BWR WATER LEVEL MODELING

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INTRODUCTION

Water level has been one of the more difficult BWR measured parameters to predict accurately. This parameter has a significant influence on RETRAN (Reference 1) transient simulations, as several trips key off the water level signal. Feedwater flow is also controlled based on water level deviation and steam-feed mismatch signals. To accurately predict level response, it is necessary to calculate transient feedwater and steam flow, the distribution of liquid inventory within the vessel and measuring device transient behavior. While each of these considerations is important, this paper concentrates on the prediction of liquid distribution within the vessel.

Results of transient simulations of level setpoint changes and a load rejection transient are presented. It is shown that the accurate prediction of separator liquid inventory is essential to achieving good comparisons to measured data for the level setpoint change tests. Use of a level adjustment to the RETRAN prediction based on vendor separator data is shown to significantly improve comparisons to data. Nodalization in the region of the separators and dryers influences the amount of adjustment required.

For more significant transients such as a load rejection, RETRAN predictions are in reasonable agreement with test data without the type of adjustment required to accurately predict level for setpoint changes. The vendor data on which the adjustment was based are essentially steady-state performance data. For significant transients the RETRAN predictions of separator inventory appear to track plant data well.

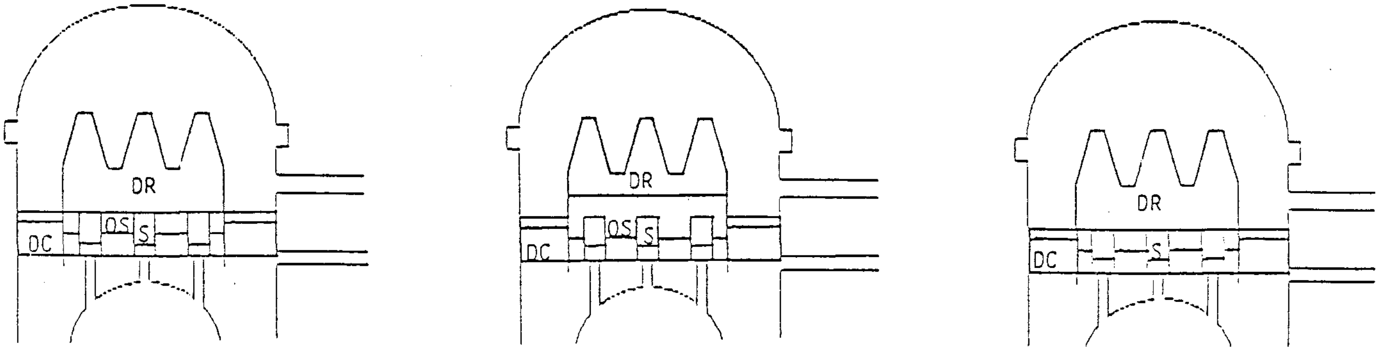
WATER LEVEL MEASUREMENT

Water level in a BWR is determined by measuring the differential pressure between reference leg and variable leg water columns attached to the reactor vessel. Level in the reference leg remains constant while level in the variable leg follows vessel level. Both wide and narrow range instruments are used with ranges of approximately sixty and two hundred ten inches, respectively. The differential pressure measurement in inches of cold water is converted to instrument level indication using a plant specific calibration curve. Since the differential pressure is not measured in the vessel itself, transient response of the instrument lines may also affect the measured level.

RETRAN WATER LEVEL MODELING

Presuming that a proper initial steady-state has been achieved, and that feedwater and steam flow are correctly predicted, the total liquid inventory of the vessel will be correct. Downcomer water level will be dependent on the distribution of liquid within the vessel. To accurately model level changes, it is necessary to predict changes in liquid inventory in the separators, downcomer, core, upper plenum and between the separators and the dryer skirt.

A number of different nodalizations have been used to model BWRs in the region of the separators. Reference 2 discusses several of these noding variations. Three such variations are shown in Figure 1.



Noding Scheme A

Noding Scheme B

Noding Scheme C

Figure 1. Separator Region Noding Schemes

Noding scheme A has one node representing the inside of the separators, a second node between the separators and the dryer skirt, and a third node between the dryer skirt and the vessel. A variation of this noding with the separator steam flow directly to the dryer node is shown as noding scheme B. Note that noding scheme A has the separator outlet junction connected to the node which represents the volume between the separators and the dryer skirt. Noding scheme C is a variation of scheme A which combines the nodes outside the separator. Noding scheme A is used for the calculations which follow.

While RETRAN calculates a collapsed liquid level in the downcomer nodes, this level is not equivalent to the measured level. The RETRAN nodes have a constant cross sectional area, whereas there are significantly more area variations with elevation in the vessel. Therefore, control system models are used to calculate the water level indications. A template of water level versus liquid volume is used to determine the collapsed liquid elevation in the downcomer. Variable leg head is then calculated as the sum of liquid head, steam head, dryer pressure drop and, in the case of wide range level, dynamic head at the lower tap elevation. The lower tap for narrow range level is located in a region of the downcomer which has a relatively large cross sectional area, and hence a low fluid velocity. Thus the dynamic head, which is proportional to velocity squared, is neglected for the narrow range instrument. Reference leg head is assumed constant. Pressure difference between the reference and variable legs is converted to inches of cold water, and then to indicated level using a plant specific instrument calibration curve.

The transient response of the instrument lines connecting the reference and variable legs to the vessel is neglected, since the frequency response is quite high compared to that of the level signals. Differential pressure instrument response is modeled as a first order lag.

WATER LEVEL ADJUSTMENT

Vendor data (Reference 3) shows that separator liquid mass inventory depends on inlet quality and is only a weak function of inlet flow rate. For a level setpoint change transient, the power and the inlet quality will remain essentially constant. Separator liquid mass inventory should, therefore, remain constant as the level outside of the separators rises or falls. A tendency for RETRAN predicted separator level and liquid inventory to follow the level outside the separator has been observed for a number of different BWR RETRAN models. The extent of the tendency varies significantly among different models. To adjust the control system calculated level, a term is calculated which is equal to the difference in separator liquid volume as determined from the vendor data and as calculated by RETRAN. The vendor data (Reference 3) gives the thickness of the annular water layer inside of the separator as a function of inlet quality. The volume of liquid which is expected to be inside the separator can be determined from this data. RETRAN initial liquid volume can also be made to be consistent with this value.

The excess liquid volume predicted by RETRAN, that is, the RETRAN liquid volume less the liquid volume determined from vendor data, is then distributed to the volume outside of the separators. No actual mass transfer takes place in the RETRAN calculations. The control system calculated level is adjusted by adding a correction term which is the excess volume divided by the cross sectional area between the separators and the reactor vessel. Since the vendor data is based on steady-state separator performance, it may not be appropriate for rapid changes in inlet quality. Tests run with various models indicate that updating the correction is not appropriate following reactor scram. Therefore, the correction term is calculated up to the time of scram and is then frozen. The frozen correction term is applied after scram. It is noted that the magnitude of the correction depends on the details of the RETRAN noding and model selection.

RETRAN SYSTEM MODEL

Figure 2 shows a noding diagram of a RETRAN model for a BWR6 plant. The model uses noding scheme A, shown in Figure 1, in the separator region. The RETRAN separator component model is not used. Separation is achieved by use of the bubble rise model. One-dimensional kinetics are used and the pressure control, recirculation flow control and feedwater control systems are modeled in considerable detail. The model is discussed further in Reference 4.

LEVEL SETPOINT CHANGE SIMULATIONS

During startup testing, the feedwater control system is tuned to achieve the desired response characteristics. The level setpoint is changed and control system parameters are adjusted until the desired responses are obtained. The RETRAN model was used to simulate both positive and negative level setpoint changes initiated at TC-6 (essentially 100P/100F state point) conditions during startup testing. Results of these simulations are compared to test data.

Figure 3 shows the comparison of RETRAN calculated level to startup test data for a plus six inch level setpoint change. The level correction term is used in this case. Figure 4 shows a similar plot for a case where the level correction term was not used. Feedwater flow versus time for these two cases is shown in Figures 5 and 6, respectively. Note that the level response without the correction is slow compared to the data. That is, the data show that the new level is reached within the twenty-five second time frame of the calculation, but the uncorrected RETRAN calculations do not reach the new desired level unless the correction term is added.

Figures 7 and 8 show level versus time compared to test data for a negative 7.8 inch setpoint change. Again the response compares much more favorably to test data when the correction term is added.

LOAD REJECTION TRANSIENT

Figure 9 shows narrow range level versus time following a load rejection transient compared to plant data. The level correction is applied only up to the time of scram. Application of the correction following scram resulted in less favorable comparison to data. The vendor data do not show that the separator fills solid when the inlet quality goes to zero, as happened for this load rejection transient during which HPCS and RCIC were initiated. Therefore, application of the correction following reactor trip is not recommended.

SENSITIVITY STUDIES

The positive setpoint change was run again with the noding schemes shown in Figure 1, Noding Schemes B and C. The correction term was about the same order of magnitude for Scheme C, but was reduced by about one-third for scheme B. It, therefore, appears desirable to connect the separator outlet junction to the "separator to dryer skirt" node rather than directly to the dryer. Several other noding schemes were also studied.

A more complete study of noding options including the manner of connecting junctions is desirable, in the absence of a mechanistic separator model. It was observed that the need for a correction term to adequately match plant data for level setpoint changes was less for some other forms of nodalization in the separator region, although all models exibited the trend of changing separator liquid inventory in the absence of inlet quality changes.

SUMMARY AND CONCLUSIONS

To a greater or lesser extent, depending upon noding in the separator region, water level inside the separator as calculated by RETRAN tends to follow the level outside the separator. While use of the separator component and modified noding schemes in the separator region may reduce this effect, it occurs to some extent in a number of RETRAN models for BWRs. The use of a correction term based on adjusting the water level to be consistent with vendor steady-state separator performance data was shown to improve level response results for level setpoint change transients.

While the adjustment improves water level response, the need for the adjustment indicates that separator modeling can still be a problem area in RETRAN-02. This indicates the need for the development of a mechanistic separator model.

REFERENCES

1. J. H. McFadden, et. al. "RETRAN-02: A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems" EPRI-NP-1850-CCM, Revision 3.

2. J. F. Harrison, et. al. "RETRAN-02: A Program for Transient Thermal Hydraulic Analysis of Complex Fluid Flow Systems" EPRI-NP-1850-CCM, Volume 5, p. IV-136.

3. General Electric Co. Report. NEDO-24154, October 1978.

4. J. S. Miller, et. al. "RETRAN Simulation of a BWR/6 Load Rejection Transient." To be presented at ANS Winter Meeting, San Francisco, California, November 1989.

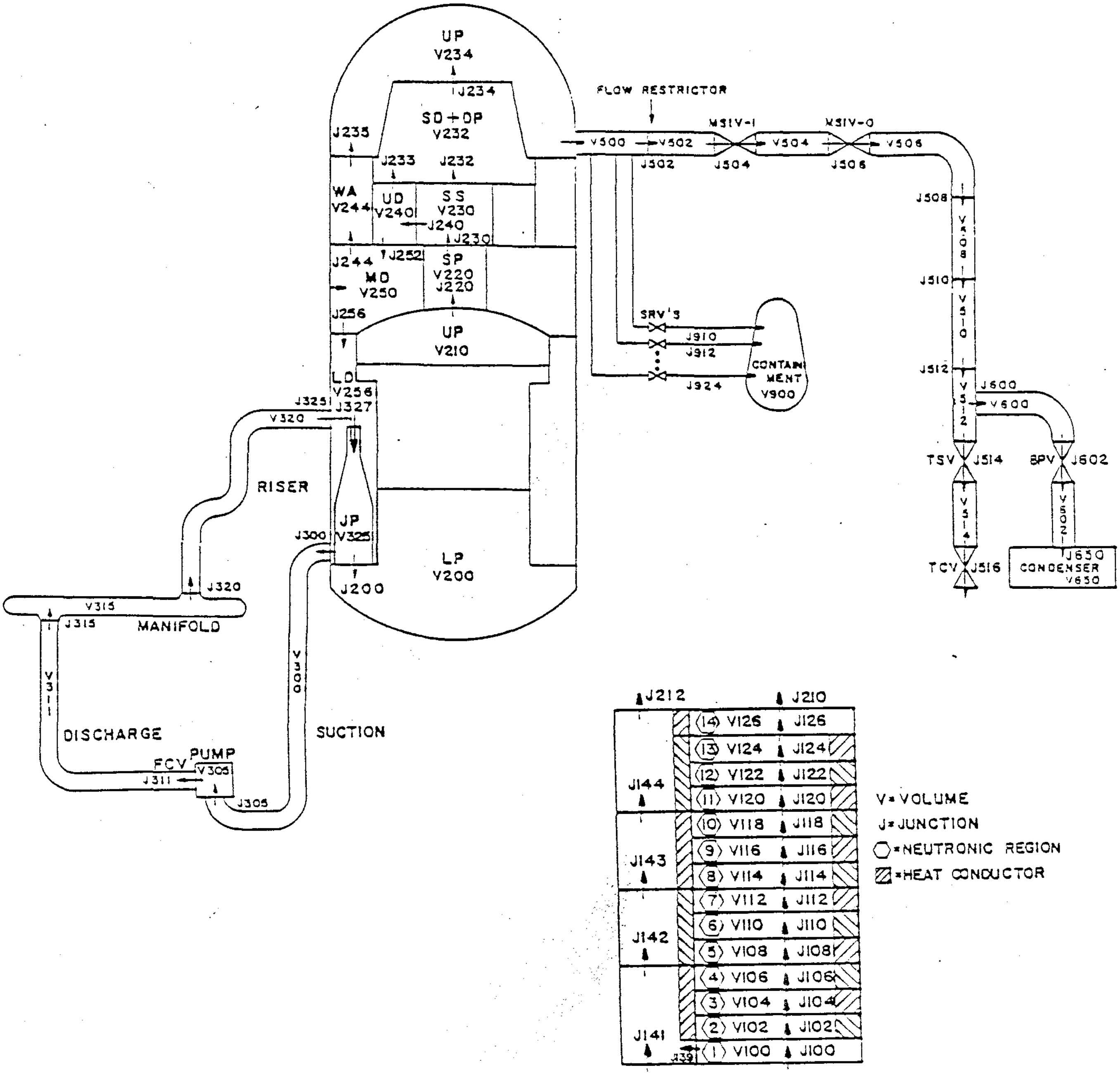


Figure 2. RETRAN Noding Diagram

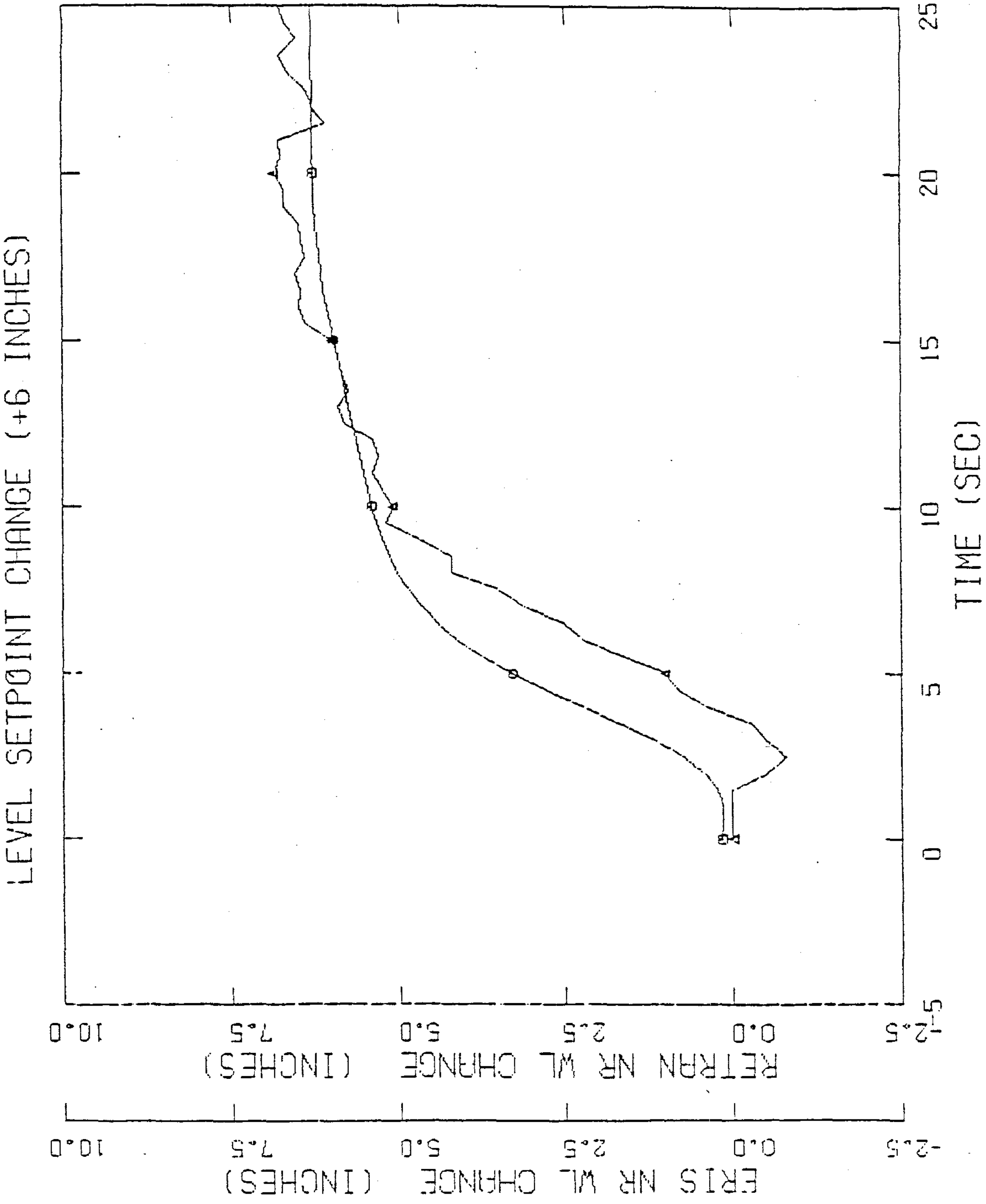


Figure 3. Level vs. Time, +6 in level setpoint change, with correction

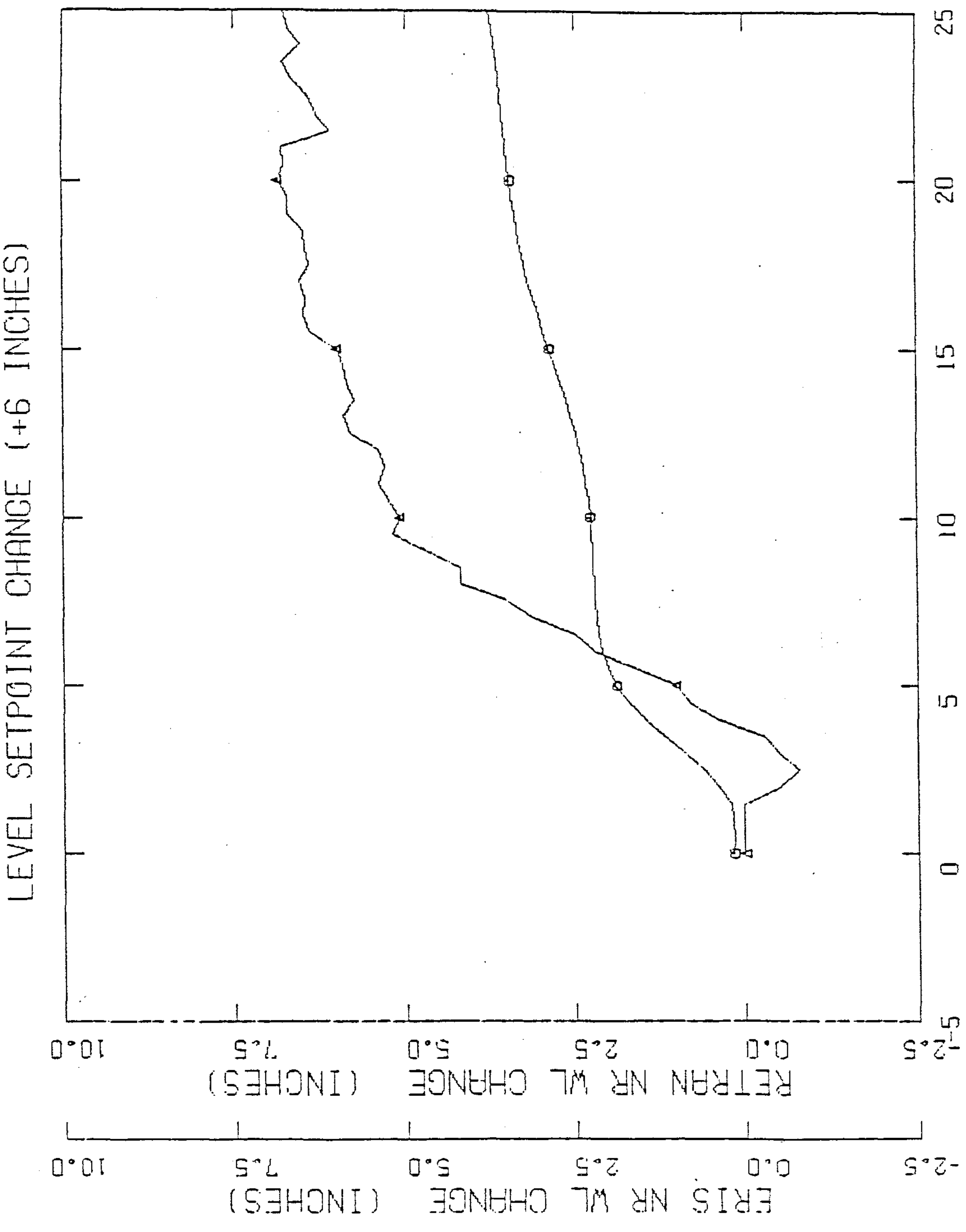


Figure 4. Level vs. Time, +6 in level setpoint change, without correction

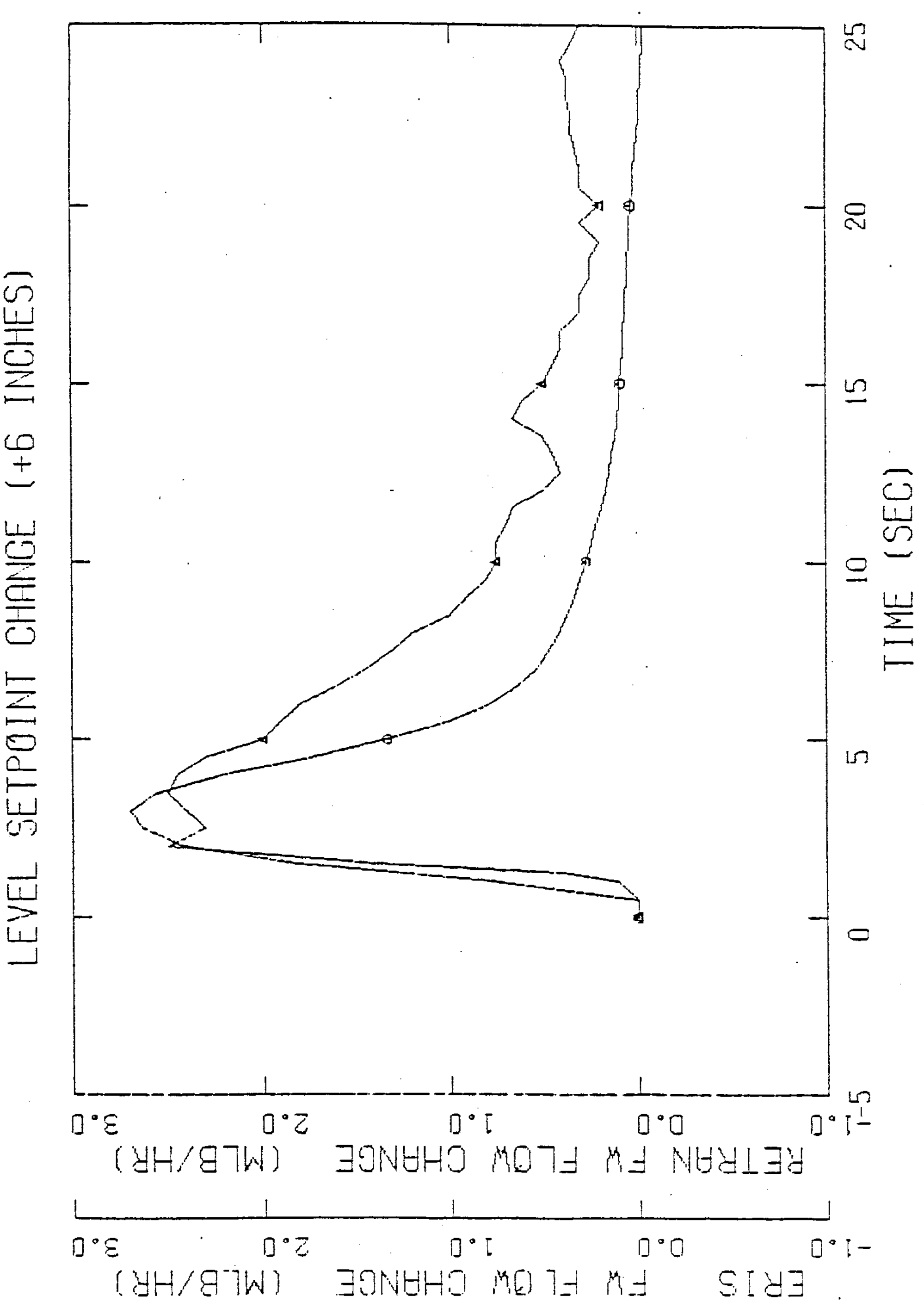


Figure 5. Feedwater Flow vs. Time, +6 in level setpoint change, with correction

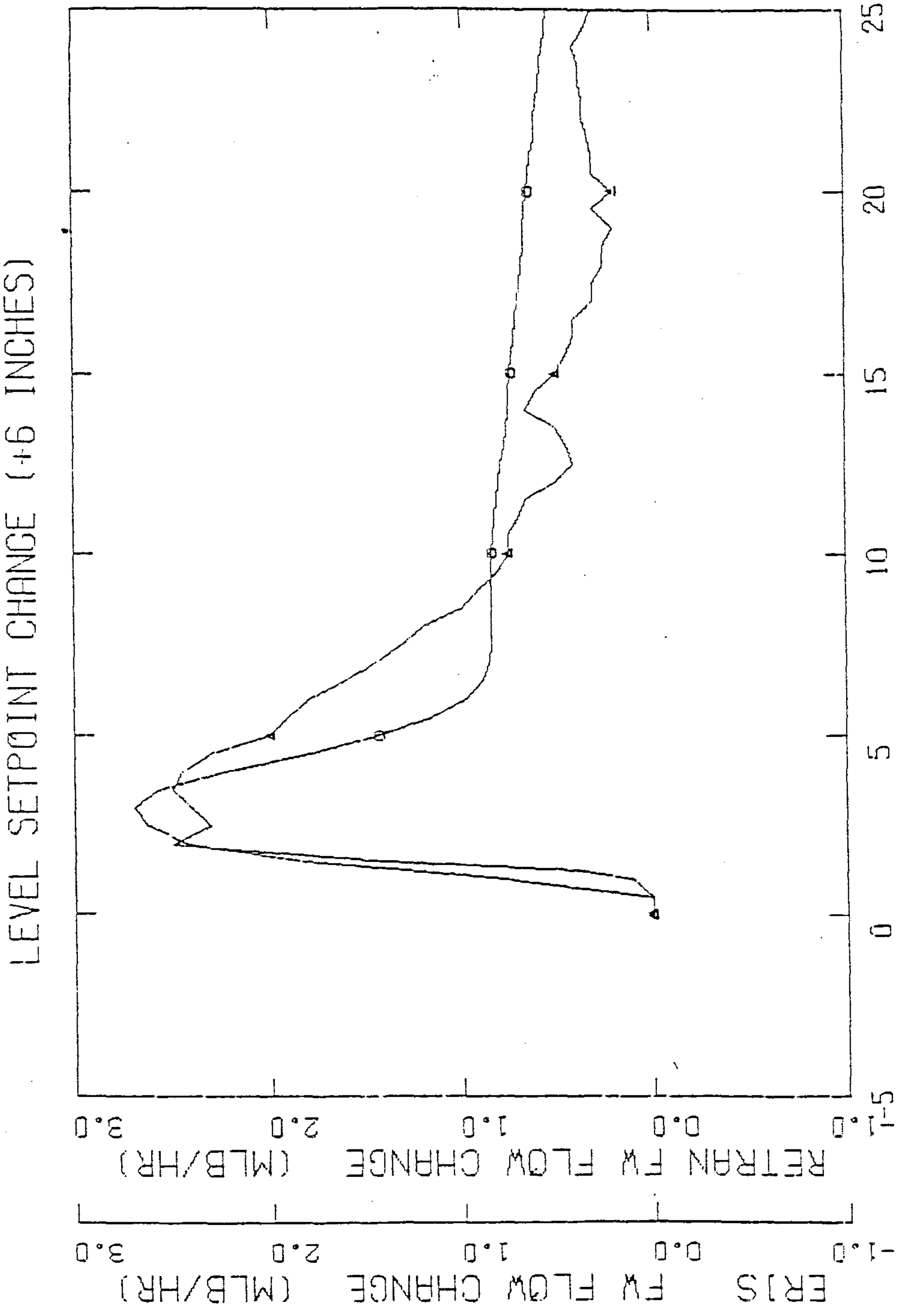


Figure 6. Feedwater Flow vs. Time, +6 in level setpoint change, without correction

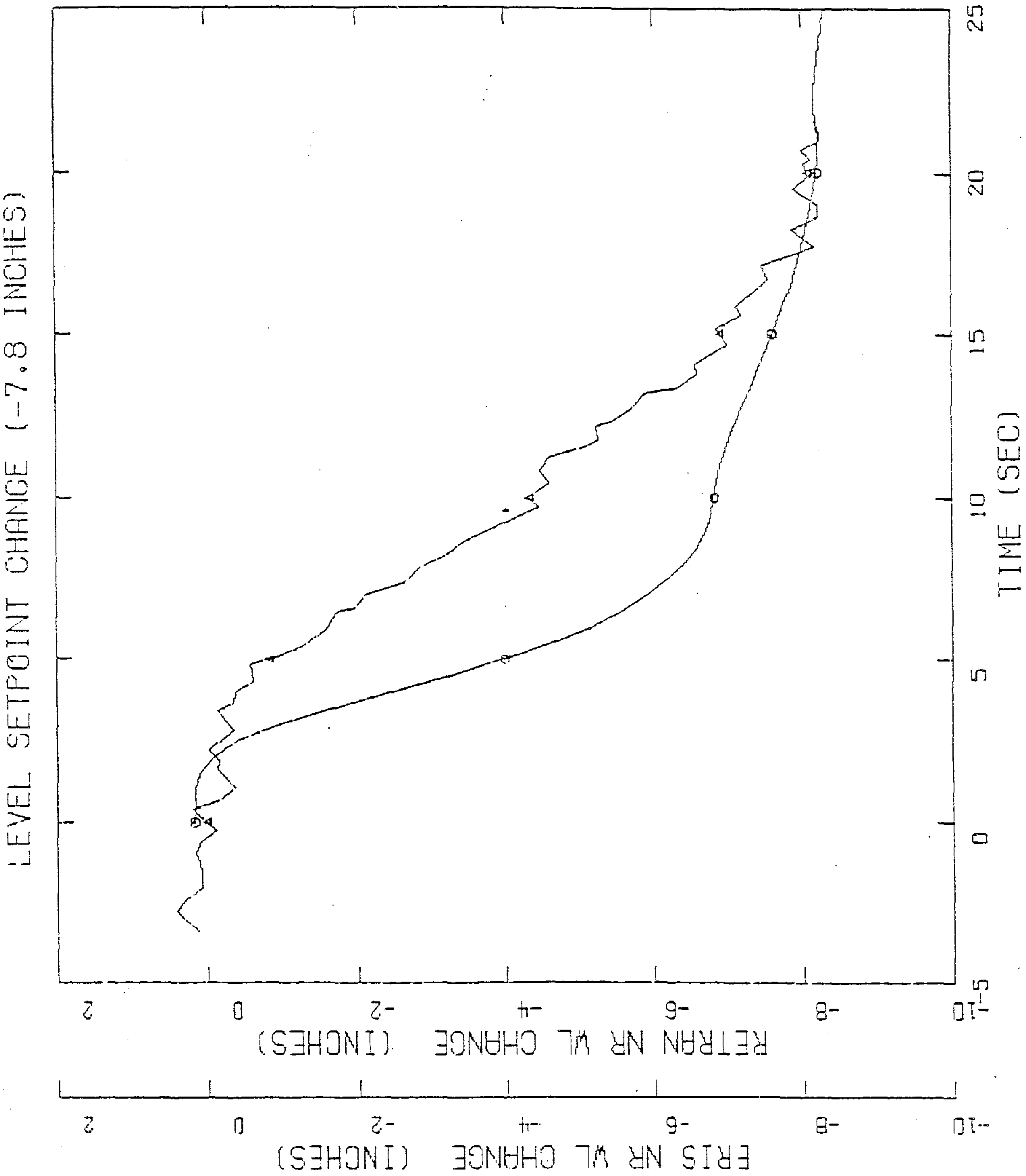


Figure 7. Level vs. Time, -7-8 in level setpoint change, with correction

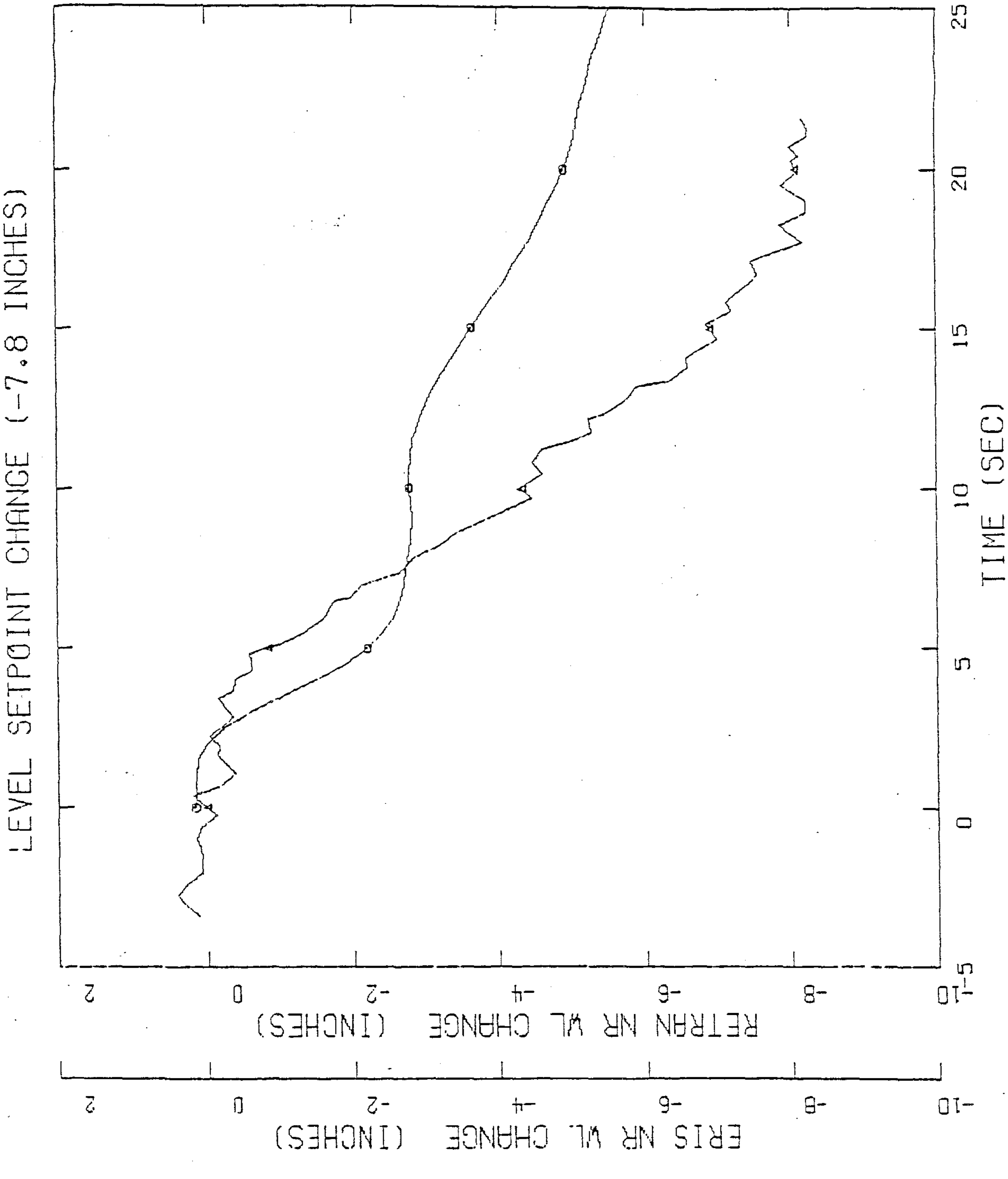


Figure 8. Level vs. Time, -7-8 in level setpoint change, without correction

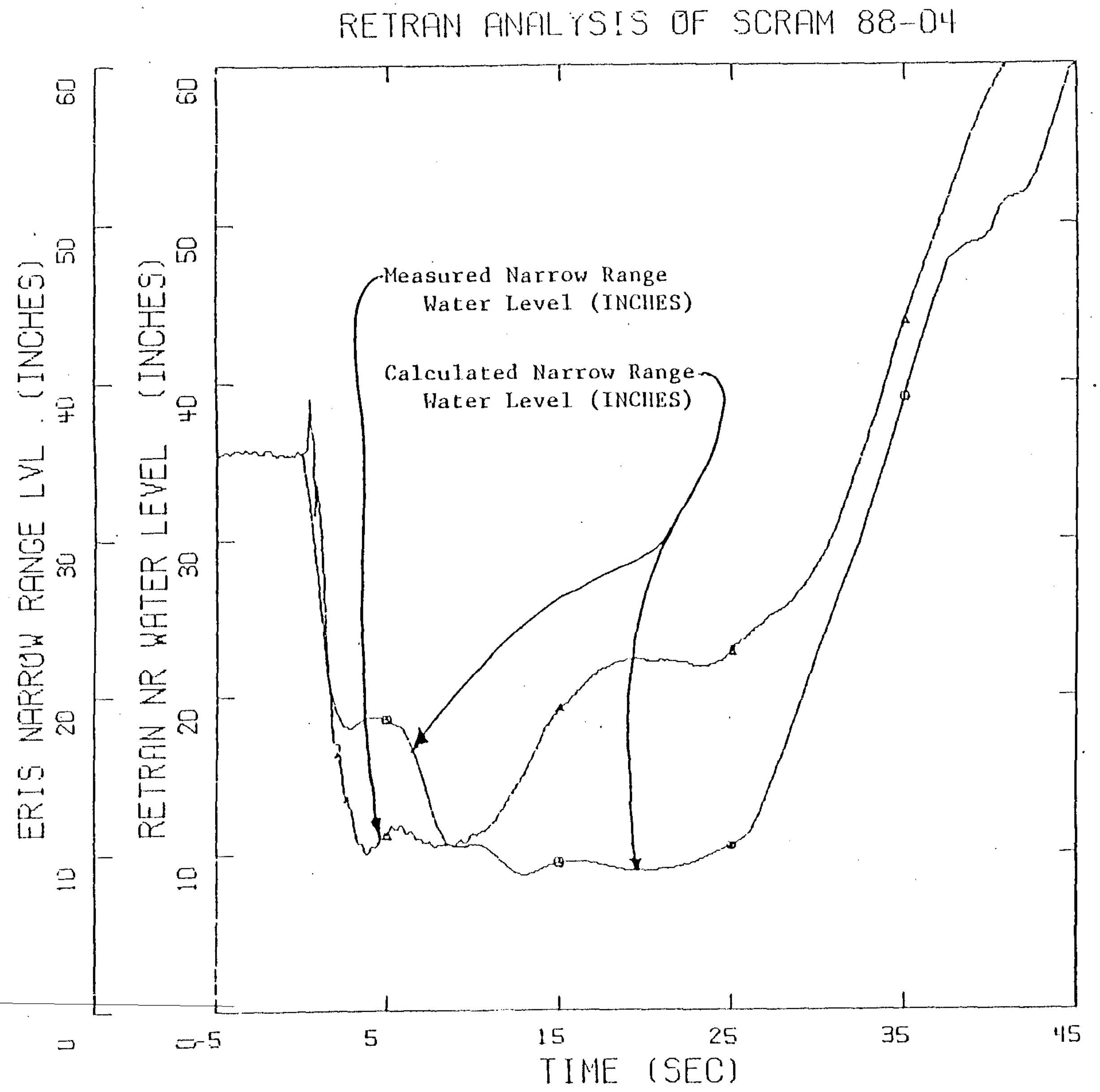


Figure 9. Narrow Range Level vs. Time for Load Rejection