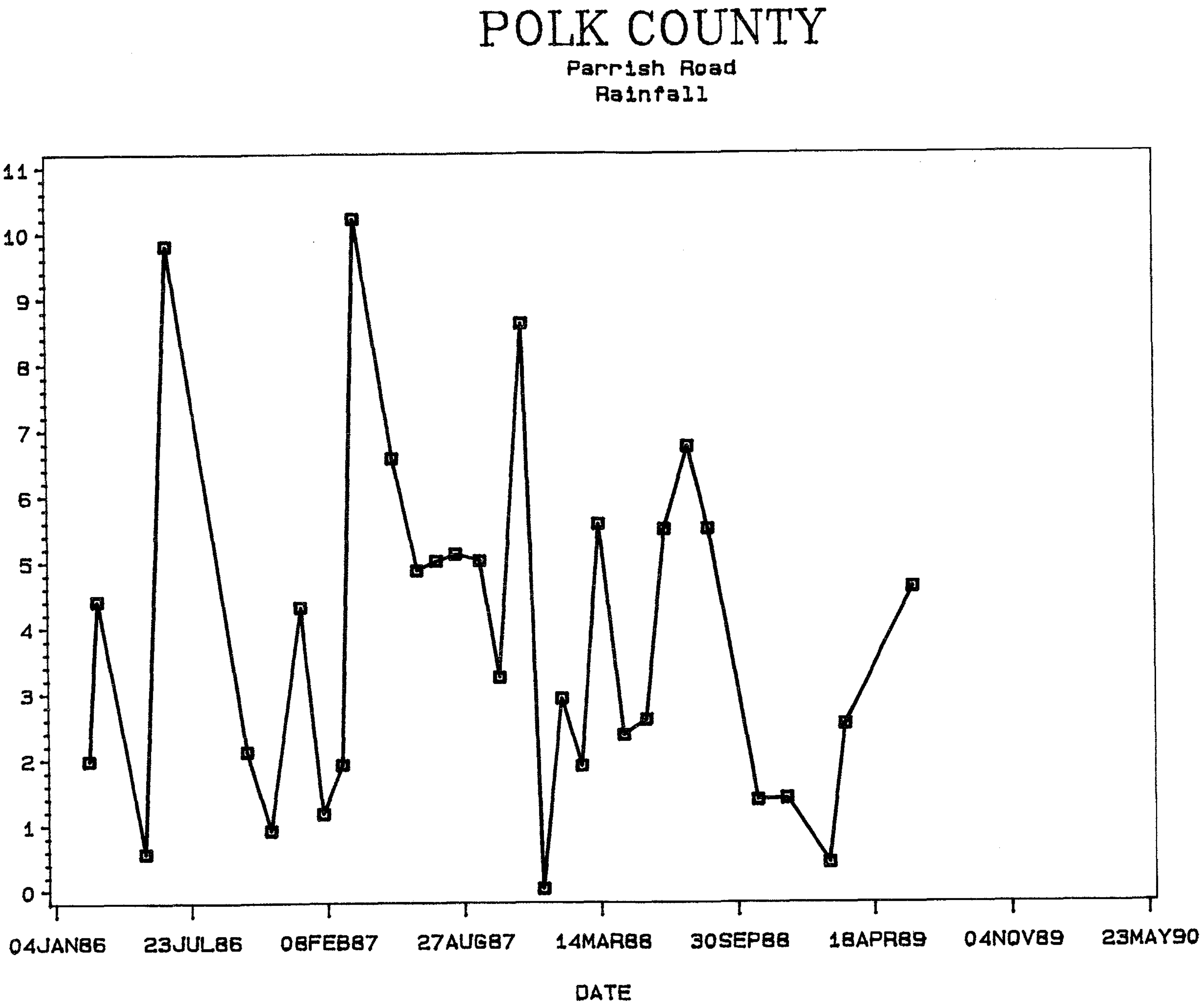


Figure 3. Rainfall, Inch Per Month

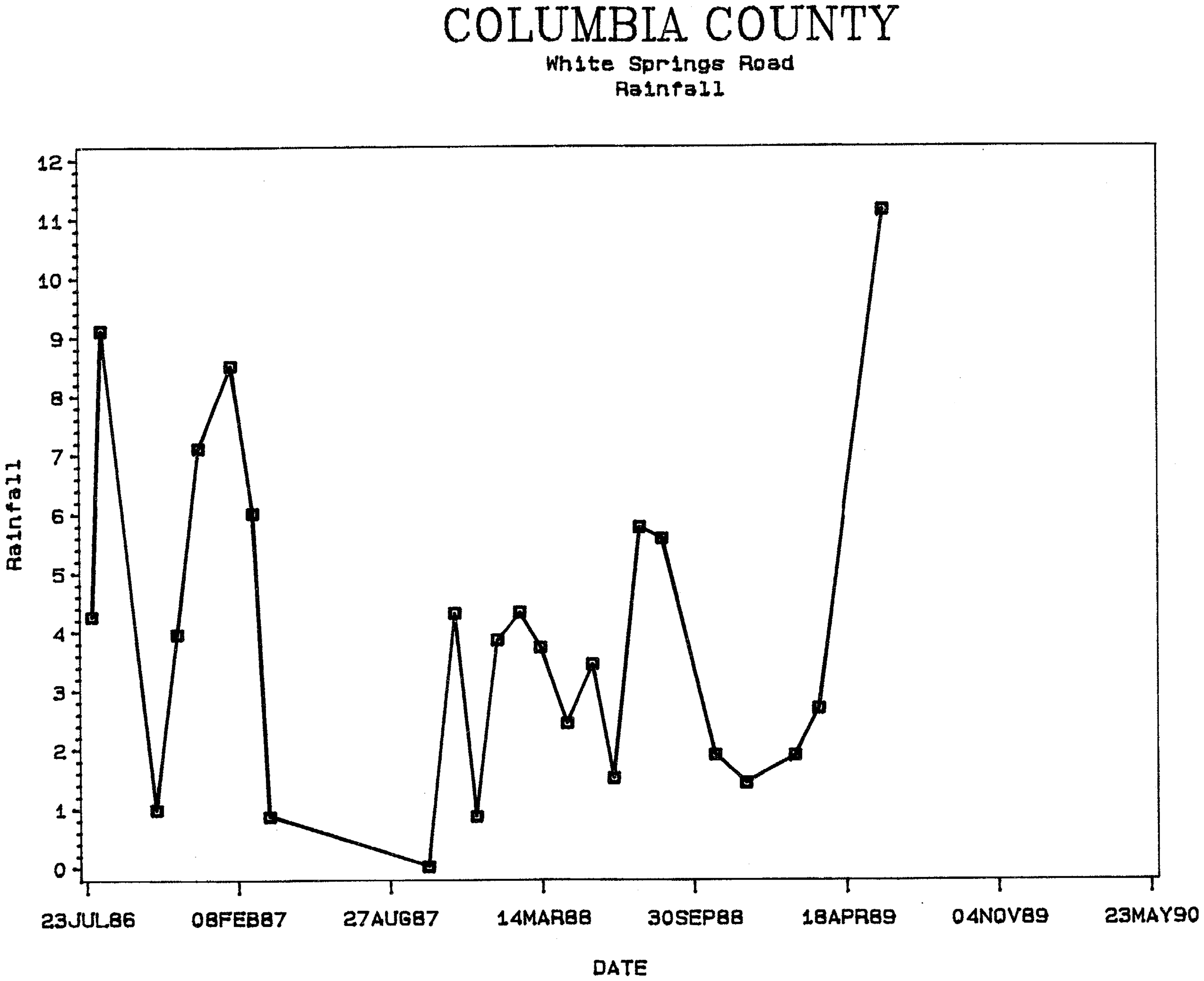


Figure 4. Rainfall, Inch Per Month

GROUNDWATER MONITORING METHODOLOGY

DESIGN OF MONITORING WELLS

The monitoring wells were designed in accordance with generally accepted criteria. The typical well specifications are shown in Figure 5. Figure 6 shows the monitoring well and the soil profile ranges for the White Springs Road project. Wells were made of 2" PVC pipe of varying length thread coupled with a 10 ft section of 2" PVC screen with 0.010" slots and inserted into a 6" diameter bore hole. The top of the screen was placed at the mean wet season water table. The space around the screen was backfilled with graded silica sand followed by 6" to 2' of bentonite pellets to restrict vertical flow of water, sand and cuttings and a 3 ft. section of cement concrete near the surface. A 4" diameter protective steel casing was placed within the cement concrete and extended 2 ft. above the surface.

DESIGN OF WELL ARRAYS

Wells were installed in pairs and symmetrically around the road. In order to detect any movement of contaminant in a outwardly direction from the roadway, wells were placed in symmetric lines of different distances from the center of the road. For the Parrish Road, the inner and the outer lines were 30 ft. and 80 ft. from the center and for the White Springs Road, those were 37 ft. and 80 ft., respectively. The distance between each pair measured along the direction of the road was 150 ft. The well orientations are shown in Figures 7 and 8.

SAMPLING PROTOCOL

General criteria

Monitoring well sampling procedures have a significant effect on the results of the chemical analyses performed on the collected sample. Therefore utmost care was taken including cleaning of sampling equipment, purging of wells prior to sampling, selection of appropriate containers compatible with analyses to be performed and proper sample handling, preservation, storage and transportation of samples.

Sampling equipment

An ISCO Model 2600 submersible well pump capable of delivering at a rate of 3.5 liters per minute was used for well purging as well as sample collection at both test road sites.

Well purging

It is generally accepted that stagnant water inside of the well casing must be removed prior to sampling the well. This evacuation procedure allows fresh water, more representative of the formation, to enter the well casing.

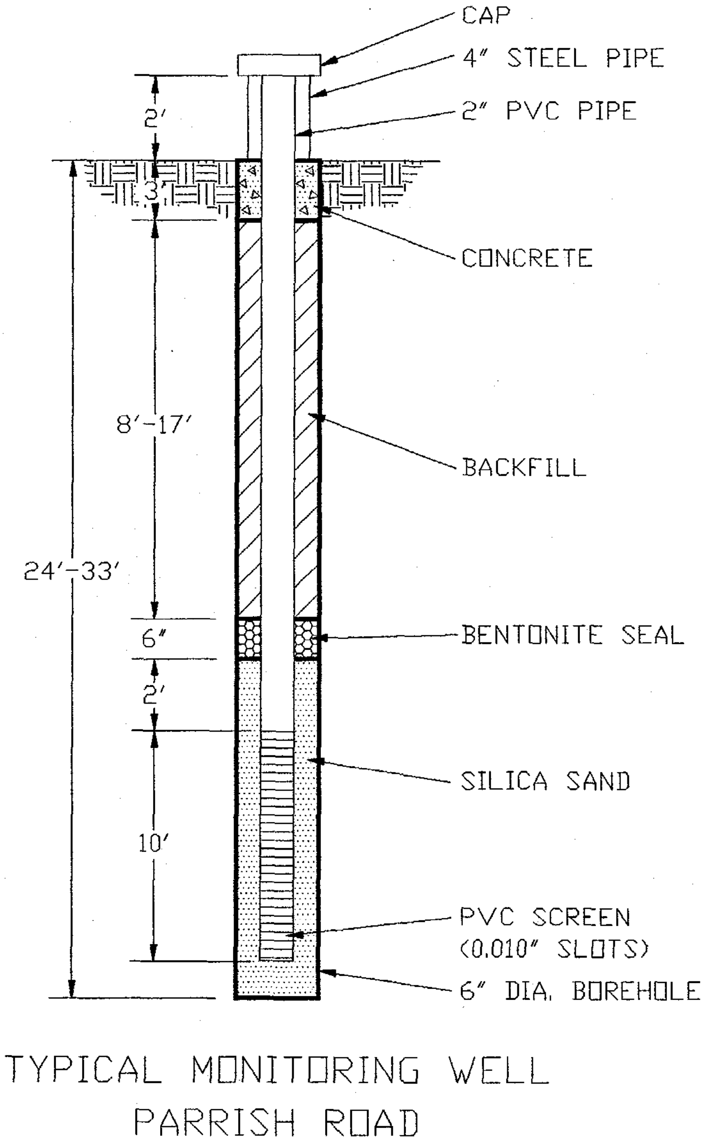
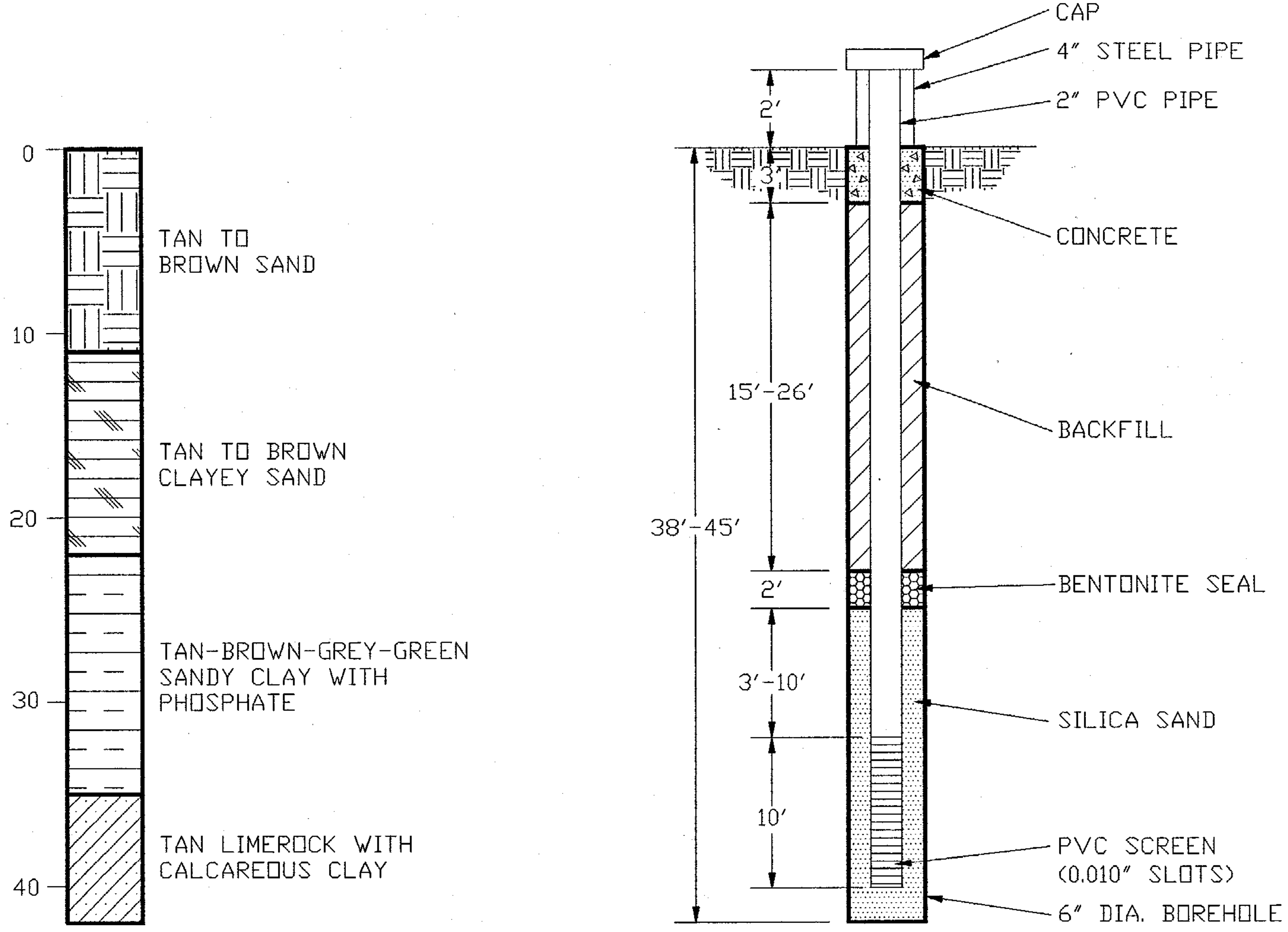


Figure 5. Typical Monitoring Well Design For Parrish Road



TYPICAL SOIL PROFILE
WHITE SPRINGS ROAD SITE

TYPICAL MONITORING WELL

Figure 6. Typical Monitoring Well Design And Soil Profile At White Springs Road

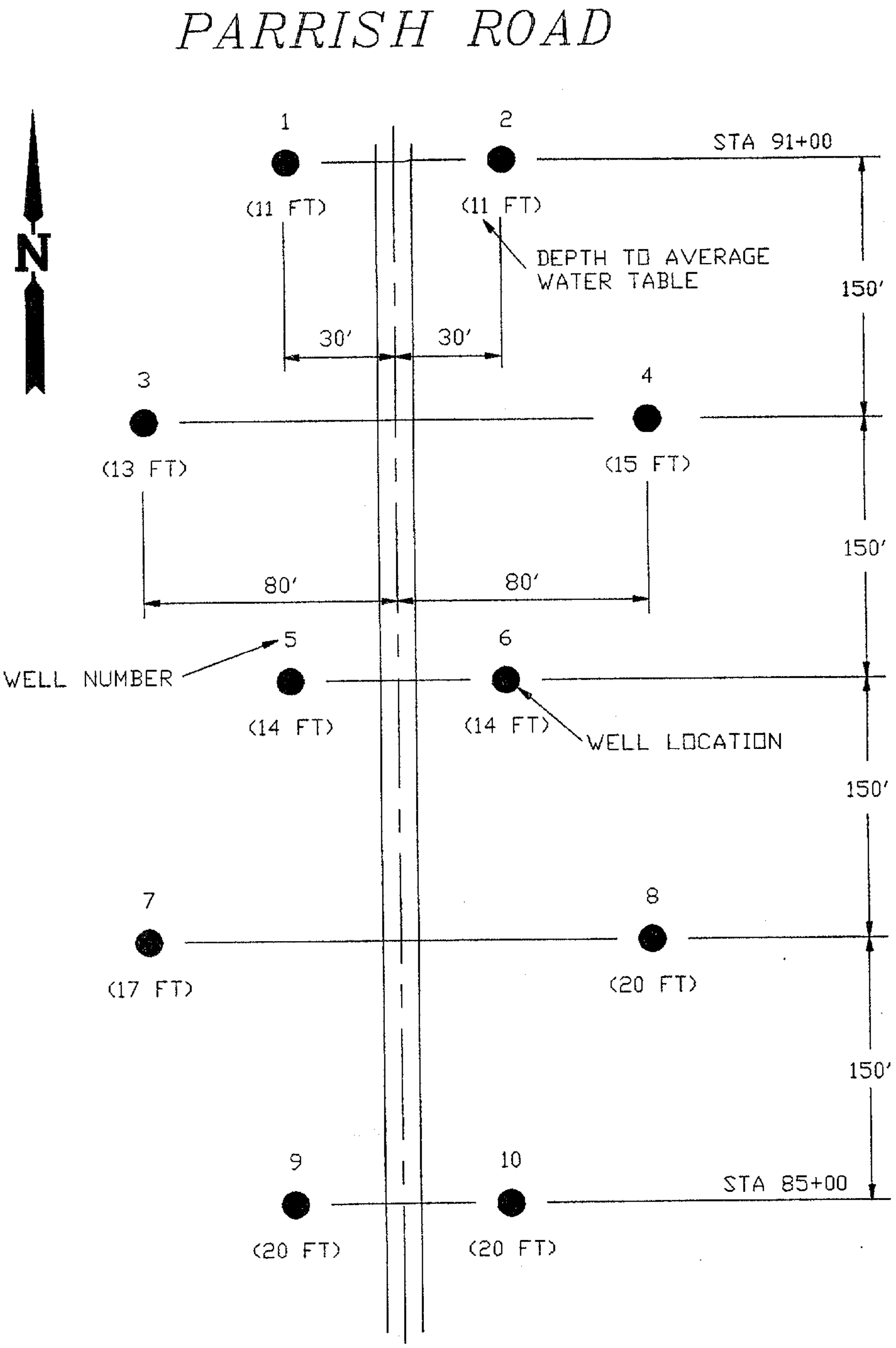


Figure 7. Design of Monitoring Well Arrays

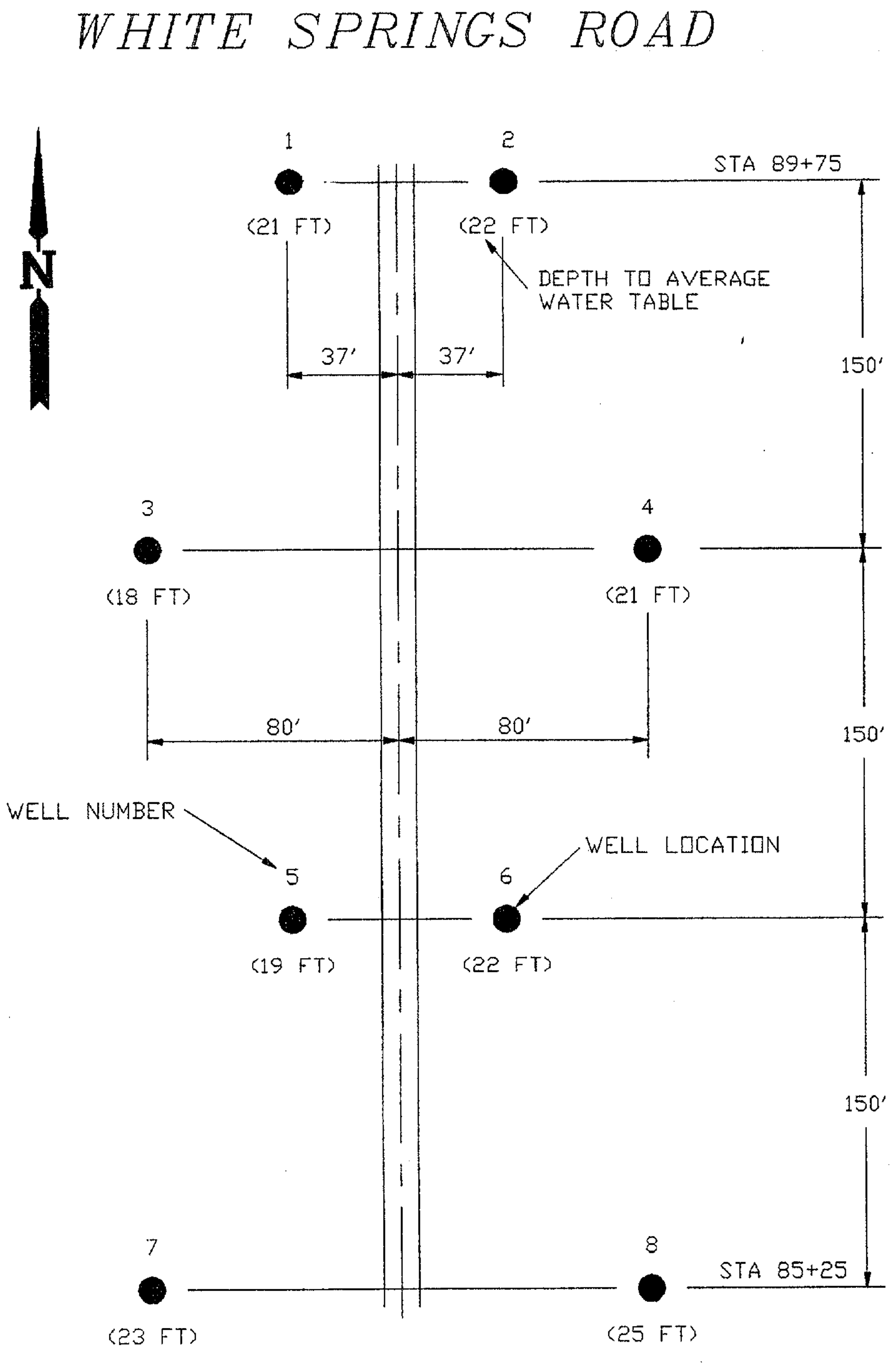


Figure 8. Design of Monitoring Well Arrays

The amount of water to be removed prior to sampling is a widely debated issue among hydrogeologists. The general rule of thumb ranges from between three to six casing volumes of water. This is equivalent to purging 95% to 99.75% of casing volume in the case when there is complete mixing within the well casing. Several investigators provide more exact recommendations based on theoretical treatment of the subject (Papadopulos and Cooper, 1967; Barber and Davis, 1987).

According to Papadopulos and Cooper (1967), the purging time, t_p, before a sample is collected is given by:

$$t_p \simeq 250\ r_c^2/T \ldots\ldots\ldots\ldots \text{Eq. 1}$$

where r_c is the radius of well casing and T is the transmissivity of the aquifer which in this case is equal to the permeability multiplied by the screen length

Barber and Davis (1987) considered the effect of mixing within the well casing. In aquifers with high transmissivities and pump intake within the screened interval, where the water in the casing can be purged with little or no backmixing with groundwater, they suggested the following equation for purging time, t_P

$$t_p > 25\ r_e^2/T \ldots\ldots\ldots\ldots \text{Eq. 2}$$

where r_e is the effective radius of the well casing and T is the transmissivity. In aquifers with low transmissivity, the purging time is given by:

$$t_p > 3.2\ V/Q - 0.9\ r_e^2/T \ldots\ldots\ldots\ldots \text{Eq. 3}$$

where V is the volume of water within the casing, and Q is the pumping rate.

The results of using the various guidelines in estimating purging time are summarized in Table I. The permeability (or hydraulic conductivity) of the Parrish Road surrounding was assumed to be that of a typical sandy fill or 23 ft/day or 0.487 cm/min. The permeability of the White Springs Road surrounding was much lower at an estimated rate of 1.6 ft/day or 0.034 cm/min.

For Parrish Road site where the permeability of the soil was high, first three methods are valid which indicates a purging time of 1 to 11 minutes should be sufficient. The actual purging time used in this site was 10 minutes. For White Springs Road site, method 2 is not valid. Other methods yielded a purging time of 5 to 14 minutes. Here, a minimum of 10 minutes of purging was used before a collecting sample. At wells that went dry within 10 minutes, the pump was turned off and the well was allowed to recover for 5 minutes. Pumping was then resumed and samples were collected.

Table I. Well Purging Times for Representative Sampling

Method	Purging Time, Min. Parrish Road	Purging Time, Min. White Springs Road
Rule of Thumb (3-6 casing volumes)	5-11	5-11
$t_p = 250\ r_c^2/T$	11	156
$t_p > 25\ r_e^2/T$	1	14
$t_p > 3.2\ V/Q - 0.9\ r_e^2/T$	5.6	5

Sample collection and preservation

After purging of the well, water was pumped into a 4 liter reservoir containing an electrical conductivity probe and a temperature indicator probe. The odor as well as temperature and the electrical conductivity of the samples were recorded and samples were then transferred into 3 polyethylene and one glass bottles after rinsing the bottles with the collected ground water. All samples were immediately transferred to a van for pH and turbidity measurements, preservation and storage.

The turbidity was qualitatively measured visually and characterized as very cloudy, cloudy, slightly cloudy or clear. The pH measurement was made with a standard portable pH meter.

Sample preservation was carried out in accordance with the guidelines for the specific chemical constituents to be analyzed. Table II summarizes the sample containers and sample preservation method used.

Table II. Sampling And Preservation Procedures

Parameter	Container	Preservation Methods
pH	P,G	Field Measured
Conductivity	P,G	Field Measured
Turbidity	G	Field Measured
Phosphorous	G	Refrigerated to 4°C
Metals	P	Field Acidified to pH 2 with HNO_3 and refrigerated (4°C)
Nitrate, Amminia	P	Field Acidified to pH 2 with sulfuric and refrigerated (4°C)
Dissolved Solid, Sulfate Chloride, Alkalinity	P	Refrigerated to 4°C

ANALYTICAL PROTOCOL

General

The chemical constituents analyzed for all samples and the analytical methods used are shown in Table III. All analyses performed were completed within the recommended maximum holding times for the constituents.

Table III. Chemical Analyses and Methods

Parameters	Analytical Method
Sodium (Na)	Atomic Absorption Spectroscopy
Potassium (K)	"
Calcium (Ca)	"
Magnesium (Mg)	"
Iron (Fe)	"
Copper (Cu)	"
Lead (Pb)	"
Chromium (Cr)	"
Manganese (Mn)	"
Cadmium (Cd)	"
Bicarbonate (HCO3)	Titrimetry
Sulfate (SO4)	Turbidimetry
Nitrate (NO3)	Cadmium Reduction
Phosphorous (P)	Stannous Chloride Reduction
Total Dissolved Solids (TDS)	Gravimetry
Chloride (Cl)	Electrode
Fluoride (F)	"
Ammonia (NH3)	"

Quality Control

The internal quality control used in the study consisted of replicate analysis of every tenth sample and analysis of field blanks of known composition to monitor accuracy and precision.

The results of the replicate analysis and the quality control program have been published (Chang et al., 1989). These are reproduced in Tables IV and V to aid in the interpretation of the results of the ground water quality study presented. It is important to note the precision and accuracy data for deviations in the chemical parameters measured which exceed the measurement errors are only meaningful.

Table IV. Results of Replicate Analyses

Constituent	Mean Difference (%)	RMS Difference (%)
Na	-0.96	3.92
K	-0.27	2.42
Ca	0.13	1.96
Mg	-0.51	2.75
Alkalinity	0.25	2.43
SO4	-0.23	11.96
Cl	0.26	2.97
F	2.31	8.26
NO3	4.74	41.19
Fe	0.50	3.42
NH3	1.12	3.98
P	-1.57	7.71
Cu	2.74	3.90
Pb	6.49	35.11
Cr	0.02	4.28
Mn	-0.46	7.37
Cd	-0.34	4.34
TDS	0.92	11.40

Table V. Results of Quality Control Analyses

Constituent	Accuracy (%)		Precision (%)	
	This Study	EPA (1979)	This Study	EPA (1979)
Na	2.09	±2	4.91	4.4
K	-0.84	±2	5.07	4.4
Ca	3.40	±2	6.24	4.4
Mg	5.65	±2	7.02	4.4
Alkalinity	0.11	10.6	1.63	15.9
SO4	-4.46	-8.26	19.49	19.3
Cl	6.21	2.2	8.51	9.1
F	4.37	-	8.14	-
NO3	-2.84	8.3	12.85	43.7
Fe	1.45	±3	4.73	27.8
NH3	11.97	-	26.10	-
P	-6.65	-	20.80	-
Cu	7.77	-	12.63	-
Pb	1.30	-	18.77	-
Cr	-5.60	-	13.45	-
Mn	-0.06	-	6.83	-
Cd	5.58	-	11.11	-
TDS	-2.55	-	8.78	-

RESULTS AND DISCUSSIONS

Data generated throughout the study are on file with the Florida Institute of Phosphate Research at Bartow, Florida and are summarized in the Appendix. In the discussion that follows, the results have been grouped together as they relate to the various aspects of ground water quality study. The emphasis of the study has been to show any time trend in analyte concentration before and after the road construction, and thus charts of analyte concentration over time are presented. The results are presented in separate charts for the two roads and on separate charts for the wells close (30 & 37 ft) to the road and the wells away (80 ft) from the road. A vertical line in the chart separates the data between pre and post construction periods.

GROUND WATER CONTAMINATION

The pH and electrical conductivity are considered good indicators of groundwater contamination. Any run-off from gypsum should lower the pH and increase conductivity.

Parrish Road Site

The pH and conductivity data for Parrish Road site are shown in Figures 9 through 12. The pH data do not show any statistically significant trend with time or between pre and post construction periods. There appears to be some correlation among the water samples taken from the many wells at any given time but variations appear random with time.

The conductivity data also do not show any time trend except for samples from well No's 1 and 7. The conductivity data for well No. 1 remained generally below 200 micro-mhos until August of 1988 and then had a upward trend through March 1989 to about 400 micro-mhos. Data from well No. 7 showed, on the other hand, statistically significant downward trend. It remained around 300 micro-mhos through October 1987, then trended downward to about 120 micro-mhos in October, 1988. The data from other 8 wells had no statistical significance. Therefore, with one showing positive trend, a second showing a negative trend and eight showing no trend, ground water contamination must be ruled out.

White Springs Road Site

The pH and conductivity data for the White Springs Road site are shown in Figures 13 through 16. As in the case of the Parrish Road Site no statistically significant time trend was noted in the pH values. The pH of water from wells 1 and 3 which are located at the same side of the road toward Suwannee River was consistently lower than from other wells. The values ranged between 4 and 5, or nearly the same values reported for Suwannee River water, indicating some ground water contamination from the river.

The conductivity data for wells 2, 3, 5, 6 and 7 showed no trend. Data from well No. 1 showed a sharp upward trend beginning in about December, 1988. The data from well No. 4 showed a declining trend before the road

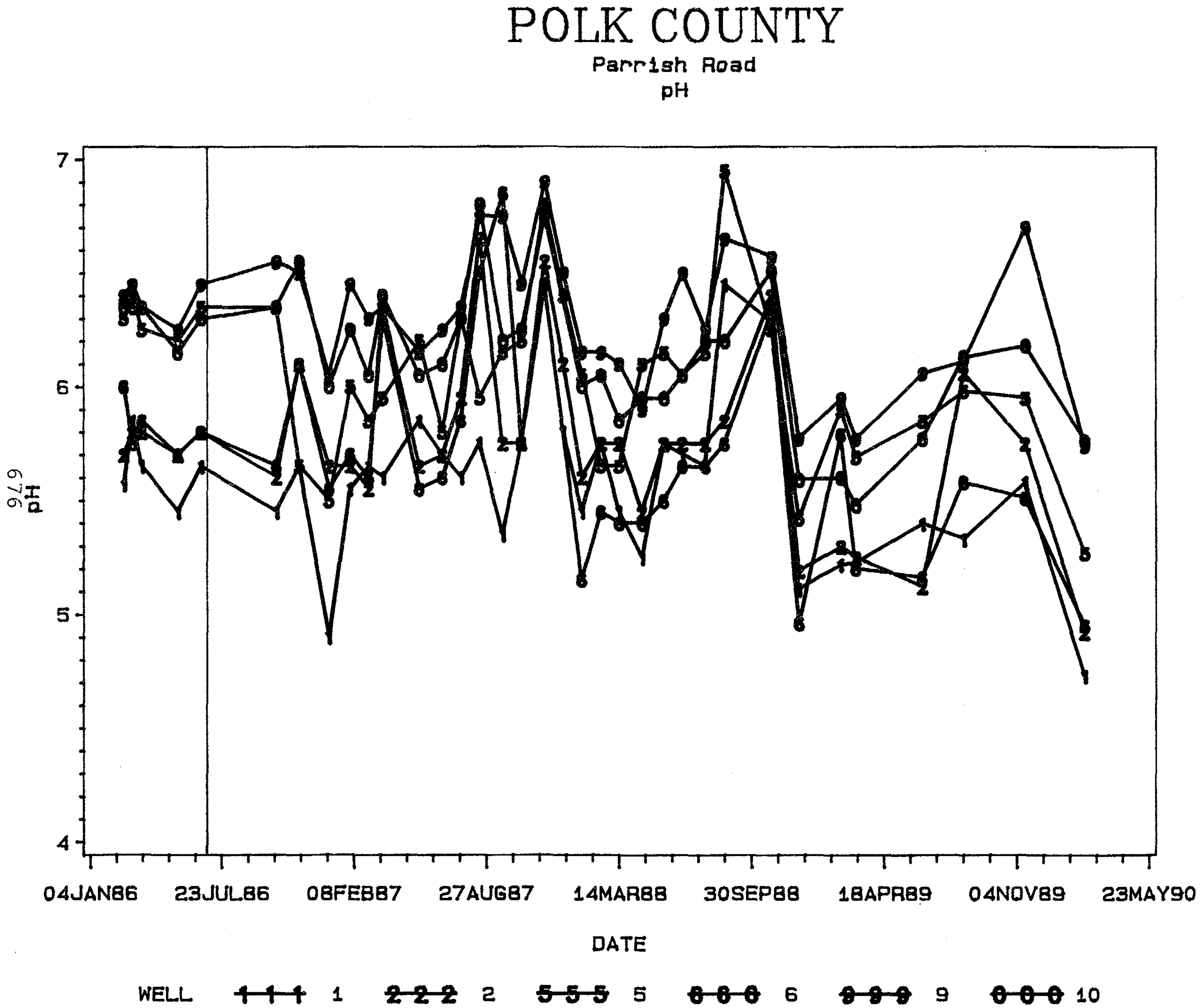


Figure 9. Ground Water pH - Inner Wells

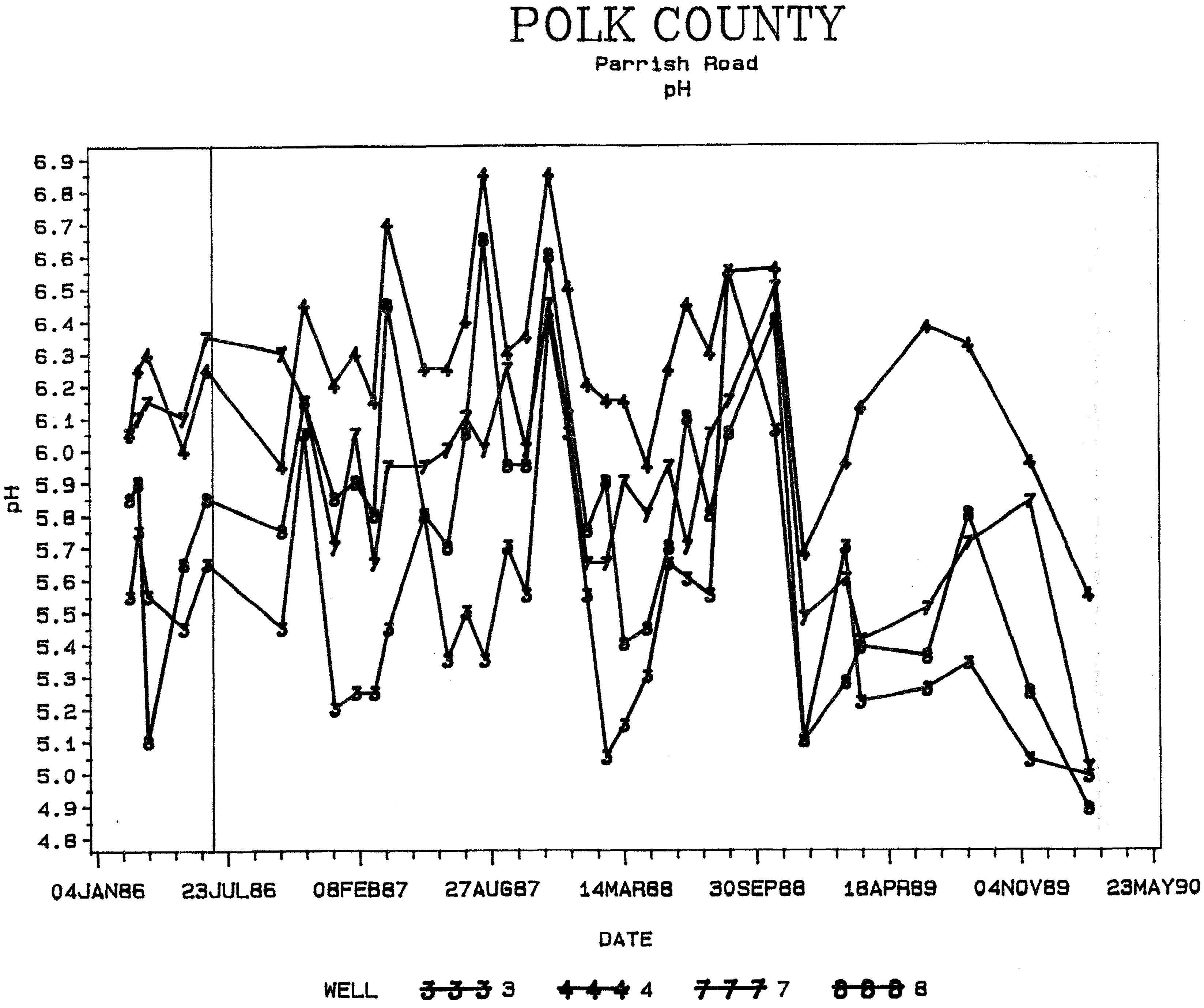


Figure 10. Ground Water pH - Outer Wells

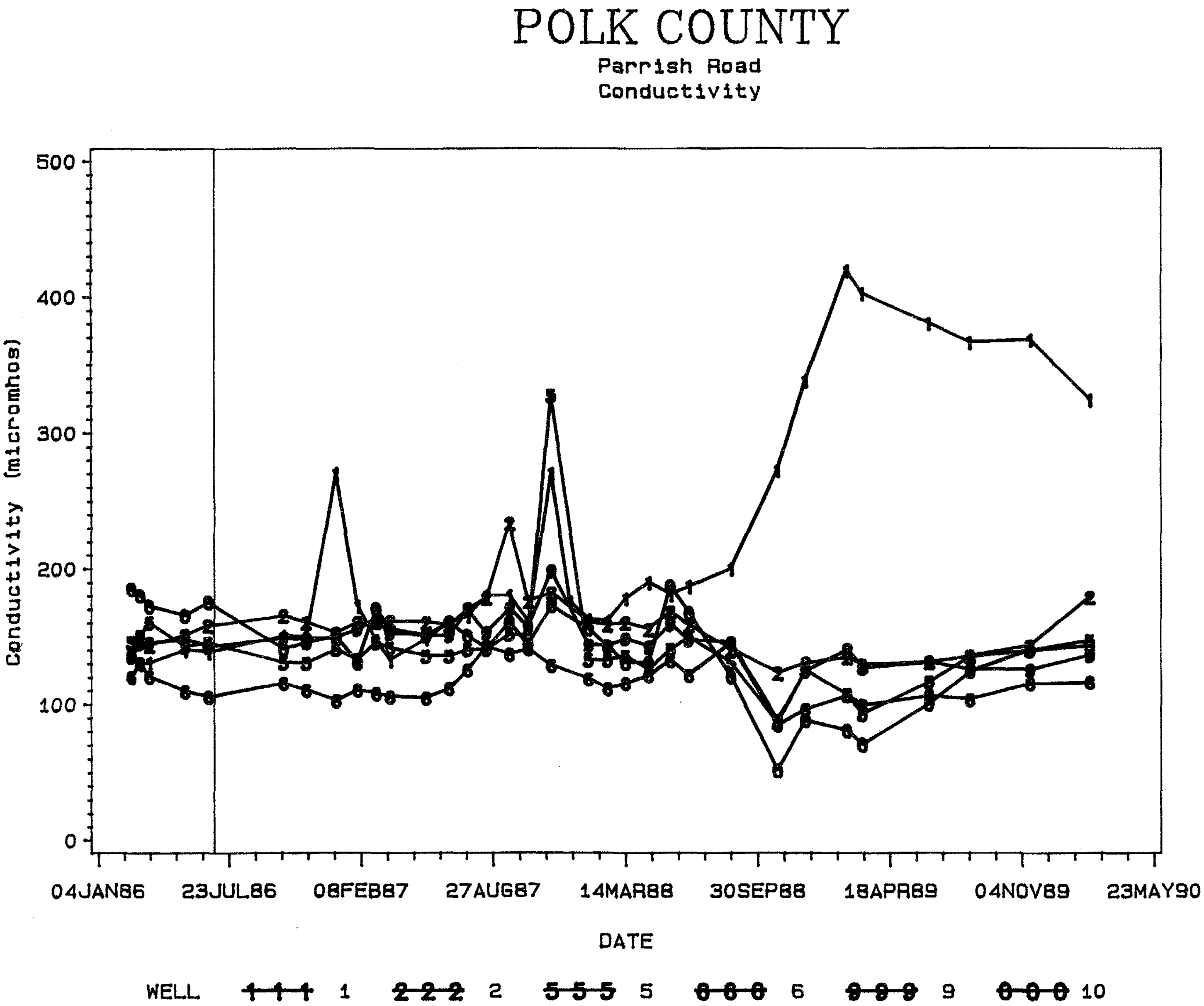


Figure 11. Ground Water Conductivity - Inner Wells

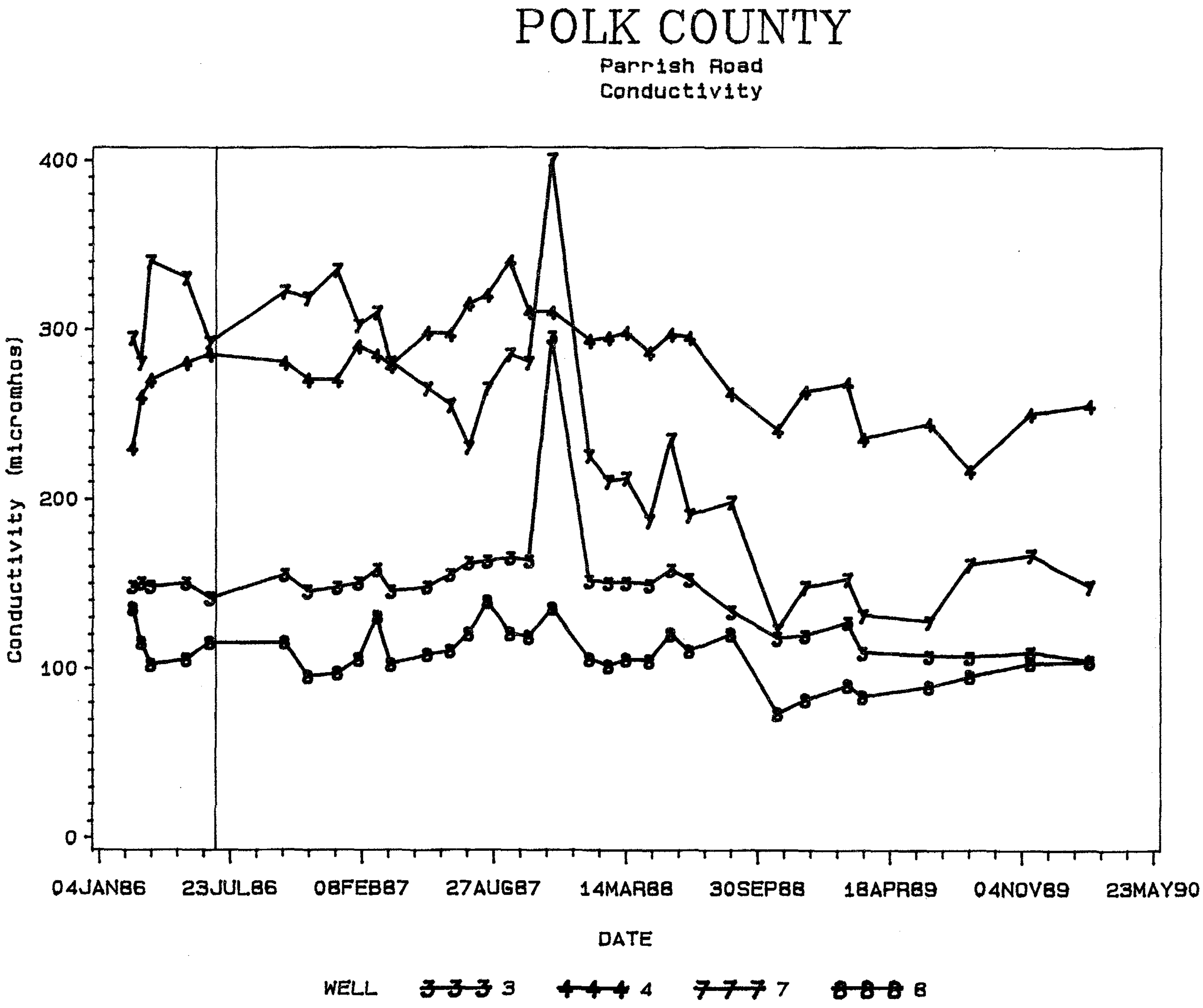


Figure 12. Ground Water Conductivity - Outer Wells

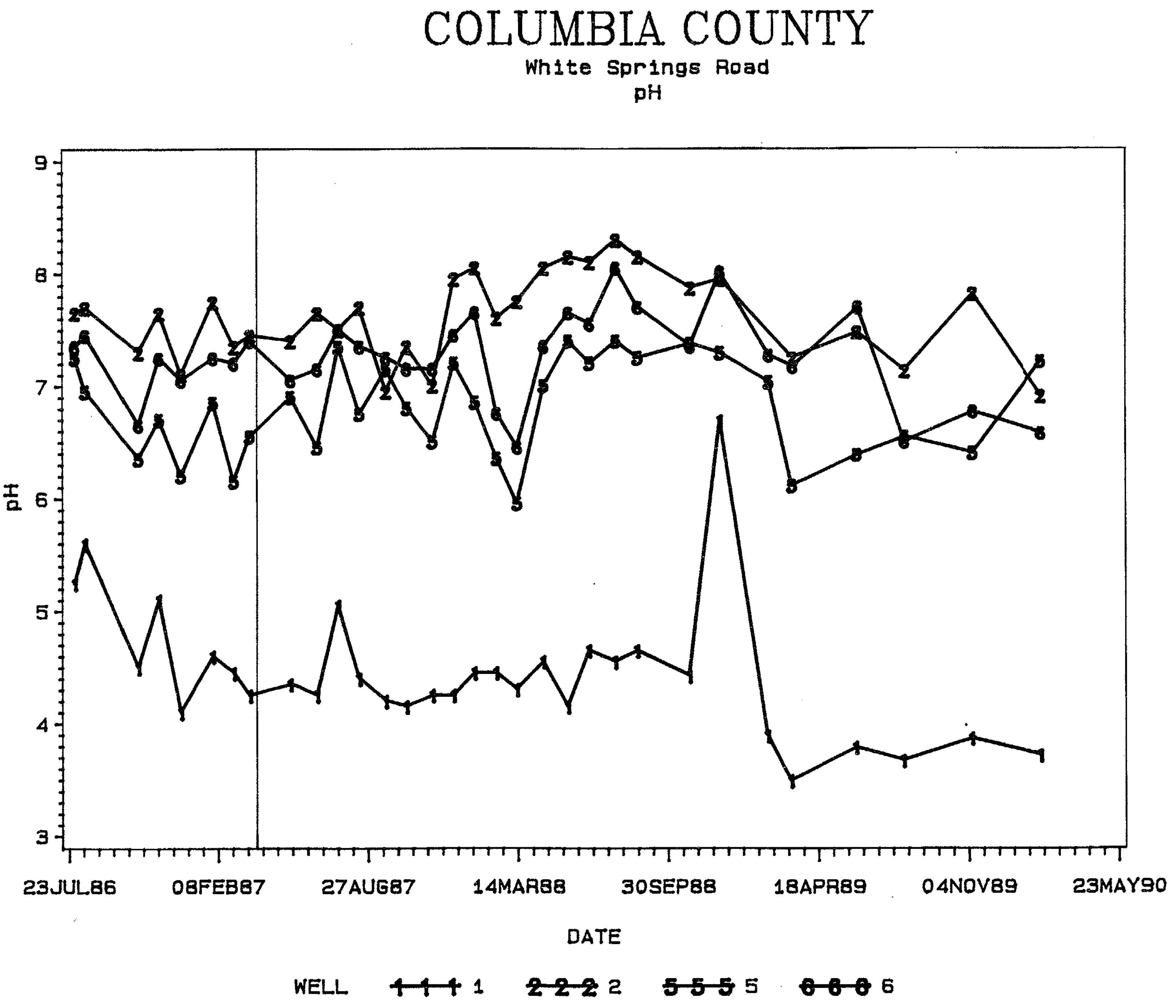


Figure 13. Ground Water pH - Inner Wells

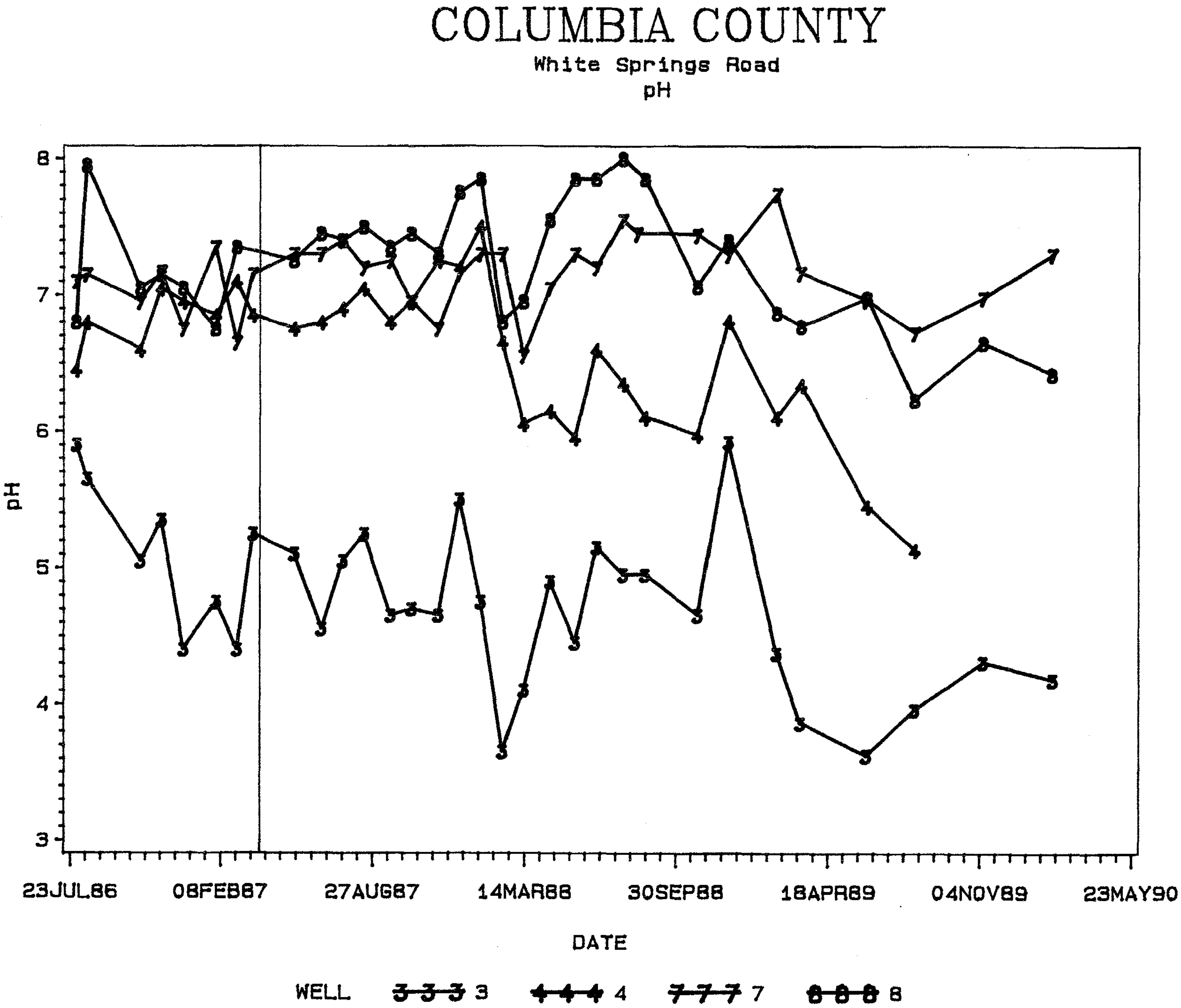


Figure 14. Ground Water pH - Outer Wells

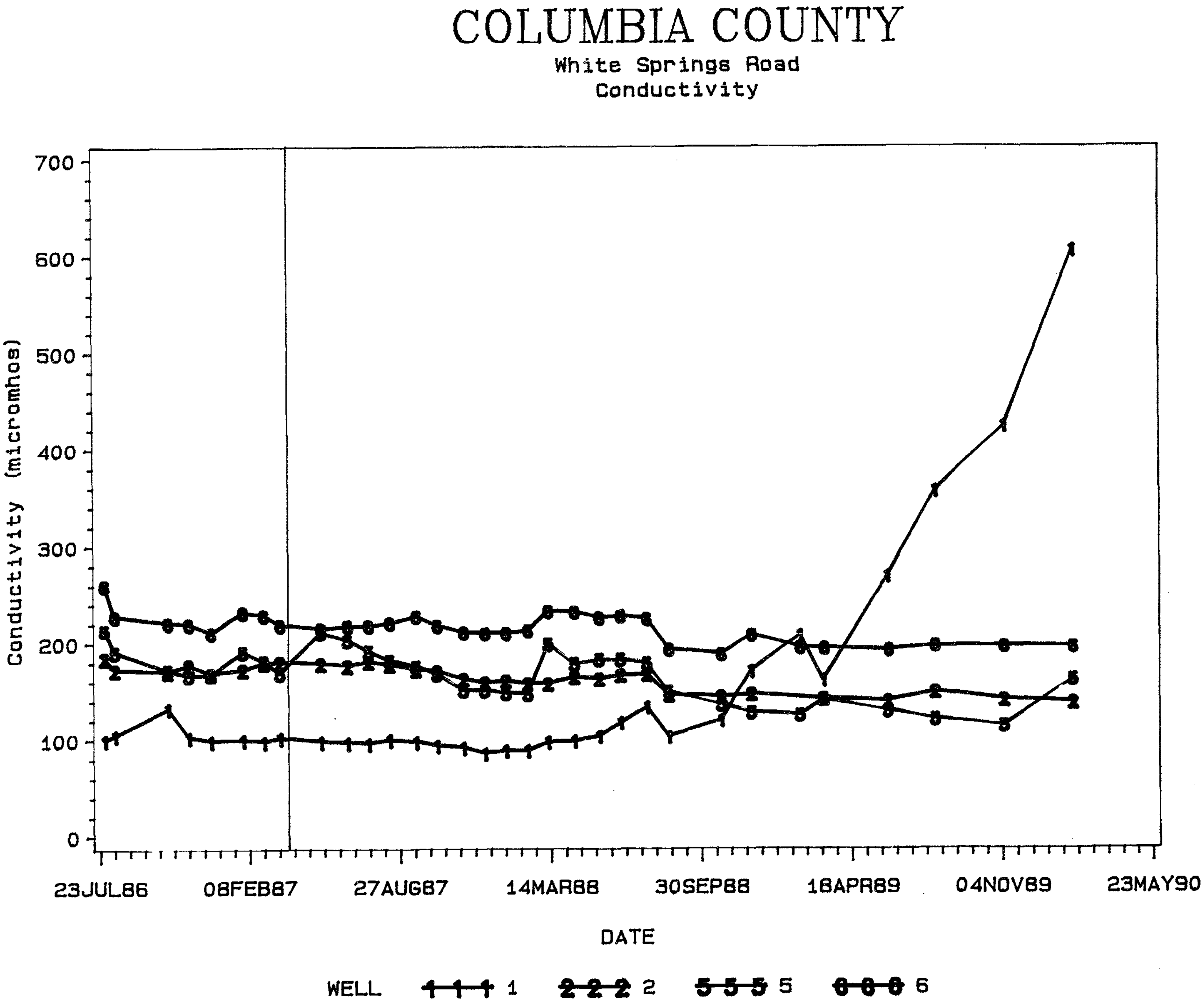


Figure 15. Conductivity in Ground Water, Inner Wells

COLUMBIA COUNTY

White Springs Road
Conductivity

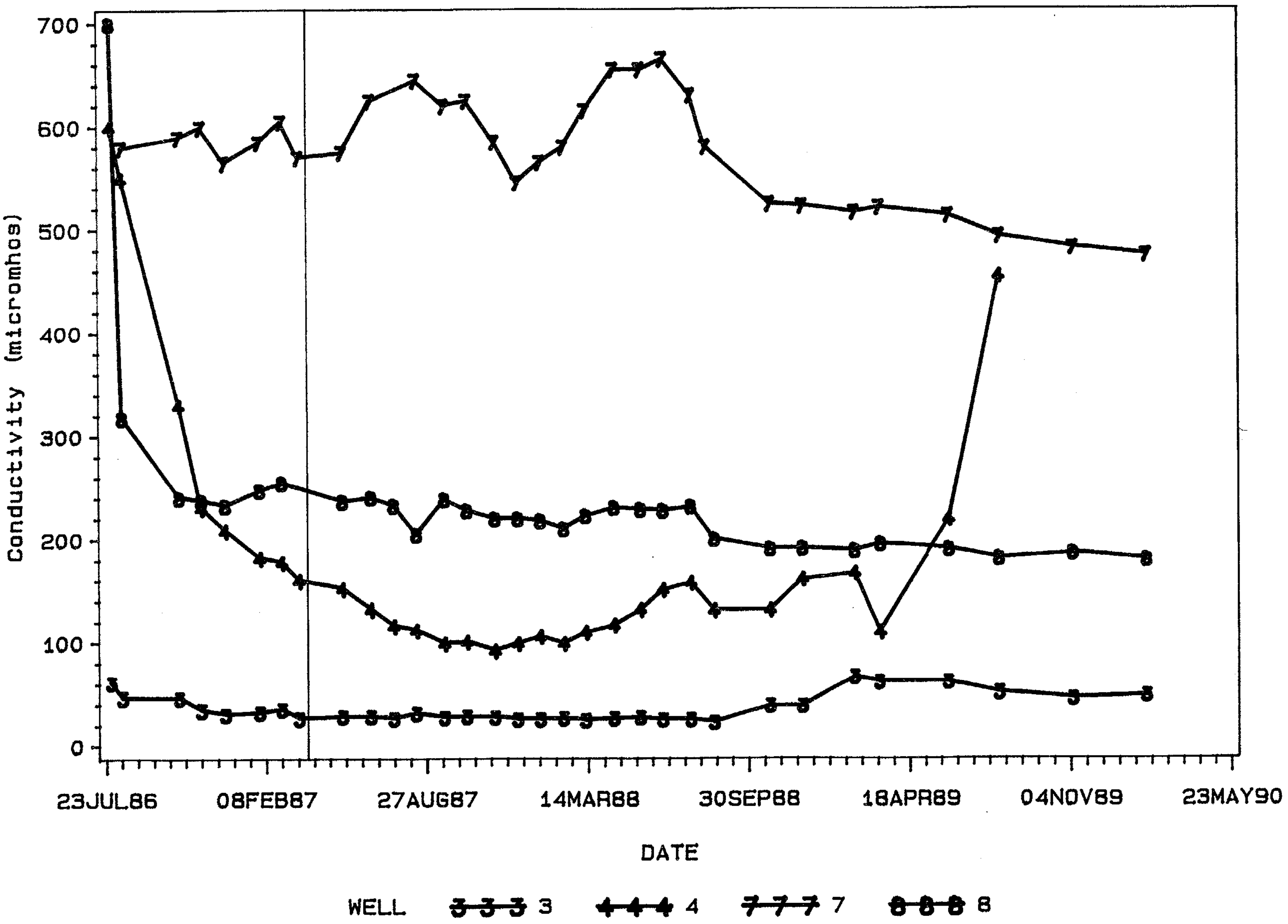


Figure 16. Conductivity in Ground Water, Outer Wells

construction followed by a leveling off during the post construction period until December 1988 when it rose sharply paralleling the trend observed in well No. 1. Conductivity data from well No. 8 dropped drastically during the post construction period and continued to drift downward during the entire period.

PHOSPHOSGYPSUM LEACHATE

The primary objective of the study was to evaluate any effect that the phosphogypsum, used in the road construction, may have on the quality of ground water through leaching. Results from five items of particular interest for examination are: the levels of calcium and sulfate, the two major components of phosphogypsum, phosphorous, fluoride and radium in the ground water. Some of these components are of interest also from the view point of natural drinking water standards.

Parrish Road Site

The calcium, sulfate, dissolved phosphorous, fluoride and radium 226 levels are presented in Figures 17 through 26. Generally, random changes in the levels of these components were noted with little or no time trend or any significant differences between pre and post construction period.

Calcium

The calcium level, for which there is no drinking water standard, varied randomly through August 1988, then showed a slow upward trend in all wells. But it continued to remain below the preconstruction values.

Sulfate

The sulfate levels in all wells remained below 50 mg/liter except for well No. 1, where a definite upward trend was noted beginning in December, 1988 and peaking in March 1989 at a level of nearly 250 mg/liter. At this well some leaching of the phosphogypsum might have occurred. It should be noted that the recommended maximum level of sulfate, per the secondary water standards, is 250 mg/liter.

Phosphorus

The dissolved phosphorous levels showed no trend during the post construction period. It is interesting that the levels of dissolved phosphorous were uniformly reduced following the road construction.

Fluoride

The fluoride level in the ground water did appear to be elevated at the inner wells during the post construction monitoring period. On several occasions, it exceeded 2 mg/liter, the maximum recommended per the secondary drinking water standards. The fluoride level in the ground water from the outer wells remained essentially unchanged throughout the monitoring period and remained at around 1 mg/liter except on one occasion. The samples taken on February 9, 1989, showed a four to five fold higher level of fluoride compared to the immediate prior sampling date. However, the fluoride levels were greatly reduced in all wells during the subsequent monitoring period.

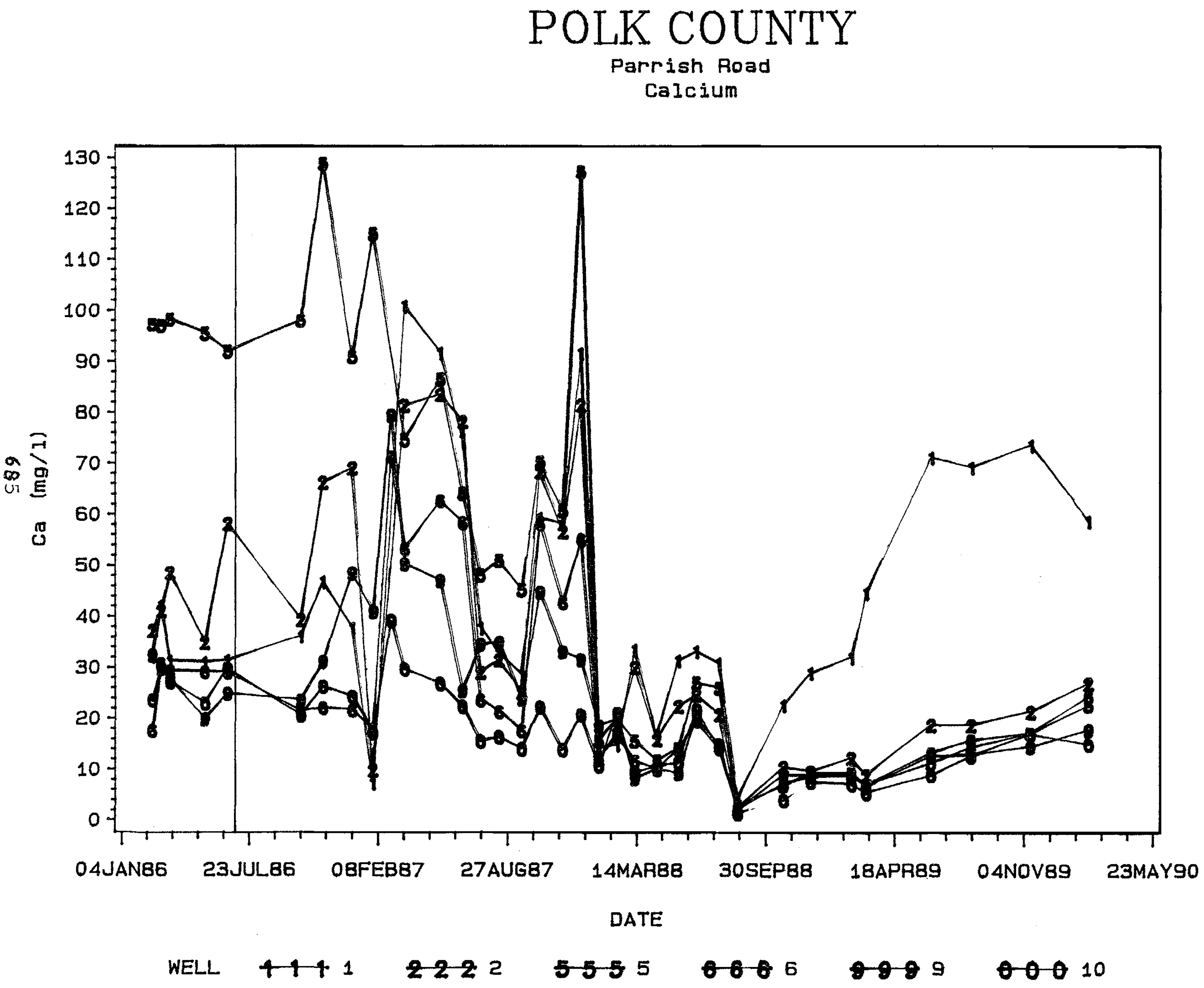


Figure 17. Calcium Level in Ground Water, Inner Wells

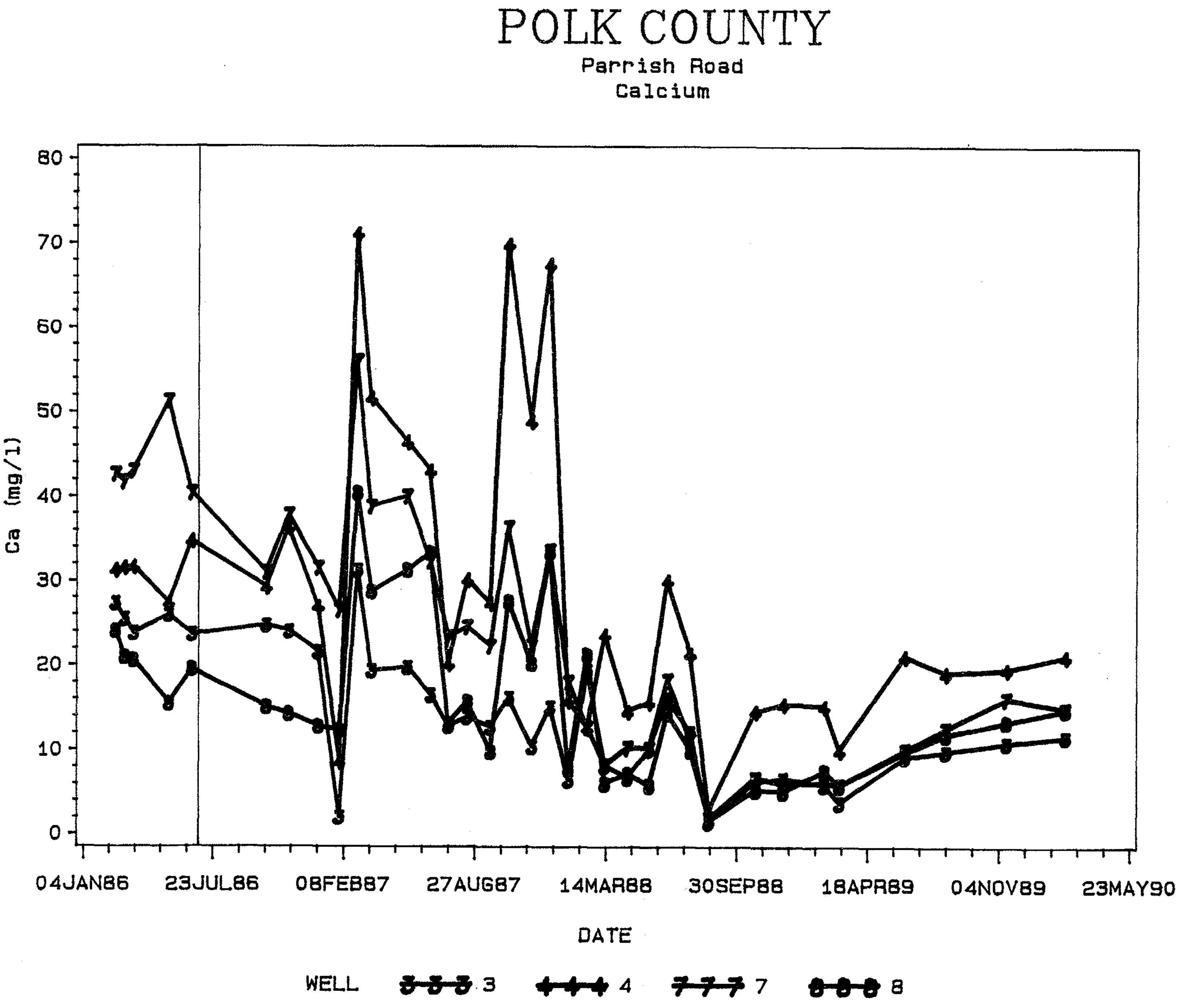


Figure 18. Calcium Level in Ground Water, Outer Wells

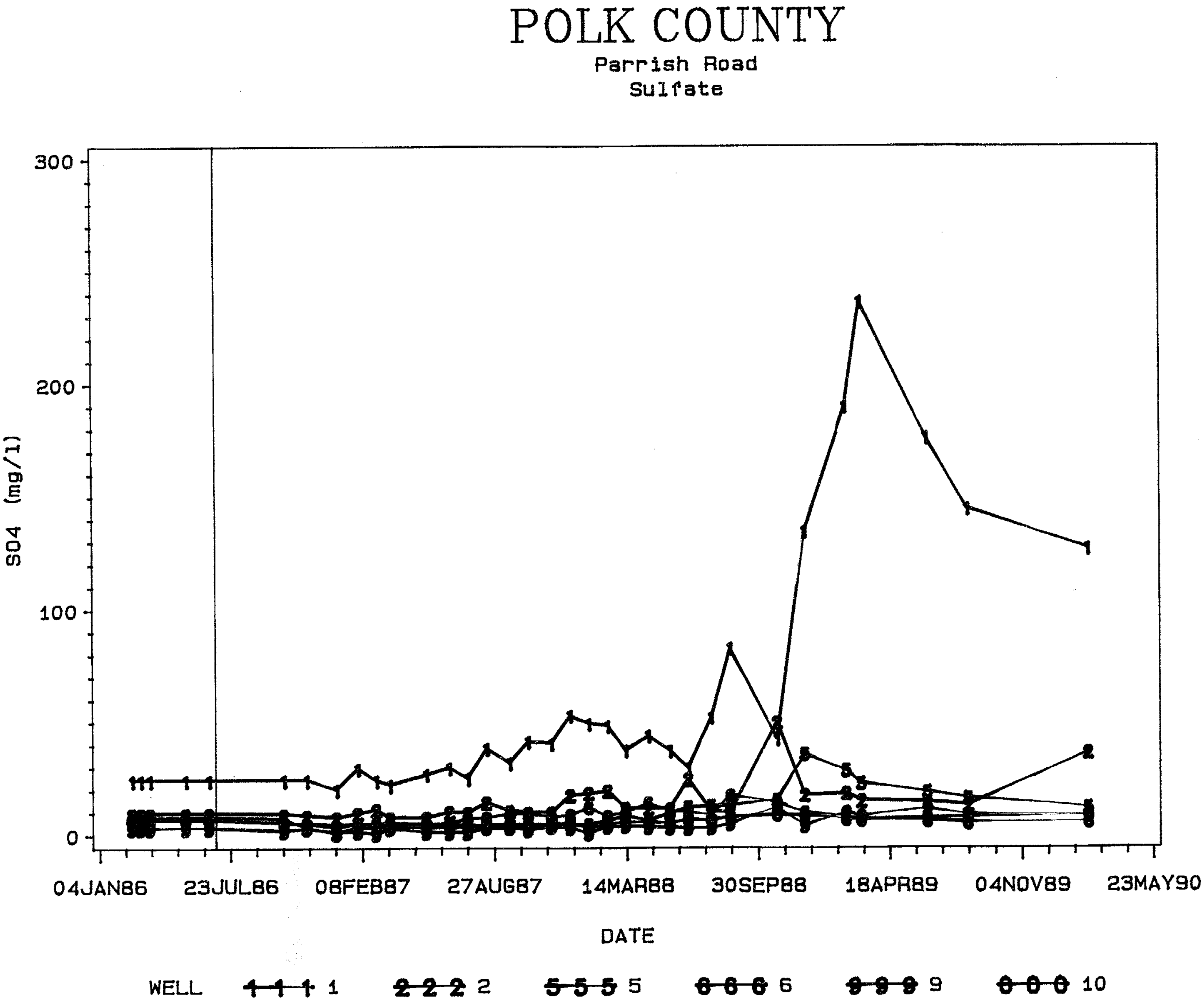


Figure 19. Sulfate Level in Ground Water, Inner Wells

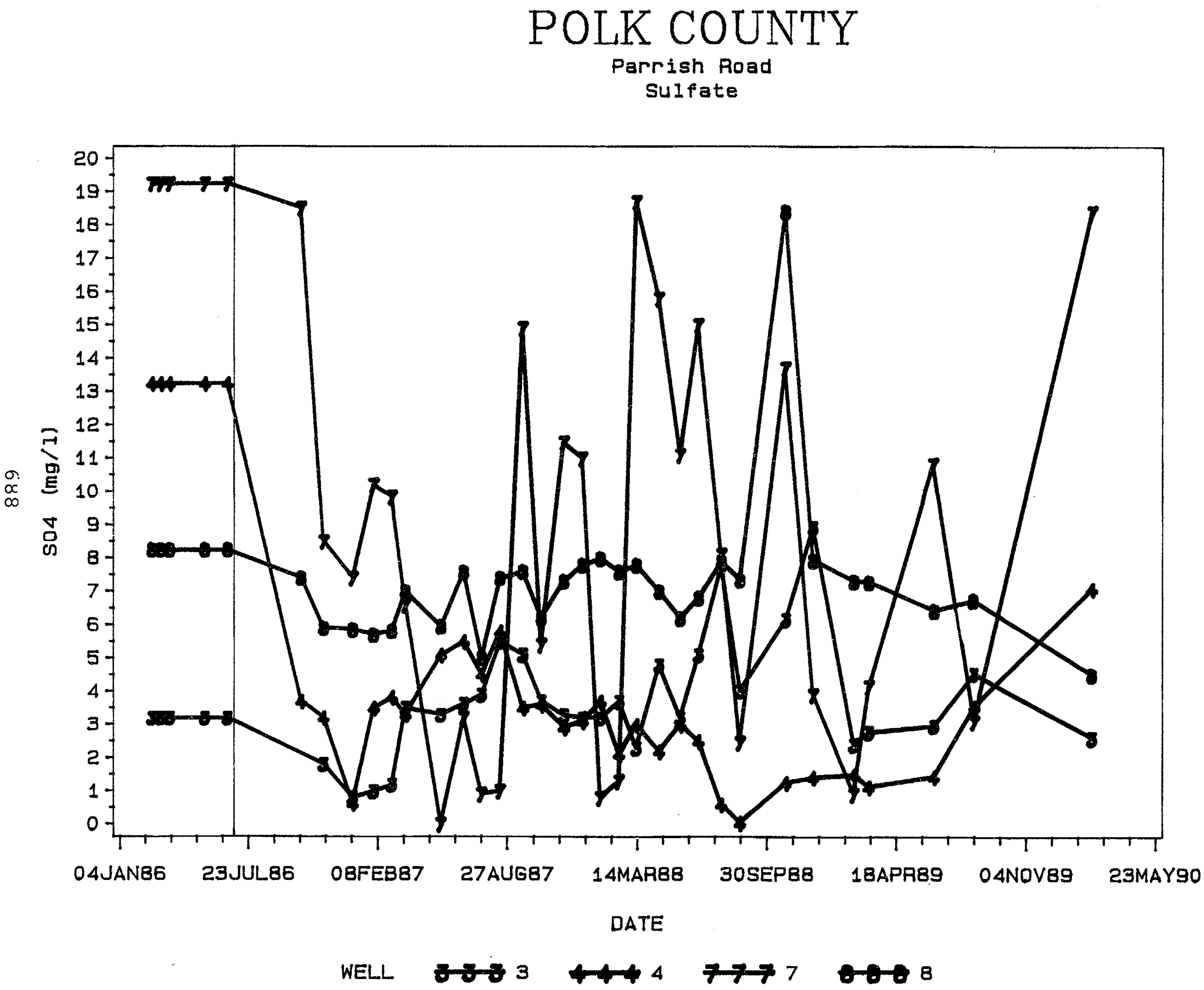


Figure 20. Sulfate Level in Ground Water, Outer Wells

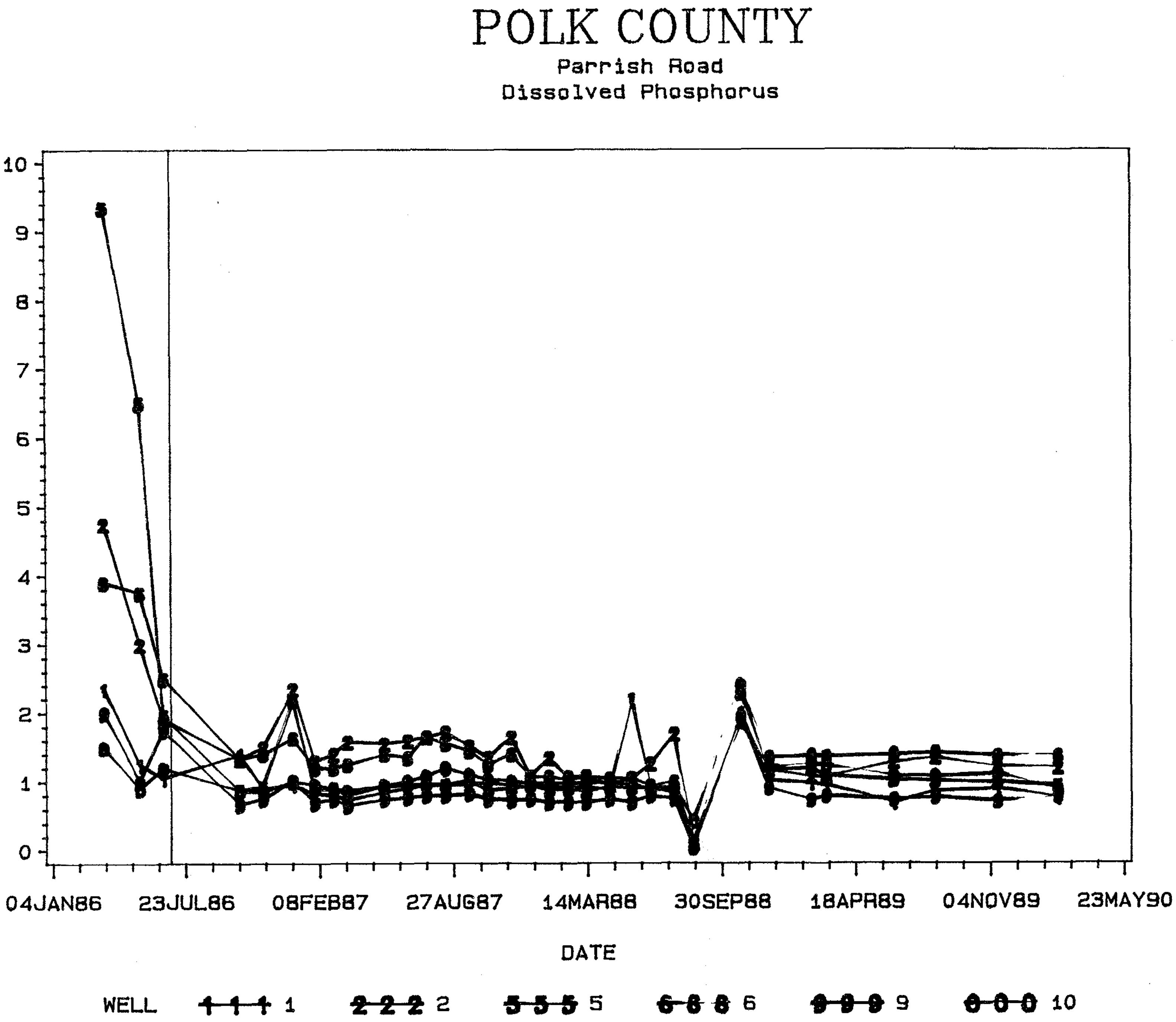


Figure 21. Dissolved Phosphorus in Ground Water, Inner Wells

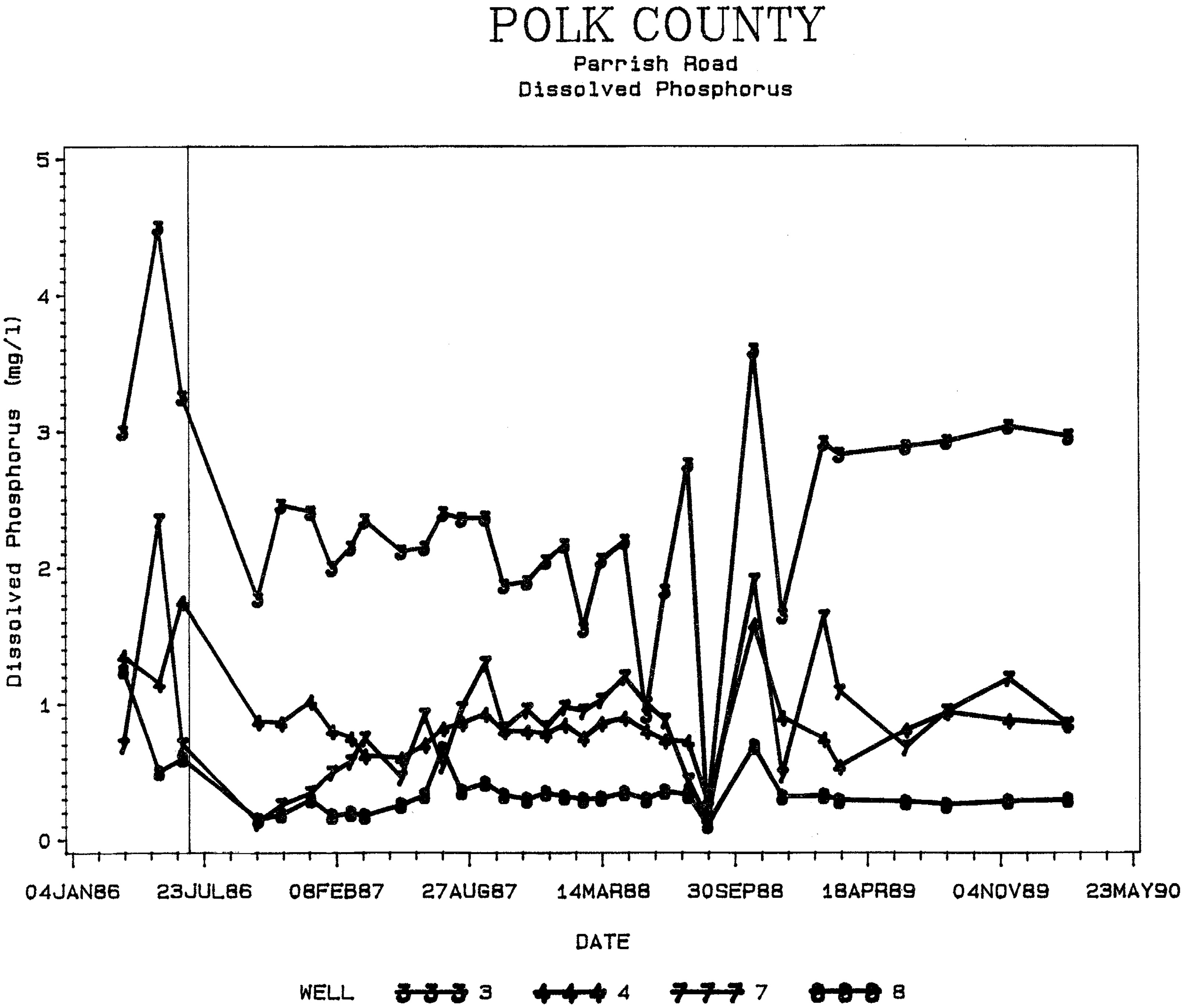


Figure 22. Dissolved Phosphorus in Ground Water, Outer Wells

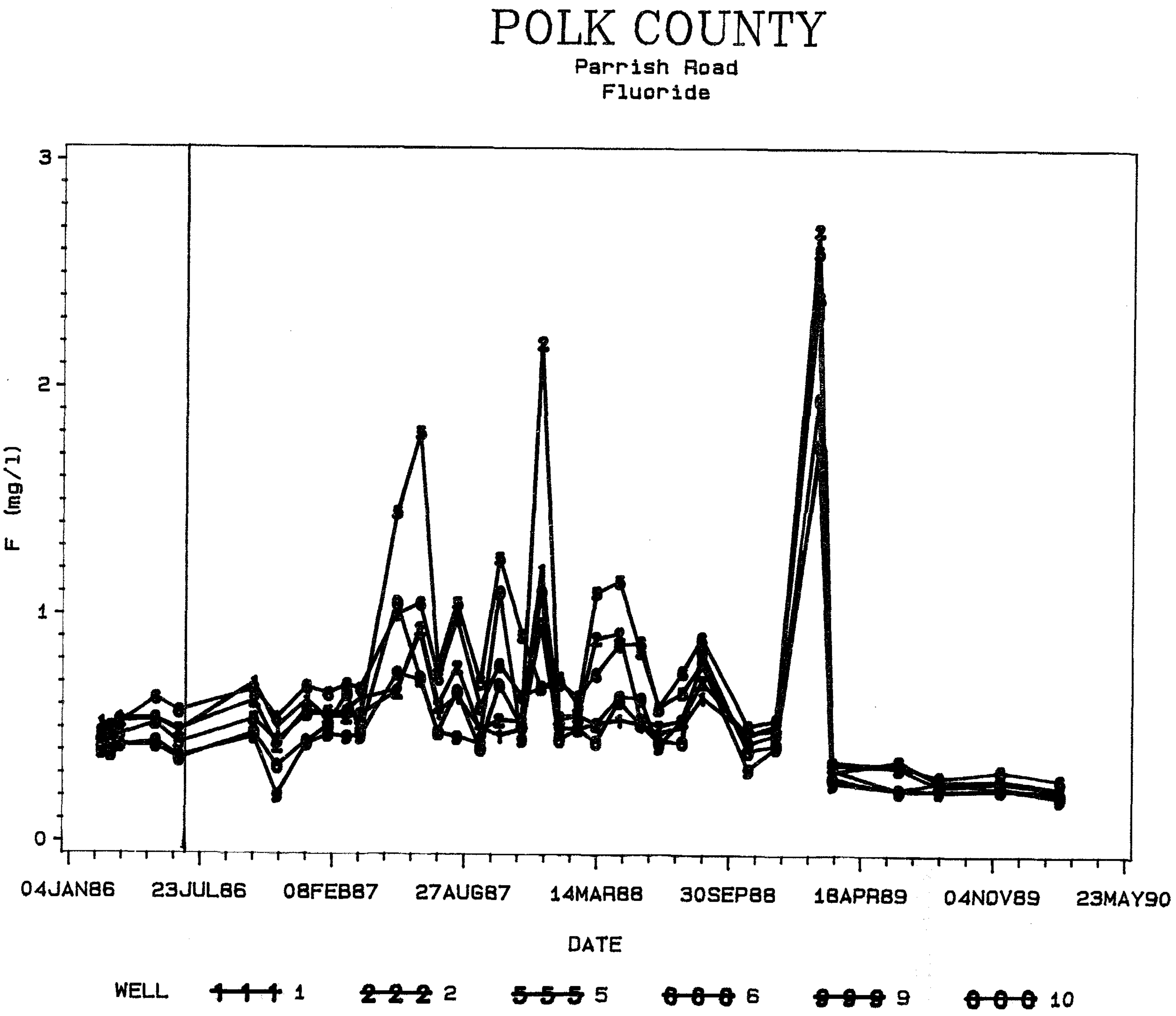


Figure 23. Fluoride Level in Ground Water, Inner Wells

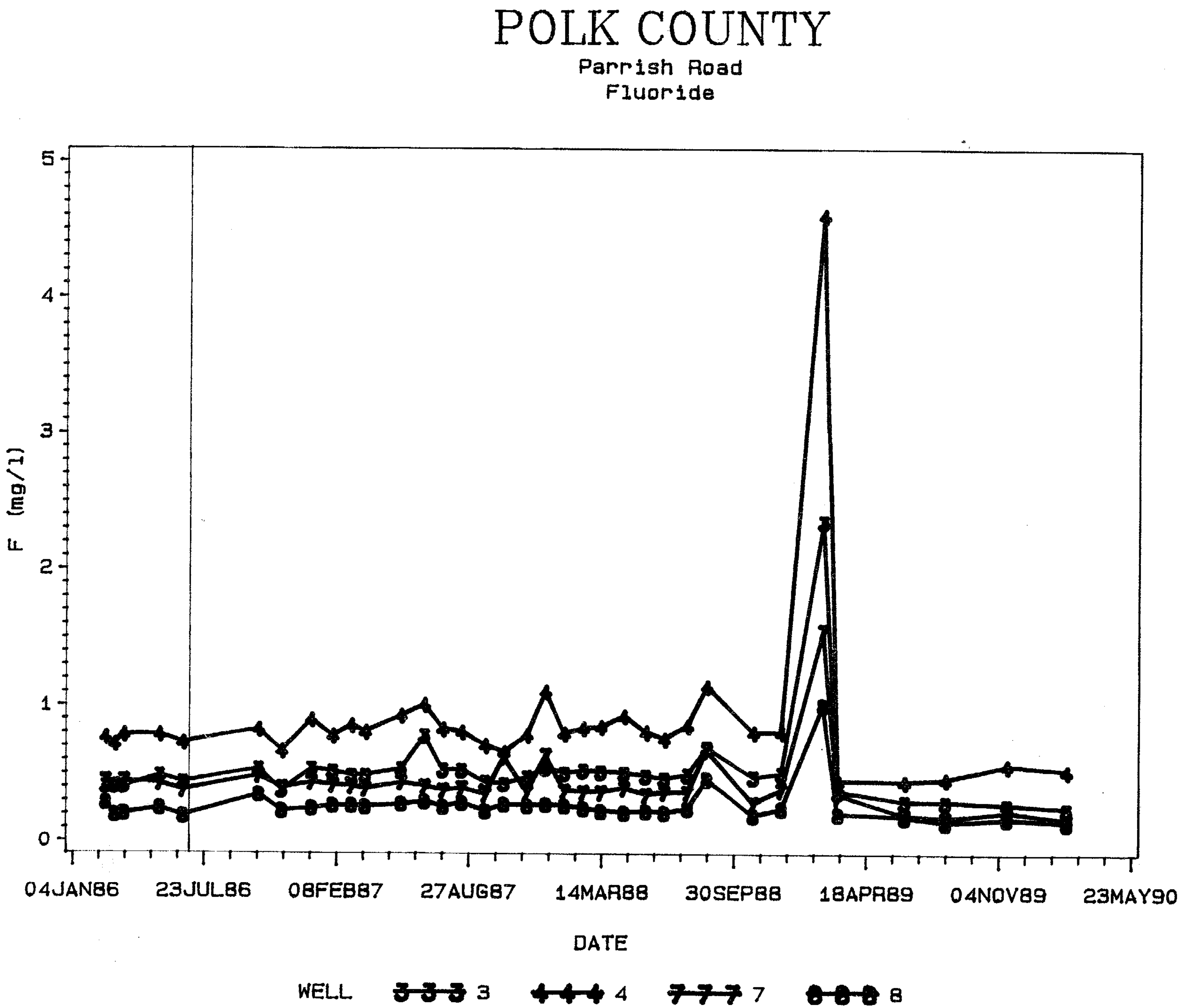


Figure 24. Fluoride Level in Ground Water, Outer Wells

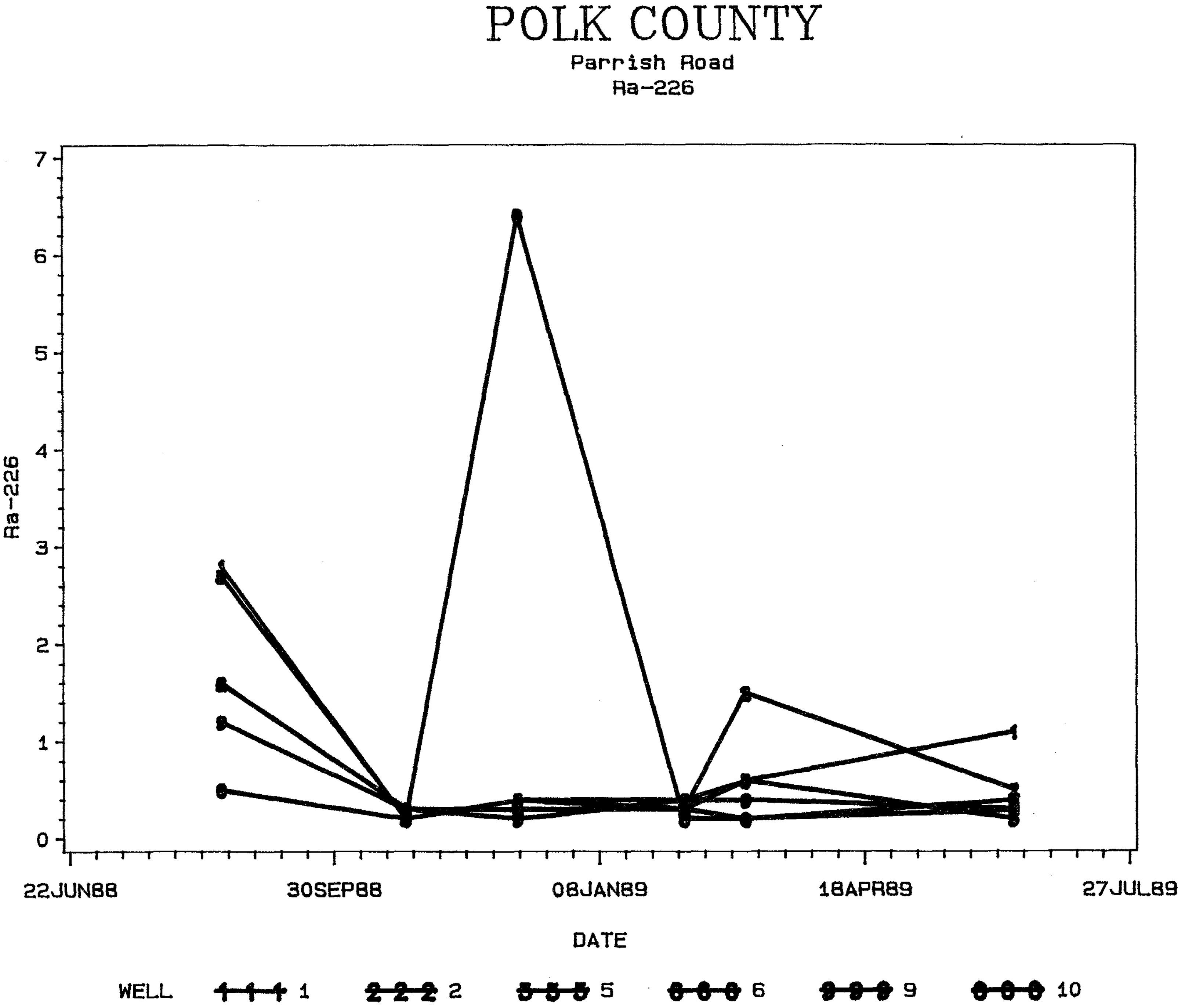


Figure 25. Ra226 Level (pCi/liter) in Ground Water, Inner Wells

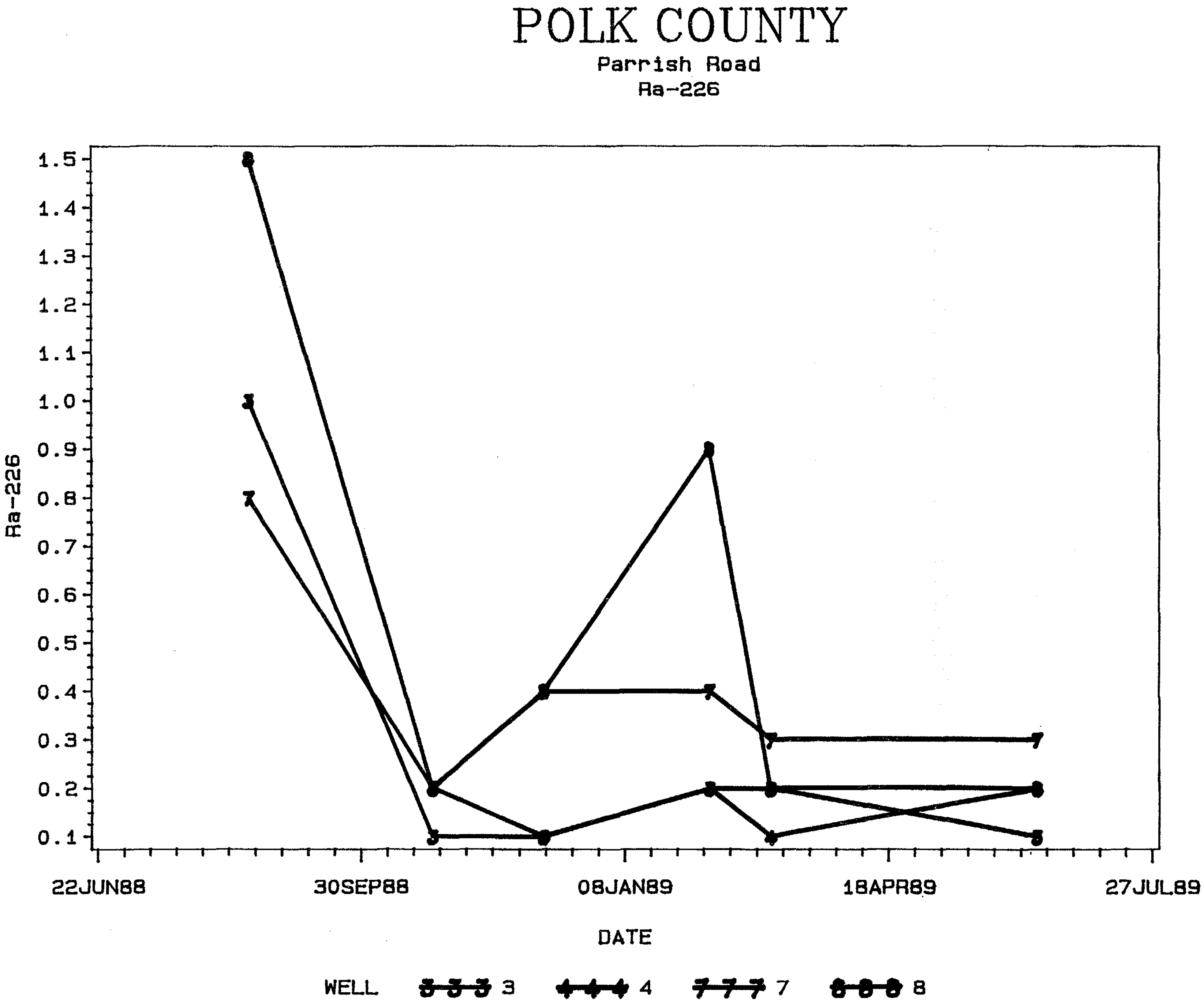


Figure 26. Ra226 Level (pCi/liter) in Ground Water, Outer Wells

It is interesting to note that the fluoride level from different wells appears to correlate with each other on any given sampling date, perhaps showing the rainfall or ground water level effect.

Radium-226

According to the Primary Drinking Water Standards radionuclide, the maximum level for combined Ra-226 and Ra-228 is 5 pCi/liter. In this case only Ra-226 was monitored since this is the element present in phosphogypsum. The Ra-226 level in the outer wells remained well below 5 pCi/liter, averaging around 0.4 pCi/liter. While essentially similar results were noted in the outer wells in all cases, samples collected in December 1988 from wells 6 and 9 exceeded the 5 pCi/liter standard. However, this is a solitary case and therefore cannot be regarded as evidence of the expected level of contamination of ground water from phosphogypsum.

White Springs Road Site

The calcium, sulfate, dissolved phosphorous, fluoride and radium-226 levels are presented in Figures 27 through 36. For the most part, the results from White Springs Road tests site were similar to those at the Parrish Road Site.

Calcium

No trend was noted for calcium in the ground water. There were isolated cases where the level of calcium peaked during a sampling period but then returned to low levels.

Sulfate

No trend were noted for sulfate in six of the eight wells from which samples are obtained. Sulfate level in well No. 1, an inner well and well No. 4, an outer well started to rise uniformly beginning in June 1989, nearly 2 years after the road construction. Contamination from phosphogypsum is strongly suspected in these cases. However, it should be noted that the highest values measured were about 175 mg/liter and 240 mg/liter for wells 1 & 4, respectively which were below the 250 mg/liter, the recommended maximum level per the Secondary Drinking Water Standards. Dissolve Phosphorous

Dissolved phosphorous levels were slightly elevated during the post construction period. But in all cases, the levels were below 0.5 mg/liter.

Fluoride

No trend was observed in the fluoride level in samples from any of the monitoring wells. However, on several instances including the preconstruction period, samples from well 3 exceeded 2 mg/liter, the maximum standard for secondary drinking water.

COLUMBIA COUNTY

White Springs Road
Calcium

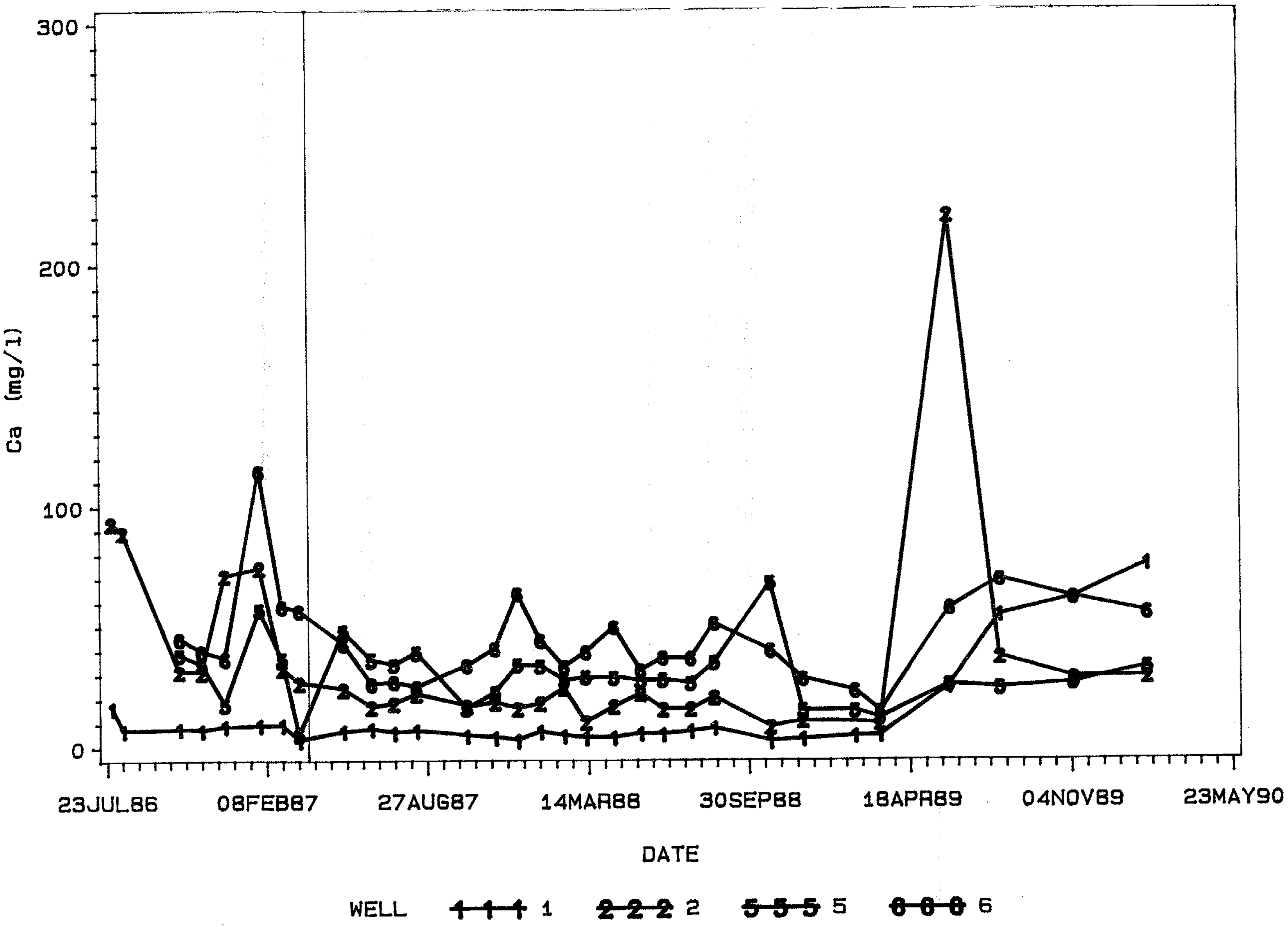


Figure 27. Calcium in Ground Water, Inner Wells

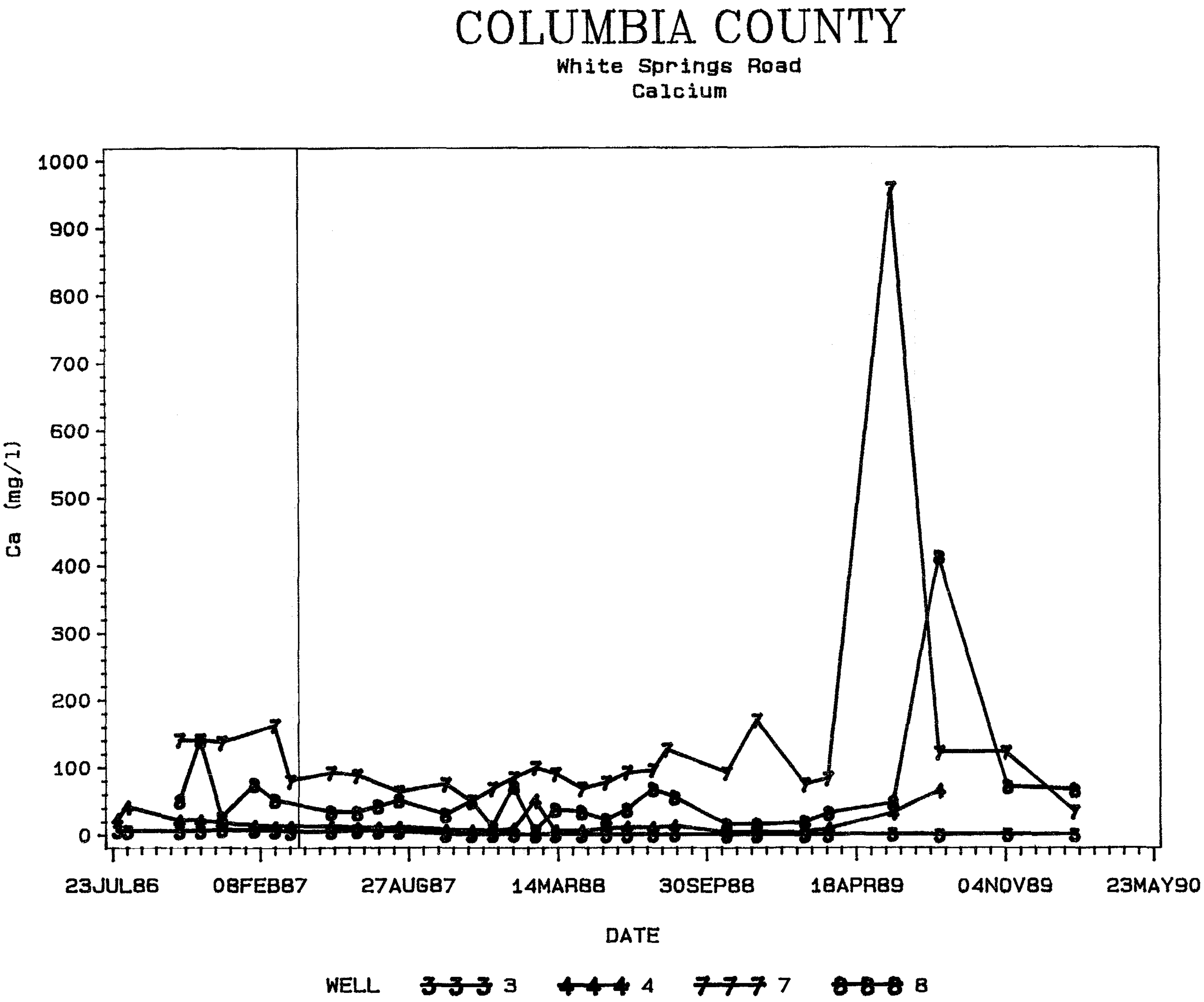


Figure 28. Calcium in Ground Water, Outer Wells

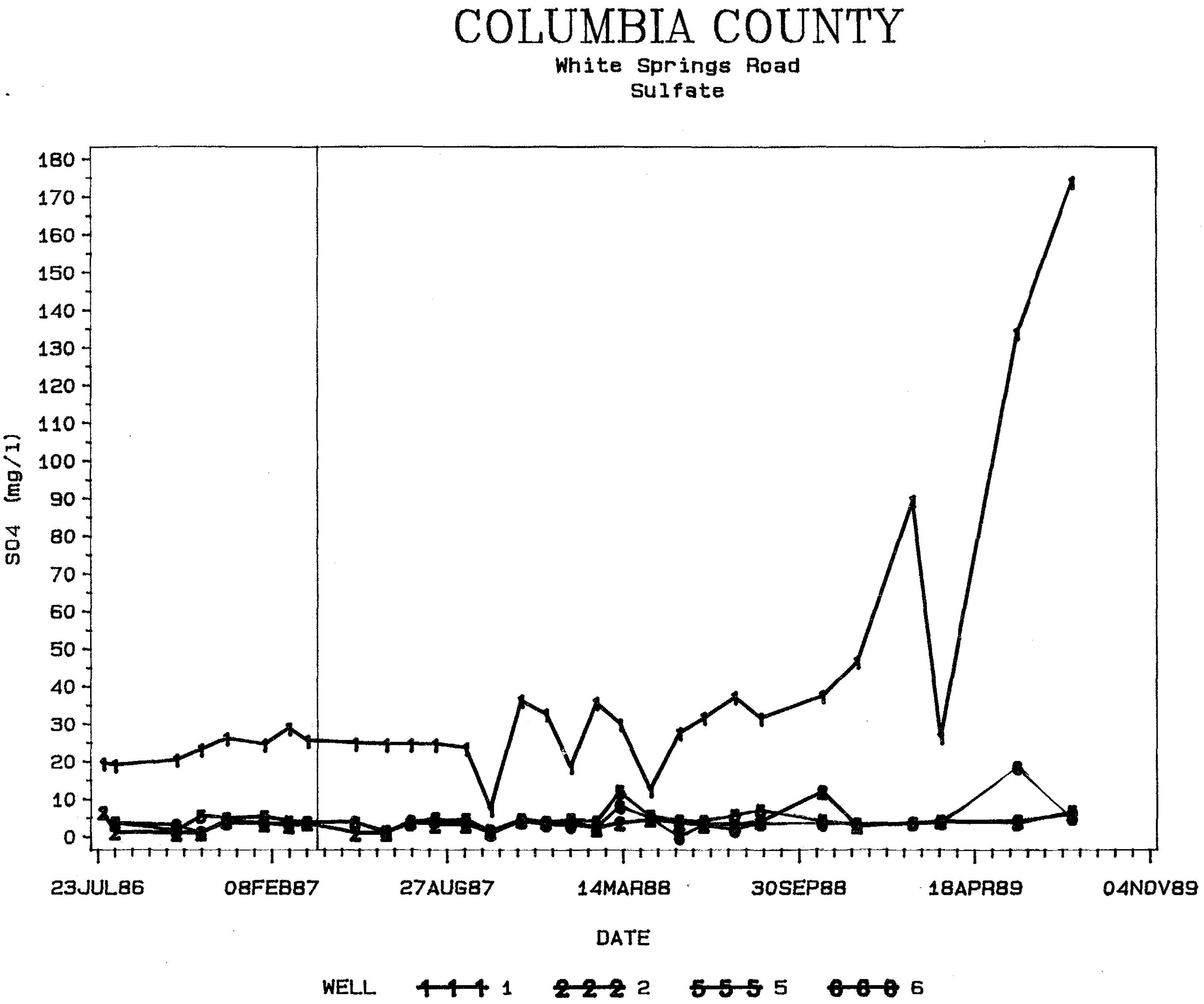


Figure 29. Sulfate, Inner Wells

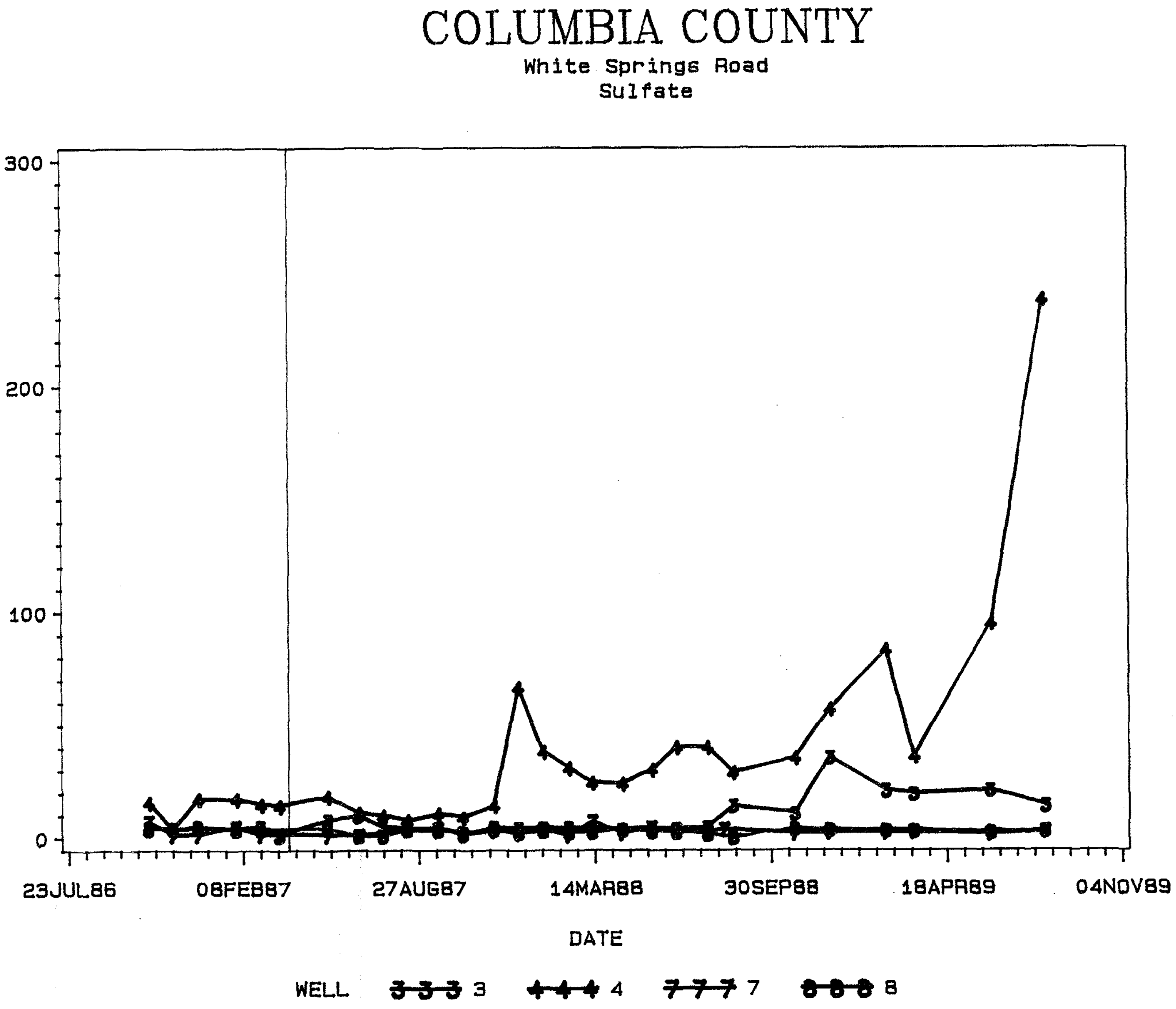
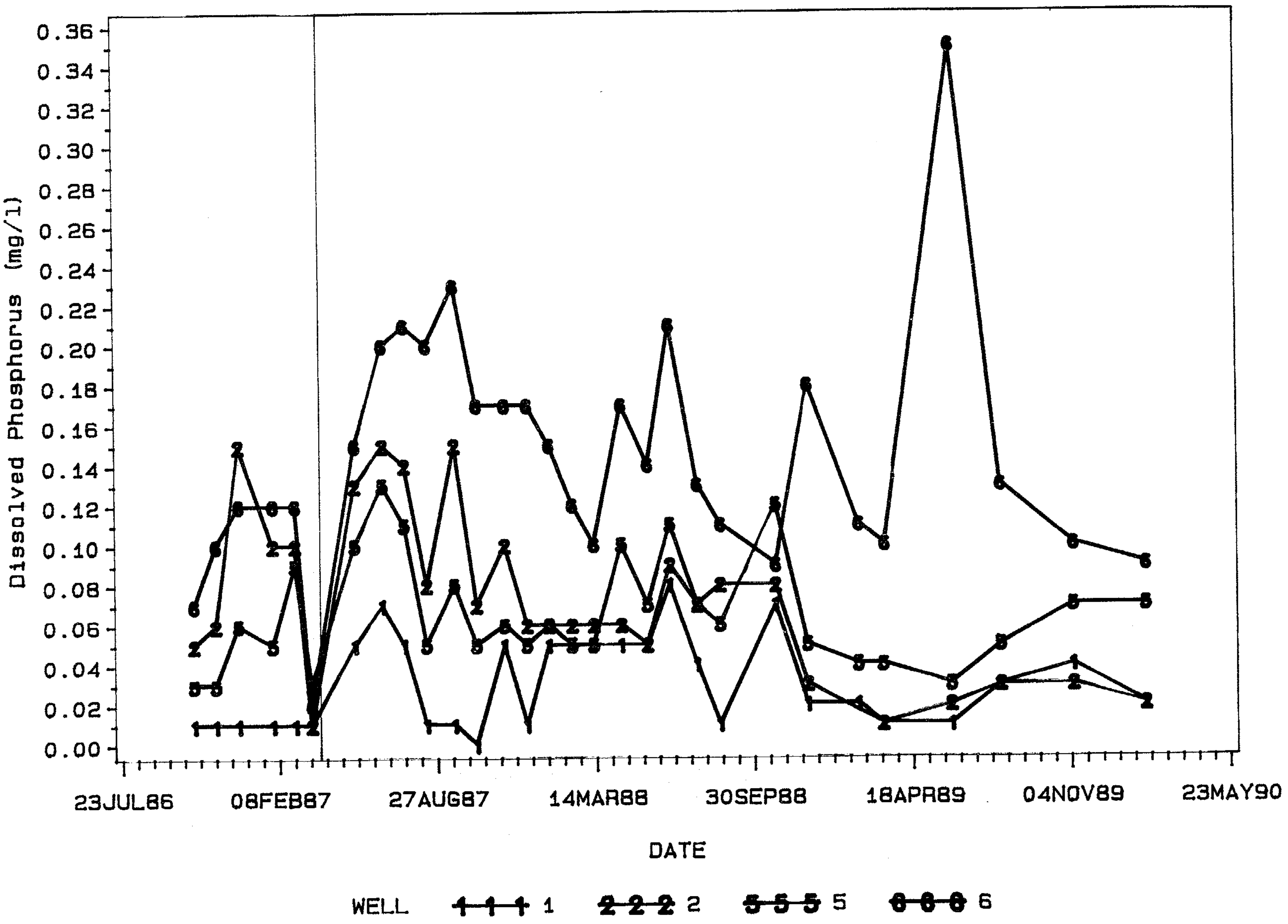


Figure 30. Sulfate, Outer Wells



COLUMBIA COUNTY
White Springs Road
Dissolved Phosphorus

Figure 31. Dissolved Phosphorus in Inner Wells

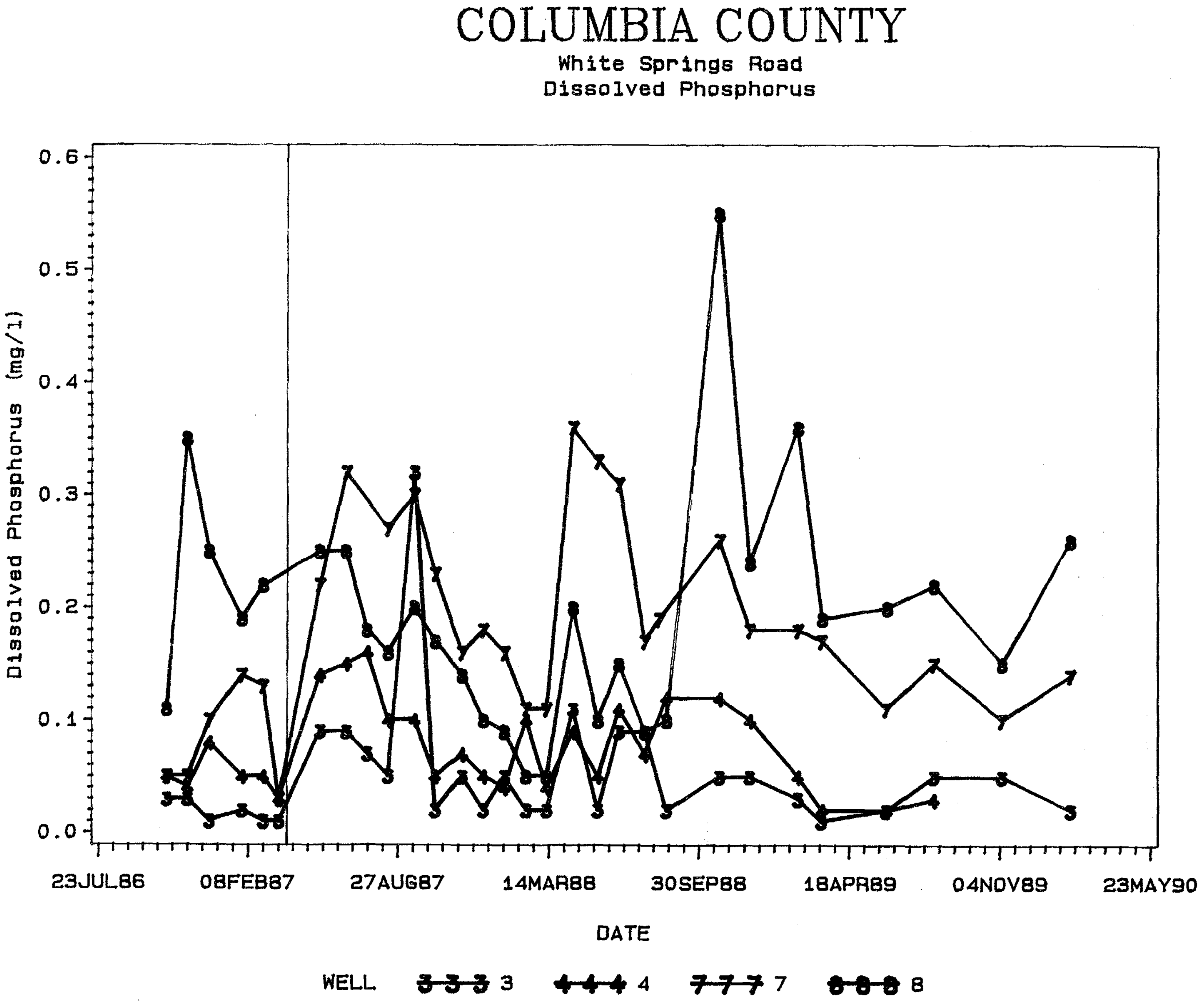


Figure 32. Dissolved Phosphorus in Outer Wells

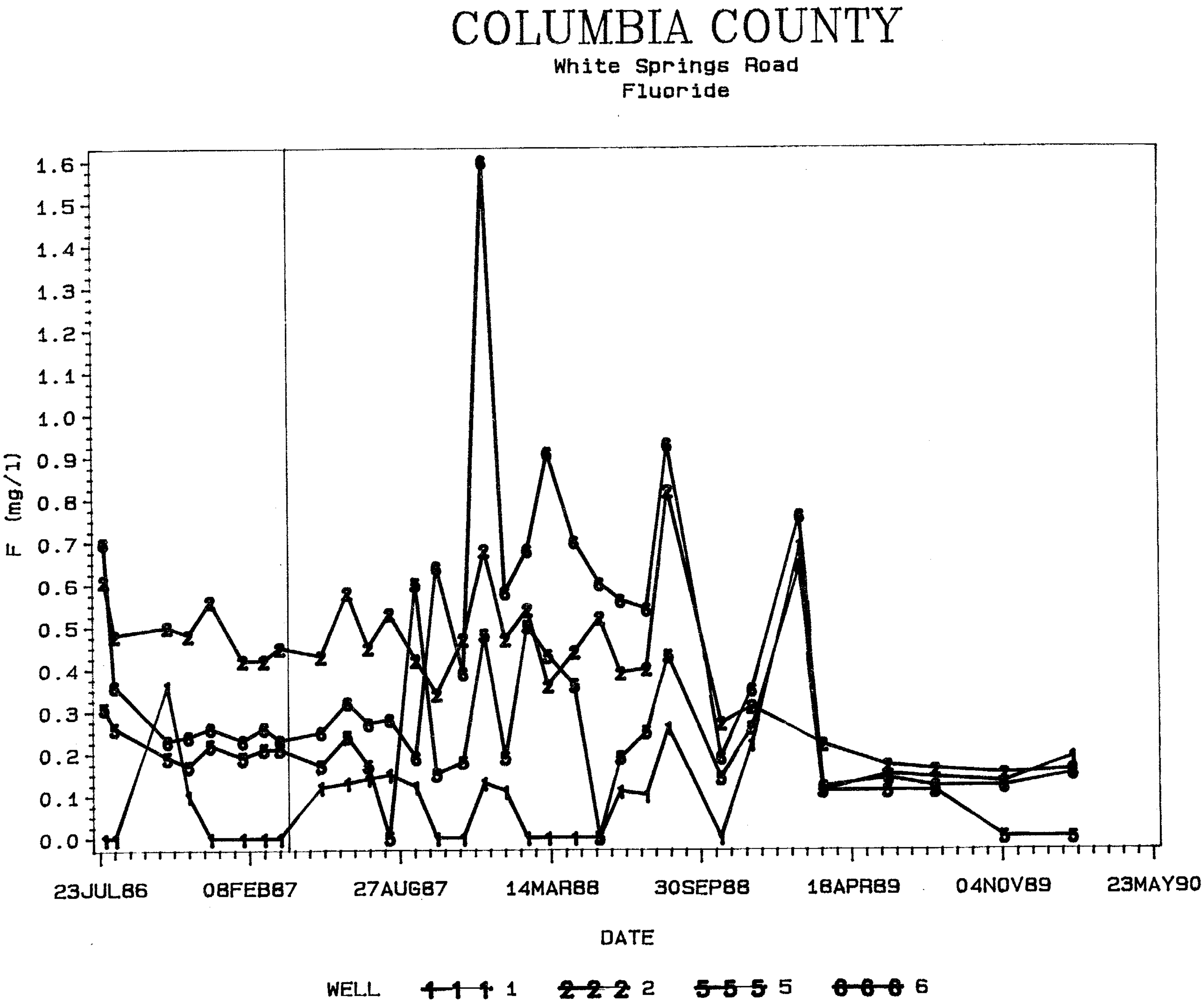


Figure 33. Fluoride in Inner Wells

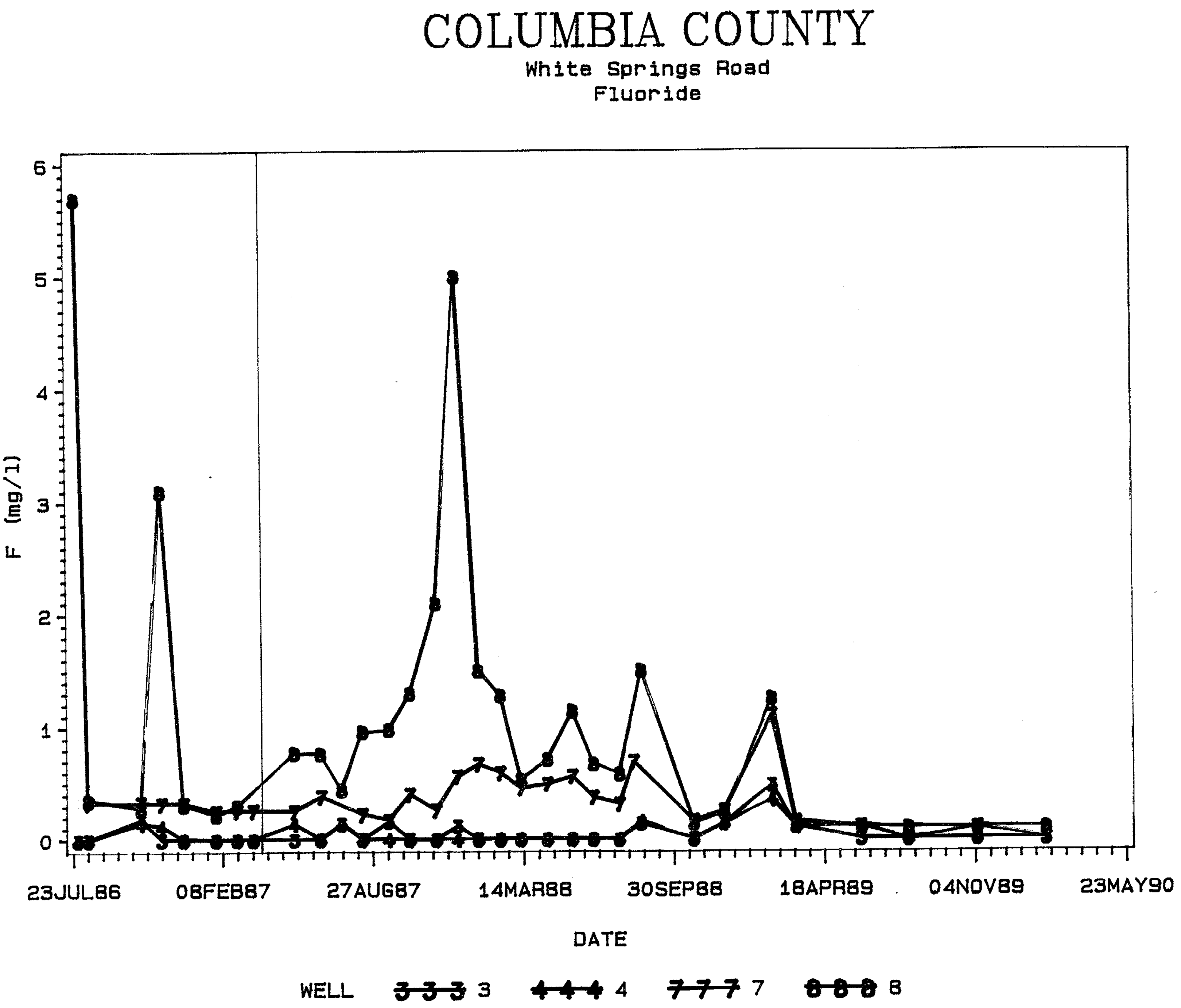


Figure 34. Fluoride in Outer Wells

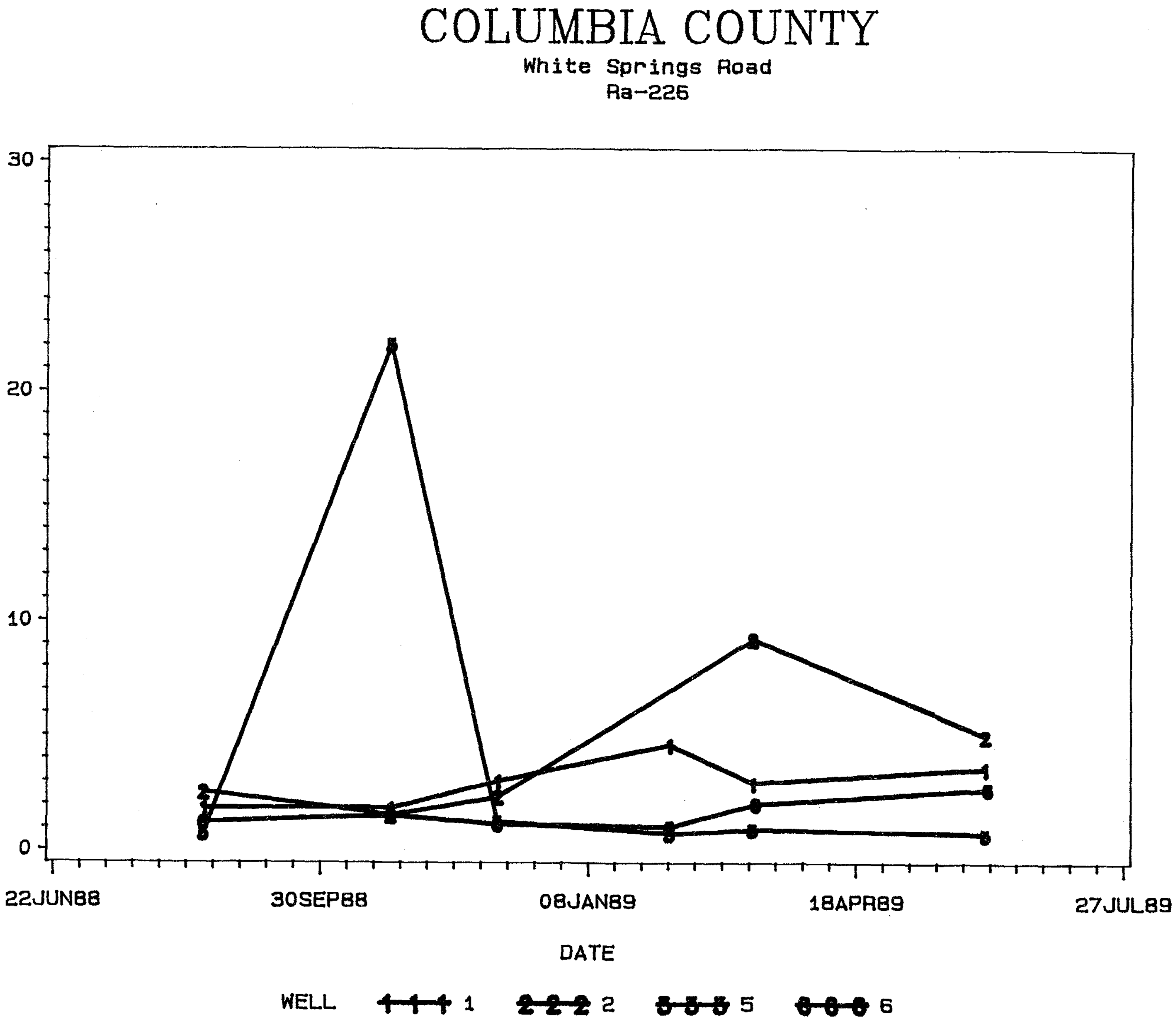


Figure 35. Ra226 (pCi/liter) in Inner Wells

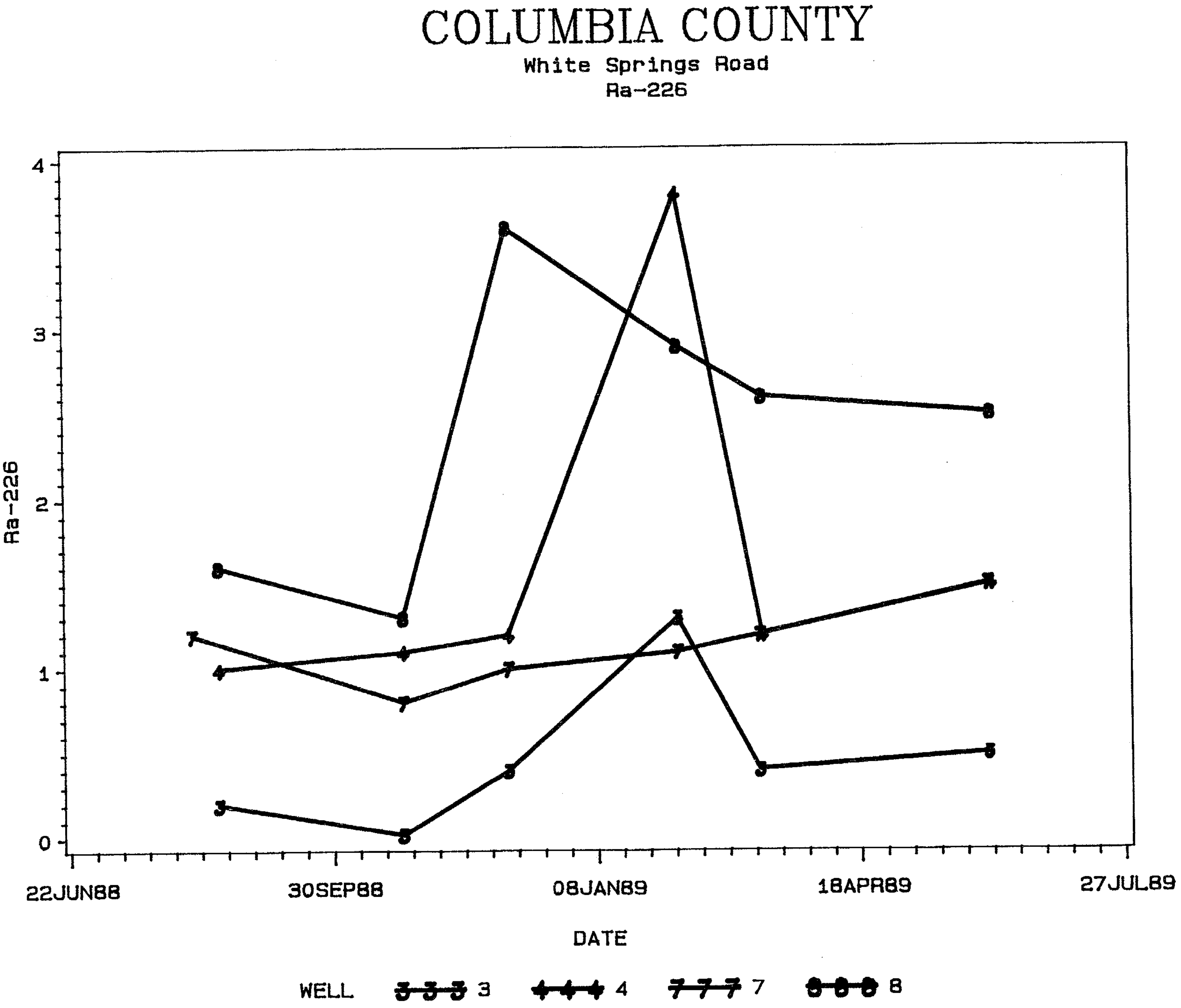


Figure 36. Ra226 (pCi/liter) in Outer Wells

Radium-226

Samples from outer wells consistently contained less than 4 pCi/liter of Ra-226. However, sample from inner wells exceeded the 5 pCi/liter standard on two occasions.

OTHER INORGANIC CONTAMINANTS

Several other chemical constituents were monitored throughout the study of ground water at both test road sites. Of interest are the levels of those contaminants which are covered either under Primary or Secondary Drinking Water Standards for public or community water systems. The results are presented below.

Contaminants for Primary Drinking Water Standards

Most inorganic contaminants of interest to Primary Drinking Water Standards were monitored. In cases of the trace elements - arsenic, barium, selenium and silver - measurements were made only on limited occasions and only from the wells in White Springs Road test site. No measurements were made for mercury level. The Primary Drinking Water Standards for inorganic contaminants are shown in Table VI.

Table VI. Primary Drinking Water Standards for Inorganic Contaminants

Contaminant	Maximum Levels mg/liter
Arsenic	0.05
Barium	1
Cadmium	0.010
Chromium	0.05
Fluoride	4.0
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Sodium	160

Parrish Road

Only cadmium, chromium, fluoride, lead, nitrate and sodium were monitored at the Parrish Road site. The cadmium levels exceeded the 0.01 mg/liter maximum standard in numerous cases (see Figures 37 and 38). However, there were no trends or differences between pre and post construction periods.

Chromium level also exceeded its maximum standard of 0.05 mg/liter in several occasions both during pre and post construction periods. Again, no trend was noted as shown in Figures 39 and 40.

Fluoride level data are covered in an earlier section. Fluoride did not exceed the 4 mg/liter standard except on one occasion.

Lead level showed no trend, as well, but exceeded the 0.05 mg/liter standard for primary drinking water on many instances. Lead levels are shown in Figures 41 and 42.

Nitrate and sodium levels remained well below their respective standards and had no trend as shown in Figures 43 through 46. Note that the 10 mg/liter standard for nitrate is expressed as N. If expressed as NO3, shown in Figures 43 and 44, the standard would be 44 mg/liter.

White Springs Road

The results for cadmium, chromium, lead, nitrate and sodium are presented in Figures 47 through 56. As in the case of Parrish Road, no trends were noted for any of the components measured although in many instances individual figures exceed the respective primary standards for the first three contaminants. Nitrate and sodium levels were well below the respective standards for drinking water.

The results of the other trace elements analyzed from well samples are shown in Table VII. On no occasion, the measured levels exceeded the respective standards.

Table VII. Trace Elements in Well Samples
(mgms/liter)

Date	Well No.	As	Ba	Se	Ag
8/17/88	1	0.01	0.08	0.01	0.01
10/26/88	2	0.01	0.01	0.01	0.01
12/5/89	3	0.01	0.06	0.01	0.01
6/6/89	4	0.01	-	0.01	0.01
4/10/89	5	-	0.01	0.01	0.01
2/7/89	6	0.01	0.03	0.01	0.01

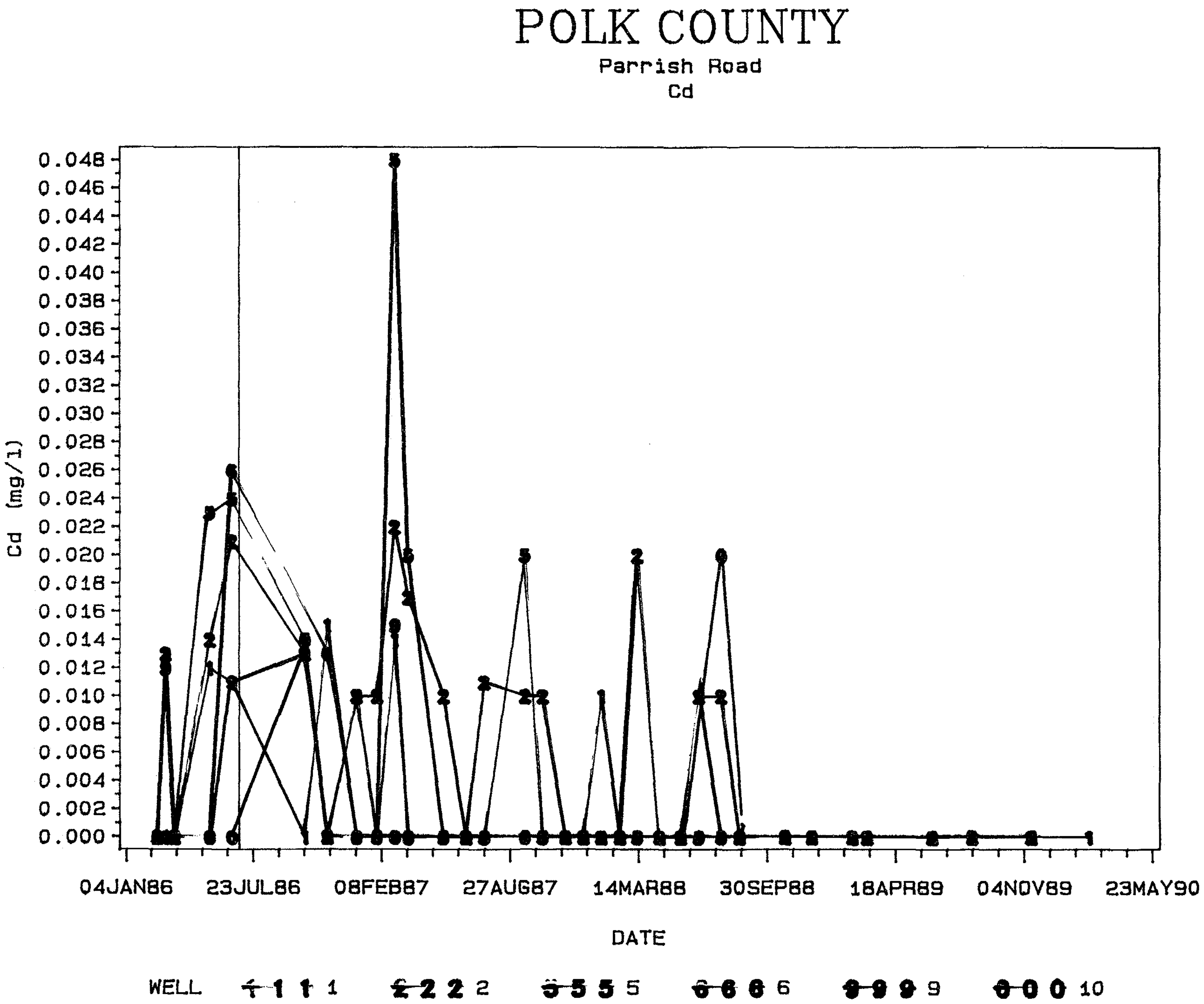


Figure 37. Cadmium Level in Inner Wells

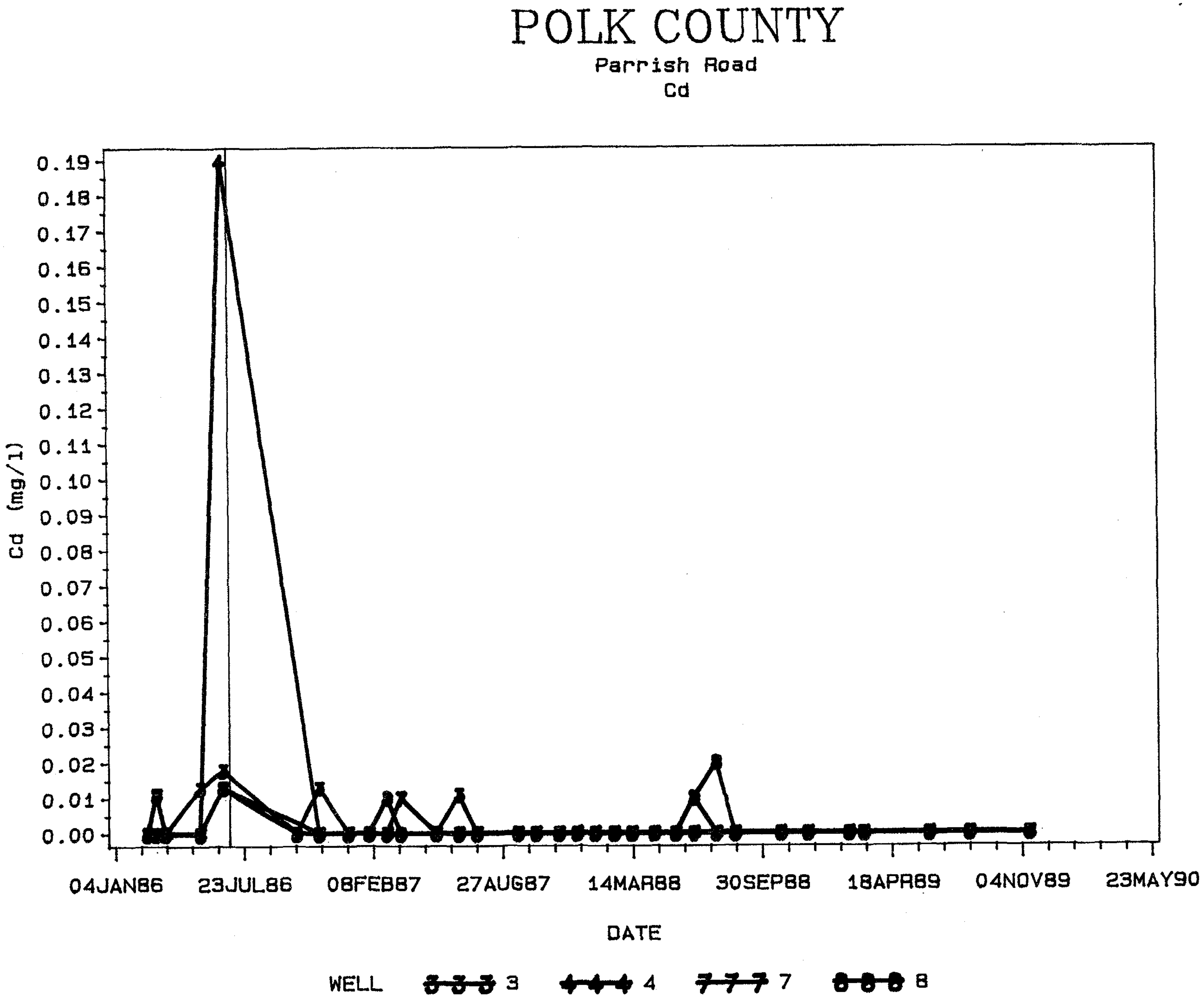


Figure 38. Cadmium Level in Outer Wells

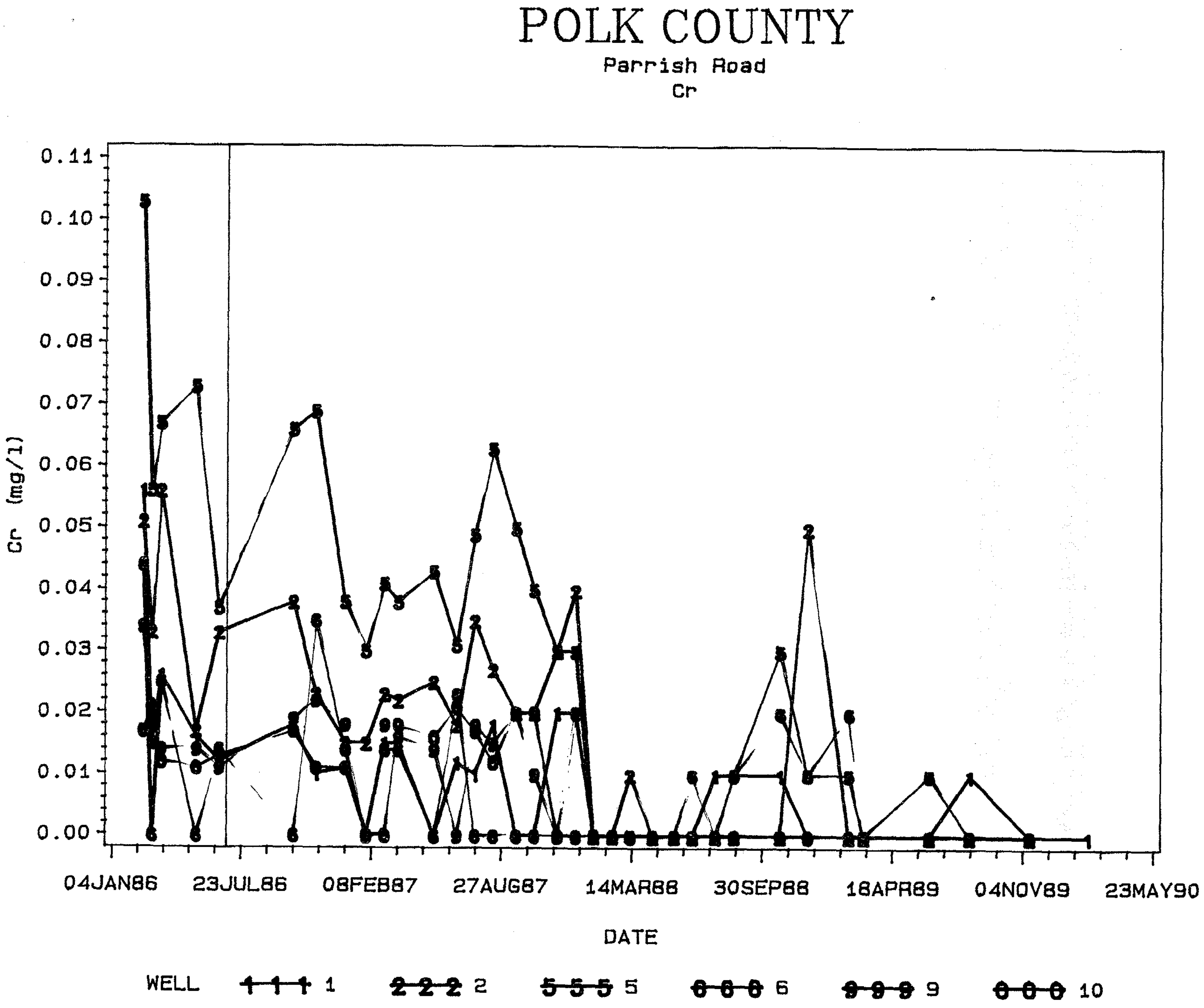


Figure 39. Chromium in Inner Wells

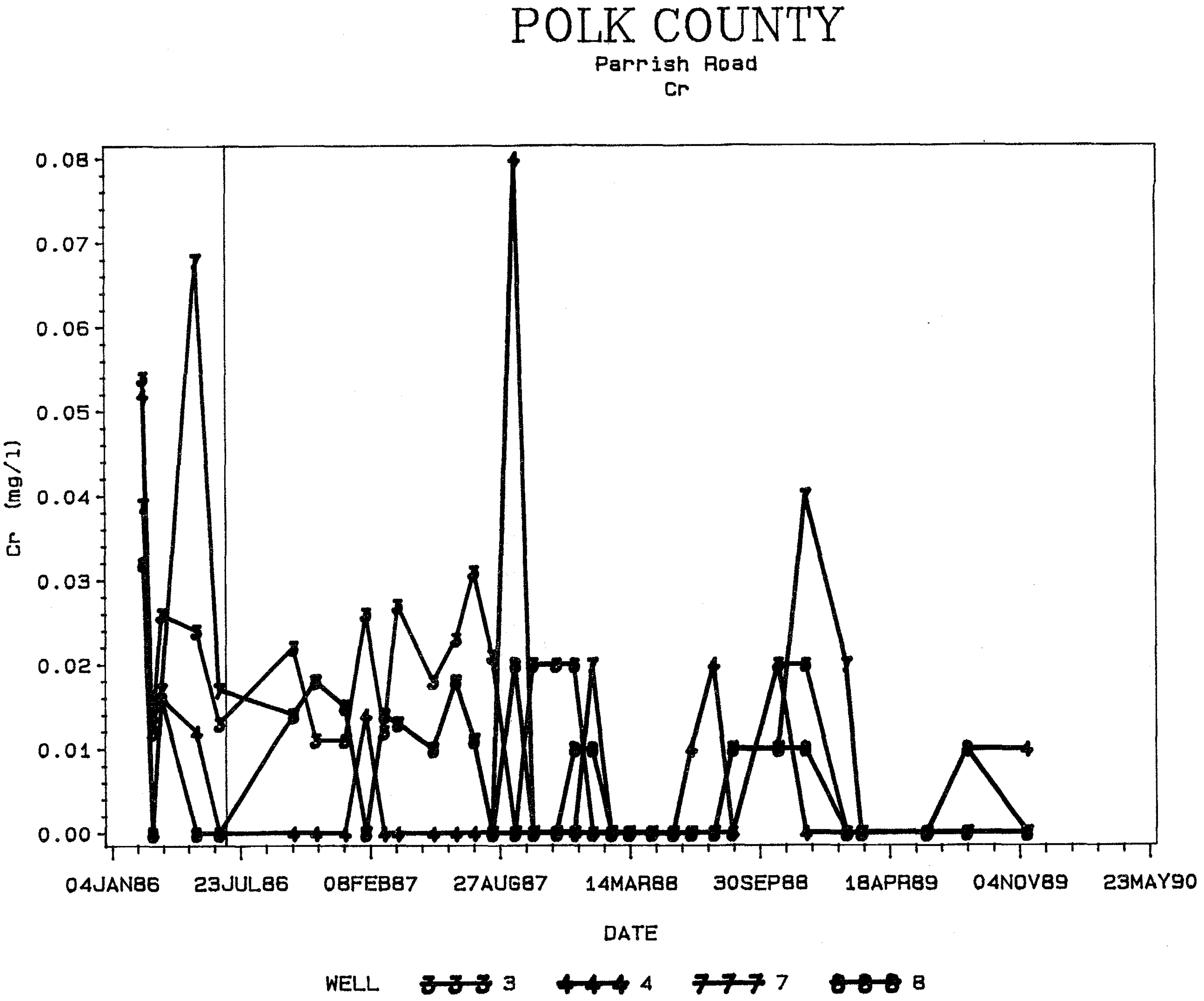


Figure 40. Chromium in Outer Wells

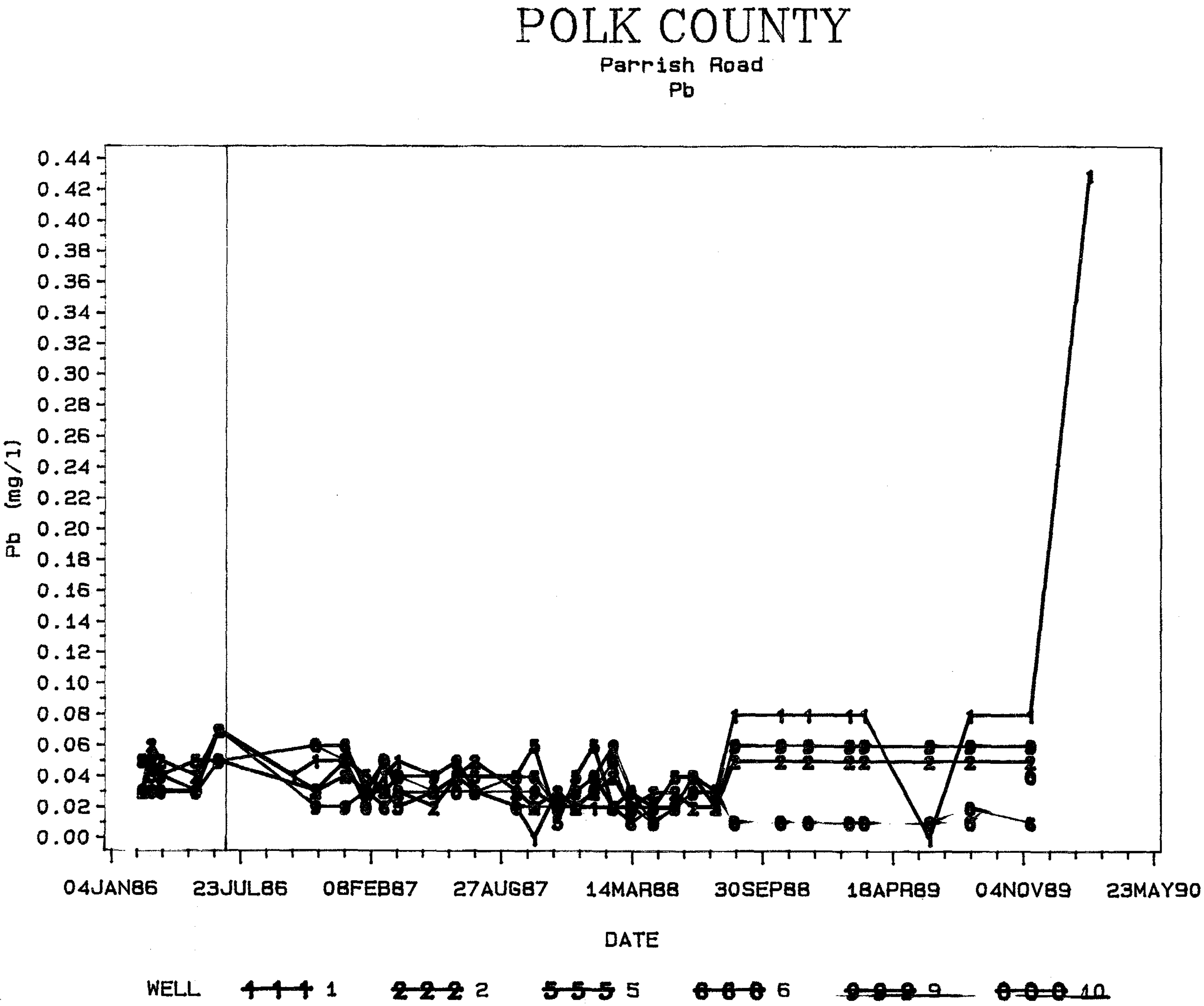


Figure 41. Lead Level in Inner Wells

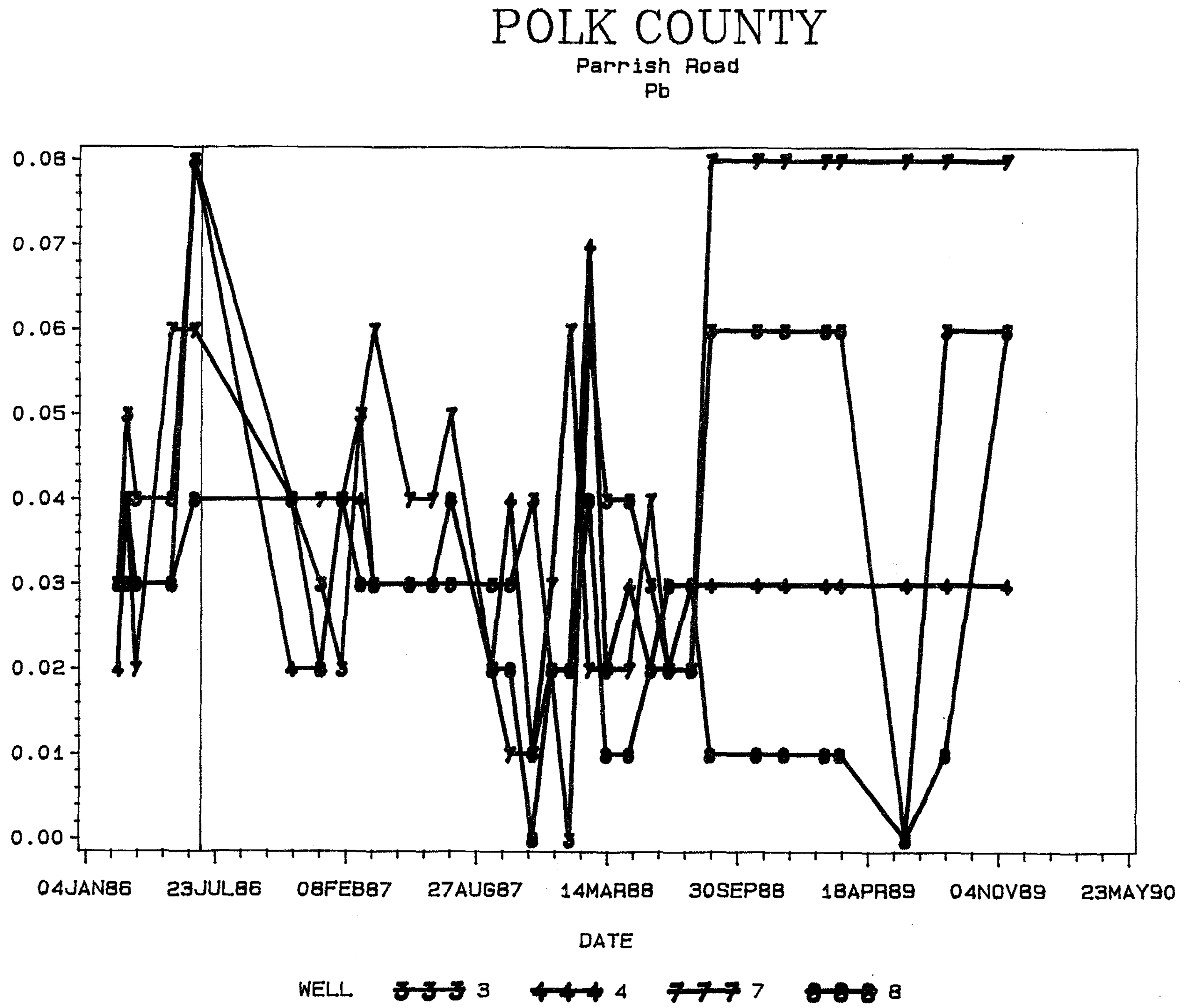


Figure 42. Lead Level in Outer Wells

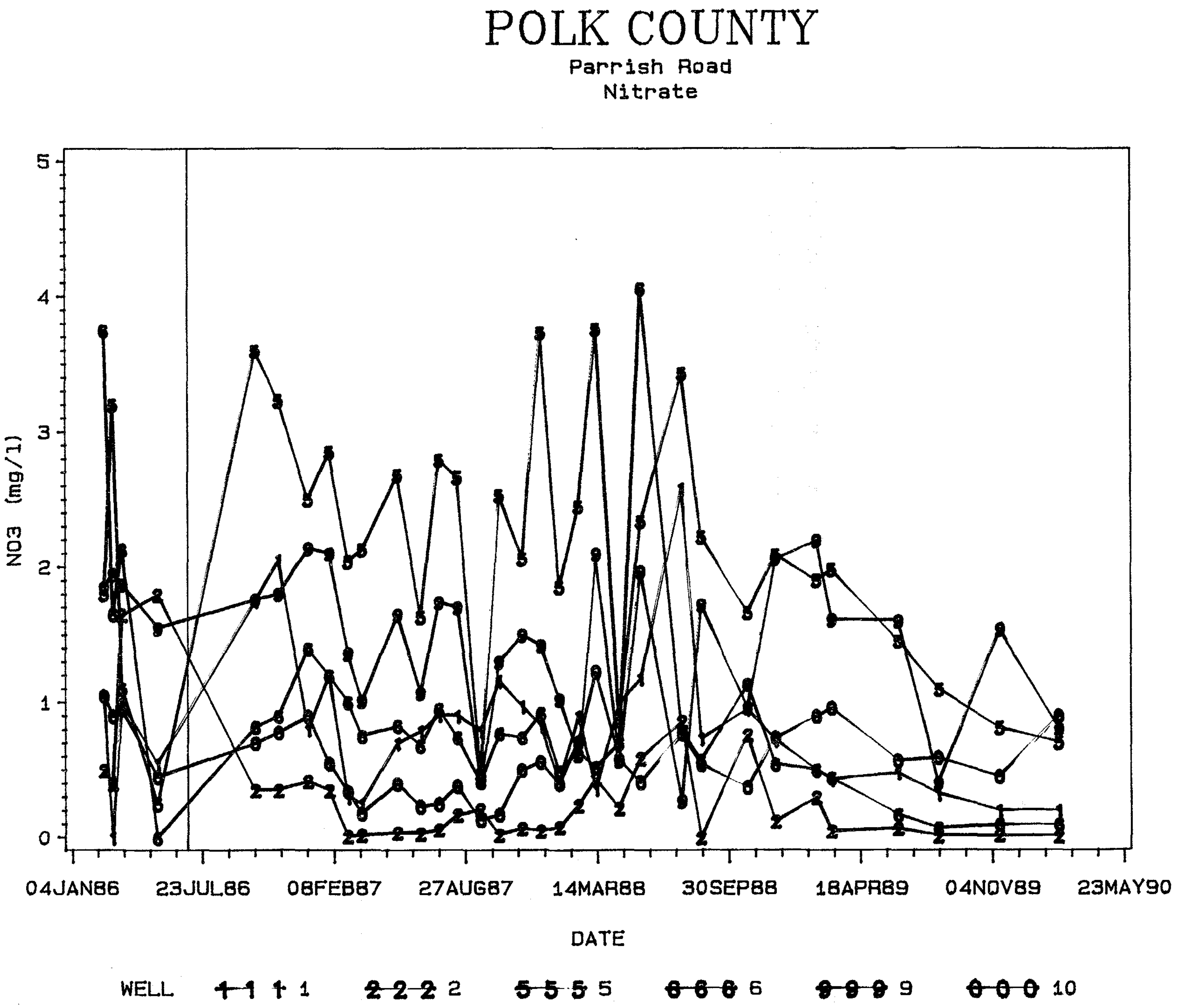


Figure 43. Nitrate Level in Inner Wells

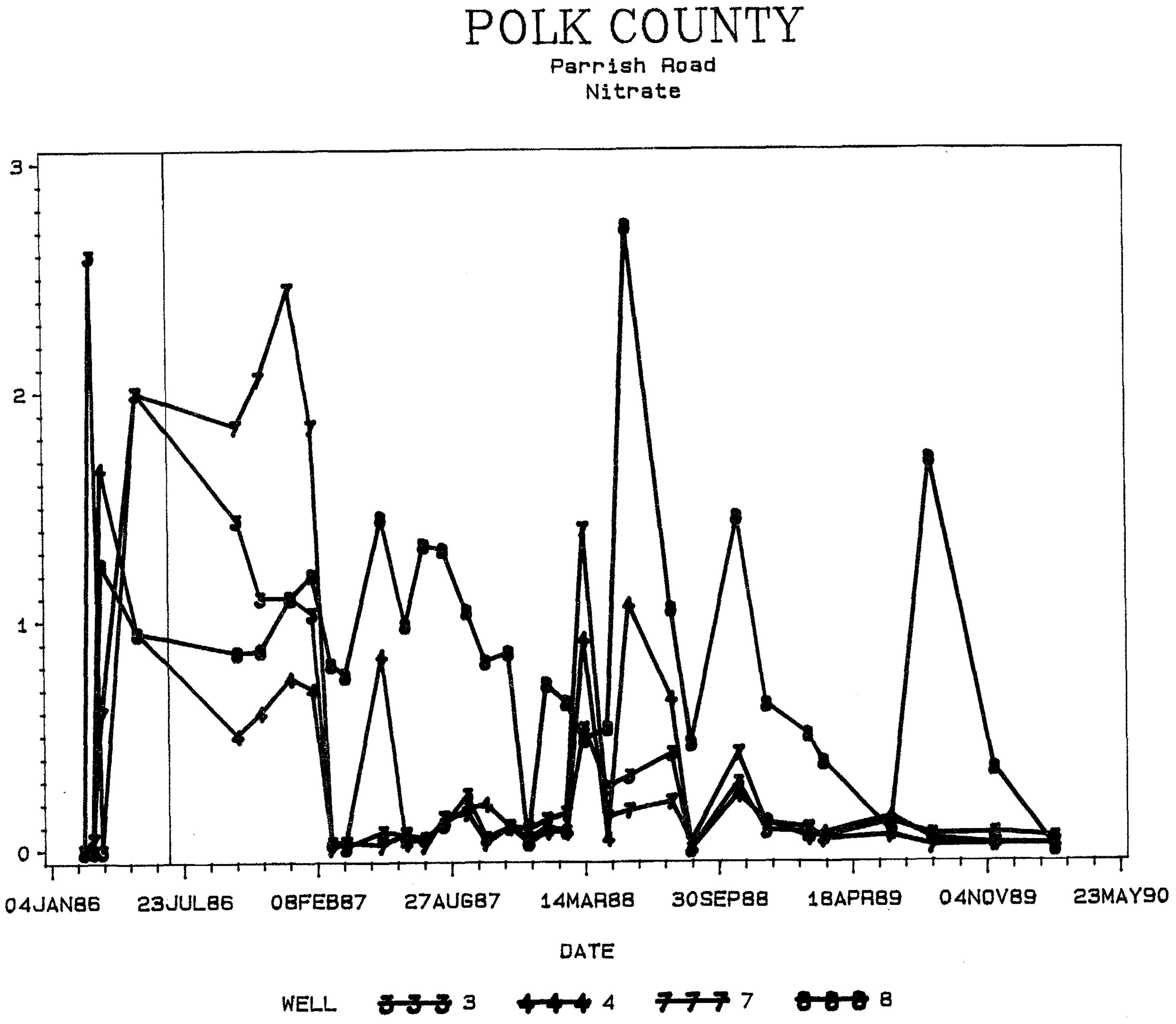


Figure 44. Nitrate Level in Outer Wells

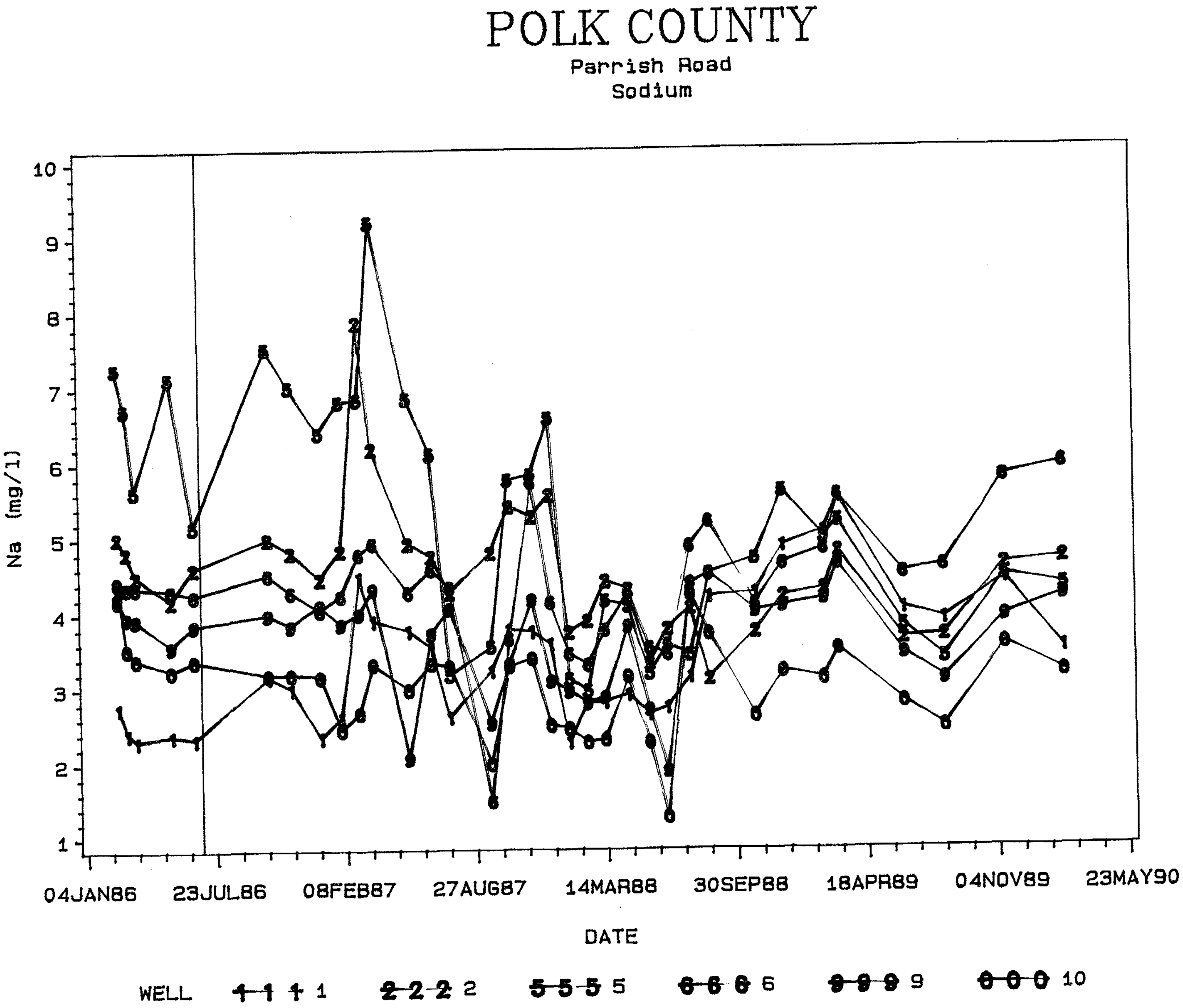


Figure 45. Sodium Level in Inner Wells

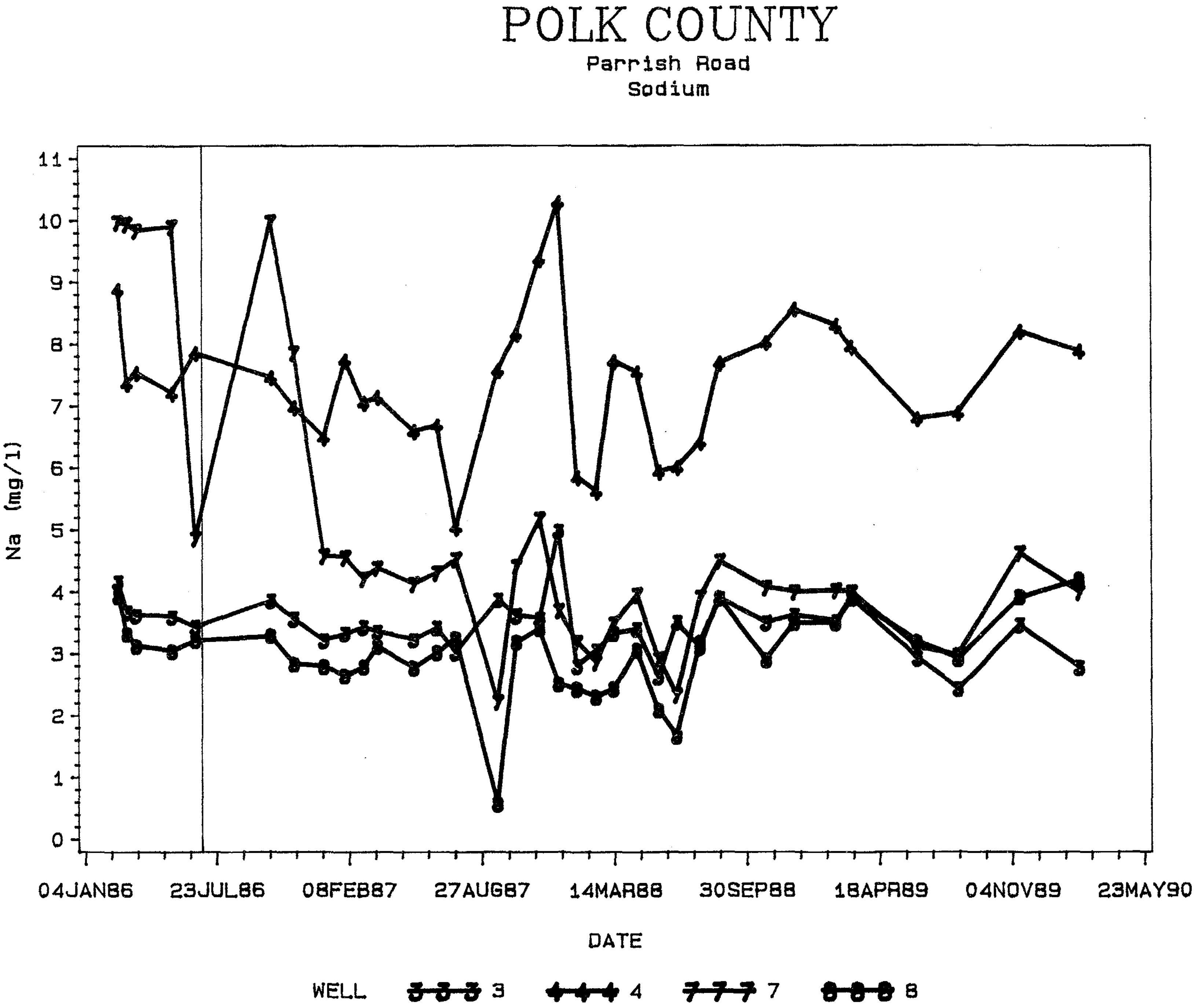


Figure 46. Sodium Level in Outer Wells

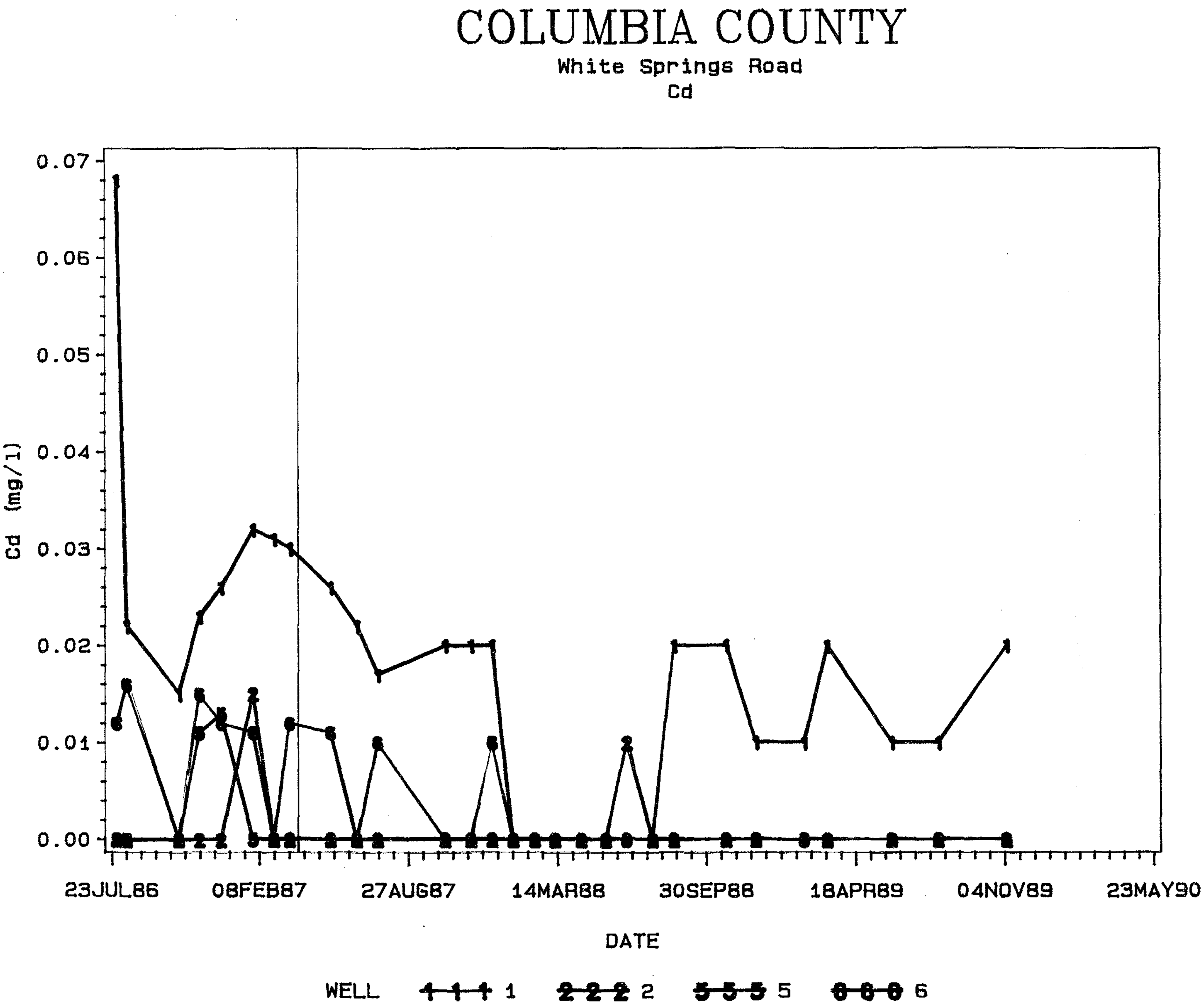


Figure 47. Cadmium Level in Inner Wells

COLUMBIA COUNTY

White Springs Road
Cd

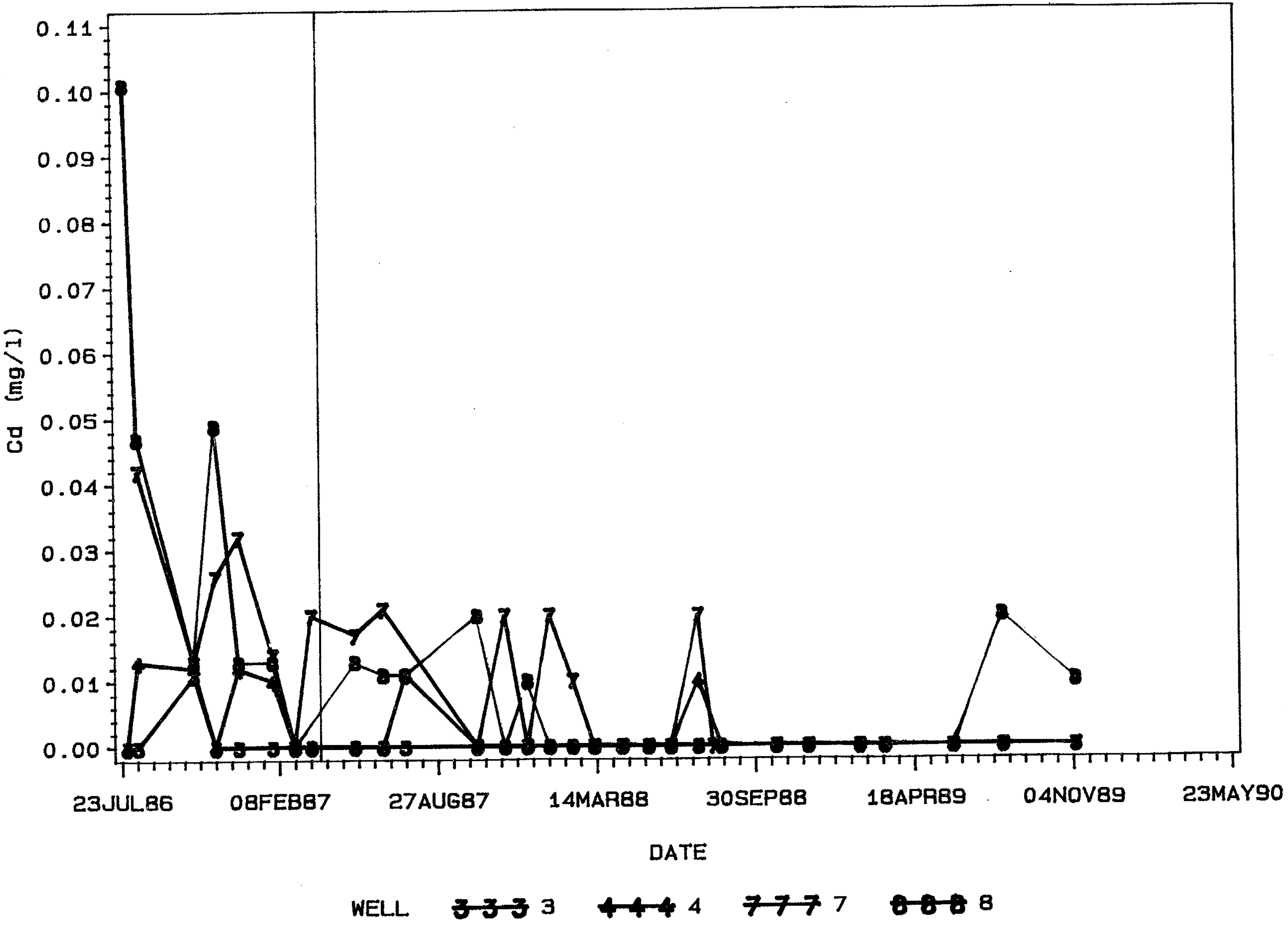


Figure 48. Cadmium Level in Outer Wells

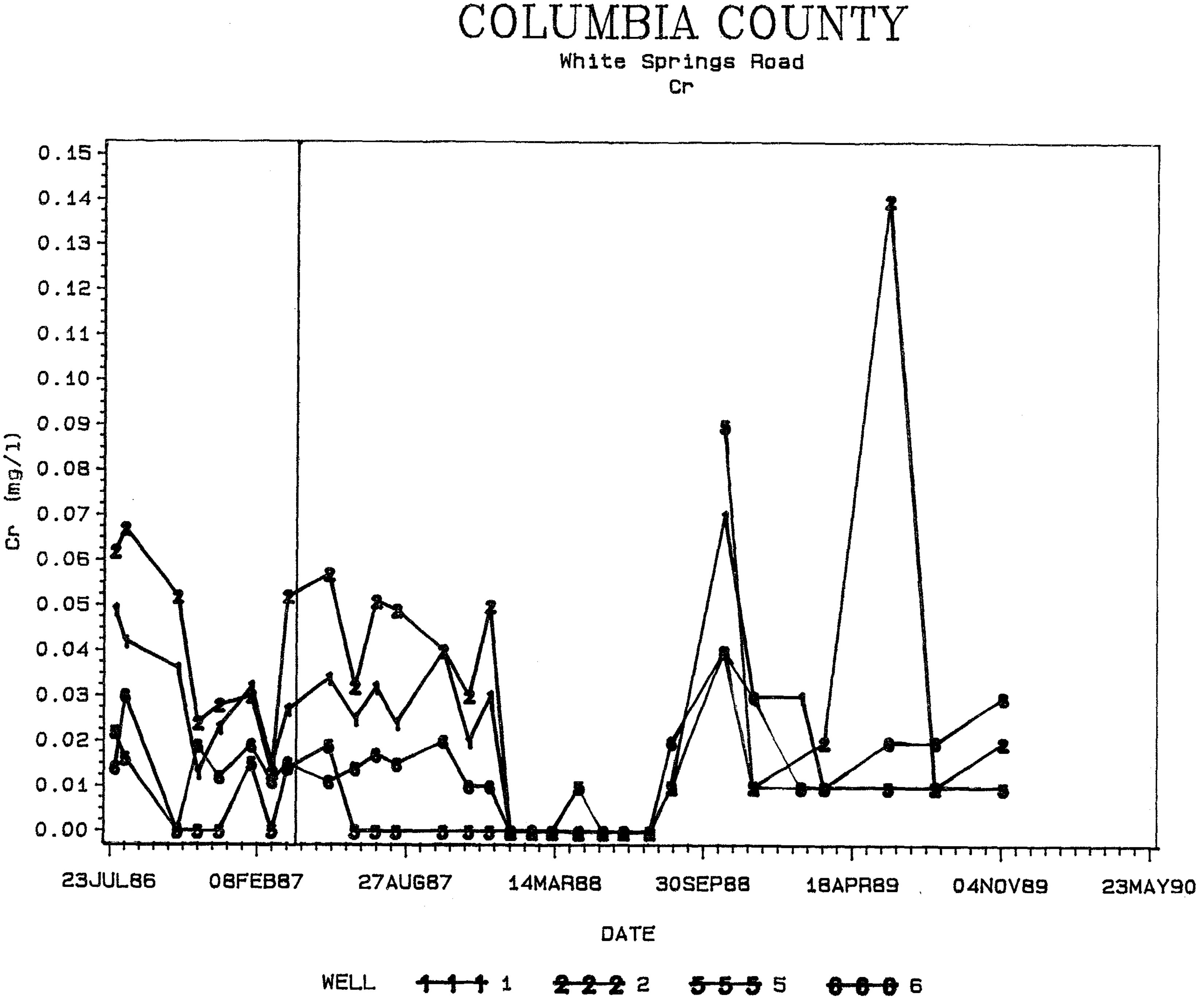


Figure 49. Chromium Level in Inner Wells

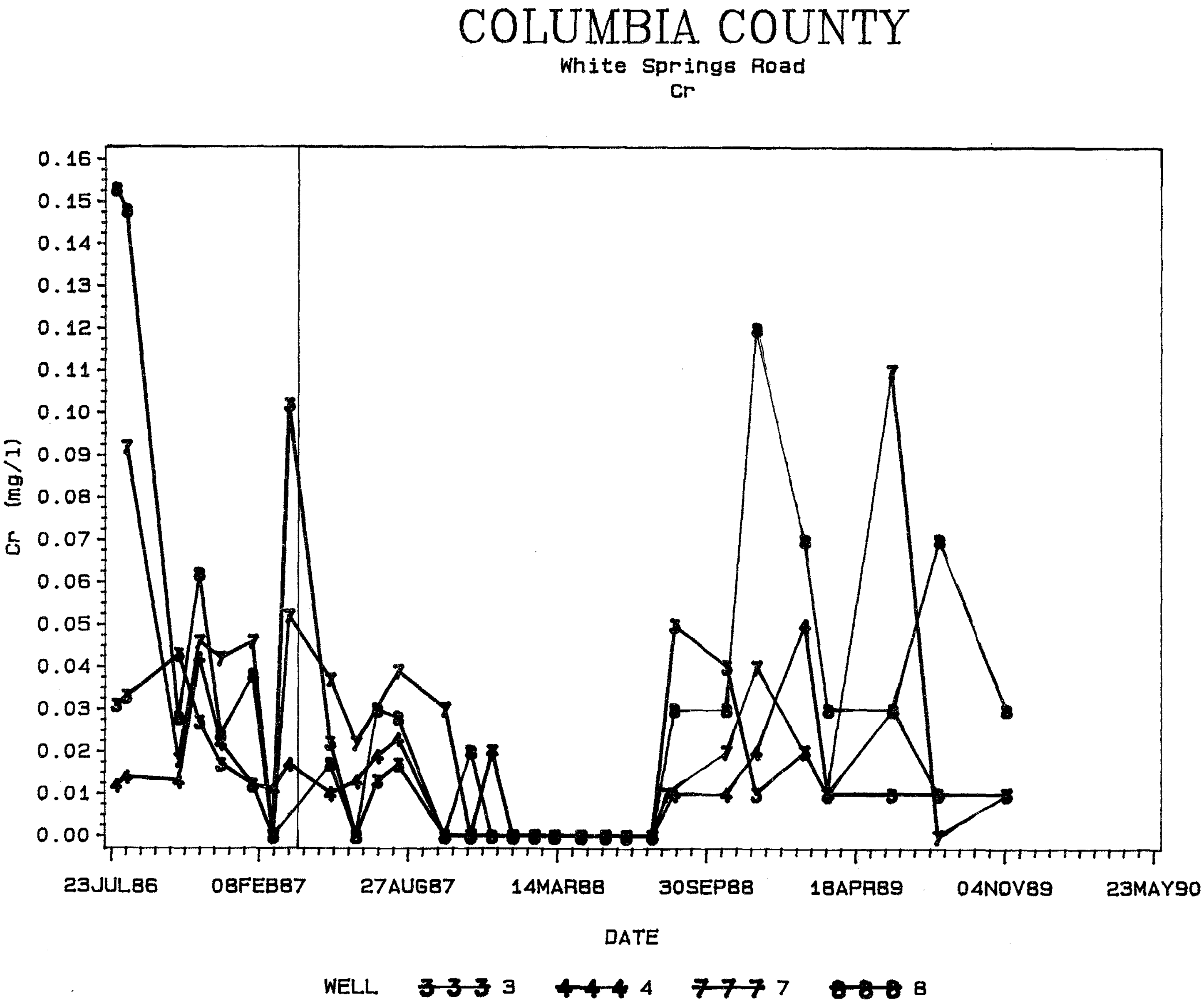


Figure 50. Chromium Level in Outer Wells

COLUMBIA COUNTY

White Springs Road

Pb

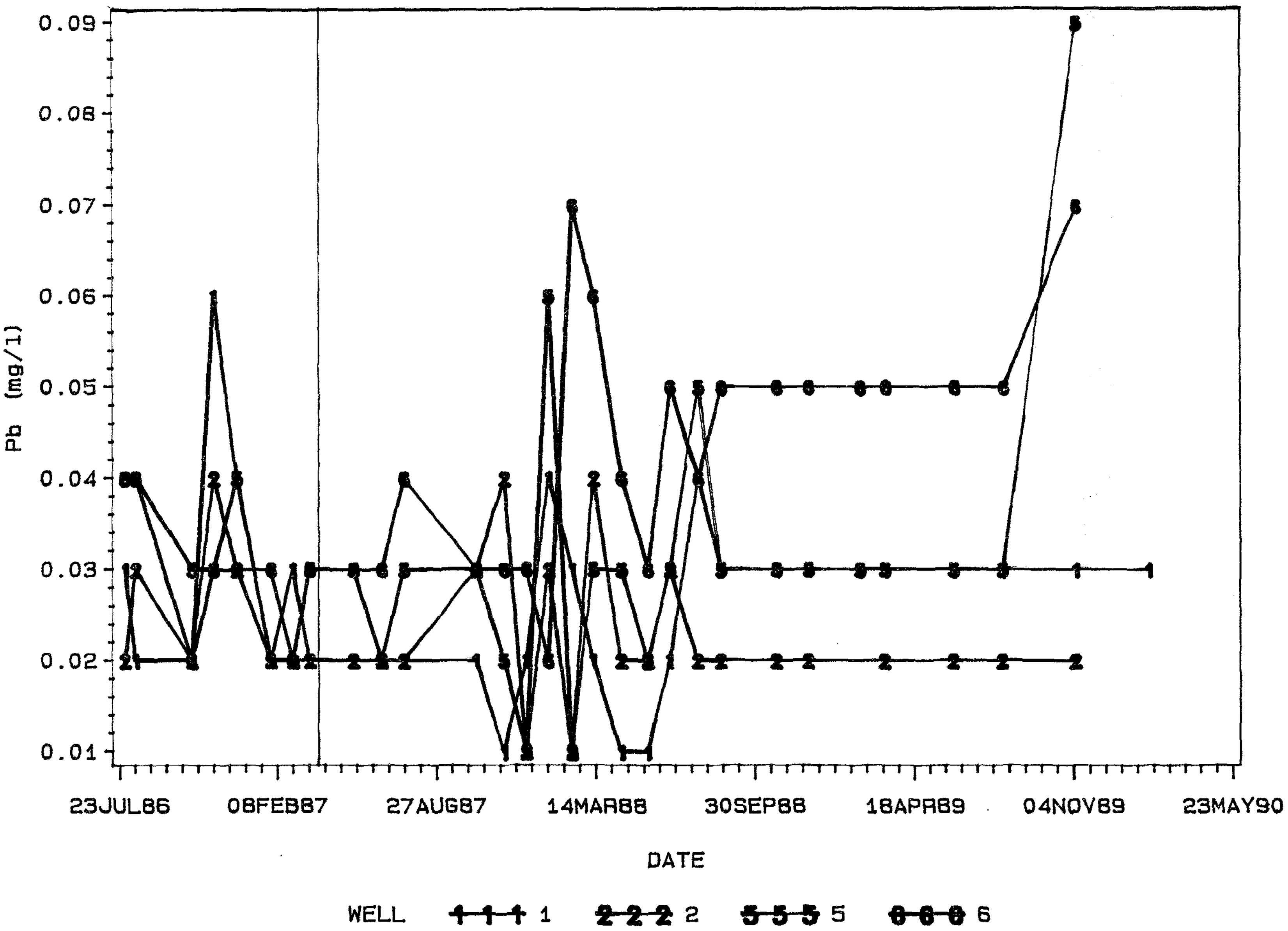


Figure 51. Lead Level in Inner Wells

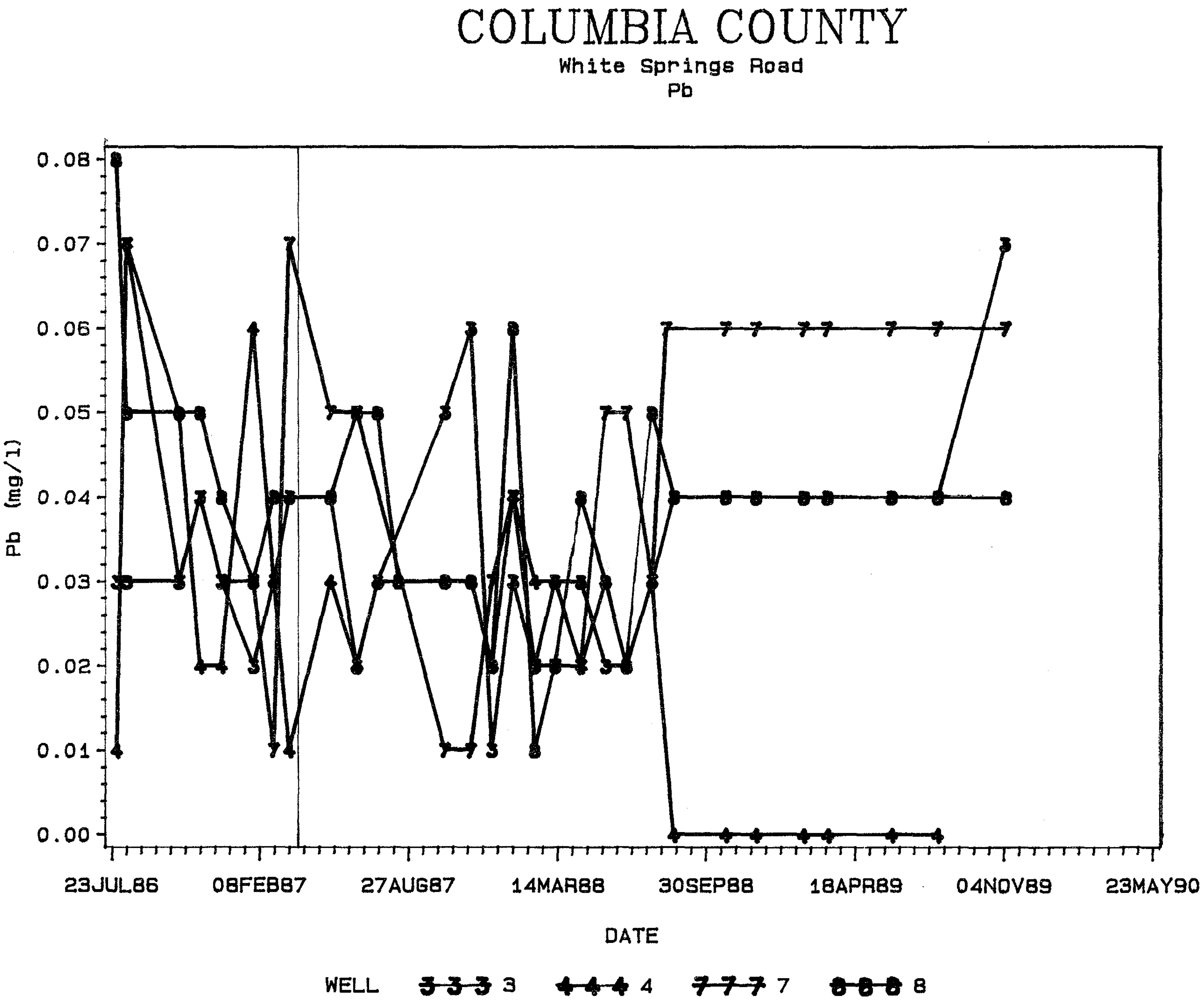

COLUMBIA COUNTY
White Springs Road
Pb

Figure 52. Lead Level in Outer Wells

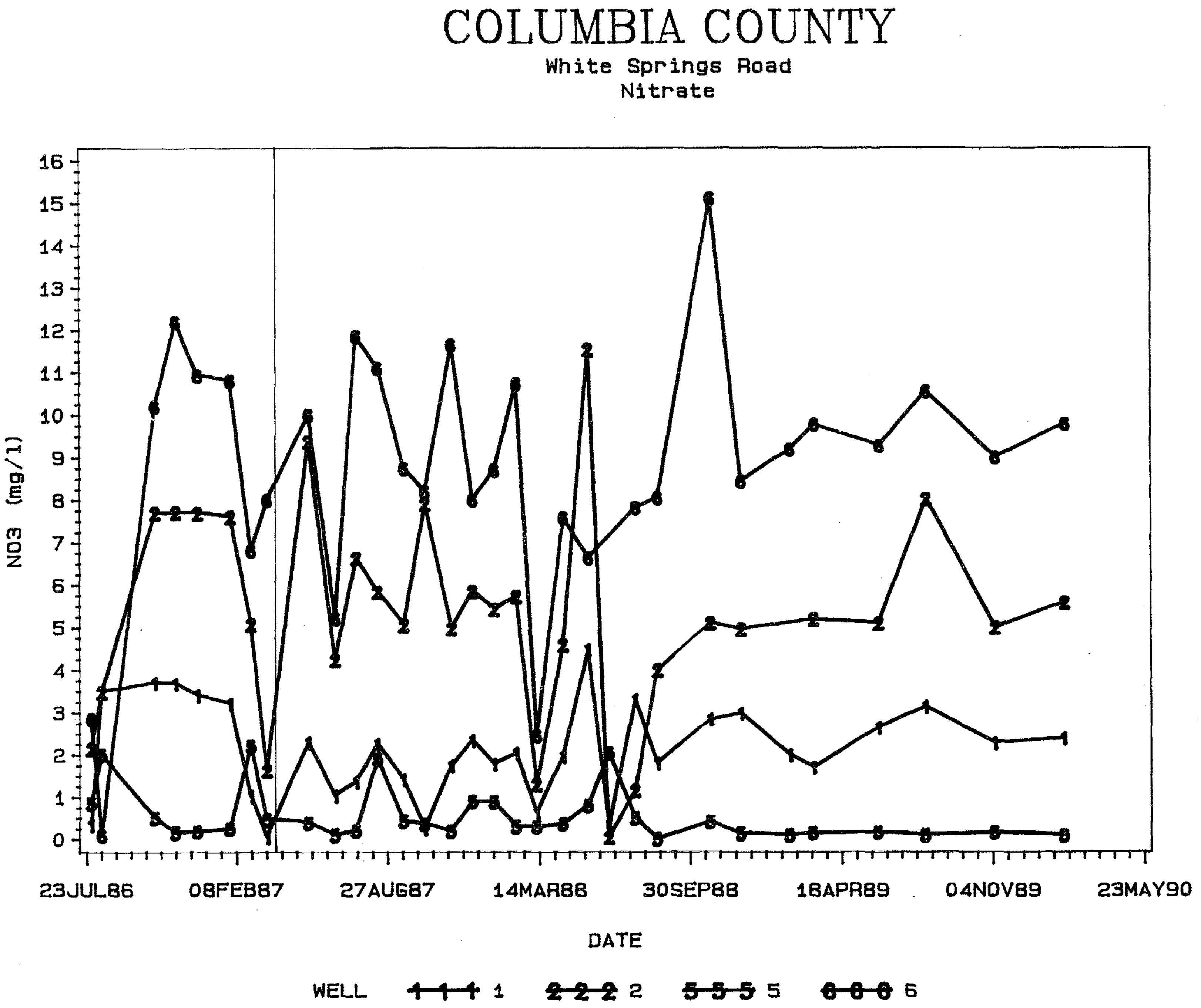


Figure 53. Nitrate Level in Inner Wells

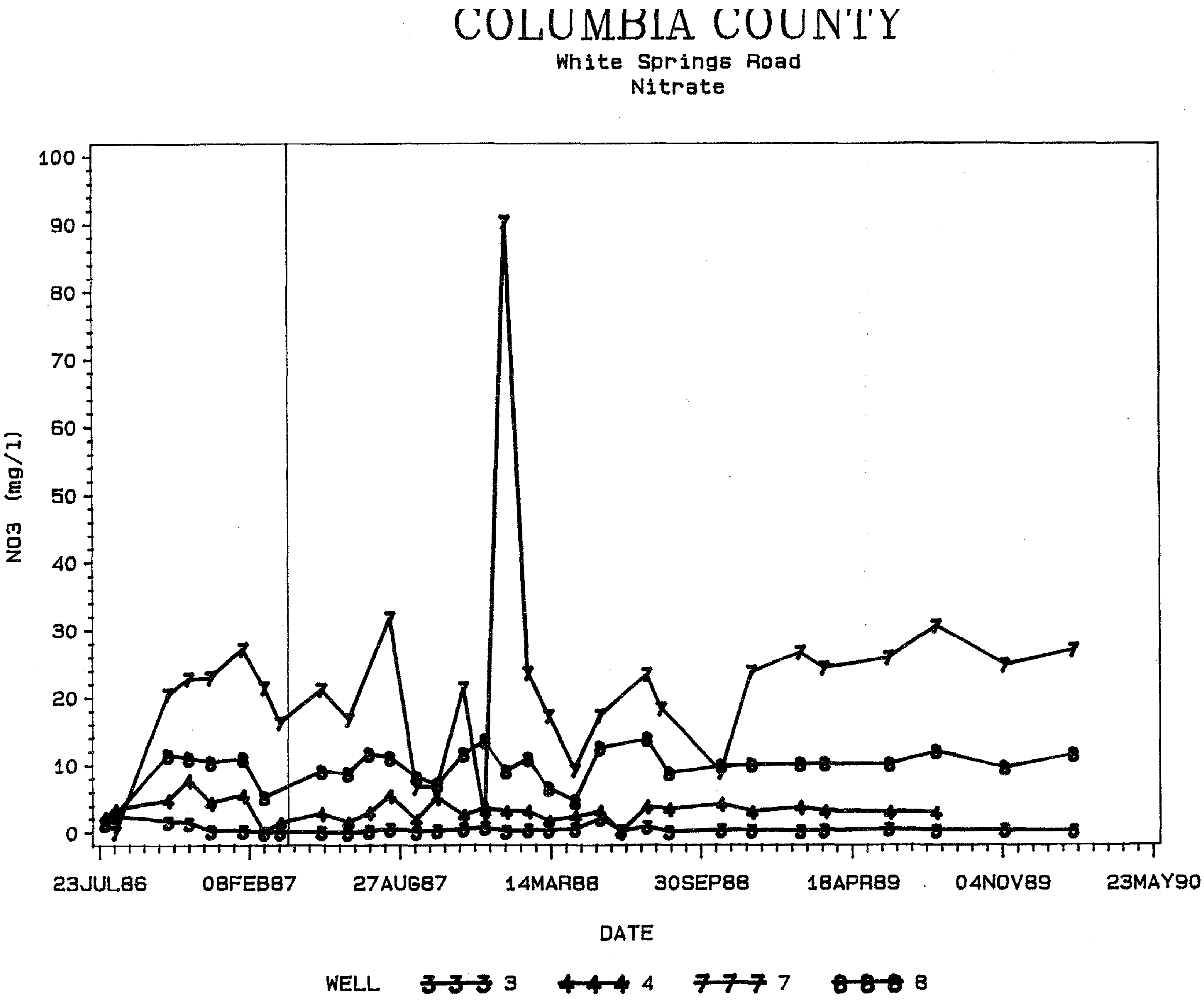


Figure 54. Nitrate Level in Outer Wells

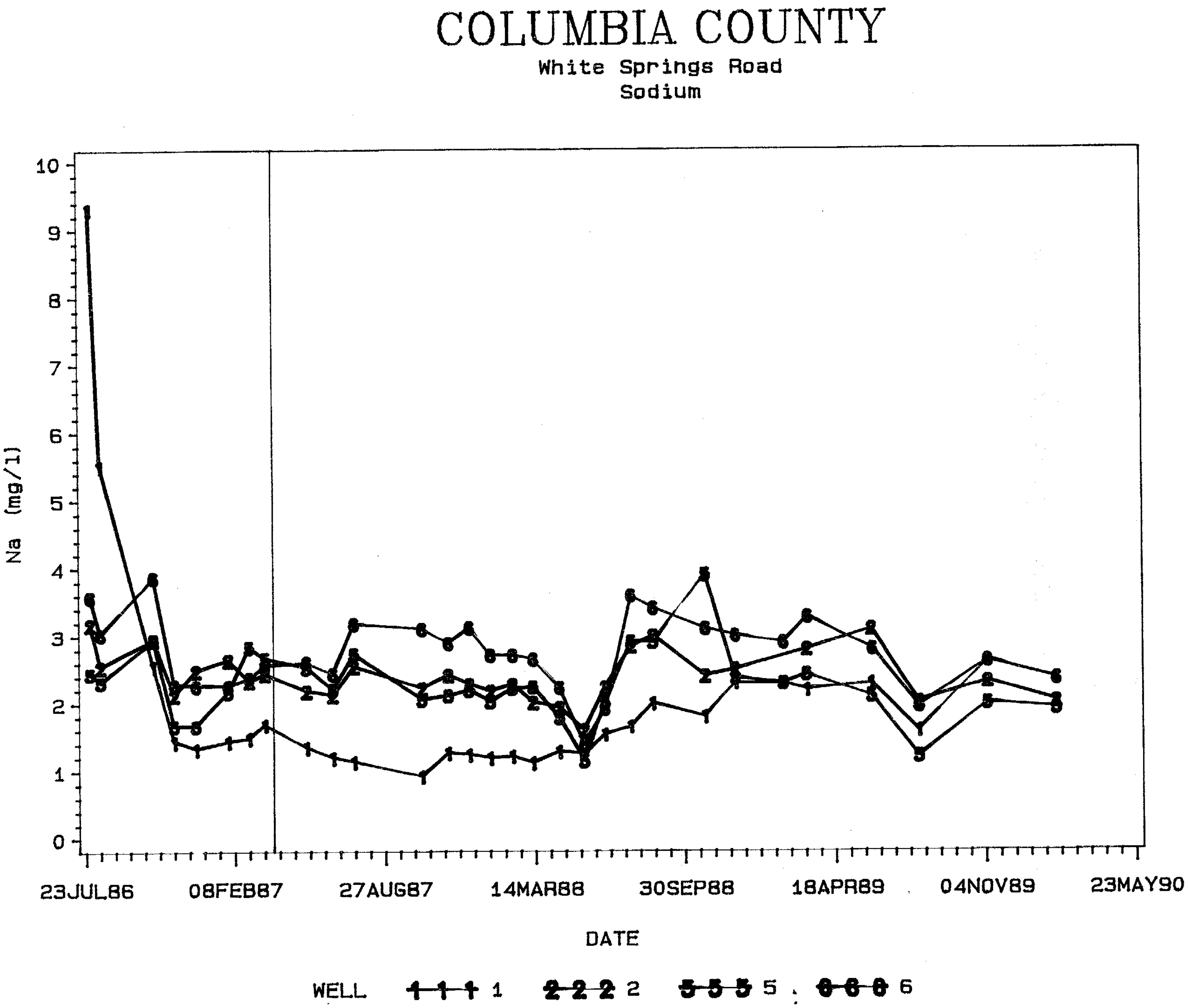

COLUMBIA COUNTY
White Springs Road
Sodium

Figure 55. Sodium Level in Inner Wells

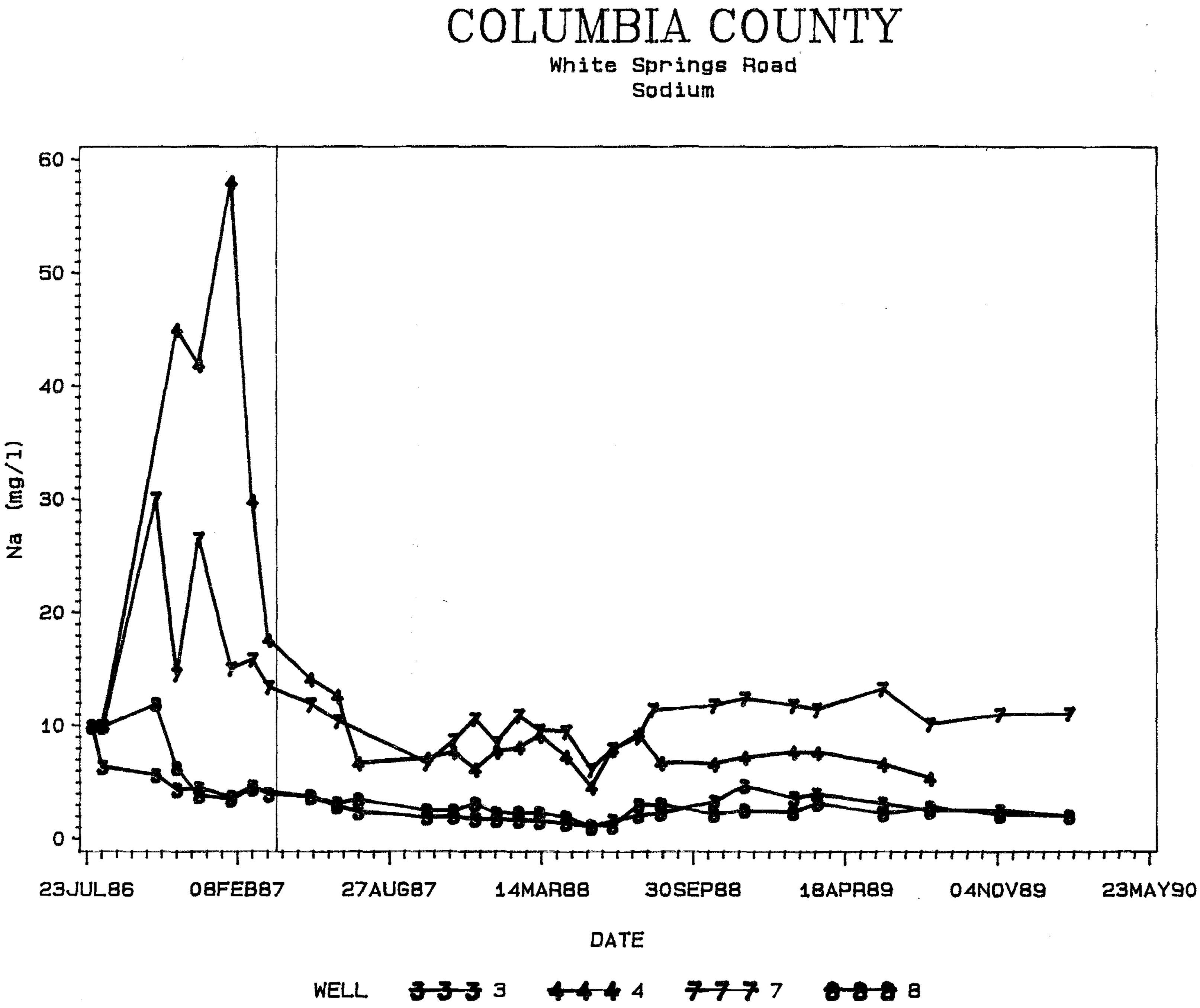


Figure 56. Sodium Level in Outer Wells

Contaminants for Secondary Drinking Water Standards

The Secondary Drinking Water Standards which apply to community water systems are shown in Table VIII.

Table VIII. Secondary Drinking Water Standards

Contaminant	Maximum Level, mg/liter
Chloride	250
Color	15 Color Units
Copper	1
Corrosivity	Non Corrosive
Fluoride	2.0
Foaming Agents	0.5
Iron	0.3
Manganese	0.05
Odor	3 (threshold odor number)
Ph (at collection point)	6.5-6.8
Sulfate	250
Total Dissolved Solids	500
Zinc	5

Of the contaminants covered under the Secondary Drinking Water Standards, the levels of fluoride and sulfate have been reported earlier in this paper.

Parrish Road

No time trends were observed on the levels of chloride, cooper, iron, manganese or total dissolved solids in the ground water samples are shown in Figures 57 through 66. The results on fluoride, pH and sulfate have been repeated earlier.

For Parrish Road, chloride, copper and TDS levels were all below the recommended maximum for secondary water. The iron and manganese levels frequently exceeded their respective standards.

White Springs Road

Results for White Springs Road were very similar to those at Parrish Road for the levels of chloride, copper, iron, manganese and total dissolved solids. The iron and manganese levels frequently exceeded their recommended standards. The TDS level from well No. 4 exceeded the 500 ppm maximum level on several occasions. No time trends were noted for any of components.

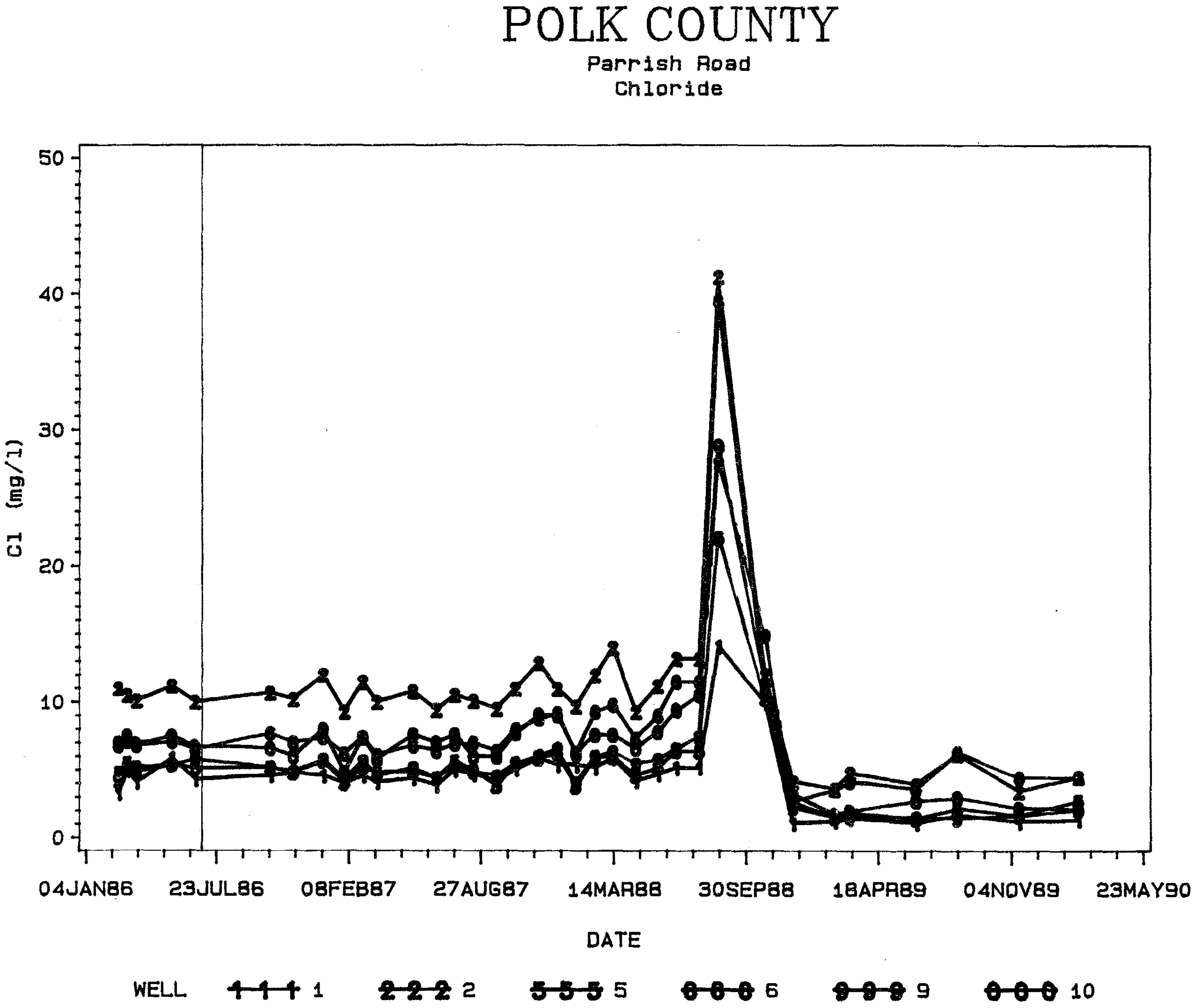


Figure 57. Chloride Level in Ground Water, Inner Wells

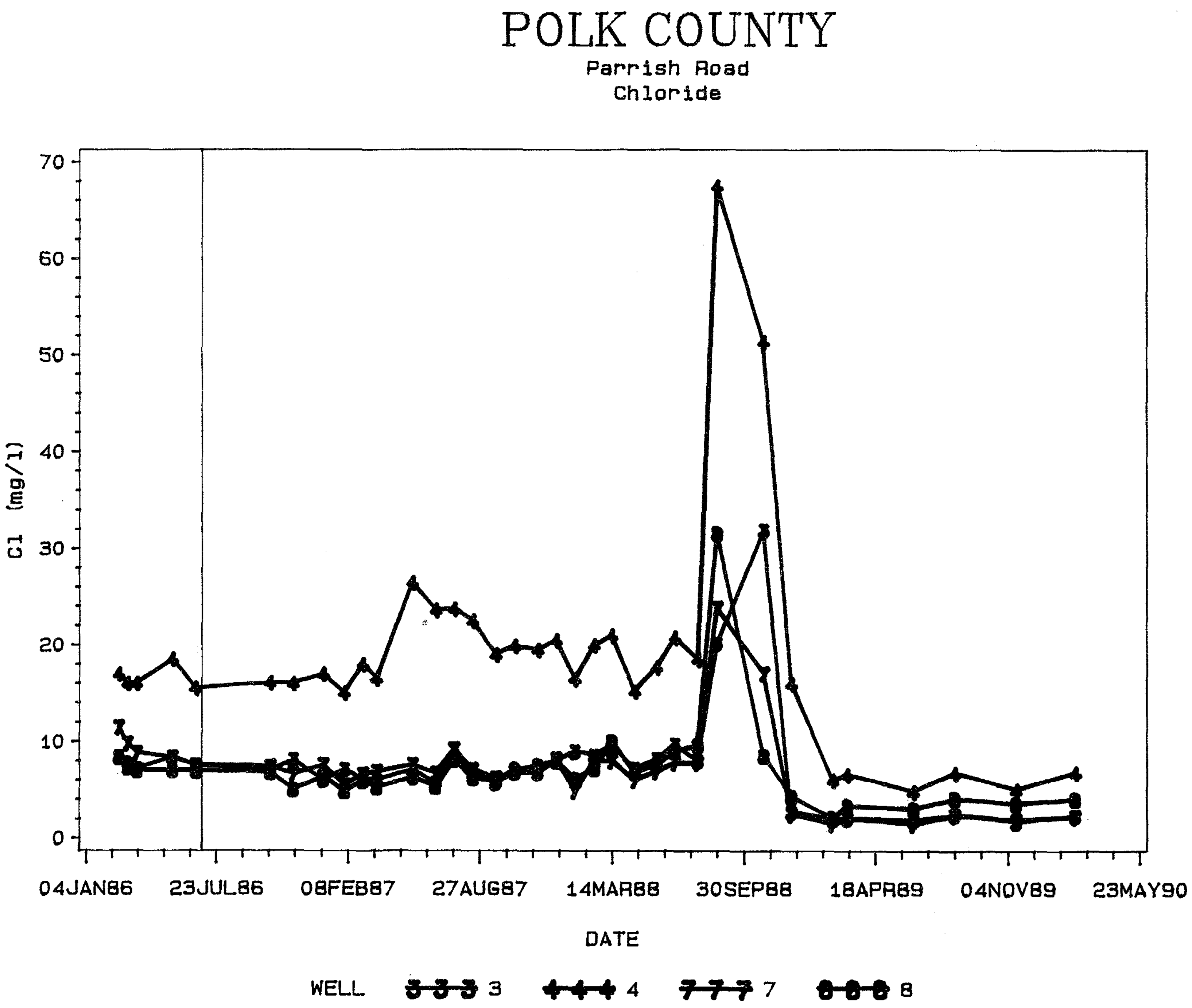


Figure 58. Chloride Level in Ground Water, Outer Wells

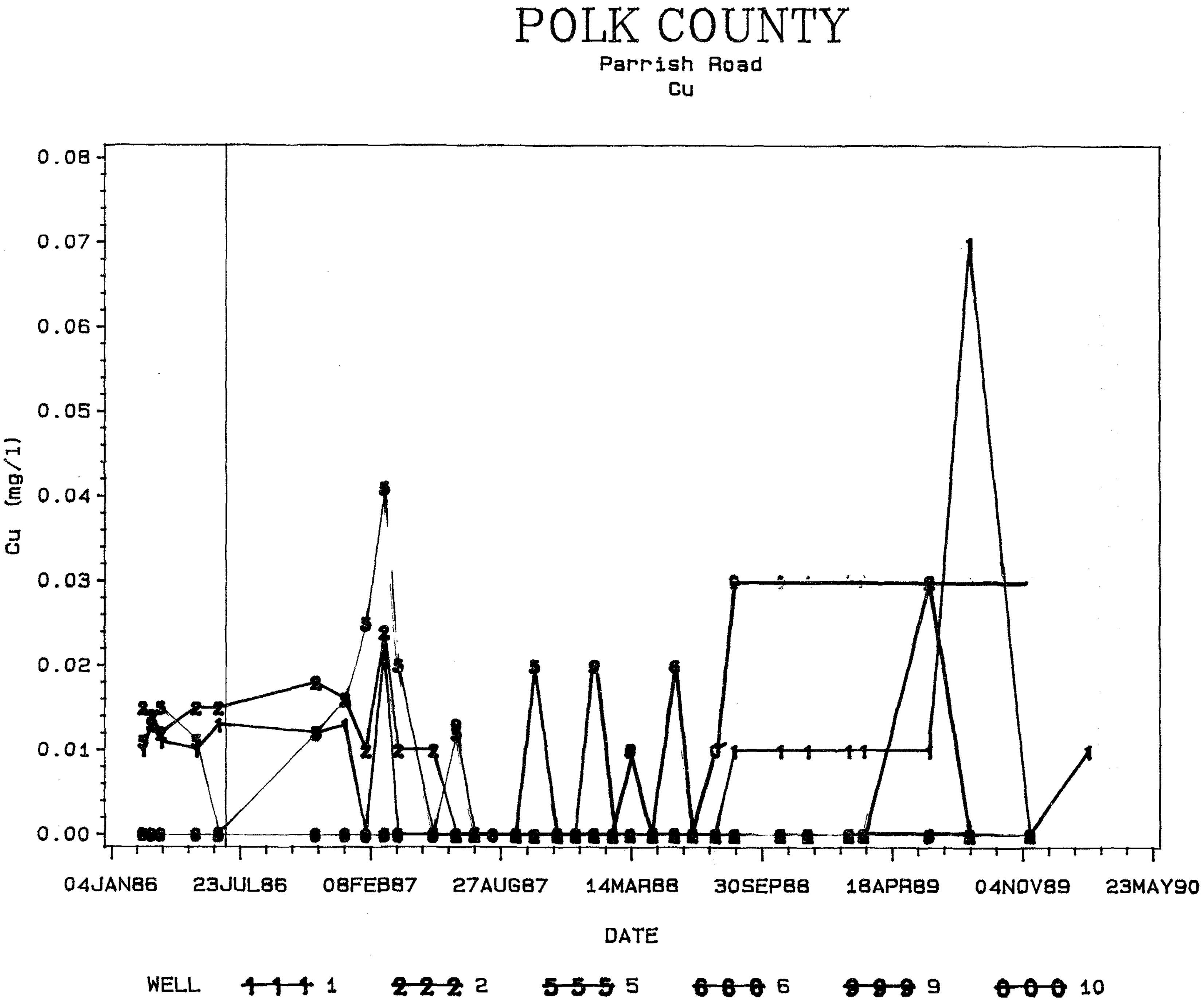


Figure 59. Copper Level in Ground Water, Inner Wells

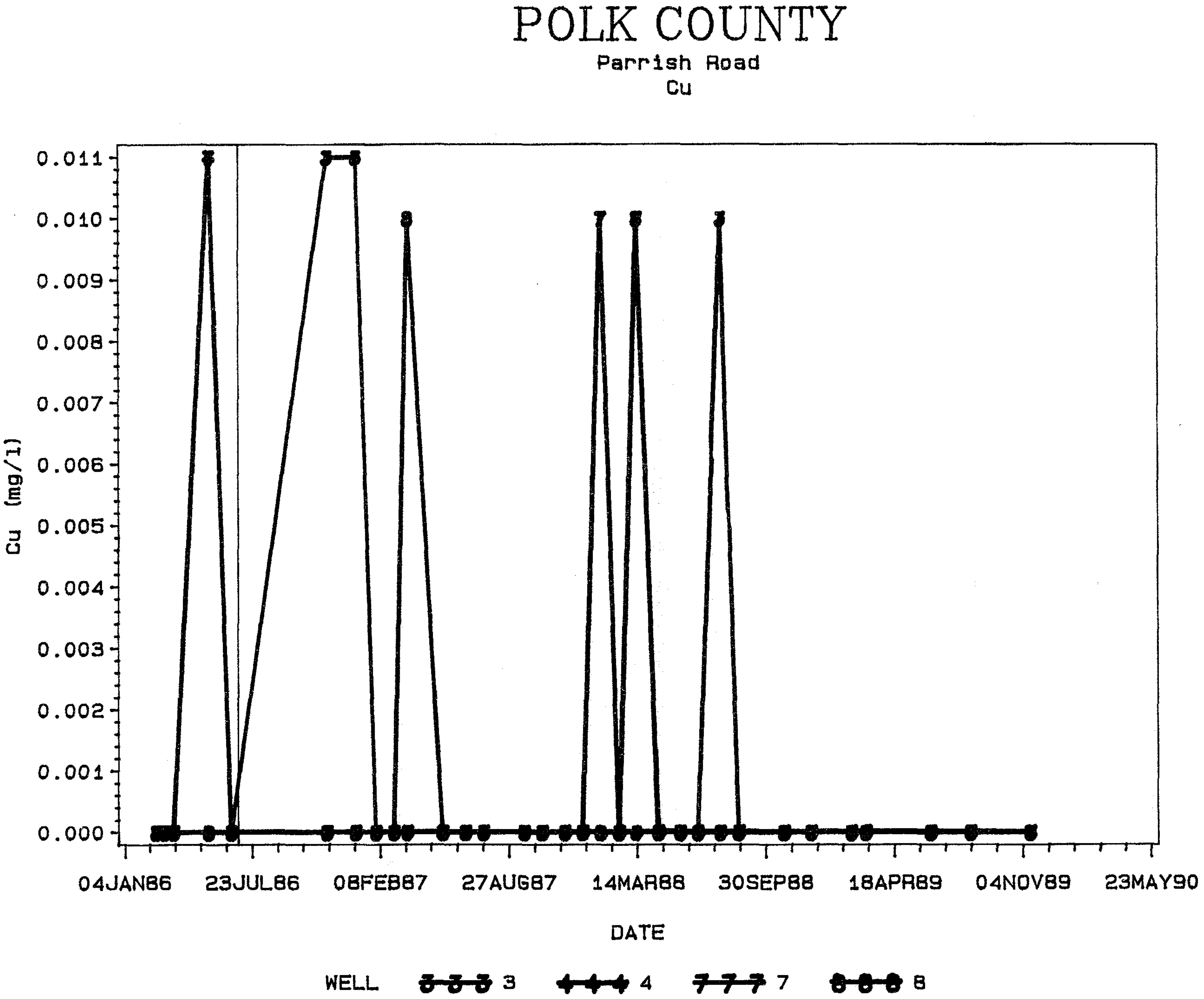


Figure 60. Copper Level in Ground Water, Outer Wells

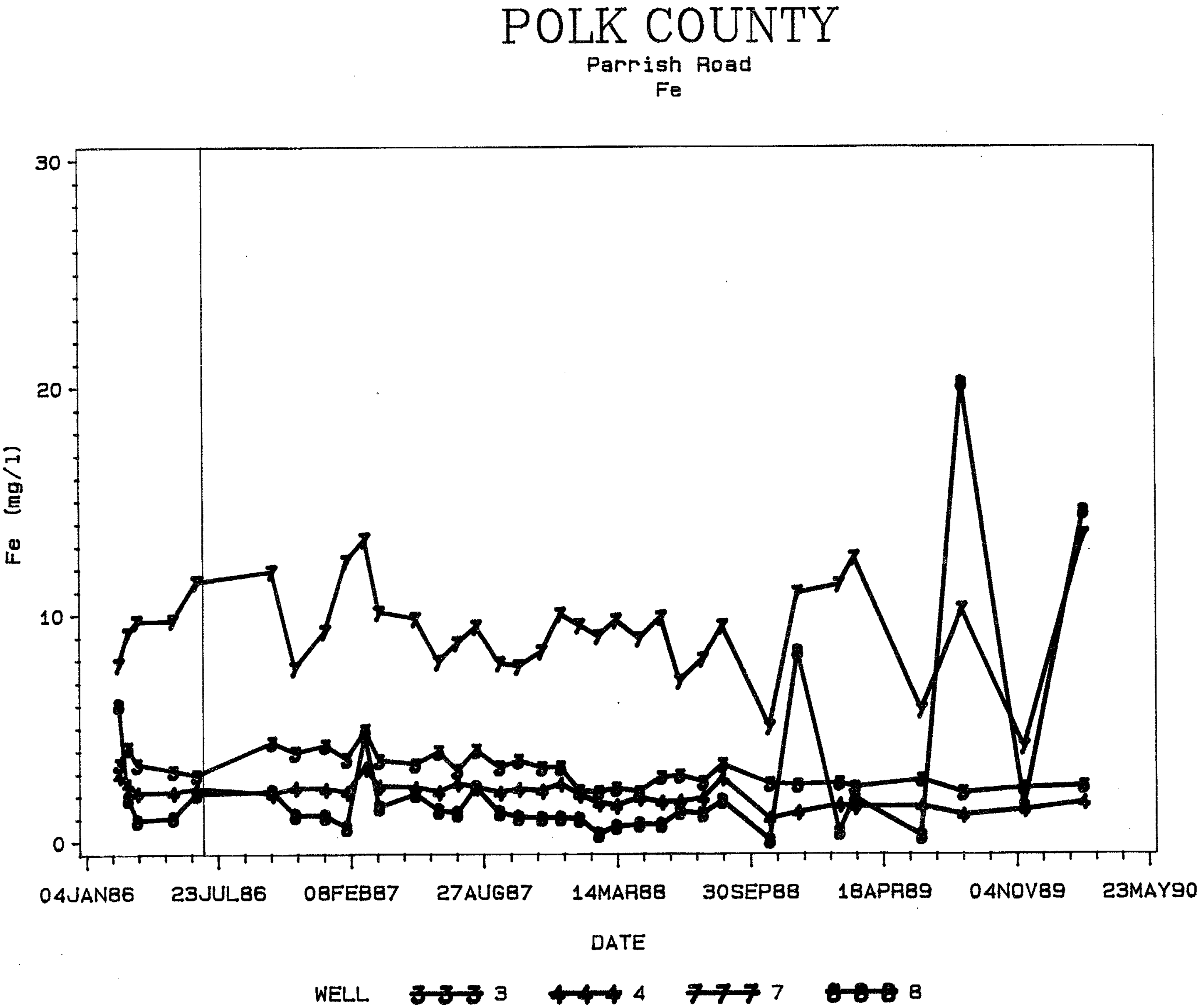


Figure 61. Iron Level in Ground Water, Inner Wells

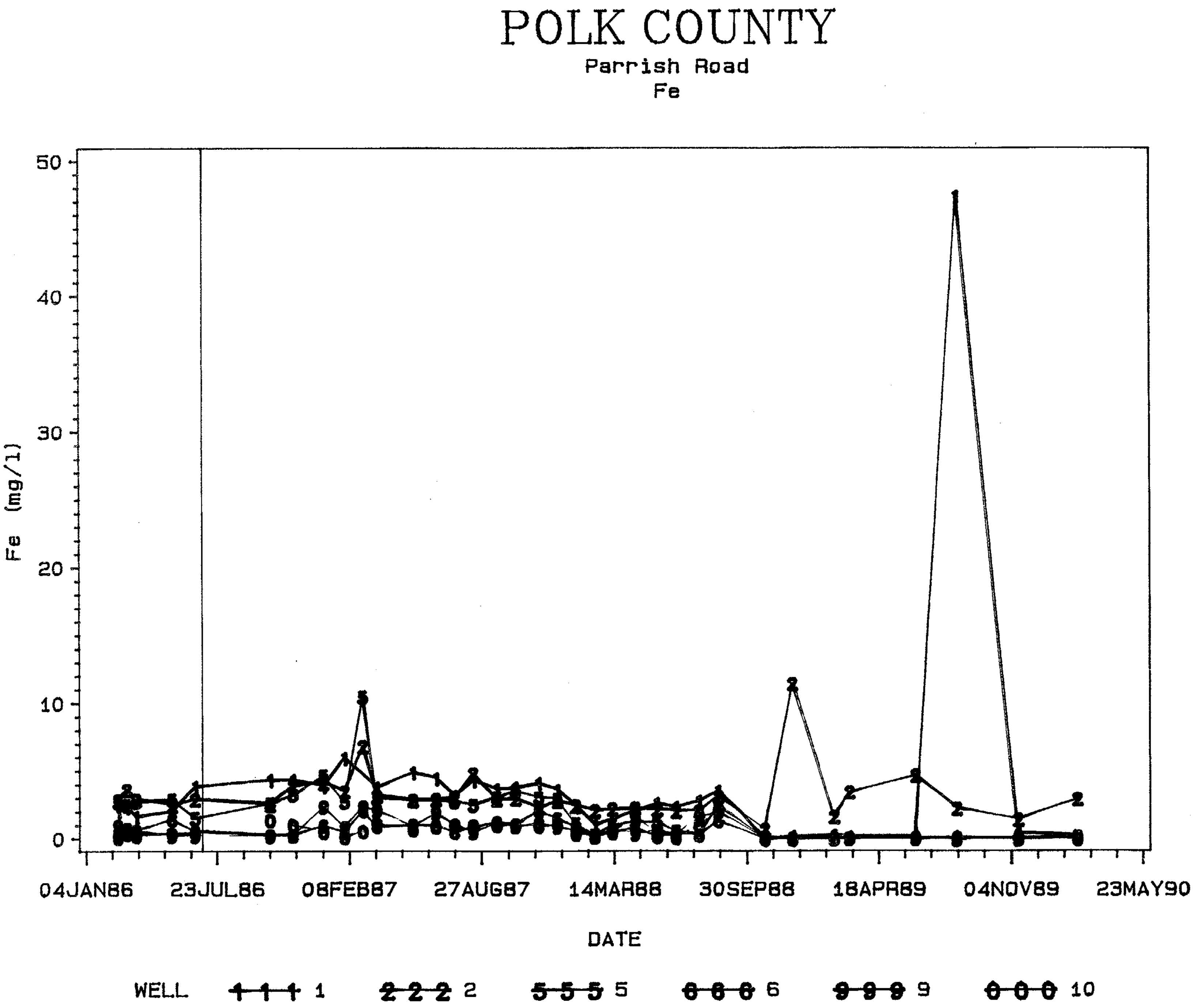


Figure 62. Iron Level in Ground Water, Outer Wells

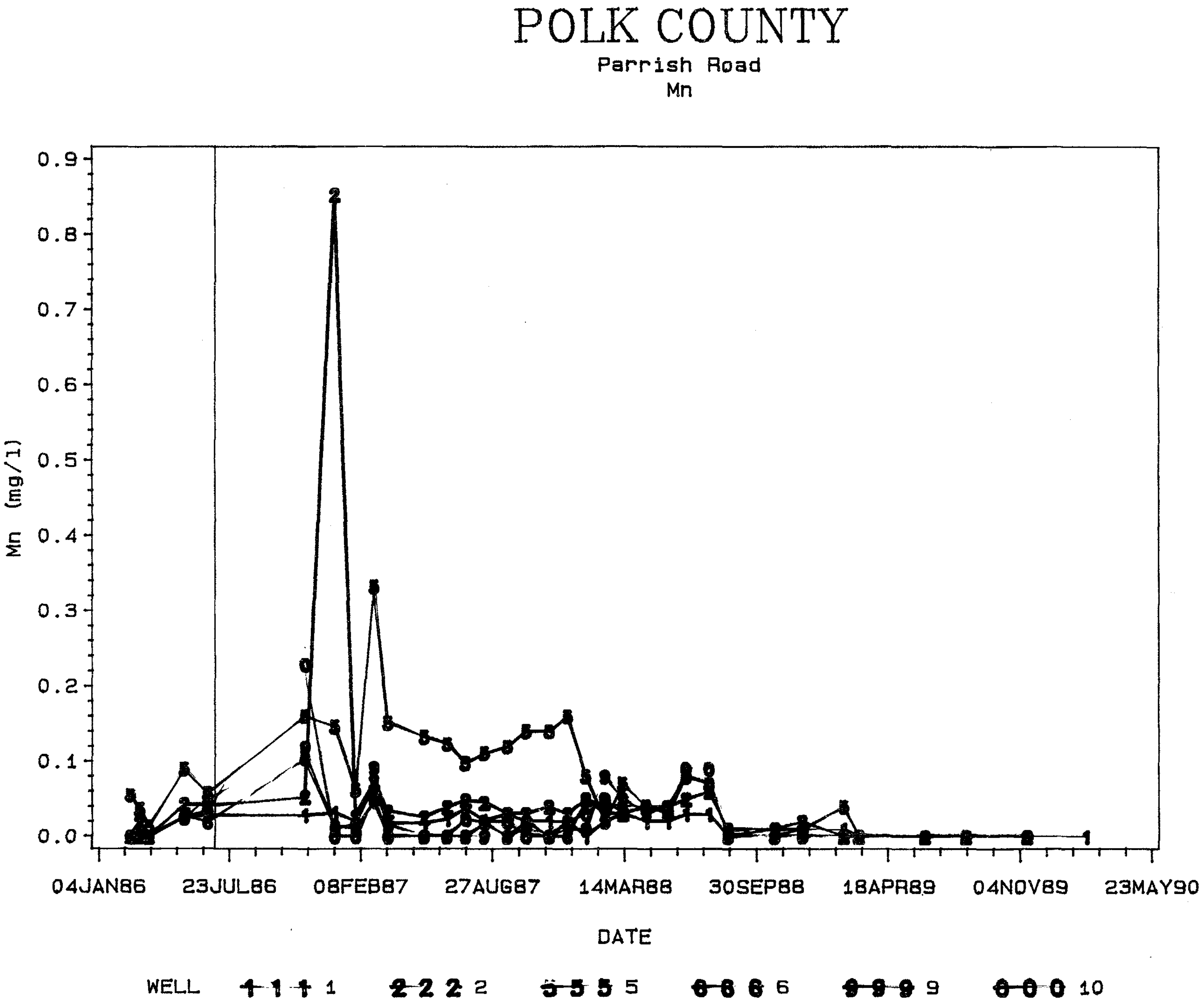


Figure 63. Manganese Level in Ground Water, Inner Wells

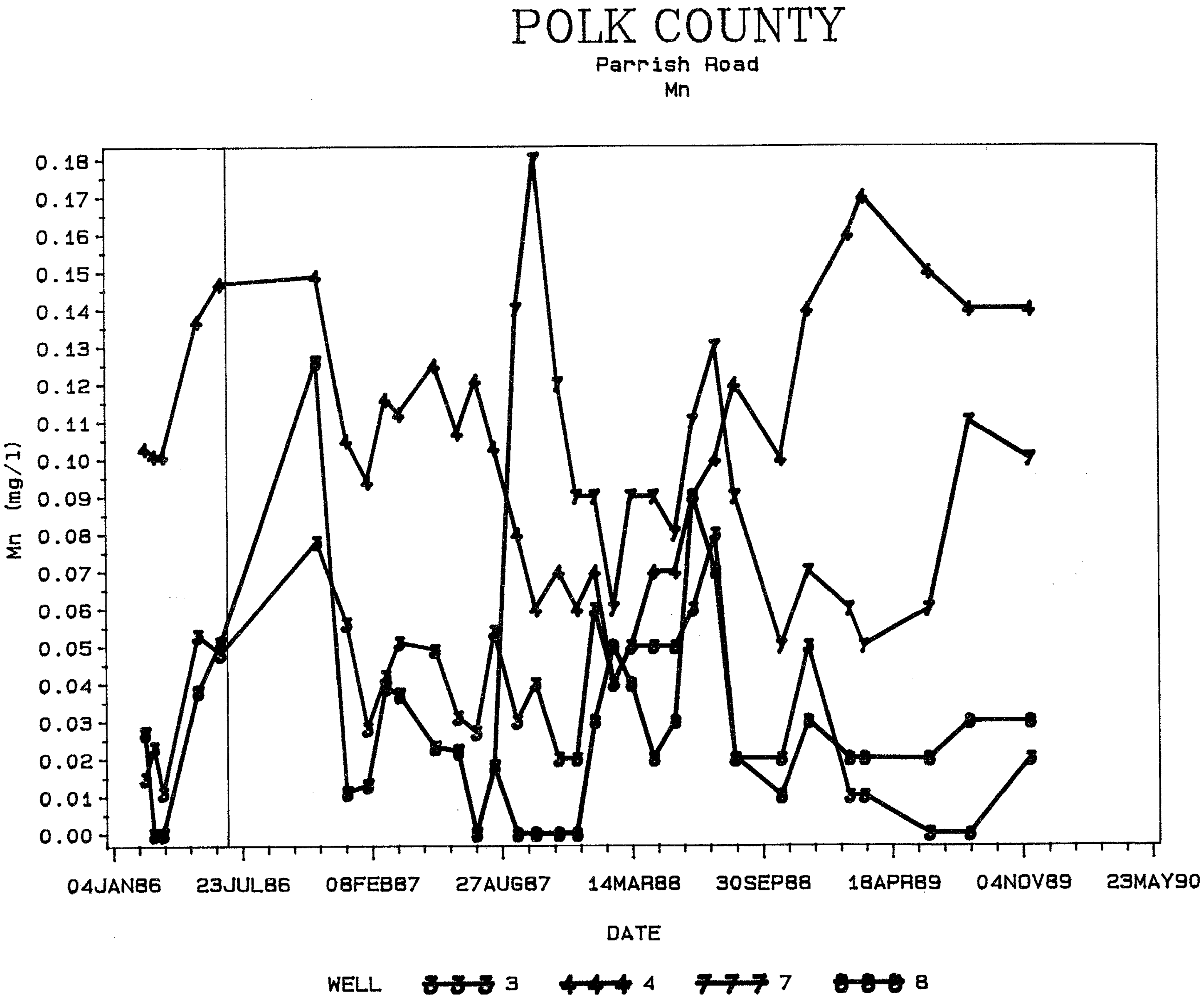


Figure 64. Manganese Level in Ground Water, Outer Wells

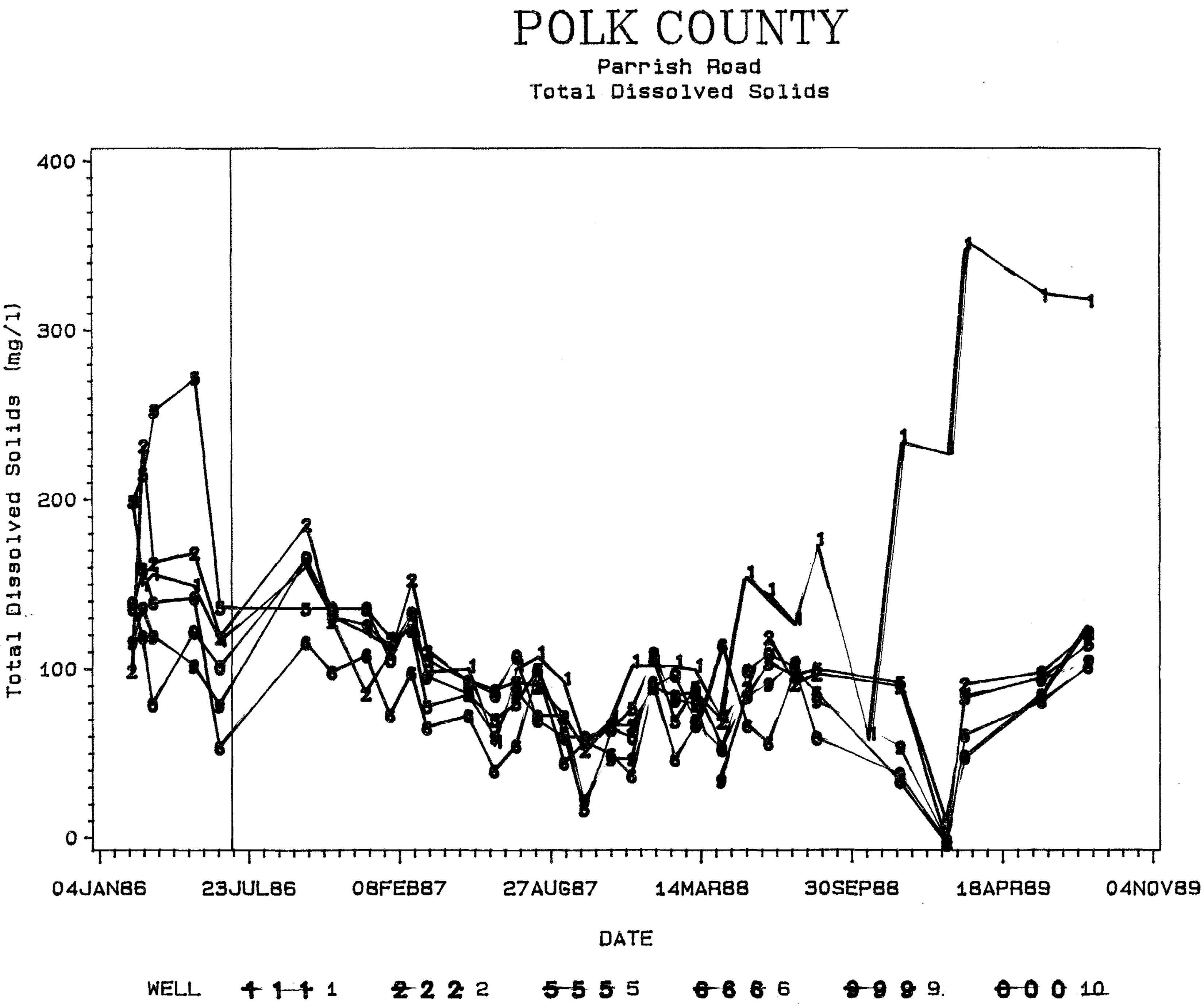


Figure 65. **Total** Dissolved Level in Ground Water, Inner Wells

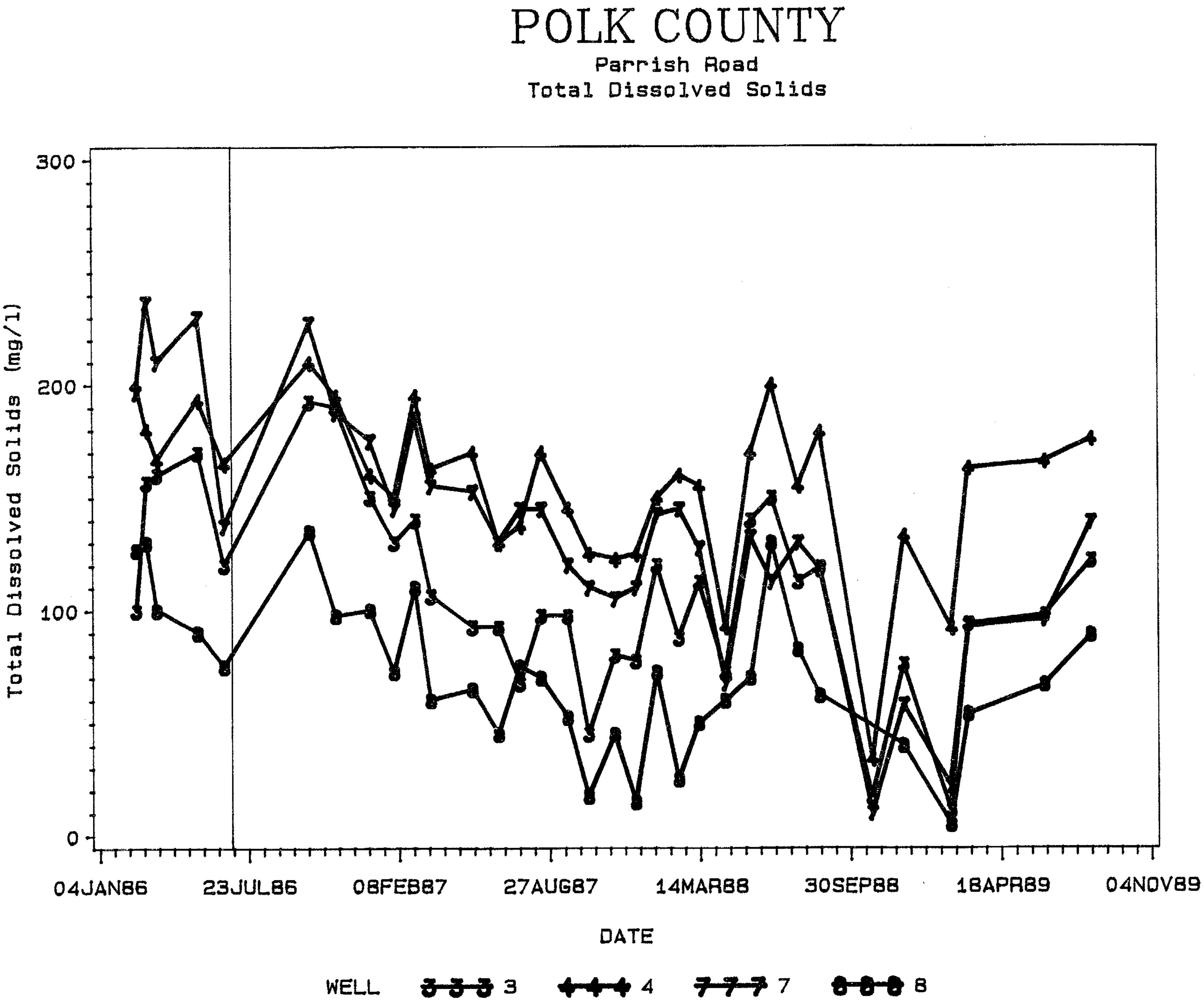


Figure 66. Total Dissolved Level in Ground Water, Outer Wells

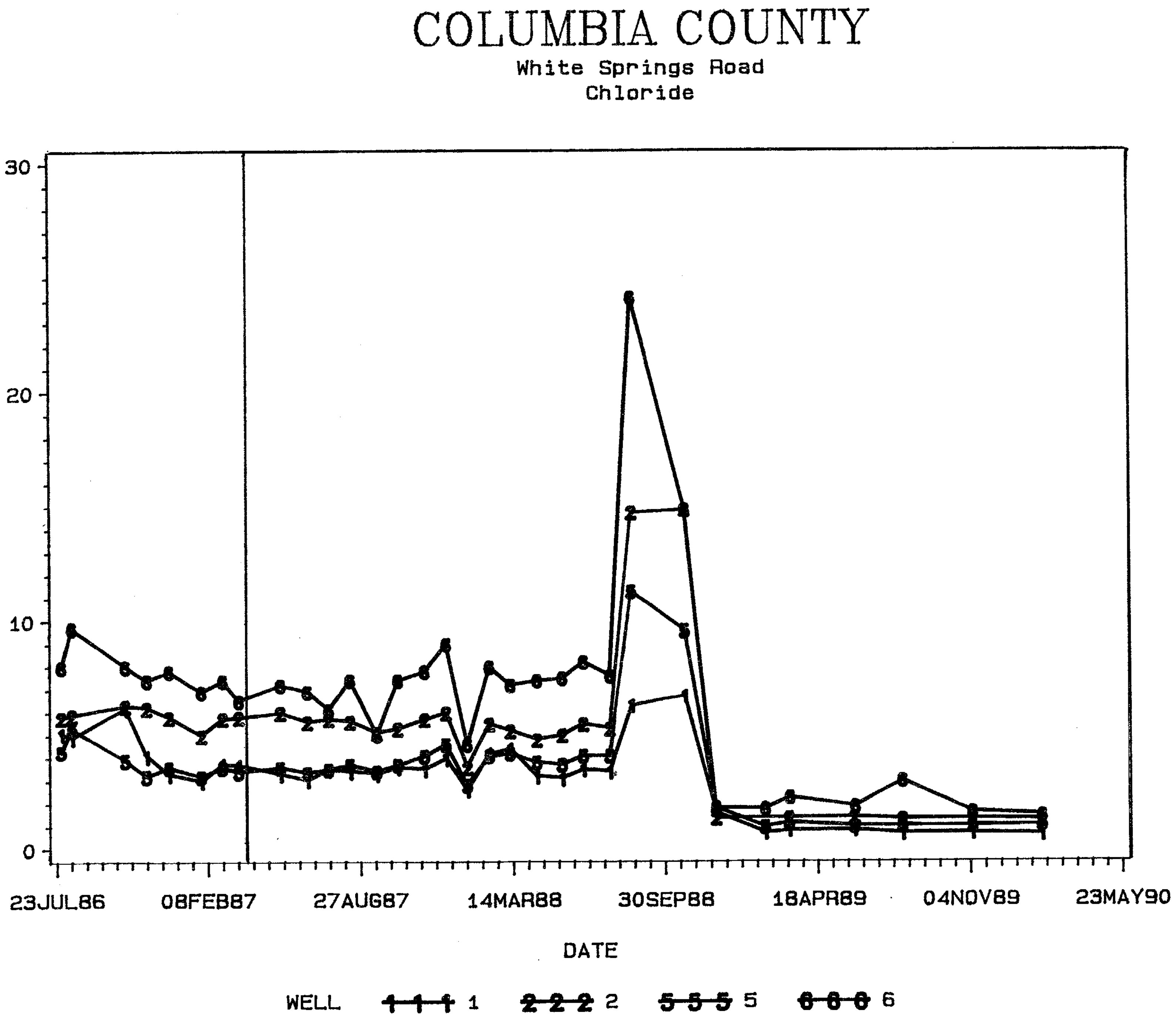


Figure 67. Chloride Level in Ground Water, Inner Wells

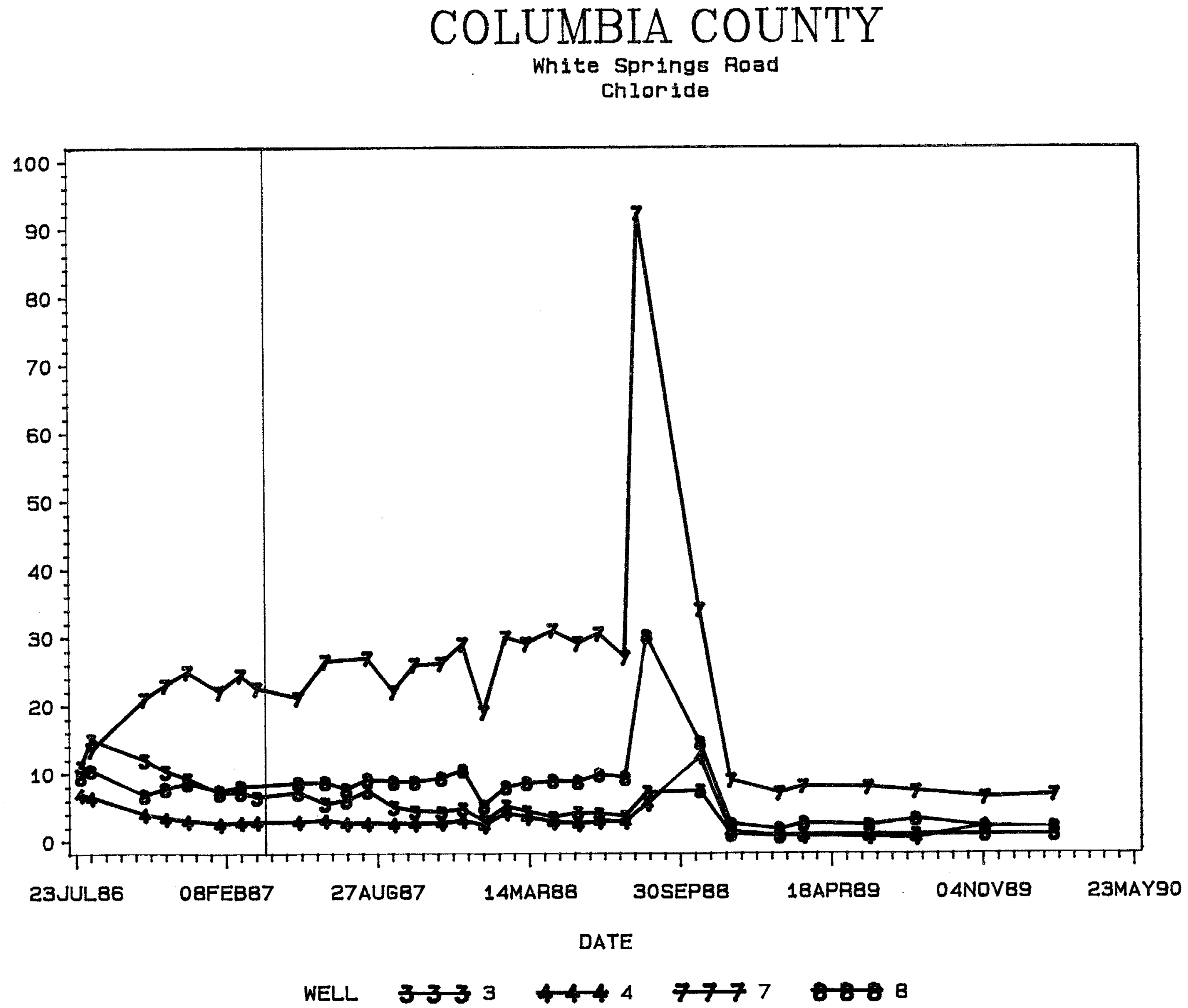


Figure 68. Chloride Level in Ground Water, Outer Wells

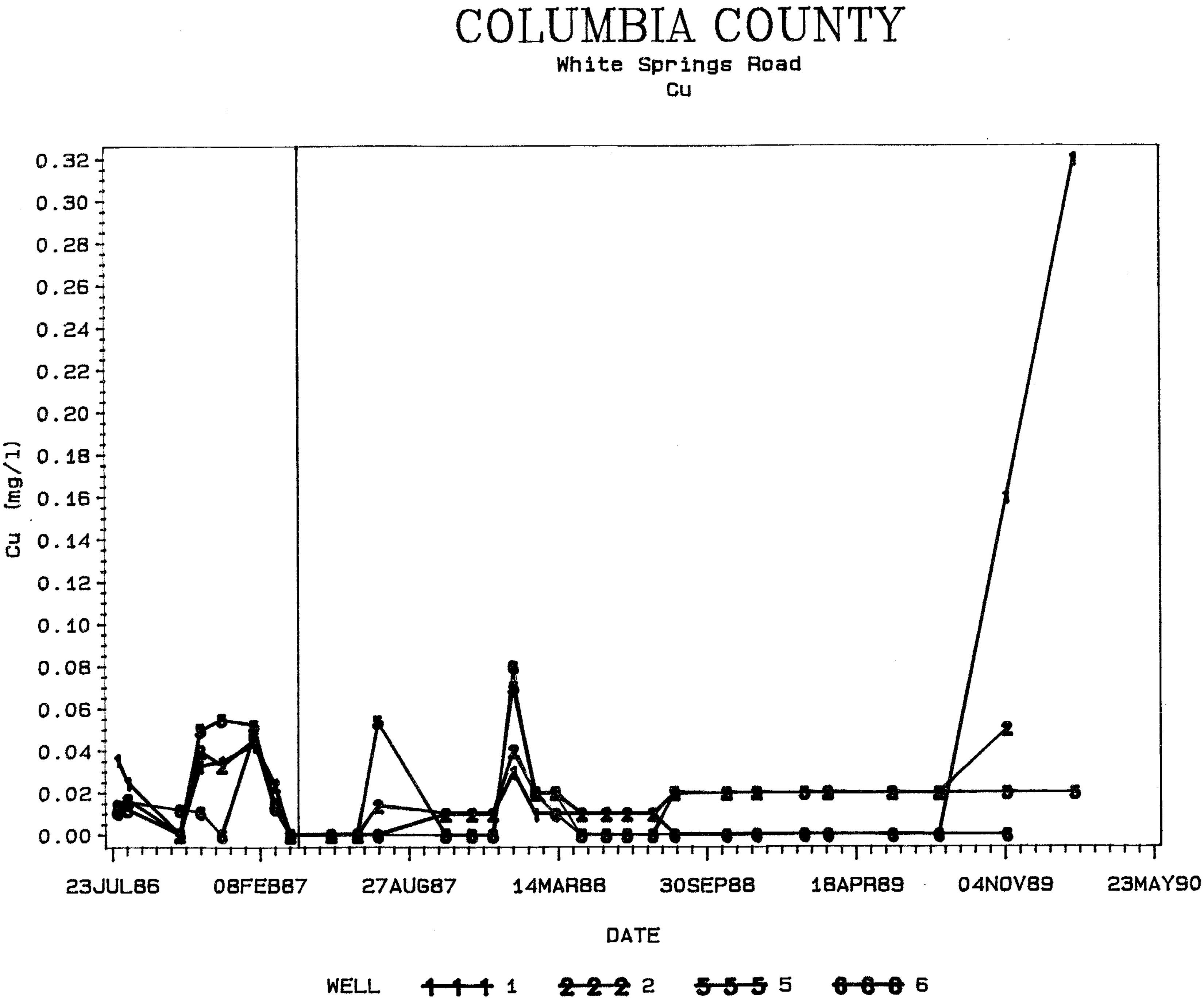
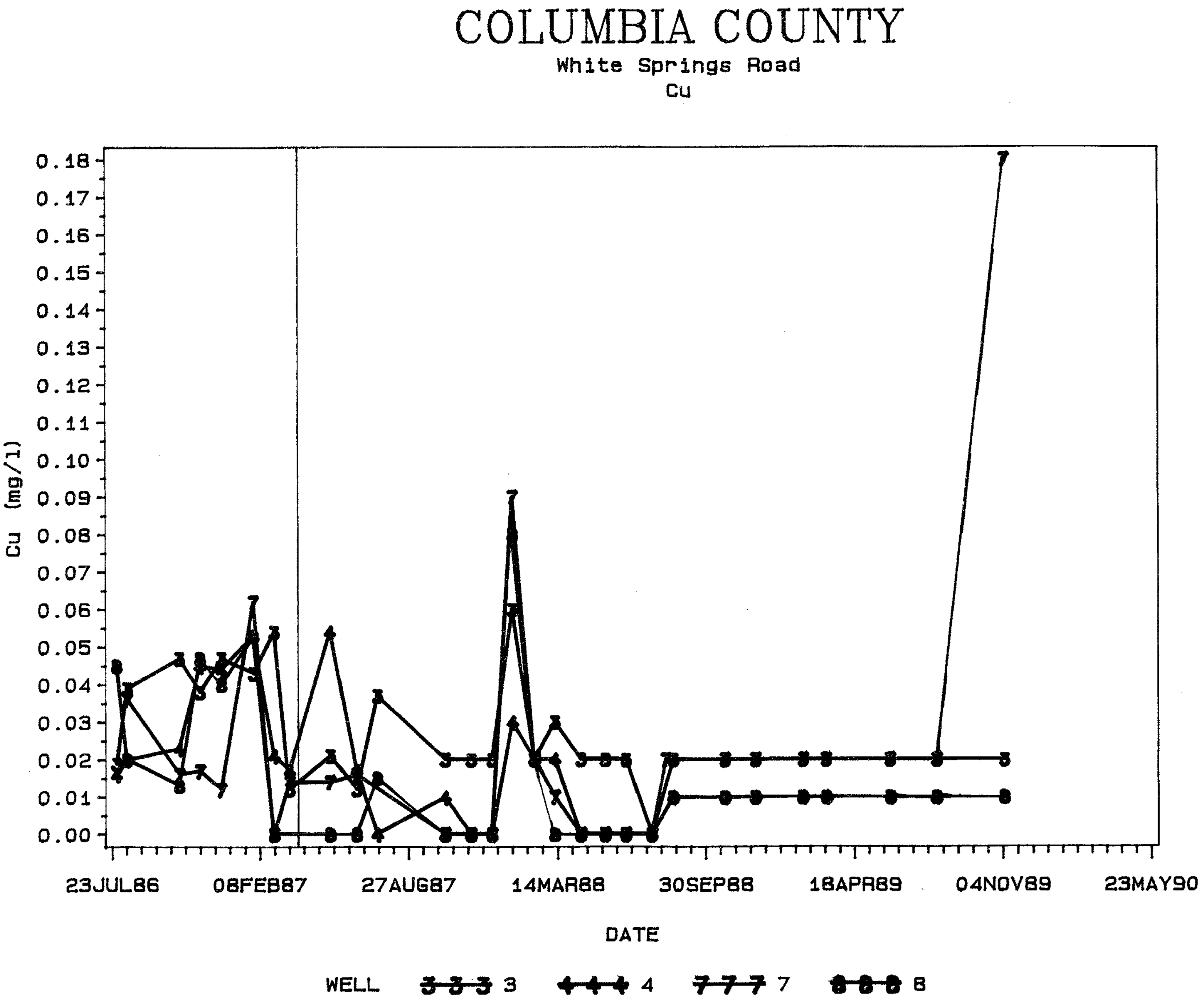


Figure 69. Copper Level in Ground Water, Inner Wells



COLUMBIA COUNTY

White Springs Road

Cu

Figure 70. Copper Level in Ground Water, Outer Wells

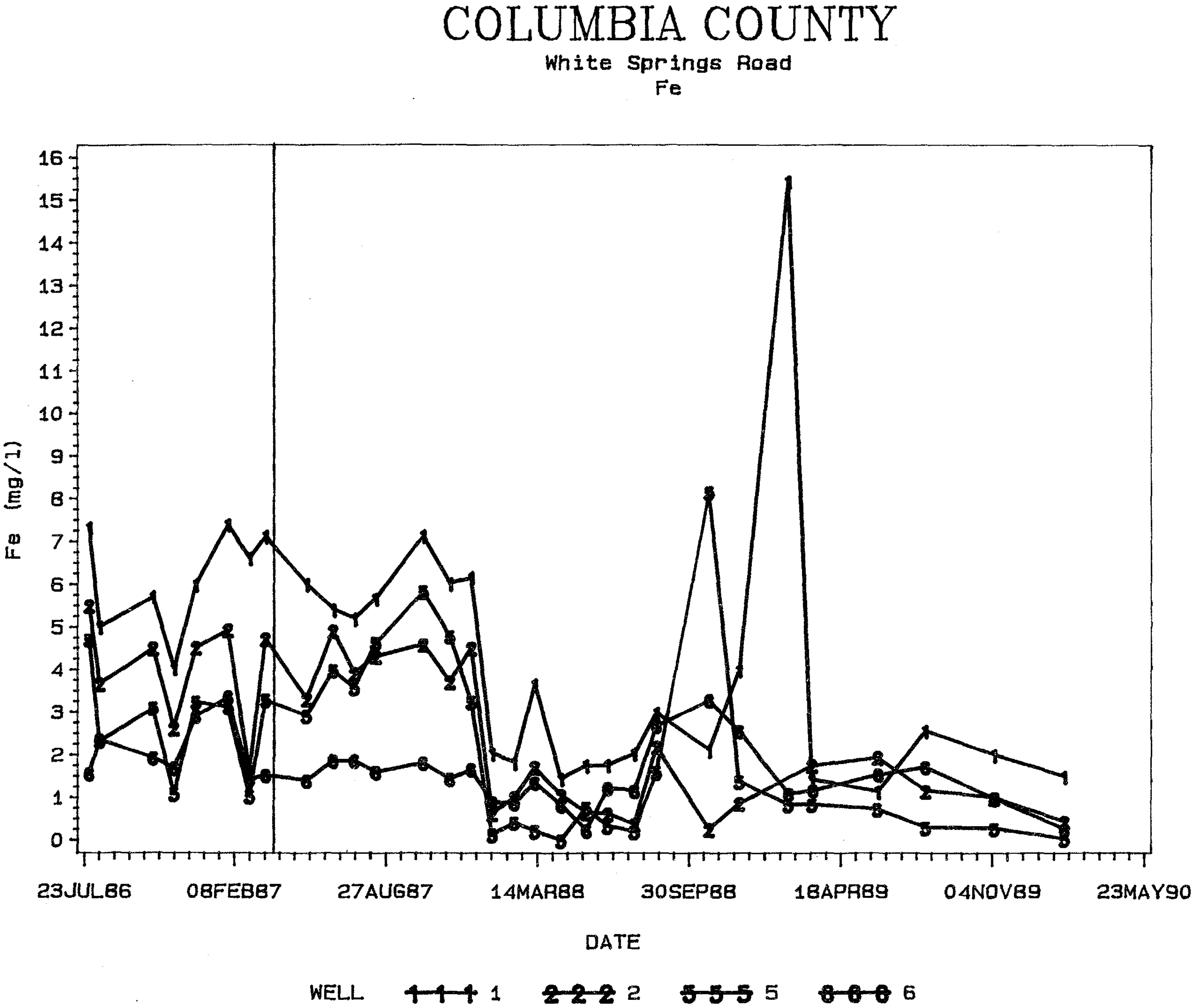


Figure 71. Iron Level in Ground Water, Inner Wells

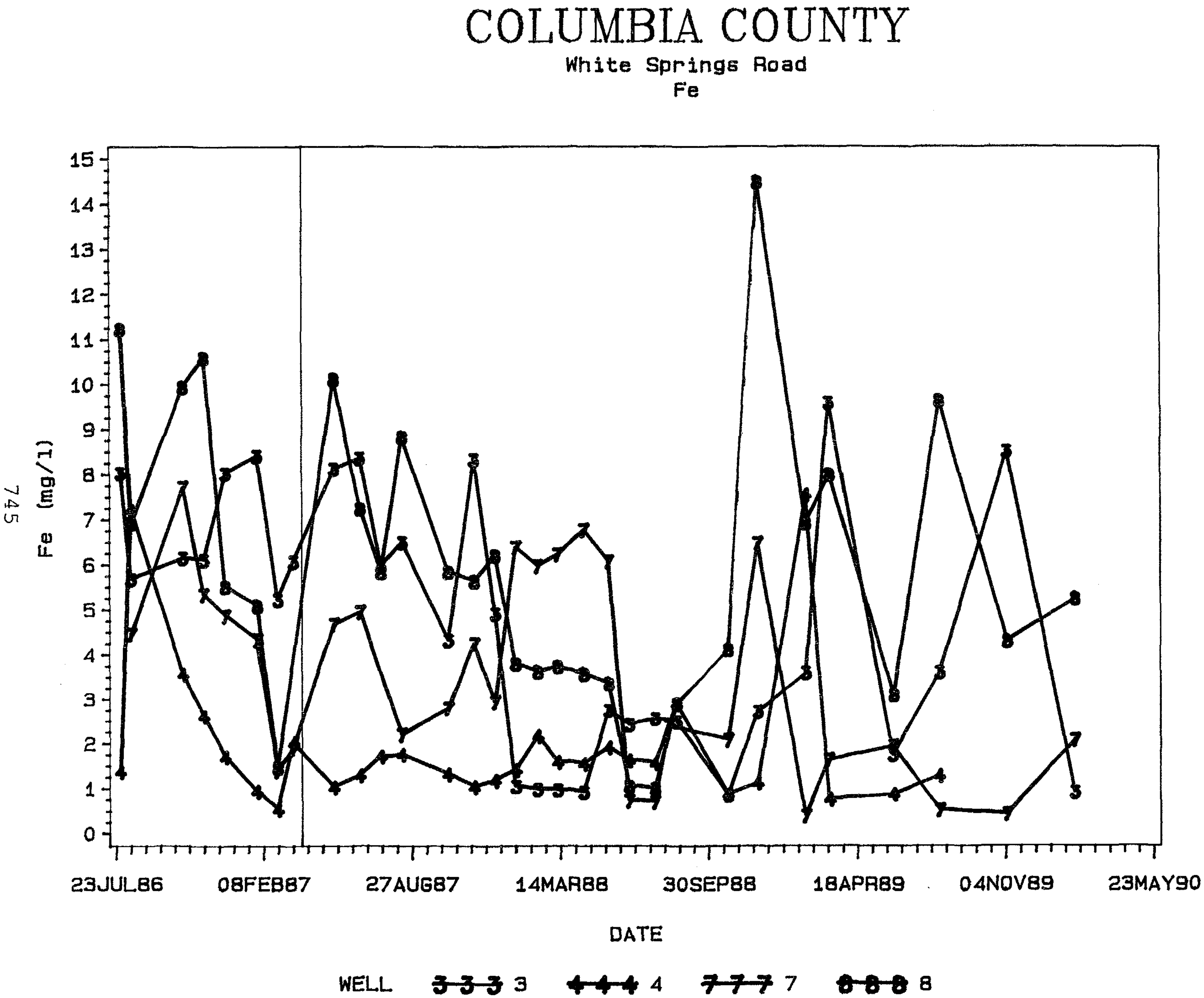


Figure 72. Iron Level in Ground Water, Outer Wells

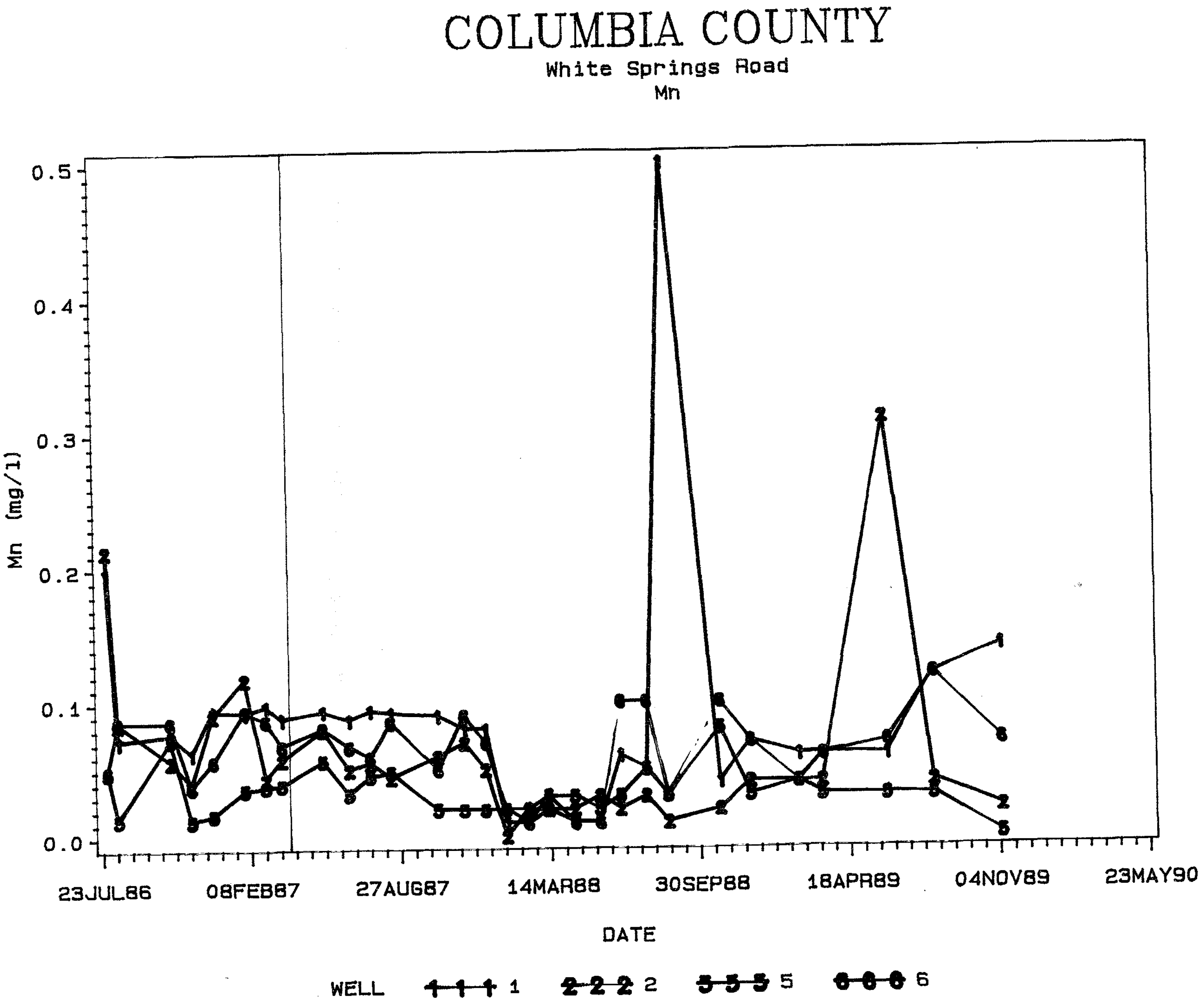


Figure 73. Manganese Level in Ground Water, Inner Wells

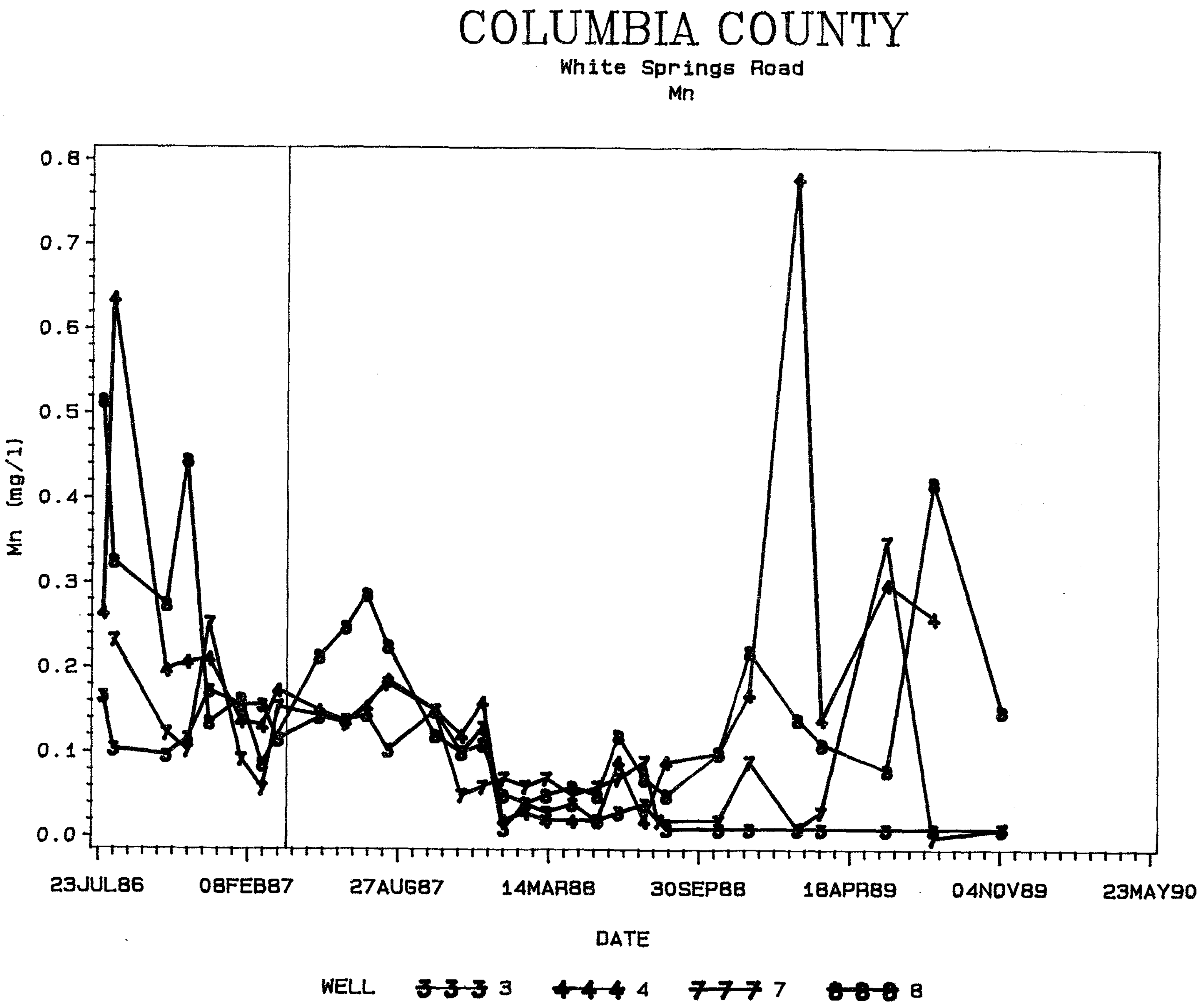


Figure 74. Manganese Level in Ground Water, Outer Wells

COLUMBIA COUNTY

White Springs Road

Total Dissolved Solids

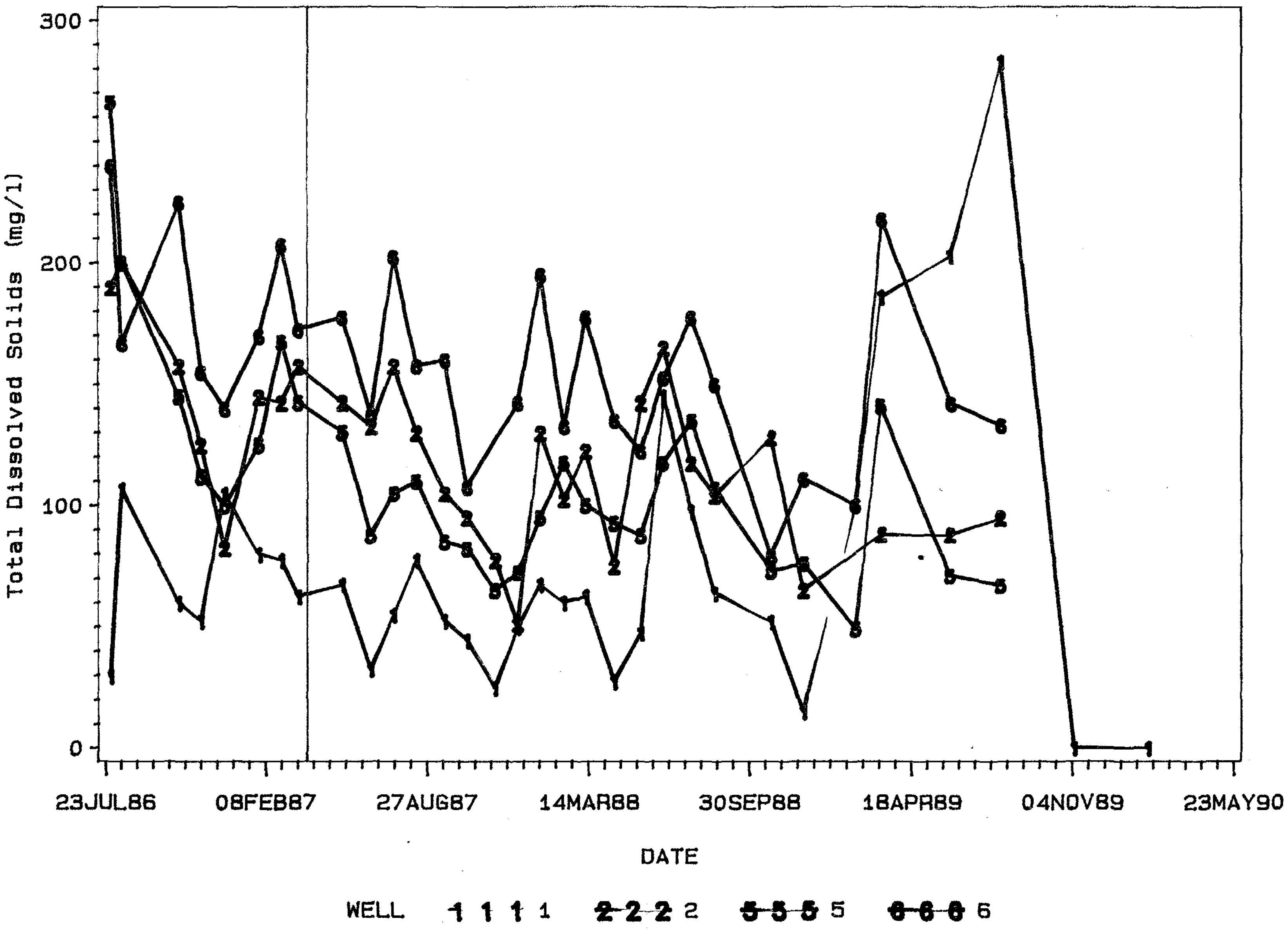


Figure 75. Total Dissolved Solids in Ground Water, Inner Wells

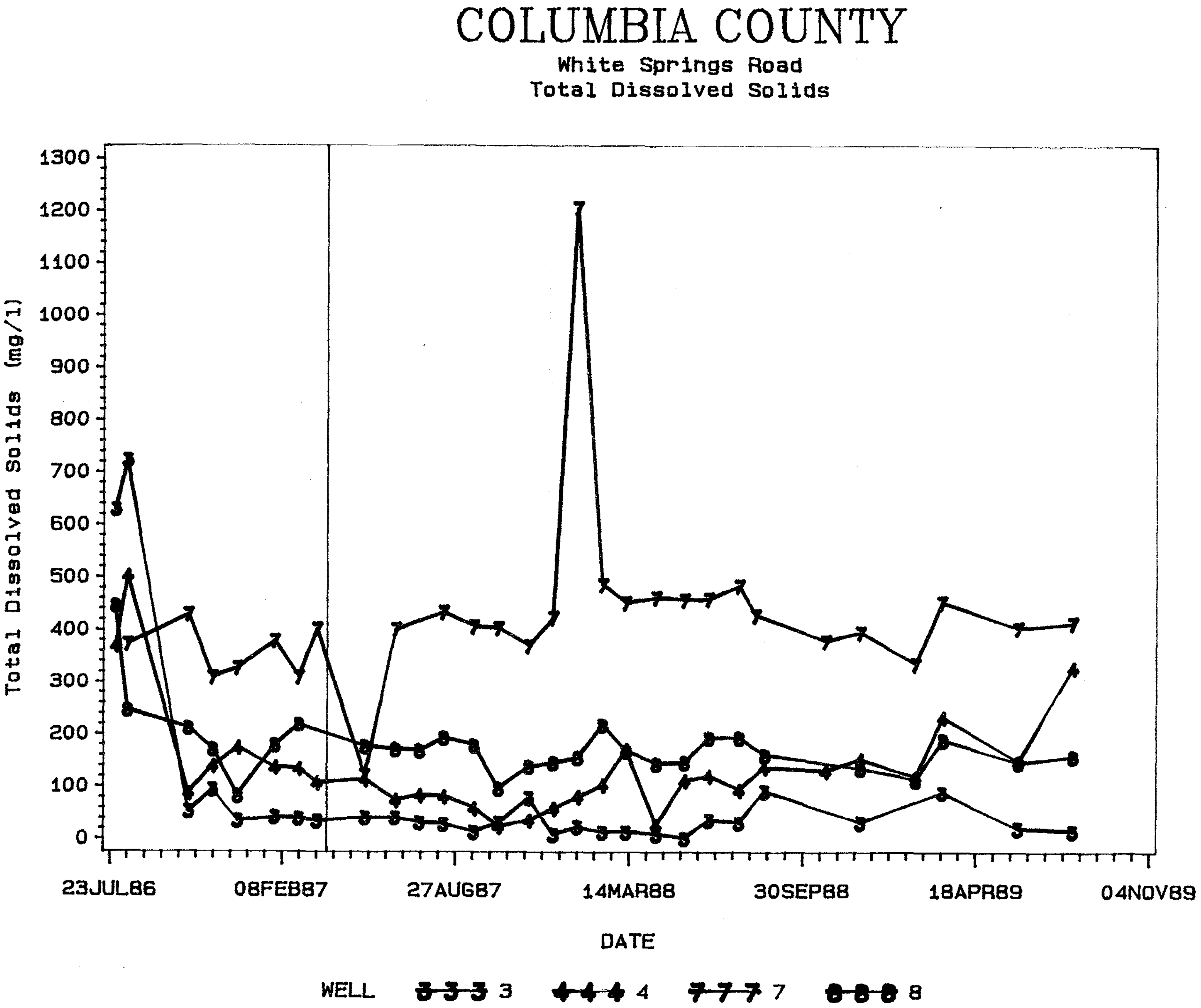


Figure 76. Total Dissolved Solids Level in Ground Water, Outer Wells

CONCLUSIONS

The groundwater monitoring studies conducted over 4 and 3 1/2 years respectively at the Parrish Road and White Springs Road sites indicate that there are no uniform and measurable adverse effects on the groundwater due to the construction of the phosphogypsum road.

Many of the chemical parameters measured from the many sampling wells at each site appear to correlate well with each other at a given point in time indicating perhaps groundwater level or rainfall effect.

The pH and electrical conductivity data, which are considered good indicators of groundwater contamination, did not show any trend except isolated instances. No systematic trend was noted.

Among the chemical constituent of phosphogypsum, sulfate level did show an increasing trend in one of ten wells in Parrish Road and in two of eight wells in White Springs Road. But in all cases, the sulfate level remained below drinking water standard. Fluoride level also showed an increase in isolated cases; but no permanent trend was evident.

The groundwater adjacent to the test road sites generally failed to meet the Primary and Secondary Drinking Water Standards before and after the construction of the roads.

ACKNOWLEDGEMENTS

The project was funded by two grants from the Florida Institute of Phosphate Research, Bartow, Florida.

The design, monitoring and testing of the roads were conducted by the University of Miami and Bureau of Materials & Research, the Florida Department of Transportation.

The Polk County and Columbia County experimental roads were constructed by the Departments of Public Works of the respective counties.

Environmental monitoring for the first two to two and a half years was conducted by the University of Miami in cooperation with the Florida Department of Environmental Regulation and the Florida Department of Health and Rehabilitative Services. The monitoring for the latter periods was conducted by the Florida Institute of Phosphate Research.

REFERENCES

Barber, C. and G. B. Davis, 1987. Representative Sampling of Ground Water from Short-Screened Boreholes. Ground Water, 25(5): 581-587.

Chang, W. F., D. A. Chin and R. Ho, 1989. Phosphogypsum for Secondary Road Construction. Florida Publication No. 01-033-077, 01-041-077, Florida Institute of Phosphate Research, Bartow, Florida.

Chang, W. F. and M. I. Mantell, 1990. Engineering Properties and Construction Applications of Phosphogypsum. Phosphate Research Institute, University of Miami.

Environmental Protection Agency, 1979. Methods for Chemical Analysis of Water and Wastes. Report No. EPA-600 14-79-020, USEPA-EMSL, Cincinnati, Ohio.

Papadopulos, I. S. and H. H. Cooper, 1967. Drawdown in a Well of Large Diameter Water Resources Research, 3(1): 241-244.

APPENDIX I

Analytical Data - Gypsum Road Building

Polk and Columbia County Roads

```
------------------------------------------------------------------- COUNTY=POLK ------------------------------------------------------------------

W
e                         Total                                                                                       Temp
l P=Pre                   Diss           Total Diss                                                                   Deg
l X=Pst  Date    F    Cl   NH4 Solids CO3  HCO3   P     P   NO3    SO4   Na    K      Ca    MG    Fe    Cu   Pb    Cr    Mn    Cd     C    pH  Conduct Color Odor

1  P  21FEB86 0.52  3.30  .   200.00  0  32.00   .     .   1.05  24.50 2.75 0.572  32.30 1.98  2.12 0.010 0.03 0.056 0.000 0.000 24.00 5.57  120.0   CD  H2S
1  P  07MAR86 0.50  5.00 0.02 150.00  0  44.00  7.90   .   0.00  24.50 2.41 0.541  42.20 1.72  2.42 0.013 0.05 0.015 0.012 0.000 23.00 5.85  130.0   CD  NONE
1  P  21MAR86 0.54  4.10 0.02 156.67  0  42.00  4.10 2.35 1.00  24.50 2.31 0.495  31.30 1.57  1.69 0.011 0.03 0.026 0.000 0.000 23.50 5.65  130.5   CD  NONE
1  P  15MAY86 0.54  5.90 0.02 150.00  0  30.00  4.60 1.25 0.55  24.50 2.38 0.482  31.00 1.49  2.08 0.010 0.03 0.016 0.026 0.012 24.00 5.45  140.0   CD  NONE
1  P  19JUN86 0.48  4.30 0.02 117.50  0  32.00  5.50 1.05  .    24.50 2.33 0.499  31.50 1.34  3.94 0.013 0.07 0.012 0.029 0.011 24.00 5.65  138.0   CD  H2S
1  X  11OCT86 0.70  4.62 0.02 162.50  0  32.00  4.25 1.40 1.75  24.50 3.15 0.506  36.20 1.45  4.44   .   0.04 0.018   .   0.000 25.00 5.45  150.0   CD  NONE
1  X  15NOV86 0.50  4.80 0.02 132.50  0  32.00  5.75 0.90 2.05  24.50 2.99 0.497  46.90 1.63  4.42 0.012 0.05 0.010 0.029 0.015 24.00 5.65  150.0   CD  SH2S
1  X  30DEC86 0.62  4.60 0.02 122.50  0  32.00  6.40 0.96 0.80  20.25 2.34 0.432  37.80 1.36  3.96 0.013 0.05 0.011 0.032 0.000 24.00 4.90  270.0   CD  SH2S
1  X  31JAN87 0.54  4.00 0.70 115.00  0  28.00  7.40 0.82 1.20  29.75 2.61 0.484   7.34 1.61  6.04 0.000 0.02 0.000 0.019 0.000 23.00 5.55  172.0   CD  NONE
1  X  28FEB87 0.58  4.60 0.14 127.50  0  22.00 23.00 0.80 0.30  24.25 4.47 1.320    .   1.74    .  0.022 0.04 0.015 0.067 0.014 23.00 5.65  147.0   CD  NONE
1  X  21MAR87 0.63  4.10 0.02 100.00  0  32.00 49.50 0.73 0.25  22.25 3.89 1.840 101.10 1.77  3.85 0.000 0.05 0.015 0.017 0.000 22.00 5.60  132.0   VCD NONE
1  X  15MAY87 0.67  4.40 0.02 102.50  0  26.00 83.00 0.85 0.70  27.00 3.76 1.850  91.80 1.32  4.96 0.000 0.04 0.000 0.018 0.000 20.00 5.85  148.0   VCD NONE
1  X  19JUN87 0.92  3.85 0.02  57.50  0  28.00 76.00 0.91 0.79  30.00 3.53 1.930  74.80 1.69  4.52 0.000 0.05 0.012 0.023 0.000 23.50 5.70  160.0   VCD NONE
1  X  17JUL87 0.57  5.00 0.02 102.50  0  22.00  7.40 0.95 0.91  25.10 2.60 0.301  37.80 1.91  3.23 0.000 0.03 0.010 0.037 0.000 23.75 5.60  165.0   SCD NONE
1  X  14AUG87 0.64  4.70 0.02 110.00  0  30.00  7.40 0.96 0.90  38.50   .    .    32.80 1.74  4.38   .     .  0.018 0.021   .   24.50 5.75  180.0   CL  NONE
1  X  18SEP87 0.50  4.20 0.00  95.00  .  36.00  7.20 0.97 0.79  32.00 3.22 0.350  28.70 1.68  3.72 0.000 0.02 0.000 0.030 0.000 24.20 5.35  180.0   CL  NONE
1  X  16OCT87 0.47  5.10 0.00  57.50  .  36.00  3.00 1.00 1.16  41.50 3.77 0.820  59.40 2.86  3.86 0.000 0.00 0.000 0.020 0.000 24.00 5.75  160.0   CD  NONE
1  X  20NOV87 0.50  5.90 0.00  72.50  .  22.00 17.40 0.94 0.97  40.61 3.74 0.820  58.20 2.54  4.17 0.000 0.03 0.020 0.020 0.000 24.50 6.45  270.0   CD  NONE
1  X  18DEC87 1.20  5.40 0.00 105.00  .  34.00 41.00 0.91 0.83  53.20 3.57 0.650  91.80 2.88  3.66 0.000 0.02 0.020 0.020 0.000 24.00 5.80  175.0   CD  NONE
1  X  15JAN88 0.54  5.40 0.24 105.00  .  22.00  4.40 0.94 0.41  49.50 2.27 0.520  14.30 1.98  2.46 0.000 0.02 0.000 0.000 0.010 23.00 5.45  162.0   CL  NONE
1  X  13FEB88 0.56  5.20 0.00 105.00  .  32.00  3.00 0.91 0.90  48.50 2.79 0.570  15.00 4.38  1.06 0.000 0.02 0.000 0.020 0.000 23.00 5.75  161.0   CL  NONE
1  X  11MAR88 0.52  5.90 0.00 102.50  .  24.00  2.80 0.91 0.36  37.60 2.80 0.550  33.60 1.99  1.52 0.000 0.02 0.000 0.030 0.000 23.00 5.45  178.0   CL  NONE
1  X  15APR88 0.54  4.20 0.00  72.50  .  22.00  3.00 0.88 0.99  44.10 2.90 0.560  16.70 2.96  2.11 0.000 0.02 0.000 0.020 0.000 21.50 5.25  190.0   CL  NONE
1  X  18MAY88 0.52  4.70 0.00 157.50  .  22.00  3.30 2.20 1.18  37.40 2.63 0.530  31.50 1.97  2.65 0.000 0.02 0.000 0.020 0.000 22.60 5.75  181.0   CL  NONE
1  X  15JUN88 0.48  5.20 0.00 147.50  .  22.00  2.90 0.90  .    29.70 2.72 0.360  33.30 2.71  2.36 0.000 0.04 0.000 0.030 0.000 23.50 5.70  187.0   CL  NONE
1  X  20JUL88 0.51  5.20 0.00 130.00  .  28.00  2.59 0.88 2.58  52.20 3.13 0.330  30.80 2.12  2.84 0.000 0.03 0.010 0.030 0.000 23.50 5.65     .    CL  NONE
1  X  18AUG88 0.64 14.11 0.00 177.00  .  20.68  7.72 0.12 0.73  82.88 4.20 1.000   4.33 2.70  3.60 0.010 0.08 0.010 0.000 0.000 23.50 6.45  200.0   CL  NONE
1  X  27OCT88 0.48  9.93 0.00  62.00  .  20.68  0.62 2.00 0.95  42.44 4.25 0.400  22.73 2.90  0.02 0.010 0.08 0.010 0.010 0.000 25.80 6.28  272.0   CL  NONE
1  X  08DEC88 0.50  1.10 0.32 238.00  .  19.42  1.10 1.01 0.72 134.77 4.87 0.490  29.07 3.73  0.21 0.010 0.08 0.000 0.010 0.000 24.20 5.11  338.0   CL  NONE
1  X  09FEB89 1.70  1.25 0.00 231.00  .  18.49  0.98 0.97 0.50 190.00 5.07 0.500  32.17 4.10  0.30 0.010 0.08 0.000 0.010 0.000 22.30 5.22  419.0   CL  NONE
1  X  04MAR89 0.32  1.45 0.00 357.00  .  17.56  0.98 0.94 0.43 236.50 5.53 0.610  44.83 5.20  0.17 0.010 0.08 0.000 0.000 0.000 24.70 5.23  402.0   CL  NONE
1  X  13JUN89 0.23  1.10 0.18 326.00  .  16.69  0.72 0.69 0.48 176.30 4.03 0.680  71.34 4.50  0.25 0.010 0.00 0.000 0.000 0.000 25.40 5.40  380.0   CL  NONE
1  X  14AUG89 0.23  1.70 0.12 323.00  .  18.22  0.86 0.86 0.32 144.68 3.88 0.280  69.38 3.85 47.45 0.070 0.08 0.010 0.000 0.000 25.10 5.33  366.0   CL  NONE
1  X  14NOV89 0.24  1.20 0.14    .    .    .    0.94 0.90 0.20     .   4.42 0.490  73.88 4.83  0.44 0.000 0.08 0.000 0.000 0.000 25.30 5.58  368.0   CL  NONE
1  X  12FEB90 0.22  1.35 0.14    .    .    .    0.78 0.76 0.20 127.00 3.49 0.480  58.95 3.92  0.24 0.010 0.43 0.000 0.000 0.000 24.00 4.73  324.0   CL  NONE
2  P  21FEB86 0.48 11.00 0.02 100.00  0  49.00    .    .  0.50   9.70 5.02 0.372  37.30 3.01  2.94 0.015 0.03 0.051 0.000 0.000   .   5.70  138.0   CD  NONE
2  P  07MAR86 0.47 10.50 0.02 233.00  0  48.00 12.87   .  0.40   9.70 4.82 0.866  41.20 3.53  3.71 0.014 0.06 0.033 0.019 0.013 24.00 5.80  150.0   CD  SH2S
2  P  21MAR86 0.53 10.10 0.02 163.33  0  48.00 14.50 4.75 1.65   9.70 4.50 0.710  48.70 3.14  2.96 0.012 0.05 0.056 0.000 0.000 23.00 5.80  143.0   CD  H2S
2  P  15MAY86 0.54 11.20 0.02 170.00  0  48.00  1.65 3.00 1.80   9.70 4.17 0.520  34.90 2.61  2.54 0.015 0.04 0.017 0.043 0.014 23.50 5.70  151.0   CD  H2S
2  P  19JUN86 0.49 10.00 0.02 120.00  0  50.00 12.85 1.90  .     9.70 4.60 0.736  58.30 3.37  2.98 0.015 0.07 0.033 0.041 0.021 23.50 5.80  158.0   VCD SH2S
2  X  11OCT86 0.62 10.70 0.02 187.50  0  48.00  6.25 1.33 0.35   9.25 4.99 0.640  39.40 2.95  2.62   .     .  0.038   .   0.013 25.00 5.60  165.0   CD  SH2S
2  X  15NOV86 0.42 10.20 0.02 130.00  0  50.00  8.50 1.50 0.35   8.60 4.81 0.643  66.40 3.79  4.02 0.018 0.03 0.023 0.053 0.000 25.00 6.10  160.0   CD  SH2S
2  X  30DEC86 0.58 12.00 0.02  87.50  0  46.00  8.50 2.35 0.42   7.70 4.45 0.330  69.20 2.78  4.23 0.016 0.04 0.015 0.853 0.010 23.50 5.65  152.0   CD  H2S
2  X  31JAN87 0.55  9.30 0.52 112.50  0  46.00 14.40 1.30 0.35   9.90 4.83 0.623   9.98 1.89  3.57 0.010 0.03 0.015 0.026 0.010 23.00 5.65  160.0   CD  H2S
2  X  28FEB87 0.55 11.50 0.02 155.00  0  44.00 24.00 1.40 0.01  11.50 7.87 1.830    .   3.07  6.89 0.024 0.05 0.023 0.073 0.022 24.00 5.55  160.5   CD  SH2S
2  X  21MAR87 0.56 10.00 0.25 112.50  0  42.00 46.50 1.58 0.02   7.63 6.18 2.310  81.60 2.77  3.24 0.010 0.03 0.022 0.033 0.017 23.50 6.35  161.0   CD  SH2S
2  X  15MAY87 0.66 10.80 0.02  95.00  0  42.00 85.00 1.55 0.04   7.90 4.92 2.500  83.70 2.89  2.89 0.010 0.02 0.025 0.025 0.010 23.50 5.65  160.0   CD  NONE
2  X  19JUN87 0.94  9.41 0.02  90.00  0  58.00 41.00 1.60 0.03  10.40 4.75 2.040  78.30 3.23  2.97 0.000 0.04 0.018 0.039 0.000 24.20 5.70  158.0   VCD SH2S
2  X  17JUL87 0.60 10.50 0.02  95.00  0  34.00  4.60 1.65 0.06  10.00 4.26 0.312  29.10 2.95  3.13 0.000 0.05 0.035 0.048 0.011 24.00 5.95  170.0   CD  SH2S
```

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
2	X	14AUG87	0.77	10.10	0.02	92.50	0	40.00	4.40	1.72	0.17	14.60	.	.	31.60	3.12	4.86	.	.	0.027	0.045	.	24.0	6.65	178.0	SCD	SH2S
2	X	18SEP87	0.49	9.50	0.00	75.00	.	26.00	5.40	1.52	0.21	10.80	4.79	0.300	25.30	2.20	2.95	0.000	0.03	0.020	0.030	0.010	25.0	5.75	233.0	CL	SH2S
2	X	16OCT87	0.54	11.00	0.16	55.00	.	40.00	4.40	1.35	0.02	10.10	5.41	1.020	68.50	3.82	3.02	0.000	0.02	0.020	0.030	0.010	24.0	5.75	175.0	CD	NONE
2	X	20NOV87	0.53	12.90	0.00	70.00	.	42.00	17.00	1.65	0.07	10.24	5.27	0.800	56.70	3.23	2.32	0.000	0.03	0.030	0.040	0.000	24.0	6.55	182.0	CD	SH2S
2	X	18DEC87	2.20	11.00	0.12	70.00	.	46.00	18.40	1.08	0.05	17.90	5.56	0.780	81.60	3.34	2.84	0.000	0.02	0.040	0.030	0.000	.	6.10	.	CD	SH2S
2	X	15JAN88	0.55	9.70	1.40	92.50	.	36.00	9.20	1.35	0.08	18.80	3.73	0.490	12.20	3.52	2.49	0.000	0.03	0.000	0.050	0.000	24.0	5.60	160.0	CL	NONE
2	X	13FEB88	0.56	12.00	0.00	87.50	.	38.00	6.00	1.07	0.24	19.80	3.88	0.440	17.30	3.85	2.11	0.000	0.04	0.000	0.030	0.000	23.5	5.75	158.0	CL	SH2S
2	X	11MAR88	0.90	14.00	0.10	90.00	.	34.00	4.20	1.08	0.44	12.00	4.41	0.460	30.20	2.78	2.25	0.000	0.02	0.010	0.030	0.020	23.5	5.75	160.0	CL	SH2S
2	X	15APR88	0.92	9.30	0.11	72.50	.	32.00	4.40	0.95	0.22	12.10	4.30	0.400	16.00	3.09	2.32	0.000	0.03	0.000	0.040	0.000	23.5	5.45	155.0	CL	SH2S
2	X	18MAY88	0.54	11.20	0.00	92.50	.	30.00	1.10	1.05	0.59	11.60	3.31	0.450	22.60	3.62	2.22	0.000	0.03	0.000	0.040	0.000	24.0	5.75	168.0	CL	SH2S
2	X	15JUN88	0.51	13.20	0.00	122.50	.	32.00	2.40	1.26	.	24.80	3.77	0.250	24.80	1.32	2.07	0.000	0.02	0.000	0.050	0.010	23.1	5.75	158.0	CL	SH2S
2	X	20JUL88	0.54	13.20	0.00	95.00	.	36.00	7.04	1.69	0.86	10.30	4.05	0.250	20.90	2.36	2.11	0.000	0.02	0.000	0.060	0.010	25.7	5.75	.	CL	SH2S
2	X	18AUG88	0.71	41.27	0.00	101.00	.	46.53	12.08	0.10	0.00	9.97	3.10	0.800	2.41	2.10	3.20	0.000	0.05	0.000	0.010	0.000	24.5	5.85	140.0	CL	NONE
2	X	27OCT88	0.47	12.00	0.00	.	.	32.05	0.69	1.88	0.76	50.07	3.73	0.320	10.60	1.70	0.75	0.000	0.05	0.000	0.010	0.000	26.6	6.40	122.6	CL	NONE
2	X	08DEC88	0.52	4.15	0.34	94.00	.	31.28	1.28	1.17	0.12	17.74	4.20	0.340	9.70	1.97	11.50	0.000	0.05	0.050	0.020	0.000	25.5	5.19	130.0	CL	NONE
2	X	09FEB89	2.70	3.60	0.00	2.00	.	32.08	1.08	1.07	0.30	18.60	4.30	0.330	12.40	2.00	1.66	0.000	0.05	0.000	0.000	0.000	23.1	5.30	134.2	SCD	NONE
2	X	04MAR89	0.31	4.80	0.35	96.00	.	34.03	1.16	1.06	0.05	15.13	4.80	0.440	9.00	2.20	3.48	0.000	0.05	0.000	0.000	0.000	26.2	5.25	128.6	CD	H2S
2	X	13JUN89	0.36	3.95	0.12	103.00	.	32.26	1.28	1.29	0.07	14.54	3.63	0.330	18.85	1.80	4.73	0.030	0.05	0.000	0.000	0.000	26.4	5.12	130.6	SCD	H2S
2	X	14AUG89	0.27	6.20	0.11	127.00	.	34.16	1.42	1.35	0.01	13.22	3.66	0.050	18.89	0.94	2.29	0.000	0.05	0.000	0.000	0.000	28.4	6.06	135.0	CL	NONE
2	X	14NOV89	0.28	3.45	0.11	.	.	.	1.28	1.21	0.02	.	4.61	0.310	21.58	1.57	1.48	0.000	0.05	0.000	0.000	0.000	26.9	5.75	143.0	CL	SH2S
2	X	12FEB90	0.24	4.50	0.12	.	.	.	1.24	1.20	0.01	36.60	4.69	0.200	27.13	2.17	2.99	.	.	.	.	.	24.5	4.92	179.0	CL	DUNG
3	P	21FEB86	0.40	8.50	2.30	100.00	0	55.00	.	.	0.00	3.20	4.17	0.951	27.40	5.42	3.47	0.000	0.03	0.054	0.015	0.000	.	5.55	148.0	BR	H2S
3	P	07MAR86	0.40	7.30	2.30	156.70	0	56.00	11.83	.	2.60	3.20	3.67	0.907	25.50	4.14	4.15	0.000	0.05	0.012	0.023	0.000	22.5	5.75	150.0	BR	H2S
3	P	21MAR86	0.40	7.20	2.70	160.00	0	54.00	4.50	3.00	0.00	3.20	3.62	0.823	23.80	4.08	3.42	0.000	0.04	0.026	0.011	0.000	23.0	5.55	148.0	BR	H2S
3	P	15MAY86	0.48	8.40	1.66	170.00	0	52.00	5.15	4.50	2.00	3.20	3.60	0.920	26.00	4.16	3.13	0.000	0.04	0.024	0.053	0.013	23.0	5.45	150.0	BR	H2S
3	P	19JUN86	0.43	7.50	2.55	120.00	0	52.00	4.60	3.25	.	3.20	3.43	0.861	23.70	4.26	2.93	0.000	0.08	0.013	0.048	0.018	24.0	5.65	141.0	BR	H2S
3	X	11OCT86	0.53	7.00	2.20	192.50	0	52.00	8.25	1.77	1.44	.	3.86	0.886	24.80	3.91	4.38	.	.	0.022	.	0.000	25.0	5.45	155.0	BR	H2S
3	X	15NOV86	0.37	8.10	4.20	190.00	0	52.00	5.75	2.46	1.10	1.80	3.56	0.647	24.10	4.28	3.92	0.011	0.04	0.011	0.078	0.013	23.0	6.05	145.0	BR	H2S
3	X	30DEC86	0.53	6.00	3.30	150.00	0	50.00	9.60	2.41	1.10	0.80	3.21	0.985	21.60	3.88	4.25	0.011	0.03	0.011	0.056	0.000	23.5	5.20	147.5	BR	H2S
3	X	31JAN87	0.51	7.10	2.30	130.00	0	52.00	9.80	2.00	1.03	1.00	3.33	0.704	2.04	1.82	3.63	0.000	0.02	0.026	0.028	0.000	23.0	5.25	150.0	BR	H2S
3	X	28FEB87	0.48	6.00	2.35	140.00	0	54.00	16.00	2.15	0.03	1.20	3.43	0.923	31.30	3.27	4.91	0.000	0.05	0.012	0.042	0.000	23.5	5.25	158.0	BR	H2S
3	X	21MAR87	0.48	6.00	2.35	106.25	0	50.00	15.48	2.35	0.01	3.50	3.36	0.935	19.40	3.11	3.57	0.000	0.03	0.027	0.051	0.000	22.5	5.45	145.0	BR	H2S
3	X	15MAY87	0.53	7.10	2.45	92.50	0	34.00	13.00	2.12	0.08	3.30	3.23	1.350	19.80	3.71	3.40	0.000	0.03	0.018	0.049	0.000	22.5	5.80	148.0	BR	H2S
3	X	19JUN87	0.77	5.65	2.70	92.50	0	30.00	12.75	2.15	0.06	3.63	3.42	1.080	16.50	3.90	3.96	0.000	0.03	0.023	0.031	0.011	24.0	5.35	155.0	BR	H2S
3	X	17JUL87	0.52	9.00	1.73	67.50	0	42.00	4.05	2.40	0.05	3.90	3.02	0.485	12.80	3.22	3.12	0.000	0.03	0.031	0.027	0.000	21.5	5.50	162.0	CD	H2S
3	X	14AUG87	0.52	6.70	2.20	97.50	0	48.00	3.40	2.36	0.11	5.50	.	.	13.90	3.56	4.03	.	.	0.021	0.054	.	23.1	5.35	163.0	CL	H2S
3	X	18SEP87	0.43	5.70	1.50	97.50	.	42.00	3.75	2.37	0.24	5.10	3.87	0.550	12.70	3.58	3.27	0.000	0.03	0.000	0.030	0.000	23.2	5.70	165.0	CL	H2S
3	X	16OCT87	0.42	6.80	2.50	45.00	.	34.00	3.10	1.87	0.05	3.70	3.61	0.560	16.20	3.75	3.57	0.000	0.03	0.020	0.040	0.000	22.2	5.55	163.0	BR	H2S
3	X	20NOV87	0.47	6.80	2.20	80.00	.	46.00	2.35	1.90	0.10	3.27	3.57	0.550	10.40	3.61	3.26	0.000	0.04	0.020	0.020	0.000	24.0	6.40	295.0	BR	H2S
3	X	18DEC87	0.54	8.00	2.20	77.50	.	54.00	2.05	2.05	0.05	3.20	4.99	0.600	15.10	3.73	3.28	0.000	0.02	0.020	0.020	0.000	.	6.05	.	SCD	H2S
3	X	15JAN88	0.50	9.00	3.30	120.00	.	46.00	2.80	2.17	0.10	3.20	2.80	0.610	6.46	4.52	2.21	0.000	0.00	0.000	0.060	0.000	23.0	5.55	151.0	CL	H2S
3	X	13FEB88	0.52	8.60	2.40	87.50	.	46.00	2.70	1.55	0.08	3.70	3.05	0.640	19.50	5.54	2.17	0.000	0.06	0.000	0.040	0.000	23.5	5.05	150.0	CL	H2S
3	X	11MAR88	0.51	9.60	2.30	112.50	.	20.00	1.30	2.06	0.53	2.30	3.33	0.690	8.15	4.23	2.34	0.000	0.04	0.000	0.050	0.000	23.2	5.15	150.0	CL	H2S
3	X	15APR88	0.50	7.20	2.32	72.50	.	40.00	2.40	2.20	0.27	4.80	3.41	0.610	6.75	4.93	2.18	0.000	0.04	0.000	0.050	0.000	22.0	5.30	149.0	CL	H2S
3	X	18MAY88	0.48	8.20	1.90	140.00	.	28.00	2.60	0.92	0.32	3.20	2.62	0.640	10.10	4.76	2.84	0.000	0.03	0.000	0.050	0.000	23.0	5.65	158.0	CL	H2S
3	X	15JUN88	0.46	9.70	1.75	150.00	.	40.00	1.10	1.83	.	5.10	3.51	0.180	16.10	2.82	2.92	0.000	0.02	0.000	0.060	0.010	24.0	5.60	152.0	CL	H2S
3	X	20JUL88	0.49	8.00	1.90	112.50	.	40.00	2.78	2.76	0.42	7.80	3.10	0.450	12.10	2.42	2.62	0.010	0.02	0.000	0.080	0.000	24.5	5.55	.	CL	H2S
3	X	18AUG88	0.69	20.18	0.11	119.00	.	51.70	10.40	0.17	0.00	4.01	3.90	1.400	1.49	3.80	3.40	0.000	0.06	0.000	0.020	0.000	24.0	6.55	133.0	CL	H2S

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
3	X	27OCT88	0.47	31.90	0.81	17.00	.	47.56	2.02	3.60	0.29	6.17	3.50	0.640	6.33	2.80	2.53	0.000	0.06	0.020	0.020	0.000	26.4	6.06	117.3	CL	NONE
3	X	08DEC88	0.50	2.75	1.60	76.00	.	40.99	2.68	1.65	0.08	8.93	3.63	0.620	6.70	2.80	2.48	0.000	0.06	0.020	0.050	0.000	24.2	5.10	119.1	CL	H2S
3	X	09FEB89	2.35	2.00	1.25	11.00	.	44.58	2.85	2.92	0.07	2.40	3.53	0.610	5.90	2.63	2.58	0.000	0.06	0.000	0.010	0.000	22.0	5.70	127.1	CL	H2S
3	X	04MAR89	0.36	2.10	1.70	94.00	.	42.81	2.84	2.83	0.05	2.77	3.90	0.750	3.80	2.78	2.37	0.000	0.06	0.000	0.010	0.000	25.2	5.22	108.8	CL	H2S
3	X	13JUN89	0.29	1.85	1.55	98.00	.	40.05	2.82	2.89	0.12	2.96	2.93	0.530	9.25	2.20	2.73	0.000	0.00	0.000	0.000	0.000	25.9	5.26	106.8	CL	H2S
3	X	14AUG89	0.29	2.45	1.90	122.00	.	36.44	3.12	2.93	0.06	4.54	2.43	0.320	9.86	1.63	2.12	0.000	0.06	0.000	0.000	0.000	24.6	5.34	106.0	CL	H2S
3	X	14NOV89	0.27	1.70	1.85	.	.	.	3.04	3.04	0.07	.	3.47	0.580	10.92	2.23	2.37	0.000	0.06	0.000	0.020	0.000	25.4	5.04	109.2	CL	SH2S
3	X	12FEB90	0.24	2.35	1.95	.	.	.	3.28	2.96	0.05	2.60	2.78	0.640	11.62	2.11	2.45	.	.	.	.	.	24.5	4.99	104.0	CL	SH2S
4	P	21FEB86	0.76	17.00	0.44	200.00	0	94.00	.	.	0.00	13.25	8.89	0.211	31.30	10.50	2.94	0.000	0.02	0.052	0.103	0.000	.	6.05	230.0	CD	H2S
4	P	07MAR86	0.71	16.00	0.42	180.00	0	86.00	3.33	.	0.00	13.25	7.36	0.237	31.60	7.67	2.56	0.000	0.04	0.000	0.101	0.000	23.5	6.25	260.0	CL	SH2S
4	P	21MAR86	0.78	16.00	0.40	166.67	0	88.00	3.25	1.35	1.67	13.25	7.54	0.208	31.70	11.20	2.18	0.000	0.03	0.016	0.101	0.000	23.0	6.30	270.0	CL	H2S
4	P	15MAY86	0.78	18.50	0.22	193.30	0	90.00	1.15	1.15	0.95	13.25	7.21	0.201	27.40	11.20	2.19	0.011	0.03	0.012	0.137	0.000	23.0	6.00	280.0	CL	H2S
4	P	19JUN86	0.72	15.50	0.68	165.00	0	90.00	2.00	1.75	.	13.25	7.86	0.315	34.80	11.80	2.36	0.000	0.08	0.000	0.147	0.190	23.5	6.25	285.0	CD	H2S
4	X	11OCT86	0.82	16.10	0.56	210.00	0	96.00	3.75	0.87	0.50	3.70	7.46	0.277	29.30	11.70	2.11	.	.	0.000	.	.	25.0	5.95	280.0	CL	H2S
4	X	15NOV86	0.66	16.00	1.40	195.00	0	96.00	4.25	0.86	0.60	3.20	6.98	0.237	36.40	12.29	2.39	0.000	0.02	0.000	0.149	0.000	25.0	6.45	270.0	CL	H2S
4	X	30DEC86	0.89	17.00	0.76	160.00	0	92.00	3.60	1.02	0.75	0.63	6.49	0.217	27.00	12.03	2.32	0.000	0.02	0.000	0.105	0.000	23.5	6.20	270.0	SCD	H2S
4	X	31JAN87	0.77	15.00	0.75	150.00	0	94.00	3.80	0.80	0.70	3.50	7.74	0.205	8.61	14.80	2.19	0.000	0.04	0.014	0.094	0.000	23.5	6.30	290.0	SCD	H2S
4	X	28FEB87	0.85	18.00	0.64	195.00	0	92.00	24.00	0.75	0.03	3.83	7.05	0.877	71.20	14.50	3.26	0.000	0.04	0.000	0.116	0.000	23.5	6.15	284.5	VCD	H2S
4	X	21MAR87	0.80	16.50	0.68	162.50	0	102.00	40.60	0.62	0.03	3.30	7.15	0.966	51.70	11.80	2.44	0.000	0.03	0.000	0.112	0.000	22.5	6.70	278.0	CD	H2S
4	X	15MAY87	0.92	26.50	0.59	170.00	0	86.00	27.00	0.60	0.85	5.10	6.59	0.832	46.50	11.10	2.38	0.000	0.03	0.000	0.125	0.000	21.0	6.25	298.0	CD	H2S
4	X	19JUN87	1.00	23.60	0.58	130.00	0	86.00	37.40	0.70	0.03	5.50	6.69	1.100	43.10	9.72	2.19	0.000	0.03	0.000	0.107	0.000	23.5	6.25	297.0	CD	H2S
4	X	17JUL87	0.82	23.70	0.39	137.50	0	96.00	14.00	0.82	0.05	4.50	5.04	0.076	20.20	10.80	2.57	0.000	0.04	0.000	0.121	0.000	24.0	6.40	315.0	SCD	H2S
4	X	14AUG87	0.80	22.50	0.45	170.00	0	102.00	3.60	0.86	0.12	5.80	.	.	30.20	11.20	2.39	.	.	0.000	0.103	.	23.0	6.85	320.0	SCD	H2S
4	X	18SEP87	0.70	19.00	0.27	145.00	.	82.00	5.40	0.93	0.18	3.50	7.58	0.200	27.40	10.50	2.17	0.000	0.02	0.080	0.080	0.000	24.0	6.30	340.0	SCD	SH2S
4	X	16OCT87	0.65	19.90	0.74	125.00	.	81.00	2.80	0.80	0.20	3.60	8.17	0.520	69.90	7.17	2.33	0.000	0.04	0.000	0.060	0.000	24.5	6.35	310.0	CD	H2S
4	X	20NOV87	0.78	19.50	0.50	122.50	.	92.00	0.40	0.80	0.10	2.91	9.38	0.460	48.90	8.37	2.25	0.000	0.01	0.000	0.070	0.000	24.5	6.85	310.0	VCD	SH2S
4	X	18DEC87	1.10	20.50	0.64	125.00	.	62.00	17.60	0.78	0.03	3.10	10.30	0.520	67.60	8.95	2.56	0.000	0.02	0.000	0.060	0.000	.	6.50	.	CD	H2S
4	X	15JAN88	0.79	16.50	1.20	150.00	.	82.00	11.00	0.85	0.08	3.70	5.85	0.380	15.90	7.51	2.07	0.000	0.02	0.000	0.070	0.000	24.0	6.20	293.0	CL	H2S
4	X	13FEB88	0.83	20.00	0.44	160.00	.	74.00	3.00	0.75	0.08	2.10	5.62	0.390	12.60	2.08	1.68	0.000	0.07	0.000	0.040	0.000	23.0	6.15	295.0	CL	H2S
4	X	11MAR88	0.84	21.00	0.00	155.00	.	84.00	5.40	0.86	0.92	3.00	7.73	0.300	23.70	8.42	1.58	0.000	0.02	0.000	0.050	0.000	22.6	6.15	298.0	CL	H2S
4	X	15APR88	0.92	15.20	0.56	92.50	.	96.00	4.20	0.90	0.05	2.20	7.55	0.400	14.60	8.19	1.92	0.000	0.03	0.000	0.070	0.000	22.2	5.95	286.0	CL	H2S
4	X	18MAY88	0.80	17.70	0.25	170.00	.	78.00	1.70	0.80	1.07	3.00	5.94	0.310	15.70	9.95	1.73	0.000	0.02	0.000	0.070	0.000	22.1	6.25	297.0	CL	H2S
4	X	15JUN88	0.75	20.80	0.30	200.00	.	82.00	6.10	0.73	.	2.50	6.01	0.070	30.10	11.30	1.77	0.000	0.02	0.010	0.090	0.000	22.1	6.45	295.0	CL	H2S
4	X	20JUL88	0.85	18.50	0.32	155.00	.	82.00	0.80	0.72	0.66	0.60	6.42	0.110	21.40	9.62	1.92	0.000	0.03	0.020	0.100	0.000	24.9	6.30	.	CL	H2S
4	X	18AUG88	1.14	67.49	1.94	179.00	.	134.42	8.08	0.29	0.00	0.04	7.70	1.000	2.90	18.60	2.80	0.000	0.03	0.000	0.120	0.000	24.0	6.55	262.0	CL	H2S
4	X	27OCT88	0.80	51.40	0.18	34.00	.	110.64	0.48	1.58	0.24	1.26	8.03	0.150	14.63	12.97	1.01	0.000	0.03	0.020	0.100	0.000	26.3	6.56	240.0	CL	H2S
4	X	08DEC88	0.80	16.00	0.62	133.00	.	114.34	0.92	0.90	0.12	1.42	8.57	0.110	15.50	14.30	1.29	0.000	0.03	0.000	0.140	0.000	24.9	5.68	263.0	CL	H2S
4	X	09FEB89	4.60	6.00	0.28	92.00	.	127.79	0.92	0.74	0.05	1.50	8.30	0.100	15.23	14.70	1.62	0.000	0.03	0.000	0.160	0.000	22.8	5.96	268.0	CL	NONE
4	X	04MAR89	0.44	6.60	0.88	163.00	.	120.74	0.92	0.54	0.07	1.13	7.95	0.130	9.98	15.85	1.51	0.000	0.03	0.000	0.170	0.000	25.4	6.13	235.0	CL	H2S
4	X	13JUN89	0.44	4.80	0.58	166.00	.	114.60	0.86	0.81	0.14	1.44	6.80	0.110	21.15	14.32	1.55	0.000	0.03	0.000	0.150	0.000	27.1	6.38	244.0	CL	H2S
4	X	14AUG89	0.46	6.80	0.40	176.00	.	113.31	0.96	0.94	0.04	3.55	6.89	0.020	19.16	17.40	1.16	0.000	0.03	0.010	0.140	0.000	28.0	6.32	216.0	CL	H2S
4	X	14NOV89	0.56	5.00	0.44	.	.	.	0.92	0.88	0.02	.	8.21	0.280	19.65	20.22	1.41	0.000	0.03	0.010	0.140	0.000	27.4	5.96	250.0	CL	SH2S
4	X	12FEB90	0.52	6.80	0.44	.	.	.	0.90	0.85	0.02	7.10	7.89	0.000	21.18	21.90	1.74	.	.	.	.	.	24.2	5.55	255.0	CL	H2S
5	P	21FEB86	0.46	4.80	0.02	200.00	0	52.00	.	.	1.80	8.00	7.27	1.780	97.40	8.02	2.76	0.011	0.05	0.103	0.056	0.000	.	6.30	145.0	CD	NONE
5	P	07MAR86	0.44	5.50	0.02	216.00	0	52.00	20.00	.	3.20	8.00	6.72	1.240	97.10	5.65	2.55	0.013	0.04	0.056	0.036	0.012	24.0	6.40	150.0	CD	NONE
5	P	21MAR86	0.47	5.20	0.02	253.33	0	54.00	23.00	9.35	1.10	8.00	5.63	1.070	98.40	7.76	2.82	0.015	0.04	0.067	0.013	0.000	23.0	6.25	160.0	CD	NONE
5	P	15MAY86	0.52	5.40	0.02	273.30	0	56.00	28.50	6.50	0.25	8.00	7.14	1.290	95.60	6.32	2.97	0.011	0.05	0.073	0.090	0.023	23.0	6.20	142.0	CD	NONE
5	P	19JUN86	0.43	5.10	0.02	137.50	0	52.00	4.10	1.95	.	8.00	5.15	0.961	92.10	6.98	1.56	0.000	0.05	0.037	0.057	0.024	24.5	6.35	145.0	CD	NONE

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
5	X	11OCT86	0.54	5.20	0.02	137.5	0	52.00	15.25	0.87	3.60	7.25	7.53	1.460	98.10	6.72	2.68	.	.	0.066	.	0.014	24.00	6.35	130.0	CD	NONE
5	X	15NOV86	0.44	4.80	0.02	137.0	0	56.00	14.25	0.93	3.23	3.30	7.01	0.736	129.00	7.17	3.33	0.012	0.03	0.069	0.161	0.000	24.00	5.65	130.0	CD	NONE
5	X	30DEC86	0.56	5.70	0.02	137.5	0	48.00	22.00	2.18	2.50	0.95	6.39	1.200	91.00	7.76	4.72	0.016	0.05	0.038	0.146	0.010	23.00	5.50	140.0	CD	NONE
5	X	31JAN87	0.57	4.05	0.02	120.0	0	54.00	14.40	0.90	2.85	3.70	6.81	0.907	115.20	5.22	2.77	0.025	0.04	0.030	0.062	0.000	23.00	6.00	132.0	CD	NONE
5	X	28FEB87	0.57	5.20	0.29	125.0	0	50.00	25.00	0.90	2.04	3.60	6.84	4.030	.	8.07	10.51	0.041	0.03	0.041	0.332	0.048	24.00	5.85	145.0	CD	NONE
5	X	21MAR87	0.54	4.80	0.02	80.0	0	42.00	65.70	0.80	2.13	3.80	9.20	4.080	74.80	7.18	3.04	0.020	0.02	0.038	0.151	0.020	23.00	5.95	141.0	CD	NONE
5	X	15MAY87	1.45	4.90	0.02	87.5	0	40.00	100.00	0.93	2.68	3.50	6.85	3.950	86.70	6.72	2.87	0.000	0.03	0.043	0.132	0.000	23.50	6.20	135.0	VCD	NONE
5	X	19JUN87	1.80	4.38	0.02	72.5	0	42.00	81.00	0.96	1.63	3.59	6.11	2.750	64.20	6.82	2.84	0.012	0.04	0.031	0.123	0.000	24.00	5.80	135.0	CD	NONE
5	X	17JUL87	0.77	5.60	0.02	82.5	0	38.00	6.60	0.97	2.79	4.00	3.16	0.424	48.10	7.14	2.78	0.000	0.04	0.049	0.097	0.000	23.00	6.30	140.0	SCD	NONE
5	X	14AUG87	1.05	5.00	0.02	102.5	0	44.00	5.60	0.95	2.66	3.60	.	.	51.10	6.99	2.54	.	.	0.063	0.111	.	21.50	5.95	140.0	SCD	NONE
5	X	18SEP87	0.70	3.80	0.00	65.0	.	34.00	7.00	1.03	0.47	4.00	3.54	0.410	45.30	4.48	3.12	0.000	0.04	0.050	0.120	0.020	23.80	6.15	151.0	SCD	NONE
5	X	16OCT87	1.25	5.50	0.00	20.0	.	42.00	6.00	0.88	2.53	3.30	5.76	1.250	70.40	5.91	3.62	0.020	0.06	0.040	0.140	0.000	24.00	6.20	150.0	CD	NONE
5	X	20NOV87	0.91	5.90	0.00	67.5	.	52.00	16.00	0.90	2.06	4.03	5.83	0.880	60.80	5.44	3.11	0.000	0.01	0.030	0.140	0.000	24.00	6.80	327.0	VCD	NONE
5	X	18DEC87	0.68	6.30	0.00	80.0	.	38.00	20.00	0.95	3.73	4.90	6.58	0.680	127.40	5.71	2.99	0.000	0.04	0.030	0.160	0.000	.	6.40	.	CD	NONE
5	X	15JAN88	0.72	3.80	1.40	110.0	.	36.00	0.00	0.88	1.85	4.80	3.10	0.340	15.80	5.34	1.12	0.000	0.06	0.000	0.080	0.000	22.00	6.05	132.0	CL	NONE
5	X	13FEB88	0.60	6.00	0.00	72.5	.	36.00	4.20	0.90	2.45	6.50	2.94	0.250	20.20	4.35	0.29	0.000	0.02	0.000	0.020	0.000	24.00	5.65	132.0	CL	NONE
5	X	11MAR88	1.10	6.00	0.00	92.5	.	36.00	6.00	0.85	3.76	8.80	4.15	0.280	15.70	5.53	1.06	0.010	0.03	0.000	0.070	0.000	23.80	5.65	135.0	CL	NONE
5	X	15APR88	1.15	4.60	0.11	57.5	.	30.00	6.00	0.93	0.87	6.40	4.08	0.270	11.70	5.45	1.35	0.000	0.02	0.000	0.040	0.000	23.00	6.10	125.0	CL	NONE
5	X	18MAY88	0.84	5.20	0.00	87.5	.	24.00	4.50	0.90	2.34	9.60	3.17	0.290	14.30	4.85	1.31	0.000	0.04	0.000	0.030	0.000	23.50	6.15	140.0	CL	NONE
5	X	15JUN88	0.59	6.40	0.00	107.5	.	32.00	1.80	0.92	.	12.60	3.55	0.060	27.10	3.92	0.56	0.000	0.04	0.000	0.080	0.000	24.50	6.05	149.0	CL	NONE
5	X	20JUL88	0.66	6.40	0.00	100.0	.	34.00	4.56	0.83	3.43	13.10	3.42	0.190	26.10	3.62	0.37	0.000	0.02	0.000	0.070	0.000	25.10	6.15	.	CL	NONE
5	X	18AUG88	0.79	22.07	0.40	104.0	.	36.19	23.23	0.06	2.22	13.61	4.50	1.000	2.91	3.70	2.50	0.000	0.06	0.010	0.000	0.000	24.00	6.95	130.0	CL	NONE
5	X	27OCT88	0.43	10.28	0.00	.	.	13.44	0.84	2.29	1.66	15.81	4.70	0.260	7.00	2.00	0.11	0.000	0.06	0.030	0.000	0.000	26.20	6.25	85.1	CL	NONE
5	X	08DEC88	0.48	2.60	0.24	96.0	.	17.26	1.30	1.17	2.09	35.97	5.60	0.270	9.50	3.43	0.05	0.000	0.06	0.010	0.010	0.000	24.30	5.42	124.7	CL	NONE
5	X	09FEB89	2.60	1.50	0.00	14.0	.	17.40	1.20	1.20	1.90	28.60	4.98	0.260	9.47	3.50	0.00	0.000	0.06	0.010	0.040	0.000	22.90	5.90	106.0	SCD	NONE
5	X	04MAR89	0.34	1.85	0.20	88.0	.	21.95	1.08	1.08	1.98	22.73	5.20	0.320	7.10	3.50	0.05	0.000	0.06	0.000	0.000	0.000	25.80	5.69	92.4	CL	NONE
5	X	13JUN89	0.33	1.40	0.12	100.0	.	31.15	1.04	1.02	1.45	19.03	3.80	0.230	11.39	3.93	0.06	0.000	0.06	0.010	0.000	0.000	26.30	5.85	116.1	CL	NONE
5	X	14AUG89	0.25	2.20	0.10	120.0	.	41.56	0.98	1.00	1.09	16.41	3.36	0.000	14.51	5.36	0.00	0.000	0.06	0.000	0.000	0.000	24.80	5.98	135.0	CL	NONE
5	X	14NOV89	0.27	1.65	0.15	.	.	.	1.00	0.98	0.81	.	4.46	0.160	17.32	6.22	0.00	0.000	0.06	0.000	0.000	0.000	25.40	5.95	139.4	CL	NONE
5	X	12FEB90	0.23	2.75	0.16	.	.	.	0.94	0.93	0.70	12.10	4.32	0.070	22.78	7.30	0.20	.	.	.	.	.	24.50	5.27	147.0	CL	NONE
6	P	21FEB86	0.42	6.80	0.02	136.7	0	31.00	.	.	3.75	7.00	4.18	0.281	17.70	3.78	0.12	0.000	0.03	0.044	0.000	0.000	.	6.00	120.0	CL	NONE
6	P	07MAR86	0.50	7.10	0.02	160.0	0	32.00	10.33	.	1.65	7.00	4.35	0.500	30.80	2.72	0.82	0.000	0.03	0.000	0.000	0.000	24.00	5.75	130.0	CL	NONE
6	P	21MAR86	0.52	6.80	0.02	140.0	0	30.00	5.50	3.90	2.13	7.00	4.35	0.435	29.40	2.31	0.66	0.000	0.03	0.025	0.000	0.000	24.00	5.85	120.0	CD	NONE
6	P	15MAY86	0.63	7.10	0.02	143.3	0	28.00	2.60	3.75	0.00	7.00	4.31	0.483	29.20	1.48	1.49	0.000	0.03	0.000	0.028	0.000	23.50	5.70	109.0	CD	NONE
6	P	19JUN86	0.57	6.50	0.02	55.0	0	28.00	2.75	2.50	.	7.00	4.24	0.610	29.10	1.34	0.58	0.000	0.05	0.014	0.019	0.026	23.80	5.80	105.0	CD	NONE
6	X	11OCT86	0.67	7.70	0.02	117.5	0	34.00	4.65	1.33	0.82	5.50	4.51	0.363	21.40	1.14	0.32	.	.	0.000	.	.	25.00	5.65	115.0	CL	NONE
6	X	15NOV86	0.54	7.00	0.02	100.0	0	22.00	3.60	1.40	0.90	4.80	4.28	0.319	22.20	1.25	0.31	0.000	0.06	0.035	0.104	0.013	25.00	6.10	110.0	CL	NONE
6	X	30DEC86	0.68	7.40	0.02	110.0	0	26.00	5.20	1.64	1.40	3.40	4.03	0.257	21.70	1.32	1.04	0.000	0.06	0.014	0.013	0.000	23.50	5.55	102.0	CD	NONE
6	X	31JAN87	0.65	6.20	0.02	75.0	0	22.00	4.08	1.20	1.20	5.20	4.23	0.253	17.80	1.14	0.52	0.000	0.03	0.000	0.010	0.000	23.50	5.70	110.0	SCD	NONE
6	X	28FEB87	0.69	7.40	0.02	100.0	0	22.00	22.00	1.20	1.00	5.40	4.78	1.000	71.40	1.24	2.14	0.000	0.02	0.014	0.047	0.000	24.50	5.60	107.5	CD	NONE
6	X	21MAR87	0.67	6.10	0.02	67.5	0	20.00	39.00	1.25	0.75	5.74	4.92	1.320	53.40	1.25	0.96	0.000	0.03	0.014	0.000	0.000	23.50	6.30	105.0	VCD	NONE
6	X	15MAY87	1.00	6.80	0.02	75.0	0	20.00	27.40	1.40	0.83	5.10	4.27	1.970	62.80	1.33	1.08	0.000	0.03	0.000	0.000	0.000	23.00	5.55	104.0	CD	NONE
6	X	19JUN87	1.05	6.40	0.02	42.5	0	30.00	38.40	1.35	0.68	5.40	4.57	1.660	58.50	1.52	1.01	0.000	0.04	0.023	0.000	0.000	24.00	5.60	111.0	CD	NONE
6	X	17JUL87	0.72	6.90	0.02	57.5	0	20.00	12.40	1.65	0.95	7.60	4.33	0.371	23.70	1.11	0.53	0.000	0.03	0.000	0.000	0.000	24.25	5.85	125.0	SCD	NONE
6	X	14AUG87	0.98	7.00	0.02	102.5	0	24.00	5.40	1.55	0.74	7.90	.	.	21.40	1.35	0.91	0.000	.	0.000	0.018	.	22.50	6.50	142.0	SCD	NONE
6	X	18SEP87	0.59	6.40	0.00	47.5	.	10.00	7.00	1.45	0.41	9.60	1.48	0.280	17.70	1.17	1.28	0.000	0.04	0.000	0.000	0.000	25.00	6.85	136.0	SCD	NONE
6	X	16OCT87	0.78	8.00	0.18	60.0	.	22.00	5.80	1.25	0.77	9.70	3.64	0.760	58.40	1.89	1.13	0.000	0.04	0.000	0.020	0.000	25.00	5.75	140.0	CD	NONE
6	X	20NOV87	0.64	8.80	0.00	52.5	.	16.00	6.00	1.40	0.74	8.13	5.73	0.620	42.80	1.59	2.10	0.000	0.02	0.000	0.000	0.000	24.50	6.45	128.0	VCD	NONE

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
6	X	18DEC87	0.68	9.20	0.00	40.0	.	22.00	14.40	1.07	0.92	9.10	4.13	0.640	55.20	1.68	1.54	0.000	0.03	0.000	0.000	0.000	.	.	.	CD	NONE
6	X	15JAN88	0.70	6.20	0.11	95.0	.	20.00	10.00	1.08	0.49	12.40	3.44	0.520	12.50	1.56	0.89	0.000	0.04	0.000	0.050	0.000	23.5	5.15	118.0	CL	NONE
6	X	13FEB88	0.64	9.30	0.00	50.0	.	22.00	4.00	1.03	0.64	8.40	3.29	0.470	16.70	1.15	0.20	0.000	0.02	0.000	0.040	0.000	23.7	5.45	111.0	CL	NONE
6	X	11MAR88	0.74	9.80	0.00	70.0	.	18.00	3.20	1.07	0.52	10.30	3.76	0.490	11.80	1.15	0.54	0.000	0.01	0.000	0.040	0.000	23.0	5.40	115.0	CL	NONE
6	X	15APR88	0.87	7.30	0.00	117.5	.	20.00	5.20	1.05	0.70	14.40	4.27	0.460	10.10	1.72	0.87	0.000	0.02	0.000	0.040	0.000	23.0	5.40	121.0	CL	NONE
6	X	18MAY88	0.88	9.00	0.00	70.0	.	14.00	4.60	1.05	4.06	10.80	3.51	0.470	14.10	1.43	0.19	0.020	0.02	0.000	0.040	0.000	23.0	5.50	132.0	CL	NONE
6	X	15JUN88	0.59	11.50	0.00	60.0	.	18.00	6.60	0.94	.	10.00	3.43	0.440	19.70	1.33	0.49	0.000	0.03	0.010	0.080	0.000	23.0	5.65	121.0	CL	NONE
6	X	20JUL88	0.75	11.50	0.00	103.3	.	20.00	1.86	1.00	0.78	8.80	4.87	0.200	14.20	1.52	0.32	0.000	0.03	0.000	0.070	0.000	25.5	5.65	.	CL	NONE
6	X	18AUG88	0.90	39.47	0.12	90.0	.	31.02	12.08	0.12	0.57	17.66	5.20	0.900	2.30	1.90	1.40	0.000	0.01	0.010	0.010	0.000	24.0	5.75	145.0	CL	NONE
6	X	27OCT88	0.51	10.98	0.00	.	.	14.48	1.20	2.34	1.13	14.33	4.10	0.170	7.40	1.30	0.01	0.000	0.01	0.020	0.000	0.000	26.5	6.33	84.0	CL	NONE
6	X	08DEC88	0.54	2.70	0.14	38.0	.	18.34	1.52	1.35	0.54	10.02	4.63	0.180	8.77	1.20	0.00	0.000	0.01	0.010	0.000	0.000	25.3	4.96	95.8	CL	NONE
6	X	09FEB89	2.40	3.55	0.00	1.0	.	18.49	1.40	1.38	0.50	7.90	4.83	0.190	8.80	1.20	0.10	0.000	0.01	0.020	0.000	0.000	23.2	5.79	106.2	CL	NONE
6	X	04MAR89	0.35	4.15	0.00	66.0	.	21.95	1.36	1.36	0.44	6.56	5.55	0.240	7.10	1.40	0.07	0.000	0.01	0.000	0.000	0.000	26.0	5.20	98.7	CL	NONE
6	X	13JUN89	0.34	3.60	0.20	86.0	.	25.59	1.40	1.40	0.17	6.23	4.50	0.220	13.35	1.20	0.12	0.000	0.01	0.010	0.000	0.000	28.1	5.16	105.9	CL	H2S
6	X	14AUG89	0.29	6.30	0.15	107.0	.	31.89	1.44	1.42	0.07	5.37	4.59	0.170	15.93	0.15	0.02	0.000	0.02	0.000	0.000	0.000	27.2	5.58	103.0	CL	NONE
6	X	14NOV89	0.32	4.45	0.14	.	.	.	1.46	1.37	0.10	.	5.78	0.390	17.30	0.08	0.08	0.000	0.01	0.000	0.000	0.000	26.7	5.51	115.0	CL	NONE
6	X	12FEB90	0.28	4.50	0.13	.	.	.	1.40	1.37	0.10	5.90	5.95	0.140	24.60	0.97	0.23	.	.	.	.	.	24.1	4.95	116.0	CL	DUNG
7	P	21FEB86	0.44	11.50	0.94	196.7	0	90.00	.	.	0.00	19.25	9.98	0.985	42.70	11.50	7.83	0.000	0.03	0.039	0.027	0.000	.	6.05	295.0	CD	NONE
7	P	07MAR86	0.40	9.80	0.82	236.7	0	82.00	3.83	.	0.05	19.25	9.95	0.825	41.80	7.75	9.17	0.000	0.04	0.013	0.000	0.011	24.5	6.10	280.0	CD	H2S
7	P	21MAR86	0.44	8.80	0.95	210.0	0	90.00	2.40	0.70	0.60	19.25	9.84	0.758	43.10	11.70	9.72	0.000	0.02	0.017	0.000	0.000	24.0	6.15	340.0	CD	SH2S
7	P	15MAY86	0.42	8.30	0.31	230.0	0	90.00	4.50	2.35	2.00	19.25	9.91	1.310	51.40	13.20	9.77	0.011	0.06	0.068	0.038	0.000	24.0	6.10	330.0	VCD	H2S
7	P	19JUN86	0.37	7.50	0.80	137.5	0	90.00	4.25	0.70	.	19.25	4.87	0.727	40.50	10.50	11.46	0.000	0.06	0.017	0.051	0.013	24.0	6.35	292.0	CD	H2S
7	X	11OCT86	0.48	7.42	0.58	227.5	0	94.00	2.65	0.13	1.85	18.50	9.98	0.599	31.10	9.84	11.93	.	.	0.014	.	.	25.0	6.30	322.0	CL	SH2S
7	X	15NOV86	0.39	6.60	1.40	187.5	0	94.00	2.35	0.26	2.06	8.50	7.86	0.522	37.90	11.33	7.64	0.000	0.04	0.018	0.126	0.000	24.5	6.15	318.0	CL	H2S
7	X	30DEC86	0.43	7.60	1.60	175.0	0	92.00	2.84	0.35	2.45	7.40	4.58	0.496	31.60	11.77	9.28	0.000	0.04	0.015	0.011	0.000	23.5	5.70	335.0	SCD	H2S
7	X	31JAN87	0.41	5.40	1.05	145.0	0	98.00	2.52	0.50	1.85	10.20	4.56	0.342	26.60	11.90	12.36	0.000	0.04	0.000	0.013	0.000	23.5	6.05	302.0	CL	H2S
7	X	28FEB87	0.40	6.60	0.88	185.0	0	98.00	15.20	0.58	0.01	9.84	4.21	0.811	56.10	14.51	13.33	0.000	0.05	0.014	0.039	0.000	24.0	5.65	310.0	CD	H2S
7	X	21MAR87	0.38	6.90	1.20	155.0	0	90.00	15.20	0.75	0.03	6.60	4.39	0.923	38.90	10.80	10.10	0.000	0.06	0.013	0.037	0.010	23.0	5.95	280.0	CD	SH2S
7	X	15MAY87	0.43	7.60	1.15	152.5	0	94.00	11.00	0.46	0.02	0.00	4.13	1.690	40.10	11.50	9.82	0.000	0.04	0.010	0.023	0.000	21.5	5.95	265.0	CD	H2S
7	X	19JUN87	0.40	6.69	1.40	130.0	0	82.00	11.75	0.92	0.07	3.20	4.31	1.090	32.40	11.10	7.90	0.000	0.04	0.018	0.022	0.000	24.0	6.00	255.0	CD	H2S
7	X	17JUL87	0.37	9.20	1.41	145.0	0	86.00	2.55	0.55	0.02	0.90	4.53	0.363	23.40	11.80	8.75	0.000	0.05	0.011	0.000	0.000	24.0	6.10	230.0	CL	H2S
7	X	14AUG87	0.39	7.10	1.05	145.0	0	88.00	1.50	0.97	0.14	1.00	.	.	24.60	12.60	9.48	.	.	0.000	0.018	.	23.8	6.00	265.0	CL	H2S
7	X	18SEP87	0.34	6.20	1.15	120.0	.	72.00	2.10	1.30	0.16	14.90	2.22	0.400	22.30	7.39	7.86	0.000	0.02	0.000	0.140	0.000	23.5	6.25	285.0	CL	H2S
7	X	16OCT87	0.62	6.80	1.90	110.0	.	98.00	2.00	0.82	0.03	5.40	4.42	0.590	36.40	6.01	7.71	0.000	0.01	0.000	0.180	0.000	23.0	6.00	280.0	CD	H2S
7	X	20NOV87	0.36	6.90	2.10	105.0	.	70.00	1.00	0.96	0.10	11.48	5.18	0.530	22.40	6.82	8.38	0.000	0.01	0.000	0.120	0.000	24.0	6.45	400.0	CD	SH2S
7	X	18DEC87	0.63	8.20	1.45	110.0	.	78.00	4.75	0.83	0.09	11.00	3.70	0.460	33.70	8.99	10.03	0.000	0.03	0.000	0.090	0.000	.	6.10	.	CD	H2S
7	X	15JAN88	0.37	4.90	2.00	142.5	.	66.00	1.75	0.98	0.13	0.80	3.19	0.560	18.10	5.90	9.53	0.010	0.06	0.020	0.090	0.000	22.0	5.65	225.0	CL	H2S
7	X	13FEB88	0.36	8.00	1.60	145.0	.	56.00	2.10	0.95	0.16	1.30	2.86	0.540	12.70	3.76	9.04	0.000	0.02	0.000	0.060	0.000	23.5	5.65	210.0	CL	H2S
7	X	11MAR88	0.36	8.00	1.80	127.5	.	48.00	4.25	1.03	1.40	18.70	3.49	0.560	8.19	5.86	9.75	0.010	0.02	0.000	0.090	0.000	23.5	5.90	212.0	CL	H2S
7	X	15APR88	0.39	6.00	0.92	67.5	.	48.00	2.45	1.20	0.14	15.80	3.96	0.570	10.30	4.45	8.93	0.000	0.02	0.000	0.090	0.000	22.8	5.80	187.0	CL	SH2S
7	X	18MAY88	0.34	6.90	0.98	132.5	.	44.00	2.20	1.00	0.17	11.10	2.92	0.540	10.20	4.72	9.88	0.000	0.04	0.000	0.080	0.000	23.5	5.95	235.0	CL	H2S
7	X	15JUN88	0.36	7.80	1.20	112.5	.	46.00	1.70	0.88	.	15.00	2.33	0.600	18.30	5.55	7.05	0.000	0.02	0.000	0.110	0.000	23.5	5.70	190.0	CL	H2S
7	X	20JUL88	0.36	7.80	2.50	130.0	.	56.00	1.55	0.44	0.21	8.10	3.92	0.390	11.20	5.20	8.04	0.000	0.02	0.000	0.130	0.000	25.1	6.05	.	CL	H2S
7	X	18AUG88	0.67	23.80	0.13	118.0	.	93.06	2.63	0.15	0.03	2.45	4.50	0.900	1.80	7.20	9.50	0.000	0.08	0.010	0.090	0.000	24.0	6.15	198.0	CL	H2S
7	X	27OCT88	0.28	17.02	0.14	10.0	.	31.02	0.62	1.91	0.42	13.71	4.07	0.300	6.73	2.30	5.03	0.000	0.08	0.010	0.050	0.000	26.0	6.50	122.3	CL	H2S
7	X	08DEC88	0.38	2.50	2.10	58.0	.	57.17	0.88	0.48	0.11	3.89	4.00	0.500	6.00	3.73	10.97	0.000	0.08	0.040	0.070	0.000	24.6	5.48	147.7	SCD	H2S
7	X	09FEB89	1.55	1.45	1.80	22.0	.	77.75	1.46	1.64	0.09	0.90	4.03	0.470	6.20	3.80	11.33	0.000	0.08	0.020	0.060	0.000	22.3	5.60	152.6	CL	NONE
7	X	04MAR89	0.34	2.05	1.15	93.0	.	42.81	1.02	1.09	0.04	4.14	4.00	0.420	5.85	3.30	12.51	0.000	0.08	0.000	0.050	0.000	25.8	5.41	130.9	CL	H2S

ANALYTICAL DATA - GYPSUM ROAD BUILDING 14:02 Thursday, May 10, 1990

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
7	X	13JUN89	0.19	1.45	0.42	96.0	.	37.83	0.98	0.68	0.06	10.82	3.10	0.280	10.06	2.45	5.76	0.000	0.08	0.000	0.060	0.000	26.6	5.51	126.8	CL	H2S
7	X	14AUG89	0.17	2.40	1.30	139.0	.	65.48	1.08	0.95	0.01	3.08	2.98	0.320	12.58	6.91	10.23	0.000	0.08	0.000	0.110	0.000	25.1	5.71	161.0	CL	H2S
7	X	14NOV89	0.22	1.90	0.56	.	.	.	1.20	1.19	0.02	.	4.63	0.420	16.18	6.01	4.15	0.000	0.08	0.000	0.100	0.000	26.2	5.84	166.6	CL	SH2S
7	X	12FEB90	0.16	2.25	0.58	.	.	.	1.00	0.85	0.02	18.40	4.00	0.240	14.93	3.28	13.48	.	.	.	.	.	24.6	5.02	148.0	CL	SH2S
8	P	21FEB86	0.28	8.40	0.02	126.7	0	32.00	.	.	0.00	8.25	3.93	0.250	24.10	3.03	6.05	0.000	0.03	0.032	0.027	0.000	.	5.85	135.0	CD	H2S
8	P	07MAR86	0.19	7.70	0.02	130.0	0	26.00	2.93	.	0.00	8.25	3.32	0.225	21.00	2.57	1.93	0.000	0.03	0.000	0.000	0.011	24.5	5.90	115.0	CL	SH2S
8	P	21MAR86	0.20	7.00	0.02	100.0	0	26.00	3.80	1.25	1.25	8.25	3.12	0.240	20.60	2.23	0.95	0.000	0.03	0.016	0.000	0.000	24.0	5.10	102.0	SCD	SH2S
8	P	15MAY86	0.24	7.00	0.02	90.0	0	28.00	.	0.50	0.95	8.25	3.04	0.183	15.50	1.76	1.07	0.000	0.03	0.000	0.038	0.000	24.0	5.65	105.0	CL	SH2S
8	P	19JUN86	0.18	6.90	0.02	75.0	0	30.00	0.85	0.60	.	8.25	3.22	0.349	19.60	2.14	2.13	0.000	0.04	0.000	0.051	0.013	23.5	5.85	115.0	CD	SH2S
8	X	11OCT86	0.34	6.80	0.02	135.0	0	30.00	1.80	0.15	0.86	7.40	3.29	0.177	15.10	1.69	2.23	.	.	0.014	.	0.000	24.5	5.75	115.0	CL	SH2S
8	X	15NOV86	0.22	5.00	0.02	97.5	0	24.00	1.30	0.19	0.87	5.90	2.83	0.123	14.30	1.82	1.18	0.000	0.04	0.018	0.126	0.000	24.0	6.15	95.0	CL	NONE
8	X	30DEC86	0.24	6.40	0.02	100.0	0	22.00	2.00	0.30	1.10	5.85	2.79	0.151	12.80	1.22	1.13	0.000	0.02	0.015	0.011	0.000	23.0	5.85	97.0	CL	NONE
8	X	31JAN87	0.26	4.80	0.28	72.5	0	24.00	1.80	0.18	1.20	5.70	2.64	0.131	12.30	1.83	0.61	0.000	0.04	0.000	0.013	0.000	23.0	5.90	105.0	CL	NONE
8	X	28FEB87	0.26	5.90	0.02	110.0	0	26.00	21.60	0.20	0.81	5.82	2.79	0.418	40.50	1.72	4.69	0.000	0.03	0.014	0.039	0.010	24.0	5.80	130.0	VCD	NONE
8	X	21MAR87	0.25	5.20	0.12	60.0	0	22.00	27.00	0.18	0.76	7.00	3.12	0.387	28.80	1.88	1.52	0.010	0.03	0.013	0.037	0.000	23.0	6.45	102.0	CD	NONE
8	X	15MAY87	0.27	6.30	0.02	65.0	0	18.00	35.00	0.26	1.45	5.94	2.77	0.878	31.30	1.57	2.10	0.000	0.03	0.010	0.023	0.000	23.5	5.80	108.0	CD	NONE
8	X	19JUN87	0.29	5.30	0.02	45.0	0	24.00	37.50	0.33	0.98	7.58	3.02	0.782	33.40	1.88	1.37	0.000	0.03	0.018	0.022	0.000	24.0	5.70	110.0	VCD	NONE
8	X	17JUL87	0.25	8.10	0.02	75.0	0	24.00	5.50	0.67	1.33	5.00	3.25	0.055	13.10	1.76	1.25	0.000	0.04	0.011	0.000	0.000	24.0	6.05	120.0	CL	NONE
8	X	14AUG87	0.28	6.20	0.02	70.0	0	22.00	2.40	0.36	1.31	7.40	.	.	15.70	1.72	2.39	.	.	0.000	0.018	.	23.0	6.65	139.0	CL	NONE
8	X	18SEP87	0.22	5.80	0.00	52.5	.	22.00	2.40	0.42	1.04	7.60	0.57	0.180	9.80	1.65	1.28	0.000	0.02	0.020	0.000	0.000	23.1	5.95	120.0	CL	NONE
8	X	16OCT87	0.27	7.10	0.00	17.5	.	20.00	2.70	0.33	0.82	6.20	3.19	0.290	27.60	1.91	1.08	0.000	0.02	0.000	0.000	0.000	23.0	5.95	118.0	CD	NONE
8	X	20NOV87	0.26	7.50	0.00	45.0	.	20.00	6.30	0.30	0.86	7.31	3.41	0.220	20.30	1.80	1.03	0.000	0.00	0.000	0.000	0.000	23.5	6.60	135.0	CD	NONE
8	X	18DEC87	0.27	8.00	0.00	15.0	.	24.00	12.00	0.35	0.03	7.80	2.51	0.280	33.50	1.87	1.05	0.000	0.02	0.010	0.000	0.000	.	.	.	CD	NONE
8	X	15JAN88	0.26	6.10	0.15	72.5	.	22.00	1.10	0.32	0.72	8.00	2.43	0.360	7.83	2.25	0.99	0.000	0.02	0.010	0.030	0.000	23.5	5.75	105.0	CL	NONE
8	X	13FEB88	0.24	7.20	1.70	25.0	.	20.00	1.50	0.30	0.64	7.60	2.30	0.380	21.30	1.62	0.31	0.000	0.04	0.000	0.050	0.000	23.5	5.90	101.0	CL	NONE
8	X	11MAR88	0.22	10.00	0.10	50.0	.	22.00	1.40	0.31	0.48	7.80	2.43	0.350	6.06	1.99	0.66	0.010	0.01	0.000	0.040	0.000	24.0	5.40	105.0	CL	NONE
8	X	15APR88	0.21	6.80	0.10	60.0	.	22.00	2.00	0.35	0.53	7.00	3.06	0.390	7.21	2.40	0.77	0.000	0.01	0.000	0.020	0.000	23.5	5.45	104.0	CL	NONE
8	X	18MAY88	0.22	7.60	0.00	70.0	.	22.00	1.30	0.30	2.72	6.20	2.09	0.380	5.79	2.29	0.73	0.000	0.02	0.000	0.030	0.000	24.0	5.70	120.0	CL	NONE
8	X	15JUN88	0.21	9.00	0.00	130.0	.	22.00	0.84	0.36	.	6.80	1.67	0.700	14.40	1.72	1.31	0.000	0.03	0.000	0.090	0.010	23.8	6.10	110.0	CL	NONE
8	X	20JUL88	0.24	9.60	0.00	82.5	.	24.00	1.57	0.33	1.05	7.90	3.18	0.060	9.94	1.17	1.22	0.000	0.03	0.000	0.070	0.020	25.2	5.80	.	CL	NONE
8	X	18AUG88	0.46	31.56	2.18	62.0	.	31.02	7.10	0.11	0.46	7.35	3.90	0.090	1.61	2.10	1.80	0.000	0.01	0.010	0.020	0.000	23.1	6.05	120.0	CL	NONE
8	X	27OCT88	0.19	8.53	0.00	.	.	15.51	0.27	0.69	1.45	18.41	2.90	0.090	5.33	1.77	0.04	0.000	0.01	0.010	0.010	0.000	25.6	6.40	72.9	CL	NONE
8	X	08DEC88	0.24	4.30	0.20	40.0	.	19.42	0.41	0.32	0.63	7.93	3.50	0.120	5.10	2.40	8.36	0.000	0.01	0.010	0.030	0.000	24.8	5.10	81.2	CL	NONE
8	X	09FEB89	1.00	2.05	0.12	5.0	.	24.47	0.34	0.33	0.50	7.30	3.50	0.110	7.60	1.87	0.40	0.000	0.01	0.000	0.020	0.000	22.8	5.28	89.9	SCD	NONE
8	X	04MAR89	0.20	3.35	0.31	54.0	.	21.95	0.30	0.29	0.38	7.27	3.90	0.150	5.82	2.10	1.93	0.000	0.01	0.000	0.020	0.000	26.0	5.39	83.0	CD	NONE
8	X	13JUN89	0.18	3.00	0.30	67.0	.	25.59	0.28	0.28	0.07	6.41	3.20	0.120	9.80	1.80	0.22	0.000	0.00	0.000	0.020	0.000	27.8	5.36	88.9	SCD	NONE
8	X	14AUG89	0.14	4.10	0.10	89.0	.	28.47	0.26	0.26	1.70	6.74	2.92	0.060	11.82	1.08	20.17	0.000	0.01	0.010	0.030	0.000	27.6	5.80	95.0	CL	NONE
8	X	14NOV89	0.17	3.55	0.12	.	.	.	0.28	0.29	0.35	.	3.92	0.260	13.41	1.66	1.52	0.000	0.06	0.000	0.030	0.000	26.5	5.25	103.0	CL	NONE
8	X	12FEB90	0.14	4.05	0.12	.	.	.	0.34	0.30	0.00	4.50	4.20	0.230	14.84	1.60	14.54	.	.	.	.	.	24.3	4.89	104.0	CL	NONE
9	P	21FEB86	0.39	4.20	0.02	116.7	0	46.00	.	.	1.85	3.20	4.22	0.433	32.50	6.36	1.04	0.000	0.05	0.034	0.000	0.000	.	6.40	135.0	SCD	NONE
9	P	07MAR86	0.38	5.30	0.02	136.7	0	48.00	4.00	.	1.95	3.20	3.95	0.332	29.80	5.55	0.66	0.000	0.05	0.015	0.000	0.012	24.0	6.45	145.0	SCD	NONE
9	P	21MAR86	0.42	4.90	0.02	120.0	0	48.00	3.50	2.00	1.87	3.20	3.92	0.295	27.70	6.75	0.55	0.000	0.04	0.014	0.000	0.000	23.0	6.35	145.0	SCD	NONE
9	P	15MAY86	0.44	5.40	0.02	103.3	0	50.00	3.75	1.00	1.55	3.20	3.56	0.242	19.90	5.69	0.26	0.000	0.03	0.014	0.025	0.000	24.0	6.25	148.0	CL	NONE
9	P	19JUN86	0.37	5.80	0.02	80.0	0	50.00	1.00	1.75	.	3.20	3.84	0.419	25.00	6.57	0.26	0.000	0.07	0.011	0.049	0.011	24.5	6.45	142.0	SCD	NONE
9	X	11OCT86	0.46	5.20	0.02	167.5	0	50.00	3.50	0.67	1.76	1.90	3.98	0.281	23.60	5.62	0.26	.	.	0.019	.	0.013	25.0	6.55	148.5	CL	NONE
9	X	15NOV86	0.20	4.90	0.02	132.5	0	50.00	4.25	0.75	1.80	3.20	3.83	0.264	31.30	6.94	0.32	0.000	0.02	0.022	0.119	0.000	24.0	6.50	148.0	CL	NONE
9	X	30DEC86	0.43	5.80	0.02	127.5	0	56.00	8.40	1.02	2.14	1.50	4.10	0.352	48.60	5.85	2.43	0.000	0.02	0.018	0.010	0.000	23.0	6.05	149.0	CD	NONE
9	X	31JAN87	0.47	4.30	0.02	115.0	0	48.00	4.20	0.70	2.10	1.70	3.85	0.268	41.00	6.29	0.91	0.000	0.03	0.000	0.017	0.000	23.0	6.45	155.0	SCD	NONE

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
9	X	28FEB87	0.46	5.70	0.02	135.0	0	52.00	15.60	0.75	1.36	0.70	3.99	0.809	79.60	6.14	2.42	0.000	0.03	0.018	0.091	0.015	24.00	6.30	162.0	CD	NONE
9	X	21MAR87	0.46	4.60	0.02	97.5	0	48.00	22.50	0.65	1.01	3.20	4.31	0.772	50.40	6.41	2.11	0.000	0.04	0.016	0.015	0.000	23.50	6.35	152.0	CD	NONE
9	X	15MAY87	0.74	5.20	0.02	87.5	0	46.00	16.50	0.75	1.65	1.40	2.06	1.530	47.10	6.31	0.94	0.000	0.04	0.014	0.000	0.000	24.00	6.15	150.0	CD	NONE
9	X	19JUN87	0.71	4.45	0.02	62.5	0	52.00	9.30	0.77	1.07	1.20	3.72	0.548	25.50	6.31	1.95	0.013	0.05	0.000	0.000	0.000	24.30	6.25	150.0	SCD	NONE
9	X	17JUL87	0.48	5.30	0.02	90.0	0	50.00	5.30	0.80	1.74	1.30	4.05	0.097	34.60	6.82	1.09	0.000	0.03	0.018	0.000	0.000	23.25	6.35	169.0	CL	NONE
9	X	14AUG87	0.46	4.90	0.02	75.0	0	50.00	2.00	0.80	1.70	3.30	.	.	35.10	6.52	0.51	.	.	0.015	0.000	.	23.50	6.75	152.0	CL	NONE
9	X	18SEP87	0.43	4.60	0.00	75.0	.	46.00	3.20	0.83	0.42	3.30	2.52	0.180	23.90	5.52	1.18	0.000	0.03	0.020	0.000	0.000	23.20	6.75	170.0	CL	NONE
9	X	16OCT87	1.10	5.50	0.00	25.0	.	46.00	1.50	0.75	1.30	2.40	3.31	0.330	44.90	5.13	0.96	0.000	0.03	0.010	0.010	0.000	23.50	6.45	156.0	SCD	NONE
9	X	20NOV87	0.45	6.10	0.00	50.0	.	46.00	0.90	0.73	1.50	3.88	4.16	0.210	33.20	5.27	1.21	0.000	0.02	0.000	0.000	0.000	23.50	6.90	198.0	SCD	NONE
9	X	18DEC87	1.10	6.60	0.00	50.0	.	48.00	4.50	0.75	1.42	3.30	3.08	0.250	31.70	6.19	0.92	0.000	0.03	0.000	0.010	0.000	.	6.50	.	CL	NONE
9	X	15JAN88	0.50	4.10	1.15	112.5	.	44.00	2.50	0.70	1.02	0.90	2.94	0.270	18.70	5.93	0.59	0.020	0.04	0.000	0.010	0.000	23.50	6.15	143.0	CL	NONE
9	X	13FEB88	0.50	6.00	0.00	85.0	.	42.00	1.70	0.70	0.61	3.90	2.78	0.220	20.10	2.89	0.17	0.000	0.06	0.000	0.080	0.000	23.50	6.15	142.0	CL	NONE
9	X	11MAR88	0.52	6.40	0.00	82.5	.	46.00	1.50	0.70	2.10	4.10	2.86	0.310	8.35	7.60	0.72	0.010	0.03	0.000	0.050	0.000	24.00	6.10	148.0	CL	NONE
9	X	15APR88	0.64	5.50	0.00	37.5	.	42.00	2.20	0.75	0.57	3.50	3.81	0.280	10.30	6.42	0.39	0.000	0.01	0.000	0.030	0.000	24.00	5.90	142.0	CL	NONE
9	X	18MAY88	0.63	5.80	0.00	87.5	.	46.00	1.75	0.70	1.97	3.20	2.69	0.290	9.35	4.85	0.68	0.000	0.02	0.000	0.040	0.000	24.00	6.30	159.0	CL	NONE
9	X	15JUN88	0.42	6.60	0.00	95.0	.	42.00	0.44	0.80	.	2.90	1.88	0.860	20.40	4.28	0.30	0.000	0.03	0.000	0.080	0.010	24.00	6.50	147.0	CL	NONE
9	X	20JUL88	0.54	7.50	0.00	107.5	.	44.00	0.70	0.75	0.27	3.10	4.37	0.090	15.10	4.26	1.72	0.000	0.03	0.000	0.070	0.000	26.00	6.25	.	CL	NONE
9	X	18AUG88	0.79	27.60	0.12	85.0	.	51.70	5.33	0.04	1.72	5.06	4.50	1.000	2.01	6.30	2.00	0.000	0.06	0.000	0.000	0.000	23.90	6.65	145.0	CL	NONE
9	X	27OCT88	0.32	14.89	0.00	.	.	24.82	0.66	1.95	0.96	12.27	4.00	0.220	9.20	4.10	0.17	0.000	0.06	0.000	0.000	0.000	25.60	6.57	87.5	CL	NONE
9	X	08DEC88	0.42	2.25	0.37	58.0	.	43.15	1.02	0.90	2.06	4.13	4.07	0.160	8.90	4.70	0.03	0.000	0.06	0.000	0.000	0.000	24.90	5.77	124.3	CL	NONE
9	X	09FEB89	1.75	1.50	0.12	3.0	.	45.67	0.76	0.73	2.20	10.10	4.17	0.190	9.30	5.23	0.00	0.000	0.06	0.000	0.000	0.000	22.60	5.95	140.1	CL	NONE
9	X	04MAR89	0.26	1.60	0.14	89.0	.	43.91	0.76	0.79	1.61	8.40	4.63	0.220	6.70	5.43	0.08	0.000	0.06	0.000	0.000	0.000	25.60	5.77	126.5	CL	NONE
9	X	13JUN89	0.23	1.55	0.20	99.0	.	44.50	0.72	0.74	1.60	11.87	3.43	0.170	12.78	4.68	0.09	0.000	0.06	0.000	0.000	0.000	29.40	6.06	130.8	CL	NONE
9	X	14AUG89	0.23	1.45	0.13	110.0	.	45.55	0.76	0.77	0.40	8.93	3.08	0.020	13.09	5.32	0.16	0.000	0.06	0.000	0.000	0.000	25.20	6.11	125.0	CL	NONE
9	X	14NOV89	0.24	1.70	0.00	.	.	.	0.71	0.71	1.54	.	3.92	0.090	14.68	5.75	0.00	0.000	0.06	0.000	0.000	0.000	25.90	6.70	125.2	CL	NONE
9	X	12FEB90	0.20	2.10	0.00	.	.	.	0.80	0.78	0.80	8.50	4.20	0.150	17.96	6.30	0.16	.	.	.	.	.	24.50	5.74	136.0	CL	NONE
10	P	21FEB86	0.40	7.00	0.02	140.0	0	56.00	.	.	1.05	7.40	4.42	0.219	23.70	8.32	0.21	0.000	0.03	0.017	0.000	0.000	24.00	6.35	185.0	SCD	NONE
10	P	07MAR86	0.38	7.50	0.02	120.0	0	54.00	5.90	.	0.90	7.40	3.53	0.281	30.20	6.48	0.43	0.000	0.03	0.021	0.000	0.013	24.00	6.35	180.0	SCD	NONE
10	P	21MAR86	0.42	6.90	0.02	80.0	0	56.00	3.20	1.50	0.95	7.40	3.39	0.269	27.20	7.98	0.27	0.000	0.03	0.012	0.000	0.000	23.00	6.35	172.0	CL	NONE
10	P	15MAY86	0.42	7.50	0.02	123.3	0	52.00	2.95	0.90	0.45	7.40	3.23	0.229	23.00	7.02	0.43	0.000	0.03	0.011	0.025	0.000	24.00	6.15	165.0	CL	NONE
10	P	19JUN86	0.36	6.70	0.02	102.5	0	56.00	1.25	1.20	.	7.40	3.37	0.402	29.90	8.10	0.47	0.000	0.05	0.013	0.034	0.000	24.50	6.30	175.0	CL	NONE
10	X	11OCT86	0.48	6.60	0.02	167.5	0	52.00	2.90	0.87	0.70	5.00	3.17	0.177	20.60	5.23	1.44	.	.	0.017	.	0.014	25.00	6.35	140.0	CL	NONE
10	X	15NOV86	0.33	6.00	0.02	137.5	0	52.00	2.15	0.85	0.78	5.50	3.18	0.196	26.40	7.06	1.06	0.000	0.06	0.011	0.229	0.000	24.00	6.55	145.0	CL	NONE
10	X	30DEC86	0.44	8.00	0.02	137.5	0	60.00	2.84	1.01	0.90	4.50	3.14	0.153	24.40	6.12	0.54	0.000	0.05	0.011	0.000	0.000	22.00	6.00	150.0	CL	NONE
10	X	31JAN87	0.51	4.80	0.24	107.5	0	40.00	2.48	0.96	0.55	5.20	2.44	0.124	17.30	4.46	0.14	0.000	0.02	0.000	0.000	0.000	23.00	6.25	130.0	CL	NONE
10	X	28FEB87	0.65	7.40	0.02	135.0	0	52.00	11.00	0.90	0.34	4.70	2.66	0.296	39.30	5.51	0.58	0.000	0.05	0.000	0.049	0.000	24.00	6.05	170.0	CD	NONE
10	X	21MAR87	0.48	5.80	0.02	107.5	0	52.00	13.84	0.86	0.18	4.95	3.31	0.311	29.80	5.32	1.15	0.000	0.04	0.018	0.000	0.000	24.00	6.40	155.0	SCD	NONE
10	X	15MAY87	1.05	7.60	0.02	95.0	0	54.00	11.00	0.95	0.40	4.60	2.97	0.756	26.90	6.11	0.71	0.000	0.03	0.016	0.000	0.000	23.00	6.05	150.0	CL	NONE
10	X	19JUN87	0.72	6.97	0.02	87.5	0	56.00	8.85	1.01	0.23	4.60	3.32	0.401	22.40	7.13	0.92	0.000	0.03	0.021	0.000	0.000	24.50	6.10	160.0	CL	NONE
10	X	17JUL87	0.48	7.60	0.02	110.0	0	54.00	3.40	1.08	0.25	4.20	3.28	0.000	15.60	7.03	1.03	0.000	0.03	0.017	0.023	0.000	24.00	6.30	150.0	CL	NONE
10	X	14AUG87	0.66	6.00	0.02	72.5	0	36.00	0.91	1.20	0.38	4.50	.	.	16.50	7.11	1.02	.	.	0.012	0.019	.	23.00	6.80	140.0	CL	NONE
10	X	18SEP87	0.41	6.00	0.00	62.5	.	48.00	1.25	1.10	0.13	5.00	1.98	0.170	14.10	4.75	1.04	0.000	0.02	0.020	0.020	0.000	22.80	6.20	160.0	CL	NONE
10	X	16OCT87	0.69	7.70	0.00	62.5	.	50.00	1.80	1.03	0.17	4.40	3.28	0.200	22.30	4.49	1.01	0.000	0.02	0.020	0.000	0.000	22.00	6.25	143.0	CL	NONE
10	X	20NOV87	0.51	9.10	0.00	67.5	.	50.00	1.50	1.00	0.50	5.29	3.38	0.120	13.90	4.37	0.98	0.000	0.02	0.000	0.000	0.000	22.80	6.75	172.0	CL	NONE
10	X	18DEC87	0.96	9.00	0.00	62.5	.	46.00	4.05	0.97	0.56	5.00	2.49	0.220	20.80	5.08	1.08	0.000	0.02	0.020	0.020	0.000	.	.	.	CL	NONE
10	X	15JAN88	0.45	6.30	0.14	92.5	.	52.00	1.25	0.99	0.40	3.10	2.44	0.240	10.90	5.21	0.38	0.000	0.03	0.000	0.030	0.000	23.50	6.00	155.0	CL	NONE
10	X	13FEB88	0.50	7.60	0.00	100.0	.	48.00	1.25	0.98	0.71	4.70	2.26	0.270	21.20	7.01	0.25	0.000	0.05	0.000	0.050	0.000	23.50	6.05	142.0	CL	NONE
10	X	11MAR88	0.44	7.60	0.00	72.5	.	38.00	1.40	0.97	1.23	5.90	2.30	0.270	9.55	6.80	0.47	0.010	0.02	0.000	0.030	0.000	23.10	5.85	130.0	CL	NONE

COUNTY=POLK
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
10	X	15APR88	0.62	6.60	0.00	56.0	.	42.00	1.80	1.00	0.58	5.70	3.14	0.27	10.70	5.48	1.87	0.00	0.01	0	0.04	0.00	24.0	5.95	130.0	CL	NONE
10	X	18MAY88	0.52	7.80	0.00	102.5	.	48.00	1.43	0.94	0.41	5.00	2.26	0.29	11.50	5.26	0.35	0.00	0.02	0	0.03	0.00	24.0	5.95	187.0	CL	NONE
10	X	15JUN88	0.44	9.40	0.00	112.5	.	52.00	0.47	0.89	.	6.90	1.26	0.76	21.90	2.42	0.11	0.00	0.04	0	0.09	0.01	23.5	6.05	167.0	CL	NONE
10	X	20JUL88	0.44	10.50	0.00	105.0	.	52.00	1.50	0.92	0.77	6.10	4.23	0.07	14.40	2.41	0.98	0.01	0.03	0	0.09	0.02	25.5	6.20	.	CL	NONE
10	X	18AUG88	0.84	28.86	0.10	63.0	.	41.36	3.60	0.43	0.54	8.15	3.70	1.00	1.39	2.40	2.10	0.03	0.01	0	0.00	0.00	23.5	6.20	120.0	CL	NONE
10	X	27OCT88	0.40	11.34	0.00	.	.	11.37	0.79	2.40	0.37	9.05	2.60	0.10	4.13	0.80	0.02	0.03	0.01	0	0.00	0.00	25.9	6.51	50.8	CL	NONE
10	X	08DEC88	0.43	3.20	0.28	42.0	.	22.65	1.32	1.20	0.74	8.42	3.20	0.11	7.70	2.00	0.05	0.03	0.01	0	0.00	0.00	24.3	5.59	88.0	CL	NONE
10	X	09FEB89	1.95	1.70	0.00	3.0	.	16.85	1.26	1.26	0.90	7.00	3.10	0.13	7.23	2.33	0.05	0.03	0.01	0	0.00	0.00	21.9	5.60	80.1	CL	NONE
10	X	04MAR89	0.28	2.00	0.00	53.0	.	19.76	1.22	1.23	0.96	6.82	3.50	0.16	5.55	2.70	0.05	0.03	0.01	0	0.00	0.00	26.1	5.48	69.9	CL	NONE
10	X	13JUN89	0.23	2.75	0.16	89.0	.	38.94	1.06	1.08	0.57	7.56	2.78	0.11	9.02	1.80	0.06	0.03	0.01	0	0.00	0.00	26.5	5.77	100.0	CL	NONE
10	X	14AUG89	0.27	3.00	0.12	127.0	.	47.83	1.06	1.07	0.59	7.95	2.44	0.00	12.79	3.51	0.09	0.03	0.01	0	0.00	0.00	26.9	6.13	124.0	CL	NONE
10	X	14NOV89	0.24	2.20	0.00	.	.	.	1.19	1.12	0.45	.	3.55	0.10	17.21	5.42	0.14	0.03	0.04	0	0.00	0.00	26.2	6.18	139.7	CL	NONE
10	X	12FEB90	0.21	2.10	0.00	.	.	.	0.90	0.87	0.90	8.50	3.17	0.22	15.10	4.10	0.00	.	.	.	.	.	24.8	5.76	143.0	CL	NONE

COUNTY=COLUMBIA

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
1	P	29JUL86	0.00	5.10	0.02	30.0	0	14.00	.	.	0.35	19.50	9.32	6.940	16.90	5.14	7.34	0.036	0.03	0.049	0.198	0.068	24.0	5.25	100.0	CD	NONE
1	P	12AUG86	0.00	4.90	.	106.7	0	4.00	.	.	3.50	19.00	5.51	1.920	7.36	6.54	5.01	0.025	0.02	0.042	0.072	0.022	.	5.60	105.0	CD	NONE
1	P	22OCT86	0.36	6.20	0.02	60.0	0	14.00	1.10	0.01	3.70	20.50	2.56	2.620	8.05	3.39	5.72	0.000	0.02	0.036	0.077	0.015	17.0	4.50	133.0	CD	NONE
1	P	19NOV86	0.10	4.10	0.14	52.5	0	4.00	0.70	0.01	3.68	23.25	1.44	2.040	7.30	3.11	4.04	0.033	0.06	0.013	0.063	0.023	24.0	5.10	103.0	CD	NONE
1	P	18DEC86	0.00	3.30	0.02	105.0	0	10.00	4.70	0.01	3.40	26.25	1.33	2.660	9.10	3.59	6.00	0.035	0.04	0.023	0.094	0.026	21.0	4.10	99.0	VCD	NONE
1	P	30JAN87	0.00	3.00	0.02	80.0	0	10.00	6.90	0.01	3.20	24.50	1.44	4.560	9.54	3.86	7.41	0.043	0.02	0.032	0.093	0.032	21.0	4.60	100.0	VCD	NONE
1	P	27FEB87	0.00	3.75	0.02	77.5	0	4.00	2.00	0.01	1.02	29.00	1.49	4.530	9.57	4.46	6.62	0.024	0.03	0.015	0.098	0.031	22.0	4.45	98.0	CD	NONE
1	P	20MAR87	0.00	3.70	0.02	62.5	0	4.00	1.58	0.01	0.05	25.50	1.69	2.860	3.20	3.54	7.14	0.000	0.02	0.027	0.088	0.030	22.0	4.25	102.0	CD	NONE
1	X	14MAY87	0.12	3.30	0.02	67.5	0	2.00	1.50	0.05	2.30	24.75	1.35	1.990	6.95	3.62	6.02	0.000	0.02	0.034	0.094	0.026	22.5	4.35	98.0	CD	NONE
1	X	18JUN87	0.13	3.03	0.02	32.5	0	4.00	1.40	0.07	1.03	24.50	1.20	1.490	7.95	4.22	5.42	0.000	0.02	0.025	0.087	0.022	24.0	4.25	97.0	VCD	NONE
1	X	16JUL87	0.14	3.50	0.02	55.0	0	2.00	2.94	0.05	1.37	24.50	1.14	1.980	6.24	3.74	5.20	0.000	0.02	0.032	0.094	0.017	19.0	5.05	96.0	VCD	NONE
1	X	13AUG87	0.15	3.40	0.02	77.5	0	2.00	1.44	0.01	2.26	24.50	.	.	7.15	3.89	5.68	.	.	0.024	0.092	.	21.5	4.40	100.0	VCD	NONE
1	X	17SEP87	0.12	3.30	0.02	52.5	0	6.00	1.30	0.01	1.41	23.50	.	.	.	.	.	.	.	.	.	.	23.5	4.20	98.0	CD	NONE
1	X	15OCT87	0.00	3.60	0.14	44.4	.	.	0.00	0.00	0.25	7.30	0.92	1.170	4.75	3.31	7.15	0.010	0.02	0.040	0.090	0.020	20.0	4.15	94.0	SCD	NONE
1	X	19NOV87	0.00	3.50	0.00	25.0	.	2.00	0.36	0.05	1.74	36.33	1.27	1.360	4.00	3.68	6.03	0.010	0.01	0.020	0.080	0.020	20.6	4.25	92.0	SCD	NONE
1	X	17DEC87	0.13	4.00	0.11	50.0	.	2.00	1.94	0.01	2.34	32.60	1.24	1.360	2.95	3.89	6.17	0.010	0.02	0.030	0.080	0.020	19.5	4.25	86.0	CD	NONE
1	X	14JAN88	0.11	2.60	0.24	67.5	.	2.00	1.30	0.05	1.78	18.60	1.19	2.110	6.71	3.02	2.04	0.030	0.04	0.000	0.010	0.000	16.9	4.45	89.0	VCD	NONE
1	X	12FEB88	0.00	4.20	0.00	60.0	.	6.00	2.04	0.05	2.04	35.70	1.22	2.060	4.83	3.65	1.83	0.010	0.03	0.000	0.010	0.000	19.1	4.45	89.0	CD	NONE
1	X	10MAR88	0.00	4.40	0.00	62.5	.	.	2.10	0.05	0.63	30.00	1.12	2.050	3.91	2.91	3.66	0.010	0.02	0.000	0.030	0.000	20.2	4.30	98.0	VCD	NONE
1	X	14APR88	0.00	3.20	0.00	27.5	.	4.00	0.60	0.05	1.97	12.40	1.29	2.030	4.16	3.81	1.45	0.010	0.01	0.000	0.010	0.000	21.7	4.55	99.0	SCD	NONE
1	X	17MAY88	0.00	3.10	0.00	47.5	.	.	0.42	0.05	4.49	27.60	1.25	1.930	5.87	5.70	1.77	0.010	0.01	0.000	0.010	0.000	22.5	4.15	104.0	SCD	NONE
1	X	14JUN88	0.11	3.50	0.00	145.0	.	.	0.36	0.08	0.36	31.80	1.54	1.120	5.44	3.22	1.77	0.010	0.02	0.000	0.060	0.000	22.9	4.65	118.0	CL	NONE
1	X	19JUL88	0.10	3.40	0.00	97.5	.	10.00	0.50	0.04	3.31	37.20	1.66	0.530	6.82	3.60	2.05	0.010	0.04	0.000	0.050	0.000	23.0	4.55	134.0	SCD	NONE
1	X	17AUG88	0.26	6.31	0.00	64.0	.	10.34	0.50	0.01	1.80	31.60	2.00	1.500	8.00	5.20	3.00	0.000	0.03	0.010	0.500	0.020	22.1	4.65	103.0	SCD	NONE
1	X	26OCT88	0.00	6.74	0.00	52.0	.	.	0.03	0.07	2.84	37.50	1.80	1.300	2.40	4.10	2.12	0.000	0.03	0.070	0.040	0.020	19.9	4.42	120.4	CLD	NONE
1	X	05DEC88	0.22	1.58	0.37	15.0	.	.	0.10	0.02	2.99	46.65	2.30	1.670	3.50	7.27	4.00	0.000	0.03	0.030	0.070	0.010	21.0	6.69	171.3	VCD	NONE
1	X	07FEB89	0.69	0.70	0.00	100.0	.	.	0.08	0.02	2.00	89.50	2.30	1.670	4.70	6.87	15.45	0.000	0.03	0.030	0.060	0.010	21.7	3.89	208.0	SCD	NONE
1	X	10MAR89	0.11	0.82	0.27	186.0	.	.	0.02	0.01	1.70	26.60	2.20	1.690	4.88	5.88	1.43	0.000	0.03	0.010	0.060	0.020	22.8	3.49	161.4	SCD	NONE
1	X	05JUN89	0.15	0.83	0.20	203.0	.	.	0.04	0.01	2.65	134.03	2.30	1.700	25.23	12.38	1.14	0.000	0.03	0.010	0.060	0.010	26.0	3.79	269.0	VCD	NONE
1	X	07AUG89	0.14	0.67	0.12	283.0	.	.	0.02	0.03	3.14	173.95	1.59	2.530	54.90	36.96	2.59	0.000	0.03	0.010	0.120	0.010	23.7	3.67	357.0	SCD	NONE
1	X	06NOV89	0.13	0.69	0.20	0.0	.	.	0.06	0.04	2.28	.	2.63	2.320	61.87	35.09	2.01	0.160	0.03	0.010	0.140	0.020	24.6	3.87	424.0	SCD	NONE
1	X	05FEB90	0.19	0.62	0.00	0.0	.	.	0.04	0.02	2.40	.	2.37	2.500	75.88	38.86	1.50	0.320	0.03	.	.	.	21.9	3.72	606.0	SCD	NONE
2	P	29JUL86	0.61	5.80	0.02	190.0	0	62.00	.	.	2.15	6.50	3.18	3.480	93.40	29.90	5.51	0.014	0.02	0.062	0.214	0.000	.	7.65	185.0	CD	NONE
2	P	12AUG86	0.48	5.90	.	200.0	0	56.00	.	.	3.48	1.20	2.55	2.620	89.40	16.20	3.67	0.017	0.03	0.067	0.085	0.000	.	7.70	173.0	CD	NONE
2	P	22OCT86	0.50	6.30	0.02	157.5	0	62.00	3.00	0.05	7.70	0.90	2.95	1.710	31.50	16.70	4.51	0.000	0.02	0.052	0.057	0.000	27.0	7.30	171.0	CD	NONE
2	P	19NOV86	0.48	6.20	0.02	125.0	0	52.00	2.60	0.06	7.72	1.00	2.13	1.820	31.10	16.40	2.63	0.040	0.04	0.024	0.040	0.000	22.5	7.65	178.0	CD	NONE
2	P	18DEC86	0.56	5.80	0.02	82.5	0	56.00	3.64	0.15	7.70	4.20	2.49	2.130	71.40	22.30	4.52	0.033	0.03	0.028	0.091	0.000	21.0	7.10	169.0	CD	NONE
2	P	30JAN87	0.42	5.00	0.02	145.0	0	42.00	7.70	0.10	7.60	3.40	2.65	2.750	74.70	26.20	4.94	0.045	0.02	0.030	0.118	0.015	20.0	7.75	173.0	CD	NONE
2	P	27FEB87	0.42	5.75	0.02	142.5	0	50.00	2.10	0.10	5.07	3.00	2.33	1.330	32.60	16.50	1.57	0.024	0.02	0.013	0.044	0.000	22.0	7.35	180.0	CD	NONE
2	P	20MAR87	0.45	5.80	0.02	157.5	0	52.00	1.62	0.01	1.63	3.60	2.44	0.833	26.80	20.40	4.74	0.000	0.02	0.052	0.058	0.000	21.0	7.45	181.0	SCD	NONE
2	X	14MAY87	0.43	6.00	0.02	142.5	0	52.00	1.54	0.13	9.38	0.90	2.18	0.780	24.20	16.30	3.32	0.000	0.02	0.057	0.080	0.000	17.0	7.40	179.0	CL	NONE
2	X	18JUN87	0.58	5.58	0.02	132.5	0	42.00	1.88	0.15	4.23	0.90	2.12	0.844	16.80	19.20	4.92	0.000	0.02	0.032	0.050	0.000	23.0	7.65	177.0	SCD	NONE
2	X	16JUL87	0.45	5.70	0.02	157.5	0	48.00	6.54	0.14	6.64	4.00	2.55	1.280	18.40	16.60	3.92	0.014	0.02	0.051	0.055	0.000	23.0	7.50	181.0	CD	NONE
2	X	13AUG87	0.53	5.60	0.02	130.0	0	46.00	3.50	0.08	5.84	3.10	.	.	22.20	16.00	4.32	.	.	0.049	0.044	.	23.0	7.70	178.0	SCD	NONE
2	X	17SEP87	0.42	5.10	0.02	105.0	0	40.00	2.14	0.15	5.06	3.10	.	.	.	.	.	.	.	.	.	.	23.0	6.95	173.0	SCD	NONE
2	X	15OCT87	0.34	5.30	0.00	95.0	.	44.00	0.36	0.07	7.91	1.40	2.22	0.470	17.10	7.34	4.60	0.010	0.03	0.040	0.060	0.000	20.0	7.35	171.0	CL	NONE
2	X	19NOV87	0.47	5.70	0.00	77.5	.	46.00	0.18	0.10	4.98	4.43	2.42	0.460	18.70	11.60	3.72	0.010	0.04	0.030	0.070	0.000	19.8	7.00	163.0	CL	NONE
2	X	17DEC87	0.68	6.00	0.00	51.3	.	48.00	1.50	0.06	5.85	3.90	2.28	0.620	16.10	7.58	4.52	0.010	0.01	0.050	0.050	0.000	17.5	7.95	159.0	CL	NONE
2	X	14JAN88	0.47	3.60	0.26	130.0	.	44.00	0.66	0.06	5.43	4.10	2.17	0.500	18.40	5.10	0.63	0.040	0.03	0.000	0.000	0.000	18.8	8.05	161.0	CL	NONE

COUNTY=COLUMBIA
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
2	X	12FEB88	0.54	5.50	0.00	102.5	.	44.00	1.00	0.06	5.73	2.10	2.28	0.60	24.60	6.94	1.02	0.020	0.01	0.0000	0.020	0.000	19.1	7.60	158.0	CL	NONE
2	X	10MAR88	0.36	5.20	0.10	122.5	.	42.00	0.38	0.06	1.30	3.70	2.01	0.38	10.50	10.21	1.72	0.020	0.04	0.0000	0.020	0.000	20.2	7.75	158.0	CL	NONE
2	X	14APR88	0.44	4.80	0.00	75.0	.	44.00	1.00	0.06	4.60	4.60	1.93	0.46	17.10	7.94	1.06	0.010	0.02	0.0000	0.020	0.000	21.8	8.05	165.0	CL	NONE
2	X	17MAY88	0.52	5.00	0.00	142.5	.	30.00	0.72	0.05	11.56	3.50	1.60	0.41	22.30	6.75	0.66	0.010	0.02	0.0000	0.030	0.000	23.4	8.15	163.0	CL	NONE
2	X	14JUN88	0.39	5.50	0.00	165.0	.	44.00	0.20	0.09	0.05	3.20	2.24	0.39	15.80	8.89	0.63	0.010	0.03	0.0000	0.020	0.010	23.0	8.10	167.0	CL	NONE
2	X	19JUL88	0.40	5.30	0.00	117.5	.	46.00	0.26	0.07	1.16	3.10	2.84	0.36	15.90	9.44	0.38	0.010	0.02	0.0000	0.030	0.000	22.9	8.30	168.0	CL	NONE
2	X	17AUG88	0.82	14.76	0.00	104.0	.	51.70	1.70	0.08	4.00	4.05	3.00	0.90	20.80	12.10	2.20	0.020	0.02	0.0100	0.010	0.000	22.4	8.15	146.0	CLR	NONE
2	X	26OCT88	0.27	14.89	0.00	128.0	.	75.48	0.03	0.08	5.11	12.03	2.40	0.42	8.40	8.40	0.27	0.020	0.02	0.0400	0.020	0.000	24.1	7.87	143.8	CLR	NONE
2	X	05DEC88	0.31	1.35	0.18	65.0	.	48.63	0.12	0.03	4.96	2.83	2.50	0.59	10.97	11.73	0.88	0.020	0.02	0.0100	0.040	0.000	19.8	7.95	146.7	VCD	NONE
2	X	07FEB89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		
2	X	10MAR89	0.22	1.35	0.18	88.0	.	47.79	0.01	0.01	5.20	4.15	2.80	0.89	9.84	11.50	1.77	0.020	0.02	0.0200	0.040	0.000	20.8	7.25	141.8	CD	NONE
2	X	05JUN89	0.17	1.40	0.11	88.0	.	47.25	0.03	0.02	5.10	4.26	3.10	0.80	220.40	33.84	1.95	0.020	0.02	0.1400	0.310	0.000	22.7	7.48	139.2	CD	NONE
2	X	07AUG89	0.16	1.30	0.12	95.0	.	57.49	0.04	0.03	8.03	6.17	2.01	0.45	37.24	20.14	1.17	0.020	0.02	0.0100	0.040	0.000	22.8	7.13	149.0	SCD	NONE
2	X	06NOV89	0.15	1.30	0.15	.	.	.	0.06	0.03	5.00	.	2.32	0.67	28.45	12.87	1.00	0.050	0.02	0.0200	0.020	0.000	22.6	7.82	140.7	SCD	NONE
2	X	05FEB90	0.16	1.25	0.00	.	.	.	0.04	0.02	5.60	.	2.02	0.50	28.60	15.39	0.44	.	.	.	.	.	21.4	6.91	138.0	CLR	NONE
3	P	29JUL86	0.00	11.10	0.02	630.0	0	16.00	.	.	1.45	.	9.94	2.82	6.79	8.27	8.03	0.019	0.03	0.0310	0.166	0.000	.	5.90	62.0	VCD	NONE
3	P	12AUG86	0.00	15.00	.	723.3	0	14.00	.	.	2.50	.	6.34	2.83	5.70	8.17	5.68	0.039	0.03	0.0330	0.103	0.000	.	5.65	47.0	BR	NONE
3	P	22OCT86	0.18	12.00	0.03	52.5	0	14.00	1.00	0.03	1.67	4.10	5.62	3.42	5.50	2.22	6.15	0.047	0.03	0.0430	0.096	0.011	19.0	5.05	47.0	BR	NONE
3	P	19NOV86	0.00	10.30	0.15	95.0	0	10.00	0.54	0.03	1.42	4.50	4.30	3.29	5.78	2.16	6.11	0.038	0.04	0.0270	0.116	0.000	23.0	5.35	35.0	BR	NONE
3	P	18DEC86	0.00	9.20	0.02	35.0	0	12.00	1.48	0.01	0.20	4.70	4.47	2.73	7.80	2.98	8.02	0.047	0.03	0.0170	0.173	0.000	21.0	4.40	31.0	BR	NONE
3	P	30JAN87	0.00	7.10	0.02	42.9	0	12.00	1.00	0.02	0.30	4.05	3.62	4.17	7.76	2.83	8.41	0.043	0.02	0.0120	0.156	0.000	22.0	4.75	33.0	BR	NONE
3	P	27FEB87	0.00	7.20	0.02	40.0	0	8.00	0.56	0.01	0.01	5.20	4.61	3.74	6.35	2.79	5.22	0.054	0.03	0.0000	0.156	0.000	22.0	4.40	36.0	BR	NONE
3	P	20MAR87	0.00	6.50	0.02	35.0	0	8.00	0.22	0.01	0.05	1.20	3.92	2.68	4.05	2.84	6.07	0.012	0.04	0.1017	0.115	0.000	22.0	5.25	27.0	BR	NONE
3	X	14MAY87	0.00	7.20	0.02	42.5	0	10.00	0.52	0.09	0.11	8.00	3.67	2.74	5.65	2.73	8.12	0.021	0.04	0.0220	0.142	0.000	22.0	5.10	29.0	BR	NONE
3	X	18JUN87	0.00	5.50	0.02	42.5	0	10.00	0.98	0.09	0.02	10.00	2.88	3.25	7.00	2.72	8.36	0.012	0.02	0.0000	0.138	0.000	23.0	4.55	29.0	BR	NONE
3	X	16JUL87	0.14	6.00	0.02	32.5	0	6.00	1.00	0.07	0.27	4.90	2.38	1.82	6.25	2.80	5.97	0.037	0.03	0.0130	0.145	0.000	18.5	5.05	27.0	BR	NONE
3	X	13AUG87	0.00	7.40	0.02	30.0	0	14.00	0.90	0.05	0.56	3.80	.	.	5.34	2.62	6.50	.	.	0.0170	0.103	.	21.5	5.25	32.0	BR	NONE
3	X	17SEP87	0.16	5.00	0.02	15.0	0	8.00	0.80	0.32	0.12	4.50	.	.	.	.	.	.	.	.	.	.	23.0	4.65	28.0	BR	NONE
3	X	15OCT87	0.00	4.40	0.00	32.5	.	6.00	0.12	0.02	0.32	1.50	1.88	0.75	1.40	1.78	4.32	0.020	0.05	0.0000	0.150	0.000	21.1	4.70	29.0	BR	NONE
3	X	19NOV87	0.00	4.30	0.00	80.0	.	12.00	0.22	0.05	0.54	4.77	1.96	0.62	0.70	1.29	8.33	0.020	0.06	0.0000	0.100	0.000	20.3	4.65	28.0	BR	NONE
3	X	17DEC87	0.12	4.80	0.10	10.0	.	8.00	0.34	0.02	0.76	4.40	1.71	0.53	0.58	1.01	4.92	0.020	0.01	0.0000	0.130	0.000	18.9	5.50	26.0	CD	NONE
3	X	14JAN88	0.00	2.90	0.30	25.0	.	24.00	0.32	0.05	0.23	4.40	1.68	0.52	1.50	0.68	1.05	0.060	0.03	0.0000	0.010	0.000	17.4	4.75	26.0	CL	NONE
3	X	12FEB88	0.00	5.20	0.00	15.0	.	8.00	0.40	0.02	0.44	4.60	1.64	0.51	0.62	0.65	0.98	0.020	0.02	0.0000	0.040	0.000	18.2	3.65	27.0	CD	NONE
3	X	10MAR88	0.00	4.40	0.00	15.0	.	6.00	0.20	0.02	0.40	4.40	1.51	0.46	0.66	1.06	0.97	0.030	0.03	0.0000	0.030	0.000	19.5	4.10	25.0	CD	NONE
3	X	14APR88	0.00	3.50	0.00	10.0	.	14.00	0.32	0.11	0.53	3.80	1.38	0.58	0.43	0.41	0.92	0.020	0.03	0.0000	0.040	0.000	22.2	4.90	27.0	CD	NONE
3	X	17MAY88	0.00	4.20	0.00	2.5	.	12.00	0.15	0.02	2.16	4.10	1.00	0.42	0.63	0.93	2.75	0.020	0.02	0.0000	0.020	0.000	23.5	4.45	28.0	CD	NONE
3	X	14JUN88	0.00	4.00	0.00	37.5	.	4.00	0.22	0.09	0.24	4.10	1.62	0.63	0.30	0.84	2.42	0.020	0.02	0.0000	0.030	0.000	24.9	5.15	26.0	CD	NONE
3	X	19JUL88	0.00	3.60	0.00	32.5	.	18.00	0.30	0.09	0.91	4.80	2.05	0.33	0.77	1.06	2.56	0.000	0.03	0.0000	0.040	0.000	22.8	4.95	26.0	CD	NONE
3	X	17AUG88	0.14	7.22	0.00	93.0	.	20.68	0.63	0.02	0.11	14.17	2.30	1.00	1.50	1.00	2.50	0.020	0.04	0.0500	0.010	0.000	23.0	4.95	23.0	VCD	NONE
3	X	26OCT88	0.00	7.44	0.00	.	.	.	0.04	0.05	0.39	10.69	3.30	0.55	0.30	0.80	0.85	0.020	0.04	0.0400	0.010	0.000	20.5	4.65	39.1	VCD	NONE
3	X	05DEC88	0.14	0.98	0.13	33.0	.	.	0.20	0.05	0.32	35.56	4.70	0.77	0.30	1.10	2.72	0.020	0.04	0.0100	0.010	0.000	21.1	5.92	38.8	VCD	NONE
3	X	07FEB89	0.48	0.69	0.00	.	.	.	0.04	0.03	0.20	20.80	3.57	0.75	0.30	1.33	3.60	0.020	0.04	0.0200	0.010	0.000	21.5	4.37	66.8	VCD	NONE
3	X	10MAR89	0.11	0.90	0.24	91.0	.	.	0.01	0.01	0.35	19.45	3.98	0.99	0.50	2.40	9.59	0.020	0.04	0.0100	0.010	0.000	21.8	3.86	61.8	VCD	NONE
3	X	05JUN89	0.00	0.95	0.29	22.0	.	.	0.04	0.02	0.52	21.16	3.10	0.55	2.04	1.93	1.75	0.020	0.04	0.0100	0.010	0.000	23.9	3.62	61.9	VCD	NONE
3	X	07AUG89	0.00	0.93	0.11	17.0	.	.	0.04	0.05	0.25	14.20	2.49	0.52	0.93	1.27	3.61	0.020	0.04	0.0100	0.010	0.000	23.6	3.96	51.3	VCD	NONE
3	X	06NOV89	0.00	0.92	0.17	.	.	.	0.08	0.05	0.37	.	2.54	0.63	1.78	1.72	8.51	0.020	0.07	0.0100	0.010	0.000	23.5	4.31	45.9	VCD	NONE
3	X	05FEB90	0.00	0.94	0.00	.	.	.	0.03	0.02	0.30	.	2.01	0.07	1.16	1.31	0.92	.	.	.	.	.	21.9	4.18	49.0	VCD	NONE
4	P	29JUL86	0.00	7.00	0.02	370.0	0	210.00	.	.	2.30	.	9.98	3.44	23.90	6.49	1.38	0.016	0.01	0.0120	0.265	0.000	.	6.45	600.0	CD	NONE

COUNTY=COLUMBIA
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
4	P	12AUG86	0.00	6.50	0.02	503.3	0	200.00	.	.	3.48	.	9.95	8.980	42.20	6.49	7.22	0.020	0.07	0.014	0.636	0.013	.	6.80	550.0	BR	NONE
4	P	22OCT86	0.15	4.00	0.02	87.5	0	196.00	0.60	0.05	4.90	16.00	.	4.850	21.30	4.37	3.57	0.023	0.05	0.013	0.197	0.012	25.0	6.60	330.0	VCD	NONE
4	P	19NOV86	0.12	3.40	0.02	140.0	0	154.00	1.30	0.04	7.80	3.75	45.02	3.780	21.90	4.59	2.62	0.045	0.02	0.042	0.207	0.000	24.0	7.05	231.0	VCD	NONE
4	P	18DEC86	0.00	3.00	0.02	175.0	0	133.00	1.22	0.08	4.40	17.50	41.87	2.790	17.10	3.02	1.70	0.044	0.02	0.022	0.211	0.012	21.0	6.95	209.0	VCD	NONE
4	P	30JAN87	0.00	2.55	0.28	137.5	0	124.00	0.96	0.05	5.60	17.63	58.02	2.170	13.70	2.32	0.94	0.053	0.06	0.012	0.137	0.010	21.0	6.85	182.0	CD	NONE
4	P	27FEB87	0.00	2.80	0.02	135.0	0	110.00	0.50	0.05	0.03	15.00	29.83	1.840	11.70	2.31	0.54	0.021	0.03	0.011	0.131	0.000	22.0	7.10	178.0	CD	NONE
4	P	20MAR87	0.00	2.85	0.02	107.5	0	36.00	0.56	0.03	1.44	14.50	17.60	2.110	11.90	5.34	2.02	0.017	0.01	0.017	0.174	0.000	20.0	6.85	160.0	BR	NONE
4	X	14MAY87	0.14	2.90	0.02	115.0	0	50.00	0.88	0.14	2.90	18.50	14.10	2.190	12.80	2.98	1.03	0.054	0.03	0.010	0.149	0.000	17.5	6.75	152.0	VCD	NONE
4	X	18JUN87	0.00	3.11	0.02	75.0	0	36.00	0.90	0.15	1.49	11.00	12.60	2.490	9.45	5.82	1.30	0.017	0.02	0.013	0.136	0.000	24.0	6.80	132.0	CD	NONE
4	X	16JUL87	0.14	2.60	0.02	85.0	0	28.00	1.76	0.16	3.00	9.90	6.68	1.620	10.40	5.12	1.72	0.000	0.03	0.019	0.154	0.011	23.0	6.90	116.0	VCD	NONE
4	X	13AUG87	0.00	2.60	0.02	82.5	0	24.00	1.50	0.10	5.50	7.60	.	.	11.80	4.55	1.76	.	.	0.023	0.186	.	22.5	7.05	112.0	BR	NONE
4	X	17SEP87	0.00	2.50	0.02	60.0	0	26.00	1.50	0.10	1.89	10.80	.	.	.	.	.	.	.	.	.	.	23.0	6.80	99.0	VCD	NONE
4	X	15OCT87	0.00	2.60	0.00	25.0	.	26.00	0.28	0.05	5.25	9.10	7.11	1.530	6.78	3.54	1.32	0.010	0.03	0.000	0.150	0.000	20.2	6.95	101.0	VCD	NONE
4	X	19NOV87	0.00	2.70	0.00	37.5	.	22.00	0.20	0.07	2.53	14.30	7.67	1.970	5.97	1.04	1.04	0.000	0.03	0.000	0.120	0.000	20.0	7.25	92.0	BR	NONE
4	X	17DEC87	0.00	3.10	0.17	60.0	.	20.00	1.58	0.05	3.69	66.70	6.12	1.910	5.20	4.35	1.19	0.000	0.02	0.020	0.160	0.000	17.0	7.20	99.0	VCD	NONE
4	X	14JAN88	0.00	2.30	0.42	82.5	.	20.00	0.54	0.04	3.17	38.20	7.69	1.920	9.39	3.58	1.42	0.030	0.04	0.000	0.020	0.000	19.2	7.50	106.0	VCD	NONE
4	X	12FEB88	0.00	4.20	0.00	105.0	.	20.00	1.30	0.10	3.23	31.00	8.10	1.800	51.60	2.79	2.17	0.020	0.03	0.000	0.030	0.000	18.2	6.65	99.0	VCD	NONE
4	X	10MAR88	0.00	3.50	0.15	172.5	.	22.00	0.40	0.04	1.66	24.30	9.15	1.890	6.29	5.35	1.59	0.020	0.03	0.000	0.020	0.000	19.8	6.05	110.0	CD	NONE
4	X	14APR88	0.00	2.80	0.00	27.5	.	32.00	0.70	0.09	2.40	24.00	7.28	2.050	5.42	3.39	1.55	0.000	0.02	0.000	0.020	0.000	21.0	6.15	117.0	CD	NONE
4	X	17MAY88	0.00	2.50	0.00	112.5	.	22.00	0.40	0.05	3.22	30.20	4.55	1.780	10.40	2.96	1.92	0.000	0.03	0.000	0.020	0.000	22.0	5.95	132.0	CD	NONE
4	X	14JUN88	0.00	2.90	0.00	122.5	.	20.00	0.32	0.11	0.03	40.20	7.86	1.590	11.40	4.87	1.63	0.000	0.02	0.000	0.090	0.000	22.0	6.60	151.0	CD	NONE
4	X	19JUL88	0.00	2.90	0.00	95.0	.	18.00	0.46	0.07	3.90	40.20	9.25	1.530	11.10	4.43	1.56	0.000	0.03	0.000	0.020	0.010	23.5	6.35	158.0	CD	NONE
4	X	17AUG88	0.16	5.52	0.00	139.0	.	25.85	0.67	0.12	3.50	28.78	6.70	1.900	13.90	4.20	2.90	0.010	0.00	0.010	0.090	0.000	23.9	6.10	131.0	CD	NONE
4	X	26OCT88	0.00	12.41	0.00	132.0	.	12.41	0.04	0.12	4.26	35.49	6.60	1.500	3.30	3.20	0.87	0.010	0.00	0.010	0.100	0.000	22.9	5.97	131.4	VCD	NONE
4	X	05DEC88	0.14	1.30	0.00	155.0	.	9.62	0.20	0.10	3.08	56.90	7.20	1.470	4.83	4.97	1.13	0.010	0.00	0.020	0.170	0.000	18.8	6.81	161.1	CD	NONE
4	X	07FEB89	0.35	0.75	0.00	120.0	.	11.96	0.08	0.05	3.80	83.20	7.67	2.200	5.27	7.47	7.55	0.010	0.00	0.050	0.780	0.000	22.7	6.10	167.0	VCD	NONE
4	X	11MAR89	0.11	0.66	0.00	235.0	.	8.89	0.02	0.02	3.17	36.04	7.63	2.280	9.67	0.83	0.76	0.010	0.00	0.010	0.140	0.000	16.0	6.34	110.2	VCD	NONE
4	X	06JUN89	0.11	0.52	0.14	150.0	.	9.89	0.04	0.02	3.01	94.93	6.58	1.500	33.78	8.23	0.88	0.010	0.00	0.030	0.300	0.000	22.4	5.45	220.0	VCD	NONE
4	X	07AUG89	0.00	0.42	0.13	330.0	.	6.63	0.04	0.03	2.93	238.35	5.34	2.340	66.81	23.08	1.29	0.010	0.00	0.010	0.260	0.000	22.7	5.13	455.0	SCD	NONE
4	X	06NOV89	0.00	2.25	0.00	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		
4	X	05FEB90	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		
5	P	29JUL86	0.31	4.30	0.02	266.7	0	124.00	.	.	0.85	.	2.45	1.270	.	7.05	4.71	0.012	0.04	0.022	0.049	0.000	.	7.25	214.0	CD	NONE
5	P	12AUG86	0.26	5.30	.	200.0	0	102.00	.	.	2.00	3.50	2.32	0.958	.	3.52	2.32	0.012	0.04	0.016	0.014	0.000	.	6.95	191.0	CD	NONE
5	P	22OCT86	0.19	3.90	0.02	145.0	0	96.00	0.70	0.03	0.50	1.50	2.95	0.812	38.60	2.55	3.10	0.000	0.03	0.000	0.073	0.000	22.0	6.35	172.0	CD	NONE
5	P	19NOV86	0.17	3.20	0.02	112.0	0	94.00	0.58	0.03	0.15	5.50	1.67	0.568	34.50	2.16	1.09	0.050	0.03	0.000	0.013	0.011	22.5	6.70	167.0	CL	NONE
5	P	18DEC86	0.22	3.60	0.02	100.0	0	96.00	1.90	0.06	0.18	4.90	1.67	1.100	17.90	3.27	3.24	0.055	0.04	0.000	0.017	0.013	21.0	6.20	168.0	CD	NONE
5	P	30JAN87	0.19	3.20	0.02	125.0	0	82.00	2.40	0.05	0.25	5.45	2.17	1.180	57.20	4.17	3.13	0.052	0.02	0.015	0.036	0.000	21.0	6.85	191.0	CD	NONE
5	P	27FEB87	0.21	3.60	0.02	167.5	0	107.50	1.24	0.09	2.20	4.00	2.83	0.811	36.70	3.37	1.03	0.015	0.02	0.000	0.038	0.000	24.0	6.15	181.0	CL	NONE
5	P	20MAR87	0.21	3.40	0.11	142.5	0	74.00	0.92	0.03	0.46	3.80	2.66	0.755	5.30	4.14	3.29	0.000	0.03	0.014	0.039	0.000	21.0	6.55	169.0	SCD	NONE
5	X	14MAY87	0.17	3.60	0.02	130.0	0	82.00	0.70	0.10	0.39	3.70	2.53	0.589	48.20	3.62	2.92	0.000	0.03	0.019	0.057	0.000	22.5	6.90	211.0	CL	NONE
5	X	18JUN87	0.24	3.35	0.02	87.5	0	84.00	1.00	0.13	0.09	1.30	2.20	0.742	36.20	3.13	3.99	0.000	0.02	0.000	0.032	0.000	23.0	6.45	203.0	CL	NONE
5	X	16JUL87	0.17	3.50	0.02	105.0	0	74.00	1.28	0.11	0.21	3.50	2.73	0.713	34.20	3.86	3.57	0.054	0.03	0.000	0.045	0.000	17.5	7.35	191.0	SCD	NONE
5	X	13AUG87	0.00	3.70	0.02	110.0	0	78.00	1.42	0.05	1.90	4.20	.	.	39.20	7.92	4.63	.	.	0.000	0.048	.	22.0	6.75	182.0	SCD	NONE
5	X	17SEP87	0.60	3.40	0.02	85.0	0	82.00	1.52	0.08	0.43	4.60	.	.	.	.	.	.	.	.	.	.	22.5	7.15	176.0	SCD	NONE
5	X	15OCT87	0.15	3.70	0.00	82.2	.	74.00	0.38	0.05	0.35	1.40	2.05	0.240	16.10	1.65	5.84	0.000	0.03	0.000	0.020	0.000	19.9	6.80	168.0	CL	NONE
5	X	19NOV87	0.18	4.10	0.00	65.0	.	60.00	0.00	0.06	0.19	4.56	2.11	0.370	22.60	1.04	4.78	0.000	0.02	0.000	0.020	0.000	20.0	6.50	151.0	CL	NONE
5	X	17DEC87	0.48	4.60	0.14	72.5	.	72.00	1.62	0.05	0.89	3.80	2.19	0.520	34.10	2.12	3.25	0.000	0.01	0.000	0.020	0.000	18.9	7.20	151.0	SCD	NONE
5	X	14JAN88	0.19	2.80	0.44	95.0	.	62.00	0.30	0.06	0.89	4.60	2.02	0.960	33.70	1.61	0.13	0.070	0.06	0.000	0.020	0.000	17.0	6.85	148.0	CL	NONE

COUNTY=COLUMBIA
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
5	X	12FEB88	0.50	4.10	0.00	117.5	.	68.00	1.12	0.05	0.29	3.90	2.22	0.89	27.80	5.80	0.43	0.020	0.01	0.000	0.020	0.000	18.5	6.35	147.0	SCD	NONE
5	X	10MAR88	0.43	4.20	0.14	100.0	.	64.00	1.24	0.05	0.30	12.00	2.24	0.93	29.10	7.48	0.22	0.020	0.03	0.000	0.030	0.000	19.1	5.95	199.0	SCD	NONE
5	X	14APR88	0.36	3.80	0.00	92.5	.	42.00	0.80	0.10	0.37	5.40	1.79	1.09	28.80	2.33	0.00	0.000	0.03	0.010	0.030	0.000	22.1	7.00	178.0	CL	NONE
5	X	17MAY88	0.00	3.70	0.00	87.5	.	60.00	0.30	0.07	0.81	4.10	1.15	1.08	27.40	2.65	0.77	0.000	0.02	0.000	0.020	0.000	23.8	7.40	183.0	CL	NONE
5	X	14JUN88	0.19	4.10	0.00	117.5	.	74.00	0.60	0.11	2.04	4.10	2.01	0.53	27.80	1.72	0.33	0.000	0.03	0.000	0.030	0.000	23.9	7.20	183.0	CL	NONE
5	X	19JUL88	0.25	4.10	0.00	135.0	.	70.00	0.30	0.07	0.51	5.80	2.91	0.35	26.40	2.01	0.21	0.000	0.05	0.000	0.050	0.000	22.7	7.40	179.0	CL	NONE
5	X	17AUG88	0.43	11.29	0.00	107.0	.	82.72	1.11	0.06	0.00	7.07	2.90	1.00	35.00	2.90	1.60	0.020	0.03	0.010	0.030	0.000	22.0	7.25	149.0	CL	NONE
5	X	26OCT88	0.14	9.57	0.10	73.0	.	66.18	0.02	0.12	0.42	4.02	3.90	3.10	68.00	5.60	8.15	0.020	0.03	0.090	0.080	0.000	20.9	7.38	135.9	SCD	NONE
5	X	05DEC88	0.26	1.80	0.37	76.0	.	62.00	0.16	0.05	0.13	2.99	2.37	0.70	15.20	2.20	1.38	0.020	0.03	0.010	0.030	0.000	20.4	7.29	127.7	SCD	NONE
5	X	07FEB89	0.64	0.95	0.00	49.0	.	67.42	0.08	0.04	0.10	3.60	2.30	0.54	15.13	1.53	0.84	0.020	0.03	0.010	0.040	0.000	21.6	7.03	125.4	SCD	NONE
5	X	10MAR89	0.11	1.15	0.16	141.0	.	68.91	0.03	0.04	0.16	4.15	2.43	0.69	11.90	1.40	0.85	0.020	0.03	0.010	0.030	0.000	21.6	6.11	141.6	SCD	NONE
5	X	05JUN89	0.11	0.98	0.11	71.0	.	65.93	0.04	0.03	0.17	3.67	2.10	0.40	25.70	1.50	0.73	0.020	0.03	0.010	0.030	0.000	23.3	6.39	129.6	SCD	NONE
5	X	07AUG89	0.11	1.00	0.12	67.0	.	61.92	0.06	0.05	0.10	6.83	1.21	0.41	24.36	0.45	0.30	0.020	0.03	0.010	0.030	0.000	23.3	6.55	121.0	CL	NONE
5	X	06NOV89	0.00	1.00	0.12	.	.	.	0.06	0.07	0.17	.	2.00	0.31	26.53	0.95	0.28	0.020	0.09	0.010	0.000	0.000	23.3	6.40	114.0	CL	NONE
5	X	05FEB90	0.00	1.05	0.00	.	.	.	0.08	0.07	0.10	.	1.92	0.54	32.98	1.66	0.03	0.020	.	.	.	.	21.9	7.22	162.4	CL	NONE
6	P	29JUL86	0.70	8.00	0.02	240.0	0	80.00	.	.	2.85	.	3.58	1.84	.	17.30	1.57	0.011	0.04	0.014	0.050	0.012	.	7.35	260.0	CD	NONE
6	P	12AUG86	0.36	9.70	.	166.7	0	70.00	.	.	0.09	3.50	3.03	2.60	.	17.30	2.36	0.016	0.04	0.030	0.086	0.016	.	7.45	228.0	CD	NONE
6	P	22OCT86	0.23	8.00	0.02	225.0	0	84.00	1.20	0.07	10.20	3.00	3.87	1.87	45.10	16.10	1.93	0.012	0.02	0.000	0.086	0.000	26.0	6.65	221.0	SCD	NONE
6	P	19NOV86	0.24	7.40	0.02	155.0	0	68.00	1.40	0.10	12.20	1.00	2.28	1.58	39.80	16.50	1.69	0.011	0.03	0.019	0.038	0.015	23.0	7.25	220.0	CD	NONE
6	P	18DEC86	0.26	7.80	0.02	140.0	0	72.00	0.20	0.12	10.92	3.80	2.26	2.45	36.90	22.80	2.91	0.000	0.03	0.012	0.057	0.012	21.0	7.05	211.0	CD	NONE
6	P	30JAN87	0.23	6.90	0.02	170.0	0	122.00	2.12	0.12	10.80	3.60	2.26	2.89	114.80	26.70	3.36	0.047	0.03	0.019	0.094	0.011	21.0	7.25	232.0	CD	NONE
6	P	27FEB87	0.26	7.40	0.02	207.5	0	66.00	1.90	0.12	6.80	3.50	2.38	2.01	58.50	19.70	1.44	0.013	0.02	0.011	0.087	0.000	22.0	7.20	229.0	CD	NONE
6	P	20MAR87	0.23	6.50	0.02	172.5	0	68.00	1.58	0.02	8.00	4.00	2.57	1.68	56.70	17.50	1.53	0.000	0.03	0.015	0.068	0.012	19.0	7.40	219.0	CD	NONE
6	X	14MAY87	0.25	7.20	0.02	177.5	0	54.00	1.54	0.15	10.00	3.80	2.61	1.32	42.90	17.80	1.40	0.000	0.03	0.011	0.081	0.011	21.5	7.05	215.0	SCD	NONE
6	X	18JUN87	0.32	6.90	0.02	137.5	0	54.00	1.14	0.20	5.21	0.95	2.44	1.48	26.30	19.70	1.87	0.000	0.03	0.014	0.067	0.000	24.0	7.15	218.0	CL	NONE
6	X	16JUL87	0.27	6.10	0.02	202.5	0	52.00	10.70	0.21	11.86	4.00	3.18	4.61	27.10	18.20	1.87	0.000	0.04	0.017	0.059	0.010	19.5	7.50	218.0	VCD	NONE
6	X	13AUG87	0.28	7.40	0.02	157.5	0	58.00	4.76	0.20	11.10	4.90	.	.	24.80	17.00	1.60	.	.	0.015	0.085	.	23.0	7.35	221.0	VCD	NONE
6	X	17SEP87	0.19	5.00	0.02	160.0	0	64.00	8.96	0.23	8.74	3.60	.	.	.	.	.	.	.	.	.	.	23.0	7.25	228.0	VCD	NONE
6	X	15OCT87	0.64	7.40	0.00	107.5	.	78.00	0.97	0.17	8.19	0.90	3.10	2.10	33.90	8.03	1.82	0.000	0.03	0.020	0.050	0.000	20.1	7.15	218.0	CD	NONE
6	X	19NOV87	0.39	7.80	0.00	.	.	56.00	0.30	0.17	11.66	4.09	2.89	1.52	40.80	9.88	1.44	0.000	0.03	0.010	0.090	0.000	19.9	7.15	211.0	CD	NONE
6	X	17DEC87	1.60	9.00	0.00	142.5	.	42.00	5.40	0.17	8.00	3.30	3.12	1.92	63.70	6.74	1.67	0.000	0.03	0.010	0.070	0.010	19.9	7.45	210.0	CD	NONE
6	X	14JAN88	0.58	4.60	0.75	195.0	.	56.00	1.78	0.15	8.70	3.00	2.71	1.55	44.20	4.86	0.89	0.080	0.02	0.000	0.020	0.000	18.6	7.65	210.0	CD	NONE
6	X	12FEB88	0.68	8.00	0.00	132.5	.	60.00	1.44	0.12	10.74	2.30	2.71	1.58	33.30	5.38	0.88	0.020	0.07	0.000	0.010	0.000	18.9	6.75	213.0	CD	NONE
6	X	10MAR88	0.91	7.20	0.00	177.5	.	62.00	3.00	0.10	2.45	8.10	2.65	1.62	39.50	7.53	1.36	0.010	0.06	0.000	0.020	0.000	19.9	6.45	233.0	CD	NONE
6	X	14APR88	0.70	7.40	0.00	135.0	.	106.00	3.26	0.17	7.59	5.00	2.23	1.18	49.80	6.86	0.83	0.000	0.04	0.000	0.010	0.000	21.9	7.35	232.0	CD	NONE
6	X	17MAY88	0.60	7.50	0.00	122.5	.	48.00	1.05	0.14	6.64	0.00	1.39	1.66	31.70	8.56	0.24	0.000	0.03	0.000	0.010	0.000	23.0	7.65	226.0	CD	NONE
6	X	14JUN88	0.56	8.20	0.00	152.5	.	56.00	0.52	0.21	.	3.20	1.92	1.55	37.00	9.30	1.23	0.000	0.05	0.000	0.100	0.000	23.0	7.55	228.0	SCD	NONE
6	X	19JUL88	0.54	7.60	0.00	177.5	.	59.00	0.44	0.13	7.83	1.90	3.59	1.12	36.70	13.60	1.17	0.000	0.04	0.000	0.100	0.000	23.1	8.05	225.0	SCD	NONE
6	X	17AUG88	0.93	24.14	0.00	150.0	.	56.87	4.89	0.11	8.06	3.67	3.40	1.70	51.20	19.80	2.70	0.000	0.05	0.020	0.030	0.000	22.6	7.70	193.0	CD	NONE
6	X	26OCT88	0.19	14.89	0.00	79.0	.	67.21	0.07	0.09	15.12	3.53	3.10	1.80	40.00	22.40	3.29	0.000	0.05	0.040	0.100	0.000	22.4	7.35	188.0	VCD	NONE
6	X	05DEC88	0.35	1.80	0.14	111.0	.	57.72	0.24	0.18	8.44	3.35	3.00	1.53	28.27	18.40	2.57	0.000	0.05	0.030	0.070	0.000	20.8	8.01	208.0	VCD	NONE
6	X	07FEB89	0.76	1.75	0.00	100.0	.	65.25	0.12	0.11	9.20	3.70	2.90	1.13	23.13	15.13	1.09	0.000	0.05	0.010	0.040	0.000	22.0	7.27	195.0	CL	NONE
6	X	11MAR89	0.12	2.25	0.12	218.0	.	70.02	0.10	0.10	9.78	3.88	3.28	1.67	14.75	14.30	1.18	0.000	0.05	0.010	0.060	0.000	20.7	7.17	194.1	CD	NONE
6	X	06JUN89	0.14	1.85	0.34	142.0	.	54.39	0.32	0.35	9.28	18.52	2.80	0.90	57.55	18.23	1.55	0.000	0.05	0.020	0.070	0.000	22.6	7.70	192.2	CD	NONE
6	X	07AUG89	0.12	3.00	0.10	133.0	.	64.13	0.10	0.13	10.56	5.07	1.95	1.17	69.58	29.52	1.73	0.000	0.05	0.020	0.120	0.000	22.3	6.50	197.0	SCD	NONE
6	X	06NOV89	0.12	1.60	0.10	.	.	.	0.12	0.10	9.00	.	2.63	1.20	61.76	24.50	0.98	0.000	0.07	0.030	0.070	0.000	21.9	6.77	196.1	SCD	NONE
6	X	05FEB90	0.15	1.45	0.00	.	.	.	0.10	0.09	9.80	.	2.36	1.17	55.48	18.07	0.26	.	.	.	.	.	21.0	6.58	196.0	SCD	NONE
7	P	29JUL86	0.36	7.60	0.02	356.7	0	202.00	.	.	2.35	.	9.98	5.25	.	18.70	9.25	0.036	0.09	0.101	0.349	0.048	.	7.10	610.0	CD	NONE

COUNTY=COLUMBIA
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
7	P	12AUG86	0.33	13.50	.	373.3	0	198.00	.	.	0.10	.	9.96	6.65	.	18.30	4.47	0.036	0.07	0.092	0.232	0.042	.	7.15	580	CD	NONE
7	P	22OCT86	0.33	21.00	.	430.0	0	180.00	4.20	0.05	20.50	7.40	30.08	4.26	140.80	16.30	7.71	0.016	0.03	0.018	0.122	0.013	27.0	6.95	590	CD	NONE
7	P	19NOV86	0.32	23.00	0.02	310.0	0	192.00	1.86	0.05	22.85	1.60	14.54	3.39	140.20	16.30	5.34	0.017	0.04	0.046	0.102	0.026	23.0	7.17	600	CD	NONE
7	P	18DEC86	0.32	25.00	0.02	327.5	0	185.00	2.00	0.10	23.00	1.60	26.55	7.31	136.40	22.20	4.87	0.012	0.03	0.042	0.253	0.032	21.0	6.75	565	CD	NONE
7	P	30JAN87	0.25	22.00	0.02	380.0	0	182.00	1.44	0.14	27.25	5.00	15.04	4.25	.	18.80	4.34	0.062	0.03	0.046	0.092	0.014	22.0	7.35	585	CD	NONE
7	P	27FEB87	0.26	24.50	0.02	310.0	0	166.00	0.70	0.13	21.50	1.60	15.86	3.55	162.20	16.50	1.39	0.000	0.01	0.000	0.057	0.000	24.0	6.65	605	CD	NONE
7	P	20MAR87	0.26	22.50	0.02	402.5	0	152.00	1.24	0.03	16.25	1.60	13.40	2.71	79.20	18.10	1.89	0.014	0.07	0.052	0.154	0.020	21.0	7.15	570	CD	NONE
7	X	14MAY87	0.25	21.10	0.02	122.5	0	124.00	1.34	0.22	21.25	1.24	11.87	2.70	92.30	17.50	4.68	0.014	0.05	0.037	0.143	0.017	23.5	7.30	575	CD	NONE
7	X	18JUN87	.	.	.	.	.	.	.	.	.	.	.	4.05	87.40	16.80	4.96	0.016	0.05	0.022	0.134	0.021	24.0	7.30	625	CD	NONE
7	X	19JUN87	0.38	26.50	0.02	402.5	0	104.00	1.60	0.32	16.73	1.00	10.40	.	.	.	.	.	.	.	.	.	.	.	.		
7	X	16JUL87	0.22	23.00	0.02	482.5	0	144.00	3.10	0.26	24.40	1.80	6.28	2.29	93.60	16.40	2.90	0.068	0.03	0.047	0.189	0.012	19.5	7.40	605	CD	NONE
7	X	13AUG87	0.22	27.00	0.02	435.0	0	146.00	12.20	0.27	31.85	4.00	.	.	63.20	17.90	2.20	.	.	0.039	0.182	.	22.0	7.20	645	CD	NONE
7	X	17SEP87	0.17	22.00	0.02	407.5	0	126.00	14.30	0.30	6.75	4.00	.	.	.	.	.	.	.	.	.	.	23.5	7.25	620	CD	NONE
7	X	15OCT87	0.40	26.00	0.00	405.0	.	112.00	1.00	0.23	6.75	1.60	6.67	4.59	75.50	8.27	2.80	0.000	0.01	0.030	0.150	0.000	19.6	6.95	625	CD	NONE
7	X	19NOV87	0.26	26.20	0.00	370.0	.	110.00	0.20	0.16	21.43	3.21	8.69	2.47	49.10	6.73	4.25	0.000	0.01	0.000	0.050	0.020	20.1	6.75	585	CD	NONE
7	X	17DEC87	0.56	29.00	0.00	425.0	.	130.00	4.40	0.18	1.98	2.10	10.60	2.26	68.40	6.48	2.94	0.000	0.03	0.020	0.060	0.000	19.0	7.15	545	VCD	NONE
7	X	14JAN88	0.67	19.00	0.75	1207.5	.	.	3.46	0.16	90.40	3.50	8.45	2.82	84.50	4.45	6.39	0.090	0.04	0.000	0.070	0.020	17.0	7.30	565	VCD	NONE
7	X	12FEB88	0.59	30.00	0.00	487.5	.	116.00	3.80	0.11	23.70	1.10	10.90	2.89	99.90	4.88	5.97	0.020	0.02	0.000	0.060	0.010	19.1	7.30	580	VCD	NONE
7	X	10MAR88	0.45	29.00	0.00	452.5	.	106.00	1.16	0.11	17.30	7.10	9.54	2.44	90.40	7.46	6.23	0.010	0.02	0.000	0.070	0.000	20.0	6.55	615	CD	NONE
7	X	14APR88	0.49	31.00	0.00	462.5	.	50.00	3.80	0.36	9.30	2.10	9.48	2.54	68.00	6.85	6.77	0.000	0.02	0.000	0.050	0.000	22.2	7.05	655	VCD	NONE
7	X	17MAY88	0.56	29.00	0.00	457.5	.	124.00	4.70	0.33	17.40	4.40	6.09	2.40	77.70	8.52	6.07	0.000	0.05	0.000	0.060	0.000	23.9	7.30	655	VCD	NONE
7	X	14JUN88	0.37	30.50	0.00	460.0	.	116.00	0.44	0.31	.	3.40	7.94	3.16	92.50	8.27	0.73	0.000	0.05	0.000	0.070	0.000	23.1	7.20	665	VCD	NONE
7	X	19JUL88	0.31	27.00	0.00	485.0	.	94.00	0.33	0.17	23.50	2.60	9.01	2.11	96.10	7.20	0.70	0.000	0.03	0.000	0.090	0.020	22.2	7.55	630	CD	NONE
7	X	07AUG88	0.69	92.30	0.00	429.0	.	180.95	7.99	0.19	18.40	3.78	11.40	2.80	127.00	12.90	2.40	0.020	0.06	0.010	0.020	0.000	22.1	7.45	580	CD	NONE
7	X	26OCT88	0.16	34.03	0.00	380.0	.	181.98	0.09	0.26	8.93	1.81	11.80	2.70	92.00	10.40	2.08	0.020	0.06	0.020	0.020	0.000	21.1	7.44	524	VCD	NONE
7	X	05DEC88	0.25	8.90	0.12	397.0	.	156.06	0.24	0.18	23.86	2.40	12.40	3.30	170.33	14.97	6.48	0.020	0.06	0.040	0.090	0.000	20.9	7.29	522	CD	NONE
7	X	07FEB89	1.10	7.00	0.00	336.0	.	159.31	0.18	0.18	26.70	2.40	11.77	2.30	74.67	8.40	0.39	0.020	0.06	0.020	0.010	0.000	21.9	7.74	516	CL	NONE
7	X	10MAR89	0.15	8.00	0.00	454.0	.	158.93	0.22	0.17	24.38	2.51	11.42	3.08	83.73	9.03	1.64	0.020	0.06	0.010	0.030	0.000	21.1	7.16	521	SCD	NONE
7	X	05JUN89	0.11	7.85	0.15	405.0	.	157.12	0.14	0.11	25.90	1.50	13.25	3.40	957.10	18.54	1.95	0.020	0.06	0.110	0.350	0.000	24.3	6.96	513	VCD	NONE
7	X	07AUG89	0.00	7.25	0.11	415.0	.	158.11	0.18	0.15	30.58	2.86	10.12	1.96	121.94	9.06	0.52	0.020	0.06	0.000	0.000	0.000	23.8	6.72	493	SCD	NONE
7	X	06NOV89	0.10	6.35	0.00	.	.	.	0.16	0.10	24.80	.	11.03	2.03	123.09	8.74	0.43	0.180	0.06	0.010	0.010	0.000	24.1	6.98	482	SCD	NONE
7	X	05FEB90	0.00	6.80	0.00	.	.	.	0.16	0.14	27.10	.	11.09	3.23	34.62	13.25	2.08	.	.	.	.	.	22.5	7.30	475	VCD	NONE
8	P	29JUL86	5.70	9.50	0.02	446.7	0	156.00	.	.	1.40	.	9.95	9.02	.	34.00	11.23	0.045	0.08	0.153	0.515	0.101	.	6.80	700	CD	NONE
8	P	12AUG86	0.35	10.50	.	246.7	0	100.00	.	.	2.75	.	9.90	2.57	.	27.70	6.92	0.020	0.05	0.148	0.325	0.047	.	7.95	318	CD	NONE
8	P	22OCT86	0.28	6.80	0.02	212.5	0	102.00	3.80	0.11	11.50	5.00	11.94	3.54	50.80	22.10	9.93	0.013	0.05	0.028	0.274	0.013	24.0	7.05	241	CD	NONE
8	P	19NOV86	3.10	7.80	0.19	172.0	0	82.00	14.00	0.35	11.02	4.30	6.28	5.56	139.70	64.40	10.59	0.047	0.05	0.062	0.445	0.049	23.0	7.15	238	VCD	NONE
8	P	18DEC86	0.31	8.60	0.02	82.5	0	64.00	1.86	0.25	10.40	5.30	3.79	3.75	25.80	21.90	5.51	0.040	0.04	0.024	0.135	0.013	20.0	7.05	233	CD	NONE
8	P	30JAN87	0.22	7.40	0.02	180.0	0	62.00	6.60	0.19	11.00	3.90	3.50	3.63	74.70	23.30	5.09	0.053	0.03	0.038	0.163	0.013	21.0	6.75	248	CD	NONE
8	P	27FEB87	0.30	8.10	0.02	220.0	0	74.00	3.70	0.22	5.25	3.90	4.44	2.07	51.10	21.60	1.46	0.000	0.04	0.000	0.086	0.000	22.0	7.35	255		NONE
8	P	20MAR87	0.25	7.90	0.02	190.0	0	62.00	4.56	0.15	8.19	4.40	4.92	1.71	46.30	31.30	5.47	0.000	0.04	0.052	0.301	0.010	21.0	7.45	254	CD	NONE
8	X	14MAY87	0.77	8.60	0.02	177.5	0	48.00	1.70	0.25	9.13	4.40	3.76	1.17	34.10	25.80	10.11	0.000	0.04	0.017	0.213	0.013	21.0	7.25	237	SCD	NONE
8	X	18JUN87	0.76	8.70	0.02	172.5	0	54.00	1.50	0.25	8.75	0.95	3.14	1.67	32.90	27.40	7.24	0.000	0.05	0.000	0.248	0.011	22.5	7.45	241	CD	NONE
8	X	16JUL87	0.44	7.60	0.02	170.0	0	58.00	4.28	0.18	11.69	1.00	3.48	1.77	43.20	29.90	5.83	0.015	0.05	0.030	0.287	0.011	21.5	7.40	233	CD	NONE
8	X	13AUG87	0.96	9.10	0.02	195.0	0	56.00	10.00	0.16	11.10	3.60	.	.	51.50	27.20	8.83	.	0.03	0.028	0.226	.	.	7.50	205	CD	NONE
8	X	17SEP87	0.98	8.70	0.02	180.0	0	64.00	16.04	0.20	8.21	3.50	.	.	.	.	.	.	.	.	.	.	23.0	7.35	239	VCD	NONE
8	X	15OCT87	1.30	8.70	0.00	97.5	.	48.00	2.28	0.17	7.09	2.10	2.51	2.07	30.30	8.55	5.84	0.000	0.03	0.000	0.120	0.020	20.2	7.45	228	SCD	NONE
8	X	19NOV87	2.10	9.30	0.00	140.0	.	48.00	0.16	0.14	11.63	3.77	2.49	1.62	50.60	11.20	5.63	0.000	0.03	0.020	0.100	0.000	20.0	7.30	220	CD	NONE
8	X	17DEC87	5.00	10.50	0.00	147.5	.	56.00	10.60	0.10	13.58	2.40	3.12	2.82	12.10	8.12	6.21	0.000	0.02	0.000	0.110	0.010	19.6	7.75	220	VCD	NONE

COUNTY=COLUMBIA
(continued)

Well	P=Pre X=Pst	Date	F	Cl	NH4	Total Diss Solids	CO3	HCO3	Total P	Diss P	NO3	SO4	Na	K	Ca	MG	Fe	Cu	Pb	Cr	Mn	Cd	Temp Deg C	pH	Conduct	Color	Odor
8	X	14JAN88	1.50	5.20	0.38	157.5	.	44.00	4.72	0.09	9.13	3.10	2.25	0.90	71.70	4.70	3.80	0.08	0.06	0.00	0.05	0.00	18.0	7.85	218.0	CD	NONE
8	X	12FEB88	1.28	8.00	0.00	220.0	.	54.00	1.60	0.05	10.98	2.50	2.34	0.92	6.04	3.06	3.62	0.02	0.01	0.00	0.04	0.00	16.5	6.80	210.0	SCD	NONE
8	X	10MAR88	0.53	8.60	0.00	170.0	.	54.00	2.00	0.05	6.55	2.60	2.30	0.93	38.10	7.34	3.74	0.00	0.02	0.00	0.05	0.00	19.0	6.95	223.0	SCD	NONE
8	X	14APR88	0.71	8.90	0.00	145.0	.	62.00	3.60	0.20	4.63	3.70	1.93	0.92	34.00	6.89	3.57	0.00	0.04	0.00	0.06	0.00	21.9	7.55	231.0	SCD	NONE
8	X	17MAY88	1.14	8.70	0.00	147.5	.	58.00	3.84	0.10	12.60	2.90	1.16	1.04	22.50	10.60	3.36	0.00	0.03	0.00	0.05	0.00	24.0	7.85	229.0	SCD	NONE
8	X	14JUN88	0.67	9.80	0.00	195.0	.	50.00	1.82	0.15	.	2.60	1.13	0.99	37.60	11.40	1.06	0.00	0.02	0.00	0.12	0.00	23.0	7.85	228.0	SCD	NONE
8	X	19JUL88	0.58	9.30	0.00	195.0	.	48.00	0.44	0.09	13.90	1.70	2.99	1.26	68.10	9.36	0.99	0.00	0.05	0.00	0.07	0.00	21.9	8.00	232.0	SCD	NONE
8	X	17AUG88	1.50	30.18	0.00	162.0	.	51.70	8.62	0.10	8.83	0.07	3.10	2.00	56.00	24.90	2.90	0.01	0.04	0.03	0.05	0.00	23.0	7.85	200.0	SCD	NONE
8	X	26OCT88	0.14	14.53	0.00	.	.	49.63	0.17	0.55	9.88	4.02	2.20	1.53	15.45	20.73	4.11	0.01	0.04	0.03	0.10	0.00	22.4	7.06	190.2	VCD	NONE
8	X	05DEC88	0.24	2.45	0.00	136.0	.	48.10	0.32	0.24	10.10	3.37	2.55	4.30	15.80	46.00	14.49	0.01	0.04	0.12	0.22	0.00	19.8	7.40	191.0	VCD	NONE
8	X	07FEB89	1.25	1.65	0.13	114.0	.	48.39	0.38	0.36	10.20	3.20	2.37	1.97	19.47	19.40	6.92	0.01	0.04	0.07	0.14	0.00	21.9	6.87	188.5	SCD	NONE
8	X	11MAR89	0.14	2.60	0.00	191.0	.	51.68	0.19	0.19	10.26	3.06	3.20	2.21	32.88	30.63	7.99	0.01	0.04	0.03	0.11	0.00	20.5	6.77	195.3	VCD	NONE
8	X	06JUN89	0.11	2.25	0.10	148.0	.	51.64	0.22	0.20	10.14	2.30	2.25	0.78	48.13	14.00	3.10	0.01	0.04	0.03	0.08	0.00	22.9	6.98	190.2	CD	NONE
8	X	07AUG89	0.10	3.25	0.11	160.0	.	51.96	0.24	0.22	11.99	3.19	2.81	2.46	412.20	135.35	9.64	0.01	0.04	0.07	0.42	0.02	22.8	6.23	181.0	SCD	NONE
8	X	06NOV89	0.10	2.00	0.12	.	.	.	0.30	0.15	9.60	.	2.15	1.85	72.13	31.70	4.30	0.01	0.04	0.03	0.15	0.01	21.5	6.65	186.5	SCD	NONE
8	X	05FEB90	0.10	1.95	0.00	.	.	.	0.28	0.26	11.60	.	2.04	1.33	66.42	29.79	5.25	.	.	.	.	.	21.3	6.42	180.0	CD	NONE

APPENDIX II

Analytical Data - Gypsum Road Building

Mean, Standard Deviation Range for
Pre- and Post- Construction Periods

Polk and Columbia County Roads

POLK COUNTY

ANALYTICAL DATA - GYPSUM ROAD BUILDING

MEAN, STANDARD DEVIATION & RANGE - PRE- AND POST BUILDING

	Well=1						Well=2					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.52	0.026	0.060	0.58	0.289	1.480	0.50	0.031	0.070	0.68	0.516	2.460
Cl	4.52	0.981	2.600	4.48	2.641	13.010	10.56	0.532	1.200	10.51	6.597	37.820
NH4	0.02	0.000	0.000	0.07	0.145	0.700	0.02	0.000	0.000	0.13	0.271	1.400
Solids	154.8	29.512	82.500	142.7	81.094	299.50	157.3	51.485	133.00	96.41	33.055	185.50
HCO3	36.00	6.481	14.000	25.56	5.955	19.310	48.60	0.894	2.000	38.73	7.416	32.000
Total P	5.53	1.686	3.800	12.51	21.484	82.380	10.47	5.929	12.850	11.47	17.786	84.310
Dissolved P	1.55	0.700	1.300	0.97	0.361	2.080	3.22	1.437	2.850	1.35	0.381	2.250
NO3	0.65	0.488	1.050	0.84	0.546	2.380	1.09	0.740	1.400	0.20	0.232	0.860
SO4	24.50	0.000	0.000	64.38	58.105	216.25	9.70	0.000	0.000	14.89	9.101	42.440
Na	2.44	0.180	0.440	3.54	0.841	3.260	4.62	0.323	0.850	4.56	0.943	4.770
K	0.52	0.036	0.090	0.69	0.461	1.650	0.64	0.197	0.500	0.69	0.645	2.450
Ca	33.66	4.798	11.200	44.36	26.037	96.770	44.08	9.514	23.400	34.34	26.071	81.290
Mg	1.62	0.244	0.640	2.67	1.140	3.880	3.13	0.354	0.920	2.63	0.783	2.910
Fe	2.45	0.872	2.250	4.24	8.492	47.430	3.03	0.424	1.170	3.24	1.948	10.750
Cu	0.01	0.002	0.003	0.01	0.014	0.070	0.01	0.001	0.003	0.00	0.008	0.030
Pb	0.04	0.018	0.040	0.06	0.076	0.430	0.05	0.016	0.040	0.04	0.012	0.030
Cr	0.03	0.018	0.044	0.01	0.007	0.020	0.04	0.016	0.039	0.01	0.015	0.050
Mn	0.01	0.014	0.029	0.02	0.015	0.067	0.02	0.021	0.043	0.06	0.157	0.853
Cd	0.00	0.006	0.012	0.00	0.004	0.015	0.01	0.009	0.021	0.01	0.007	0.022
Temp	23.70	0.447	1.000	23.66	1.230	5.800	23.50	0.408	1.000	24.56	1.323	5.400
pH	5.63	0.146	0.400	5.58	0.383	1.720	5.76	0.055	0.100	5.75	0.402	1.730
Conductivity	131.7	7.903	20.000	227.1	90.798	287.00	148.0	7.714	20.000	157.7	21.942	110.40

	Well=5						Well=6					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.46	0.035	0.090	0.77	0.501	2.370	0.53	0.079	0.210	0.71	0.378	2.120
Cl	5.20	0.274	0.700	5.19	3.701	20.670	6.86	0.251	0.600	8.19	6.329	36.770
NH4	0.02	0.000	0.000	0.11	0.264	1.400	0.02	0.000	0.000	0.05	0.064	0.200
Solids	216.0	52.667	135.80	91.26	30.855	123.50	127.0	41.236	105.00	74.12	28.657	116.50
HCO3	53.20	1.789	4.000	37.11	11.221	42.560	29.80	1.789	4.000	21.56	5.433	24.000
Total P	18.90	10.476	24.400	15.25	24.320	100.00	5.29	3.612	7.730	8.47	10.254	37.800
Dissolved P	5.93	3.732	7.400	1.00	0.382	2.230	3.38	0.769	1.400	1.28	0.346	2.220
NO3	1.59	1.248	2.950	2.19	0.896	3.290	1.88	1.543	3.750	0.79	0.707	3.990
SO4	8.00	0.000	0.000	9.64	8.407	35.020	7.00	0.000	0.000	8.33	3.319	14.260
Na	6.38	0.943	2.120	5.07	1.620	6.260	4.29	0.074	0.170	4.37	0.901	4.470
K	1.27	0.315	0.820	0.93	1.208	4.080	0.46	0.120	0.330	0.53	0.451	1.830
Ca	96.12	2.461	6.300	44.65	39.276	126.09	27.24	5.377	13.100	25.10	19.334	69.100
Mg	6.95	0.986	2.370	5.44	1.554	6.070	2.33	0.995	2.440	1.27	0.389	1.820
Fe	2.53	0.564	1.410	2.00	2.140	10.510	0.73	0.496	1.370	0.68	0.601	2.140
Cu	0.01	0.006	0.015	0.01	0.010	0.041	0.00	0.000	0.000	0.00	0.004	0.020
Pb	0.05	0.005	0.010	0.04	0.016	0.050	0.03	0.009	0.020	0.03	0.015	0.050
Cr	0.07	0.024	0.066	0.02	0.023	0.069	0.02	0.019	0.044	0.01	0.009	0.035
Mn	0.05	0.029	0.077	0.08	0.075	0.332	0.01	0.013	0.028	0.02	0.029	0.104
Cd	0.01	0.012	0.024	0.00	0.010	0.048	0.01	0.012	0.026	0.00	0.003	0.013
Temp	23.62	0.750	1.500	23.96	1.114	4.800	23.82	0.236	0.500	24.45	1.417	5.600
pH	6.30	0.079	0.200	6.01	0.363	1.680	5.82	0.115	0.300	5.69	0.456	1.900
Conductivity	148.4	7.092	18.000	138.7	40.074	241.90	116.8	9.935	25.000	115.1	14.609	61.000

	Well=3						Well=4					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.42	0.035	0.080	0.53	0.360	2.110	0.75	0.033	0.070	0.90	0.719	4.160
Cl	7.78	0.622	1.300	7.45	5.836	30.200	16.60	1.194	3.000	19.15	12.619	62.690
NH4	2.30	0.398	1.040	2.09	0.747	4.090	0.43	0.164	0.460	0.59	0.380	1.940
Solids	141.3	29.874	70.000	103.2	42.387	181.50	181.0	15.610	35.000	150.8	36.859	176.00
HCO3	53.80	1.789	4.000	43.00	8.397	34.000	89.60	2.966	8.000	95.46	16.918	72.420
Total P	6.52	3.552	7.330	5.27	4.381	14.900	2.43	1.050	2.180	7.85	10.844	40.200
Dissolved P	3.58	0.804	1.500	2.23	0.664	3.430	1.42	0.306	0.600	0.81	0.201	1.290
NO3	1.15	1.350	2.600	0.27	0.389	1.440	0.66	0.811	1.670	0.27	0.326	1.070
SO4	3.20	0.000	0.000	3.73	1.850	8.130	13.25	0.000	0.000	2.99	1.648	7.060
Na	3.70	0.279	0.740	3.39	0.486	2.560	7.77	0.670	1.680	7.31	1.134	5.260
K	0.89	0.052	0.130	0.70	0.265	1.220	0.24	0.049	0.120	0.36	0.313	1.100
Ca	25.28	1.561	3.700	12.86	7.098	29.810	31.36	2.631	7.400	28.38	18.331	68.300
Mg	4.41	0.567	1.340	3.38	0.948	3.910	10.47	1.634	4.130	12.08	4.146	19.820
Fe	3.42	0.464	1.220	3.10	0.754	2.790	2.45	0.317	0.760	2.01	0.509	2.250
Cu	0.00	0.000	0.000	0.00	0.003	0.011	0.00	0.005	0.011	0.00	0.000	0.000
Pb	0.05	0.019	0.050	0.04	0.018	0.060	0.04	0.023	0.060	0.03	0.011	0.060
Cr	0.03	0.017	0.042	0.01	0.011	0.031	0.02	0.021	0.052	0.01	0.016	0.080
Mn	0.03	0.019	0.042	0.04	0.021	0.080	0.12	0.022	0.046	0.10	0.035	0.130
Cd	0.01	0.009	0.018	0.00	0.004	0.013	0.04	0.085	0.190	0.00	0.000	0.000
Temp	23.12	0.629	1.500	23.67	1.200	4.900	23.25	0.289	0.500	24.09	1.653	7.000
pH	5.59	0.114	0.300	5.52	0.392	1.560	6.17	0.135	0.300	6.27	0.295	1.300
Conductivity	147.4	3.715	9.000	146.2	35.321	191.00	265.0	21.794	55.000	280.7	28.360	124.00

	Well=7						Well=8					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.41	0.030	0.070	0.42	0.243	1.390	0.22	0.041	0.100	0.27	0.151	0.860
Cl	9.18	1.542	4.000	6.78	4.460	22.350	7.40	0.644	1.500	6.97	5.046	29.510
NH4	0.76	0.263	0.640	1.25	0.585	2.370	0.02	0.000	0.000	0.20	0.486	2.180
Solids	202.2	39.498	99.200	124.5	46.727	217.50	104.3	23.684	55.000	65.44	31.936	130.00
HCO3	88.40	3.578	8.000	71.54	21.420	66.980	28.40	2.608	6.000	22.94	3.322	15.510
Total P	3.75	0.938	2.100	3.48	4.085	14.580	2.53	1.516	2.950	5.95	10.296	37.240
Dissolved P	1.25	0.953	1.650	0.83	0.404	1.780	0.78	0.407	0.750	0.31	0.122	0.580
NO3	0.66	0.932	2.000	0.41	0.722	2.440	0.55	0.647	1.250	0.87	0.559	2.720
SO4	19.25	0.000	0.000	8.18	5.972	18.700	8.25	0.000	0.000	7.23	2.338	13.910
Na	8.91	2.259	5.110	4.21	1.514	7.760	3.33	0.354	0.890	2.94	0.731	3.630
K	0.92	0.238	0.580	0.57	0.292	1.450	0.25	0.062	0.170	0.27	0.213	0.830
Ca	43.90	4.310	10.900	20.89	13.224	54.300	20.16	3.100	8.600	15.21	10.015	38.890
Mg	10.93	2.023	5.450	7.36	3.521	12.210	2.35	0.479	1.270	1.80	0.314	1.320
Fe	9.59	1.306	3.630	9.33	2.234	9.330	2.43	2.091	5.100	2.60	4.363	20.130
Cu	0.00	0.005	0.011	0.00	0.003	0.010	0.00	0.000	0.000	0.00	0.003	0.010
Pb	0.04	0.018	0.040	0.05	0.025	0.070	0.03	0.004	0.010	0.02	0.014	0.060
Cr	0.03	0.023	0.055	0.01	0.010	0.040	0.01	0.014	0.032	0.01	0.007	0.020
Mn	0.02	0.023	0.051	0.07	0.045	0.180	0.02	0.023	0.051	0.03	0.028	0.126
Cd	0.00	0.007	0.013	0.00	0.002	0.010	0.00	0.007	0.013	0.00	0.004	0.020
Temp	24.12	0.250	0.500	24.01	1.219	5.100	24.00	0.408	1.000	24.19	1.348	5.000
pH	6.15	0.117	0.300	5.89	0.320	1.480	5.67	0.333	0.800	5.80	0.427	1.760
Conductivity	307.4	26.054	60.000	230.7	73.128	277.70	114.4	12.915	33.000	106.3	15.780	66.100

	Well=9						Well=10					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.40	0.029	0.070	0.54	0.321	1.550	0.40	0.026	0.060	0.55	0.332	1.740
Cl	5.12	0.606	1.600	5.66	4.880	26.150	7.12	0.363	0.800	7.05	4.862	27.160
NH4	0.02	0.000	0.000	0.08	0.217	1.150	0.02	0.000	0.000	0.04	0.074	0.280
Solids	111.3	21.176	56.700	86.72	35.655	164.50	113.2	22.821	60.000	90.02	35.337	164.50
HCO3	48.40	1.673	4.000	46.19	5.440	31.180	54.80	1.789	4.000	44.03	12.449	48.630
Total P	3.06	1.390	3.000	4.13	5.361	22.060	3.33	1.923	4.650	2.98	3.443	13.370
Dissolved P	1.58	0.520	1.000	0.77	0.267	1.910	1.20	0.300	0.600	1.04	0.299	1.970
NO3	1.80	0.175	0.400	1.39	0.574	1.930	0.84	0.266	0.600	0.56	0.268	1.100
SO4	3.20	0.000	0.000	4.25	3.259	11.570	7.40	0.000	0.000	5.80	1.538	5.950
Na	3.90	0.237	0.660	3.60	0.732	2.750	3.59	0.477	1.190	2.91	0.604	2.970
K	0.34	0.082	0.190	0.36	0.332	1.510	0.28	0.072	0.180	0.25	0.227	1.000
Ca	26.98	4.822	12.600	24.91	17.281	77.590	26.80	3.368	7.200	16.35	8.332	37.910
Mg	6.18	0.535	1.200	5.65	0.994	4.710	7.58	0.791	1.840	4.65	1.836	6.330
Fe	0.55	0.324	0.780	0.82	0.758	2.430	0.36	0.115	0.260	0.66	0.570	2.100
Cu	0.00	0.000	0.000	0.00	0.005	0.020	0.00	0.000	0.000	0.01	0.014	0.030
Pb	0.05	0.015	0.040	0.04	0.017	0.050	0.03	0.009	0.020	0.03	0.015	0.050
Cr	0.02	0.009	0.023	0.01	0.008	0.022	0.01	0.004	0.010	0.01	0.009	0.021
Mn	0.01	0.022	0.049	0.02	0.034	0.119	0.01	0.016	0.034	0.03	0.048	0.229
Cd	0.00	0.006	0.012	0.00	0.004	0.015	0.00	0.006	0.013	0.00	0.005	0.020
Temp	23.87	0.629	1.500	24.29	1.333	6.800	23.90	0.548	1.500	24.04	1.360	5.000
pH	6.38	0.084	0.200	6.30	0.310	1.160	6.30	0.087	0.200	6.11	0.317	1.320
Conductivity	143.0	4.950	13.000	145.7	19.337	110.50	175.4	7.635	20.000	135.4	31.965	136.20

COLUMBIA COUNTY
ANALYTICAL DATA - GYPSUM ROAD BUILDING
MEAN, STANDARD DEVIATION & RANGE - PRE- AND POST BUILDING

	Well=1						Well=2					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.06	0.127	0.360	0.13	0.142	0.690	0.49	0.067	0.190	0.40	0.171	0.670
Cl	4.26	1.068	3.200	2.96	1.672	6.120	5.82	0.389	1.300	5.11	3.569	13.640
NH4	0.04	0.045	0.120	0.07	0.108	0.370	0.02	0.000	0.000	0.05	0.077	0.260
Solids	71.78	26.092	76.700	75.62	67.172	283.00	150.0	36.791	117.50	110.2	30.433	113.70
HCO3	8.00	4.536	10.000	4.36	3.113	8.340	54.00	6.590	20.000	47.06	8.395	45.480
Total P	2.83	2.443	6.200	0.80	0.854	2.940	3.44	2.200	6.080	1.04	1.496	6.530
Dissolved P	0.01	0.000	0.000	0.04	0.023	0.080	0.08	0.049	0.140	0.07	0.041	0.140
NO3	2.36	1.594	3.650	2.04	0.963	4.240	5.38	2.656	6.090	5.34	2.498	11.510
SO4	23.44	3.548	10.000	42.32	39.853	166.70	2.97	1.922	5.600	3.79	2.272	11.130
Na	3.10	2.879	7.990	1.63	0.515	1.710	2.59	0.337	1.050	2.33	0.369	1.500
K	3.52	1.713	5.020	1.73	0.483	2.000	2.08	0.848	2.650	0.61	0.233	0.920
Ca	8.88	3.837	13.700	13.87	20.668	73.480	56.36	28.587	66.600	28.31	43.439	212.00
Mg	4.20	1.146	3.430	8.91	11.312	35.950	20.57	5.207	13.700	12.54	6.355	28.740
Fe	6.16	1.205	3.370	3.89	3.165	14.310	4.01	1.316	3.940	2.05	1.602	4.650
Cu	0.02	0.016	0.043	0.03	0.073	0.320	0.02	0.017	0.045	0.02	0.012	0.050
Pb	0.03	0.014	0.040	0.03	0.009	0.030	0.02	0.008	0.020	0.02	0.008	0.030
Cr	0.03	0.013	0.036	0.02	0.018	0.070	0.04	0.020	0.054	0.03	0.033	0.140
Mn	0.10	0.042	0.135	0.08	0.100	0.490	0.09	0.057	0.174	0.05	0.063	0.310
Cd	0.03	0.016	0.053	0.01	0.009	0.026	0.00	0.005	0.015	0.00	0.002	0.010
Temp	21.57	2.370	7.000	21.69	2.057	9.100	22.25	2.485	7.000	21.40	2.001	7.100
pH	4.73	0.526	1.500	4.34	0.616	3.200	7.49	0.231	0.650	7.65	0.416	1.390
Conductivity	105.0	11.539	35.000	163.0	129.11	520.00	176.3	5.574	16.000	159.4	13.882	43.000

	Well=5						Well=6					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.22	0.045	0.140	0.24	0.189	0.640	0.31	0.162	0.470	0.47	0.351	1.480
Cl	3.81	0.704	2.100	3.56	2.477	10.340	7.71	0.960	3.200	6.67	4.898	22.690
NH4	0.03	0.034	0.090	0.08	0.117	0.440	0.02	0.000	0.000	0.07	0.164	0.750
Solids	157.3	54.307	166.70	93.92	24.428	92.000	184.6	35.398	100.00	148.1	34.988	139.00
HCO3	96.94	15.256	50.000	69.14	9.763	42.000	78.75	18.576	56.000	60.94	12.614	64.000
Total P	1.29	0.721	1.820	0.59	0.557	1.620	1.40	0.675	1.920	2.14	2.890	10.630
Dissolved P	0.05	0.024	0.060	0.07	0.028	0.100	0.09	0.040	0.100	0.16	0.059	0.260
NO3	0.82	0.821	2.050	0.46	0.527	2.040	7.73	4.290	12.110	9.04	2.469	12.670
SO4	4.09	1.393	4.000	4.51	2.157	10.700	3.20	1.018	3.000	4.13	3.623	18.520
Na	2.34	0.486	1.280	2.24	0.569	2.750	2.78	0.642	1.610	2.73	0.526	2.200
K	0.93	0.238	0.700	0.76	0.582	2.860	2.12	0.474	1.310	1.61	0.731	3.710
Ca	31.70	17.989	51.900	29.84	11.850	56.100	58.63	28.874	77.900	40.58	14.324	54.830
Mg	3.78	1.493	4.890	2.83	2.034	7.470	19.24	3.712	10.600	14.51	6.694	24.660
Fe	2.74	1.227	3.680	1.97	2.248	8.150	2.10	0.712	1.920	1.46	0.717	3.050
Cu	0.02	0.024	0.055	0.02	0.018	0.070	0.01	0.015	0.047	0.01	0.018	0.080
Pb	0.03	0.008	0.020	0.03	0.017	0.080	0.03	0.008	0.020	0.04	0.014	0.050
Cr	0.01	0.009	0.022	0.01	0.019	0.090	0.02	0.009	0.030	0.01	0.011	0.040
Mn	0.03	0.020	0.060	0.03	0.016	0.080	0.07	0.021	0.056	0.06	0.033	0.110
Cd	0.00	0.006	0.013	0.00	0.000	0.000	0.01	0.006	0.016	0.00	0.004	0.011
Temp	21.92	1.201	3.000	21.32	1.988	6.900	22.00	2.366	7.000	21.48	1.510	5.400
pH	6.62	0.385	1.100	6.87	0.438	1.450	7.20	0.255	0.800	7.27	0.435	1.600
Conductivity	181.6	16.370	47.000	160.7	27.812	97.000	227.5	14.745	49.000	211.1	14.131	45.000

	Well=3						Well=4					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.02	0.064	0.180	0.05	0.109	0.480	0.03	0.063	0.150	0.05	0.089	0.350
Cl	9.80	2.906	8.500	3.89	2.307	6.750	4.01	1.751	4.450	2.91	2.382	11.990
NH4	0.04	0.049	0.130	0.06	0.097	0.300	0.05	0.092	0.260	0.05	0.098	0.420
Solids	206.7	291.77	688.30	33.92	25.923	90.500	207.0	148.36	415.80	114.5	69.223	305.00
HCO3	11.75	2.915	8.000	11.29	5.676	20.000	145.4	58.091	174.00	21.42	9.981	43.370
Total P	0.80	0.448	1.260	0.33	0.315	0.990	0.86	0.352	0.800	0.63	0.566	1.740
Dissolved P	0.02	0.010	0.020	0.06	0.063	0.310	0.05	0.017	0.050	0.08	0.042	0.140
NO3	0.95	0.931	2.490	0.43	0.422	2.140	3.74	2.476	7.770	3.07	1.192	5.470
SO4	3.96	1.416	4.000	9.46	8.365	34.060	14.06	5.210	13.880	43.17	49.567	230.80
Na	5.35	2.056	6.320	2.43	0.952	3.700	30.32	18.742	48.070	7.79	2.210	9.550
K	3.21	0.543	1.490	0.86	0.768	3.180	3.74	2.343	7.140	1.87	0.312	1.020
Ca	6.22	1.248	3.750	1.77	2.090	6.700	20.46	9.959	30.500	14.55	16.275	63.510
Mg	4.03	2.602	6.110	1.45	0.740	2.390	4.37	1.701	4.180	5.08	4.483	22.250
Fe	6.71	1.237	3.190	4.01	2.929	8.740	2.50	2.133	6.680	1.74	1.418	6.790
Cu	0.04	0.015	0.042	0.02	0.011	0.060	0.03	0.015	0.037	0.01	0.013	0.054
Pb	0.03	0.006	0.020	0.04	0.014	0.060	0.03	0.023	0.060	0.02	0.014	0.040
Cr	0.03	0.031	0.102	0.01	0.014	0.050	0.02	0.010	0.031	0.01	0.013	0.050
Mn	0.14	0.031	0.077	0.05	0.055	0.140	0.24	0.164	0.505	0.15	0.165	0.760
Cd	0.00	0.004	0.011	0.00	0.000	0.000	0.01	0.006	0.013	0.00	0.003	0.011
Temp	21.50	1.378	4.000	21.57	1.970	7.500	22.17	1.941	5.000	21.01	2.386	8.000
pH	5.09	0.552	1.500	4.63	0.570	2.300	6.83	0.219	0.650	6.49	0.591	2.370
Conductivity	39.75	11.474	35.000	35.44	13.326	43.800	305.0	175.11	440.00	143.3	75.951	363.00

	Well=7						Well=8					
Component	Pre Road Building			Post Road Building			Pre Road Building			Post Road Building		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
F	0.30	0.041	0.110	0.35	0.255	1.100	1.31	2.028	5.480	0.93	1.025	4.900
Cl	19.89	6.111	17.400	23.95	17.397	85.950	8.33	1.188	3.700	7.94	5.855	28.530
NH4	0.02	0.000	0.000	0.05	0.155	0.750	0.04	0.064	0.170	0.04	0.084	0.380
Solids	361.3	43.651	120.00	449.0	185.52	1085.0	218.8	104.10	364.20	162.9	28.993	122.50
HCO3	182.1	16.583	50.000	131.2	31.444	131.98	87.75	31.901	94.000	52.50	4.979	20.000
Total P	1.91	1.216	3.500	2.72	3.841	14.210	5.75	4.321	12.140	3.14	4.155	15.880
Dissolved P	0.08	0.046	0.110	0.21	0.077	0.260	0.21	0.084	0.240	0.19	0.107	0.500
NO3	16.73	10.057	27.150	22.76	16.801	88.420	7.69	4.037	10.100	10.07	2.196	9.270
SO4	3.13	2.494	5.800	2.75	1.396	6.100	4.47	0.575	1.400	2.73	1.069	4.330
Na	16.93	7.419	20.120	10.01	1.998	7.160	6.84	3.279	8.440	2.51	0.660	2.630
K	4.67	1.617	4.600	2.80	0.649	2.630	3.98	2.362	7.310	1.66	0.817	3.520
Ca	131.8	31.079	83.000	127.1	183.08	922.48	64.73	39.887	113.90	55.27	80.169	406.16
Mg	18.15	1.954	5.900	10.57	4.440	14.090	30.79	14.367	42.800	23.65	26.797	132.29
Fe	4.91	2.643	7.860	3.29	2.221	6.380	7.02	3.344	9.770	5.59	3.133	13.500
Cu	0.02	0.020	0.062	0.03	0.042	0.180	0.03	0.022	0.053	0.01	0.017	0.080
Pb	0.05	0.027	0.080	0.04	0.018	0.050	0.05	0.015	0.050	0.04	0.012	0.050
Cr	0.05	0.034	0.101	0.02	0.026	0.110	0.06	0.057	0.153	0.02	0.030	0.120
Mn	0.17	0.099	0.292	0.09	0.080	0.350	0.28	0.150	0.429	0.14	0.096	0.380
Cd	0.02	0.016	0.048	0.01	0.009	0.021	0.03	0.033	0.101	0.00	0.007	0.020
Temp	23.00	2.280	6.000	21.69	1.969	7.300	21.83	1.472	4.000	21.23	1.815	7.500
pH	7.03	0.234	0.700	7.19	0.271	1.190	7.19	0.389	1.200	7.27	0.484	1.770
Conductivity	588.1	16.243	45.000	575.7	59.166	190.00	310.9	159.48	467.00	212.4	20.361	61.000