Elf Aquitaine Norge A/S
Reservoir Department
311E-R 84/435/AT/meø

Stavanger, November 13, 1984 .

FRIGG FIELD

RESERVOIR SIMULATION

Fall 1984

Prepared by
A. THOUAND

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1. SUMMARY

The main target of this study is to evaluate the consequences on Frigg production profile and recovery using models in which the results from well 10/1-A25 have been matched.

The water level in well 10/1-A25 has been found 54 m higher than the initial WOC. This value is 11 m or 14 m more than those obtained previously with the Greater Frigg Model for residual gas saturation of 19 % or 29 %, respectively. For the following and due to time constraints, only cases with a residual gas saturation of 29 % are simulated.

An updating of the model was first done to account for an increase in the satellites accumulation, the description of saddles in East Frigg area and for the modified aquifer description.

Then, matching of the model was achieved with new representations of the window in the barrier zone. Two matches were successfully realized based on two different hypotheses regarding the nature of the window in the barrier zone between the Frigg Aquifer and the Cod formation.

Based on the two matching runs, simulated up to August 1984, prediction cases were run. The production profile has been slightly modified for NEF and East Frigg has been put on production as from October 1st, 1988.

The main modification compared to previous simulations has been made on the Frigg Field for which complementary production facilities were introduced to increase recovery.

Parallel simulations have been run with the two models of the Frigg field geology. Preliminary runs were performed in order to simulate what is the future of the Frigg Field with only the present production facilities. The important remaining gas at the end of the life of the present production facilities was in the two cases mainly located north of DP2.

When adding new production facilities, a recovery similar to the one obtained with previous simulations (April 1984) was achieved. The unfavourable location of the present facilities is balanced by an appropriate location of new producing facilities which allow a good sweeping efficiency and recoverable reserves in the range 205 to 209 x 10^9 std m^3.
The simulation runs are summarized in table 0.

SUMMARY OF SIMULATION RUNS
(Sgrw = 29%)

Table no. 0

Case	Recoverable Reserves (10^9 std m^3)	Minimum pressure (bar a)	Number of new wells on present PF	Number of new wells on new location	Remark
Present facilities	FR: final recovery PR: partial recovery				
Previous simulations	FR = 204,6	121,9			Without water rise match at well 10/1-A25
South Eastern Window case SEW 1	PR = 183,9	128,9			Simulation stopped at end of the plateau rate
Western Window case WW 1	PR = 157,9	143,1			
With new Production facilities					
South Eastern Window case SEW 2	FR = 209,1	125,2	7	16	Frigg Field shut in: January 1993
Western window case WW 2	FR = 205,4	131,4	8	16	Frigg field shut in: June 1993

2. INITIALIZATION

2.1. Updating of accumulation

Recent informations have allowed us to increase the gas in place (GIP) estimation for all Frigg field satellites.

2.1.1. NEF

On North East Frigg (NEF) log interpretation of development wells provided E.A.N. with lower values for irreducible water saturation than the one obtained in the exploration well and this was then entered into the model.

The accumulation was increased from 16.42 to 18.7 Gstdm^3 by a modification of the effective porosity ($\alpha.\emptyset$) whose value increased from 24.6 % to 27.2 %. The initial water saturation is the same for all rock types in the model due to numerical reasons.

2.1.2. Odin

On Odin (Esso operator), new information, new preliminary maps and estimations led to a substantial increase in the gas accumulation.

The new estimation is 38.0 Gstdm^3 instead of 26.15 Gstdm^3. As for NEF, the effective porosity was modified; from 18.4 % to 26.8 %.

2.1.3. East Frigg and South East Frigg

On East Frigg (EF) and South East Frigg (SEF), seismic data were reinterpreted using the interval method and gave a new isopach map. The shape of the structures were strongly modified (including the saddles towards Frigg) and resulted in strong increase of gas in place volumes.

To increase the EF and SEF accumulations, the porosity and the gas height were increased. It was also necessary to double the number of cells of SEF.

	GFM			Present model		
	GIP Gstdm^3	Ø (%)	Average gas bearing height (m)	GIP Gstdm^3	Ø (%)	Average gas bearing sand height (m)
EF	9.01	28.5	22	15.6*	36.1	30
SEF	0.87	20.9	13	8.1*	44.2	25

* These values of gas in place were calculated before the 1984 seismic campaign and well 25/2-8, but are very close to the figures retained after the appraisal well: 15.0 G st m^3 (EF) and 7.4 G st m^3 (SEF).

GFM = Greater Frigg Model
MGFM = Modified Greater Frigg model (as of August, 1984)

2.2. Saddles adjustment

Modelling of saddles was done in accordance with principles kept on the GFM. Communication was increased from East Frigg and South East Frigg towards Frigg and created between East Frigg and South East Frigg. These modifications are important as they rule fluid transfers from the satellites towards Frigg.

Saddle EF => Frigg: H = 10 m (21 m previously)
Saddle SEF => Frigg: H = 35 m (38 m previously)
Saddle SEF => EF : H = 30 m (no communication in the GFM).

This modelling results in easier gas transfer, direct from EF to Frigg, indirect from SEF to Frigg (through EF). It means more accurate pressure decline for EF/SEF, linked to the Frigg pressure evolution.

2.3. Updating of the geological scheme

2.3.1. Aquifer description

Cod Aquifer: The regional study of these sands and the localisation of possible communication with underlaying aquifers (Heimdal formation) are considered to improve the previous modelling. (see plate no.1)

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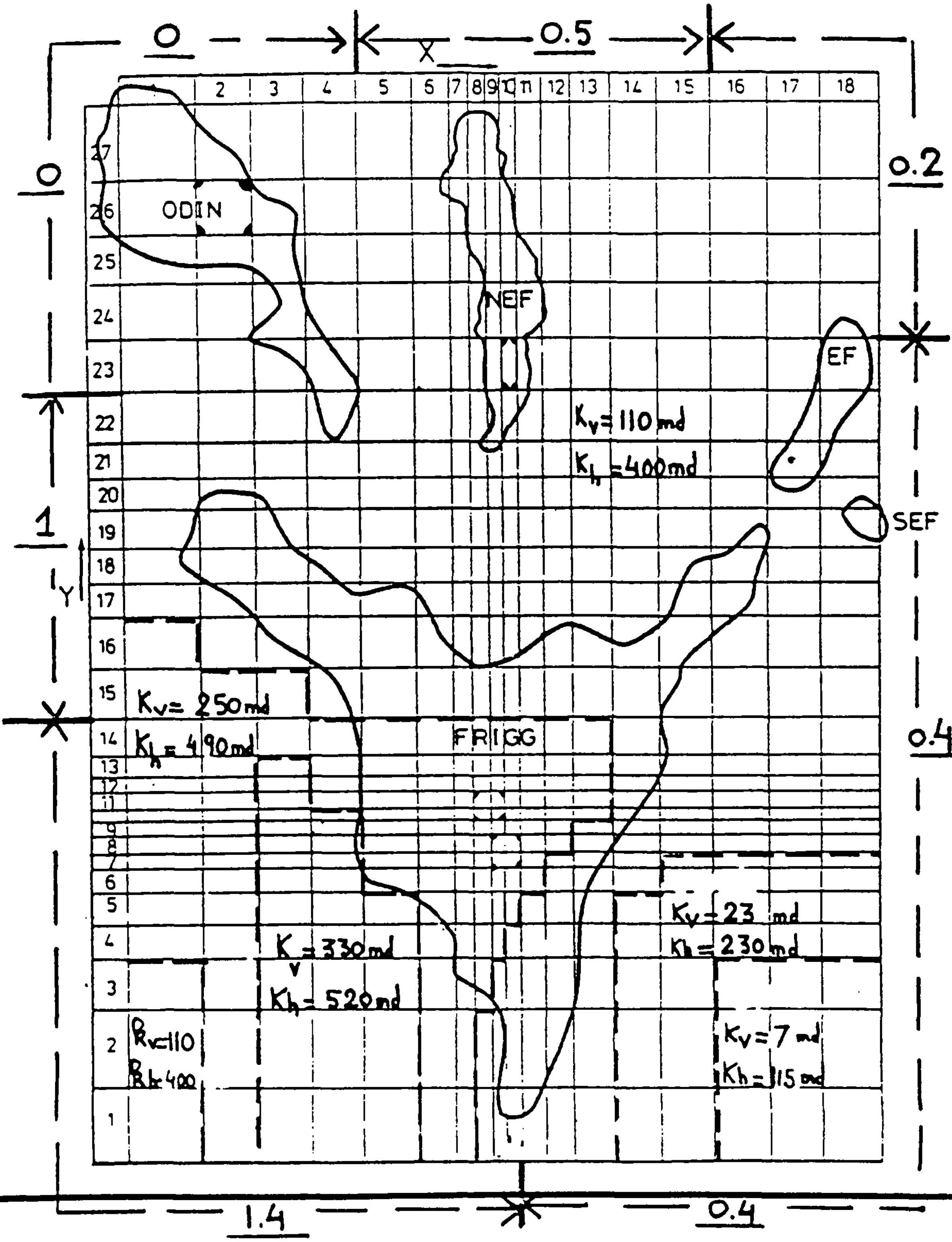
FRIGG AREA 1984 model
Cod Aquifer representation
Boundary influx

Attached to report no. Title Author: ALAIN THOUAND Original filing plan: FRIGG F SYN 2	PL. 1	Date: NOV 84 Author: J.P.L. Drawing: L.N. Filing no:

Cod Aquifer Infinite - Carter Tracy 270°

(Kss = 575 md Ksh = 1 md)



Frigg Aquifer: The main modifications for this aquifer are:

- a different representation of the boundary influx: Carter Tracy functions instead of over porosity.
- a decrease of the horizontal permeability in the area beneath NEF. This modification was necessary to match NEF pressure. (see plate no.2)

2.3.2. Barrier between Cod Aquifer and Frigg Aquifer

The modelling of the barrier zone was based on two hypotheses concerning the location of the window in the barrier zone. Both hypotheses are acceptable with respect to the sedimentology of the Frigg fan:

- The Western window which represents an increase of barrier permeability due to lower content, or even absence, of tuffitic material
- The South-Western window which represents increased barrier permeability due to lower barrier thickness.

For more detail on the subject see the report:
"Sedimentological report on lower tertiary sandy deposits in Great Frigg Region". Ref. no. 311D/84/200R AC/mr.

These two possibilities were used to get an appropriate match of the model with actual measurements, i.e. until August 1984.

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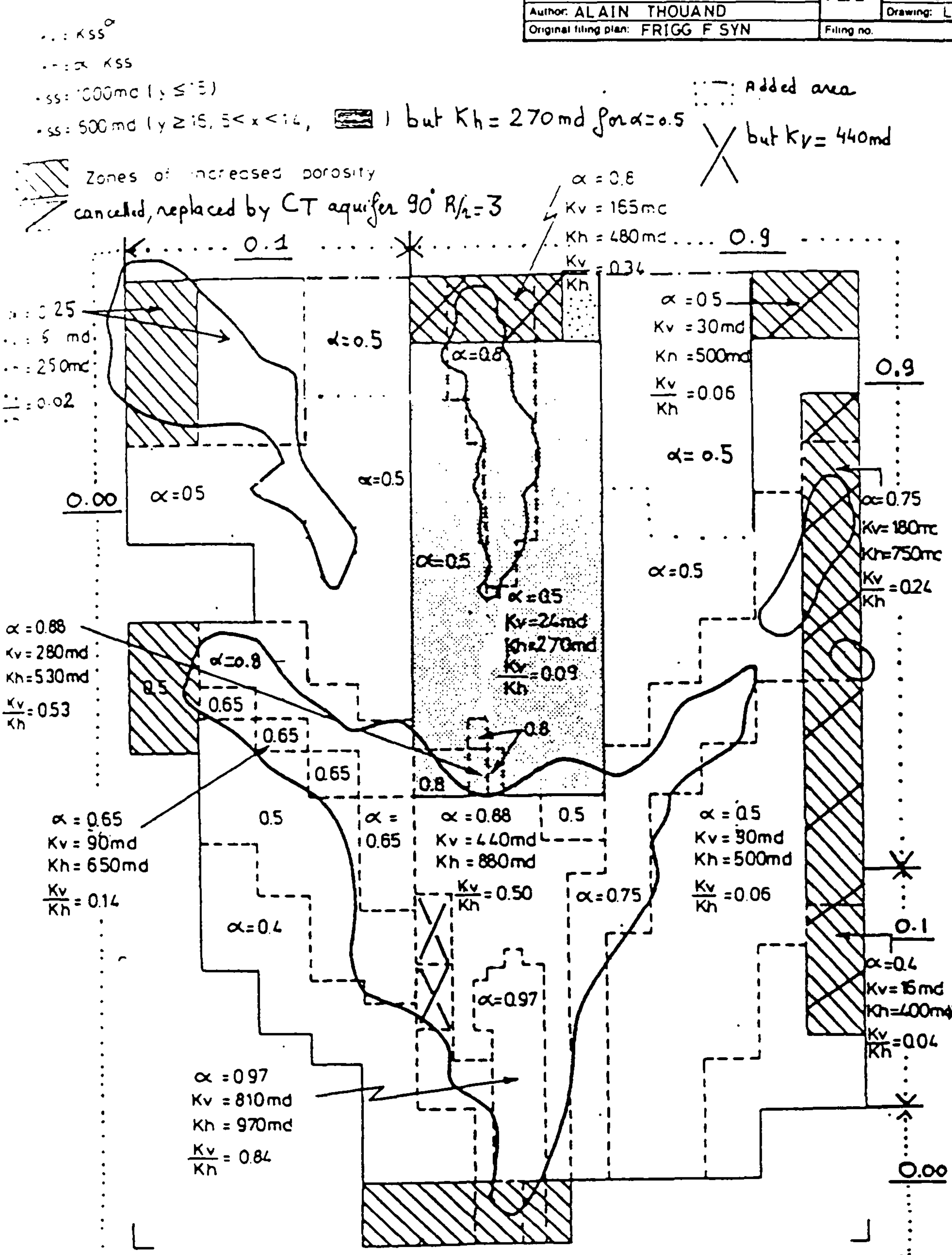
FRIGG AREA 1984 model

FRIGG aquifer representation

Attached to report no:	PL. 2	Date: NOV 84
Title:		Author: J.P.L
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN	Filing no.	

DISTRIBUTION OF α IN FRIGG AQUIFER



COMMENTS

1. For all satellites, sweeping efficiency and water coning are probably not accurately described. On EF/SEF, geometry is very rough. Reason is that gridding (in the GFM) is not suited for a proper description of satellite fields.

2. No special care has been taken concerning possible modifications of oil in place. It remains the same except on SEF where it was doubled (model surface is increased with respect to the GFM, while we keep the same fluid contacts levels).

These imperfections or inadequate details should remain negligible, as being without consequences on Frigg gas recovery.

Some additional modifications have been made, on NEF and Odin, for history pressure matching purpose, and are described in the next chapter.

3. HISTORY MATCHING

The history matching has been perfomed using the input data presented in the report "Greater Frigg 1983 - 1984 reservoir engineering study, input data"; (ref. 311E-R 84/044/SH). Modifications brought to these data are described in chapter 2 of the present report and in this chapter.

In this chapter, the pressure match of the Frigg area which is a regional pressure match, is separated from the pressure and water rise match of the Frigg field which is a more local phenomenon. The second match involves mainly the window in the barrier zone.

3.1. Pressure match (Frigg area)

The GFM (including satellites) represented a total accumulation equal to 317.6 10^9 $stdm^3$ (free gas). The modified GFM represents a total accumulation equal to 345.2 10^9 $stdm^3$ (free gas).

The additional 29.3 10^9 $stdm^3$ (split between the four satellites) induce a total free gas increase of 9 %, and means more potential energy and modifies the necessary pressure match of the model.

We required a very good matching of Frigg and NEF and an acceptable matching on Odin (on which there are still many uncertainties). A matching was also performed on EF/SEF as pressure information was brought in Summer 1984 by the well 25/2-8 drilled on EF.

The following measurements were available:
. Cod sand pressure history (below Frigg)
. Frigg sand pressure history (CDP1 and DP2)
. NEF pressure: gas (2 measurements)
. Odin pressure: gas and Cod aquifer (1 measurement).
. EF pressure: gas and Cod aquifer (1 measurement).

The pressure match was performed following the same principle as for the previous GFM match. It is however, important to note more precisely the conditions.

* no interference corrections are done on the measured down-hole pressures.

* in a shut-in well, 0.5 bars variation can be observed during a day (on Frigg).

* on satellites, model-well position does not reflect position of true wells (Odin and NEF). For model calculations, wells are put into the center of the cell, while they can be at one edge. Distance between well cell and real wells can exceed one kilometer (Odin).

The additional alterations carried out on the GFM are the following:

3.1.1. NEF

In the initialization, accumulations were increased (+ 10%). Consequently, we had to face a pressure drop in the model too low compared to reality.

To avoid too many distortions on various possible matching parameters, we decided "to play" with the same parameters (when possible) which were used for the previous matching on the GFM.

Fortunately, in that case, model pressure drops were more important than in reality. It was then easy for us to cancel alterations made for the GFM, obsolete today.

Communication outside the saddle was reduced by:

. decreasing the width of the high α-values in the Frigg aquifer below NEF respecting the initial zonation for α-values map.

. decreasing vertical permeability across the Tuff barrier in the northern row (Y = 27, X = 6 to 12).
$Kv = 0.5$ mD => $Kv = 0.02$ mD.

The effect of this is to lower the communication existing between Frigg and Cod sand aquifers for the part of Frigg sand falling outside the gridding limits.

3.1.2. Odin

Odin accumulation jumped from 26 to 38 10^9 std m^3. As late as January 1984, no pressure measurements were available on Odin since the initial pressures obtained in exploration wells.

We have to be very cautious with present figures, because discrepancies seem to exist between Esso data and GFM, on absolute pressures in Odin (ΔP = 1 bar).

So we decided to represent in the model the pressure drop which was observed since 1977, which would be of the same order of magnitude as the pressure decline monitored by Esso:

ΔP Esso = 10 bars (ΔP gas = 9.2 b, ΔP cod = 10.3 b).
ΔP Model = 9 bars (ΔP gas = 8.6 b, ΔP cod = 9.3 b).

This matching was obtained by supressing the water influx from the Cod aquifer, in the cells below Odin. It remains rough but sufficient for our purpose. In addition, the gridding is not suitable to a precise description of Odin. Well cell dimensions here reach 1 700 m x 1 700 m, and the average cell pressure may differ significantly from the one recorded in the wells.

3.1.3. Frigg

As we said before, we already had a fairly good matching on Frigg without any correction. But supression of Cod active cells below Odin reinforced the local effect of Cod aquifer below Frigg. We then proceeded to an adjustment of its strength.

3.1.4. East Frigg/South East Frigg

The actual pressure in well 25/2-8 in the gas was 180.3 bars abs. at 1930 m MSL on 26.07.84. This value is about 2 bars lower than the one simulated by the GFM. The pressure drop was also underestimated in the Cod aquifer; the previous model gave a value about 4 bars higher than measured.

The adjustment were performed on the aquifer gas influx in the EF/SEF area.

COMMENTS

1. In October 1983, there are no significant differences in fluid transfers from satellites towards Frigg when comparing the GFM and the present model in spite of a major increase of their accumulations.

2. When comparing the remaining gas in place on the same date (October 1st, 1983), we find:

   GFM : 233 10^9 std m^3 (free gas)
   MGFM: 260 10^9 std m^3 (free gas)

3.2. Pressure and water rise match (Frigg Field)

The matching of the measurements available in the central part of the Frigg Field was based on

- Cod sand pressure history below Frigg, well 25/1-A22
- Cod sand pressure measurement below Frigg, well 10/1-A25
- Frigg sand pressure history CDP1 and CDP2
- Water rise measurement on 10/1-A25

The principles used as guidelines for the matching are the following:

1. In the Cod formation, the window of the barrier zone acts as a well, giving small horizontal pressure gradients just below it or far from it. High horizontal pressure gradients are present in the Cod formation in the border areas below the window.

2. Through the barrier, the water flows according to Darcy´s law between Cod and Frigg aquifers.

3. Due to point 1, the vertical dynamic gradients, between Cod and Frigg aquifer are strong when close to the window boundary (in platform area).

   In 10/1-A25, Δ P Cod/Frigg $\simeq$ 4 bars

The successive trials which were necessary to obtain a good match of the said matching parameters lead us to conclude that:

. to increase the water rise in location of 10/1-A25, the window in the barrier has to be partially below CDP1. A large window far away does not allow a match.

. For the same Kv a window close to the platforms needs a smaller area than one far away.

. A window with high Kv is necessarily of a limited extent and must be close to or directly below the platforms.

. Due to the pressure drop between Frigg and Cod aquifers, the window limit must be at the same distance from 25/1-A22 and 10/1-A25.

Two configurations of the window, in accordance with the two different hypotheses as regards its nature were found satisfactory to obtain a good match.

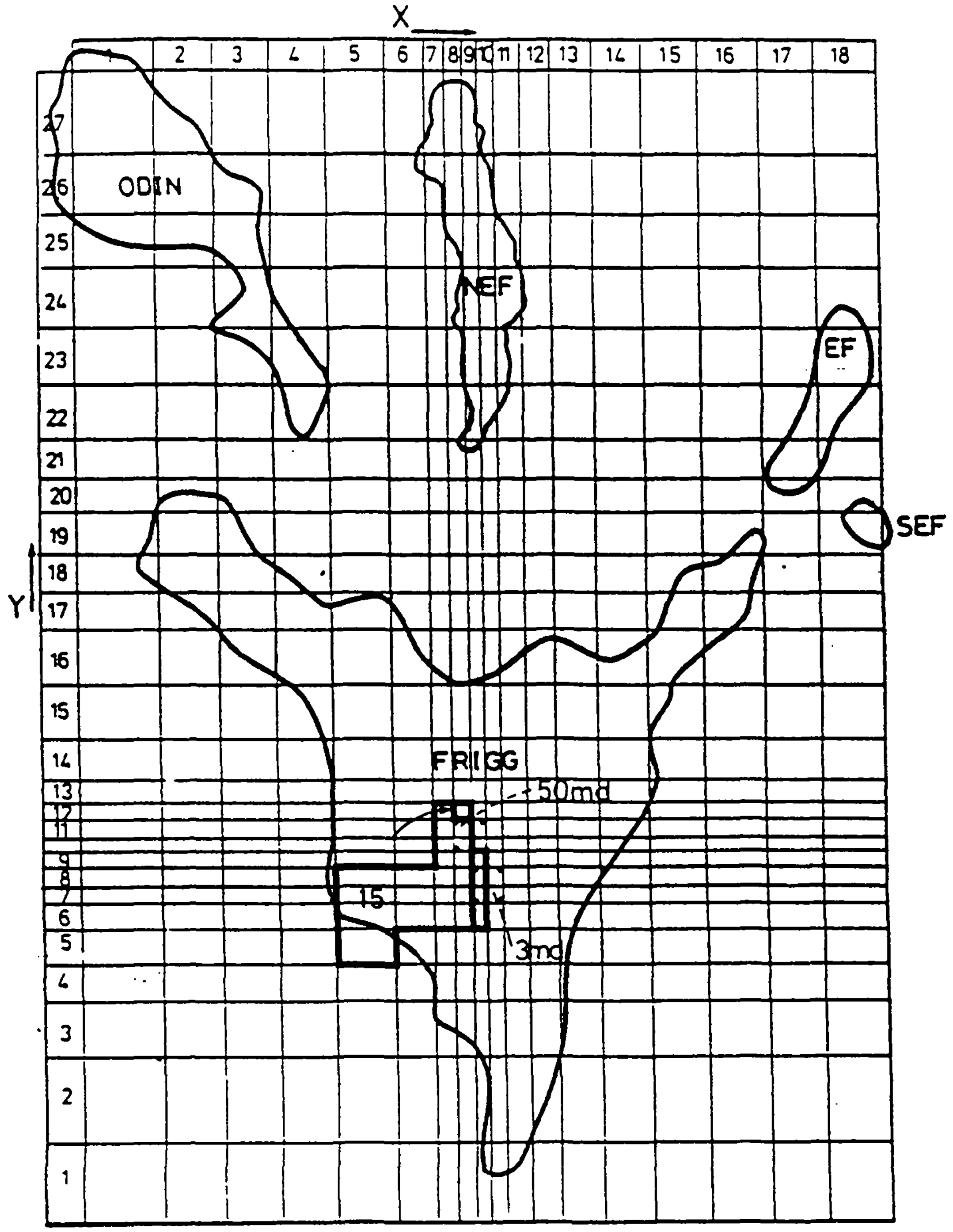
The western Window case (pl. 3) corresponds to the western window geological hypothesis (lower content of tuffitic material).

elf	Block / Licence 024 Operator ELF AQUITAINE NORGE Field: FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model

Western Window in the barrier

Attached to report no.	PL. 3	Date: NOV. 84
Title		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2		Filing no:



The south-eastern window case (pl. 4) correspond to the south-western geological hypothesis (lower barrier thickness).

The obtained matches are illustrated by the following plates:

a) Western window case:

pl. 5 . Pressure gradient in well 10/1-A25 on 17.08.84.
pl. 6 . Pressure evolution in Cod sands well 10/1-A22.
pl. 7 . Pressure evolution in gas bearing Frigg sand NEF.
pl. 8 . Pressure gradient in well 30/10-A4 on 01.01.84.
pl. 9 . Pressure gradient in well 25/2-8 on 26.07.84.
. Gas/liquid contact rise evolution in well 10/1-A25.*
. Gas/liquid contact rise evolution in well 25/1-A22.*

b) South-Eastern window case:

pl. 10 . Pressure evolution in Cod sands well 10/1-A22.
. Gas liquid contact rise in well 10/1-A25*.
. Gas liquid contact rise in well 25/1-A22*.

* These plates are presented with the predictives runs. The fluid rise in well 25/1-A22 is no longer representative due to the presence of shaly layers.

The vertical permeability of the window in each case is 15 md. The water rise on well 10/1-A25 is matched with the average values of cells X = 9, Y = 7 and X = 10, Y = 7.

In both cases, the matching is very sensitive to the shape of the window in the vicinity of the observation wells 25/1-A22 and 10/1-A25. The northernmost part of the window is in both cases justified by the matching of 25/1-A22 pressure gradient between Cod and Frigg aquifers.

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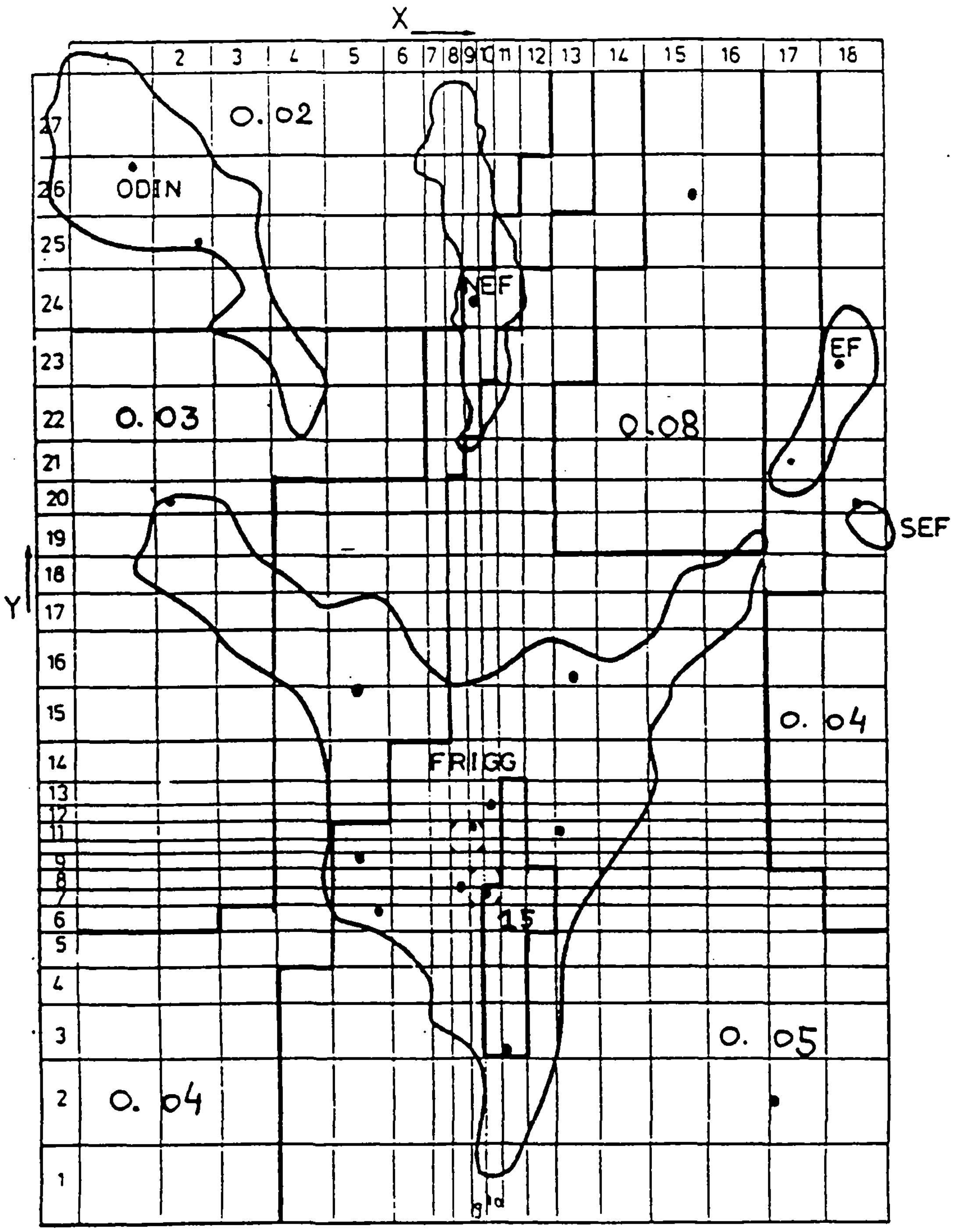
FRIGG AREA 1984 model
South Eastern Window
in the barrier

Attached to report no:	PL. 4	Date: NOV. 84
Title:		Author: J. P. L.
Author: ALAIN THOUAND		Drawing: L. N.
Original filing plan: FRIGG F SYN 2	Filing no:	

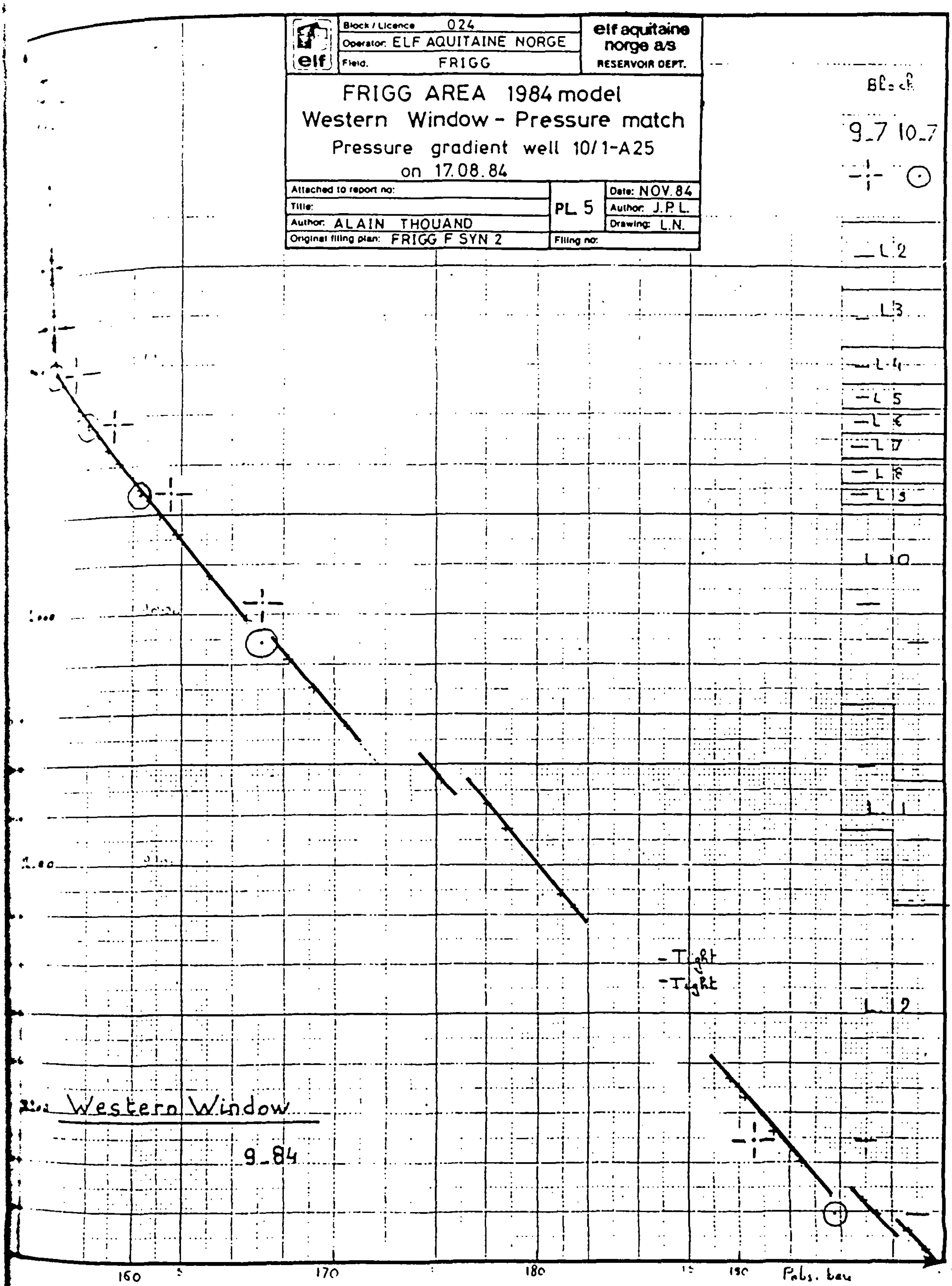
Kv barrier (md)



Block / Licence 024		elf aquitaine norge a/s
Operator: ELF AQUITAINE NORGE		RESERVOIR DEPT.
Field: FRIGG		

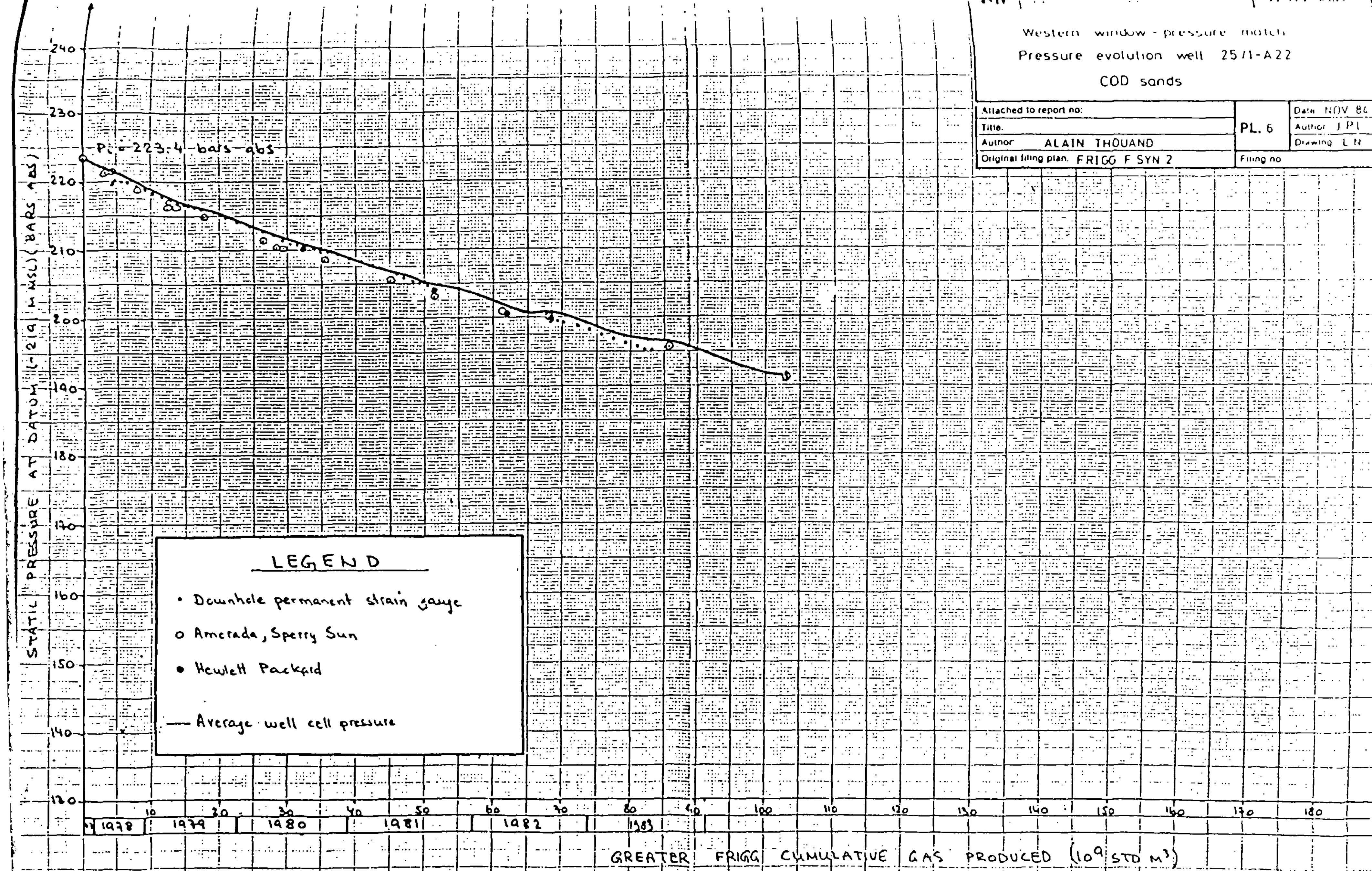
FRIGG AREA 1984 model
Western Window - Pressure match
Pressure gradient well 10/1-A25
on 17.08.84

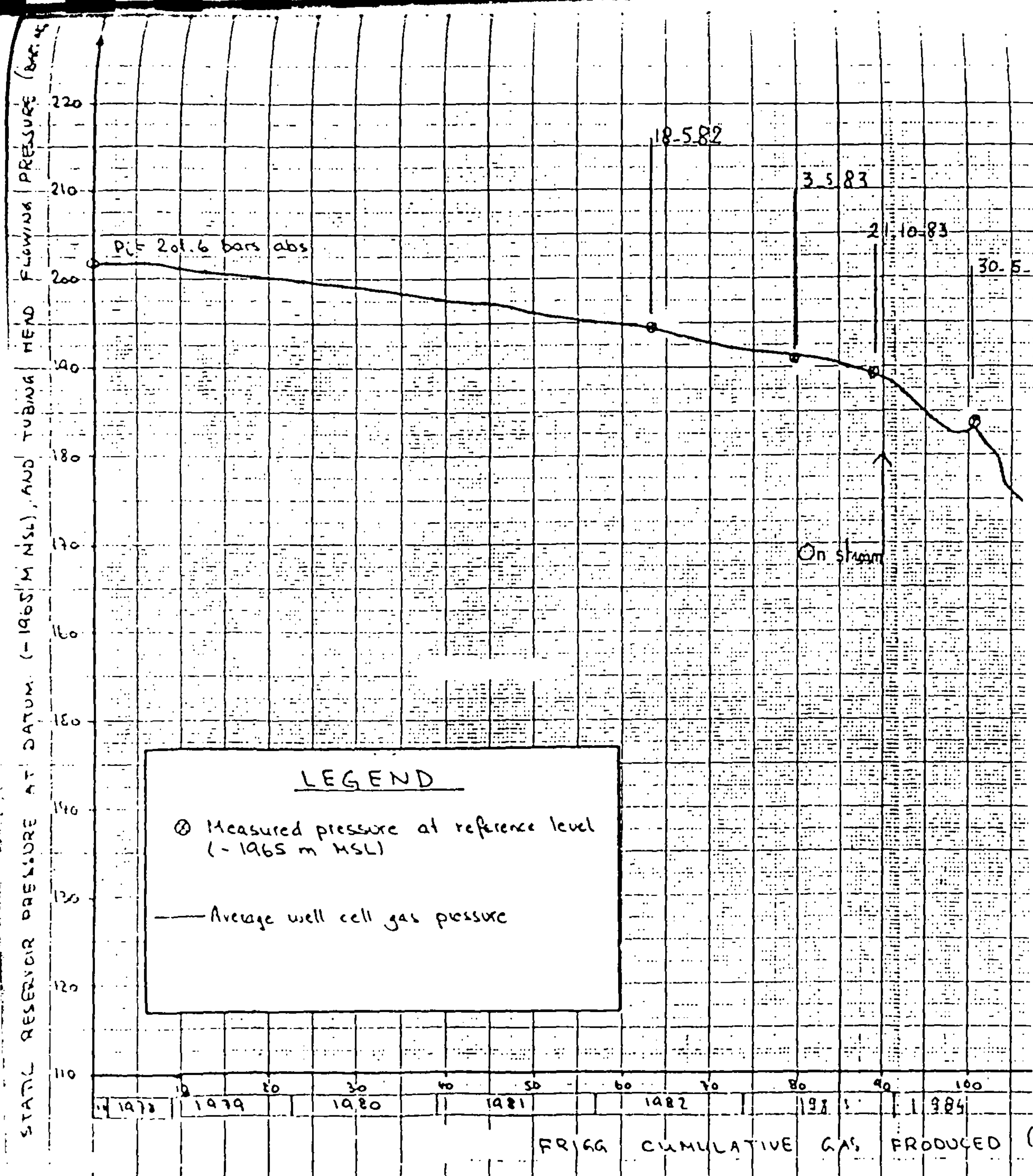
Attached to report no:	PL. 5	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2		Filing no:



Western window - pressure match
Pressure evolution well 25/1-A22
COD sands

Attached to report no:	PL. 6	Date NOV 84
Title.		Author J P L
Author ALAIN THOUAND		Drawing L N
Original filing plan. FRIGG F SYN 2		Filing no





elf

FRIGG AREA 1984 model

Western window - pressure match

NEF Pressure evolution

Attached to report no	PL. 7	Date NOV 84
Title		Author J.P.L.
Author ALAIN THOUAND		Drawing L.N.
Original filing plan. FRIGG F SYN 2		Filing no

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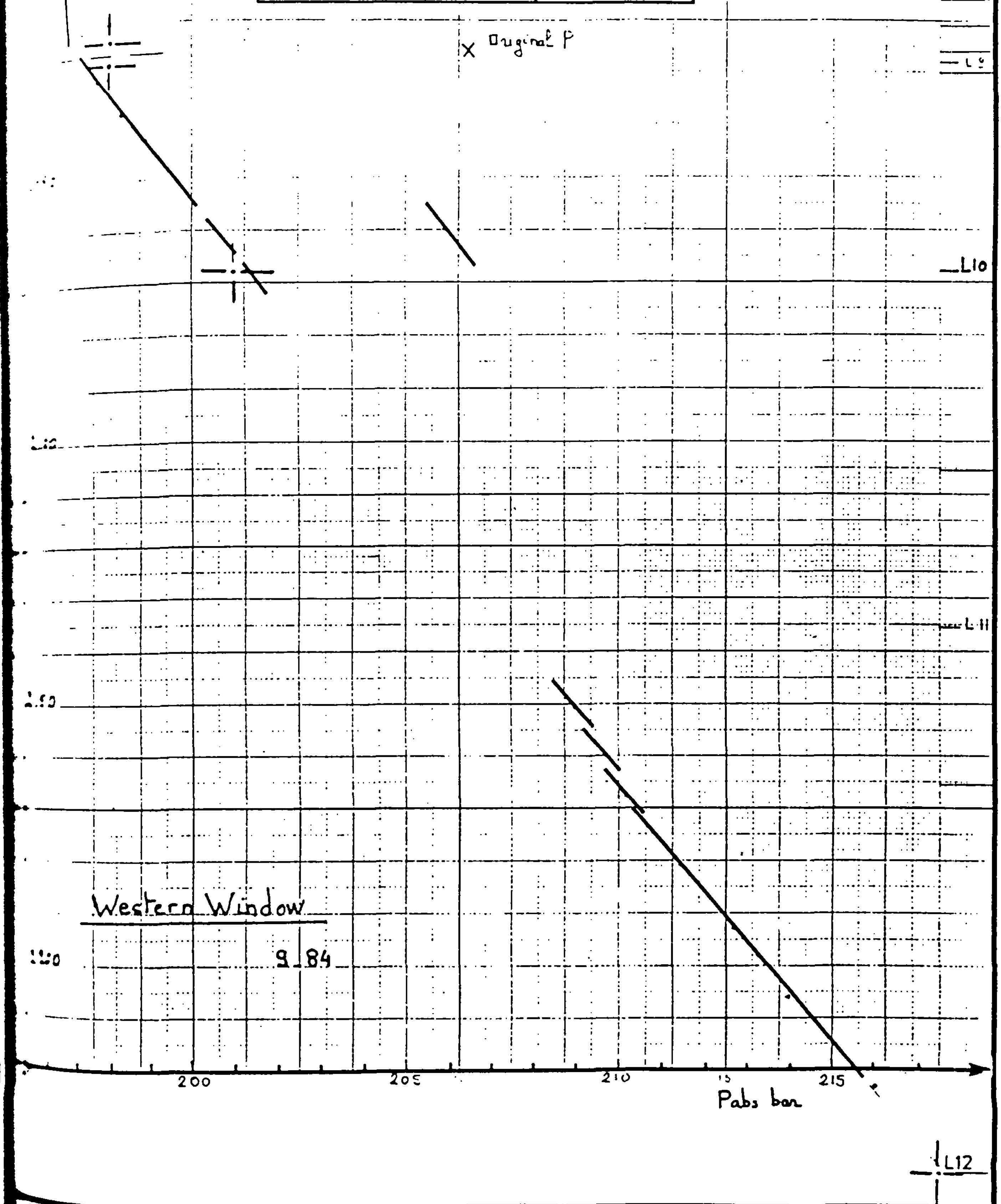
FRIGG AREA 1984 model

Western Window - Pressure match

Pressure gradient ODIN

Well 30/10-A4 on 01.01.1984

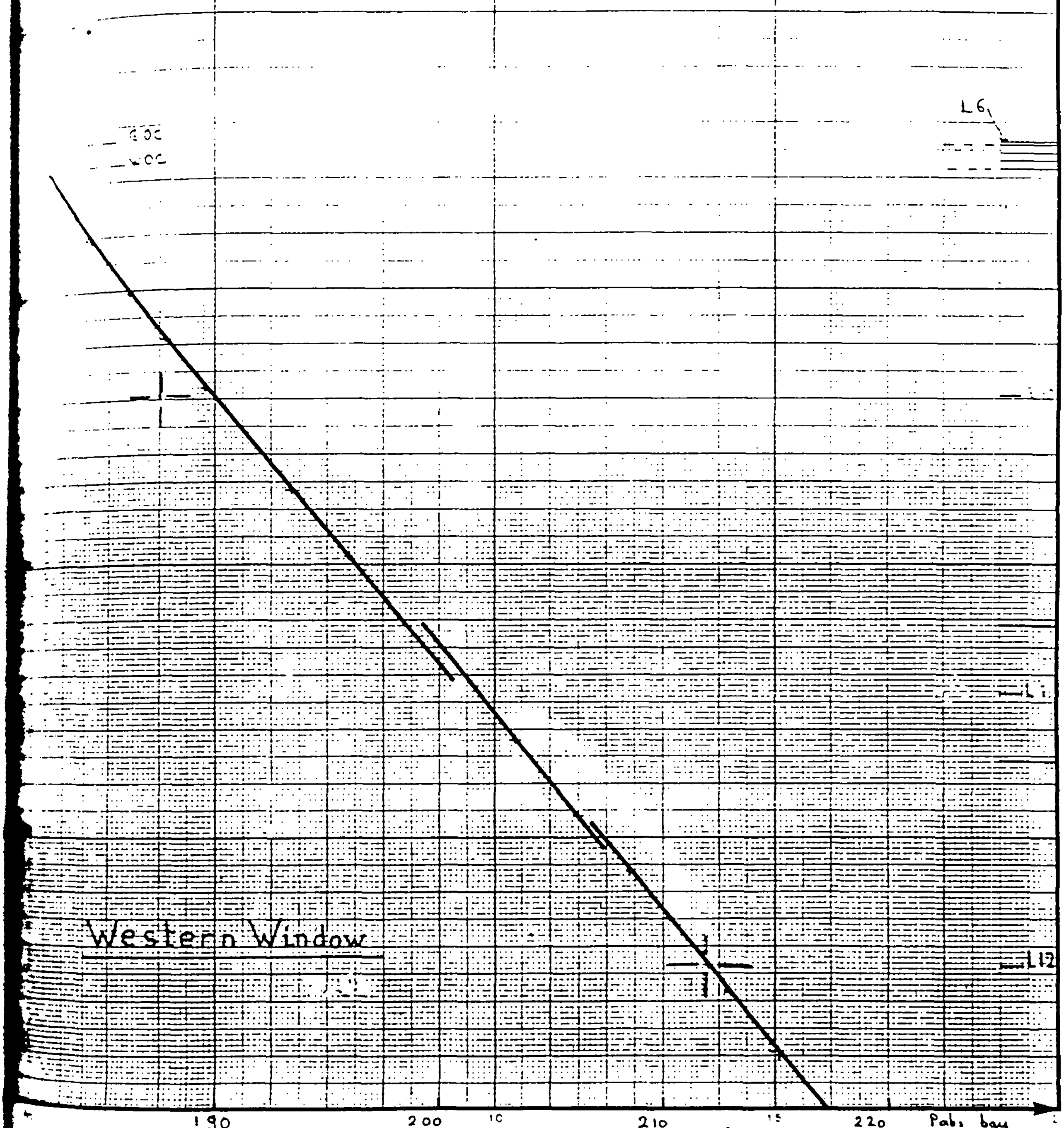
Attached to report no:	PL 8	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2		Filing no:

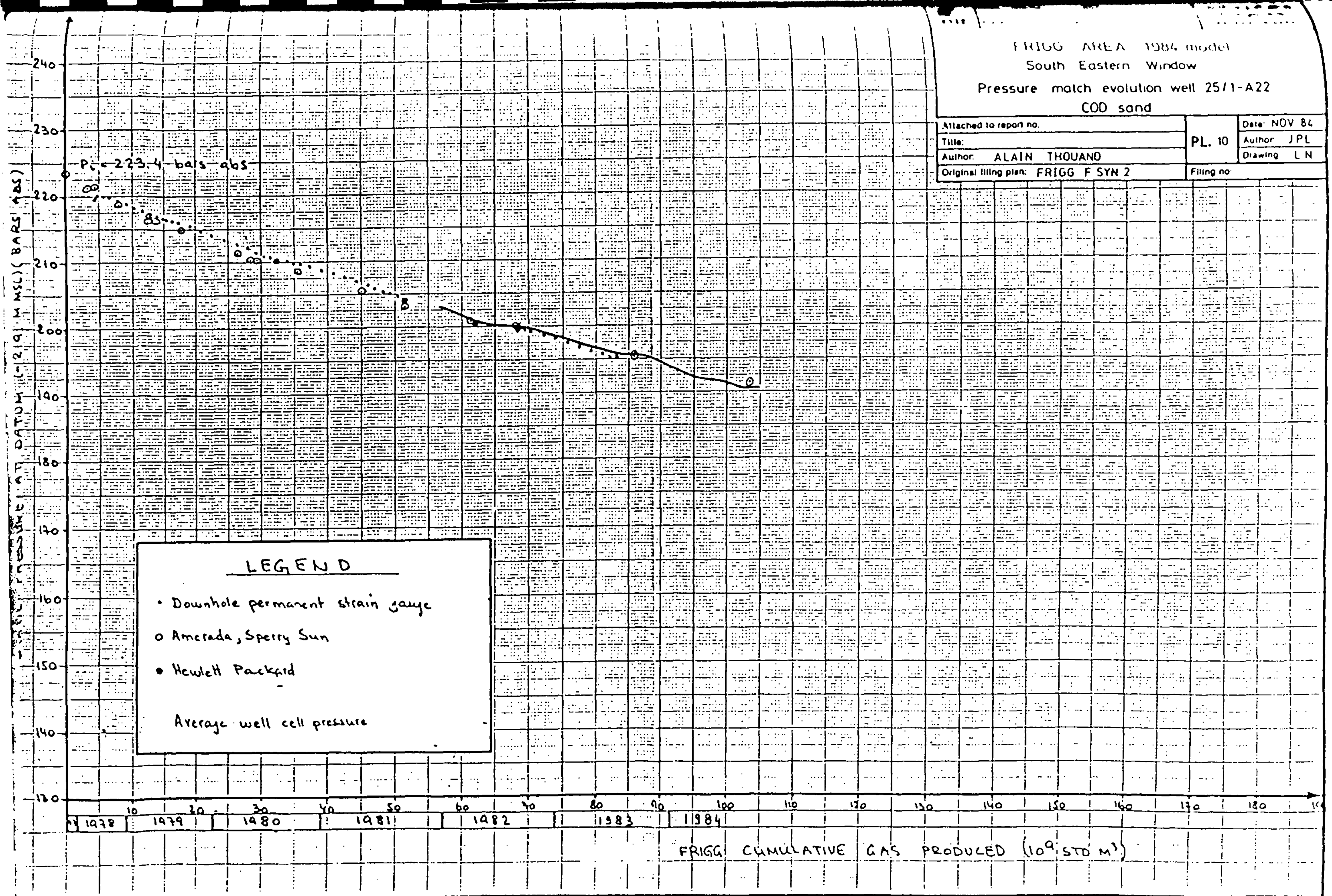


elf	Block / Licence: 024 Operator: ELF AQUITAINE NORGE Field: FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model
Western Window - Pressure match
Pressure gradient East Frigg
Well 25/2-8 on 26.07.1987

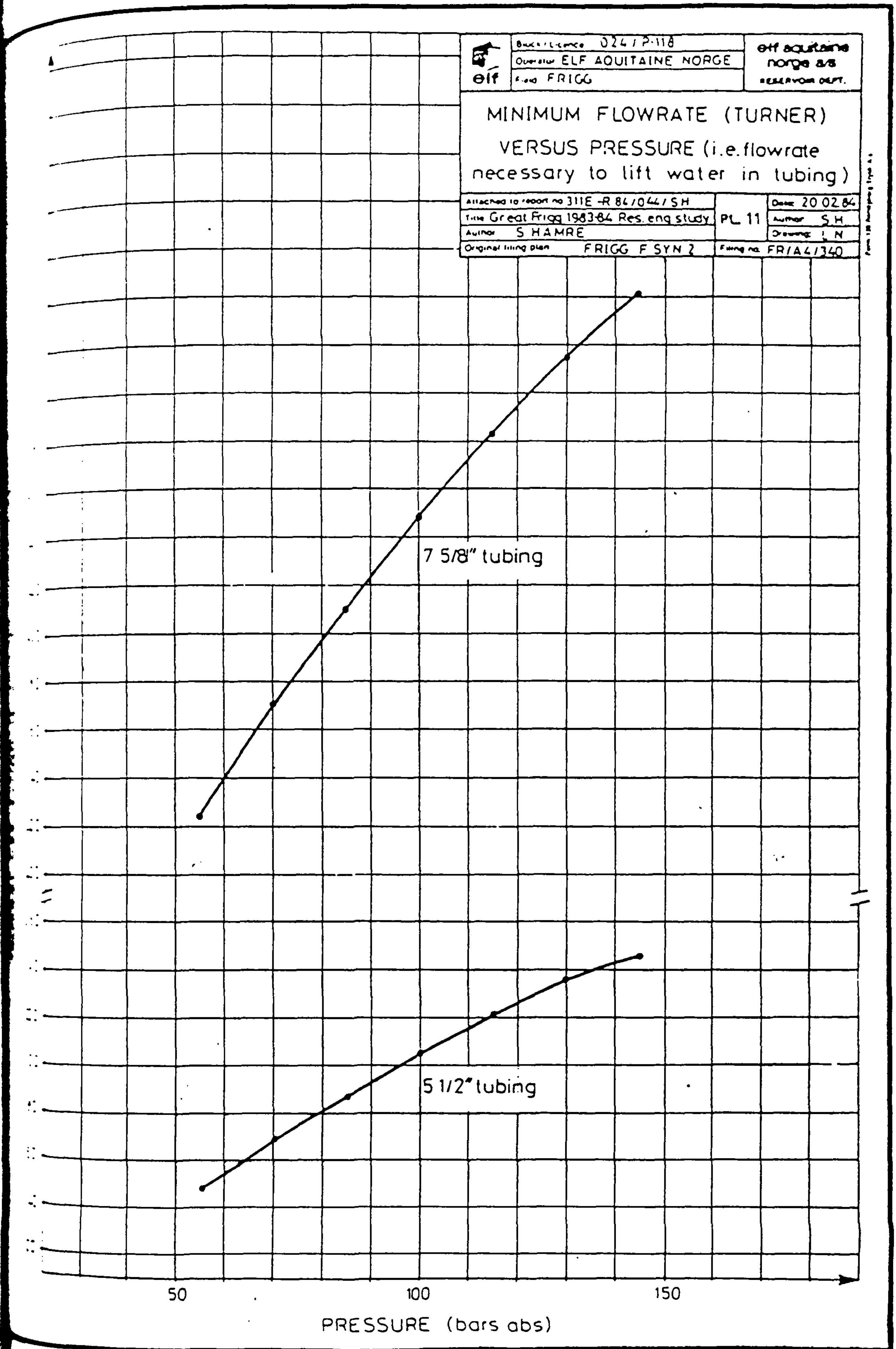
Attached to report no:	PL. 9	Date: NOV 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2	Filing no:	



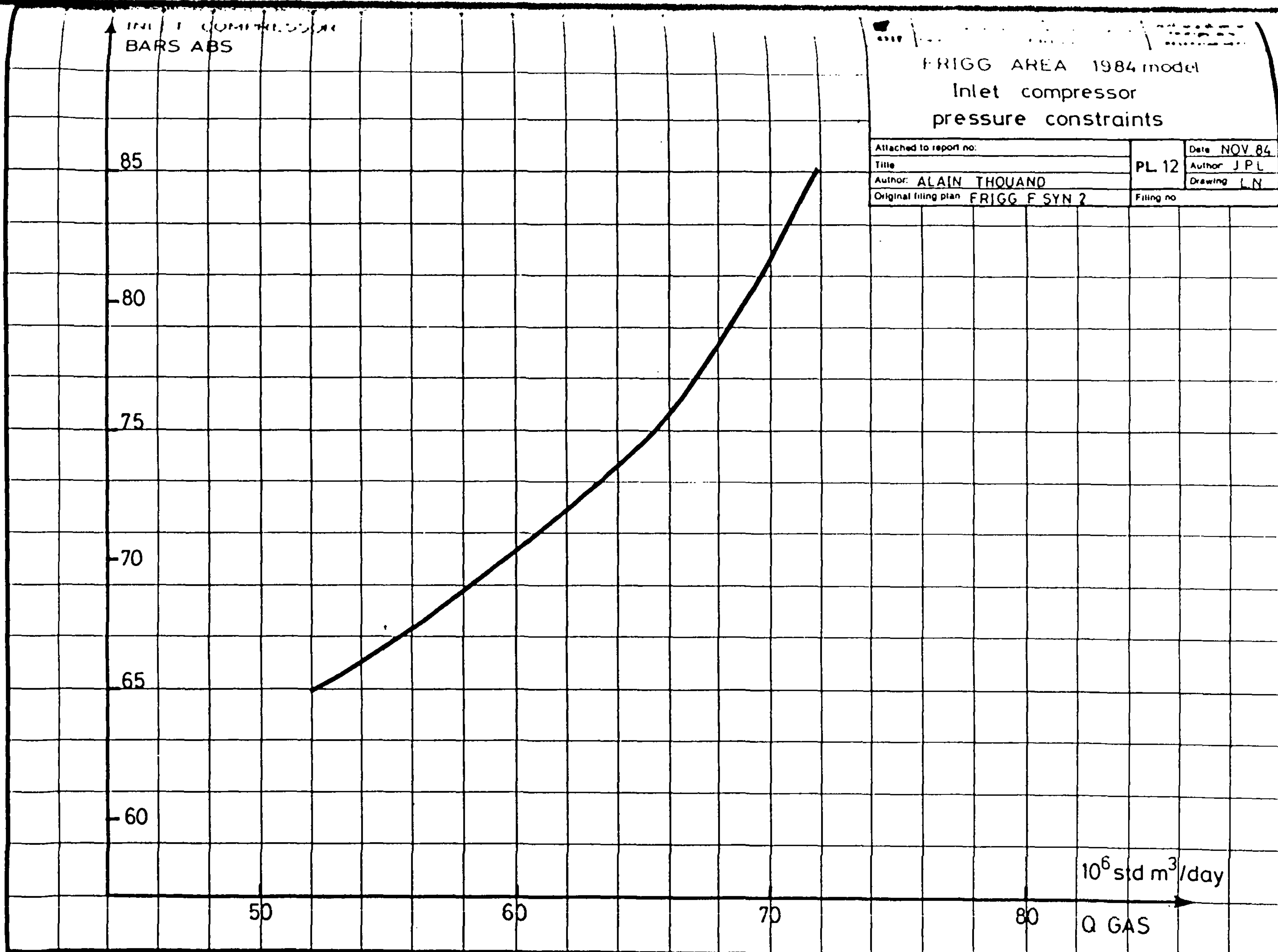


FRIGG AREA 1984 model
South Eastern Window
Pressure match evolution well 25/1-A22
COD sand
Attached to report no.
Title:
Author: ALAIN THOUAND
Original filing plan: FRIGG F SYN 2
PL. 10
Date: NOV 84
Author JPL
Drawing LN
Filing no:
Pi = 223.4 bars abs
LEGEND
• Downhole permanent strain gauge
o Amerada, Sperry Sun
• Hewlett Packard
Average well cell pressure
240
230
220
210
200
190
180
170
160
150
140
130
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
1978
1979
1980
1981
1982
1983
1984
FRIGG CUMULATIVE GAS PRODUCED (10^9 STD M^3)

The difference between these two matches can mainly be seen on the location of the water rise below CDP2. As well 10/1-5X is scheduled in the western side of CDP2 to check the actual water rise, the expected evolution of the water rise in that location is plotted for each simulation case in chapter 4. In October 1984 the water-rise is 32 m for the South Eastern Window case, it is 68 m for the Western Window case. As a preliminary consequence, the remaining gas will not be located in the same position for the two geological hypothesis and in the Western Window case, the water will reach at about the same time the producing wells of the two platforms.



Block-Licence 024/P.118
Operator ELF AQUITAINE NORGE
Field FRIGG
elf
elf aquitaine norge a/s
RESERVOIR DEPT.
MINIMUM FLOWRATE (TURNER) VERSUS PRESSURE (i.e. flowrate necessary to lift water in tubing)
Attached to report no 311E-R 84/044/SH
Title Great Frigg 1983-84 Res. eng study
Author S HAMRE
Original filing plan FRIGG F SYN 2
PL. 11
Date 20.02.84
Author S.H
Drawing L.N
Filing no. FR/A4/340
7 5/8" tubing
5 1/2" tubing
50
100
150
PRESSURE (bars abs)


INLET COMPRESSOR
BARS ABS
85
80
75
70
65
60
50
60
70
80
10^6 std m^3/day
Q GAS
FRIGG AREA 1984 model
Inlet compressor
pressure constraints
Attached to report no:
Title
Author: ALAIN THOUAND
Original filing plan FRIGG F SYN 2
PL 12
Filing no
Date NOV 84
Author J P L
Drawing L N

4. FORECAST: PRODUCTION SCHEMES

Preliminary remark

Limits of possible comparisons with the previous GFM results have to be noted:

1. Production rates on Odin, NEF and EF are significantly different.
2. Frigg fuel gas consumption is lower.
3. Piper/Tartan production and sales forecasts have been changed. Though P/T is not modelled, it interferes with Frigg DCQ (because of banking/debanking effects).
4. Constraints of Frigg production: one important limit in capability to sustain DCQ rate is pressure decline at the inlet compressor, the characteristics of which have been reviewed.

4.1. General constraints and hypotheses

As previously described, two models have been defined in order to match the water rise in well 10/1-A25, and are used as predictive tools. As they are similar but for the description of the window in the barrier, all common features are described herebelow. The features of each case are presented in the Results paragraph.

4.1.2. All fields

- Residual gas saturation = 29 %.
- Limited water production rates.
- No through screen gas velocity limit.
- No tubing head gas velocity limit.
- Pressure drops in sea-lines are calculated and taken into account for Frigg only.
- Wells are shut-in when the minimum gas flowrate to lift water is reached (Turner limit) (see plate no. 11).
- Capacity of Frigg St. Fergus pipe lines is 84.10^6 std m^3/day.
- A curve P mini inlet compressor/Q gas produced by all fields (minus consumption) determines the maximum permissible gas volume which can be compressed (see plate no. 12).

4.1.3. Frigg constraints

. As the present production facilities are not able to maintain the present DCQ during a long period, new production facilies are necessary. They are described with the results of the simulation.

. Frigg DCQ is with a swing factor:
1.3 from 1st October to 1st April.
0.835 from 1st April to 1st July.
0.57 from 1st July to 1st October.

. Fuel gas consumption depends on time and evolves according to table no. 1.

. Frigg production profile is calculated according to the banking agreements for NEF, Odin, Piper/Tartan and EF.

. Maximum water production is 20 m^3/day/model well as long as possible, then 250 m^3/day/platform, for the present facilities.

4.1.4. NEF constraints

. NEF contractual DCQ is 2.2 10^6 std m^3/day with the same swing factor as Frigg.

. NEF is put on stream from 01.10.83 and is producing at a constant rate of 7 10^6 std m^3/day from 01.08.84.

. Maximum water production is 20 m^3/day.

. A minimum gas flowrate of 1.6 10^6 std m^3/day is necessary to lift water slugs in TCP2 riser.

FRIGG FIELD FUEL GAS CONSUMPTION

FROM 01/10	84 85	85 86	86 87	87 88	88 89	89 90	90 91	91 92	92 93
October to March	0.67	0.69	0.71	0.71	0.79	0.79	0.79	0.13	0.13
April to June	0.17	0.17	0.28	0.39	0.39	0.39	0.18	0.13	0.13
July to September	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.13	0.13

(10^6 std m^3/day)

Annual consumption	153	157	170	181	195	195	176	48	38

(10^6 std m^3/day)

Table n° 1

4.1.5. Odin constraints

. Field production/deliverability/sales quantities are in strict accordance with the note 311E-R 82/214/MB dated 29.10.82, and are presented in table no. 2.

. Odin is put on stream on 01.10.84, with one model well.

. No pressure constraint (P TCP2) has been set into the model.

. Maximum water production is 20 m^3/day. In the model, when this level is reached, we put on production another well, in an adjacent cell, and close to the first one. This cell happens to still have its initial gas saturation.

The problem comes from the gridding; size of the northern cells can reach 2.5 km x 2.5 km and do not allow a proper positionning for model well.

. A minimum gas flow-rate (2.5 10^6 std m^3/day) is necessary to lift water slugs in TCP2 riser.

4.1.6. East Frigg and South East Frigg

. East Frigg and South East Frigg production and sales are taken into account for calculation of Frigg rate (banking/debanking effect) forecasted rates appear in table no. 3.

. No special constraint has been introduced for the fields (when developed) except on water: 20 m^3/day/field.

4.1.7. Piper/Tartan

. P/T production and sales are taken into account for calculation of Frigg rate (banking/debanking effects). Forecasted rates appear in table no. 4; the same swing factor as on Frigg is applied. (table 4 is given for the sake of complitness; it does no longer reflect the present forecasts).

ODIN FIELD - PRODUCTION AND DELIVERIES
BEFORE RUNNING THE MODEL

	FROM 01/10	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92	92-93	TOTAL
SALES	DCQ (10^6 std m³/day)	7.65	7.65	7.65	7.65	7.65	7.65	5.20	4.03	3.22	2.52	
	YCQ (10^6 std m³/day)	2 792	2 792	2 792	2 792	2 792	2 792	1 899	1 471	1 176	920	22 220
DELIVERY	DCQ (10^6 std m³/day)		10.19	10.19	10.19	9.28	7.08	5.29	4.10	3.28	2.89	
	YCQ (10^6 std m³/day)		3 719	3 719	3 719	3 388	2 584	1 931	1 497	1 197	525 [2]	22 276
PRODUCTION	DCQ (10^6 std m³/day)		10.24	10.24	10.24	9.33	7.12	5.32	4.12	3.30	2.90	
	YCQ (10^6 std m³/day)		3 739	3 739	3 739	3 739	2 598	1 492	1 505	1 203	529	22 400

(1) FROM NOTE "FRIGG FIELD 1982 REMODELIZATION - PRODUCTION CONSTRAINTS FOR PREVISIONAL RUNS" (REF. 311E - R82/214/MB - SOURCE : DGN).

(2) CONTRACTUAL END 30.03.1993.

Table n°2

EF/SEF : IMPOSED SALES AND PRODUCTION RATES

FROM 01/10		86 87	87 88	88 89	89 90	90 91	91 92	92 93	93 94
Sales	DCQ (10^6 std m^3/d)	2.5	2.5	2.5	2,5	2,5	2.5	2.5	2.5
	ACQ (10^6 std m^3)	912	912	912	912	912	912	912	912
PRODUCTION	DCQ (10^6 std m^3/d)	0	0	5	5	2.5	2.5	2.5	2.5
	ACQ (10^6std m^3/d)	0	0	1825	1825	912	912	912	912

. In these runs Frigg debanks Piper/Tartan an additional 2.5 10^9 std m^3 from 01.10.86 to 10.10.88. Modulation appears in table no. 5, this again is just one possible scenario.

. We do not have an exact balance between sales and production for P/T versus Frigg. It is the only exception: for all satellite fields, quantities produced in advance by Frigg are reimbursed by each field at the end of its life.

REMARKS

As an addition, the pressure loss calculations on Frigg and the applied swing factor for every field are given in tables no. 6 and no. 7.

4.2. Results

4.2.1. Preliminary simulation

In order to obtain a good idea of the location of the gas bubble which is supposed to be bigger now than the one found in previous simulation studies, preliminary runs were performed with only the present production facilities.

Sout Easter Windown Case 1 (SEW 1)

Main features:

- Present production facilities

Main events (summary of this case table no. 8)
- 01.01.87 BT on CDP1
- 01.01.89 BT on DP2
- 15-05-89 CDP1 platform is shut in.
- 01-10-89 End f DCQ.

Table n°5

PIPER/TARTAN : FRIGG ADDITIONAL DEBANKING

FROM TO	01.10.86 01.10.87	01.10.87 15.02.88	15.02.88 01.10.88	TOTAL 10^9 std m^3
SALES	5.3	2.8	0.8	2.50
DCQ (10^6 std m^3)				
Swing factor	1.1/0.945/0.857	1.0	1.0	

Table n° 6

PRESSURE LOSS CALCULATIONS ON FRIGG

1 - BOTTOM HOLE ———> TUBING HEAD

ΔP_1 according to tables

$\Delta P_{THP} = P_{BHP} - \Delta P_1$

2 - TUBING HEAD ———> CHOKE MANIFOLD

$$\Delta P_2 = \frac{Q \text{ model well}}{0.888}^2 \frac{1}{P_{THP}}$$

$P \text{ manifold} = P_{THP} - \Delta P_2$

3 - CHOKE MANIFOLD ———> INLET COMPRESSOR

$$\Delta P_3 = \left(\frac{Q \text{ FRIGG}}{3.322}\right)^2 \frac{1}{P \text{ Manifold}} \qquad Q_{CDP1} > 10^7 \text{ std m}^3\text{/day}$$

$$\Delta P_3 = \left(\frac{Q \text{ FRIGG}}{2.58}\right)^2 \frac{1}{P \text{ Manifold}} \qquad Q_{CDP1} < 10^7 \text{ std m}^3\text{/day}$$

P inlet compressor : $P_{BHP} - \Delta P_1 - \Delta P_2 - \Delta P_3$

P inlet compressor and $Q_{Frigg + satellites}$ have to be compatible with the compressor curve. If not, we have to reduce Q_{Frigg} flow rate until we reach adequate flow.

Table no 8

FRIGG FIELD

SOUTH–EASTERN WINDOW CASE SEW1

MAIN RESULTS AND EVENTS

DATE	GAS RATE	CUM GAS	P GAS	EVENTS
1–01–87	60.3	137.6	147.4	BT CDP1–3
7–11	64.2	151.1		SHUTIN CDP1–3
1– 1–88	64.2	154.6	140.7	BT CDP1–2,4
1–04	62.4	160.4	137.5	BT CDP1–1
15–04	62.4	161.3		SHUTIN CDP1–4
2–09	23.6	162.8		SHUTIN CDP1–2
1–01–89	64.9	171.9	133.5	BT DP2–7;WO CDP1–1 END OF PLATEAU RATE
1–03	64.9	175.8		BT DP2–8
1–04	64.9	177.8	129.9	BT RCDP1–1
18–05	40.4	178.9		SHUTIN RCDP1–1 ;END CDP1
1–07	40.4	181.4	128.9	SHUTIN DP2–7,BT DP2–5
1–08	26.6	182.3		BT DP2–6
18–08	26.6	182.8		SHUTIN DP2–8
1–10–89	26.6	183.9	129.2	Qw DP2=160M3/D 2 WELLS PRODUCING . END OF PLATEAU RATE .

UNITS;GAS RATE :10^6 STD M3/D;CUM GAS : 10^9 STD M3;P GAS : BARS ABS

Cumulative production = 183.9 10^9 m^3. Only two model wells are still producing on DP2.

This run was not continued after 01-10-89 but only a very small amount of gas could have been produced from the last wells. The main part of the remaining free gas is located north of DP2 (pl. no. 13).

Following plates are attached:

Pl. no.14 - Gas liquid rise: expected evolution at well 10/1-A25

Pl. no.15 - " " " " " " " 25/1-A22

Western Windown Case 1 (WW 1)

Main features:

- present production facilities

Cumulative production 157.9 G $stdm^3$

This case was also stopped after the date of the end of plateau rate. The remaining free gas, due to the location of the water influx is extended in a large area (pl. no. 16) mainly in the eastern side of the present platforms but also in a part of the bubble location of case SEW 1.

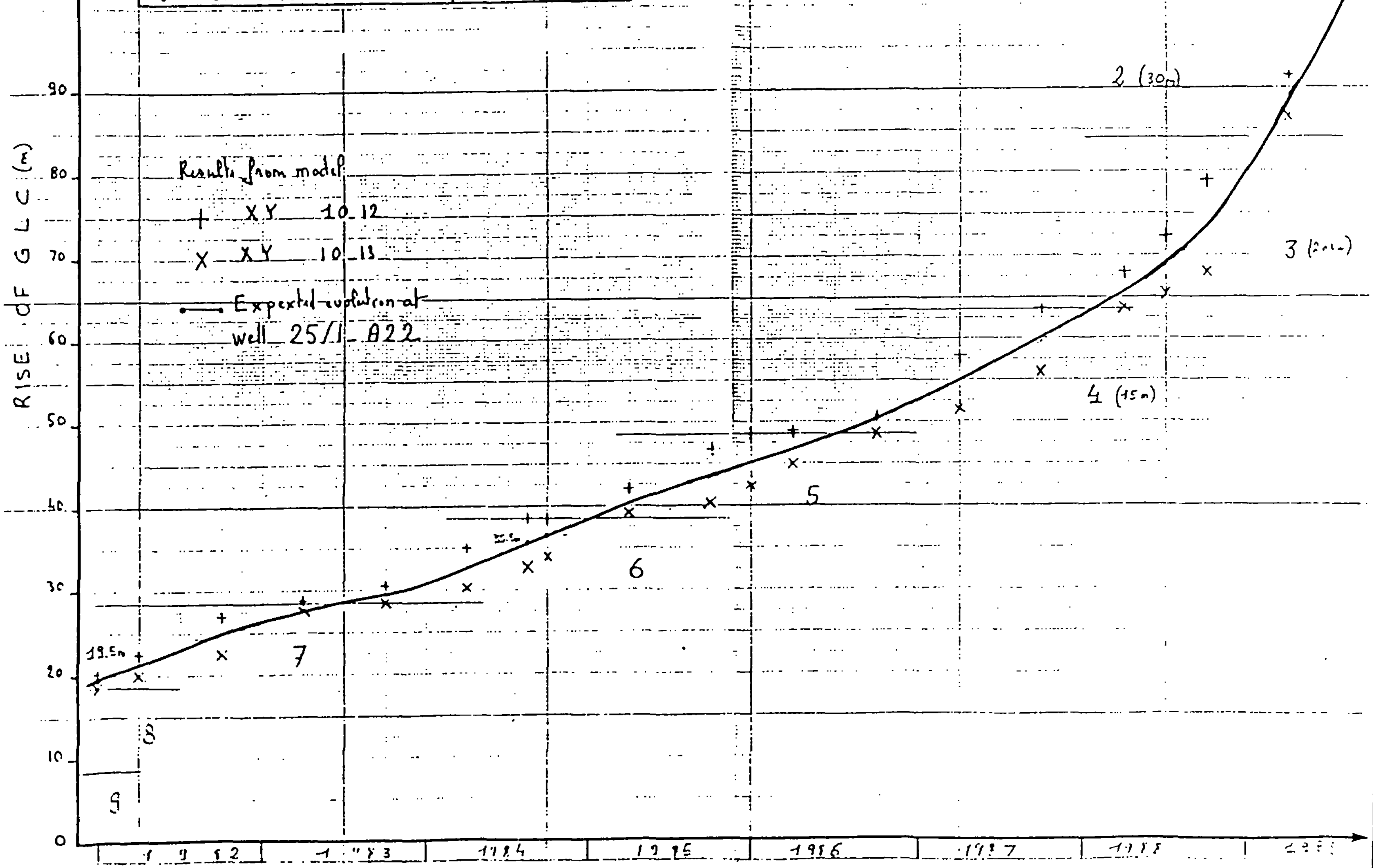
elf	Licence: 026 Operator: ELF AQUITAINE NORGE Field: FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model

South Eastern Window (Case SEW 1)

Water rise at well 25/1-A22

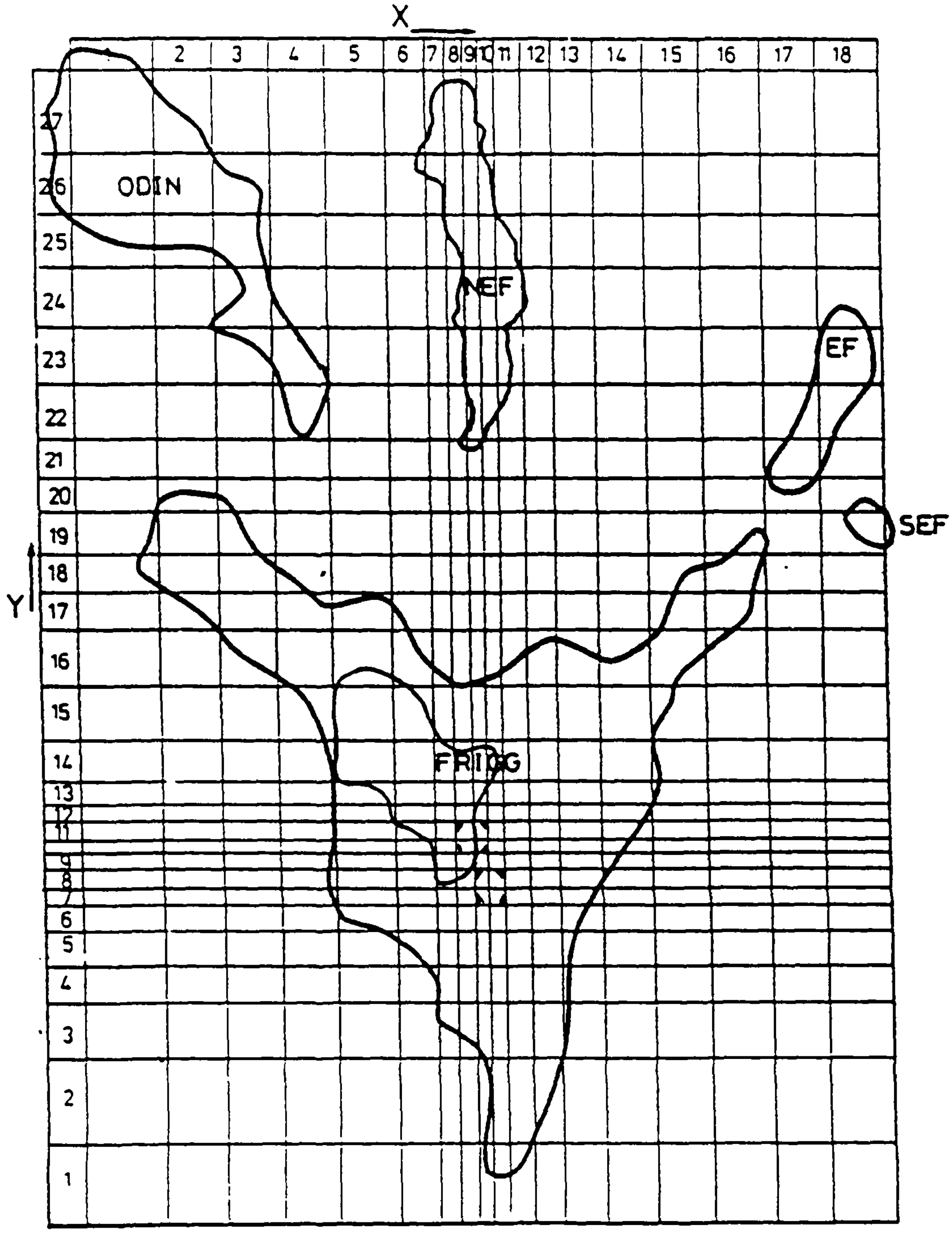
Attached to report no:	PL. 15	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2		Filing no:



elf	Block / Licence 024 Operator ELF AQUITAINE NORGE Field FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model
South Eastern Window
Remaining free gas on 01.10.1988
over 40m gas hight area

Attached to report no.	PL 13	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2	Filing no:	



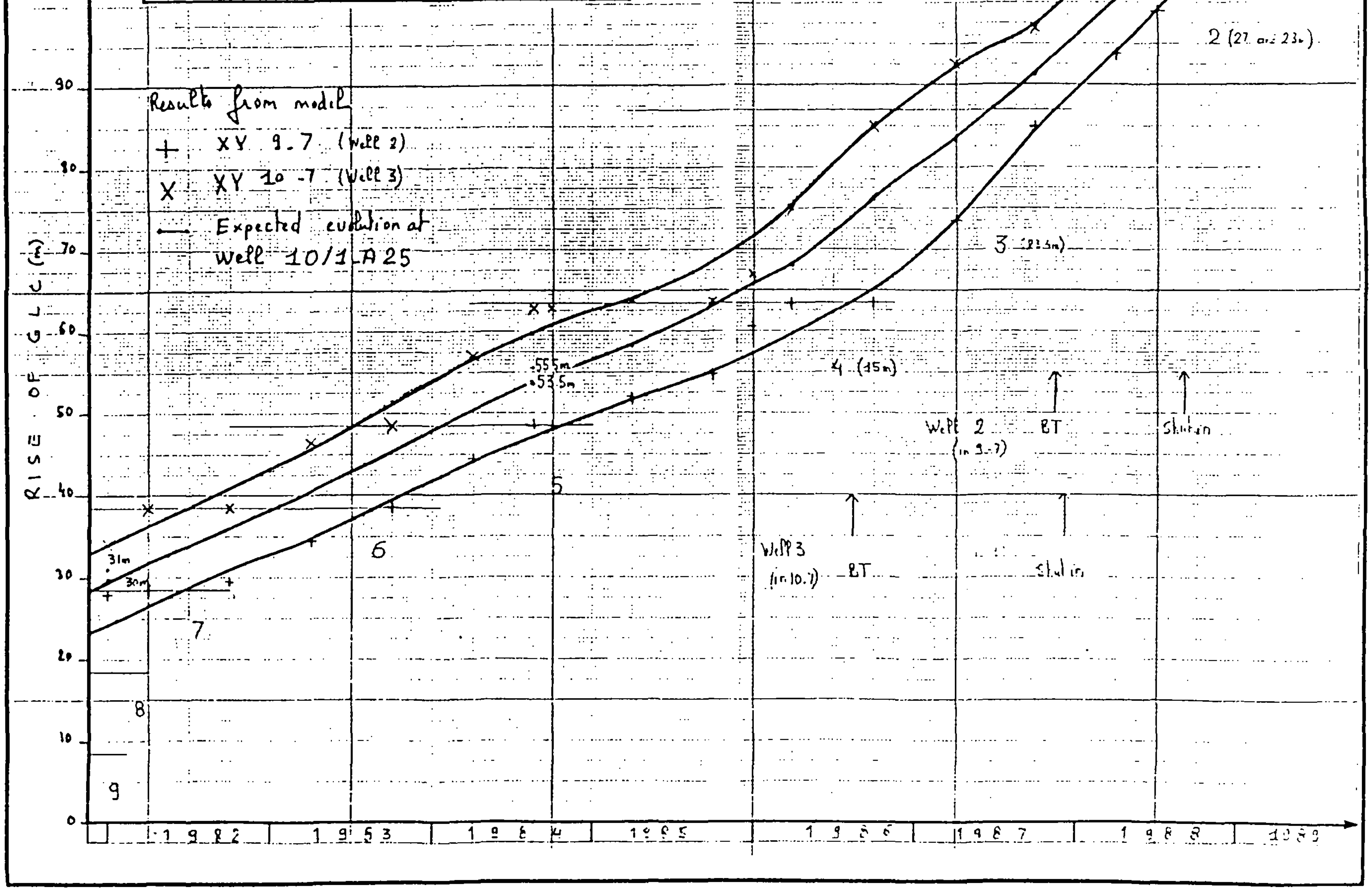
[redacted] elf	Block / Licence: 024 Operator: [redacted]F AQ[redacted]NE [redacted] Field: FRIGG	[redacted] norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model

South Eastern Window Case SEW 1

Water rise at well 10/1-A25

Attached to report no: Title: Author: ALAIN THOUAND Original filing plan: FRIGG F SYN 2	PL. 14 Filing no:	Date: NOV 84 Author: J.P.L Drawing: L.N

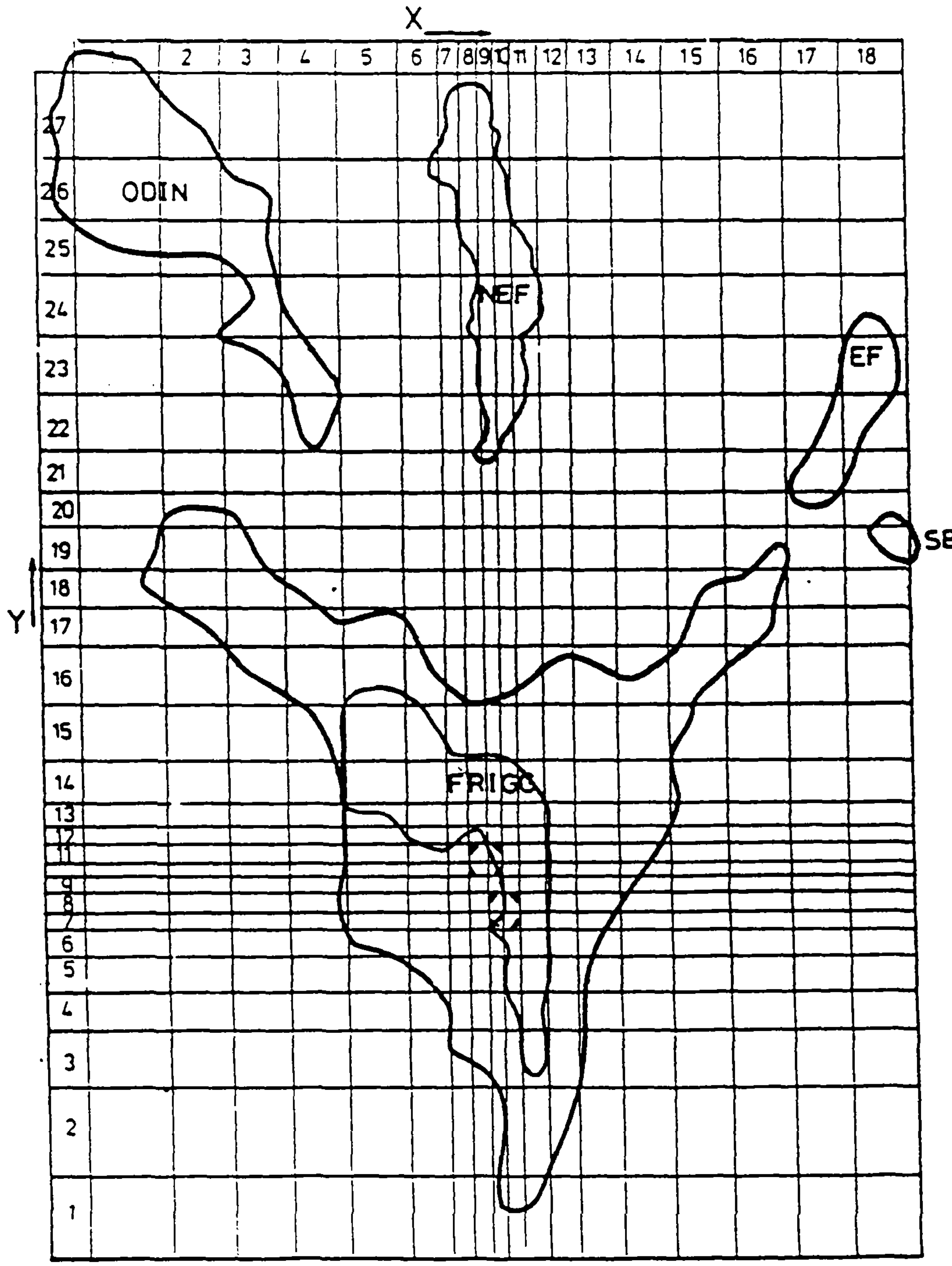


Block / Licence 024
Operator ELF AQUITAINE NORGE
Field. FRIGG

elf aquitaine norge a/s
RESERVOIR DEPT.

FRIGG AREA 1984 model
Western Window
Remaining free gas on 01.10.1988 over 40m gas hight area

Attached to report no:	PL. 16	Date: NOV.84
Title.		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2	Filing no:	



4.2.2. Comparison with other simulations

Cases SEW 1 and WW 1 can be directly compared with a previous simulation, done in spring 1984 where results of 10/1-A25 were not available. This reference case is case BB in report "Greater Frigg - 1983 - 1984 Reservoir Engineering study. Predictions (as of April 1984) ref. 311E-R 84/093/SH/JPL/meø". The difference between this reference case and those which are run now is in the barrier. As the pressure behaviour is not invalidated by the last field data, the recovery might be the same if the same sweeping efficiency is reached during the same period.

The cumulative production of the reference case is 204,5 G stdm^3 without producing the small "bubble" evidenced in that case. It can be assumed that with a proper complementary development including new wells in appropriate position, a comparable recovery could be achieved.

A tentative schedule has been constructed for new production facilities which could be available to continue Frigg Field production at the end of the present facilities. It is described in table no. 10.

However, the two following cases were run without this schedule.

4.2.3. Simulations with new production facilities

For the purpose of the model, new production facilities are classified in three categories:

- Deviated work over (DWO) wells from existing platforms, to produce remaining gas close to the present platform (offset = 1200 m)
- Sub sea Cluster (SSC) wells: to produce with only a few wells away from the platforms
- DP3 platform, used when a large number of wells are needed in a specific area (offset = 2500 m).

Production constraints which apply are water production limit which is 20 m^3/d for SSC and 250 m^3/d for DP3.

Possible new production facilities

1) On CDP 1 and DP2

- workover on present wells:

  2 per platform/year from 1985

- Deviated workover from present wells:
  number of wells available per platform

1	01.10.86
1	01.10.87
1	01.10.88
1	01.02.89
1	01.06.89
1	01.10.89
6 wells	

2) On well locations away from CDP1 and DP2

6 wells	01.10.88
8 wells	01.10.89
6 wells	01.10.90
20 wells	

O [redacted] ELF [redacted] AIN [redacted] GE [redacted] elf aquitaine norg [redacted]

elf | Field: FRIGG | RESERVOIR DEPT.

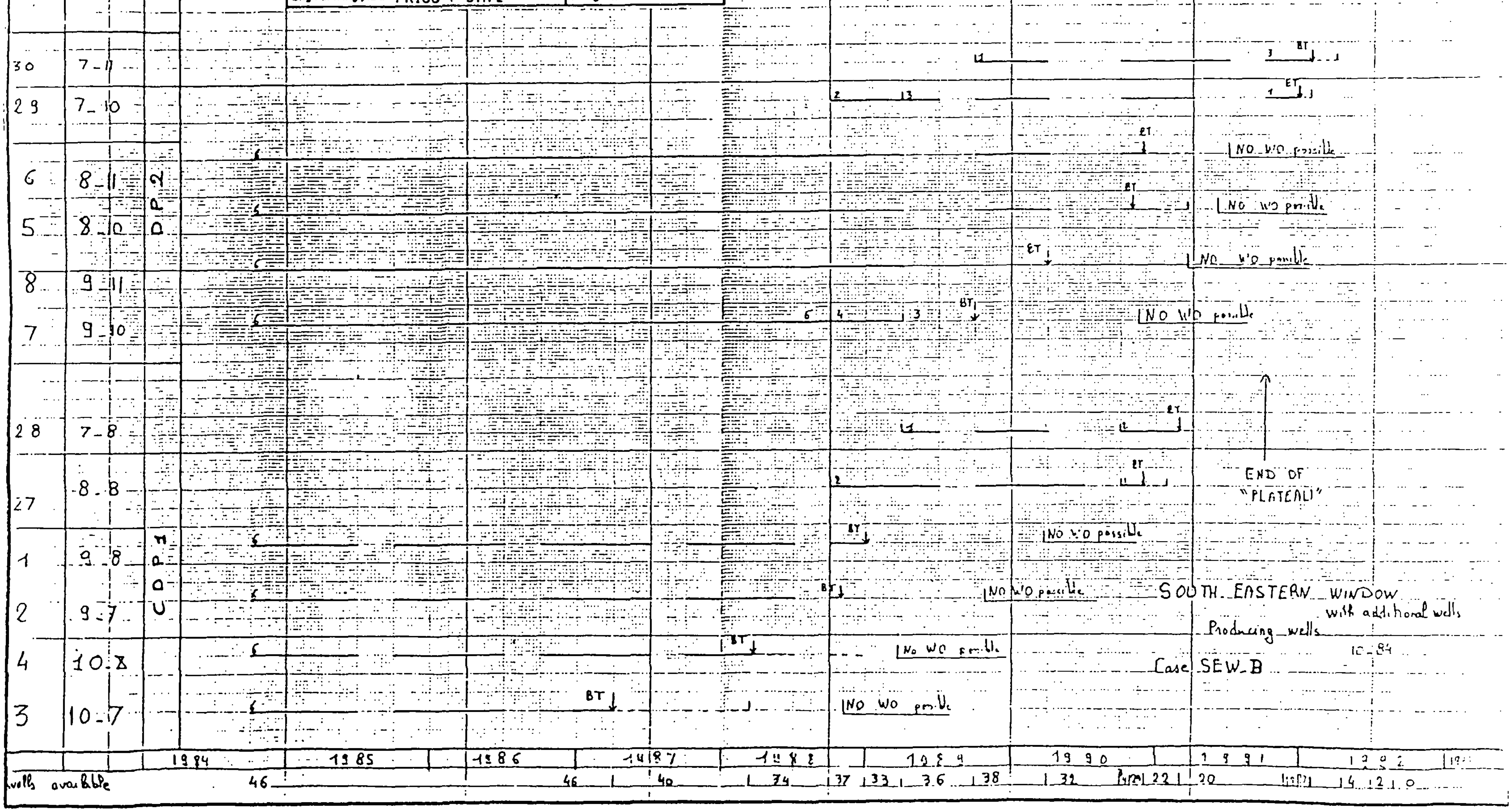
FRIGG AREA 1984 model

Case SEW 2

Production facilities

(producing wells)

Attached to report no:	PL. 17	Date: NOV 84
Title:		Author: J P L
Author: ALAIN THOUAND		Drawing: L N.
Original filing plan: FRIGG F SYN 2	Filing no:	



elf

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Operator: ELF AQUITAINE NORGE
Field: FRIGG

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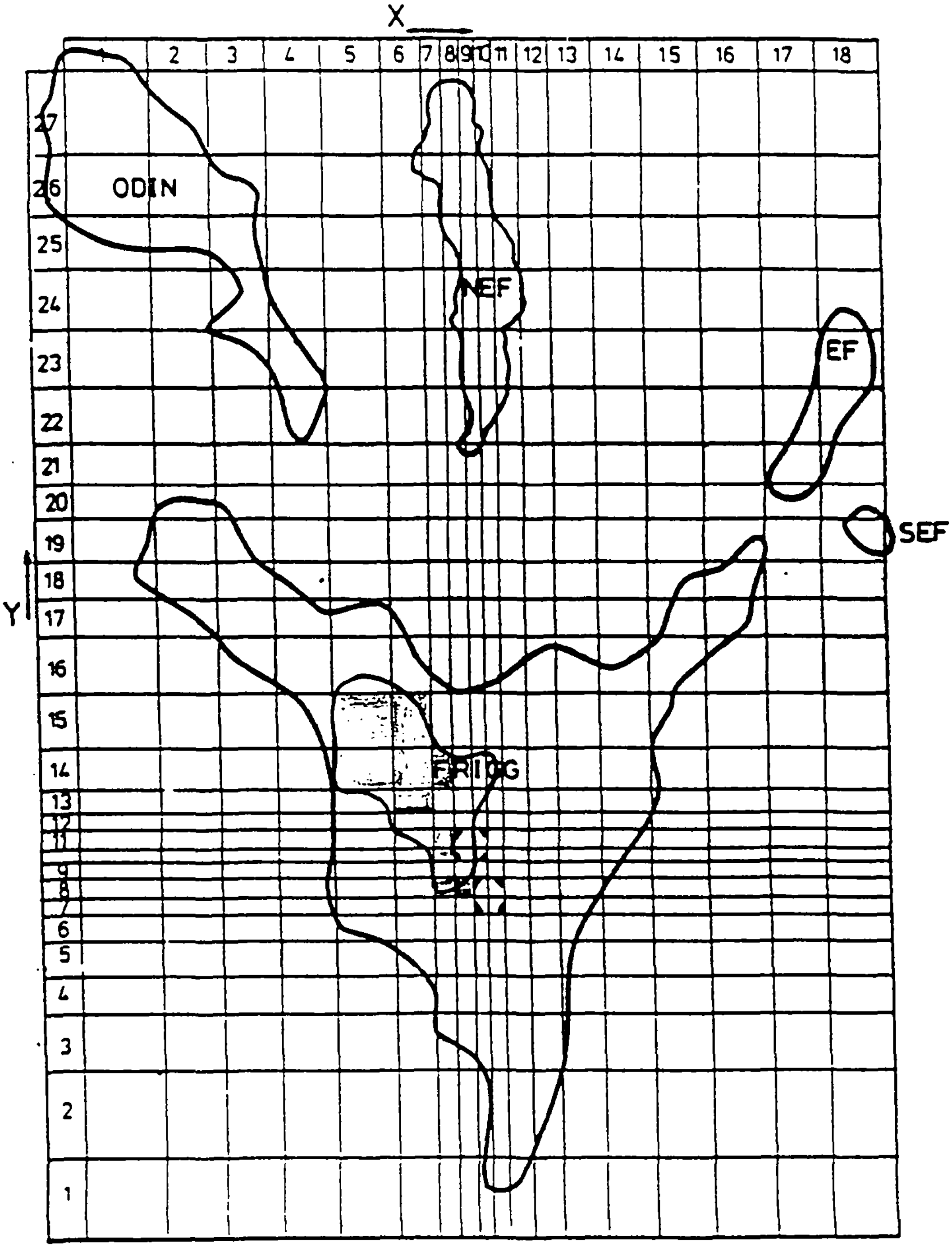
RESERVOIR DEPT.

FRIGG AREA 1984 model

Case SEW 2

Production facilities (map)

Attached to report no.	PL 18	Date: NOV 84
Title:		Author: J P L.
Author: ALAIN THOUAND		Drawing: L N
Original filing plan: FRIGG F SYN 2	Filing no:	



Licence ... 024

Operator: ELF AQUITAINE NORGE

Field: FRIGG

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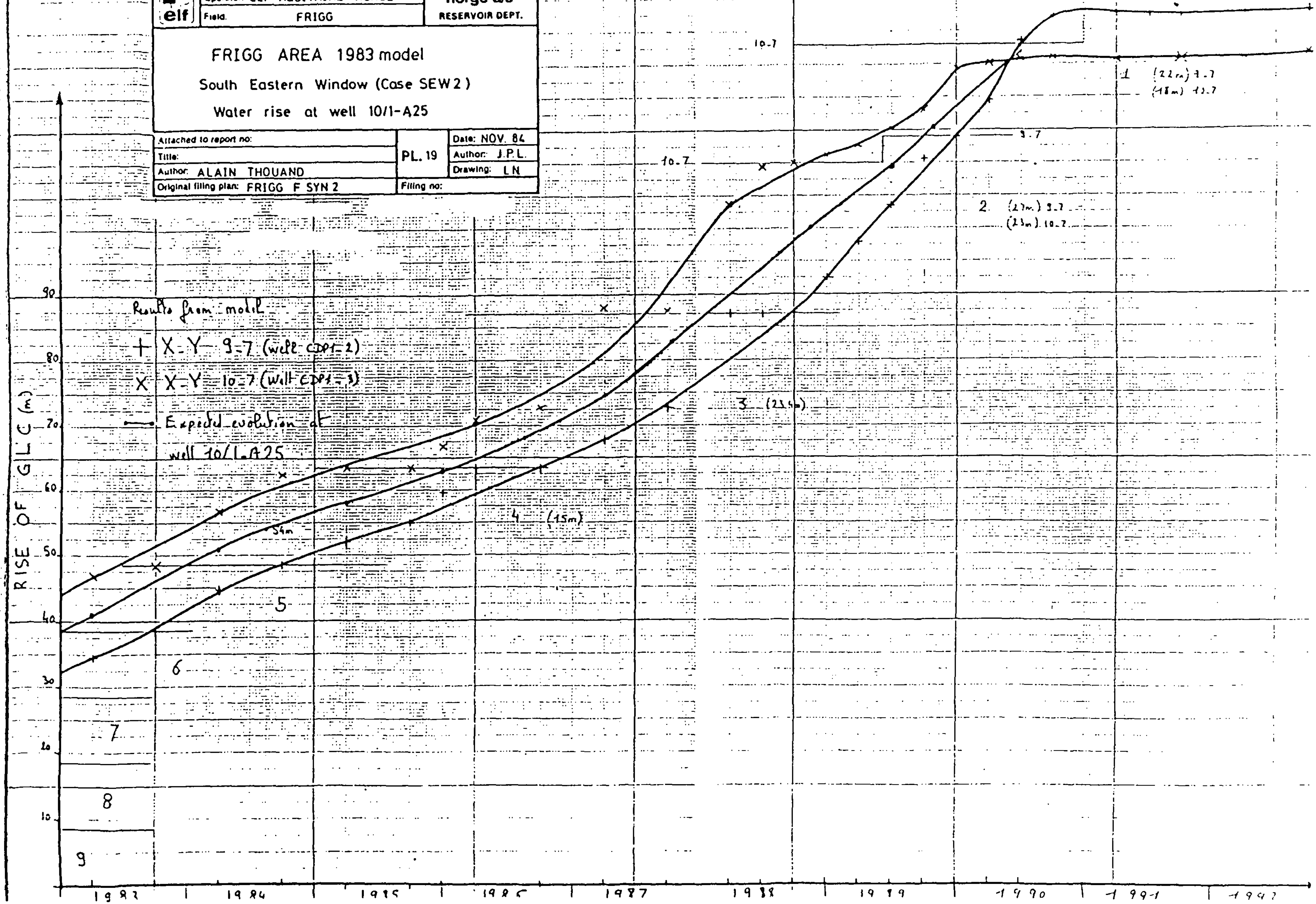
FRIGG AREA 1983 model

South Eastern Window (Case SEW2)

Water rise at well 10/1-A25

Attached to report no:	PL. 19	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: LN
Original filing plan: FRIGG F SYN 2		Filing no:



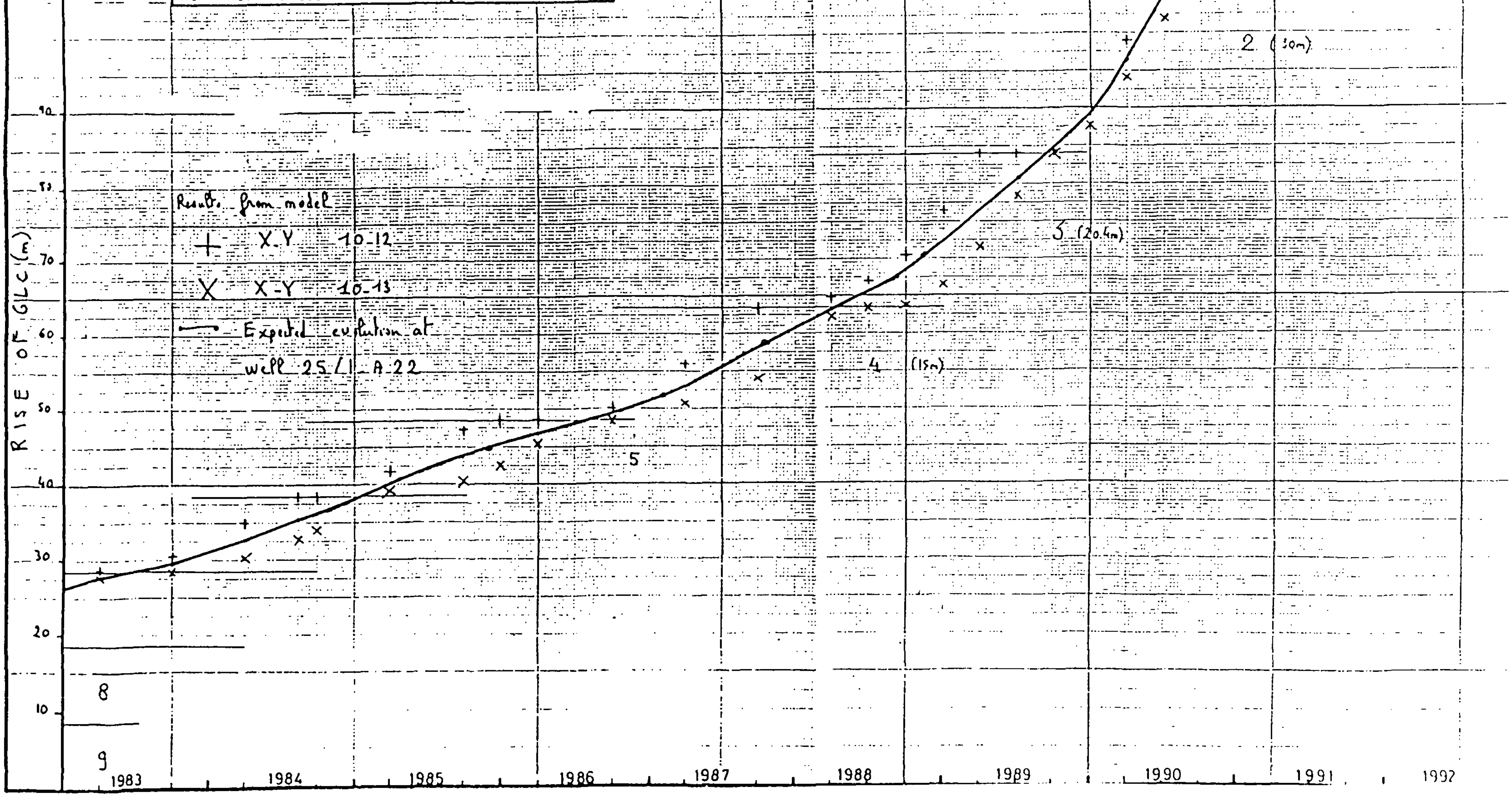
Block / Licence: 024	elf aquitaine norge a/s RESERVOIR DEPT.
Operator: ELF AQUITAINE NORGE	
Field: FRIGG	

FRIGG AREA 1984 model

South Eastern Window (Case SEW 2)

Water rise at well 25/1-A22

Attached to report no.	PL. 20	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: LN
Original filing plan. FRIGG F SYN 2	Filing no:	



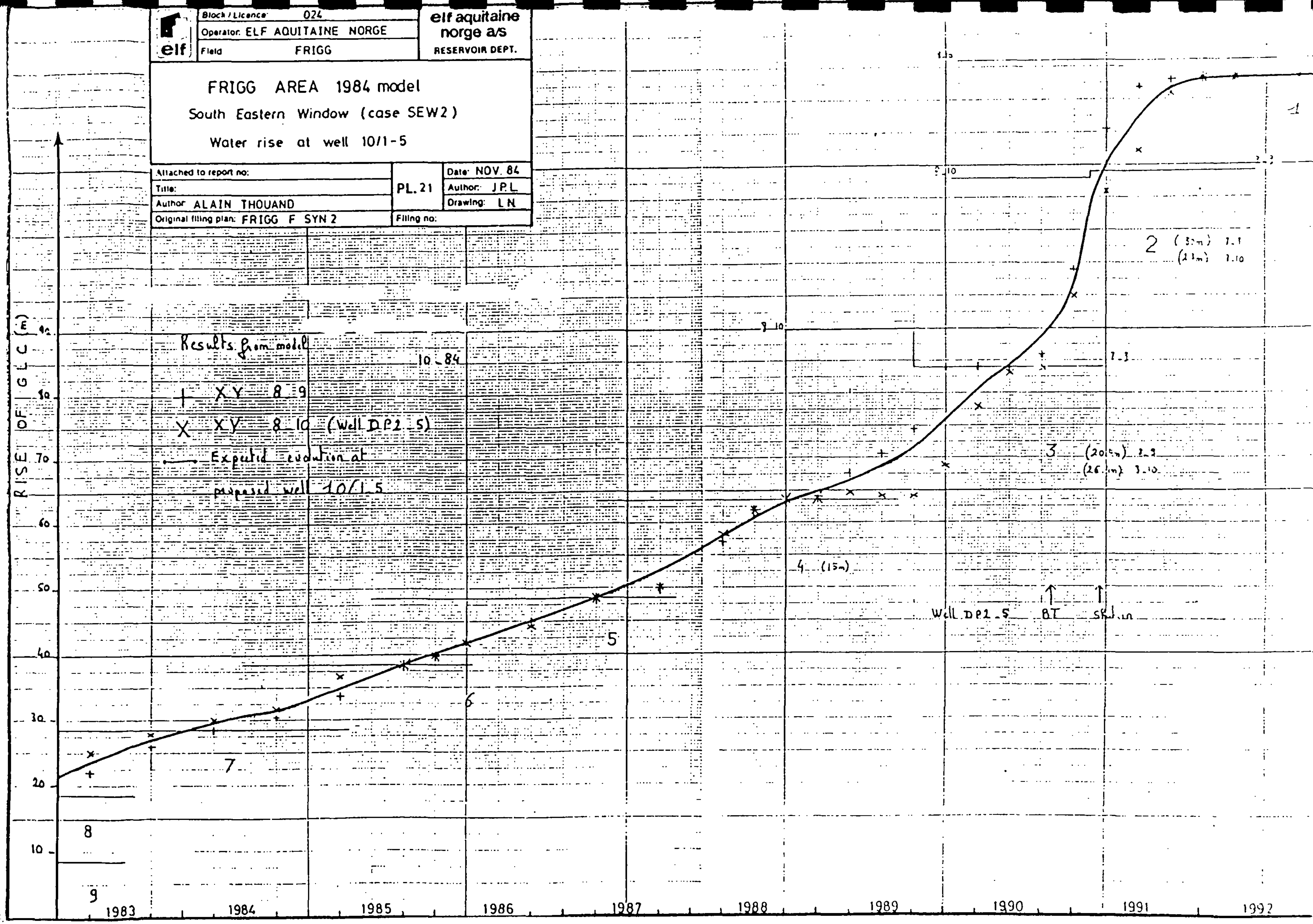
Block / Licence: 024		elf aquitaine norge a/s RESERVOIR DEPT.
Operator: ELF AQUITAINE NORGE		
Field: FRIGG		

FRIGG AREA 1984 model

South Eastern Window (case SEW2)

Water rise at well 10/1-5

Attached to report no:	PL. 21	Date: NOV. 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L.N.
Original filing plan: FRIGG F SYN 2	Filing no:	



Western Window Case 2 (WW 2)

Main features:

New production facilities (number of wells)

	CDP1	DP2	SSC	DP3	Total
01-10-87	4	4			8
01-01-88			4	6	10
01-01-89				2	2
01-04-89				2	2
01-10-89				2	2
TOTAL	4	4	4	12	24

Cumualtive production 205,4 $Gstdm^3$.

The detailed summary of producing wells is attached plate no. 22, the position of the new wells in the gridding is presented in plate no. 23. The production time is slightly increased compared to case SEW 2 because the last wells need a long period to produced the remaining gas in the north of DP2. The decrease of recovery compared to case SEW 2 is mainly explained by the higher minimum pressure 131,4 bar abs. instead of 125,2 bar abs.

Following plates are attached:

- No. 24 : Gas liquid rise: expected evolution at well 10/1-A25
- No. 25 : " " " " " " " 25/1-A22
- No. 26 : " " " " " " " 10/1-5X

Block / Licence: 024
Operator: ELF AQUITAINE NORGE
Field: FRIGG

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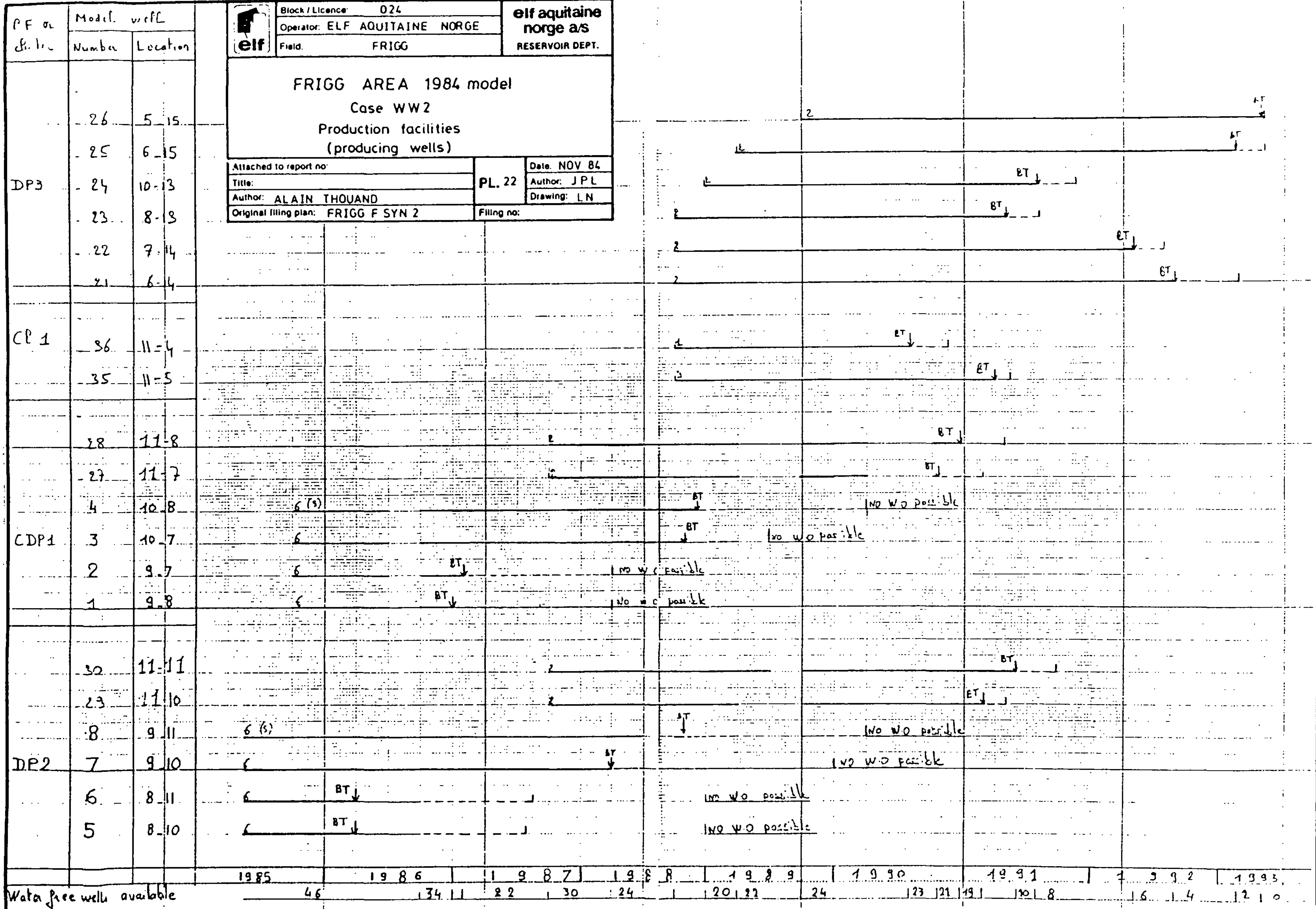
FRIGG AREA 1984 model

Case WW2

Production facilities
(producing wells)

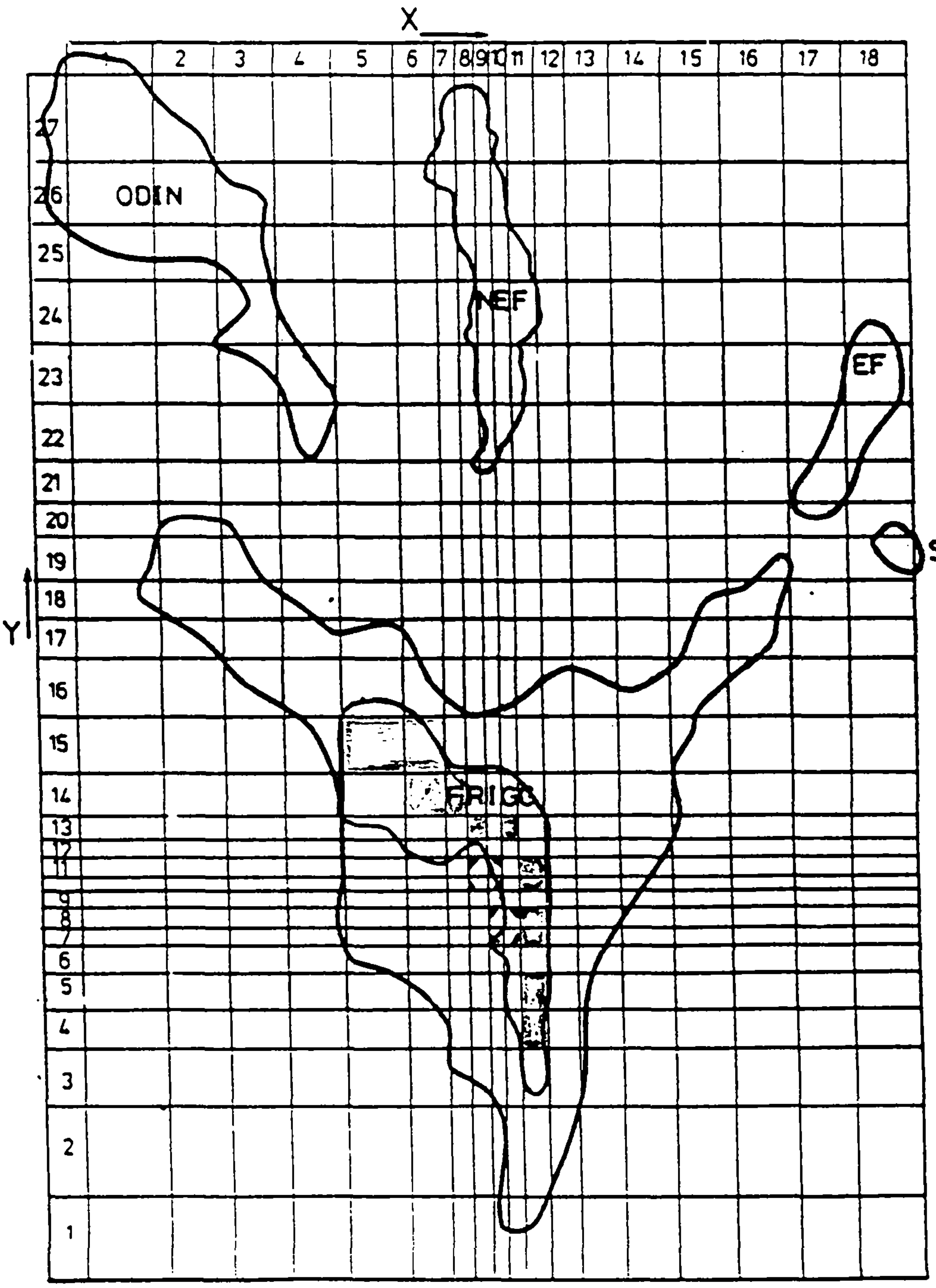
Attached to report no:		PL. 22	Date: NOV 84
Title:			Author: JPL
Author: ALAIN THOUAND			Drawing: LN
Original filing plan: FRIGG F SYN 2		Filing no:	



elf	Block / Licence: 024 Operator: ELF AQUITAINE NORGE Field: FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

FRIGG AREA 1984 model
Case WW 2
Production facilities (map)

Attached to report no:	PL 23	Date: NOV 84
Title:		Author: J.P.L.
Author: ALAIN THOUAND		Drawing: L N
Original filing plan: FRIGG F SYN 2	Filing no.	



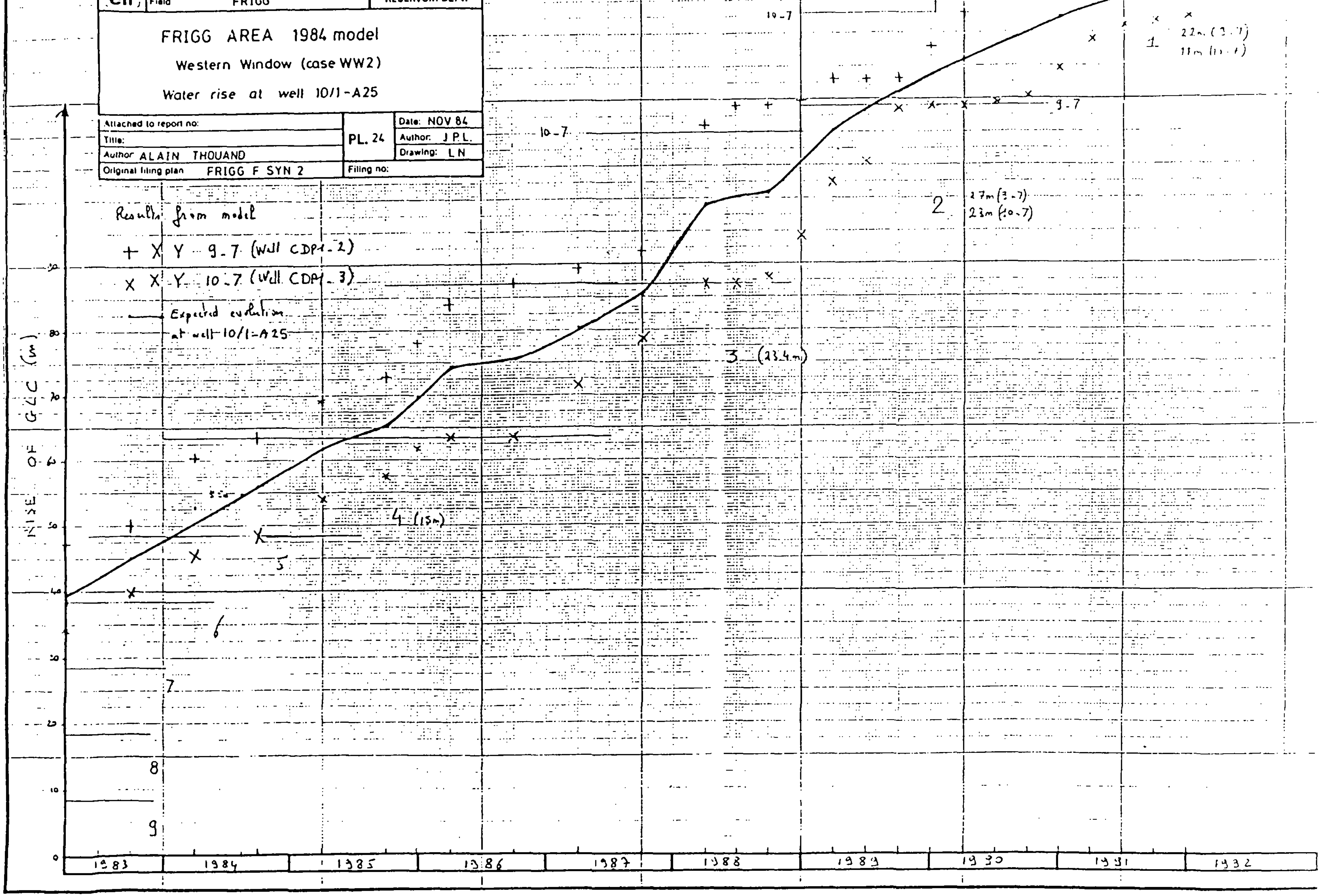
elf	Operator: ELF AQUITAINE NORGE Field: FRIGG	elf aquitaine norge a/s RESERVOIR DEPT.

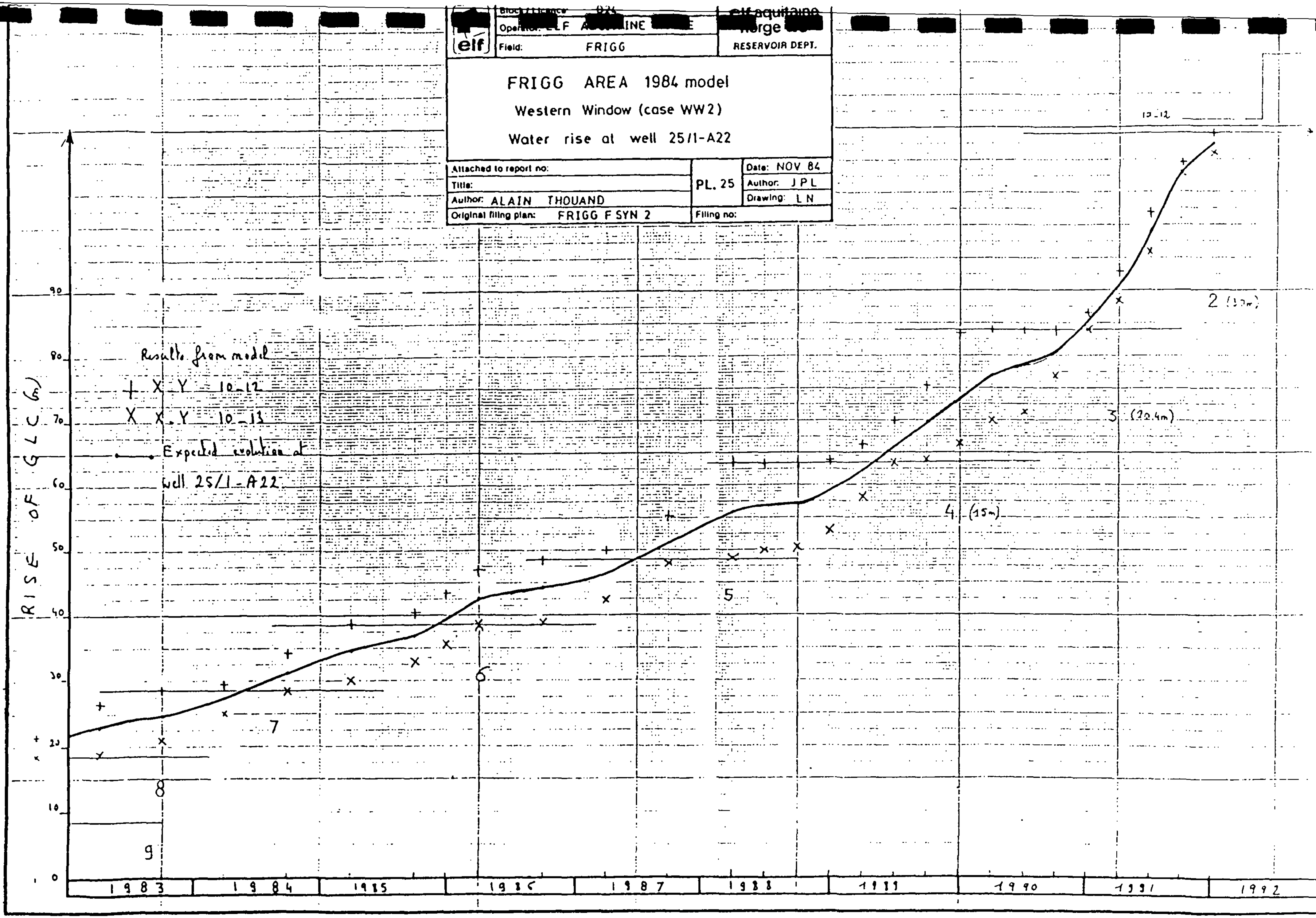
FRIGG AREA 1984 model

Western Window (case WW2)

Water rise at well 10/1-A25

Attached to report no:	PL. 24	Date:	NOV 84
Title:		Author:	J.P.L.
Author: ALAIN THOUAND		Drawing:	LN
Original filing plan: FRIGG F SYN 2	Filing no:		





elf
Field: FRIGG
RESERVOIR DEPT.
FRIGG AREA 1984 model
Western Window (case WW2)
Water rise at well 25/1-A22
Attached to report no:
Title:
Author: ALAIN THOUAND
Original filing plan: FRIGG F SYN 2
PL. 25
Date: NOV 84
Author: J P L
Drawing: L N
Filing no:
RISE OF GLC (m)
Results from model
+ X Y 10 12
X X Y 10 13
Expected evolution at well 25/1-A22
0
10
20
30
40
50
60
70
80
90
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
2 (13m)
3 (22.4m)
4 (15m)
5
6
7
8
9

elf	Block / Licence. 024	elf aquitaine norge a/s
	Operator: ELF AQUITAINE NORGE	
	Field. FRIGG	RESERVOIR DEPT.

FRIGG AREA 1984 model

Western Window (case WW2)

Water rise at well 10/1-5x

Attached to report no:	PL. 26	Date: NOV 84
Title		Author: JPL
Author: ALAIN THOUAND		Drawing: LN
Original filing plan: FRIGG FSYN 2	Filing no: