NATIONAL EXAMS – May 2015

98-PET-A6 : Reservoir Mechanics

3 HOURS DURATION

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit a clear statement of any assumptions made along with the answer paper.

2. The candidate must answer problems 1 and 2, and can choose any three of the remaining six problems. Only the first three questions, in addition to problems 1 and 2, will be marked.

3. Candidates may use one of two calculators, the Casio or Sharp approved models. This is closed book examination.

4. All questions have equal value.

5. Equations sheet, conversion factors and useful charts are enclosed. Please use the graph paper provided where warranted.

PROBLEM 1 (25 points total, each question worth 5 points)

Answer the following questions, with the aid of a drawing/graph/diagram if necessary:

1. Explain retrograde behavior. What is the difference between retrograde condensation and retrograde vaporization?

2. Explain why you would want to waterflood an undersaturated oil reservoir.

3. Give four examples of independent cases where a straight line is used for determination of reserves.

4. Which method is the most generally applicable to determine the amount of aquifer influx? Explain why.

5. Explain how and when you would use reservoir simulation to determine reserves.

PROBLEM 2 (15 points)

The following production and gas injection data pertain to a reservoir:

cumulative oil production, N_p (MMstb)	producing gas-oil ratio, R_p (scf/stb)	cumulative gas injected (MMscf)
0	300	--
1	280	--
2	280	--
3	340	--
4	560	--
5	850	0
6	1,120	520
7	1,420	930

Plot on the same graph the producing GOR, the cumulative produced gas, the net cumulative produced gas, and the cumulative injected gas versus cumulative oil production (4 curves). Show all you calculations.

PROBLEM 3 (20 points)

Consider a gas well with the following production history for the year 2002:

date	production rate (MMscf/month)
1/1/02	1,000
2/1/02	962
3/1/02	926
4/1/02	890
5/1/02	860
6/1/02	825
7/1/02	795
8/1/02	765
9/1/02	735
10/1/02	710
11/1/02	680
12/1/02	656
1/1/03	631

a) Plot these data on graph paper to investigate the type of decline.
b) Calculate the reserves to be produced from 1/1/03 to the economic limit of 25 MMscf/month.
c) When will the economic limit be reached?

PROBLEM 4 (20 points)

Two oil wells near the Rocky Mountains are drilled on the same structure, and tests indicate that the fluid properties are identical. Determine whether the wells are in pressure communication and, if so, whether they could be in the same reservoir. Fluid properties and well data are provided below.

a) **fluid properties**

γ_o (°API) = 32
γ_g = 0.723
R_s (scf/stb) = 500
T (°F) = 200
ρ_o (lbm/ft^3)= 62.366
B_o (res bbl/stb) = 1.3

b) **well data**

	well 1	well 2
elevation of Kelly bushing (ft)	7,134	7,028
depth from Kelly bushing (ft)	5,652	5,426
pressure (psia)	2,453	2,306

c) **other information**

MW_{air} = 28.97 lbm/lb-mole
R = 10.732 psi·ft^3/lb-mole·°R

PROBLEM 5 (20 points)

The following data are available for an initially undersaturated reservoir, with no water drive and initial gas cap. The hydrocarbon pore volume is $3 \cdot 10^6$ rm^3. As pressure dropped from the initial to 13 MPa, $0.8 \cdot 10^6$ sm^3 of oil has been produced.

	initial pressure, p_i = 23 MPa	**final pressure, p = 13 MPa**
S_w	22%	22%
B_o	1.333 rm^3/sm^3	1.49 rm^3/sm^3
R_s	175 sm^3/sm^3	110 sm^3/sm^3
B_g		0.0111 rm^3/sm^3

i) Calculate the reservoir oil and gas saturations at 13 MPa.

ii) This reservoir, from top to bottom, consists of 10 m of 350 md sand, 1 m of 0.5 md shale, 4 m of 1230 md sand, 2 m of 2.4 md shale and 8 m of 520 md sand. What is its average vertical permeability?

PROBLEM 6 (20 points)

An oil property is estimated by material balance to have an ultimate recovery of 795,000 STB. The reservoir will produce unrestricted from an initial rate of 425 bbl of oil per day (BOPD), declining to an economic limit of 30 BOPD.

Determine, assuming i) exponential and ii) harmonic declines:

1. the total time on production
2. the decline rate
3. the yearly cumulative production over the producing life of the property.

Plot the respective decline curves as straight lines.

PROBLEM 7 (20 points)

A well producing only oil and dissolved gas has produced 12,173 STB. The well has not been stimulated, nor is there any reason to believe that there is a significant amount of formation damage. A pressure buildup test is run with the primary objective of estimating static drainage-area pressure. During buildup, there is a rising liquid level in the wellbore. Well and reservoir data are:

$\varphi = 0.14$
$\mu = 0.55$ cp
$c_t = 16 \cdot 10^{-6}$ psi^{-1}
$r_w = 0.5$ ft
$A_{wb} = 0.0218$ ft^2
$r_e = 1{,}320$ ft (well centered in cylindrical drainage area)
$\rho = 54.8$ lbm/ft^3
$q = 988$ STB/d
$B = 1.126$ rbbl/STB
$h = 7$ ft

Data recorded during the buildup test are given below:

Δt (h)	**p_{ws} (psia)**	**Δt (h)**	**p_{ws} (psia)**
0.0	709	19.7	4,198
1.97	3,169	24.6	4,245
2.95	3,508	29.6	4,279
3.94	3,672	34.5	4,306
4.92	3,772	39.4	4,327
5.91	3,873	44.4	4,343
7.88	3,963	49.3	4,356
9.86	4,026	59.1	4,375
14.8	4,133		

Determine:

1. time at which afterflow ceased distorting the buildup test data
2. formation permeability
3. skin factor
4. pressure drop across the altered zone

Draw the appropriate graph(s) and show all your assumptions and calculations.

PROBLEM 8 (20 points)

Describe a method for determining the gas volume initially in place. Develop the equations needed. State all assumptions and possible errors/limitations of the method you are proposing.

USEFUL EQUATIONS

$$t_a = \frac{\ln(q_i/q_a)}{D} \qquad (\Delta p)_{skin} = S\left(\frac{q_o \mu_o B_o}{2\pi kh}\right) \qquad T_r = \frac{T}{T_{sc}} \qquad G\left(\frac{z}{p}\right) - G\left(\frac{z_i}{p_i}\right) = G_p\left(\frac{z}{p}\right)$$

$$pV = nzRT \qquad E_o = (B_o - B_{oi}) + (R_{si} - R_s)B_g \qquad G(B_g - B_{gi}) + W_e = G_p B_g + W_p B_w$$

$$q = -\frac{kA}{\mu}\frac{dp}{ds} \qquad p_r = \frac{p}{p_{sc}} \qquad t_D = 2.309\frac{kt}{\phi\mu\bar{c}r_o^2} \qquad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad DR = \frac{k_{nodamage}}{k_{actual}}$$

$$B_g = \frac{zT}{p}\frac{p_{sc}}{T_{sc}} \qquad J_i = \frac{ck_{oi}}{B_{oi}\mu_{oi}} \qquad E_{w,f} = \frac{(1+m)B_{oi}(c_w S_{wc} + c_f)\Delta p}{1 - S_{wc}} \qquad \bar{k} = \frac{\sum_{j=1}^{n} k_j A_j}{\sum_{j=1}^{n} A_j}$$

$$k = 162.6\frac{qB_o\mu_o}{mh} \qquad F = N_p\left[B_o + B_g(R_p - R_s)\right] + W_p B_w = N(E_o + mE_g + E_{w.f}) + W_e B_w$$

$$\bar{k} = \frac{\ln(r_e/r_w)}{\sum_{j=1}^{n}\frac{\ln(r_j/r_{j-1})}{k_j}} \qquad E_g = B_{oi}(B_g - B_{gi})/B_{gi} \qquad \Delta t_e = \Delta t/(1 + \Delta t/t_p) \qquad N_{Re} = \frac{\rho v d}{\mu}$$

$$N_{p,a} = \frac{(q_i - q_a)}{D} \qquad s = 1.151\left[\frac{(p_{1hr} - p_{wf})}{m} - \log\left(\frac{k}{\phi\mu_o c_t r_w^2}\right) + 3.23\right] \qquad J = \frac{q_o}{p_e - p_w}$$

$$U = 1.119\phi h\bar{c}r_o^2 \qquad \Delta p_t = \frac{q_{sc}\mu_o B_o}{14.16k_e h}\left[\ln\left(\frac{14.22k_e t}{\mu\phi c r_w^2}\right) + 2S\right] \qquad q_{sc} = \frac{703kh(p_e^2 - p_w^2)}{\mu T z \ln(r_e/r_w)}$$

$$p_{wf,j} = C + \frac{\mu}{2\pi kh}\left[q_j \ln r_{w,j} + \sum_{i=1\neq j}^{n} q_i \ln a_{ij}\right] \qquad DF = 1 - PR \qquad c = -\frac{1}{V}\frac{dV}{dp} = \frac{1}{\rho}\frac{d\rho}{dp} \qquad \Phi = p/\rho + gz$$

$$PR = \frac{\ln(r_e/r_w)}{\ln(r_e/r_w) + S} \qquad q = q_i(1 - Dt)^{-1} \qquad p_e = C + \frac{\mu \ln r_e}{2\pi kh}\sum_{i=1}^{n} q_i \qquad k = \frac{dW_e/dt}{p_1 - p}$$

$$J = \frac{7.08kh}{B_o\mu_o(\ln(r_e/r_w) - 0.5)} \qquad q = \frac{7.08kh(p_e - p_w)}{\mu\ln(r_e/r_w)} \qquad t_a = \frac{(q_i - q_a) - 1}{D} \qquad N_{p,a} = (q_i/D)\ln(q_i/q_a)$$

$$W_e = 2\pi\phi h\bar{c}r_o^2(\Delta p)W_D(t_D) \qquad \rho_{o,res} = \frac{\rho_{o,sc} + (\rho_{g,sc}R_s)}{B_o} \qquad MW = \sum_i n_i MW_i \qquad q = q_i e^{-Dt}$$

AID TO METRICATION

Factors, tables help convert to SI metric units

These conversion factors and tables have been assembled to help you make a fast change from customary units to the International (SI) System of metric units.

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Earl Seaton, Editor
Oil, Gas & Petrochem Equipment

Table 1—Base SI metric units

Quantity	Name	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Table 2—Important derived and supplementary SI units

Quantity	Name	Symbol	Formula
Electric capacitance	farad	F	A-s/V
Electric charge	coulomb	C	A-s
Electric conductance	siemens	S	A/V
Electric inductance	henry	H	Wb/A
Electric potential	volt	V	W/A
Electric quantity	coulomb	C	A-s
Electric resistance	ohm	Ω	V/A
Electromotive force	volt	V	W/A
Energy	joule	J	N-m
Energy flux	watt	W	J/s
Force	newton	N	kg-m/s²
Frequency	hertz	Hz	1/s
Illuminance	lux	lx	lm/m²
Luminous flux	lumen	lm	cd-sr
Magnetic flux	weber	Wb	V-s
Magnetic flux density	tesla	T	Wb/m²
Power	watt	W	J/s
Pressure	pascal	Pa	N/m²
Quantity of heat	joule	J	N-m
Solid angle	steradian	sr	—
Work	joule	J	N-m

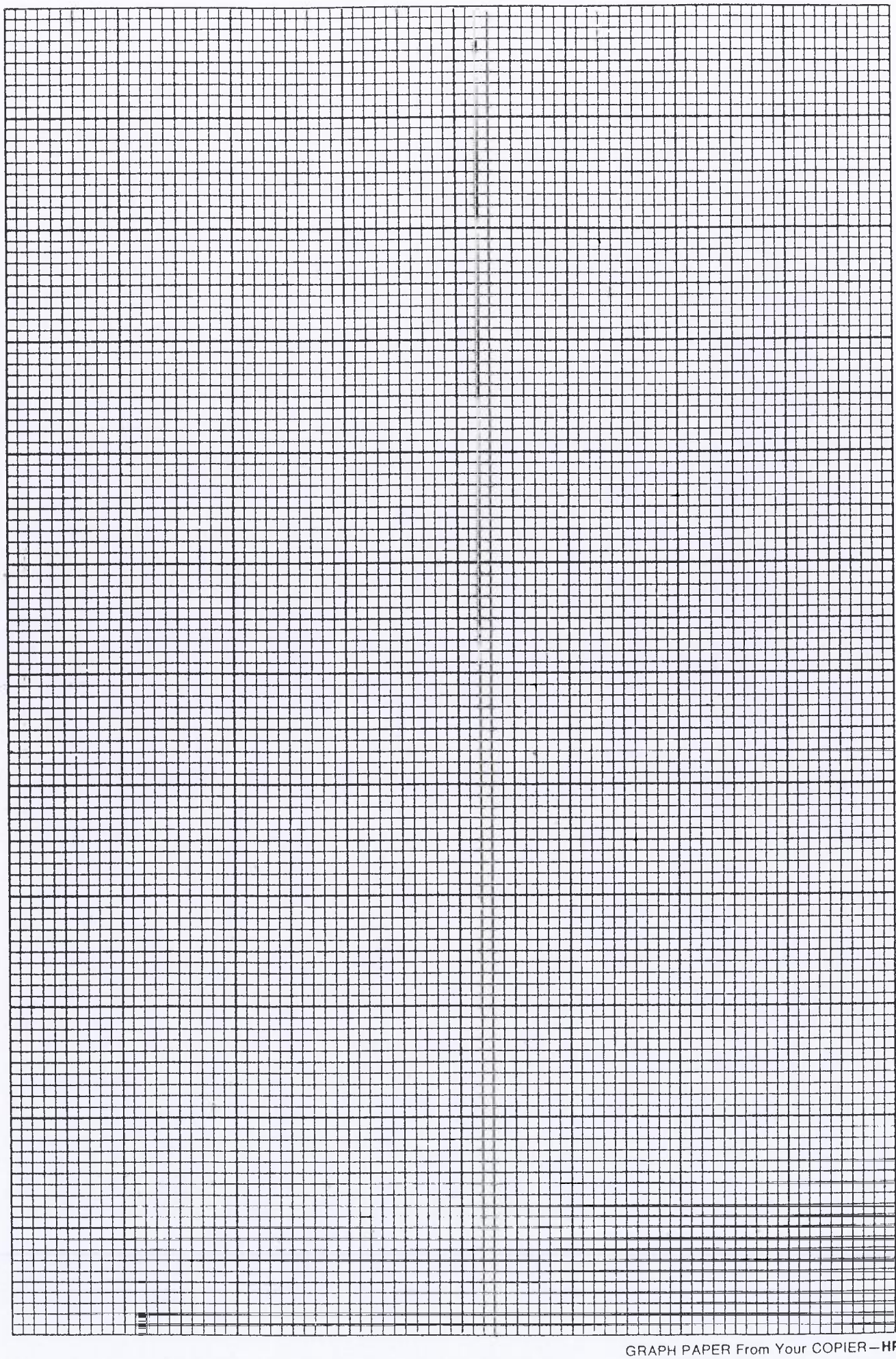
Table 3—SI prefixes and multiplication factors

Prefix	SI Symbol	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

To convert from	To	Multiply by
acre	hectare	0.40469
acre	metre²	4,046.9
acre-feet	metre³	1,233.5
ampere-hour	coulomb	3,600.0
angstrom	nanometre	0.10000
astronomical unit	gigametre	149.598
atmosphere	bar	1.01325
atmosphere (normal)	kilopascal	101.325
atmosphere (normal)	pascal	101,325
atmosphere (1 kgf/cm³)	pascal	98,067
bar	kilopascal	100.000
bar	pascal	100,000
barrel (42 US gal)	metre³	0.15899
barrel/acre-foot	decimetre³/meter³	0.12889
barrel/day	decimetre³/second	0.00184
barrel/day	metre³/day	0.15899
barrel/day (1 kg/dm³)	tonne/annum	58.0304
barrel/foot	metre³/meter	0.52161
barrel/hour	decimetre³/second	0.04416
barrel/hour	metre³/hour	0.15899
barrel/US ton	metre³/tonne	0.17525
board-foot	metre³	0.00236
British thermal unit	joule	1,055.1
British thermal unit	kilojoule	1.05506
British thermal unit	watt-hour	0.29288
BTU/bhp-hour	watt/kilowatt	0.39301
BTU/foot³	kilojoule/metre³	37.2590
BTU/foot³	kilowatt-hour/metre³	0.01035
BTU/US gallon	kilojoule/metre³	278.716
BTU/US gallon	kilowatt-hour/metre³	0.07742
BTU/hour	watt	0.29307
BTU/minute	watt	17.5843
BTU/second	kilowatt	1.05506
BTU/hour-foot²	watt/metre²	3.15459
BTU/hour-foot³	watt/metre³	10.3497
BTU/hr-foot²-°F.	watt/metre²-kelvin	5.67826
BTU/second-foot²-°F.	kilowatt/metre²-kelvin	20.4418
BTU/hour-foot³-°F.	watt/metre³-kelvin	18.6295
BTU/second-foot³-°F.	kilowatt/metre³-kelvin	67.0661
BTU/hour-foot²-°F./foot	watt/metre-kelvin	1.73074
BTU/hour-foot²-°F./inch	watt/metre-kelvin	0.14428
BTU/second-foot²-°F./in.	watt/metre-kelvin	519.220
BTU/pound mass	joules/gram	2.32600
BTU/pound mass	watt-hour/kilogram	0.64611
BTU/pound mol	joules/mol	2.32600
BTU/pound-°F.	joules/gram-kelvin	4.18680
BTU/pound mol-°F.	joules/mol-kelvin	4.18680
bushel	decimetre³	35.2391
bushel	metre³	0.03524
calorie	joule	4.18400
calorie/pound	joule/kilogram	9.22414
centipoise	newton-second/metre²	0.00100
centipoise	pascal-second	0.00100
centistoke	millimetre²/second	1.00000
chain	metre	20.1168
cycle/second	hertz	1.00000
darcy	micrometre²	0.98692
degree (angle)	radian	0.01745
°F/100 foot	millikelvin/meter	18.2269
°F.-foot²-hour/BTU	kelvin-metre²/watt	0.17611
dyne	millinewton	0.01000
erg	microjoule	0.10000
erg	millijoule	0.00010
fathom	metre	1.82880
foot	centimetre	30.4800
foot	metre	0.30480
foot/day	metre/day	0.30480
foot/°F.	metre/kelvin	0.54864
foot/hour	metre/hour	0.30480
foot/hour	millimetre/second	0.08467

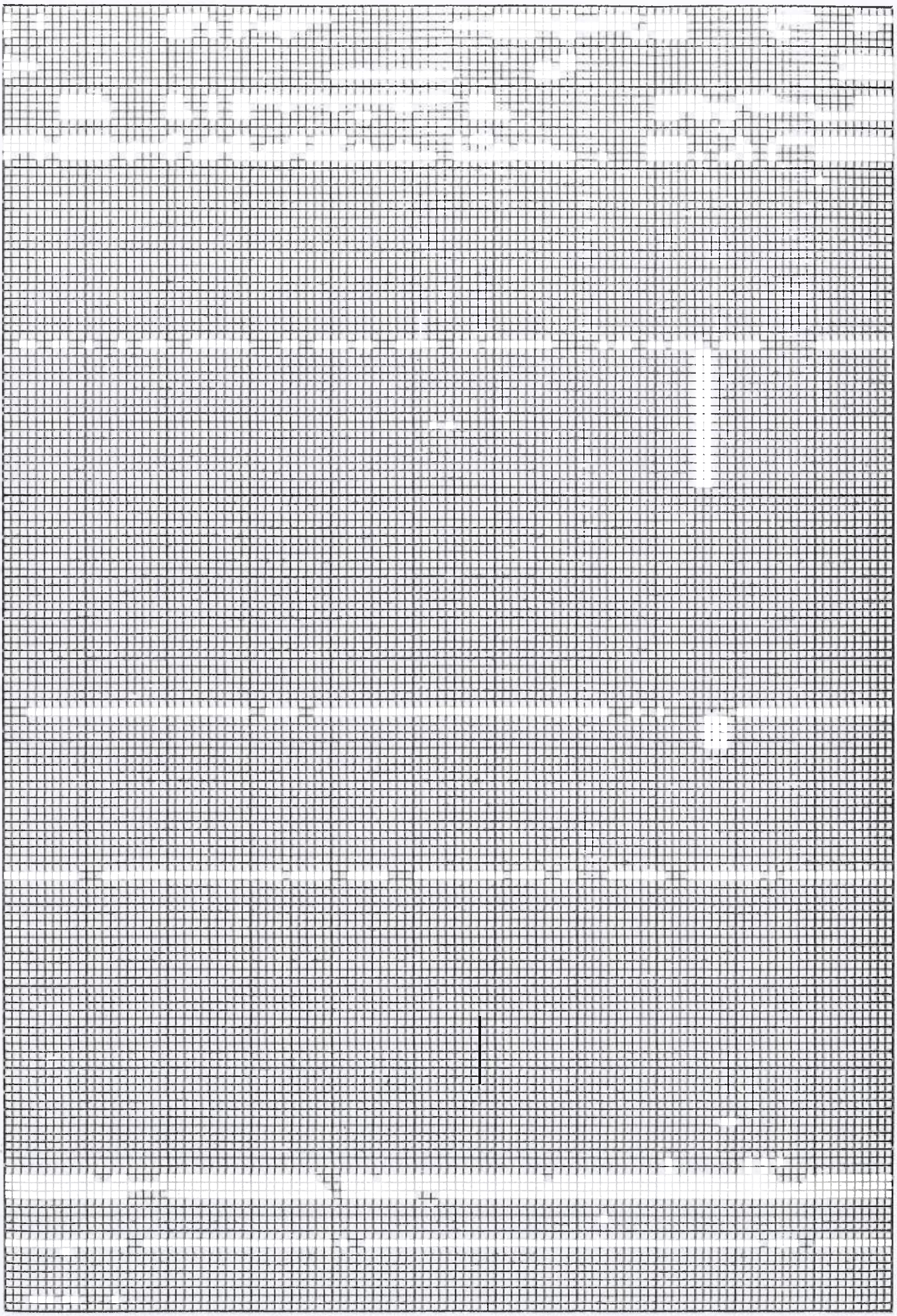
To convert from	To	Multiply by
foot/minute	centimetre/second	0.50800
foot/minute	metre/minute	0.30480
foot/minute	metre/second	0.00508
foot/second	metre/second	0.30480
foot/second²	metre/second²	0.30480
foot³	centimetre³	929.030
foot³	metre³	0.09290
foot³/hour	millimetre³/second	25.8064
foot³/second	millimetre³/second	92.903
foot³	decimetre³	28.3169
foot³	metre³	0.02832
foot³/day	decimetre³/second	0.00033
foot³/day	metre³/day	0.02832
foot³/day	metre³/hour	0.00118
foot³/foot	metre³/metre	0.09290
foot³/hour	decimetre³/second	0.00787
foot³/hour	metre³hour	0.02832
foot³/minute	decimetre³/second	0.47195
foot³/minute	metre³/minute	0.02832
foot³/pound	metre³/kilogram	0.06243
foot³/pound mol	metre³/kilomol	0.06243
foot³/second	metre³/second	0.02832
footcandle	lux	10.0764
footcandle-second	lux-second	10.0764
foot-pound force	joule	1.35582
foot-pound/US gallon	kilojoule/metre³	0.35817
foot-pound/minute	milliwatt	22.5970
foot-pound/minute	watt	0.02260
foot-pound/second	watt	1.35582
gallon US liquid	metre³	0.00379
gallon US/foot	metre³/metre	0.01242
gallon US/horsepower-hr.	decimetre³/megajoule	1.41009
gallon US/horsepower-hr.	millimetre³/joule	1.41009
gallon US/1,000 barrel	centimetre³/metre³	23.8095
gallon US/foot³	decimetre³/metre³	133.681
gallon US/hour	decimetre³/second	0.00105
gallon US/hour	metre³/hour	0.00379
gallon US/mile	decimetre³/100 kilometre	235.215
gallon US/minute	decimetre³/second	0.06309
gallon US/minute	metre³/hour	0.22712
gallon US/ton US	decimetre³/tonne	4.17270
grain	milligram	64.7989
grain/gallon US	gram/metre³	17.1181
grain/100 foot³	milligram/metre³	22.8835
horsepower	kilowatt	0.74570
horsepower (boiler)	kilowatt	9.80950
horsepower/foot³	kilowatt/metre³	26.3341
horsepower-hour	kilowatt/hour	0.74570
horsepower-hour	megajoule	2.68452
inch	centimetre	2.54000
inch	millimetre	25.4000
inch	pica	6.02250
inch	point	72.2700
inch Hg (60°F)	kilopascal	3.37685
inch H_2O (60° F)	kilopascal	0.24884
inch/minute	centimetre/minute	2.54000
inch/second	centimetre/second	2.54000
inch/second	millimetre/second	25.4000
inch/year	millimetre/annum	25.4000
inch²	centimetre²	6.45160
inch²	millimetre²	645.160
inch²/second	millimetre²/second	645.160
inch³	centimetre³	16.3871
inch⁴	centimetre⁴	41.6231
joule	British thermal unit	0.00095
joule	foot-pound force	0.73756
kilogram	pound mass av.	2.20462
kilogram/metre³	pound mass/foot³	0.06243
kilometre/hour	mile/hour statute	0.62137
kilowatt-hour	kilojoule	3,600.0
kilowatt-hour	megajoule	3.60000
knot	kilometre/hour	1.85200
lambert	candela/metre²	3,183.1
link	metre	0.20117
metre	foot	3.28084
metre²	foot²	10.7639
metre³	barrel (42 US gal)	6.28981
metre³	foot³	35.3147
metre/minute	foot/minute	3.28084
metre³/minute	gallon US/minute	264.172
micron	micrometre	1.00000
mil	micrometre	25.4000
mile, nautical	kilometre	1.85200
mile, US statute	kilometre	1.60934
mile² US statute	kilometre²	2.58999
mile (US stat.)/US gal	kilometre/decimetre³	0.42514
mile (US stat.)/hour	kilometre/hour	1.60934

To convert from	To	Multiply by
minute (angle)	radian	0.00029
newton	pound force av.	0.22481
ounce force av	newton	0.27801
ounce mass av	gram	28.3495
ounce mass av	kilogram	0.02835
ounce US fluid	centimetre³	29.5735
ounce troy	gram	31.1035
part/million (volume)	centimetre³/metre³	1.00000
pascal	pound force/foot²	0.02089
pascal	pound force/inch²	0.00015
pica	centimetre	0.42175
pica	inch	0.16604
pint US dry	decimetre³	0.55061
pint US liquid	decimetre³	0.47318
point	centimetre	0.03515
point	inch	0.01384
pound force	newton	4.44822
pound mass av	kilogram	0.45359
pound mass troy	kilogram	0.37324
pound mol	kilomol	0.45359
pound force/foot²	pascal	47.8803
pound force/inch²	kilopascal	6.89476
pound force/inch²/foot	kilopascal/metre	22.6206
pound mass/barrel	gram/decimetre³	2.85301
pound mass/barrel	kilogram/metre³	2.85301
pound mass/foot	kilogram/metre	1.48816
pound mass/foot²	kilogram/metre²	4.88243
pound mass/foot³	kilogram/metre³	16.0185
pound mass/US gallon	gram/centimetre³	0.11983
pound mass/US gallon	kilogram-decimetre³	0.11983
pound mass/horsepower-hr.	kilogram/kilowatt-hour	0.60828
pound mass/horsepower-hr.	kilogram/megajoule	0.16897
pound mass/horsepower-hr.	milligram/joule	0.16897
pound mass/hour	tonne/day	0.45359
pound mass/minute	kilogram/minute	0.45359
pound mass/second	kilogram/second	0.45359
pound mass/hour-foot	gram/second-metre	0.41338
pound mass/second-foot	kilogram/second-metre	1.48816
pound mass/second-foot	pascal-second	1.48816
pound mass/second foot²	kilogram/second-metre²	4.88243
pound mol	kilomol	0.45359
pound mol/foot³	kilomol/metre³	16.0185
pound mol/US gallon	kilomol/metre³	119.826
pound mol/hour	kilomol/hour	0.45359
pound mol/second	kilomol/second	0.45359
pound force-foot	joule	1.35582
pound force-foot	newton-metre	1.35582
pound force-inch	joule	0.11298
pound force-inch	newton-metre	0.11298
pound force-foot²	kilogram-metre²	0.04214
pound force-foot/inch	newton-metre/metre	53.3787
pound force-inch/inch	newton-metre/metre	4.44822
pound force-foot/inch²	joule/centimetre²	0.00210
pound force-foot/second	kilogram-metre/second	0.13826
pound force-second/foot²	pascal-second	47.8803
quart US	decimetre³	0.94635
radian (angle)	degree	57.2958
radian (angle)	revolution	0.15915
radian (angle)/minute	revolution/minute	0.15915
°Rankine	kelvin	0.55556
revolution	radian (angle)	6.28319
revolution/minute	radian/minute	6.28319
section	hectare	258.999
therm	megajoule	105.506
ton force US	kilonewton	8.89644
ton mass US short	kilogram	907.185
ton mass US short	tonne	0.90718
tonne	kilogram	1,000.0
tonne	megagram	1.00000
ton force US/foot²	megapascal	0.09576
ton force US/inch²	megapascal	13.7895
ton force US-mile	megajoule	14.3174
ton mass US/day	tonne/hour	0.03780
ton mass US/hour	tonne/day	0.90718
ton mass US/day	kilogram/second	0.01050
ton mass US/hour	kilogram/second	0.25120
ton mass US/minute	kilogram/second	15.1197
ton mass US/year	tonne-annum	0.90718
ton mass US/foot²	tonne/metre²	9.76486
torr	pascal	133.322
watt	BTU/minute	0.05687
watt	joule/second	1.00000
watt-hour	joule	3,600.0
watt-second	joule	1.00000
yard	metre	0.91440
yard²	metre²	0.83613
yard³	metre³	0.76455

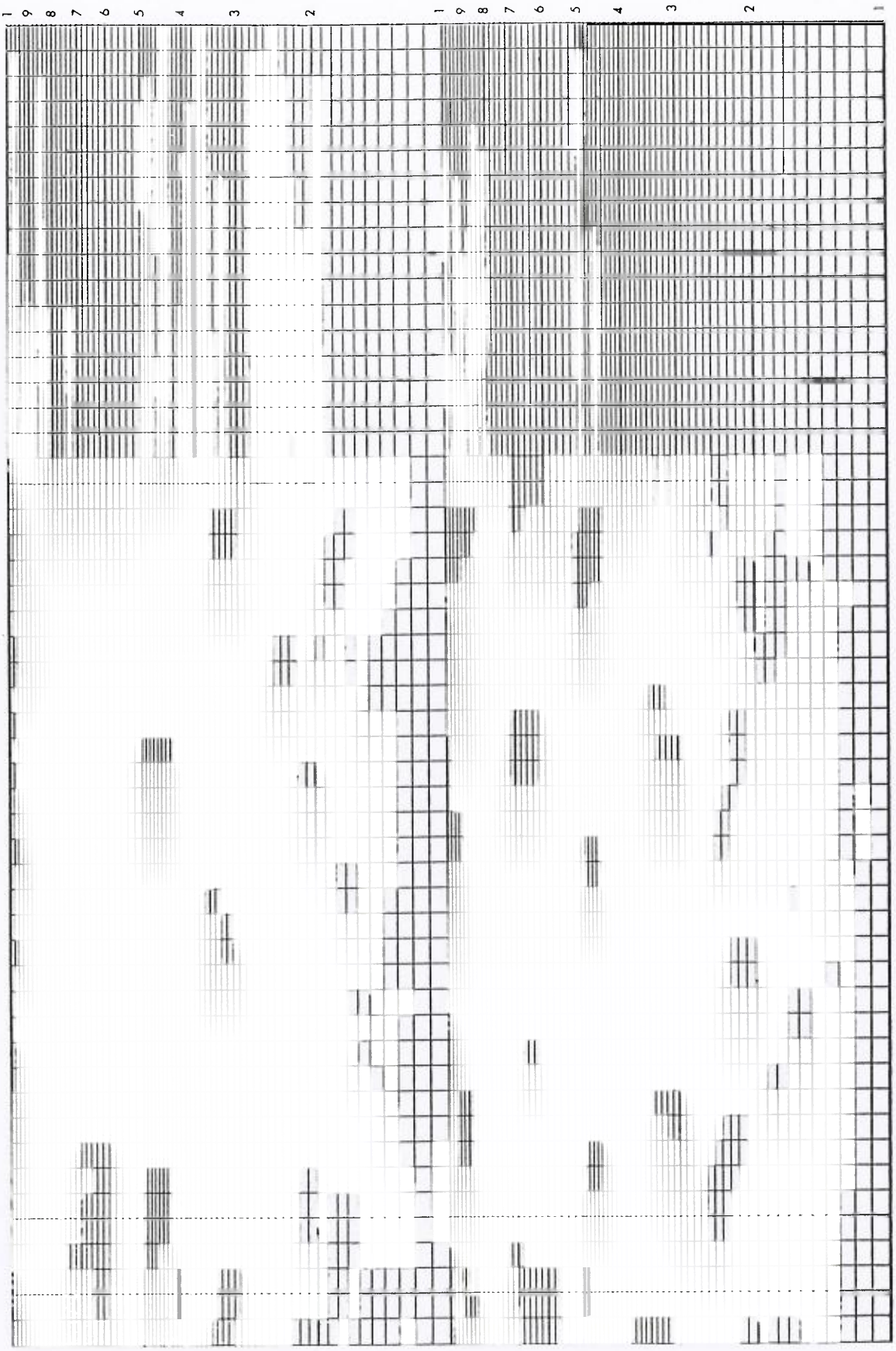


Graph 1 of 9, Pet-A6, I

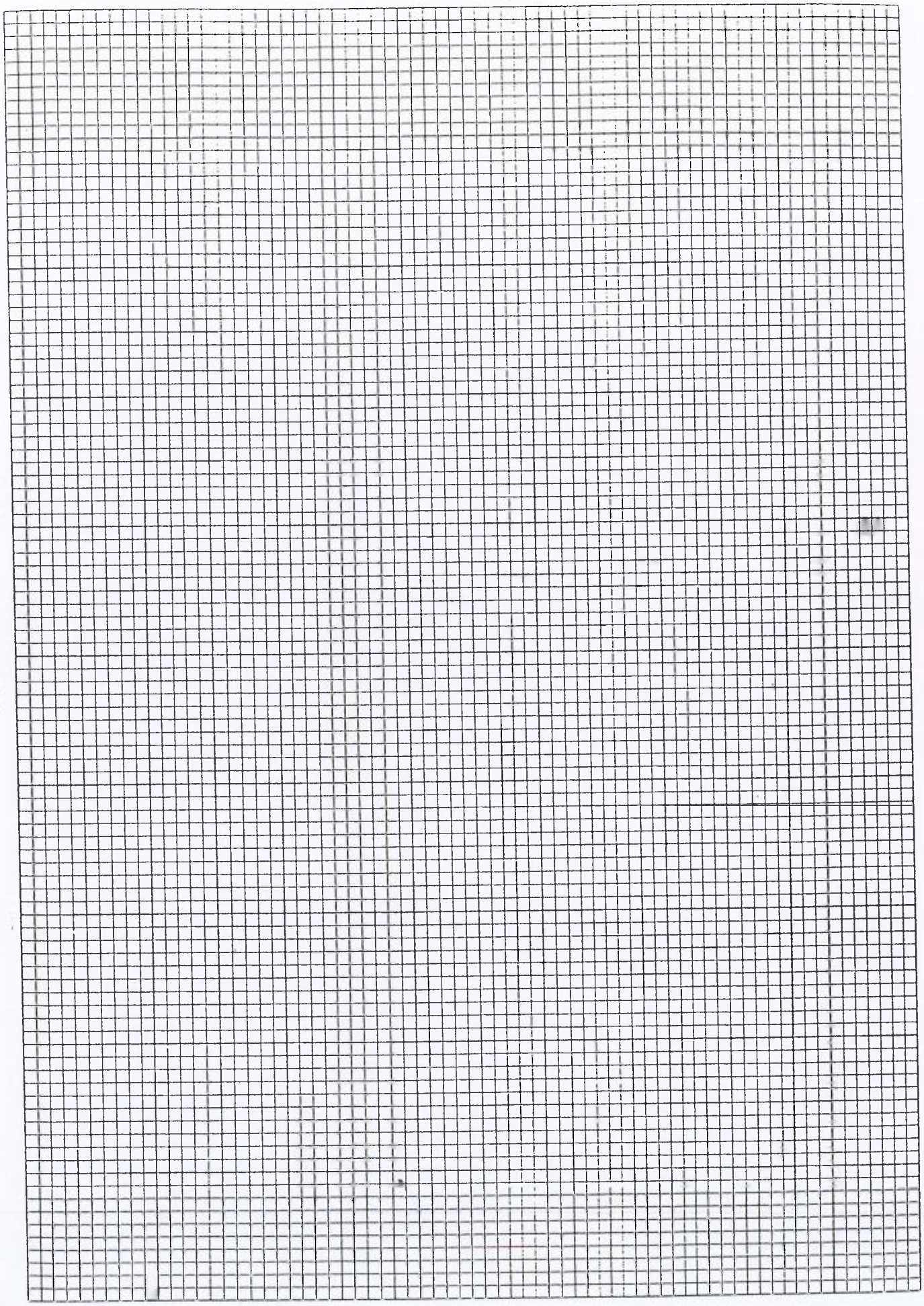
16 Divisions/Inch 5th, 10th Accent



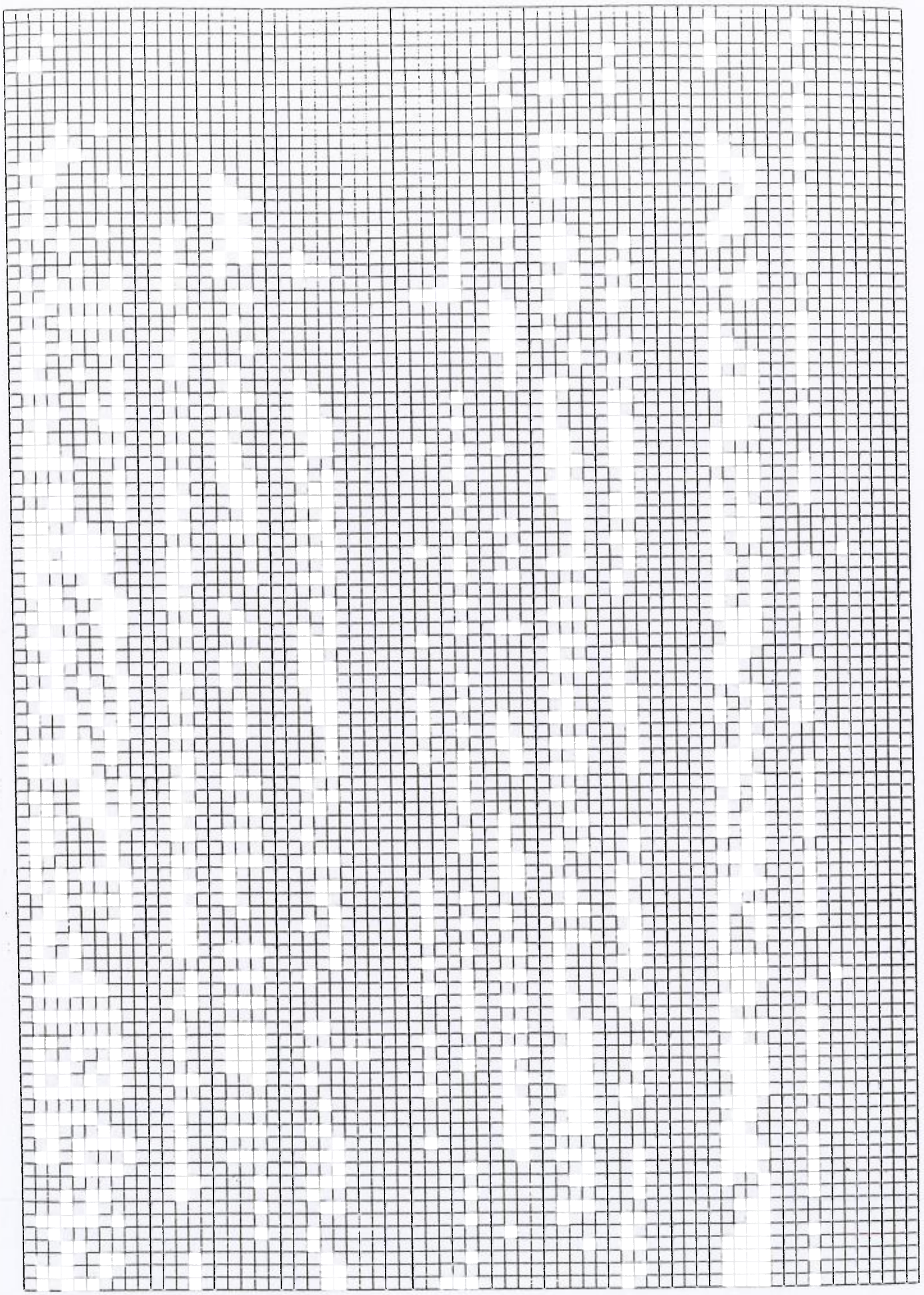
Graph 2 of 9, Pet-A6,



Graph 3 of 9, Pet-A6.

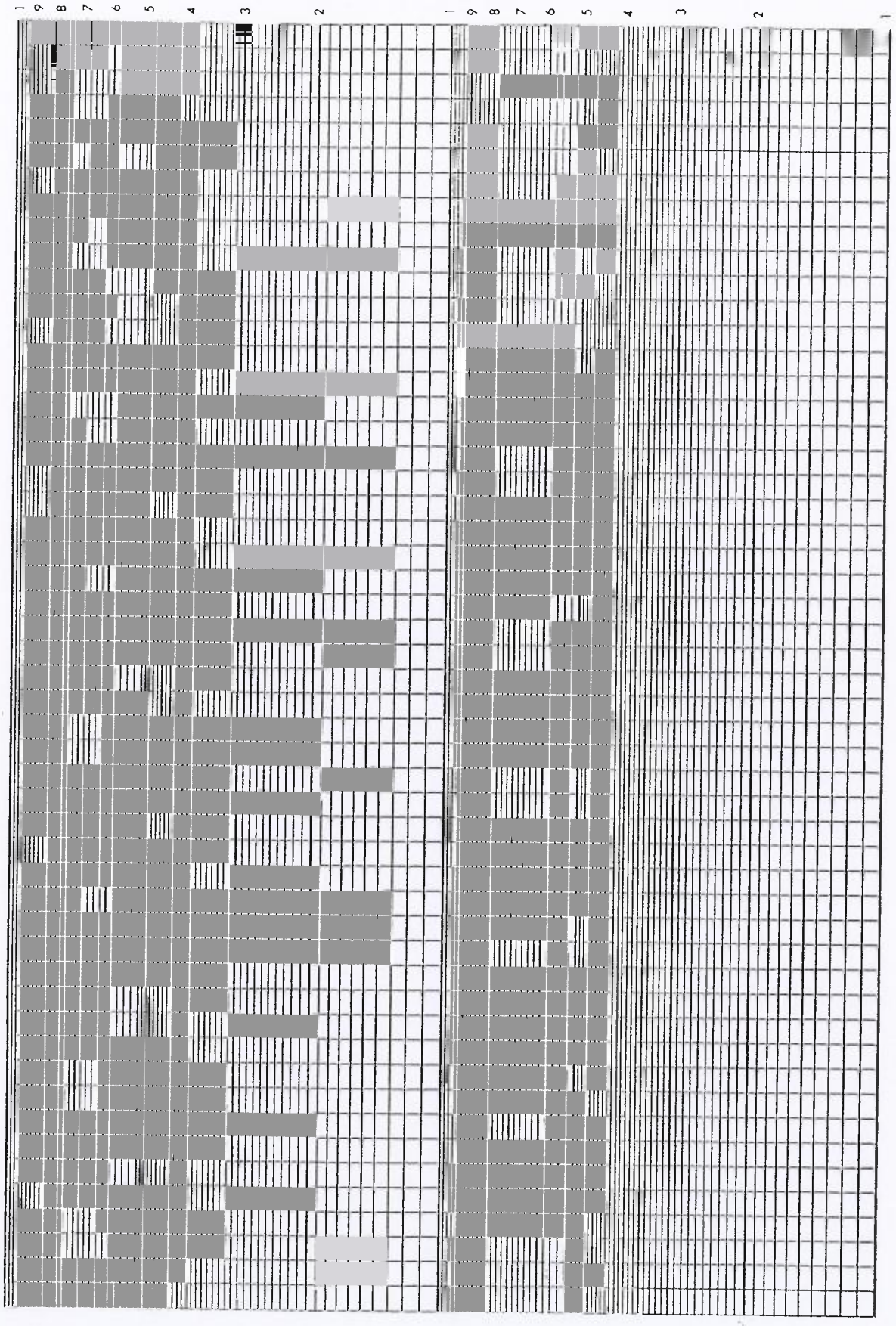


Graph 4 of 9, Pet-A6,



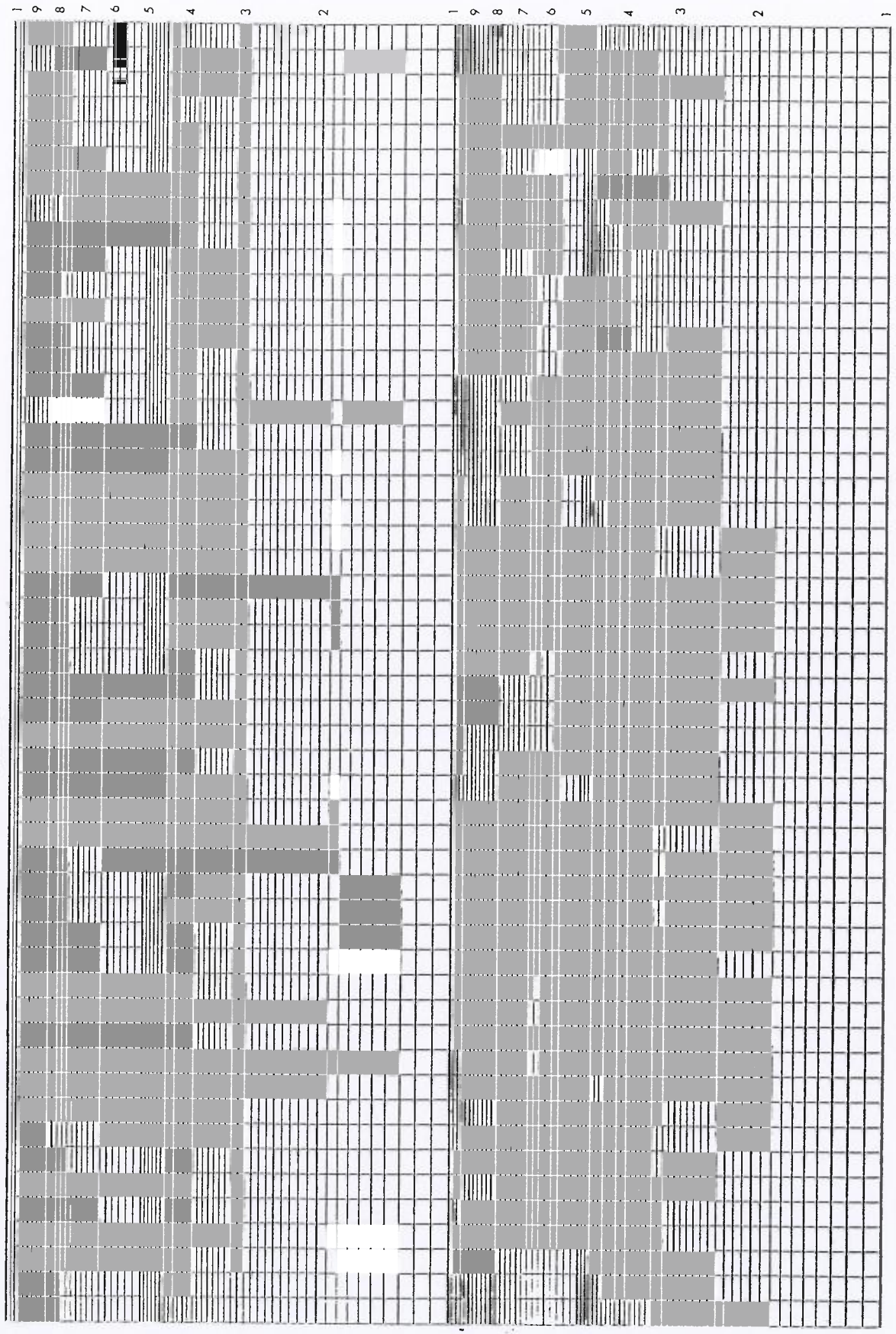
Graph 5 of 9, Pet-A6, ¯

52 Divisions by 2 Cycle (Long Axis) Semi-Log

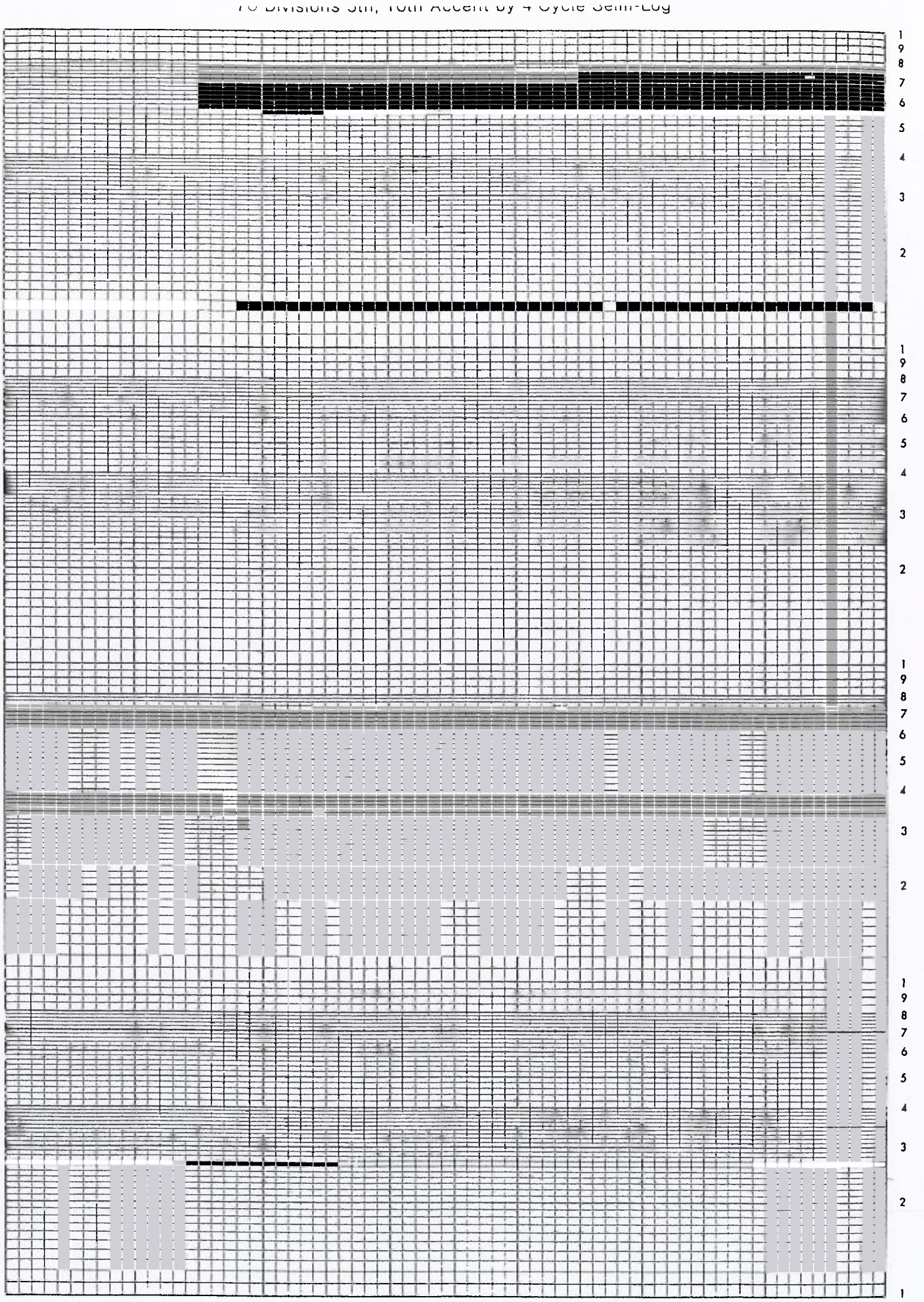


Graph 6 of 9, Pet-A6,

52 Divisions by 2 Cycle (Long Axis) Semi-Log

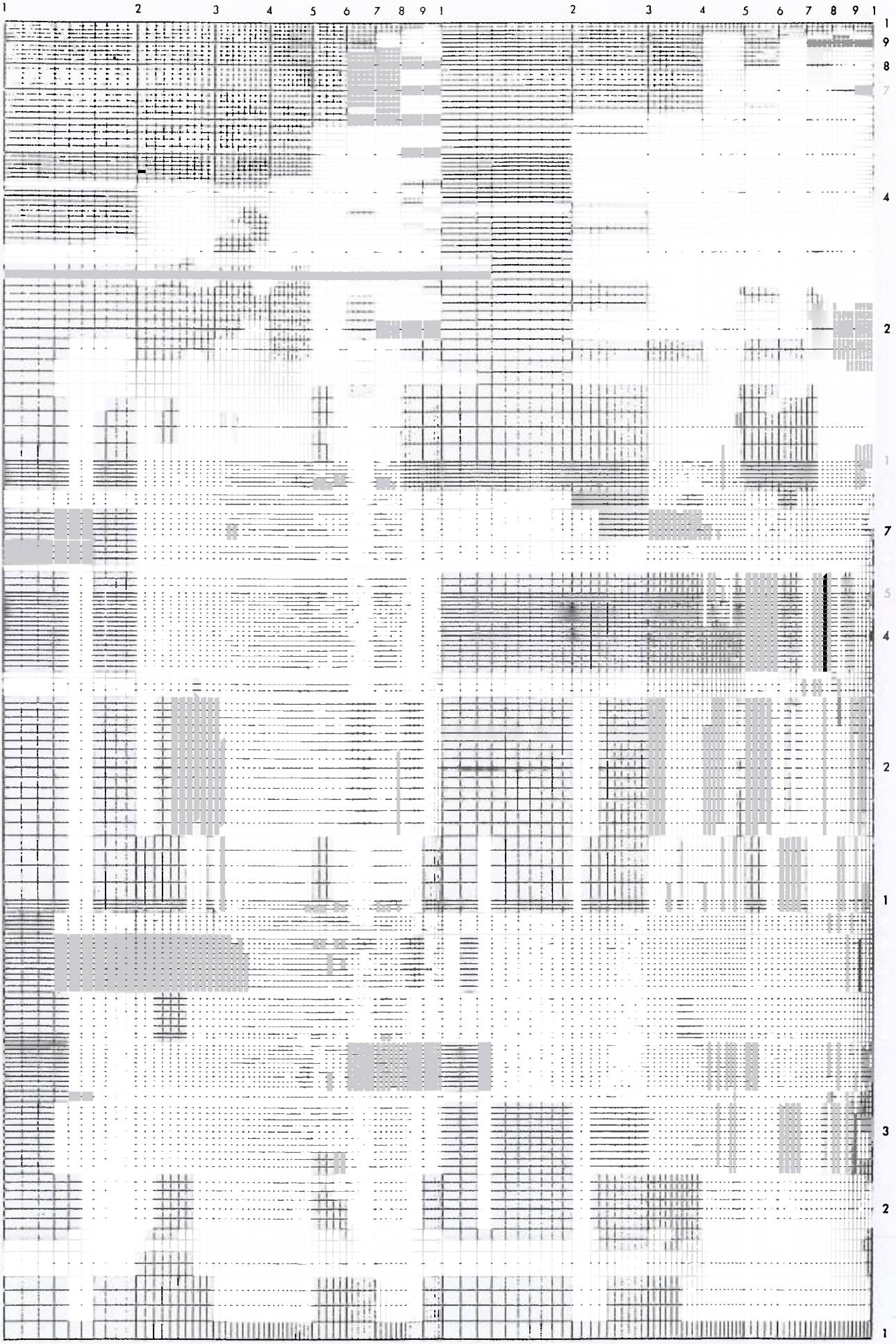


Graph 7 of 9, Pet-A6,



Graph 8 of 9, Pet-A6, 1

2 Cycle by 3 Cycle Log-Log



Graph 9 of 9, Pet-A6,