

WATERFLOOD EVALUATION
PROPOSED VIRDEN-ROSELEA UNIT NO. 3
VIRDEN-ROSELEA FIELD
MANITOBA

CHEVRON STANDARD LIMITED
PRODUCING, CALGARY DIVISION

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PROPOSED VIRDEN-ROSELEA UNIT NO. 3

VIRDEN-ROSELEA FIELD, MANITOBA

SUMMARY:

I. INTRODUCTION

The purpose of this study was to investigate the feasibility of secondary recovery of oil by waterflooding the Mississippian limestone reservoir in a proposed portion of the Virden-Roselea Field. See Figure 1.

II. FINDINGS

1. The estimated original oil-in-place from volumetric calculations within the proposed waterflood area was 51,000,000 barrels.
2. Under primary depletion the indicated ultimate production from the proposed area would be 8,100,000 barrels or 15.9% of the original oil-in-place. The estimated cumulative production for the area to January 1, 1967 will be 6,110,000 barrels or 12.0% of the original oil-in-place.
3. The bottom hole pressure in the developed area has declined to an estimated average pressure of less than 300 psi.
4. Waterflood calculations indicate a total ultimate primary plus secondary recovery of 17,850,000 barrels or 35% of the original oil-in-place in the proposed waterflood area. This is an increase of 9,750,000 barrels over the ultimate primary recovery which represents 19.1% of the original oil-in-place.

III. CONCLUSION

The area outlined in Figure 1 should be waterflooded as increased ultimate recovery and increased production rates can be realized.

PROPOSED VIRDEN-ROSELEA UNIT NO. 3

WATERFLOOD EVALUATION

This report is a waterflood evaluation of the proposed Virden-Roselea Unit No. 3 area. The area of proposed waterflooding is outlined on Figure 1. For greater detail in methods used, reference can be made to a report entitled "Waterflood Evaluation - Virden-Roselea Field - Manitoba" dated September 1963, which was prepared for the Virden-Roselea Unit No. 1.

1. GENERAL

There are 108 wells in the proposed waterflood area, the ownership being as follows:

<u>COMPANY</u>	<u>WELLS</u>
The British American Oil Co. Ltd.	5
Canadian Export Gas & Oil Ltd.	10
Chevron Standard Limited	64
Fargo Oils Ltd.	1
Imperial Oil Limited	6
Mineraloid Limited	9
Paradise Petroleums Limited	2
Rundle Petroleums Limited	7
Sun Oil Company	<u>4</u>
Total.....	108

The majority of the wells in the proposed waterflood area were drilled during 1955 and 1956. Completion techniques in this area varied; however, most of the wells have been cased through and selectively perforated. Initial stimulation usually consisted of an acid wash and squeeze. In some cases this was followed by some form of hydraulic fracturing.

Re-stimulation, other than scale removal, has in recent years generally proved ineffective due to the depleted reservoir condition.

2. ORIGINAL OIL-IN-PLACE DETERMINATION

Isopachs

The reservoir was treated as four separate zones for oil-in-place determination in this study. The four zones considered were the Crinoidal, Sandhill, Oolitic and Cherty zones. Core analyses are available for each zone in the number of wells indicated below:

<u>ZONE</u>	<u>NUMBER OF WELLS WITH ANALYSES</u>
Crinoidal	30
Sandhill	30
Oolitic	30
Cherty	17

In several cases, the analysis for the complete zone is not available.

Separate pay isopachs, based on core analyses, core descriptions, and log interpretations have been prepared for each of the four zones. These are presented in Figures 2, 3, 4 and 5 for the Crinoidal, Sandhill, Oolitic and Cherty zones respectively. Figure 6 represents a total pay isopach.

Original Oil-in-Place

The isopachs were planimetered to obtain the average pay thickness for each zone. An average footage weighted porosity was obtained for each zone from available core analyses in the area. The values used for the initial water saturation were those obtained for the Virden-Roselea Unit No. 1. A formation volume factor of 1.05 bbl./bbl. was also used.

The results are as follows:

<u>ZONE</u>	<u>AVERAGE PAY THICKNESS</u>	<u>AVERAGE POROSITY</u>	<u>SUBSURFACE AREA (ACRES)</u>	<u>INITIAL WATER SATURATION</u>
Crinoidal	8.50	9.6%	3210	52%
Sandhill	6.07	12.7	3800	48
Oolitic	7.61	11.5	4320	52
Cherty	9.14	12.6	4080	52
Total.....	31.32		4320	

Original Oil-In-Place - Cont'd

The original oil-in-place calculations for each of the three zones are as follows:

Crinoidal Zone

N = 7758 (.096) (28820) (0.48) (1/1.05)
 = 9,800,000 barrels, or
 N = 7758 (0.96) (40) (0.48) (1/1.05)
 = 13,580 bbls./ft./40 acre lease, or
 N = 7758 (0.96) (.48) (1/1.05)
 = 340 bbls./acre - foot.

Sandhill Zone

N = 7758 (.127) (23040) (0.52) (1/1.05)
 = 11,200,000 barrels, or
 N = 7758 (.127) (40) (0.52) (1/1.05)
 = 19,470 bbls./ft./40 acre lease, or
 N = 7758 (.127) (.52) (1/1.05)
 = 487 bbls./acre - foot.

Oolitic Zone

N = 7758 (.115) (32860) (0.48) (1/1.05)
 = 13,400,000 barrels, or
 N = 7758 (.115) (40) (0.48) (1/1.05)
 = 16,270 bbls./ft./40 acre lease, or
 N = 7758 (.115) (0.48) (1/1.05)
 = 407 bbls./acre - foot.

Cherty Zone

N = 7758 (.126) (37280) (0.48) (1/1.05)
 = 16,600,000 barrels, or
 N = 7758 (.126) (40) (0.48) (1/1.05)
 = 17,830 bbls./ft./40 acre lease, or
 N = 7758 (.126) (0.48) (1/1.05)
 = 446 bbls./acre - foot

A summary of the original oil-in-place by zone and the relative amounts are as follows:

<u>ZONE</u>	<u>OIL-IN-PLACE</u>	<u>PERCENT OF TOTAL</u>
Crinoidal	9,800,000	19.2%
Sandhill	11,200,000	22.0%
Oolitic	13,400,000	26.3%
Cherty	16,600,000	32.5%
<hr/>		
Total.....	51,000,000	100.0%

3. PRIMARY PERFORMANCE

An estimate of primary performance was made employing a rate versus time plot for the total proposed waterflood area (see Figure 7). The indicated ultimate primary recovery is 8,100,000 barrels or 15.9% of the original oil-in place.

On January 1, 1967 which is the assumed date of waterflooding, it is estimated that the remaining primary recoverable reserves will be 1,990,000 barrels. The cumulative production for the area to January 1, 1966 was 5,760,000 barrels or 11.3% of the original oil-in-place. The estimated cumulative production for the area to January 1, 1967 will be 6,110,000 barrels or 12.0% of the estimated original oil-in-place.

4. WATERFLOOD RECOVERY PREDICTION

The waterflood recovery prediction was based on a combination of Welge's (1) displacement efficiency concept, Dykstra and Parsons (2) vertical sweep efficiency or permeability variation efficiency, and the concept of area sweep efficiency in pattern flood as explained by Caudle, Erickson and Slobod (3) and Dyes, Caudle and Erickson (4). The various efficiencies were found as functions of the water-oil ratios and were combined to yield the effective recovery of the waterflood.

Only one set of flooding efficiencies were applied to the total oil-in-place since the zones are similar in characteristics. The efficiencies used were based on the Cherty Zone. Any error incurred is believed to be within the accuracy of the prediction methods used.

Assumptions made in the prediction are that the economic limit will be 7 BOPD per well and that the area will be produced to a water-oil ratio of 10.5:1.

Assuming that waterflooding is initiated on January 1, 1967, the remaining oil-in-place at the start of the flood will be 44,890,000 barrels.

The predicted recovery to breakthrough is 6,060,000 barrels or 11.9% of the original oil-in-place or 13.5% of the oil-in-place at the beginning of the waterflood. The ultimate oil recovery under waterflood operations is estimated at 11,740,000 barrels or 23% of the original oil-in-place. The increase in oil recovery due to waterflooding is estimated to be 9,750,000 barrels or 19.1% of the original oil-in-place. The predicted total recovery would be composed of 6,110,000 barrels of primary oil production to January 1, 1967 and 11,740,000 barrels of oil recovered under waterflood operations for a total of 17,850,000 barrels or 35% of the original oil-in-place.

5. INJECTIVITY AND FLOOD PATTERN

Flood Pattern

The proposed flood pattern for the area is indicated on Figure 8. It consists primarily of an inverted ninespot pattern with some modification in the northeast portion of the area. A total of twenty five injection wells with an estimated stabilized injectivity of 5,500 BWPd are proposed.

Injectivity Calculations

The formula employed in the calculation of the water injectivity rates is derived from Darcy's flow formula as indicated below:

$$Q = \frac{0.003541 K_{wh} \Delta P}{\mu (\ln d/r_w - 0.6190)}$$

where Q = injection rate in barrels per day
 K_w = reservoir permeability to water in millidarcies
 h = vertical thickness in feet
 ΔP = pressure differential (P surface + well bore - P reservoir)
 μ = viscosity of injection water at reservoir conditions in centipoise
 d = distance from injection well to producing well in flood pattern in feet
 r_w = effective well bore radius in feet

By assuming the following values, the formula reduces to the simplified form shown below:

Pwb = 0.433 psi/ft x 2100 ft. = 900 psi
 Pinj = 1100 psi (not to exceed overburden pressure)
 Pres = 500 psi (average over flood life)
 $\therefore \Delta P = 1100 + 900 - 500 = 1500$ psi
 $\mu = 0.864$ cp at reservoir conditions
 d = 1320 feet between injector and nearest producer
 $r_w = 25$ feet (radius of acidizing and fracturing assumed)

Then $Q = 1.84 K_{wh}$

Where core analyses were available, they were employed in the injectivity determinations. Where core analyses were not available, the average values for the proposed waterflood area were used.

The following are the average parameters by zone for the area:

<u>Zone</u>	<u>Kmax (air)</u>	<u>Kmax (water)</u>	<u>Injectivity (BWPd/FT)</u>
Grinoidal	21.91	2.30	4.23
Sandhill	20.53	2.10	3.86
Oolitic	25.45	2.85	5.24
Cherty	43.96	6.60	12.14

Table 1 presents estimates of injectivities for the twenty-five proposed injection wells. Satisfactory injectivity for waterflooding is indicated for the proposed waterflood area.

6. REFERENCES

1. Welge, H. J.
"A Simplified Method for Computing Oil Recovery by Gas or Water Drive." Journal of Petroleum Technology, April, 1952, P.91.
2. Dykstra, H. and Parsons, R.L.
"The Prediction of Oil Recovery by Water Flood."
Secondary Recovery of Oil in the United States,
American Petroleum Institute 1950, P.160.
3. Caudle, B.H. Erickson, R.A. and Slobod, R.L.
"The Encroachment of Injected Fluids Beyond the Normal Well Pattern." Journal of Petroleum Technology, May 1955, P. 79.
4. Dyes, A.B., Caudle, B.H. and Erickson, R.A.
"Oil Production after Breakthrough as Influenced by Mobility Ratio." Journal of Petroleum Technology, April 1954, P.27.

7. ECONOMIC EVALUATION

The economic evaluation was based on the Canadian Tax System.

The major assumptions made were:

1. Reservoir response would be similar to that predicted for and currently being experienced at the North Virden Scallion Unit.
2. Waterflooding would be initiated January 1, 1967.
3. Peak production would be 3100 BOPD reached during 1970 and maintained to 1973.
4. The waterflood recovery life would be 22 years at which time production would decline to an economic limit of 756 BOPD or 7 BOPD per well.

The calculated economics based only on additional oil due to waterflooding are:

Payout	2.5 Years
Rate of Return	85%
Cumulative Net Profit	\$8,290,000

The estimated waterflood investment used in the evaluation was \$450,000.

Figure 9 represents the cash flow for the proposed waterflood based only on additional oil due to waterflood operations.

PROPOSED VIRDEN-ROSELEA UNIT NO. 3

SUMMARY OF

PROPOSED INJECTION WELL INJECTIVITIES

<u>WELL</u>	<u>INJECTION RATE (BWPD)</u>
10-7-10-25	290
12-7-10-25	140
14-7-10-25	235
4-18-10-25	325
6-1-10-26	205
14-1-10-26	230
8-2-10-26	125
14-2-10-26	115
16-2-10-26	280
16-3-10-26	105
6-10-10-26	140
8-10-10-26	200
6-11-10-26	220
8-11-10-26	200
14-11-10-26	200
16-11-10-26	475
6-12-10-26	185
14-12-10-26	165
6-13-10-26	170
9-13-10-26	315
14-13-10-26	350

TABLE 1 (CONT'D)

<u>WELL</u>	<u>INJECTION RATE (BWPD)</u>
4-14-10-26	225
11-14-10-26	165
1-23-10-26	170
3-23-10-26	225
	<hr/>
TOTAL	5,455
	<hr/> <hr/>

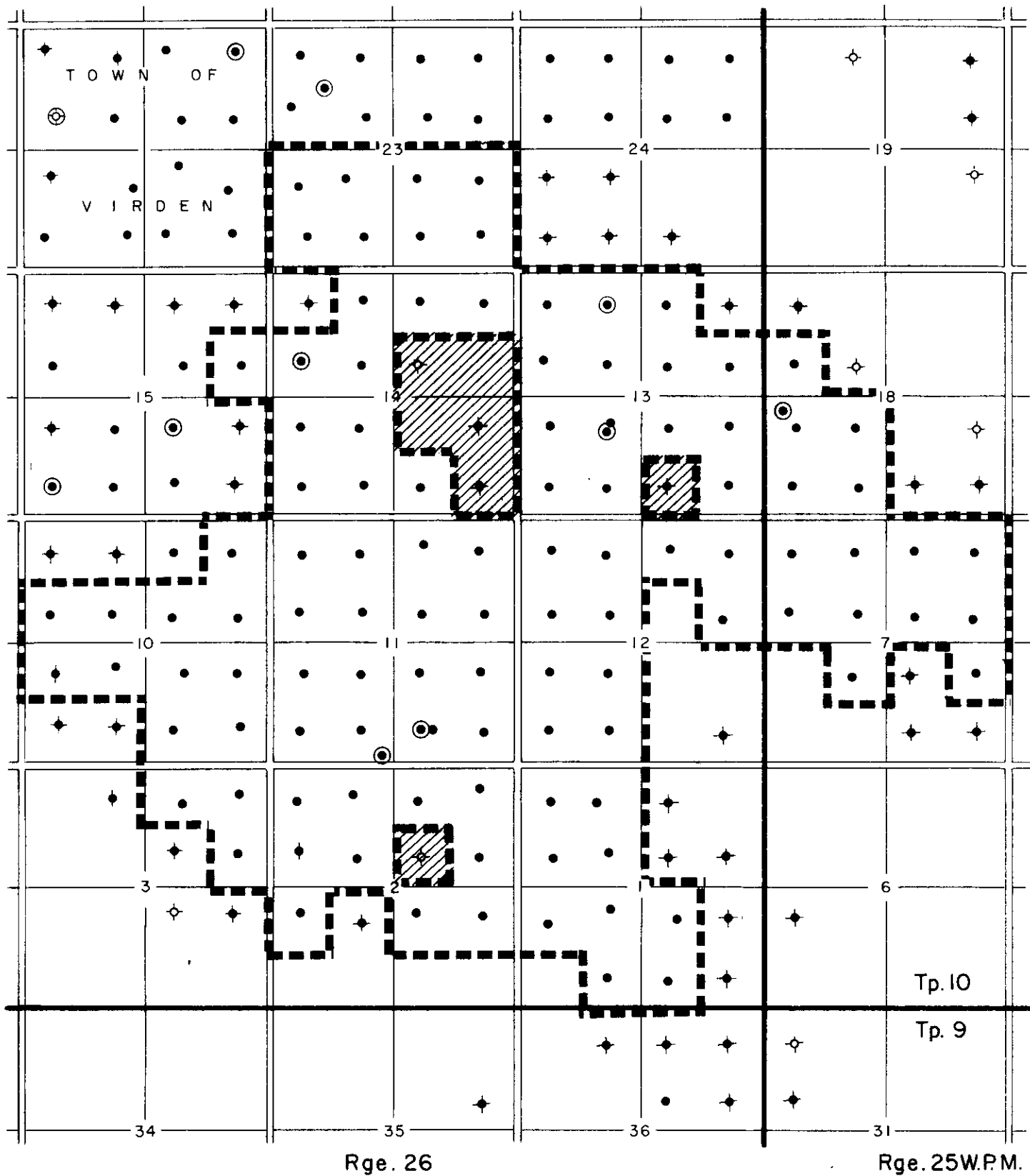


FIG. 1

PROPOSED VIRDEN ROSELEA UNIT No. 3

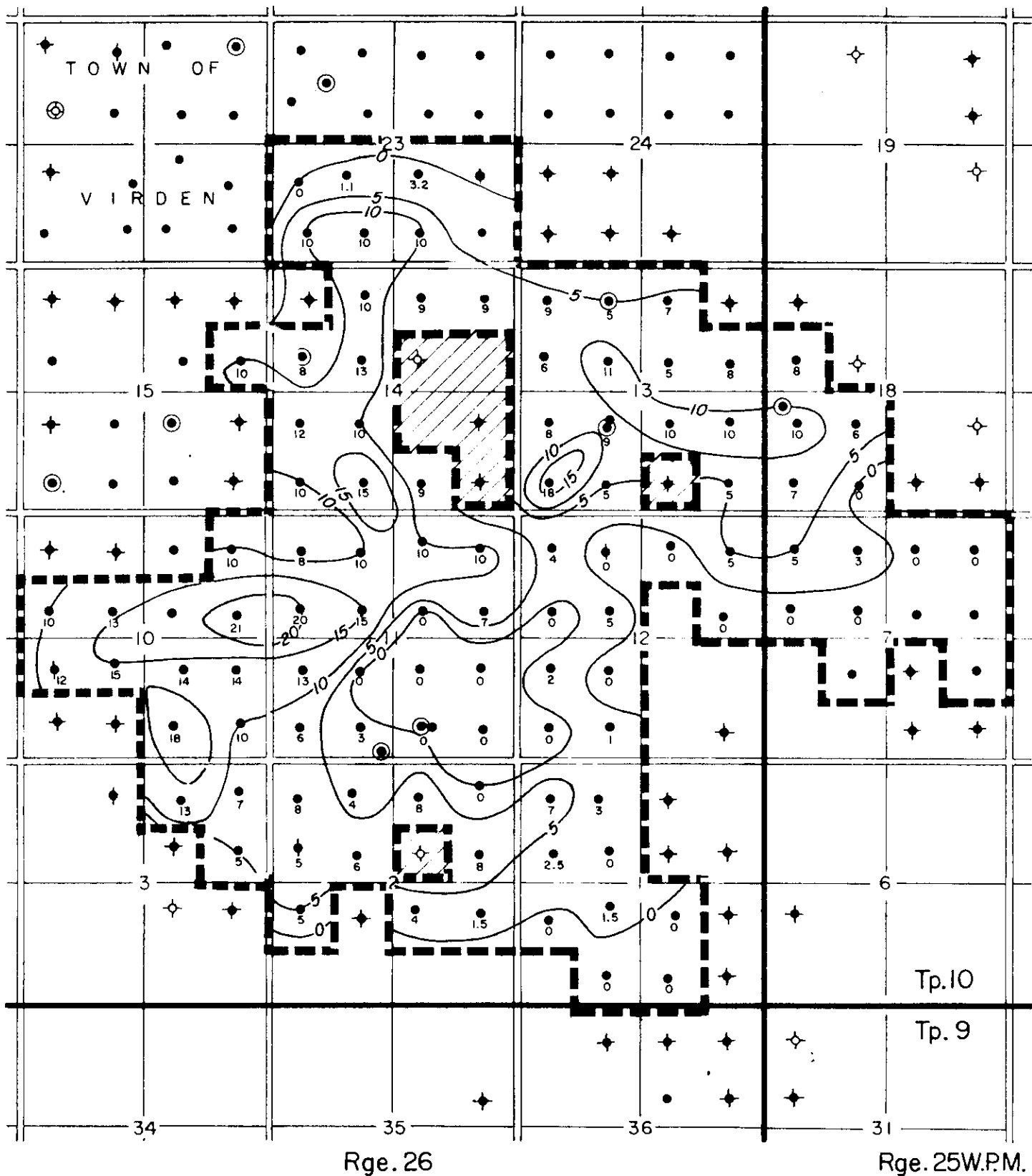


FIGURE 2

PROPOSED VIRDEN ROSELEA UNIT No. 3

CRINOIDAL ZONE PAY ISOPACH

C.I. = 5'

UNIT BOUNDARY

Scale: 1" = 3000'

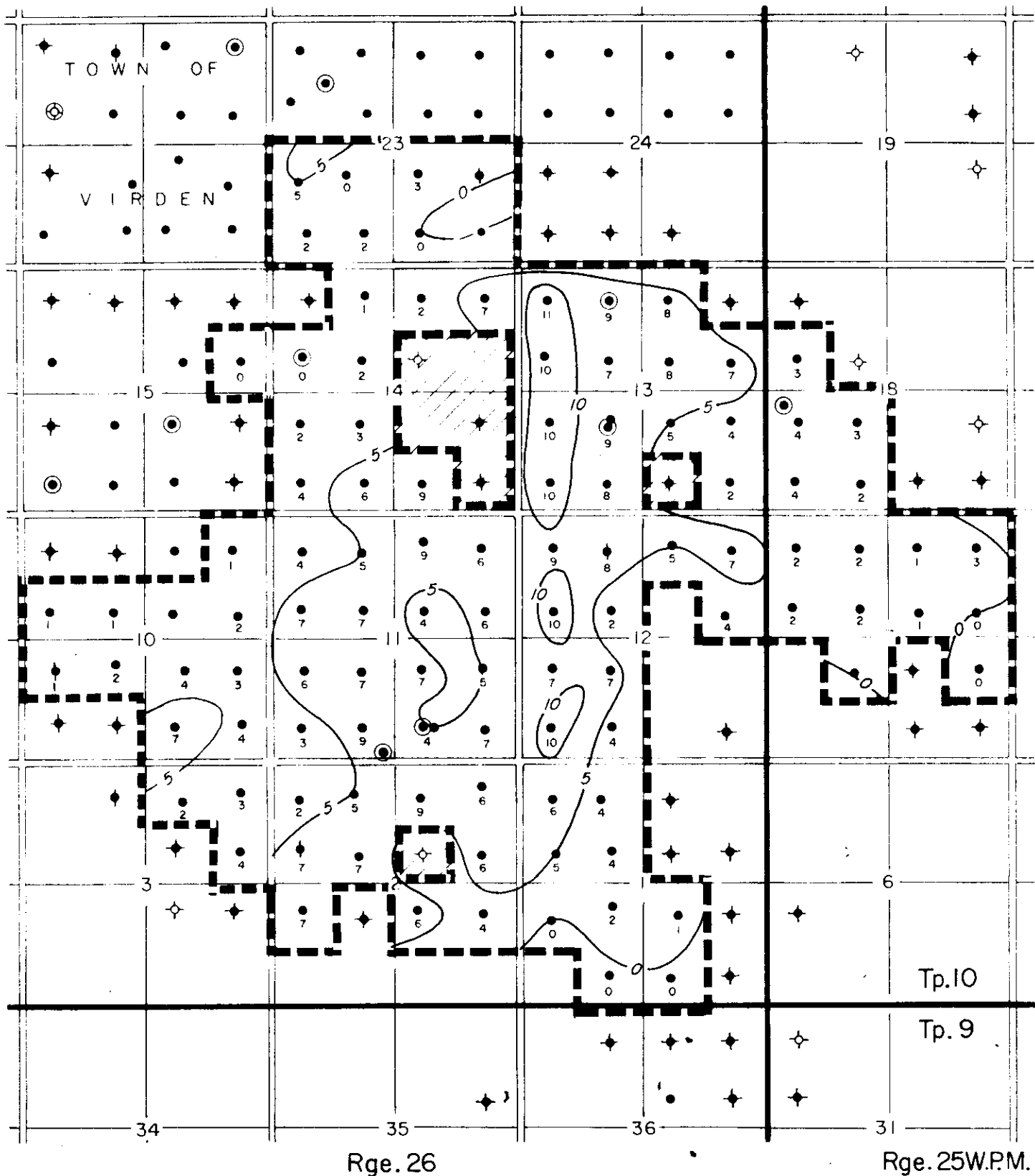


FIGURE 3
 PROPOSED WARDEN ROSELEA UNIT No. 3
 SANDHILL ZONE PAY ISOPACH

C. I. = 5'

--- UNIT BOUNDARY

Scale: 1" = 3000'

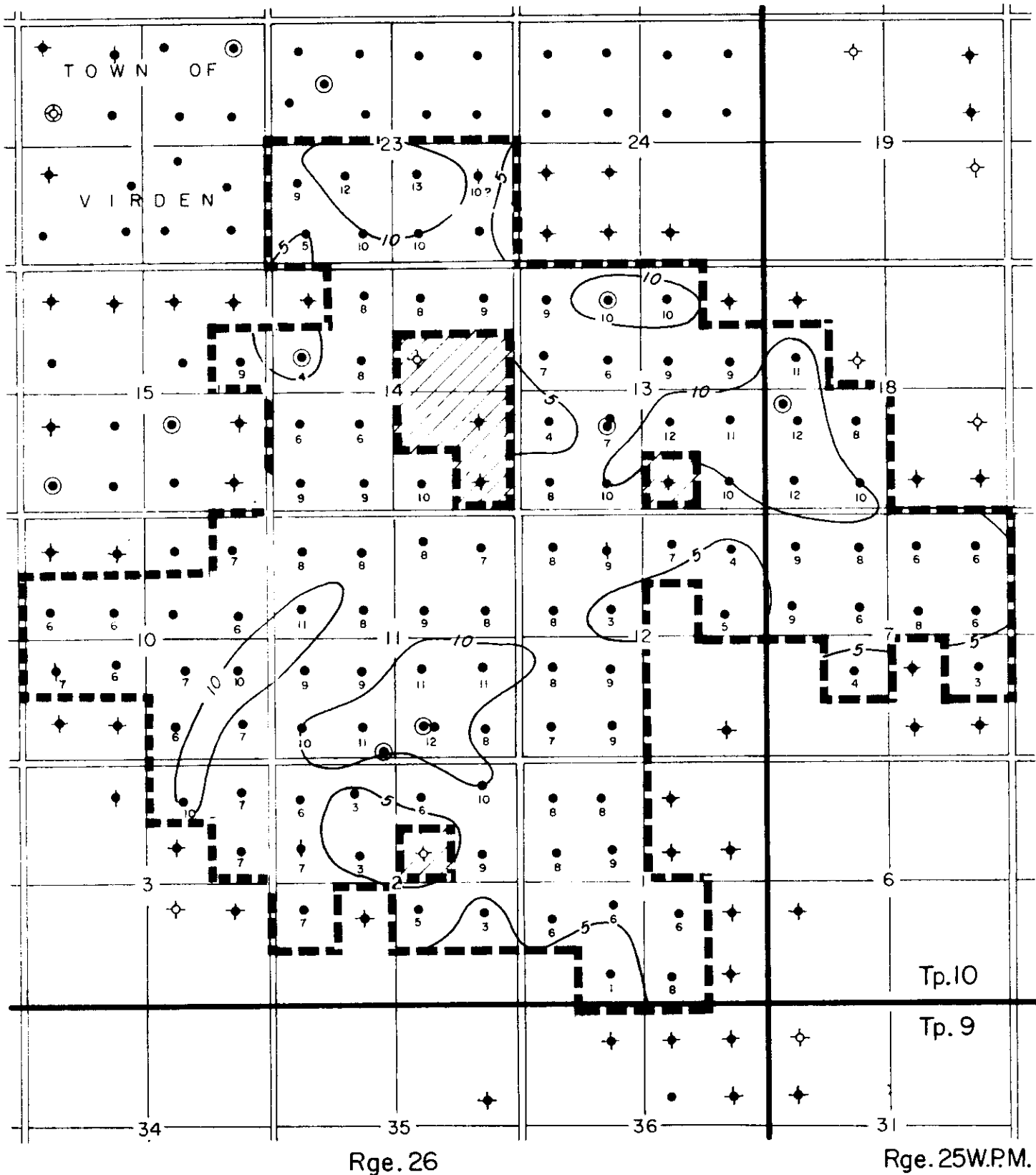


FIGURE 4

PROPOSED VIRDEN ROSELEA UNIT No. 3
 OOLITIC ZONE PAY ISOPACH

C.I. = '5'

UNIT BOUNDARY

Scale: 1" = 3000'

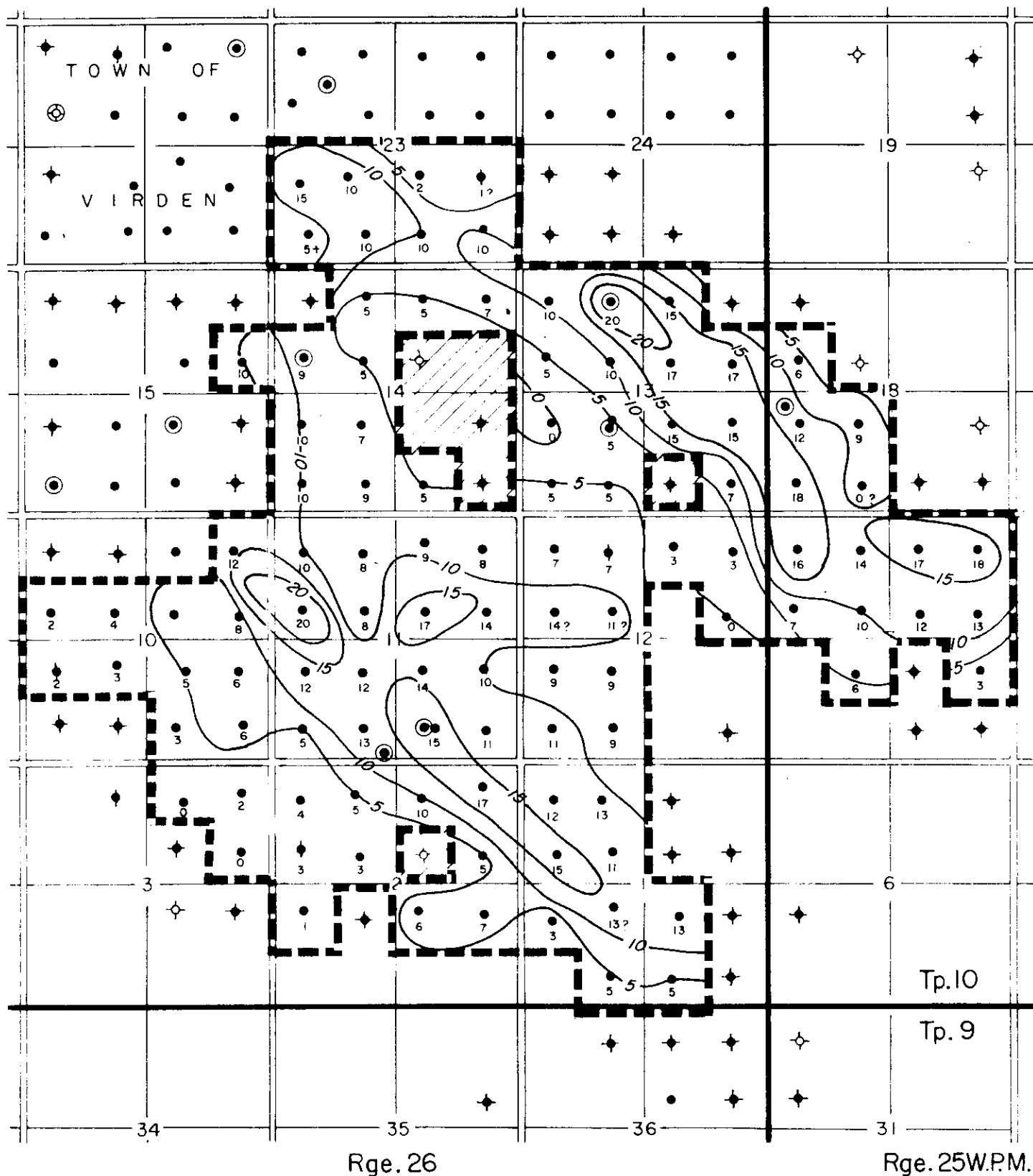


FIGURE 5

PROPOSED VIRDEN ROSELEA UNIT No. 3
CHERTY ZONE PAY ISOPACH
C.I. = 5'

UNIT BOUNDARY

Scale: 1" = 3000'

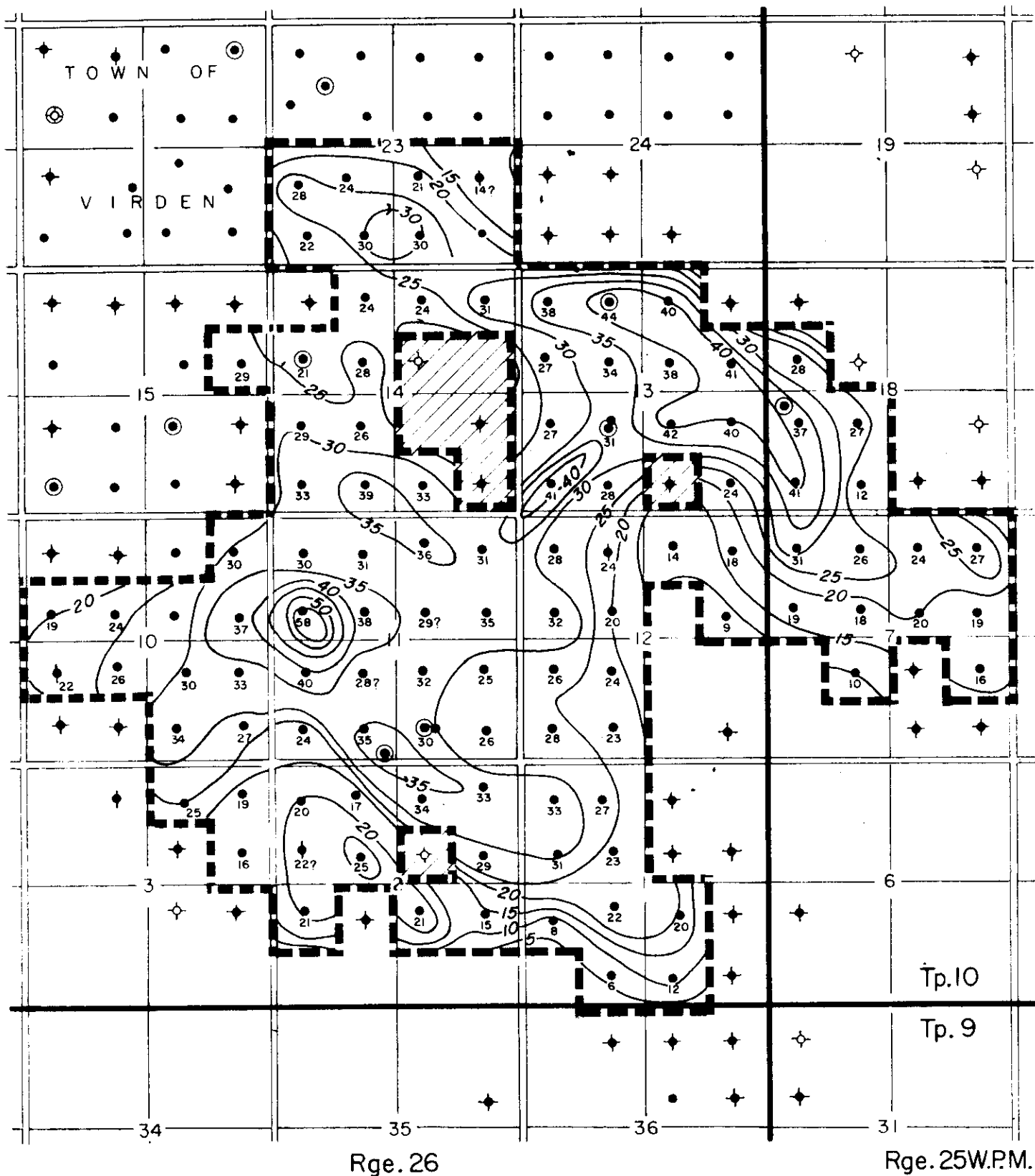


FIGURE 6

PROPOSED VIRDEN ROSELEA UNIT No. 3

TOTAL PAY ISOPACH

C.I.=5'

FIGURE 7
PROPOSED VIRDEN-ROSELEA UNIT NO. 8
(108 WELL UNIT)
PREDICTED PRIMARY AND WATERFLOOD PRODUCTION

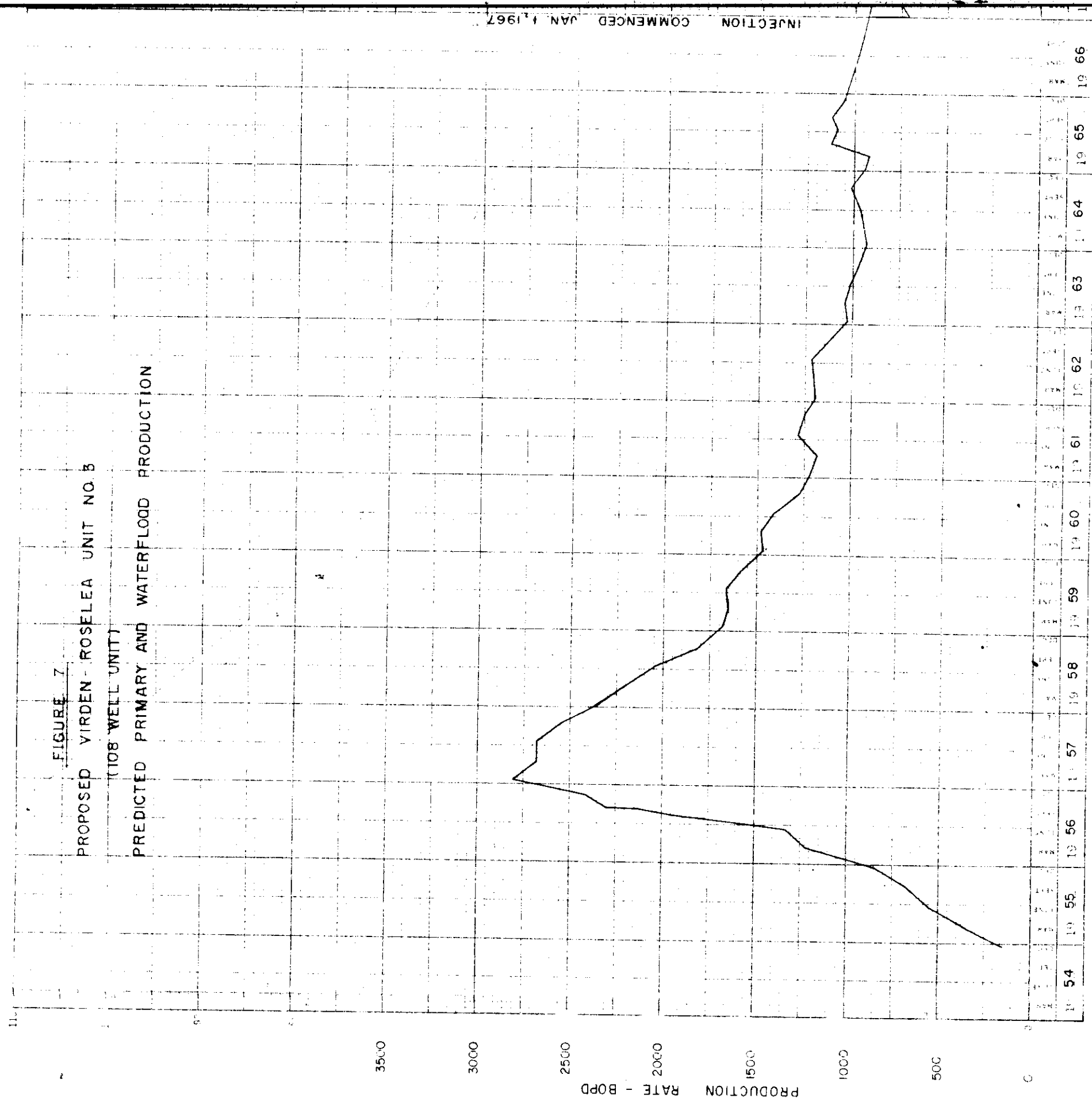


FIGURE 7
PROPOSED VIRDEN-ROSELEA UNIT NO. 8
(108 WELL UNIT)
PREDICTED PRIMARY AND WATERFLOOD PRODUCTION

INJECTION COMMENCED JAN. 1, 1967

19 65	19 66	19 67	19 68	19 69	19 70	19 71	19 72	19 73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
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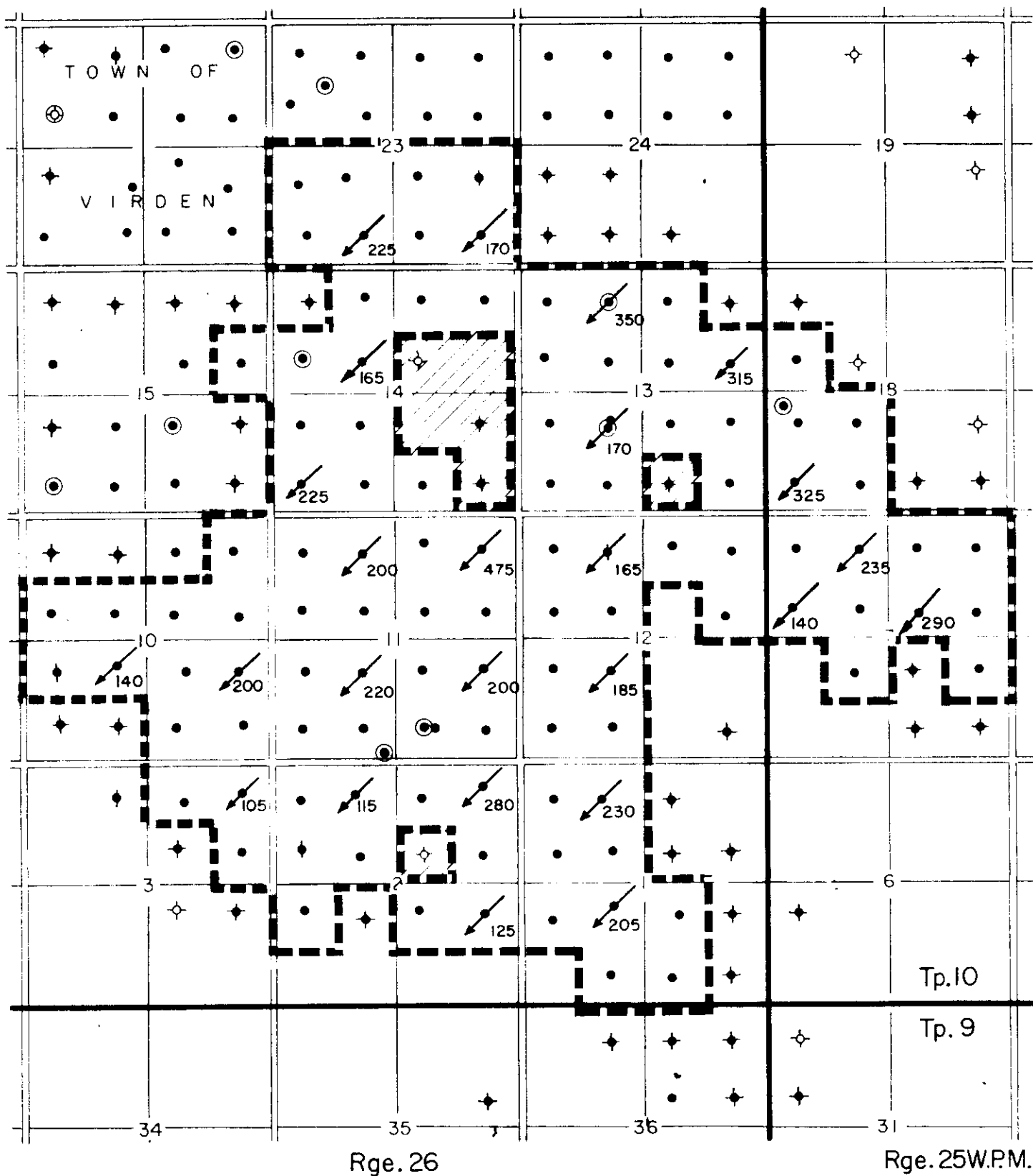


FIGURE 8

PROPOSED VIRDEN ROSELEA UNIT No. 3 WATERFLOOD INJECTION PATTERN

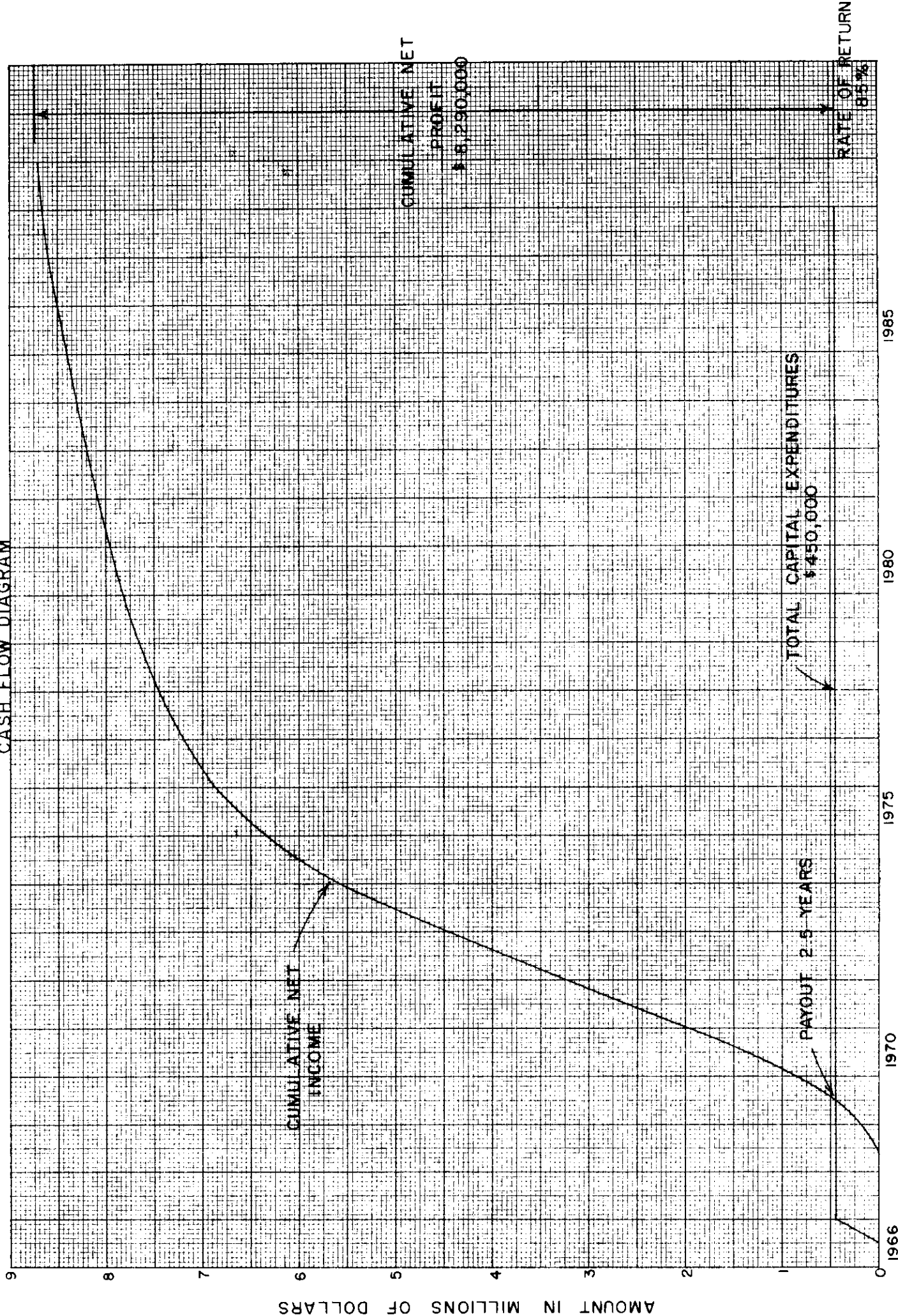
INJECTION WELL AND RATE

100

UNIT BOUNDARY

Scale: 1" = 3000'

FIGURE 9
 PROPOSED VIRDEN-ROSELEA UNIT No. 3
 CASH FLOW DIAGRAM



R. 26

R. 25

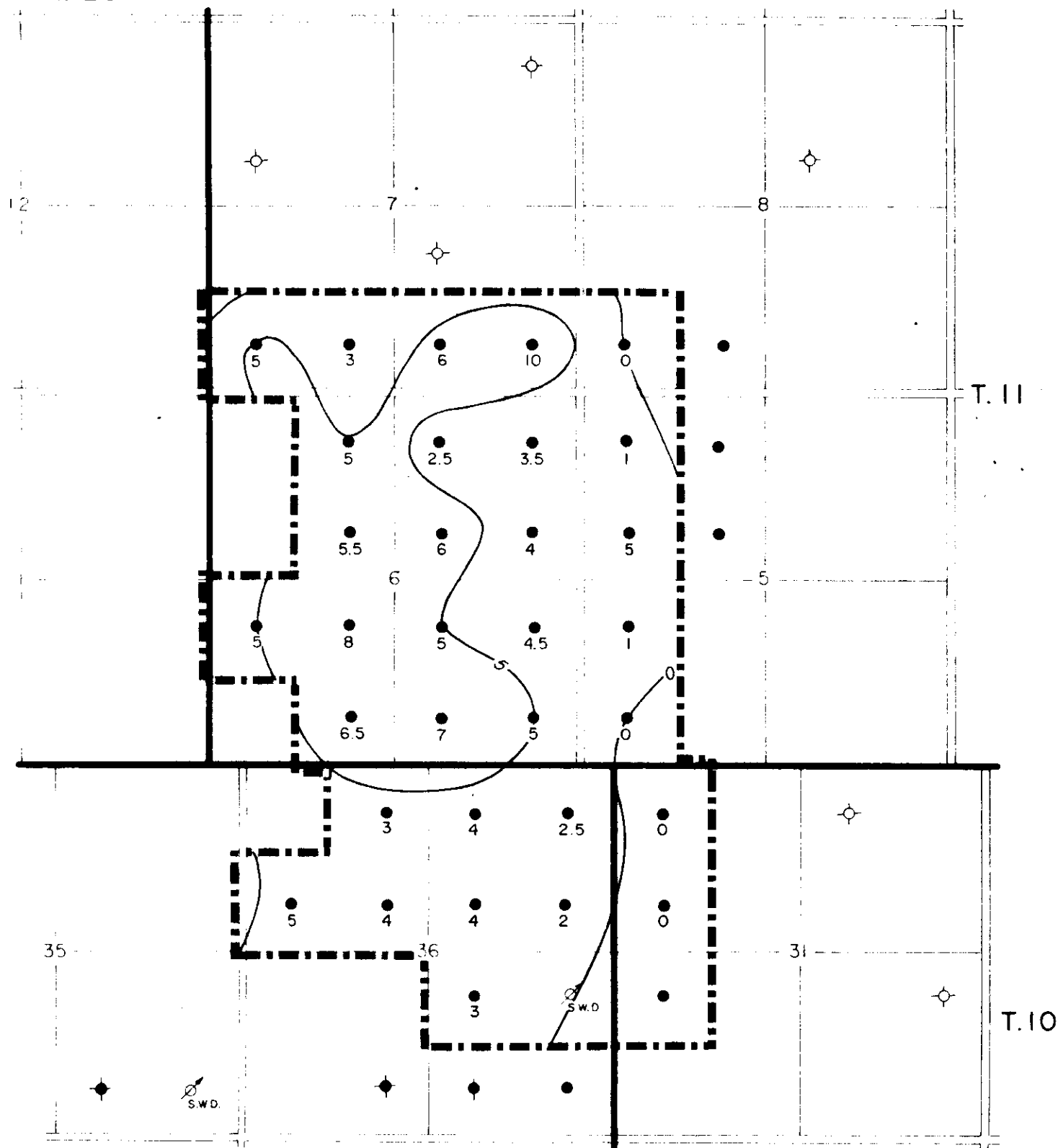


FIGURE 2

PROPOSED VIRDEN ROSELEA UNIT No. 2

CRINOIDAL ZONE PAY ISOPACH

C.I. = 5'

--- UNIT BOUNDARY

Scale: 1" = 2000'

R. 26

R. 25

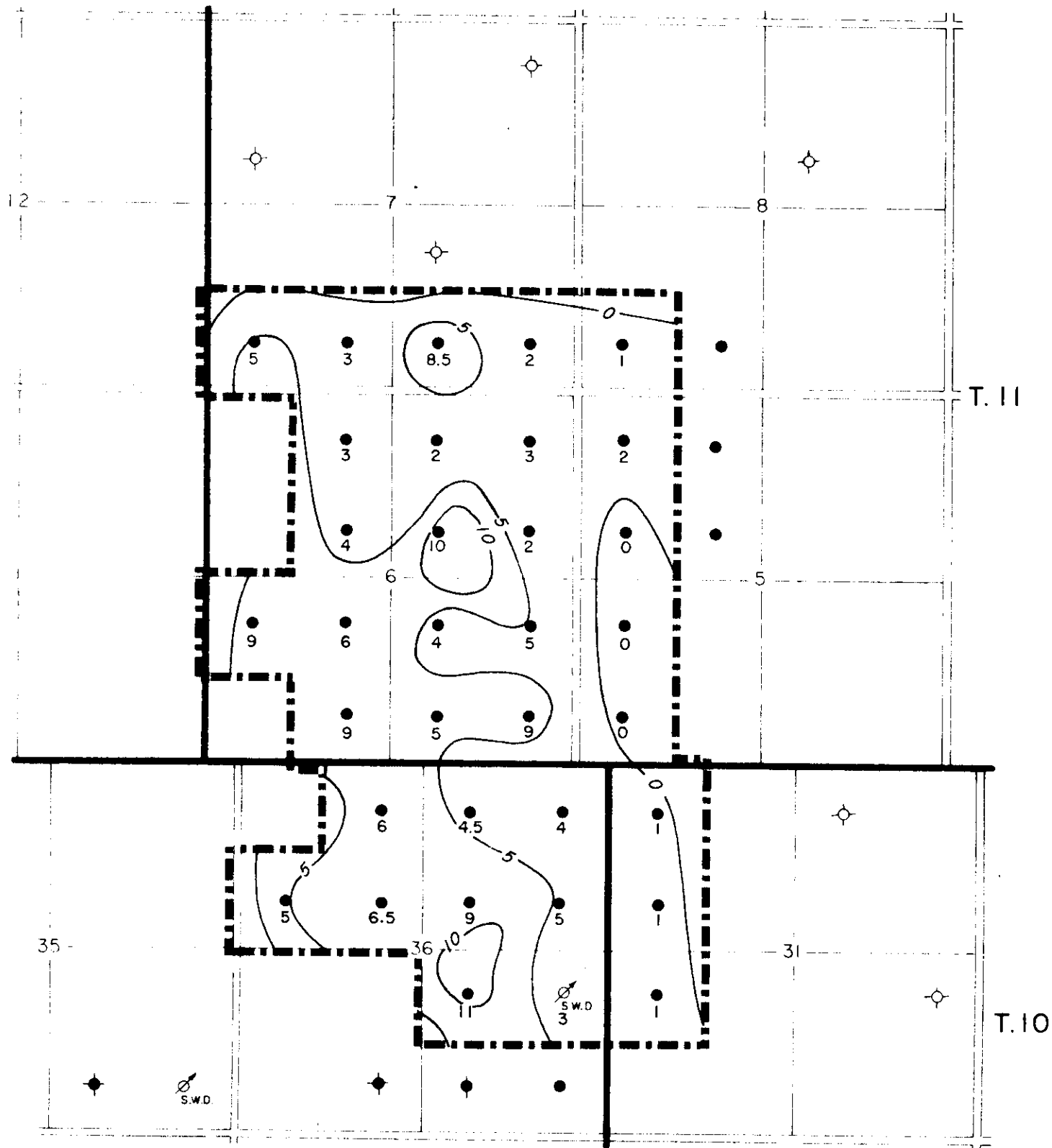


FIGURE 3

PROPOSED VIRDEN ROSELEA UNIT No. 2

OOLITIC ZONE PAY ISOPACH

C.I. = 5'

UNIT BOUNDARY

Scale: 1" = 2000'

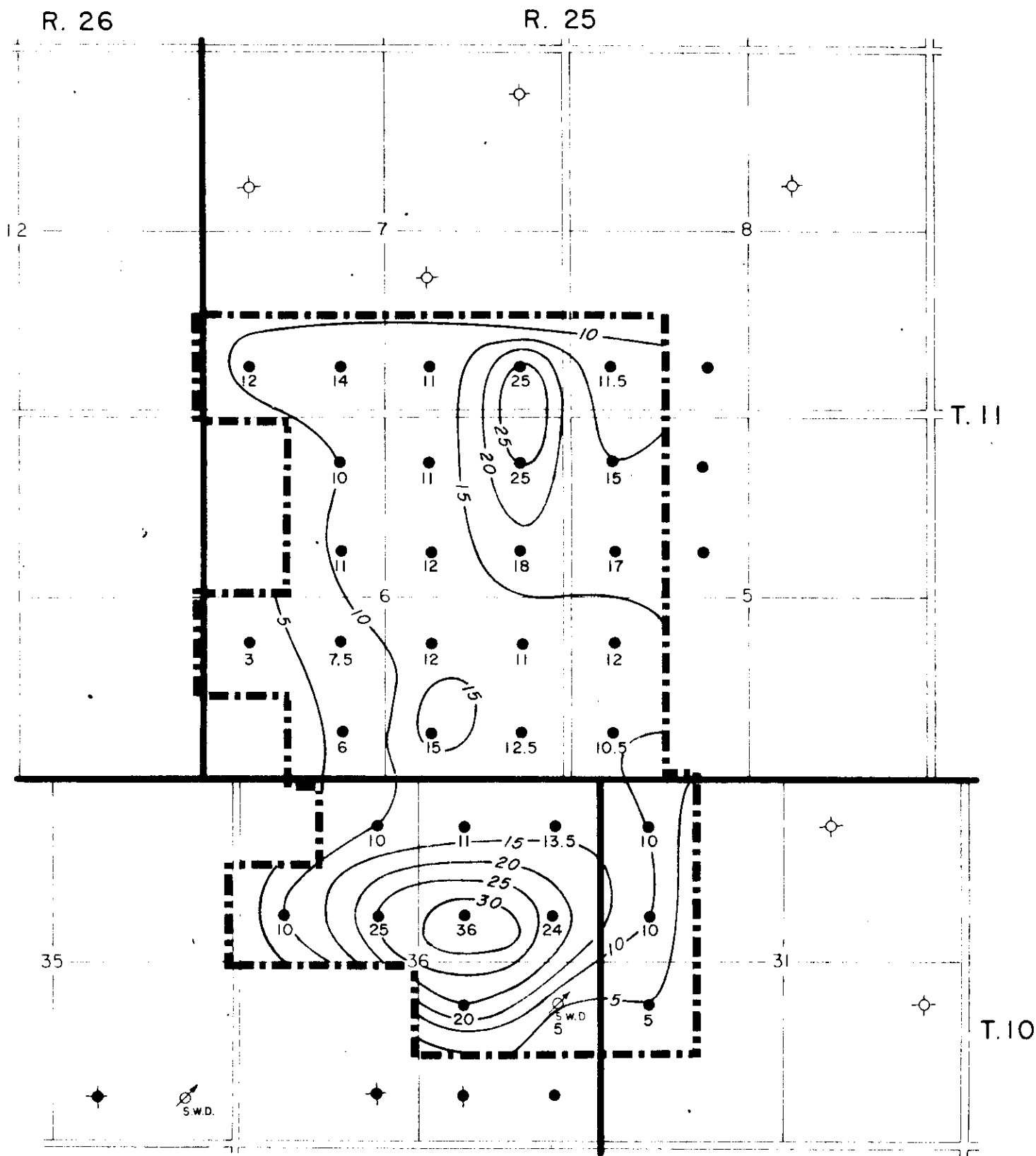


FIGURE 4

PROPOSED VIRDEN ROSELEA UNIT No. 2

CHERTY ZONE PAY ISOPACH

C. I. = 5'

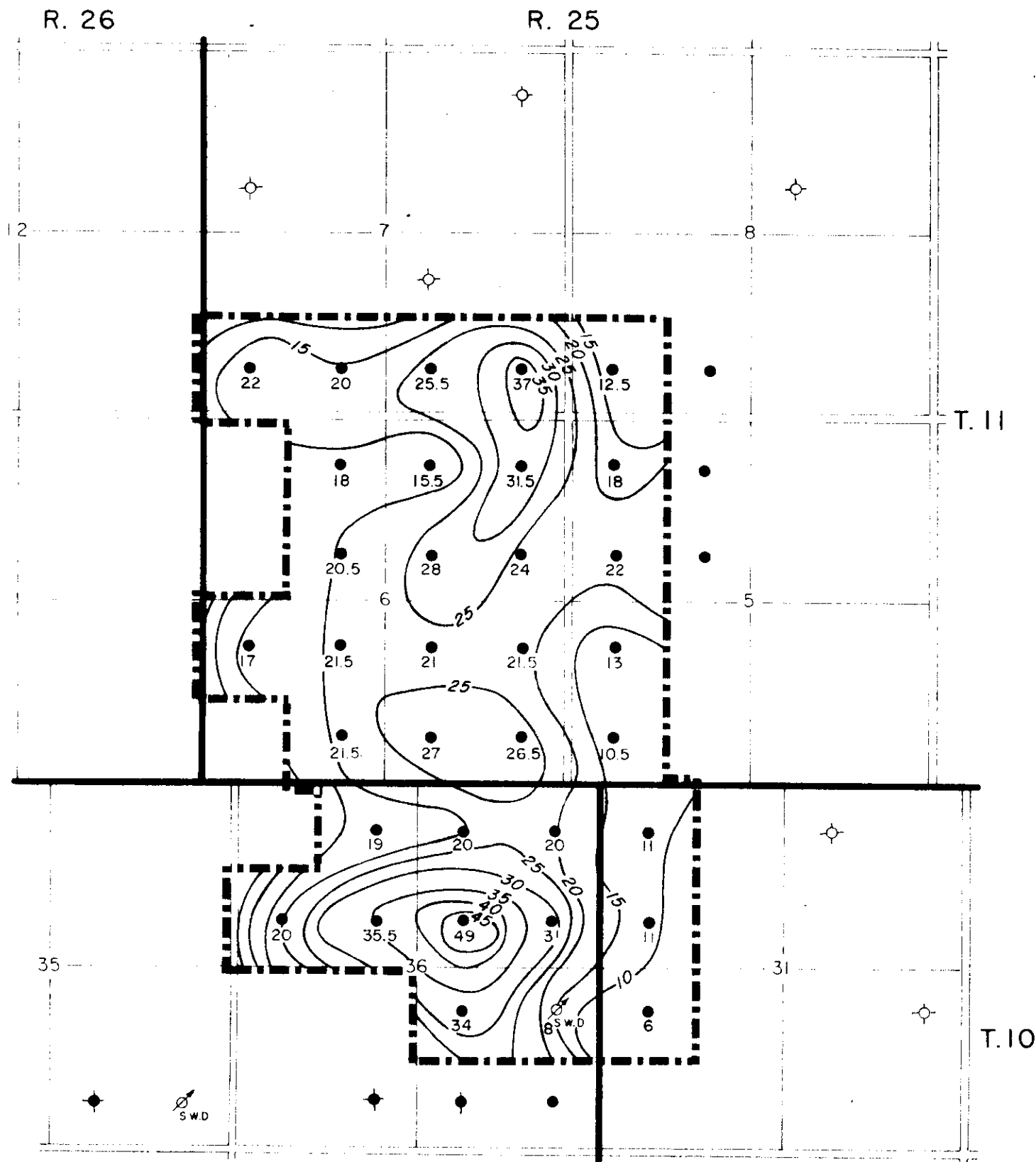


FIGURE 5
 PROPOSED VIRDEN ROSELEA UNIT No. 2
 TOTAL PAY ISOPACH
 C.I. = 5'

PROPOSED VIRDEN ROSELEA UNIT No. 2
PREDICTED PRIMARY AND WATERFLOOD PRODUCTION

FIGURE 6

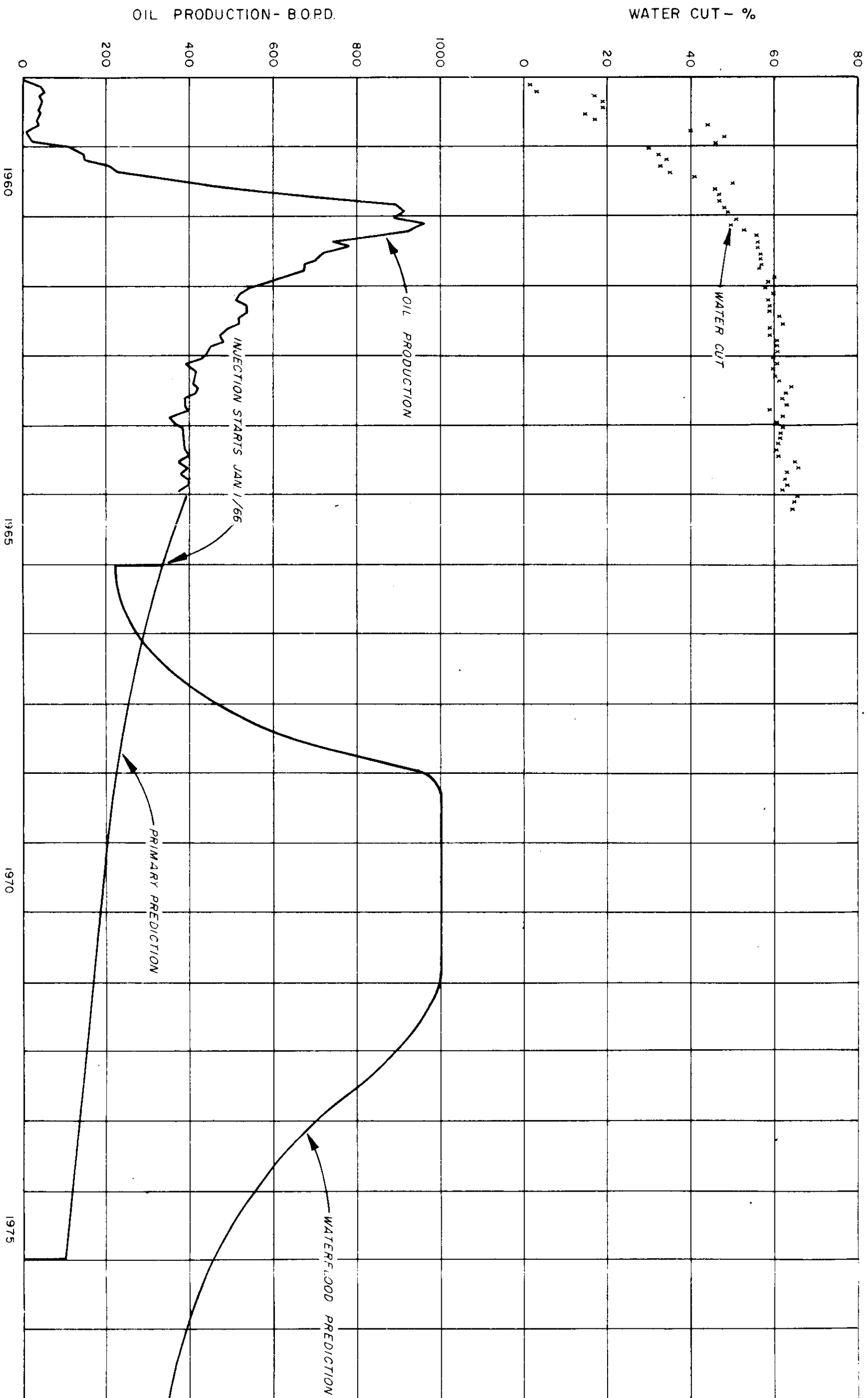
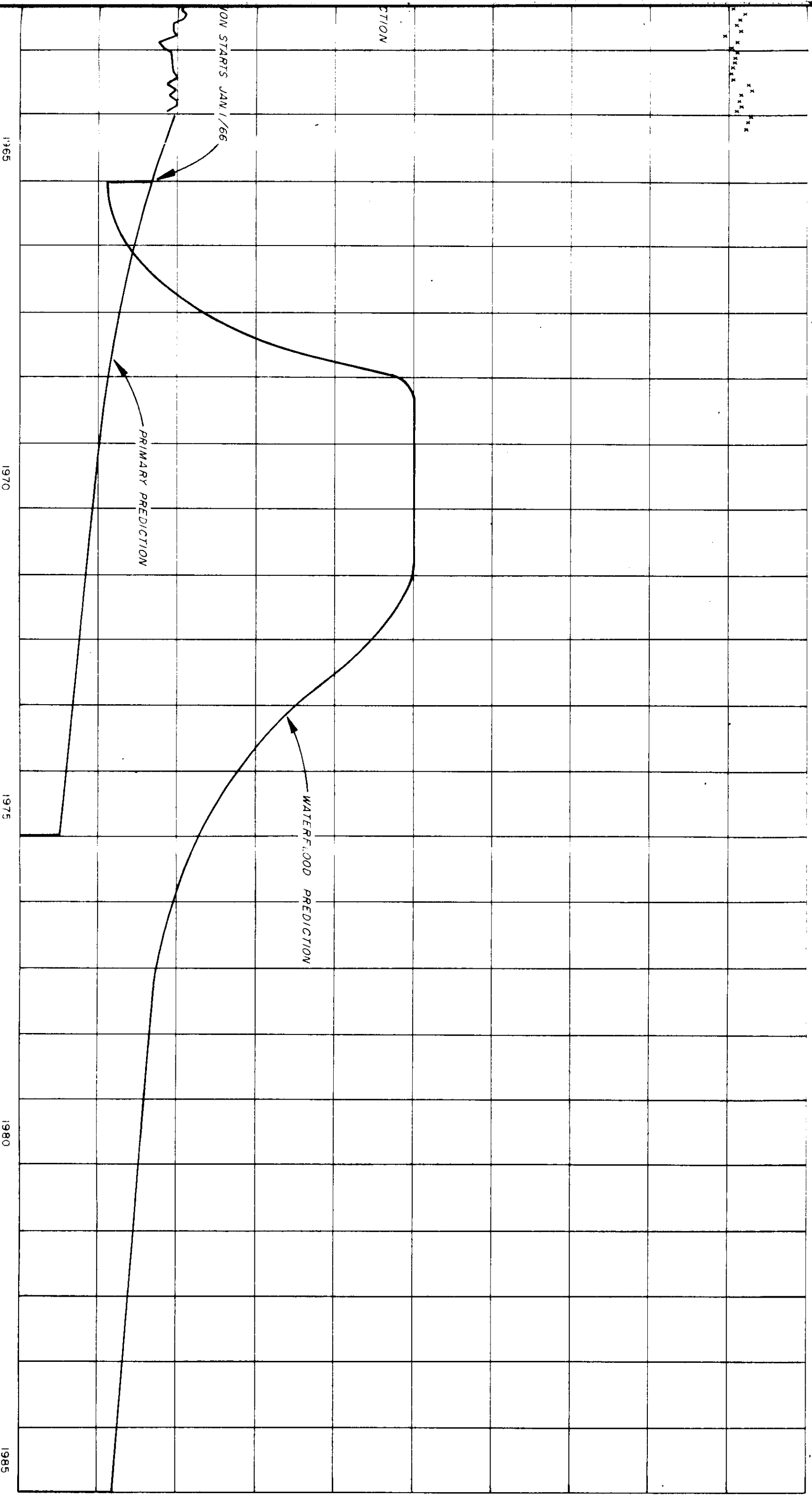


FIGURE 6
PROPOSED VIRDEN ROSELEA UNIT No. 2
PREDICTED PRIMARY AND WATERFLOOD PRODUCTION



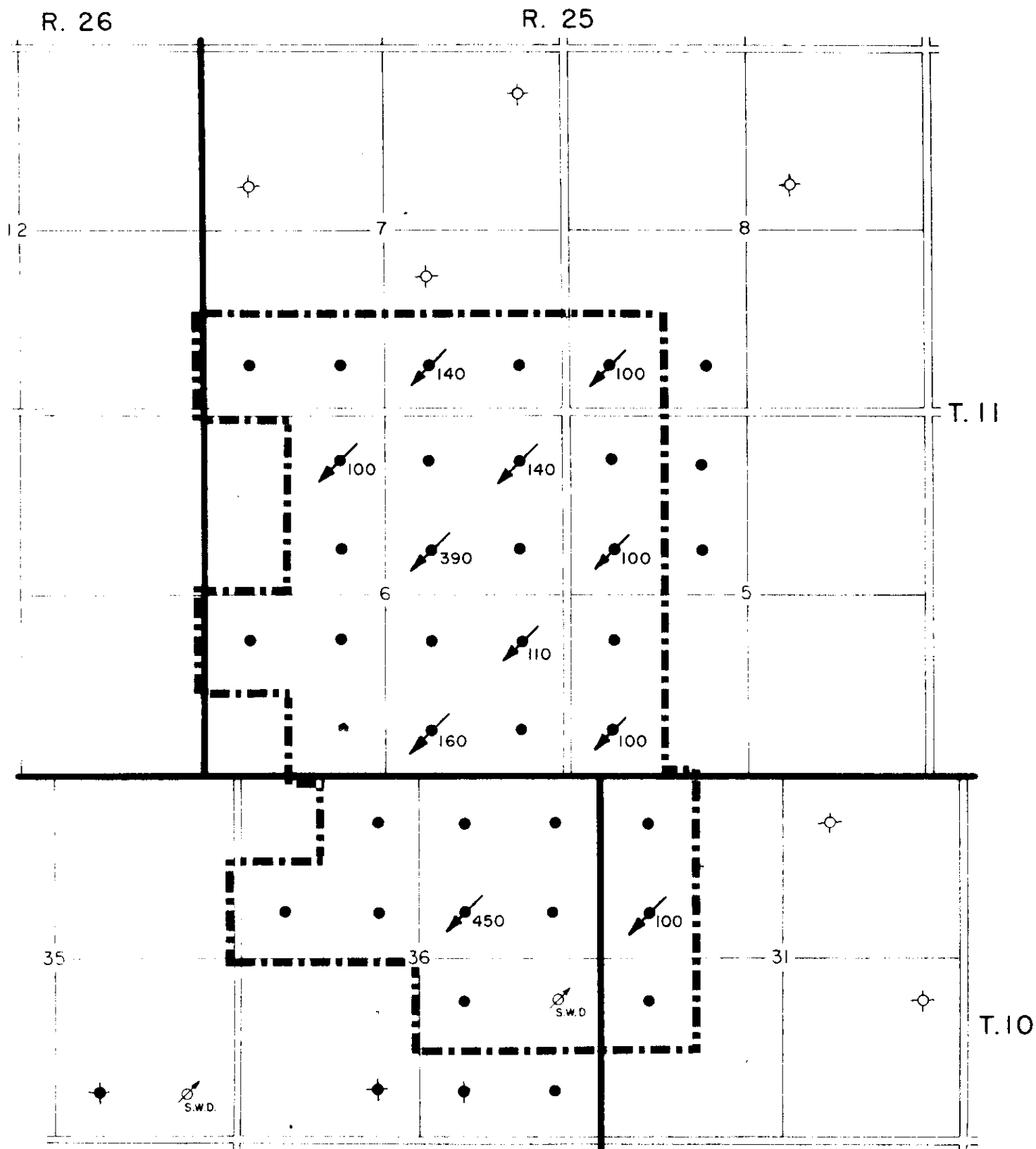


FIGURE 7

PROPOSED VIRDEN ROSELEA UNIT No. 2

INJECTION WELL & RATE

UNIT BOUNDARY

Scale: 1" = 2000'

FIGURE 8
VIRDEN ROSELEA UNIT No. 2
CASH FLOW DIAGRAM

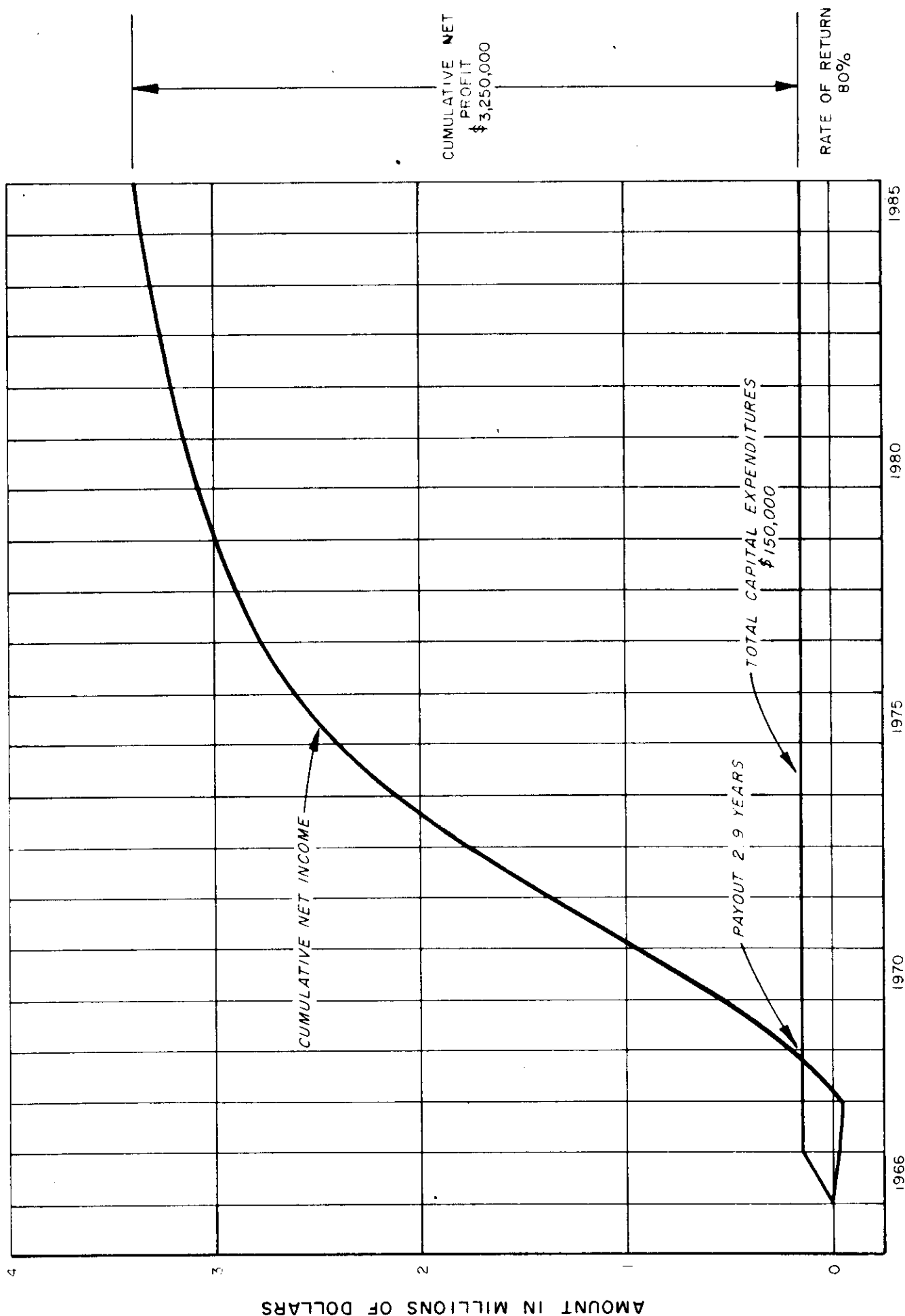


TABLE 1

PROPOSED VIRDEN ROSELEA UNIT NO. 2

SUMMARY OF

PROPOSED INJECTION WELL INJECTIVITIES

<u>WELL</u>	<u>INJECTION RATE (BWPD)</u>
12 - 31 - 10 - 25	100
10 - 36 - 10 - 26	450
4 - 5 - 11 - 25	100
12 - 5 - 11 - 25	100
2 - 6 - 11 - 25	160
8 - 6 - 11 - 25	110
10 - 6 - 11 - 25	390
14 - 6 - 11 - 25	100
16 - 6 - 11 - 25	140
2 - 7 - 11 - 25	140
4 - 8 - 11 - 25	100
	<hr/>
TOTAL	1,890