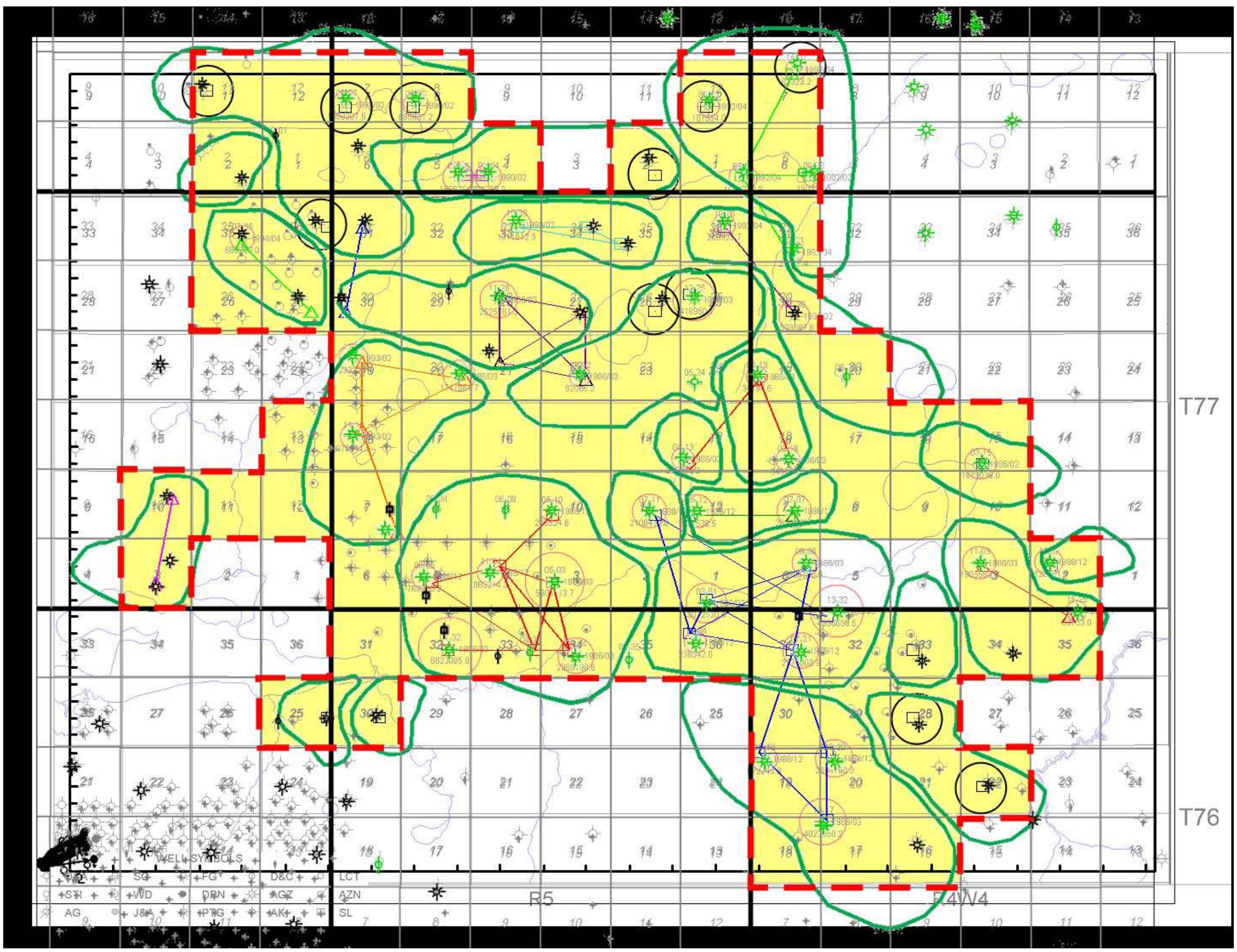
Appendix D - Development of Automatic Pool Grouping Algorithm by GRC Ltd.

As an independent check, Epic commissioned Dr. Ian Gates of GRC Ltd. to develop an algorithm to group wells based on engineering criteria. It was felt that the work could be used to efficiently detect groups and to understand the potential ROI better. The diagram below shows the well pairs detected by Dr. Gates algorithm (shown by lines between wells) and Epic's pool outlines overlain. The two approaches result in similar findings.



Dr. Gates report follows.

Paramount Gas Study Project for EPIC Consulting Ltd.

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Introduction

In this project, a simple algorithm was developed to detect if pressure versus time data from different wells were aligned as an indicator that the wells are sourced from the same pool. The algorithm was coded in the C programming language and the input data required are the pressure versus time data plus two parameters: the maximum allowable pressure deviation (typically 150 kPa) and the range of interaction (3200 m, i.e. the width of two sections). For those wells with pressure data that were detected as being aligned, they were assigned to groups and the results were written out in text files.

The pressure and production data of the gas wells listed in Table 1 were supplied by EPIC Consulting Limited (EPIC).

Table 1: Gas wells evaluated in this study.

100/13-17-076-04W4/00	100/13-19-076-04W4/00	100/13-20-076-04W4/00
100/06-22-076-04W4/00	100/06-28-076-04W4/02	100/07-31-076-04W4/00
100/13-32-076-04W4/00	100/06-33-076-04W4/02	100/15-35-076-04W4/00
100/07-30-076-05W4/00	*100/07-32-076-05W4/00*	100/06-34-076-05W4/00
100/12-36-076-05W4/00	100/08-25-076-06W4/00	100/11-02-077-04W4/00
100/11-03-077-04W4/00	*100/09-06-077-04W4/00*	100/07-07-077-04W4/00
100/03-15-077-04W4/00	*100/02-18-077-04W4/00*	100/05-19-077-04W4/00
100/07-30-077-04W4/00	100/02-31-077-04W4/00	*100/03-01-077-05W4/00*
100/05-03-077-05W4/00	100/11-04-077-05W4/00	100/06-05-077-05W4/00
100/01-07-077-05W4/00	100/05-10-077-05W4/00	100/07-11-077-05W4/00
100/05-12-077-05W4/00	100/04-13-077-05W4/00	100/11-18-077-05W4/00
100/11-19-077-05W4/00	*100/08-20-077-05W4/00*	*100/11-21-077-05W4/00*
100/07-22-077-05W4/00	100/12-25-077-05W4/00	*100/07-26-077-05W4/00*
100/07-27-077-05W4/00	100/11-28-077-05W4/00	*100/05-30-077-05W4/00*
100/11-31-077-05W4/00	100/10-33-077-05W4/00	*100/10-34-077-05W4/00*
100/05-35-077-05W4/00	100/10-36-077-05W4/00	100/06-03-077-06W4/00
100/10-10-077-06W4/00	*100/07-25-077-06W4/00*	100/07-35-077-06W4/00
100/09-36-077-06W4/00	100/08-06-078-04W4/00	100/15-07-078-04W4/00
100/08-01-078-05W4/00	100/07-02-078-05W4/00	100/05-04-078-05W4/00
100/08-05-078-05W4/00	*100/05-07-078-05W4/00*	100/05-08-078-05W4/00
100/06-12-078-05W4/00	100/02-02-078-06W4/00	*100/12-11-078-06W4/00*
100/08-33-076-05W4/00		

Of these sixty-four wells, twenty of the wells had five or more pressure data points and are indicated in italics font in Table 1. For the calculation of the gas compressibility, the reservoir temperature was taken to be 12°C.

Algorithm

The algorithm is depicted graphically in Figure 1.

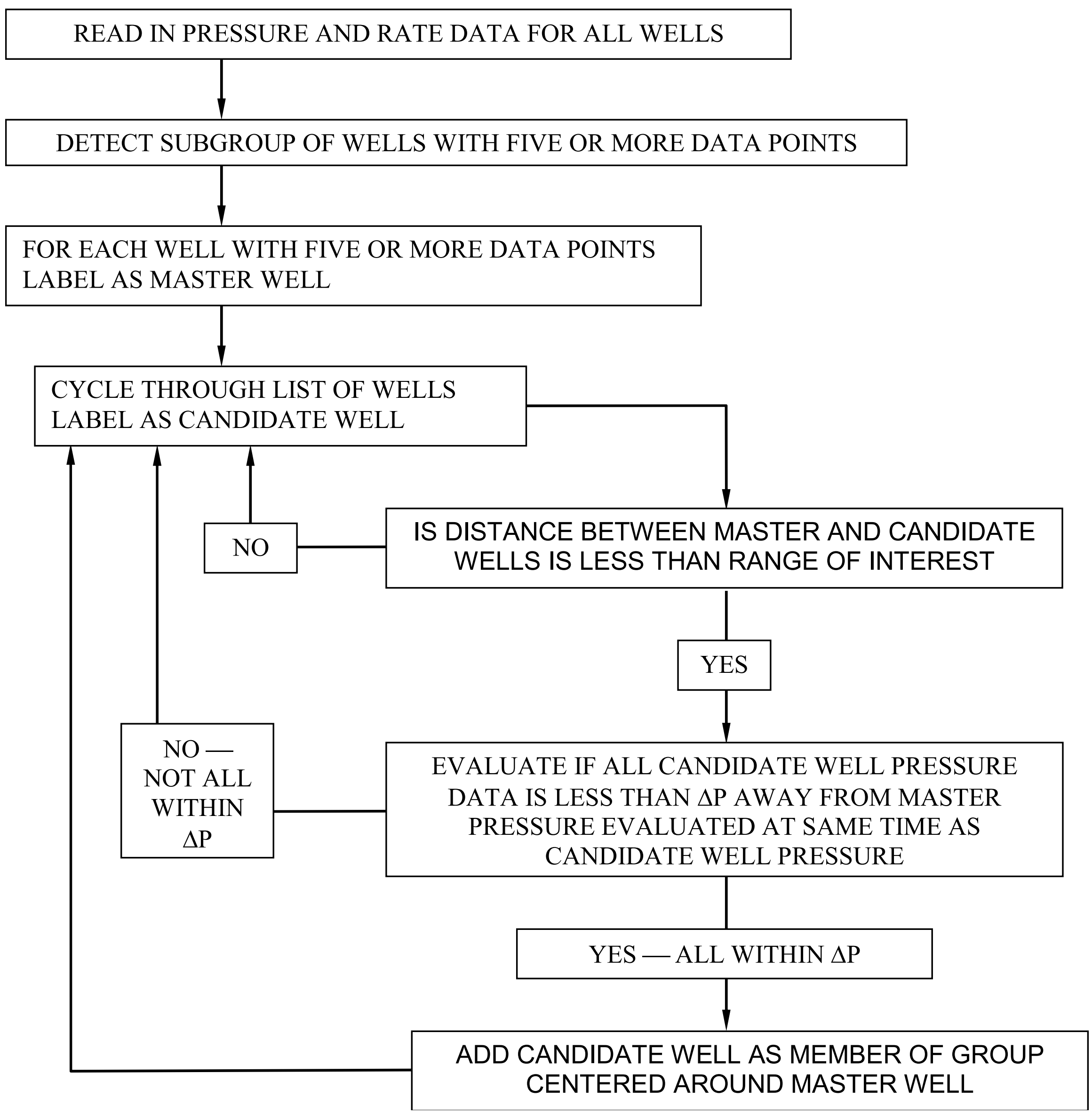

Figure 1: Algorithm to determine if pressure data was closely aligned.

After the pressure and rate data of all the wells are read in, the algorithm builds a subgroup of wells that are considered to have a sufficient number of pressure data points against which comparisons of pressure data can be made. These wells are labelled “master” wells and in this work, any well with two or more pressure data points was considered a master well. For each master well, all of the remaining wells (labelled as “candidate” wells) are examined to check if it is within the range of interest. This is the maximum allowable distance between a master well and a candidate well. If a candidate well is found that lies within the range of interest, then each pressure data point is examined over the range of time overlap of the master and candidate wells as displayed in Figure 2.

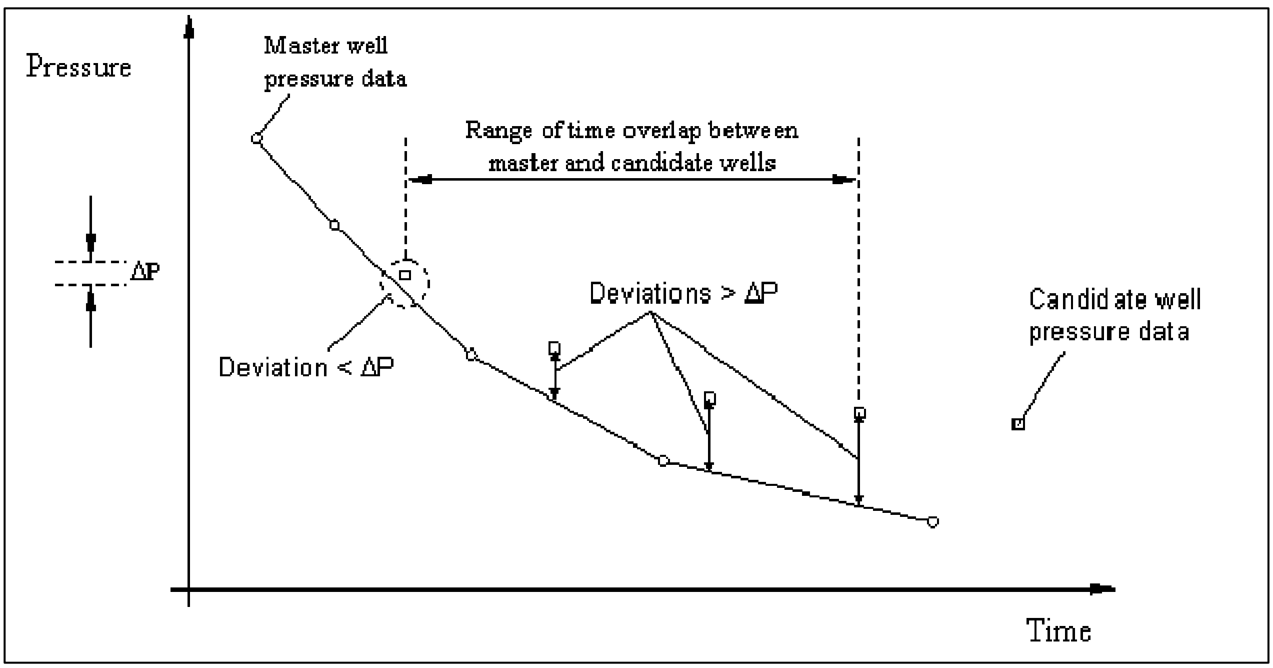

Figure 2: Schematic of master and candidate well pressure data: case where master and candidate well are not considered as aligned.

If all of the deviations between the candidate well pressure and the interpolated pressure value at the same time from the master well are less than the maximum allowable pressure deviation, ΔP, then the candidate well is accepted as a potential member of the group centered around the master well. That is, the candidate well is considered to be in hydraulic and pressure communication with the master well. An example schematic where the pressure data from the master and condidate wells would not be considered as aligned is displayed in Figure 2. An example schematic with pressure data alignment is displayed in Figure 3.

For fitting the master pressure data, several fitting functions were tested including cubic spline, exponential, and polynomial functions. However, it was determined that the best representation of the master pressure data was realized from a piece-wise continuous linear interpolation between each consecutive pressure data point.

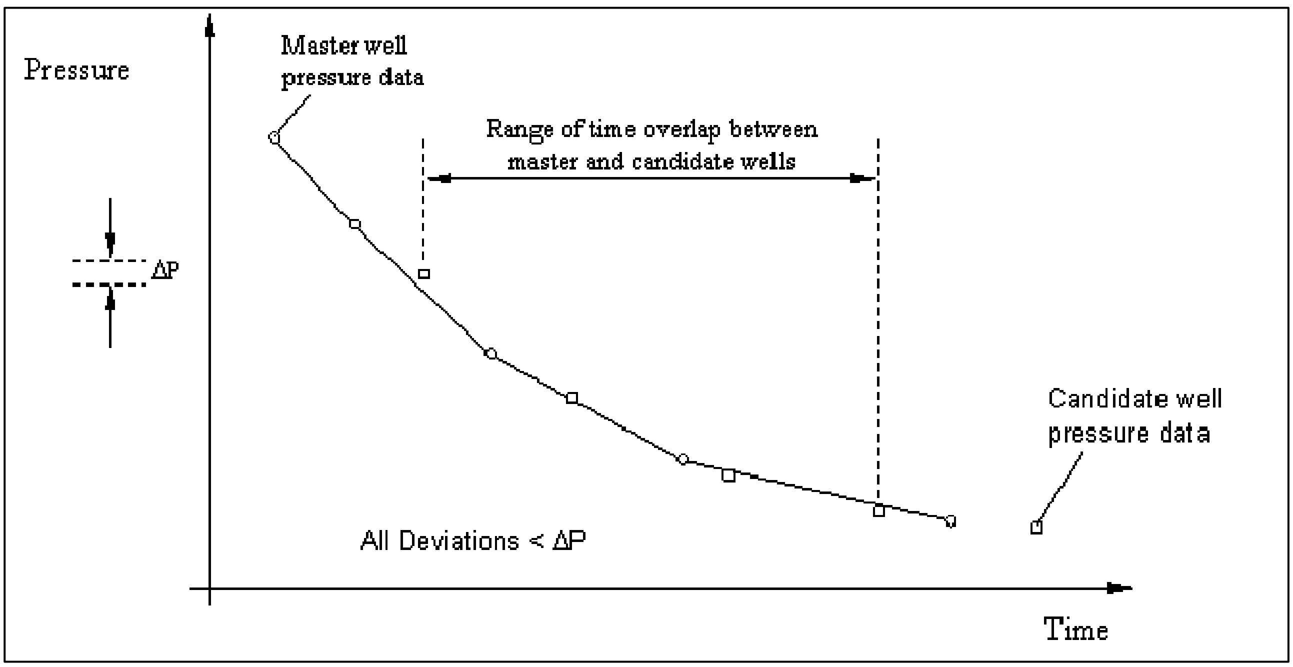

Figure 3: Schematic of master and candidate well pressure data: case where master and candidate well are considered as aligned.

After all groups associated with master wells were determined, then the P/Z data versus cumulative gas produced were generated. The data was then plotted in MS Excel. If the P/Z versus cumulative gas produced data trend appeared to be linear, i.e. straight, then the group was considered as being isolated. If the data trend is curved downwards, then this indicates that the group is losing gas to another group. On the other hand, if the trend is curved upwards, then there is another source of volume e.g. solution gas, aquifer, communication with another gas pool that is providing pressure support to the group pool.

The algorithm forms groups that are seeded from master wells. Originally, a well was considered a master well if it had five or more pressure data points. This requirement, however, leads to a limitation of the algorithm: if a candidate well is determined to have pressure data that is congruent with a master well and there is a neighboring well to the candidate well that is within the range of interest from the candidate well but outside the range of interest from the master well, then the neighboring well is not included in the group. To deal with this limitation, any well with two or more pressure data points were considered as master wells. Then, the pressure data of the candidate wells were compared and groups were formed. Next, any groups with identical members were merged to form the overall groups. The reason why two distinct groups might have one or more identical members is because they fall into the region of interest of another common well but not with each other. By merging the groups, there is a possibility that the band of the pressures are wider than the maximum pressure deviation. This is because even though comparisons between the individual members are less than the maximum allowable pressure difference, when compared to all of the members of the group, the pressure differences can lie on each side of a central point (if on one side difference is 90 kPa and on the other it is 100 kPa, then overall band is 190 kPa wide). This band can be reduced by raising the number of data points required to be defined as a master well.

Results

Figure 4 displays the results of the algorithm when the range of interest is 3200 m and the maximum allowable deviation of pressure is 150 kPa. Each group is centered on a master well, in this case, a well with five or more pressure data points. The wells that comprise the groups displayed in Figure 4 are listed in Table 2.

The results show that the algorithm detects distinct groups of wells where the pressure versus time is aligned.

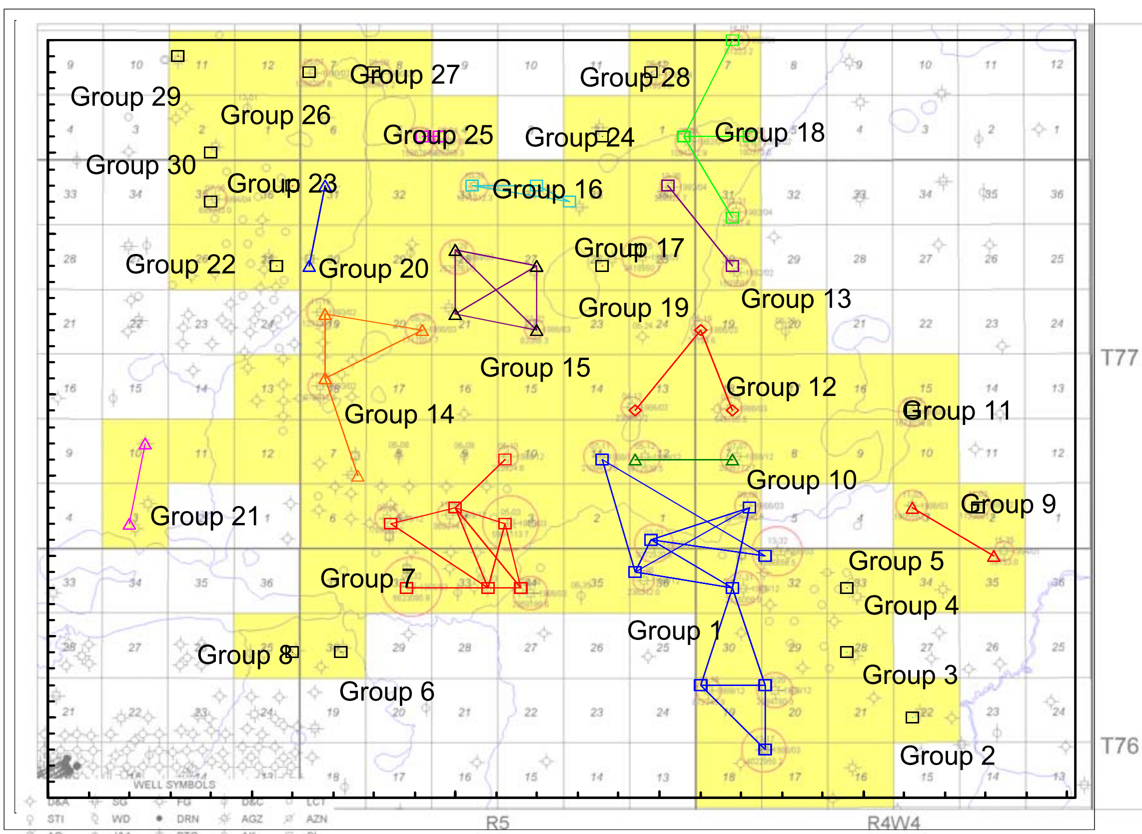

Figure 4: Groups derived when the range of interest is 3200 m and maximum allowable pressure deviation is 150 kPa (and definition of master well is five or more pressure data points). The red circles are bubbles indicating the relative gas production from

each well. The plot of the well locations does not exactly align with the map.

Table 2 lists the members in the groups detected when the range of interest is 3200 m and maximum allowable pressure deviation is 150 kPa (and definition of master well is two or more pressure data points). The total number of groups detected was 30.

Table 2: Group members derived when the range of interest is 3200 m and maximum allowable pressure deviation is 150 kPa (and definition of master well is five or more pressure data points).

Group	Members
1	100/13-17-076-04W4/00
	100/13-19-076-04W4/00
	100/13-20-076-04W4/00
	100/07-31-076-04W4/00
	100/09-06-077-04W4/00
	100/12-36-076-05W4/00
	100/13-32-076-04W4/00
	100/03-01-077-05W4/00
	100/07-11-077-05W4/00 (questionable because nearly at distance tolerance and other unconnected pool too close)
2	100/06-22-076-04W4/00
3	100/06-28-076-04W4/02
4	100/06-33-076-04W4
5	100/11-03-077-04W4/00
	100/15-35-076-04W4/00
6	100/07-30-076-05W4/00
7	100/07-32-076-05W4/00
	100/08-33-076-05W4/00
	100/06-34-076-05W4/00
	100/11-04-077-05W4/00
	100/05-03-077-05W4/00
	100/05-10-077-05W4/00
	100/06-05-077-05W4/00
8	100/08-25-076-06W4/00
9	100/11-02-077-04W4/00
10	100/07-07-077-04W4/00
	100/05-12-077-05W4/00

11	100/03-15-077-04W4/00
12	100/02-18-077-04W4/00
	100/05-19-077-04W4/00
	100/04-13-077-05W4/00
13	100/07-30-077-04W4/00
	100/10-36-077-05W4/00
14	100/01-07-077-05W4/00
	100/11-18-077-05W4/00
	100/11-19-077-05W4/00
	100/08-20-077-05W4/00
15	100/11-21-077-05W4/00
	100/11-28-077-05W4/00
	100/07-27-077-05W4/00
	100/07-22-077-05W4/00
16	100/10-34-077-05W4/00
	100/10-33-077-05W4/00
	100/05-35-077-05W4/00
17	100/12-25-077-05W4/00
18	100/08-01-078-05W4/00
	100/02-31-077-04W4/00
	100/08-06-078-04W4/00
	100/15-07-078-04W4/00
19	100/07-26-077-05W4/00
20	100/05-30-077-05W4/00
	100/11-31-077-05W4/00
21	100/06-03-077-06W4/00
	100/10-10-077-06W4/00
22	100/07-25-077-06W4/00
	100/07-35-077-06W4/00
23	100/09-36-077-06W4/00
24	100/07-02-078-05W4/00
25	100/05-04-078-05W4/00
	100/08-05-078-05W4/00
26	100/05-07-078-05W4/00
27	100/05-08-078-05W4/00
28	100/06-12-078-05W4/00
29	100/12-11-078-06W4/00
30	100/02-02-078-06W4/00

Pressure versus time data is displayed for several groups in Figure 5. The P/Z versus cumulative gas produced for several of the groups are shown in Figure 6.

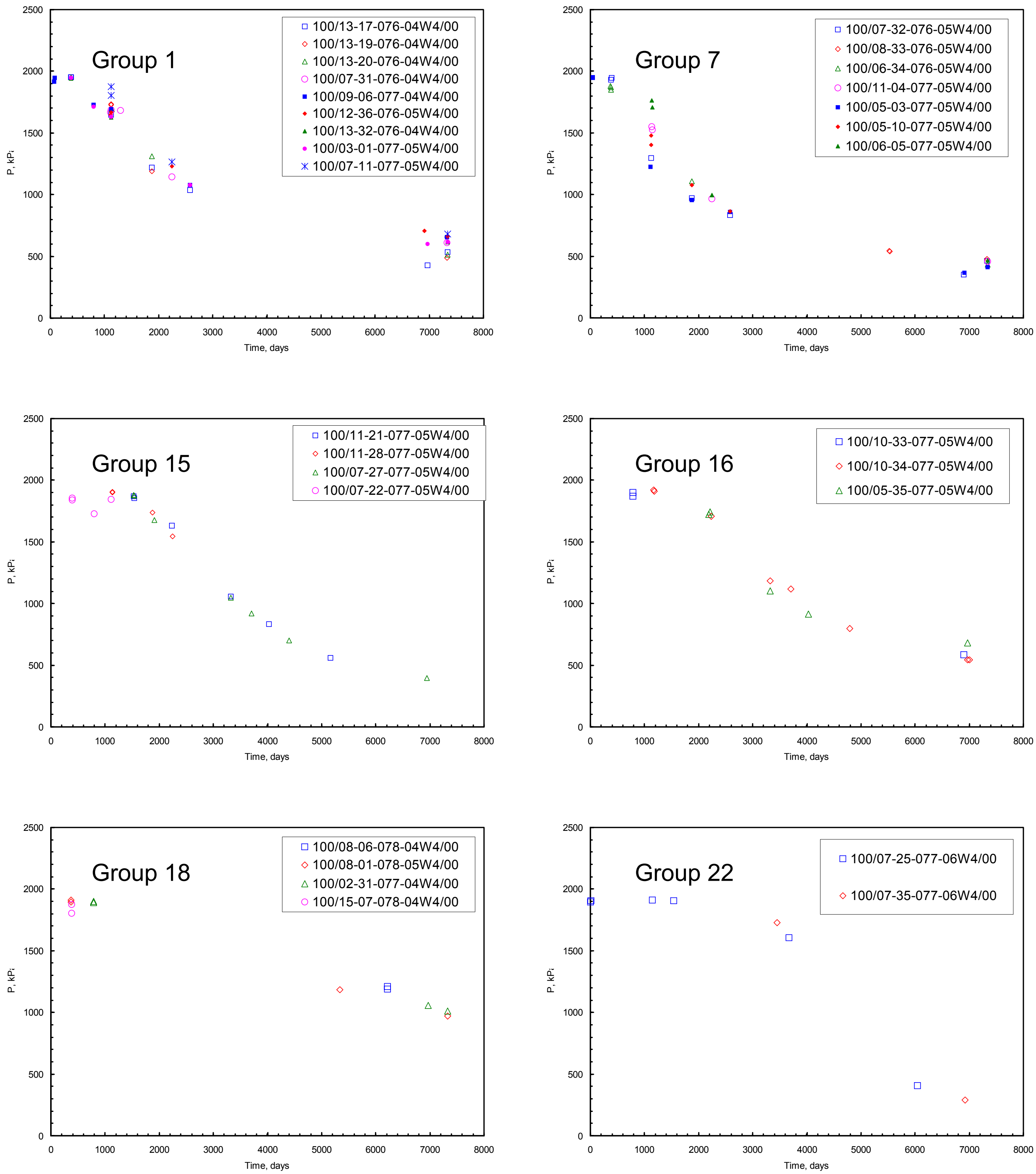

Figure 5: Pressure versus time for several groups.

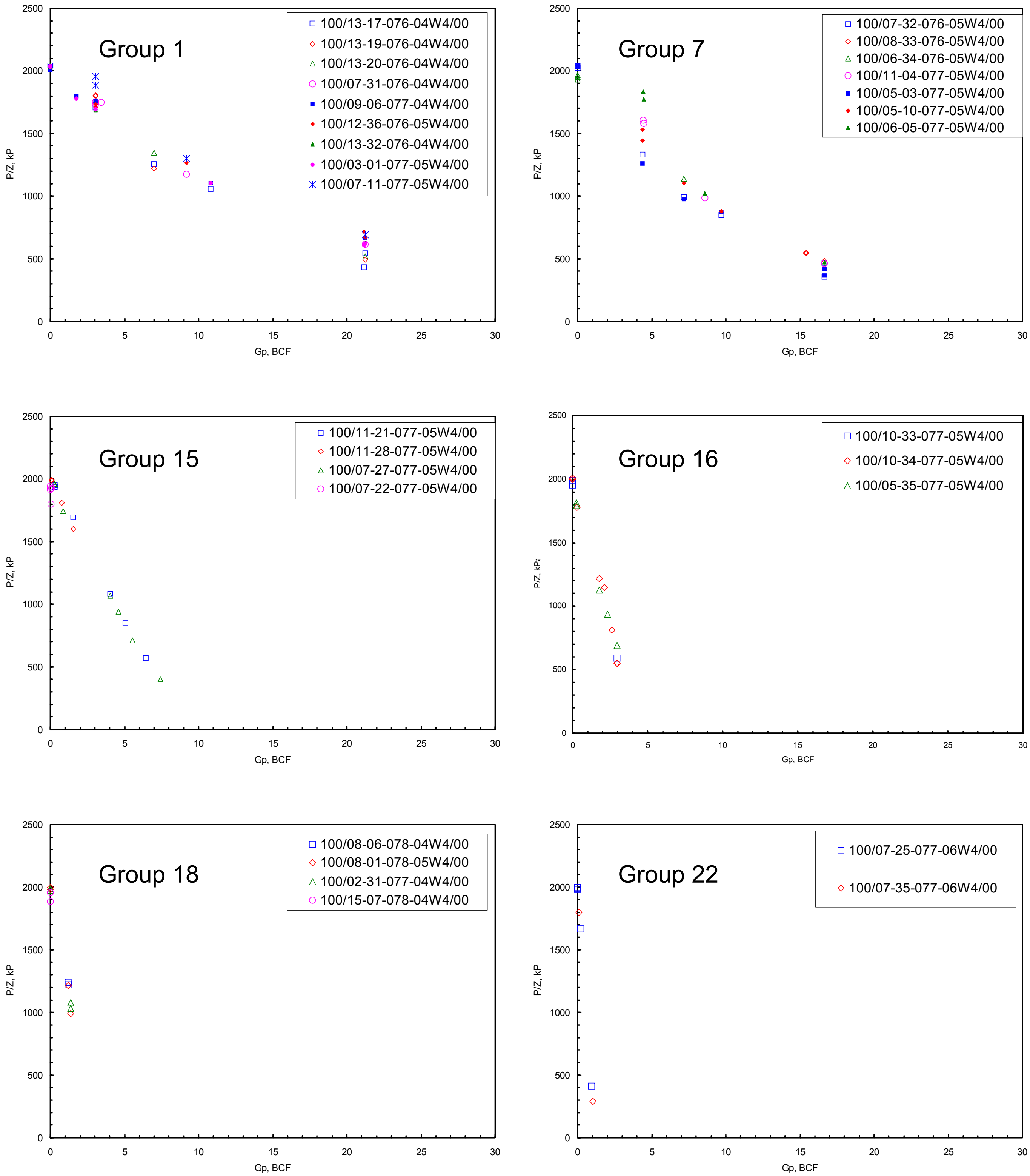

Figure 6: P/Z versus cumulative gas produced for several groups.

The results show that some of the plots of P/Z versus cumulative gas produced are straight thus indicating that the group of wells is being sourced from an isolated gas pool (examples are groups 7, 15, 18, and 22). Other plots show slight downturn or upturn towards the end of the plot. An example of a slight upturn is displayed in Figure 6, Group 1. This implies that there is a weak source of pressure support for the gas pool that feeds the Group 1 wells. This pressure support might take the form of gas communication from another neighboring pool (either laterally or vertically offset from the Group 1 pool) or solution gas from bitumen-rich zone below, or water support. An example of a slight downturn is shown in Figure 6, Group 16. This implies that this pool's pressure is falling faster than what would be accounted for from production of gas from the Group 16 wells. *However, the results show that these deviations from a linear P/Z versus cumulative gas trend are relatively small.*

The pressure data for Group 7 shows an apparent overall pressure spread of more than the maximum pressure deviation at time 1000 days. The reason for this is because of the merging operation that occurs after groups are found. The data before and after 1000 days follow the overall trend very well.

Conclusions

An algorithm was developed to detect potential wells that are sourced from the same gas pool. The results from the analysis indicate that there are several isolated gas pools that are feeding well groups. Several of the group plots of P/Z versus cumulative gas produced are straight indicating that these well groups are sourced from isolated gas pools. Several of the group plots of P/Z versus cumulative gas produced are slightly curved towards the end of their trajectory suggesting that some of the groups detected by the algorithm are suffering mild pressure loss or receiving mild pressure support.

References

Craft, B.C., and Hawkins, M.F. Applied Petroleum Reservoir Engineering. Prentice-Hall Inc. 1959.

Dake, L.P. Fundamentals of Reservoir Engineering. Elsevier. 1978.