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Review of Statistical Analysis of Trapped Gas

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Abstract: A review was conducted of trapped gas estimates in Hanford waste tanks. Tank waste levels were found to correlate with barometric pressure changes giving the possibility to infer amounts of trapped gas. Previous models of the tank waste level were extended to include other phenomena such as evaporation in a more complete description of tank level changes.

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Review of Statistical Analysis of Trapped Gas

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EXECUTIVE SUMMARY

A general model of the waste level in Hanford tanks was developed to assess methods of estimating the amount of trapped gas. The model is an extension of a simpler model based on level correlations with barometric pressure fluctuations. It can include waste level responses to other phenomena such as evaporation and discontinuities in the amounts of waste and trapped gas.

The general model was applied to a set of generated pseudo data (verification) and actual tank data (validation). Results were compared with existing methods.

It was found that the simpler model developed by Whitney (1995) of Pacific Northwest Laboratories is robust and generally gives results in agreement with the current method. The more general model can provide a more complete picture of surface-level variations.

Estimated amounts of trapped gas are semi-quantitatively supported by undocumented void fraction measurements and reasonable general trends. For example, the estimated amounts of trapped gas for tank SY-101 are much larger than for most other tanks and the amount after mitigation is substantially reduced.

The general model developed here provides a sound basis for incremental improvements that could be of significant benefit.

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REVIEW OF STATISTICAL ANALYSIS OF TRAPPED GAS

1.0 INTRODUCTION

Surface level changes are being used to estimate the amount of trapped gas in Hanford tanks. These level changes include both level fluctuations that are correlated with barometric pressure changes as well as changes associated with increasing or decreasing amounts of trapped gas and other tank waste phenomena.

This review provides a detailed examination of these estimates. A general model is developed to describe tank level changes. The model is then applied to data from a few selected tanks including three with void-fraction measurements. The model is also applied to a set of generated pseudo data as a separate check on the numerical methods. This process is used to evaluate the current methods being used to estimate trapped gas.

2.0 TRAPPED GAS MODEL

2.1 CONCEPTUAL MODEL

A mathematical model of surface level changes requires a clear description of the phenomena being modeled, i.e., a conceptual model. Three conceptual models are described here that provide examples of where surface-levels models may or may not be appropriate.

The first model depicted in Figure 1 shows an example where surface-level changes are most likely to be successful. Gas is trapped in a lower solids layer that is covered by a liquid layer of supernatent. The liquid effectively averages the volume of trapped gas so that the spatial distribution of trapped gas, other than its average depth, is unimportant. A variation on this model (not shown) is where a small amount of crust is floating on the liquid layer. This situation could produce anomalous level measurements; however, it is unlikely to effect the results that arise from barometric pressure flucuations.

A conceptual model where the connection between surface-level measurements and trapped gas is obscure is also shown in Figure 1. The surface is composed of salt cake with a lower level of interstitial liquid.

2.2 PHYSICAL MODEL

A physical (or mathematical) model is given here that most closely reflects the first conceptual model consisting of a liquid layer over mixed liquids and solids containing trapped gas. Aspects related to barometric pressure fluctuations closely follow the work of Whitney (1995).

The volume, V_g, of gas trapped at a pressure P_g and temperature T is described by the ideal gas law:

$$P_g V_g = nRT \ ,$$

where n denotes the amount of gas, and R is the ideal gas law constant.

Let the gas pressure be split into the ambient atmospheric pressure P_a and an overburden pressure Δ_p

$$P_g = P_a + \Delta_p \ .$$

An effective gas height, h_g, is readily obtained by dividing the gas volume, V_g, by the tank area A giving

$$h_g = \frac{nRT}{A} \frac{1}{P_a + \Delta_p} \ .$$

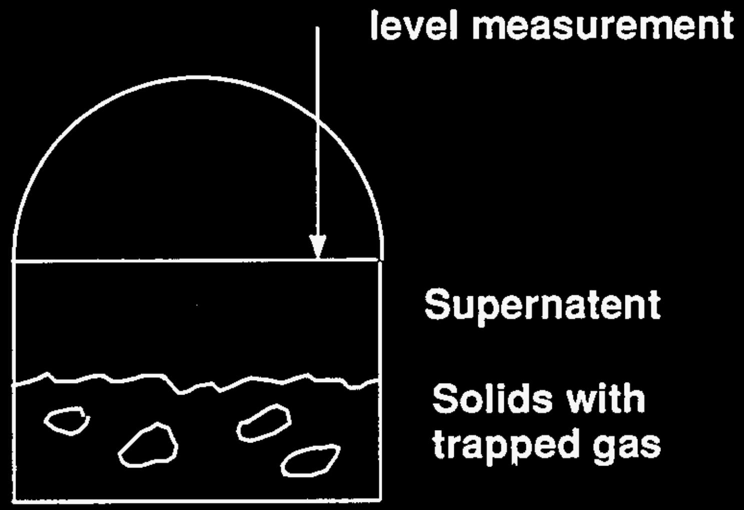
Barometric pressure fluctuations, δ_p, are made explicit by defining an average barometric pressure, P^*_a, such that the ambient atmospheric pressure is given by

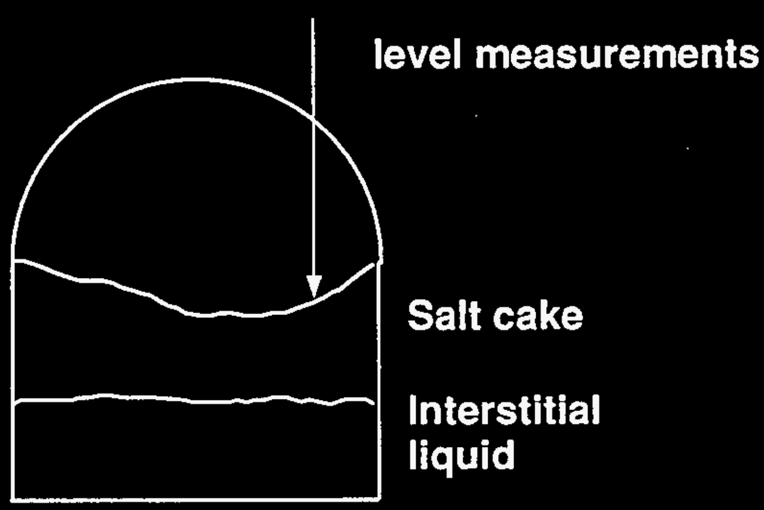
$$P_a = P^*_a + \delta_p$$

The average gas pressure is then given by

$$P^*_g = P^*_a + \Delta_p \ .$$

Figure 1. Conceptual Models.





The level, L, of the tank waste is the sum of the voided waste height, h_w, and the effective gas height, h_g:

$$L(t)=h_w(t)+h_g(t) \;,$$

where the time-dependence, t, has been made explicit. The model becomes more general if the waste height, h_w, includes other phenomena such as crust anomalies and gauge calibrations. The overburden pressure is also quite general at this point and could, in principle, include matrix forces and surface tension.

2.3 GAS MODEL

A simple gas model describing the amount of trapped gas is given by

$$n=\frac{A}{RT}(r+st) \;,$$

where r represents the initial amount of trapped gas, and s represents a constant production rate. (These parameters are defined such that the quantities, r/P_g and s/P_g, represent an effective initial gas height and rate of change in height respectively.) Note the production of trapped gas is distinct from the production of gas which may or may not remain trapped.

2.4 OVERBURDEN MODEL

The overburden pressure may vary in some cases. Gas may migrate through the waste. Selective release of gas may also shift the average overburden pressure. A simple first-order representation of a time-dependent gas pressure is given by

$$P_g^*=P_{go}^*+\beta t \;,$$

where P^*_{go} is the average gas pressure at time, t=0, and ß describes the time dependence.

2.5 EVAPORATION AND OTHER PHENOMENA

Additional phenomena can be explicitly included in the model by replacing the time-dependent, voided-waste height, $h_w(t)$, by a fixed value h_{wo} and adding the term

$$Q(t)=q_1t+q_2t^2$$

to the tank waste level L(t). For example, the linear term, q_1t, can represent the evaporation of waste (negative q_1), while the quadratic term can represent other unidentified time-dependent phenomena not suitably described by the linear term. This step completes the currently developed physical model. Implementation in a least-squares model is discussed next.

2.6 LEAST-SQUARES MODEL

The complete physical model is now given by

$$L(t)=h_{wo}+\frac{r+st}{P_g^*+\delta_p}+Q(t)\ .$$

A least-squares model is now obtained by evaluating the right-hand side at a series of discrete times $\{t_i\}$ corresponding to a set of measured levels $\{L_i\}$. Corresponding measured pressures may be represented by the set of pressure fluctuations $\{\delta_i\}$.

A fully linear model may be created by expanding this equation with respect to both the average gas pressure P^*_g and the pressure fluctuations δ_p. Expansion about the point defined by $P^*_g=P^*_{go}$ and $\delta_p=0$ yields

$$L_i = \left(h_{wo}+\frac{r}{P^*_{go}}\right)-\left(\frac{r}{P^{*2}_{go}}\right)\delta+\left(\frac{s}{P^*_{go}}-\frac{\beta r}{P^{*2}_{go}}+q_1\right)t+\frac{1}{P^*_{go}}\left(\frac{2\beta r}{P^{*2}_{go}}-\frac{s}{P^*_{go}}\right)t\delta$$
$$+\left(q_2-\frac{\beta s}{P^*_{go}}2\right)t^2+\frac{2}{P^*_{go}}\left(\frac{\beta s}{P^{*2}_{go}}\right)t^2\delta\ .$$

The terms in this rather complicated expression can be readily interpreted and give some insight into what can be deduced from an analysis of tank waste levels. First rewrite the equation as

$$L_i = x_1+x_2\delta+x_3t+x_4t\delta+x_5t^2+x_6t^2\delta\ .$$

where the six coefficients $\{x_k\}$ are defined by comparison with the previous equation and are to be determined from a least-squares fit to the measured level data.

The first term is the coefficient, $x_1 = h_{wo} + r/P^*_{go}$, giving the initial level of the tank waste as composed of the voided waste height, h_{wo}, and the compressed gas height, r/P^*_{go}.

The second term, $x_2 = r/P^{*2}_{go}$, is the coefficient of the pressure fluctuations. It gives a direct measure of the amount of trapped gas given the average gas pressure, P^*_{go}. Alternatively, the absolute amount of trapped gas is sensitive to the value assumed for P^*_{go}.

The third term gives the change in waste level unrelated to pressure fluctuations, at least when the t^2 terms are relatively small. This term is important in using surface level changes to estimate trapped gas. Observe that x_3 represents three indistinguishable phenomena: gas generation given by s/P^*_{go}, evaporation or waste additions given by q_1, and a term $\beta r/P^{*2}_{go}$ that arises from changes in the overburden pressure.

The fourth term includes gas production $s/P^*_{go}{}^2$ during time t plus a correction term for overburden variations.

The fifth term shows that linear changes in overburden pressure can manifest themselves as a quadratic term in time. The sixth term is a higher order term expected to be small.

3.0 PACIFIC NORTHWEST NATIONAL LABORATORY MODEL

The model developed by Whitney (1995) of Pacific Northwest National Laboratories (PNNL) assumed a constant amount of waste and a gas generation model that corresponds to including only the first four terms. Phenomena such as evaporation and changes in overburden pressure were neglected. However these effects do not enter into the x_2 term that is the basic estimator of trapped gas. Consequently, with respect to barometric pressure fluctuations, the PNNL analysis provides a robust estimator of trapped gas. The most significant issue other than the quality of level data concerns the value used for the overburden pressure.

A significant disadvantage of the PNNL method is that it is restricted to an analysis of barometric pressure fluctuations. The model developed here represents a more complete surface-level model that explicitly includes several sources of surface-level changes in a consistent analysis. Phenomena such as evaporation can be included along with the barometric pressure fluctuations rather than treated in a separate analysis.

4.0 SOLVING THE LEAST-SQUARES PROBLEM

Multiple regression analyses that include several terms as in the model developed here can require robust numerical methods. Without delving into details, these issues are briefly noted here.

The basis for any least-squares analysis is minimization of the difference between a set of measured values $\{L_{mi}\}$ and a set of calculated values $\{L_i\}$:

$$S^2=\sum_{i=1}^{N_m} (L_{mi}-L_i)^2$$

The calculated values are based on a least-squares model:

$$L_i=\sum_{k=1}^{N_x} A_{ik}x_k \ ,$$

that gives the calculated values in terms of a set $\{x_k\}$ of N_x coefficients to be fitted.

The classic least-squares problem is an overdetermined problem where the number of data points, N_m, is larger than the number of fitted coefficients, N_x: ($N_m > N_x$). For the case, ($N_m = N_x$), one may be able to solve the linear equations (in matrix form):

$$L_m = Ax$$

for the desired coefficients. Formally one can write

$$x = A^{-1} L_m \, .$$

Normally the underdetermined case, ($N_m < N_x$), does not have a solution. Unfortunately, practical least-squares problems can be simultaneously underdetermined and overdetermined; there is abundant data to determine some coefficients, but other coefficients are weakly determined if they are fixed at all.

A solution to this problem can be concisely expressed in terms of a Moore-Penrose (Albert 1972) pseudo inverse where the inverse matrix A^{-1} in the previous equation may or may not exist and is replaced by its pseudo inverse A^{+}. Pseudo inverses can be computed by singular value decomposition (Press et al. 1989) with readily available routines.

An alternative form for computing the least-squares coefficient vector x, convenient for the present application, is

$$x = \left(\sum_s A_s^t V_s^{-2} A_s\right)^{+} \sum_s A_s^t V_s^{-2} L_m$$

where the s-sums denote sums over independent sets of measured data and V_s^2 is a covariance matrix representing uncertainties for the s-th data set. (Note the "+" sign denoting a pseudo inverse.)

This partitioning into independent data sets serves two useful functions in the present context. First the problem becomes simpler both conceptually and in implementation by subdividing the measured level data into discrete blocks, e.g., between gas release events (GREs). Secondly, one can readily impose additional constraints on the least-squares solution by treating those constraints as a measured data set with small uncertainties.

This form is also suitable for computing uncertainties on the final fitted coefficient vector x since the factor in parentheses is directly proportional to the covariance matrix for x.

5.0 VALIDATION

Validation of the method consists of two distinct issues. Given known representative data, do the analyses adequately extract the desired information, and do they reflect the correct values in a practical case (similar to verification and validation). The first issue is addressed next by application to a set of pseudo data generated from known assumptions.

5.1 APPLICATION TO PSEUDO DATA

A set of pseudo data suitable for testing the general least-squares method was generated from the following mathematical model:

$$L(t) = h_{wo} + (h_{go} + m_g t)\frac{1}{1+\delta_p/P_g^*} + q_1 t + \epsilon_h .$$

The initial compressed gas height h_{go} is equal to r/P^*_g previously defined. The gas production rate m_g is similarly defined by s/P^*_g.

Values for L(t) were generated for two sequential period of 5000 hr each at 50 hr intervals. An initial voided waste height, h_{wo}, of 100 in. was assumed with a constant evaporation rate, q_1=-1x10^{-4} in./hr. The initial compressed gas height was taken as 5 in. with a production rate of 2x10^{-4} in./hr. A average atmospheric pressure of 30 in. Hg was assumed along with a 5 in. Hg overburden pressure to give a total gas pressure of 35 in. Hg.

Pressure fluctuations were modeled using a random number generator to generate numbers with a uniform distribution between ±0.2 in. Hg. A loss of 1 in. of gas at 5000 hr was assumed but no change in the amount of voided waste. The possibility of discontinuous changes in gas and waste are part of the current model; although they are not explictily identified in the previous equations.

The least-squares analyses was then applied to the this set of pseudo data for two sets of measurement qualities, good data and bad data. The good data were modeled by describing the noise term, ϵ_h, representing level-measurement errors by uniform random fluctuations between ±0.01 in. The bad data were modeled by fluctuations 10 times larger or ±0.1 in.

Application to the "good" data is depicted in Figure 2 where the data and the fit nearly coincide. A similar picture is shown in Figure 3 for the "bad" data where the large level measurement errors are seen to dominate the smaller fluctuations arising from pressure fluctuations.

The results of both analyses are summarized in Table 1 where they are compared with the "true" values.

Table 1. Comparison of Generalized Least-Squares Analysis for "Good" and "Bad" Data.

Description	Variable	True value	Good data Value	Good data Std. dev	Poor data Value	Poor data Std. dev
Gas + waste production	Q1+mg	1.0	1.0	0.0	1.1	0.1
Gas production	mg	2.0	2.7	0.9	7.2	9.5
First time interval						
Waste +initial gas height	hw+hg	105.0	105.0	0.0	105.0	0.0
Initial gas height	hgo	5.0	4.9	0.3	3.8	2.9
t^2 - dependence	q2	0.0			-0.0	0.2
Second time interval						
Waste + initial gas height	hw+hg	104.5	104.5	0.0	104.5	0.0
Initial gas height	hgo	5.0	5.2	0.3	7.4	2.7
t^2 - dependence	q2	0.0			-0.1	0.2

As shown in the table, the least-squares analysis with good data generally recovers the true values consistent with the corresponding standard deviations (std.dev.). In particular, the initial gas heights are well represented; although the gas-production rates are quite uncertain. The initial gas height is also recovered for the poor data but with larger uncertainties.

5.2 APPLICATION TO TANK DATA

The method was applied to several cases of actual waste-tank level data.

5.2.1 Tank S-106

The first example is tank S-106, a case with good data and where previous studies have consistently shown significant amounts of trapped gas. Figure 4 shows a plot showing the data along with the least-squares fit. Two independent time intervals were fit: 20,000-80,000 hr and 90,000-120,000 hr. The interval 80,000-90,000 hr had anomalous data and was not included.

Numerical results are shown in the computer output shown in Figure 5. The compressed inches of trapped gas for each time interval is given by the x(4) coefficient in the output. The results are summarized in Table 2 and compared with other studies. Two lines are given in Table 2 for tank S-106 representing the two time intervals. The gas amounts in compressed inches in column 2 are converted to dL/dP (change in level with respect to a change in pressure) values in column 5 under the heading "Gen.LS" for convenient comparison with 75th percentile values (column 6) and with nominal values based on PNL's work (column 7). The least-squares values are in good agreement with the PNL values that were obtained by a visual inspection of dL/dP plots. The 75th percentile values are conservative (larger) compared to these values.

Figure 2. Generalized Least-Squares Analysis for "Good" Pseudo Data.

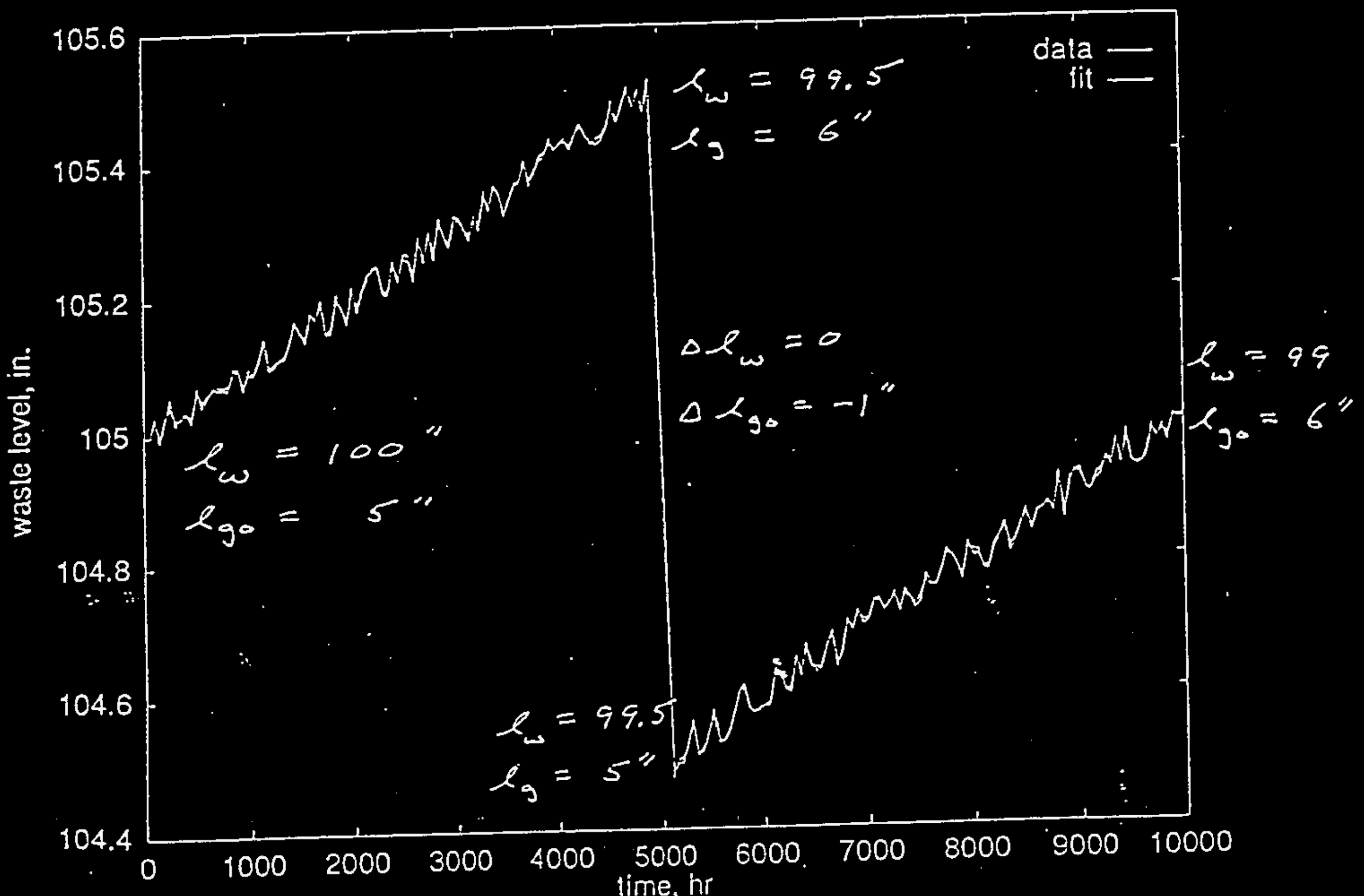


Figure 3. Generalized Least-Squares Analysis for "Bad" Pseudo Data.

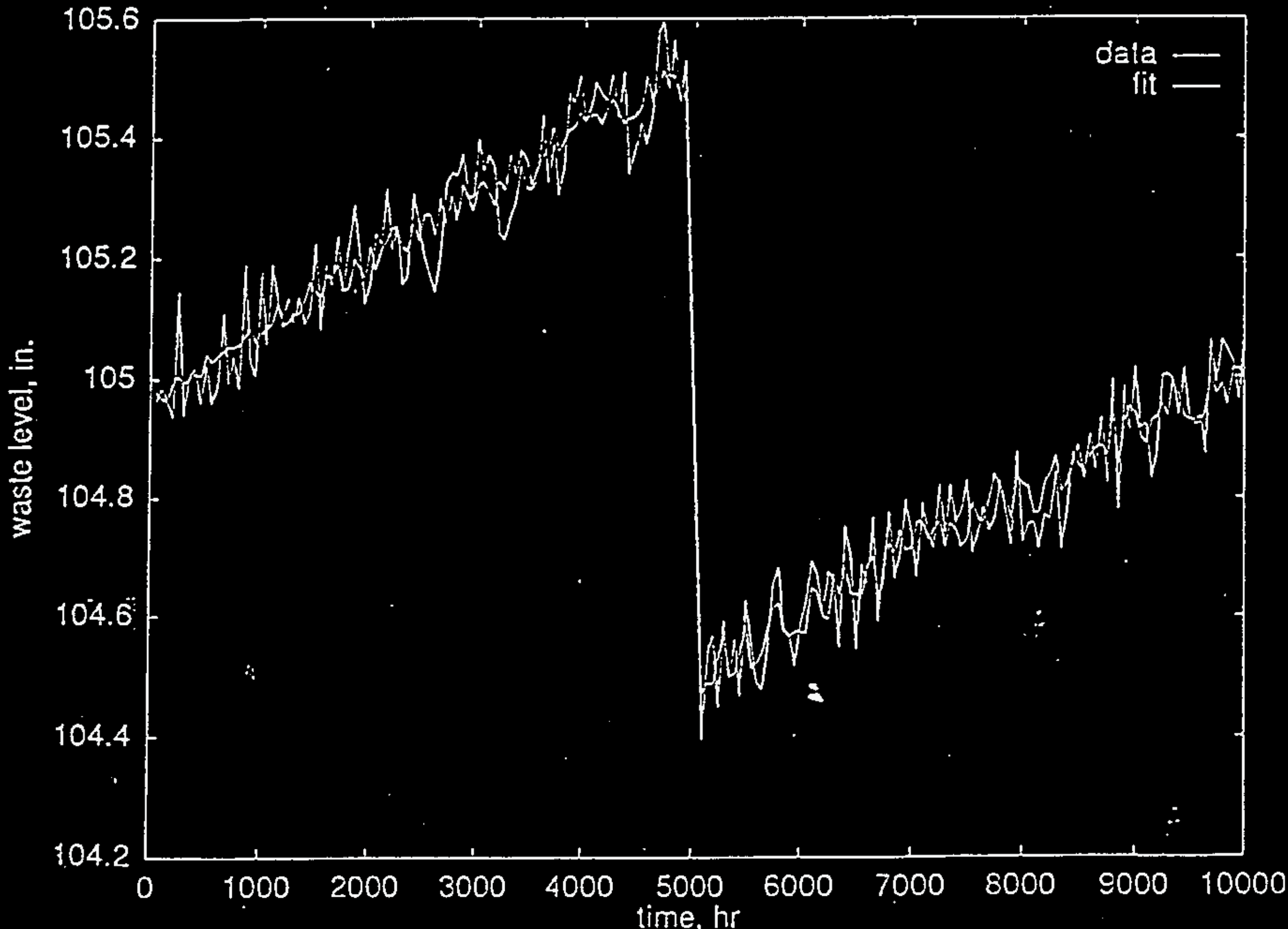


Figure 4. Least-Squares Analysis for Tank S-106.

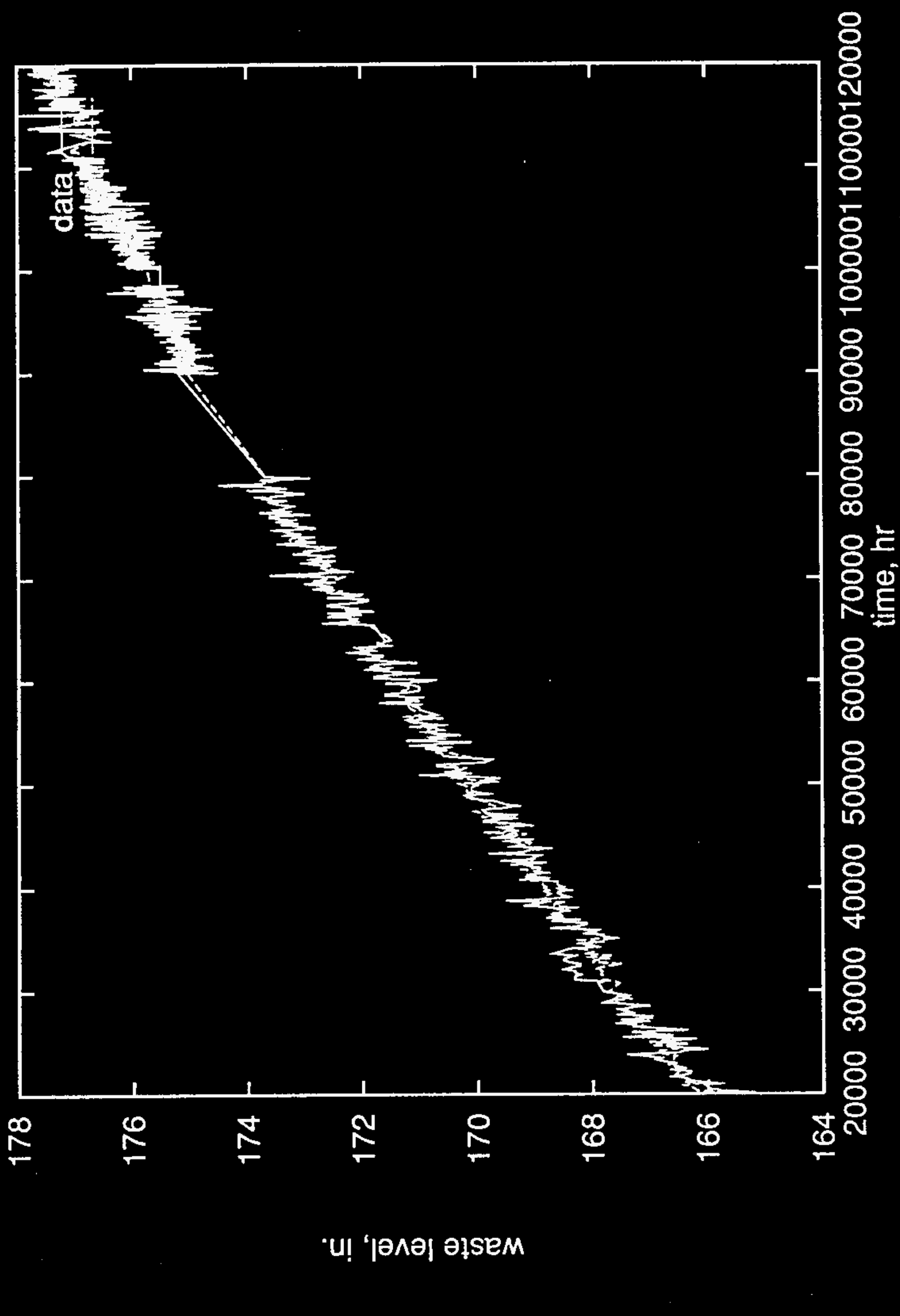


Figure 5. Computer Output for Tank S-106 Analysis.

```
s106.dat
pdel, psi =  7.4      pave, psi = 14.4
q1, sgq =    1000000.   1000000.
info =   0
 ir      s(ir)
   1  9.1556E+04
   2  3.7555E+02
   3  2.6117E+01
   4  9.3937E-02
   5  1.8775E-03
   6  0.0000E+00
irank =   5
--------------------------------
sigf =  2.29E-01
modl = 0,  ityp = 0
            x(i)        std-dev.
       1    1.382E+00    2.860E-02
       2    2.839E+00    1.526E+00
       3    1.661E+02    3.799E-02
       4    3.804E+01    5.108E+00 <------
       5   -1.773E-02    4.577E-03
pave =      29.3
np =  342
t1 =   20000.   t2 =   80000.
Elapsed time, hr =   60000.

q1, sgq =    1000000.   1000000.
info =   0
 ir      s(ir)
   1  1.7624E+04
   2  5.4585E+02
   3  3.7750E+01
   4  5.9661E-02
   5  3.2401E-03
   6  0.0000E+00
irank =   5
--------------------------------
sigf =  1.42E-01
modl = 0,  ityp = 0
            x(i)        std-dev.
       1    1.011E+00    1.983E-02
       2   -1.642E+00    1.327E+00
       3    1.748E+02    1.336E-02
       4    5.256E+01    2.197E+00 <------
       5   -5.829E-02    6.369E-03
pave =      29.3
np =  948
t1 =   90000.   t2 =  120000.
Elapsed time, hr =   30000.

------------ Input ----------------PNL
s106.dat
 7.4  14.4     pdel, psi
  75           ft dia.
 -5, 0, 0  0.6   (nx, modl, ityp, hbreak)
1e6 1e6 1e6  1  1
1e6 1e3
20e3  80e3
90e3 120e3
```

5.2.2 Tank SY-103

The second example is based on recent ENRAF data for tank SY-103. The results are shown in Figure 6. A simple algorithm was used to break the analysis into several discrete time intervals at major discontinuities. Results expressed as compressed inches of trapped gas are shown on the graph. In general, the fit is excellent with small uncertainties on the amount of trapped gas indicating good correlations between the level measurements and the barometric pressures values.

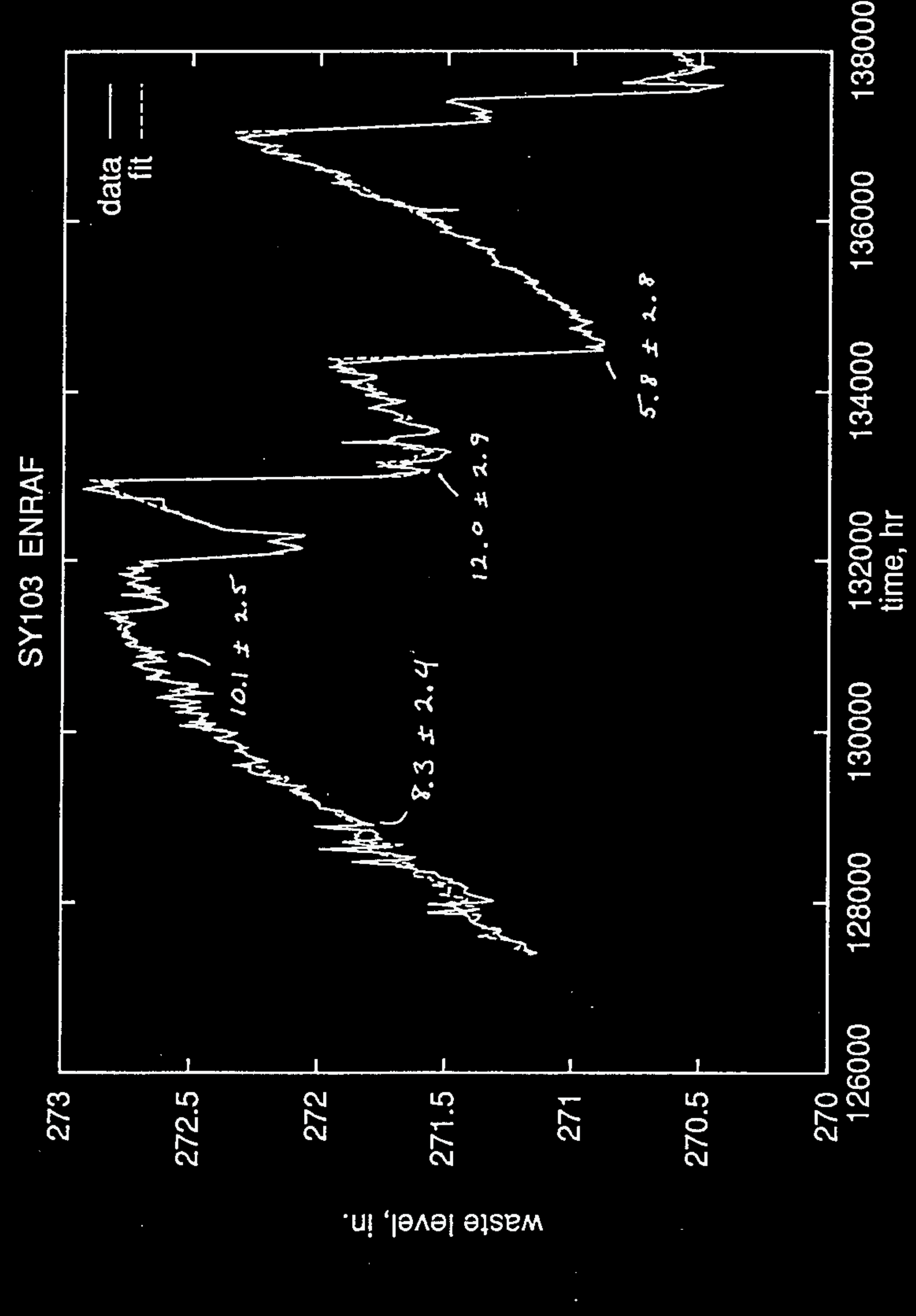
A typical value of 10 in. of trapped gas was entered into Table 2 for comparsion with other results. This value implies a dL/dP value in agreement with the PNL result and smaller by a factor of two than the 75th percentile value. The equivalent gas volume is also shown to be near an undocumented void measurement.

Table 2. Least-Squares Results for Actual Tank Data.

				-dL/dP			Gas vol., SCF	
Tank	Lg, in.	Std. dev.	P* (psi)	Gen.LS	75%	PNNL	LS	Void-meas.
S-106 > 1990	8.00 52.30	5.10 2.20	22.10	0.84 1.16	1.44 1.44	0.70 1.00		
SY-103 AW-101 SY-101	10.00 12.00 13.90	3.00 5.00 3.70	24.70 30.00 16.70	0.20 0.20 0.41	0.40 0.30 0.80	0.20 0.20 0.50	6186 9016 5814	7500 6200 5800
AZ-101 S-101	8.80 6.60	5.90 0.70	28.94 21.43	0.15 0.15	0.00 0.28	?? 0.20		
BY-106	10.00	6.00	25.20	0.19	0.30	0.10		

A notable feature of this analysis is that the drops in estimated amounts of trapped gas are somewhat inconsistent with the observed level changes. It is very possible that this effect is a consequence of the assumption of a constant overburden pressure. For example, the low value of 5.8 in. near 134,000 hr may be an underestimate if the overburden pressure is higher than assumed. This would be the case if the gas from the apparent GRE was released preferentially from the higher waste levels. Additional study may be able to discern the source of the released gas.

Figure 6. Least-Squares Analysis for Tank SY-103.



5.2.3 Tank AW-101

A second tank having void measurements is AW-101. There are several types of level measurements available for this tank including auto FIC, manual FIC, manual Tape, and manual ENRAF values. There is a lot of structure in the level measurements, and the different methods are frequently inconsistent. Nevertheless an an analysis of the auto FIC data shown in Figure 7 generally shows significant amounts of trapped gas. The good correlations observed in the fit after about 102,000 hr led to choosing a representative value of 12 in. of compressed gas, the value entered into Table 2. Again, the value in Table 2 is in good agreement with the PNL value and is less than the 75th percentile value. The equivalent gas volume is in reasonable agreement with the undocumented void measurement.

While the present analysis generally supports the previous work, it also clearly demonstrates that there are pitfalls to blind application of any method to a given set of data. A preliminary analysis (not shown) of recent ENRAF data supports the values presented here.

5.2.4 Tank SY-101

The last tank considered with void measurements was tank SY-101. In order to meet schedule constraints, results based on an earlier analysis method are given here. The tank SY-101 data was reviewed with the focus on GRE events. A typical example with reasonably good data is depicted in Figure 8. As expected, the estimated amount of trapped gas is large consistent with the known behavior of tank SY-101. A similar analysis (not shown) for a following GRE event resulted in smaller but still very significant estimates near 26 in. of compressed gas. Finally, Figure 9 shows results based on recent data after tank SY-101 mitigation. The leasts-squares estimate of 13.9 in. of compressed gas is consistent with the effects of mitigation. These results are preliminary and are only indicative of a more complete and up-to-date analysis.

The value, 13.9 in., obtained after mitigation was entered into Table 2. The results are reasonable compared to the PNNL value, the 75th percentile, and a void measurement.

5.2.5 Tank AZ-101

Tank AZ-101 illustrates the diverse behaviour of different tanks. The waste level decreases linearly with respect to time as a consequence of evaporation punctuated by abrupt increases from batch dumps of condensate. Another difference is that although there is extended FIC data, the data intervals are too sparse to be of use. This problem is apparent in PNNL's study where results are either non-existent or have large uncertainties. There is also manual tape data, but they have not yet been shown to be reliable for pressure fluctuation analysis.

Figure 7. Least-Squares Analysis for Tank AW-101.

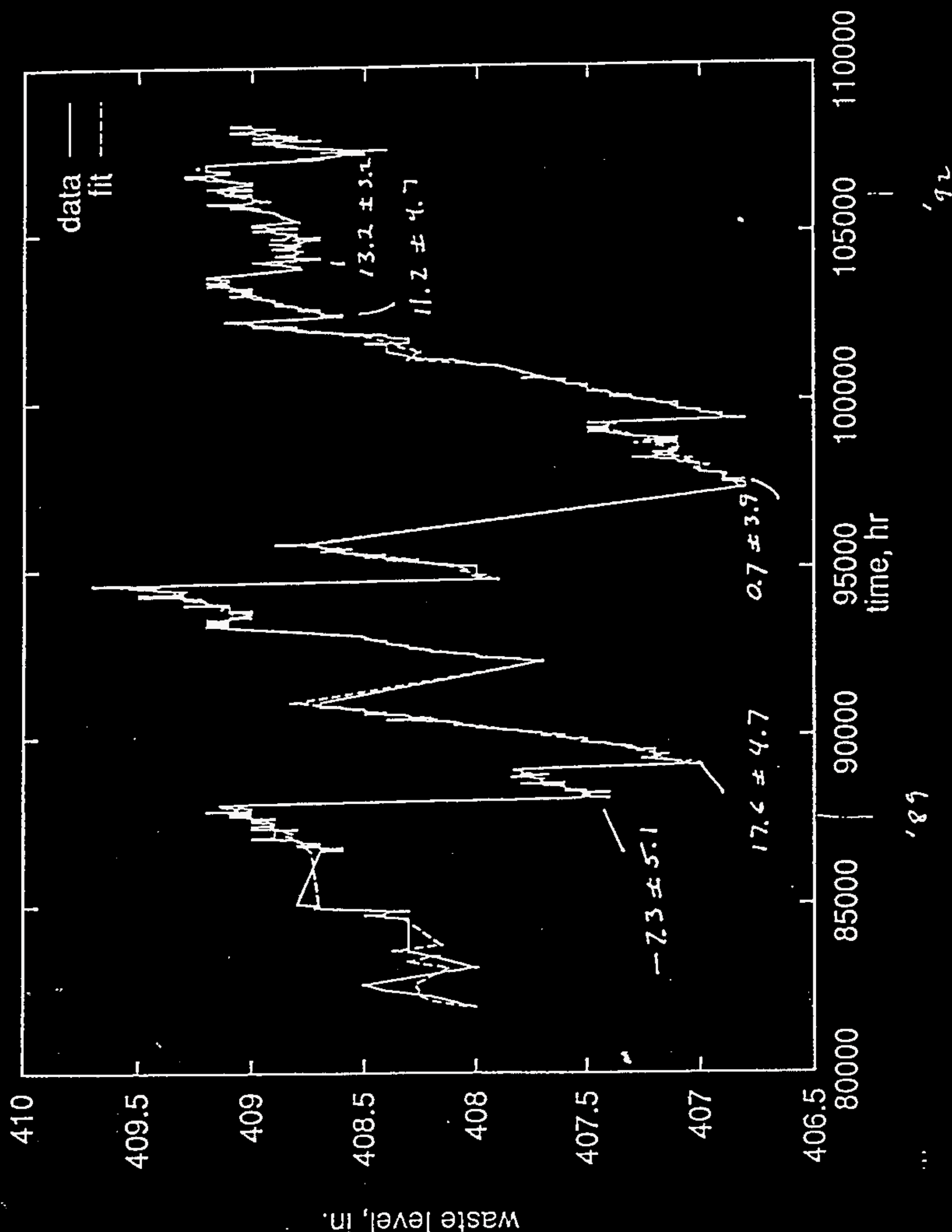


Figure 8. Least-Squares Analysis for Tank SY-101.

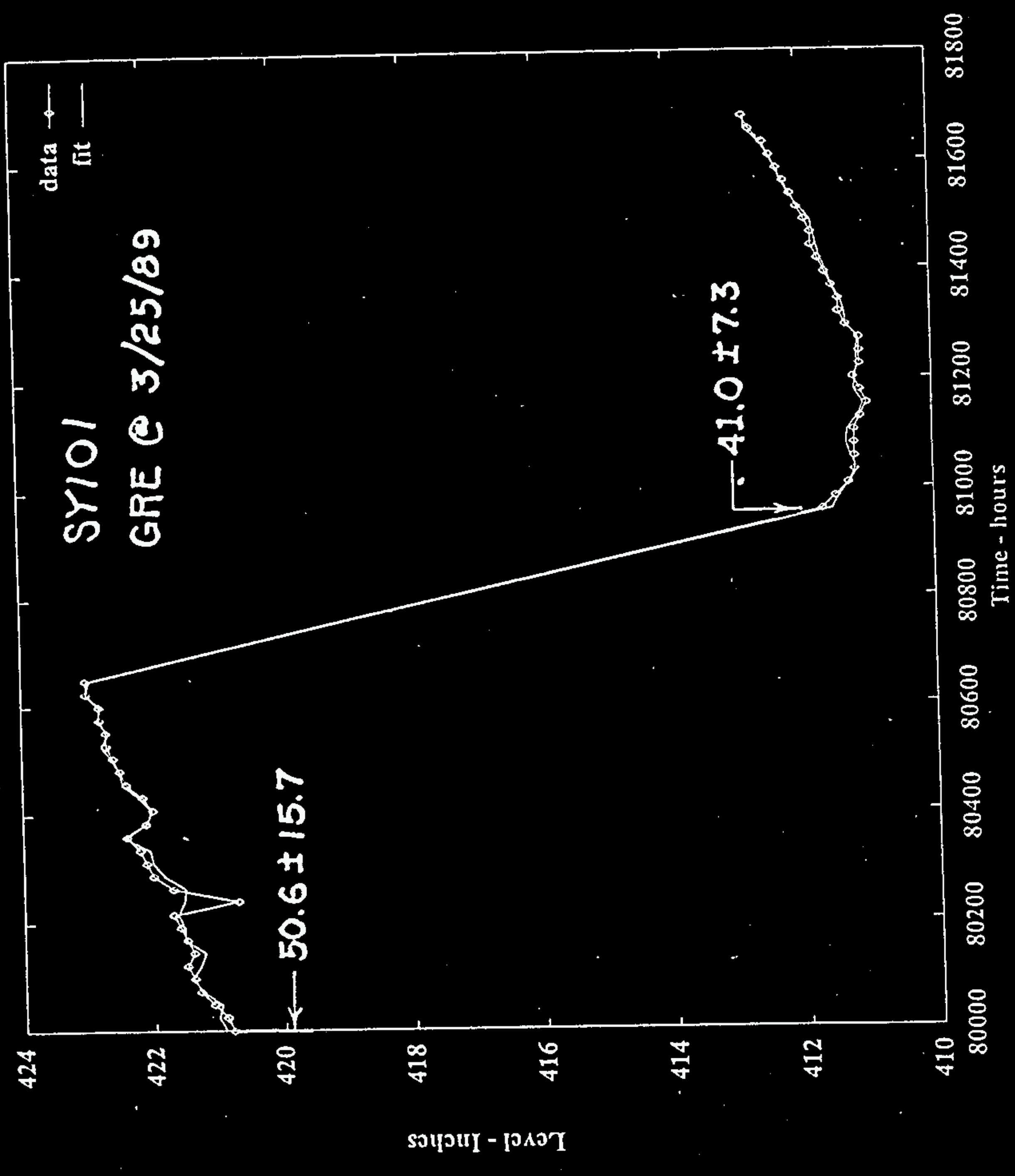
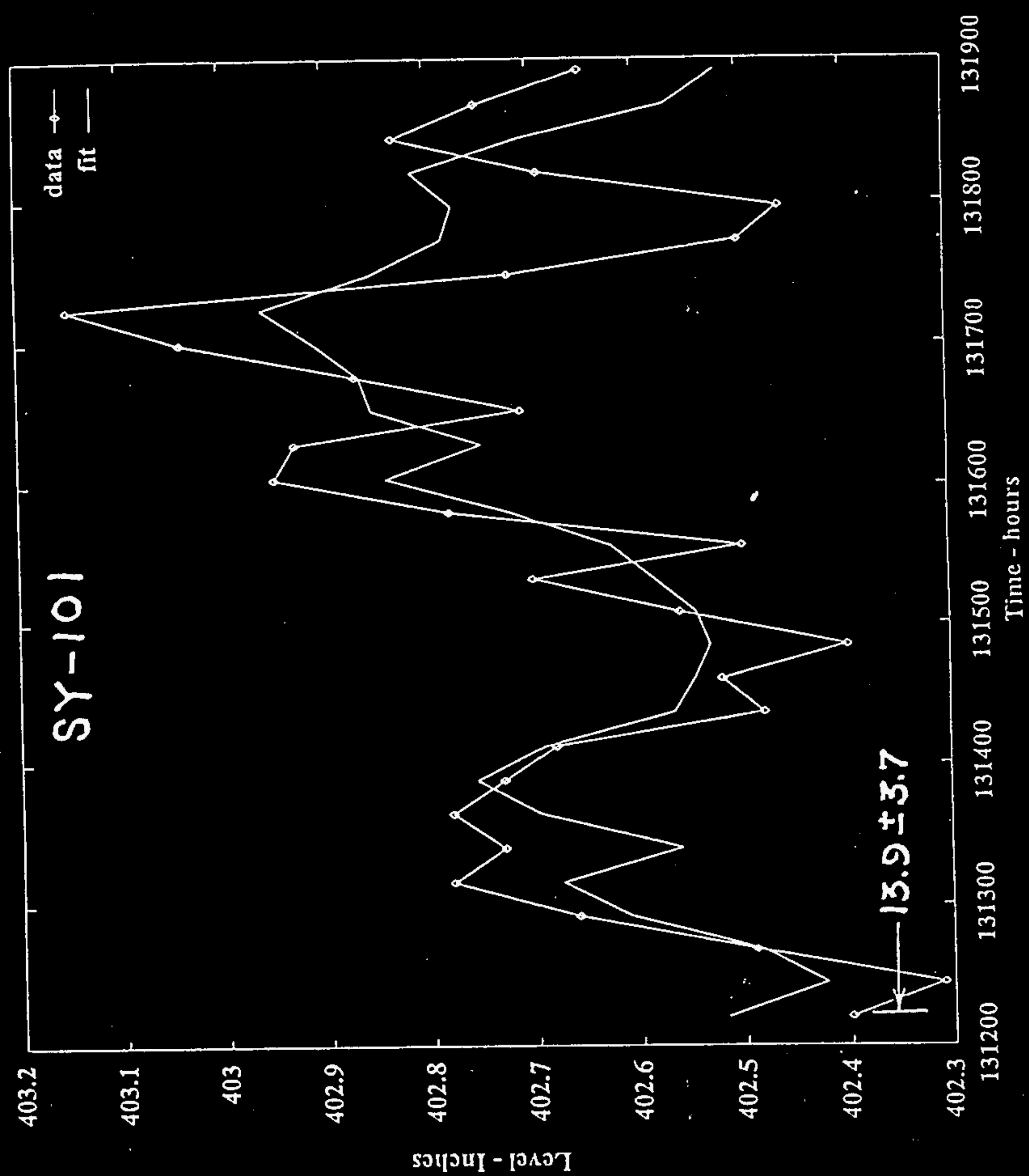


Figure 9. Least-Squares Analysis for Tank SY-101 After Mitigation.



Recent ENRAF data are available for about 3500 hours (~5 months) as shown in Figure 10. The least-squares estimate for this tank is 8.8 ± 5.9 in. of trapped gas, a value consistent with zero. On the other hand, because of the relatively large uncertaintes, trapped gas is not ruled out. This analysis gives a good example where statistical uncertainties are an important aspect of the result.

Graphing residuals provides another way to gain added insight into the least-squares analysis. Rather than plotting just the difference between the calculated (or fitted) results and the measured values, residuals are plotted absent the pressure fluctuations. In other words, values are detrended by subtracting the fitted results with the pressure fluctuation terms set to zero. In Figure 11, the solid curve with points represents the detrended residuals for the measured data. The dotted curve shows the detrended residuals for the fitted values. It represents the fitted pressure fluctuation term.

The residual plots in Figure 11 provide striking detail compared to the featureless results seen in Figure 10. As one can see, there is no obvious correlation between the measured residuals and the computed residuals. An increased amount of trapped gas would not improve the fit. However there are two other notable features in the measured residuals. First there is a strong systematic deviation near 136,400 hr that looks similar to tanks that have annual temperature variations. Secondly, there are very pronounced outlier values spaced about 10 days or more. It seems quite likely that these outliers along with the more systematic deviations noted are responsible for the larger than expected uncertainties on the trapped gas estimates, especially since there are clearly significant pressure fluctuations during this period. Further analysis could well reduce these uncertainties.

5.2.6 Tank S-101

Two sets of data were analyzed for tank S-101, some limited auto FIC data taken during 1992 and 1993, and more recent ENRAF data taken since February 1995. An analysis for the earlier FIC data is shown in Figure 12. Results shown on the graph for three separate time intervals all clearly indicate trapped gas. The fine resolution of the vertical axis clearly shows a discreteness in the measured data. There is evidence that the larger values in the middle time interval are again a consequence of temperature effects not included in the model.

The ENRAF data and fit shown in Figure 13 exhibit excellent pressure fluctuation correlations and give a good estimate of 6.6 ± 0.7 in. of compressed gas. This result is again consistent with the alternative estimates given in Table 2.

Figure 10. Least-Squares Analysis for Tank AZ-101.

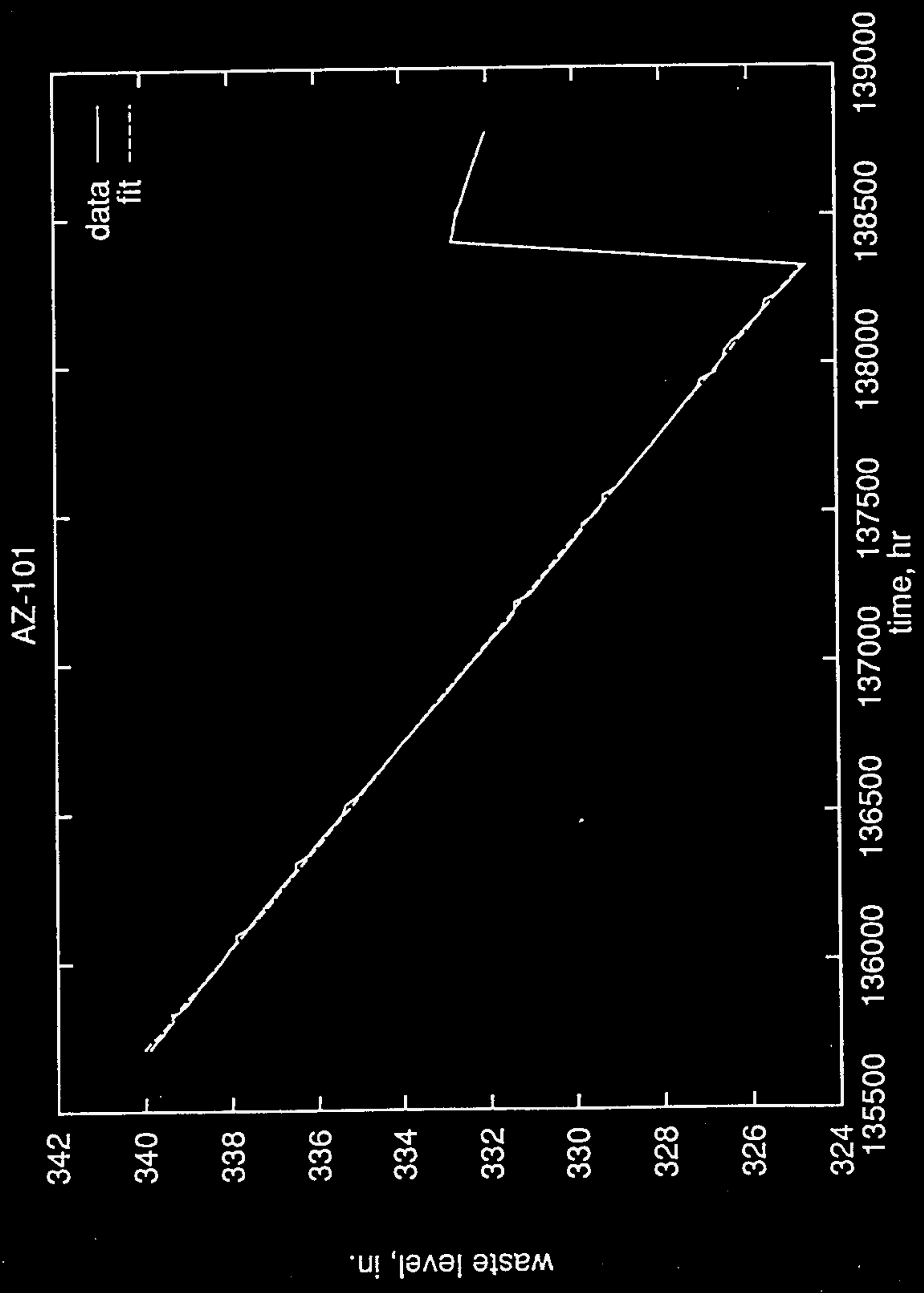


Figure 11. Residuals Graph for Tank AZ-101.

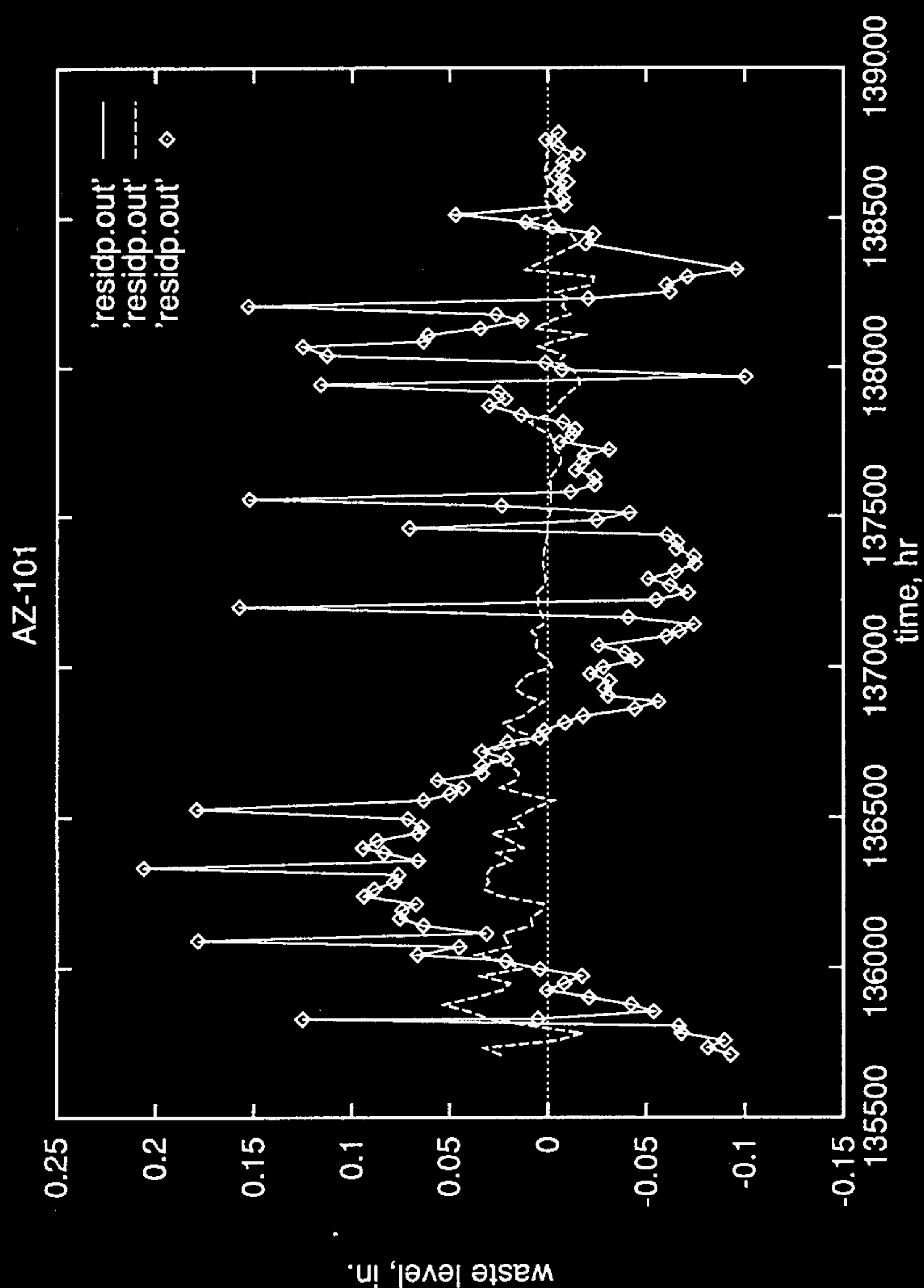


Figure 12. Least-Squares Analysis for Tank S-101 FIC Data.

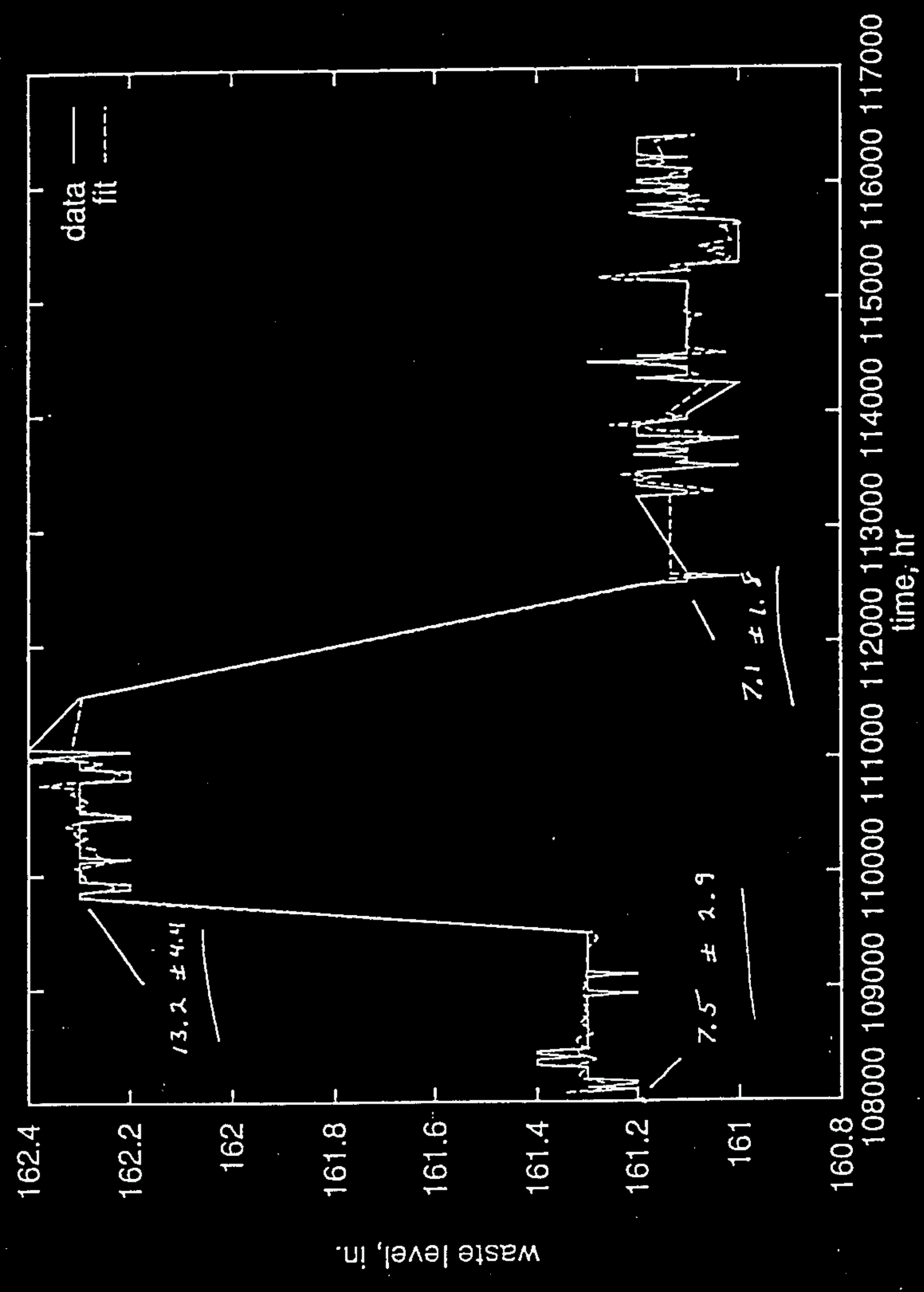
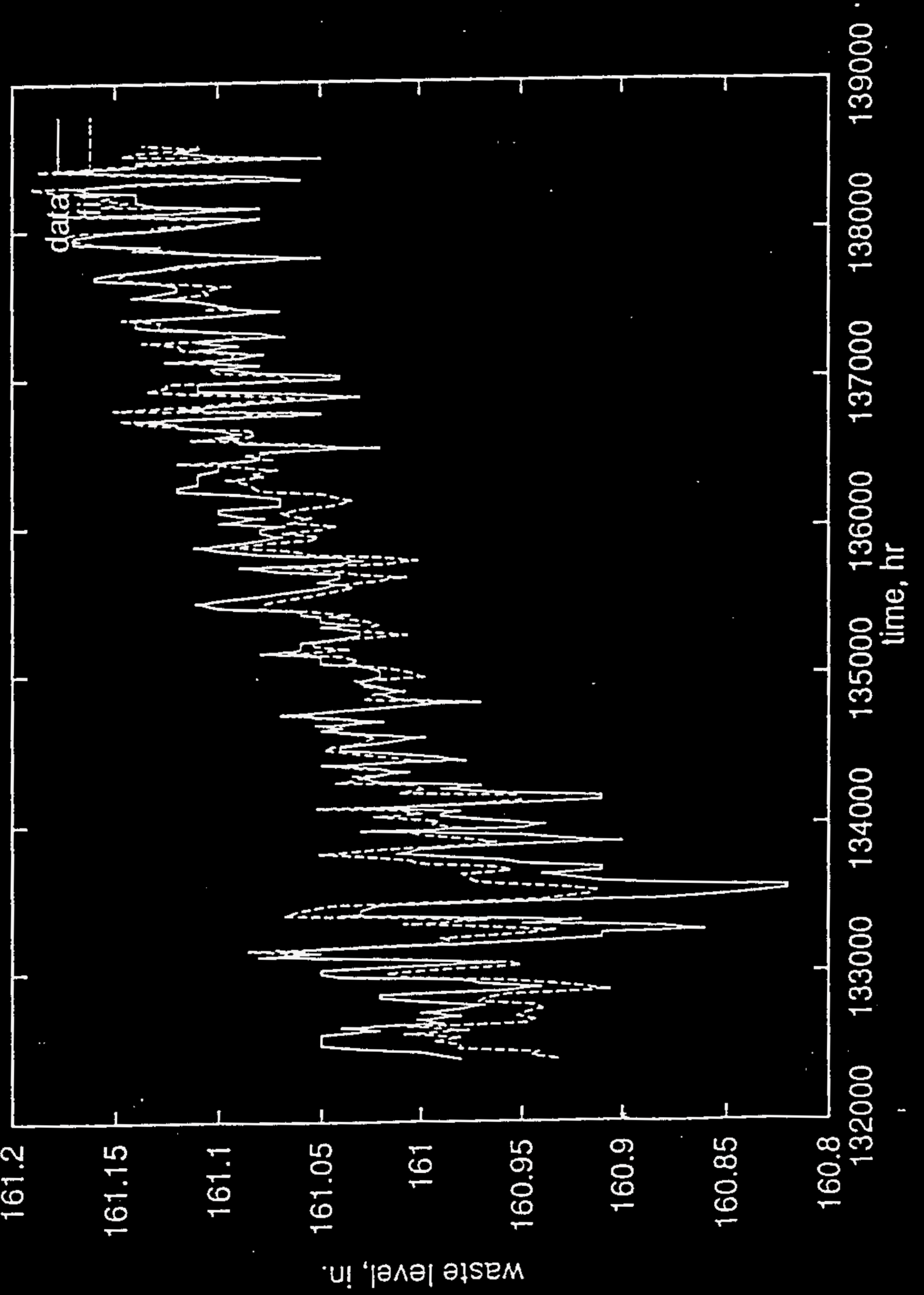


Figure 13. Least-Squares Analysis for Tank S-101 ENRAF Data.



5.2.7 Tank BY-106

The final example considered was some manual tape data for tank BY-106. In general, manual tape data have not been demonstrated to give reliable estimates of trapped gas. Indeed, as shown in Figure 14, the level data are of poor quality. Nevertheless, the least-squares analysis gives weak statistical evidence of trapped gas and the possibility that the manual tape data may be of some value.

6.0 CONCLUSIONS

A general model of the waste level in Hanford tanks was developed to assess methods of estimating the amount of trapped gas. A variety of effects such as discontinuities in both waste and trapped gas, evaporation, and unknown effects in addition to variations arising from barometric pressure fluctuations were included. The model was implemented in a generalized least-squares framework based on singular value decomposition.

The model was applied to both artifically created pseudo data as well as actual tank data. In this way, verification of the model and validation with actual tank data can be separately approached.

In comparisons with a simpler model developed by PNNL, it was found that the PNNL procedure for estimating dL/dP's is robust and generally gives values comparable to the more general model developed here. The general approach has the advantage of providing a more complete and robust picture of surface level variations. As such it provides the higher level of confidence that comes from a more detailed understanding of the relevant processes.

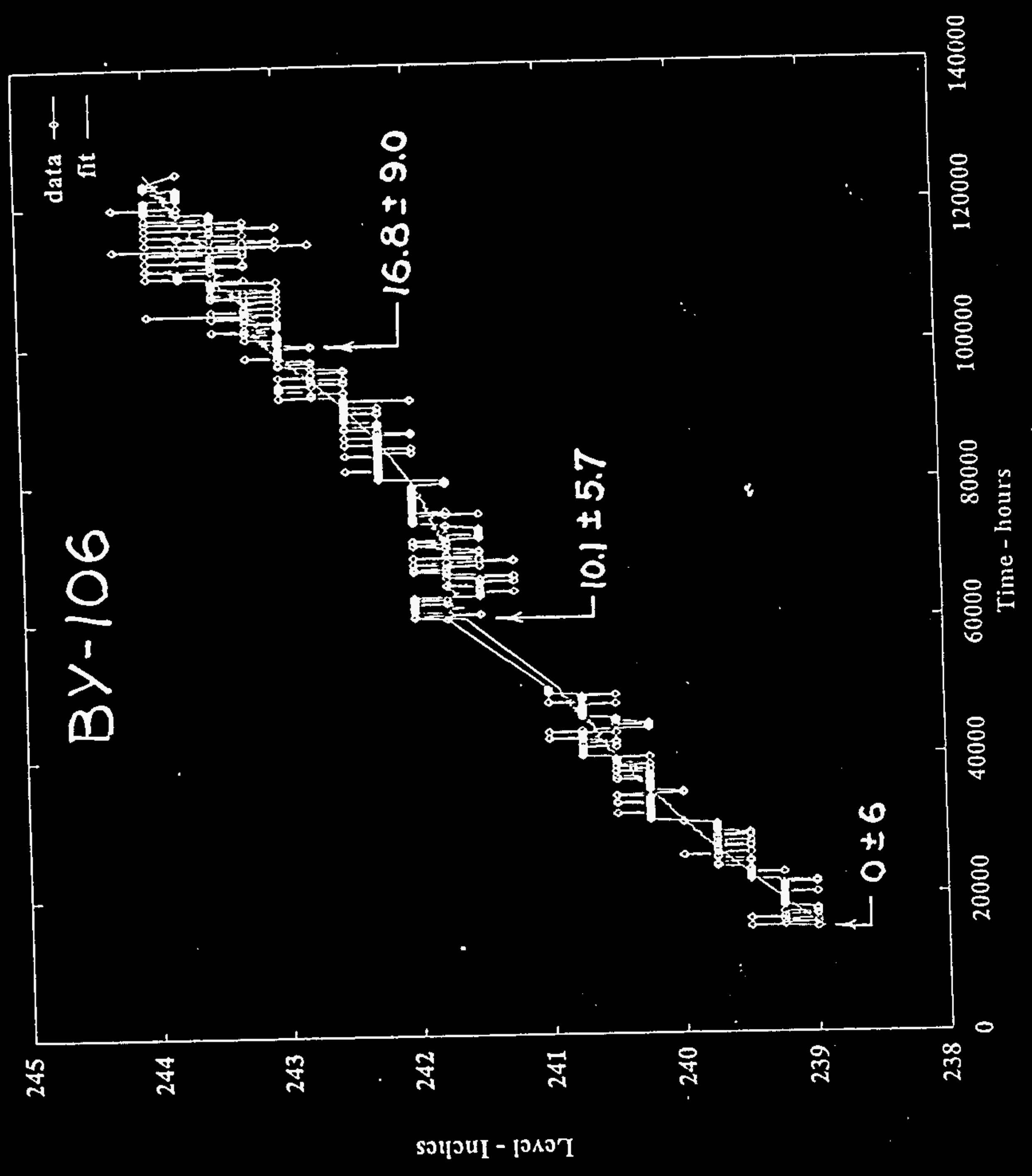
Specific cases of flawed data were identified and illustrate the importance of understanding the data used. The Hanford tanks often have unique characteristics that must be considered.

The estimated amounts of trapped gas are semi-quantitatively supported by undocumented void fraction measurements and reasonable general trends. For example, the estimated amounts of trapped gas for tank SY-101 are much larger than for most other tanks, and the amount after mitigation is substantially smaller than before.

The overburden pressure is identified as a sensitive parameter needing further study. Preliminary analyses of GRE events indicate that changes in overburden pressure may be necessary to be to obtain a consistent interpretation.

The general model developed here provides a sound basis for incremental improvements that could be of significant benefit. A key benefit is the more defensible analyses that accrue from a better understanding of the physical phenomena involved.

Figure 14. Least-Squares Analysis for Tank BY-106.



8.0 REFERENCES

Albert, A. 1972, *Regression and the Moore-Pensose Pseudoinverse*, Academic Press, New York, New York.

Press, W. H., et al. 1989, *Numerical Recipes*, Cambridge University Press, New York, New York.

Whitney, P. 1995, *Screening the Hanford Tanks for Trapped Gas*, PNL-10821, Pacific Norhtwest Laboratory, Richland, Washington.

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