CHAPTER 4. Investigations of vertical hydraulic conductivity in the confining bed separating the Wyodak coal from the overlying Wasatch sand lens aquifer.

I. Introduction

This investigation proceeds in similar fashion to that of chapter 3. The simplest case is considered first, and degrees of complexity are added in a step-wise fashion. The results of case 3b of chapter 3 are fixed in the cases of chapter 4; coal K=2.4, transition zone K=63, non-clinker cropline cells are inactive. Layer 1 remains as it was in chapter 3. The nature of the data available for layer 1 and the details of its construction do not allow for a systematic investigation of its aquifer properties. Layer 1 has been developed from all the available data in accordance with the conceptual model and its properties are not estimated in this study. Two additional monitoring wells are added inside the sand lens of layer 1, bringing the total number of calibration wells to 57. All 57 wells are used in the calculation of the mean residual or bias of the model. However, the two sand lens wells are also looked at apart from the rest of the wells to examine the fit of each model to the sand lens layer.

A range of plausible KV values and geometries given homogeneous coal are examined. The same investigation is conducted in chapter six given heterogeneous coal.

II. Method

Case KV1, homogeneous KV.

Case KV1 included only one KV zone over the entire model domain. The value of KV was varied in steps of half an order of magnitude from 1e-3 to 1e-7 feet/day. Once a value was arrived at, the estimate was refined by bisection.

Case KV2, heterogeneous KV, two zones.

Case KV2 broke the KV zone array into two zones, one underlying the sand lens (zone 1), and one underlying the Wasatch outside of the sand lens (zone 2) (Figure 4-1). KV in zones 1 and 2 was varied from 5e-5 to 1e-7 in steps of one-half an order of magnitude.

Case KV3, heterogeneous KV, three zones.

If one considers that KV may be different at either of the monitoring wells in the sand lens, a three-zone approach may prove beneficial (Figure 4-2). Consisting of three zones, the

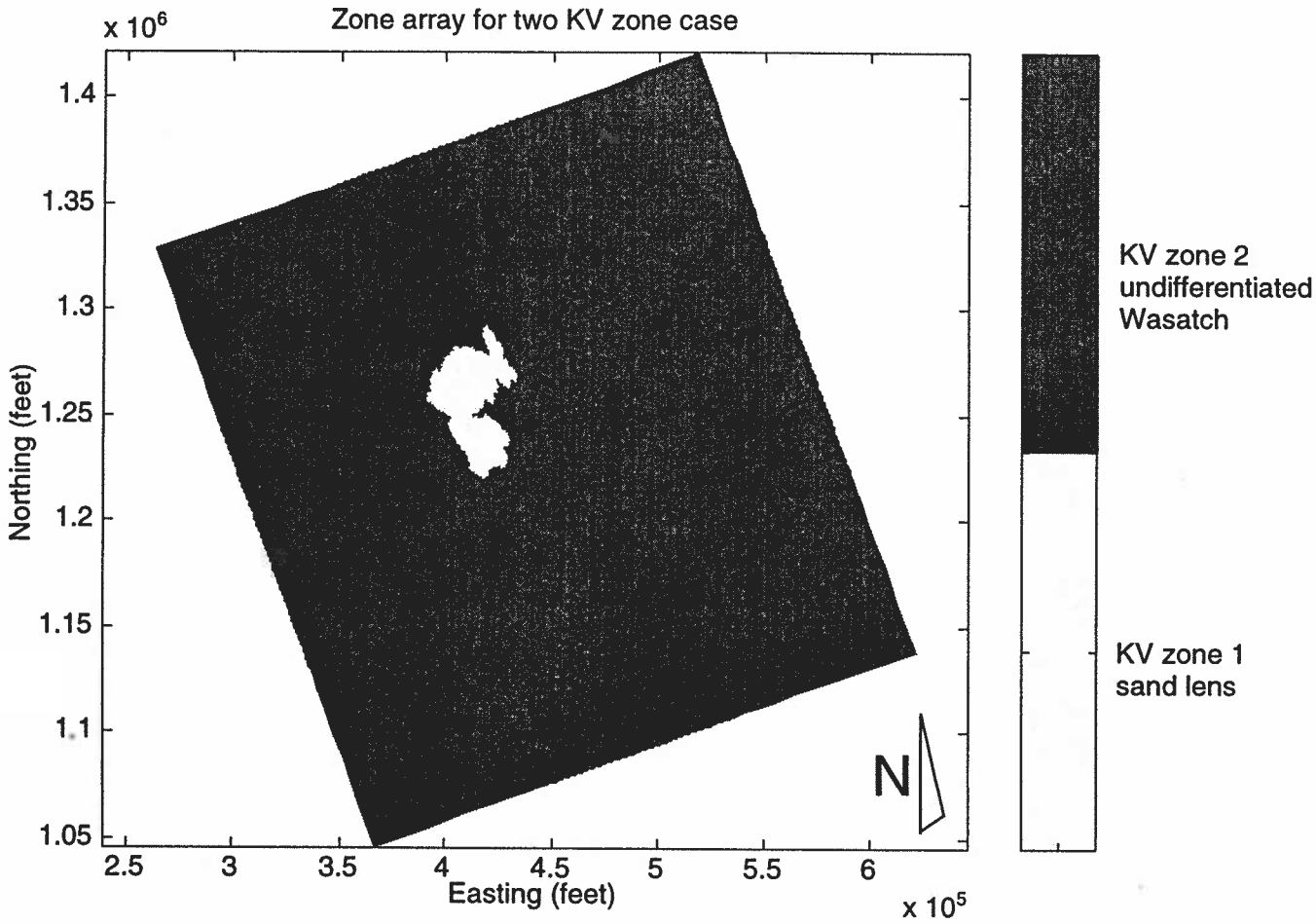


Figure 4-1. Zone array for KV, two zone case.

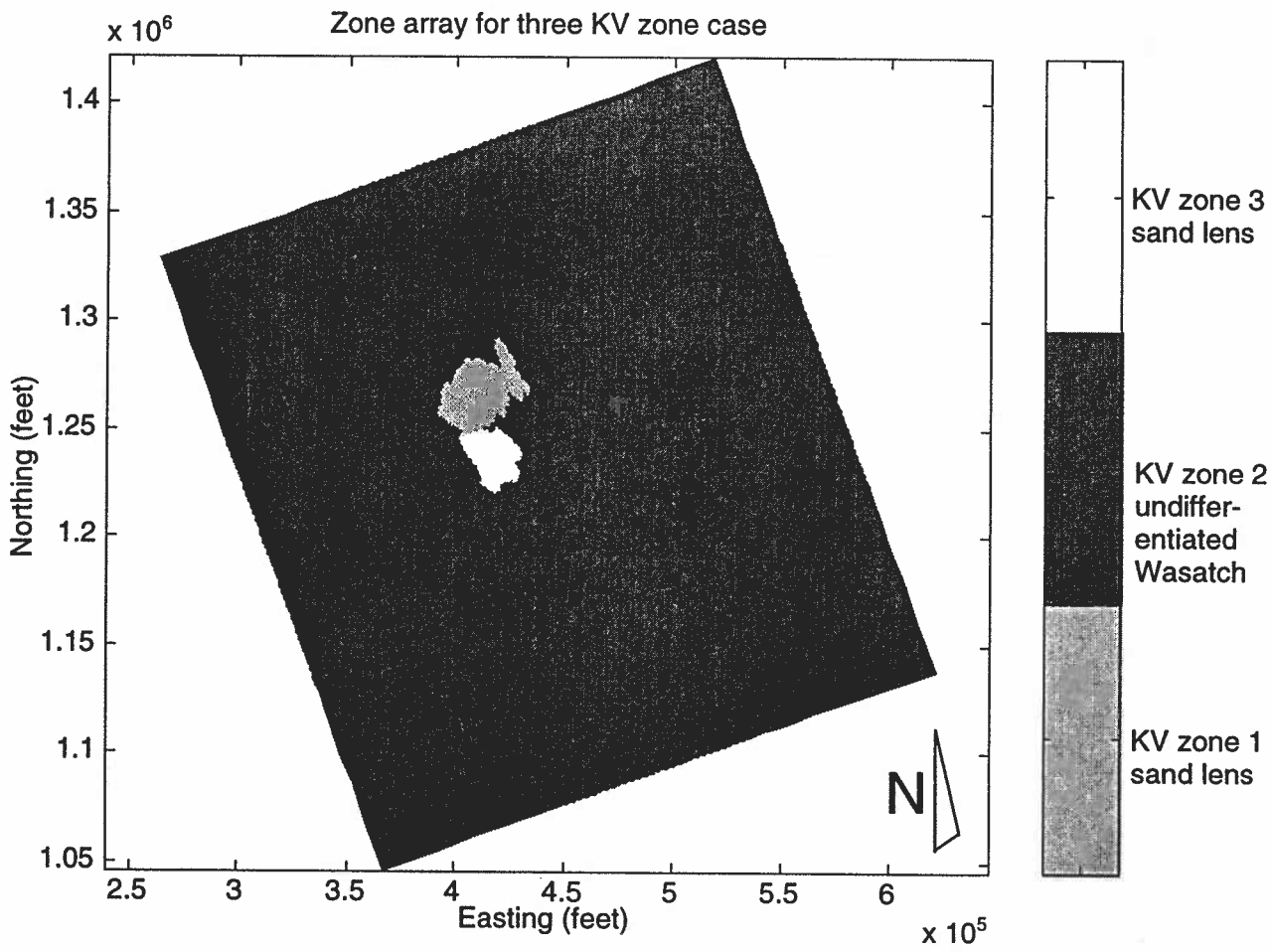


Figure 4-2. Zone array for KV, three zone case.

zone array for case KV3 was subdivided into two zones underlying the sand lens, one for each lobe (zones 1 and 3), and one zone underlying the Wasatch outside of the sand lens (zone 2). The KV in zones 1,2 and 3 was varied up and down from the best-fit scenario in case KV2 by an order of magnitude in steps of one-half an order of magnitude.

III. Results

Case KV1

The results indicate a best fit in the vicinity of 5e-6 feet/day resulting in a mean residual of -4.64 a budget discrepancy of -0.47% and a mean sand lens residual of 8.535 feet (Figures 4-3, 4-4). Complete results are shown in figures 4-3 and 4-4 and table 4-1. The estimate was further refined by bisection to 4.5e-6 feet/day. The head for layers 1 and 2, as calculated in case KV1 are shown in figures 4-5 and 4-6.

Case KV2

The best fit occurred with a KV in zone 1 equal to 1e-6 feet/day and a KV in zone 2 equal to 5e-6 feet/day. The resulting calibration values were a mean residual of -4.12 feet, a budget discrepancy of -0.19%, and a mean sand lens residual of -7.0. According to the charts (Figures 4-7 to 4-9) the mean sand lens residual may be improved to approximately 0 by moving KV of zone 1 to 2e-6. Complete results are shown in figures 4-7 through 4-9 and table 4-2.

Case KV3

The best fit occurred with a KV in zone 1 of 5e-6 feet/day, a KV in zone 2 of 5e-6 feet/day and a KV in zone 3 of 5e-7 feet/day. These values of KV result in a mean residual of -4.00 feet, a budget discrepancy of -0.20% and a mean sand lens residual of -3.62 feet. Complete results are shown in figures 4-10 through 4-12 and table 4-3.

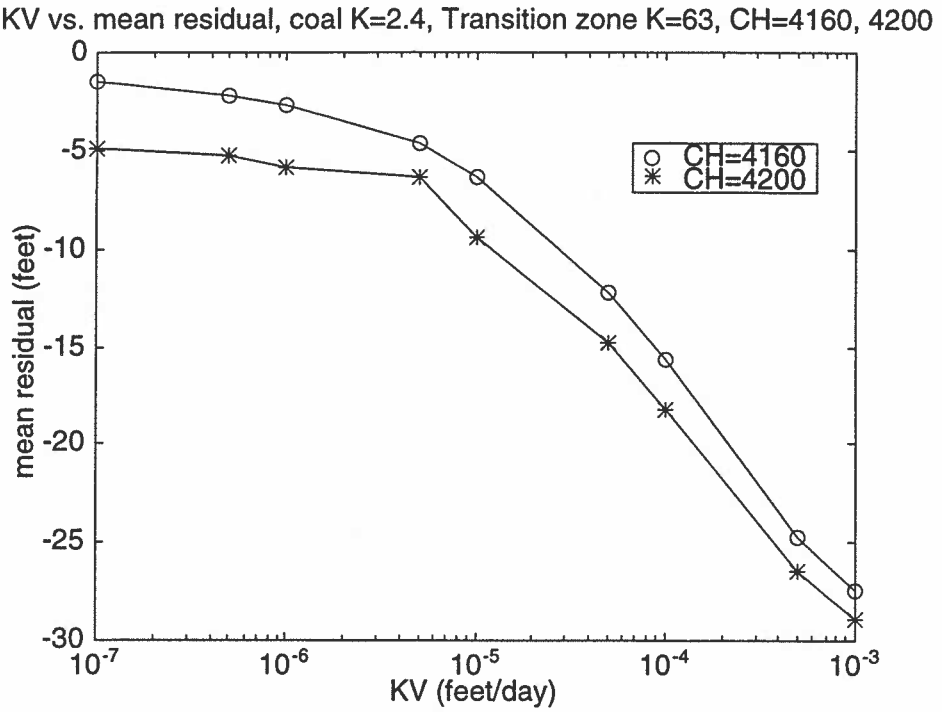
IV. Conclusions

Case KV1

4.5e-6 feet/day is a good first order approximation of the KV for the entire model domain. The model is clearly sensitive to this parameter.

Case KV2

Case KV2 demonstrates that the model is not sensitive to the zonation of the confining



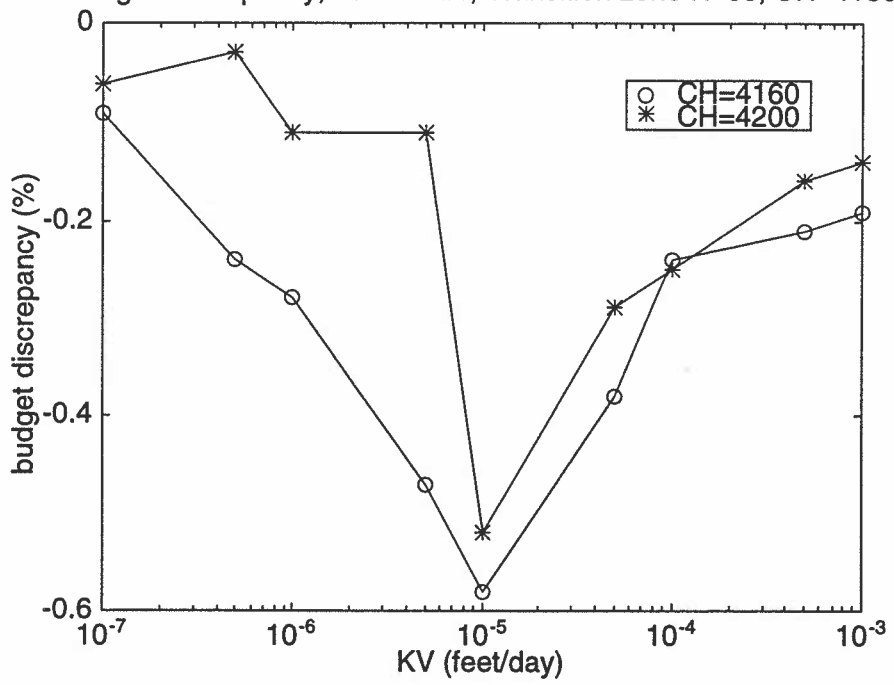


Figure 4-3. KV vs. mean residual and budget discrepancy for KV case 1; homogeneous KV, in one zone. Coal K=2.4, transition zone K=63, CH=4160 and 4200.

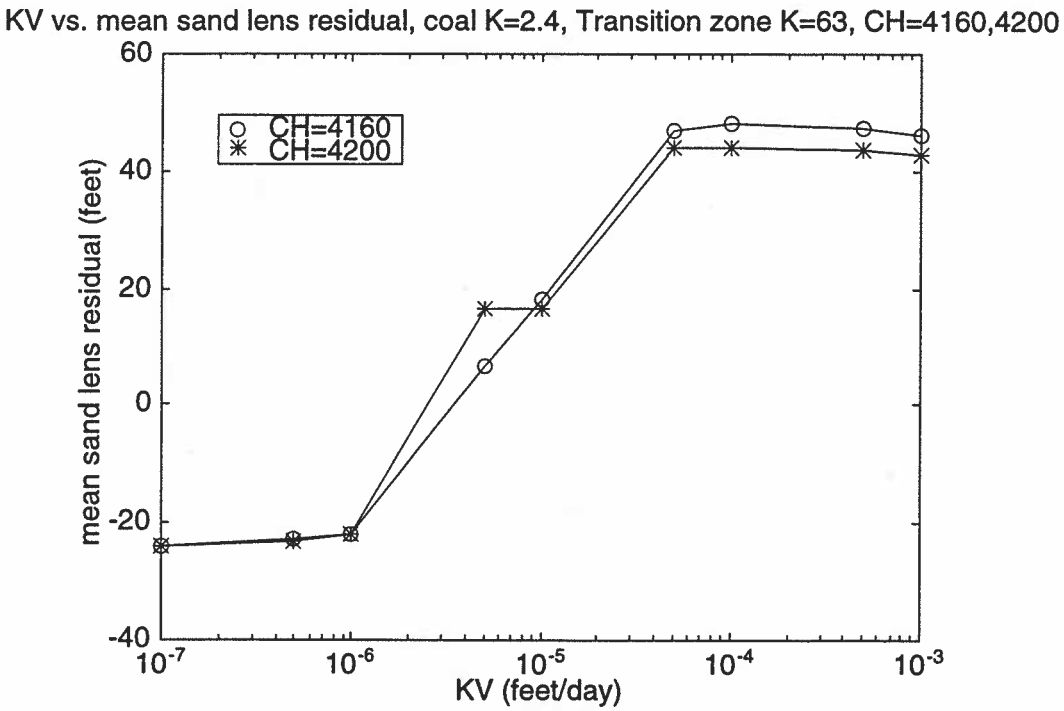


Figure 4-4. KV vs. mean sand lens residual for KV case 1; homogeneous KV, in one zone. Coal K=2.4, transition zone K=63, CH=4160 and CH=4200.

Table 4-1. Results of chapater 4 case KV1

CH=4160

simulation no.	KV (feet/day)	sum of the squared residuals	mean residual (feet)	budget discrepancy (%)	sand lens resid. #1	sand lens resid. #2	rmse (feet)
1	1.00E-04	119770	-15.7	-0.24	96.3	91.7	45.8
2	5.00E-05	114850	-12.3	-0.38	94.3	88.8	44.9
3	1.00E-05	99620	-6.4	-0.58	37.3	27.1	41.8
4	5.00E-06	100180	-4.6	-0.47	13.9	3.17	41.9
5	1.00E-06	111550	-2.8	-0.28	-43.7	-61.7	44.2
6	5.00E-07	113080	-2.2	-0.24	-45.5	-63.7	44.5
7	1.00E-07	114770	-1.5	-0.09	-47.7	-64.4	44.9
8	5.00E-04	142600	-24.7	-0.21	94.7	86.7	50.0
9	1.00E-03	153960	-27.4	-0.19	92.3	86.1	52.0

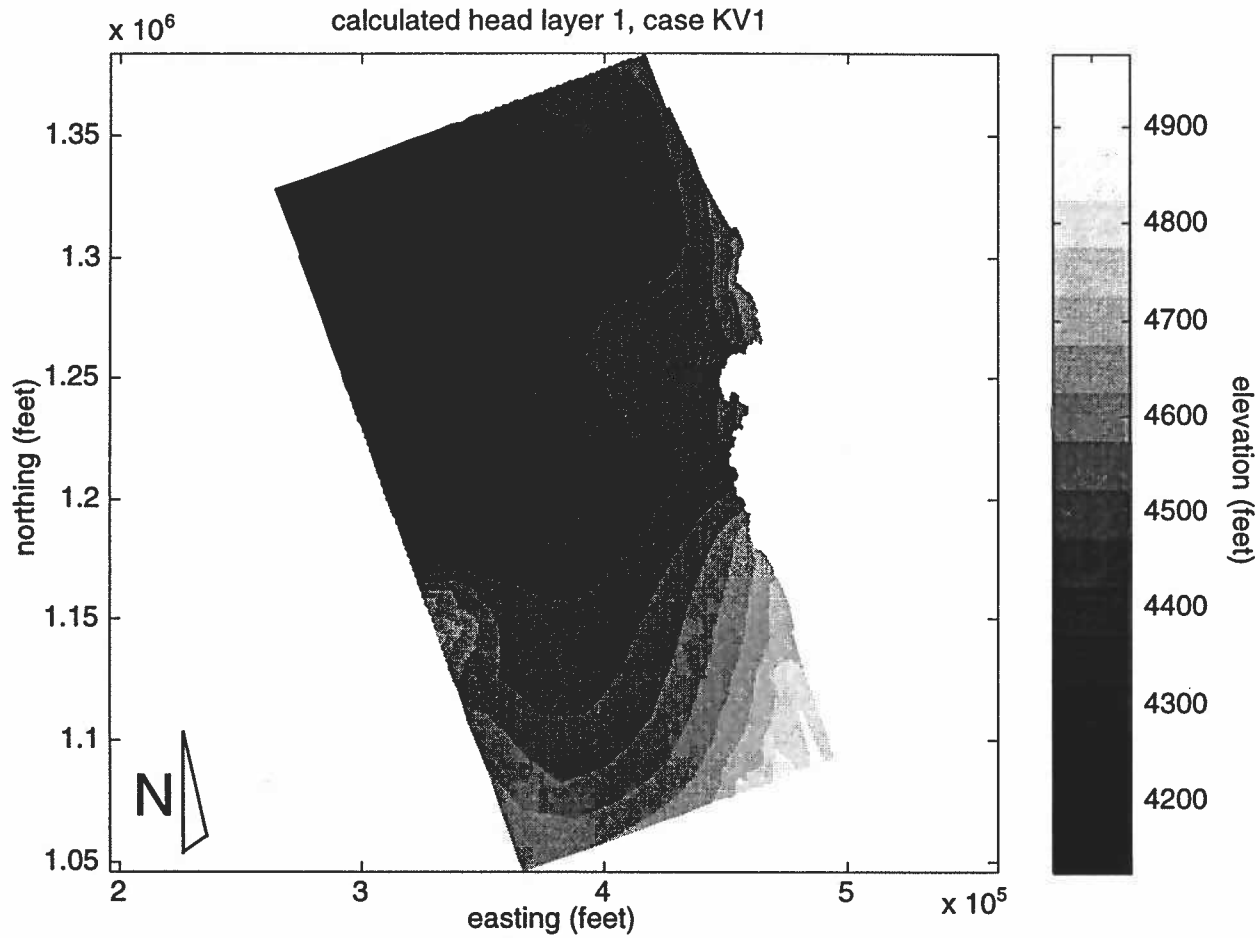


Figure 4-5. Head calculated in case KV1 layer 1; homogeneous coal, heterogeneous transition zone, non-clinker cropline cells inactive, KV = 4.5E-06 feet/day.

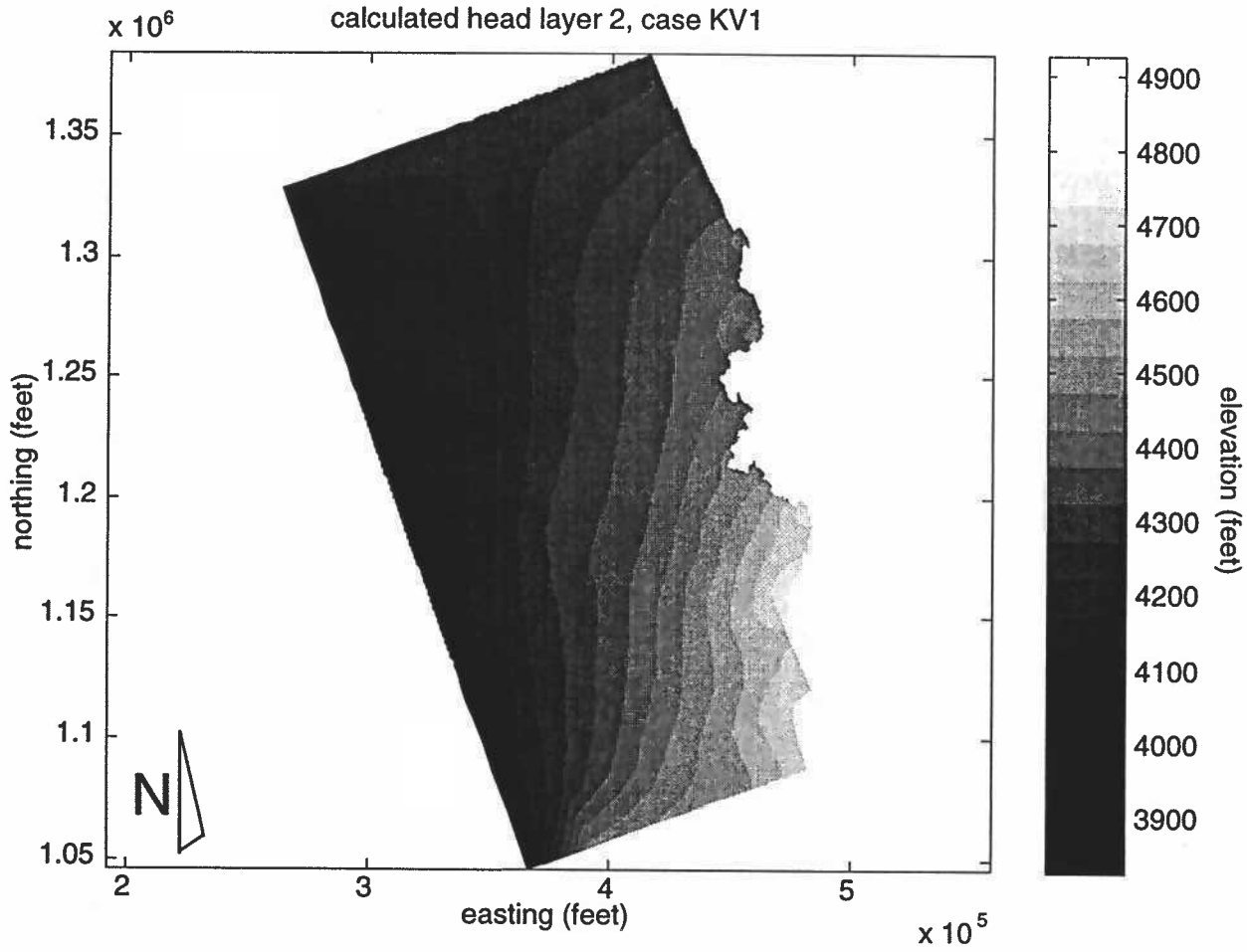


Figure 4-6. Head calculated in case KV1, layer 2; homogeneous coal, heterogeneous transition zone, non-clinker cropline cells inactive, KV = 4.5E-06 feet/day.

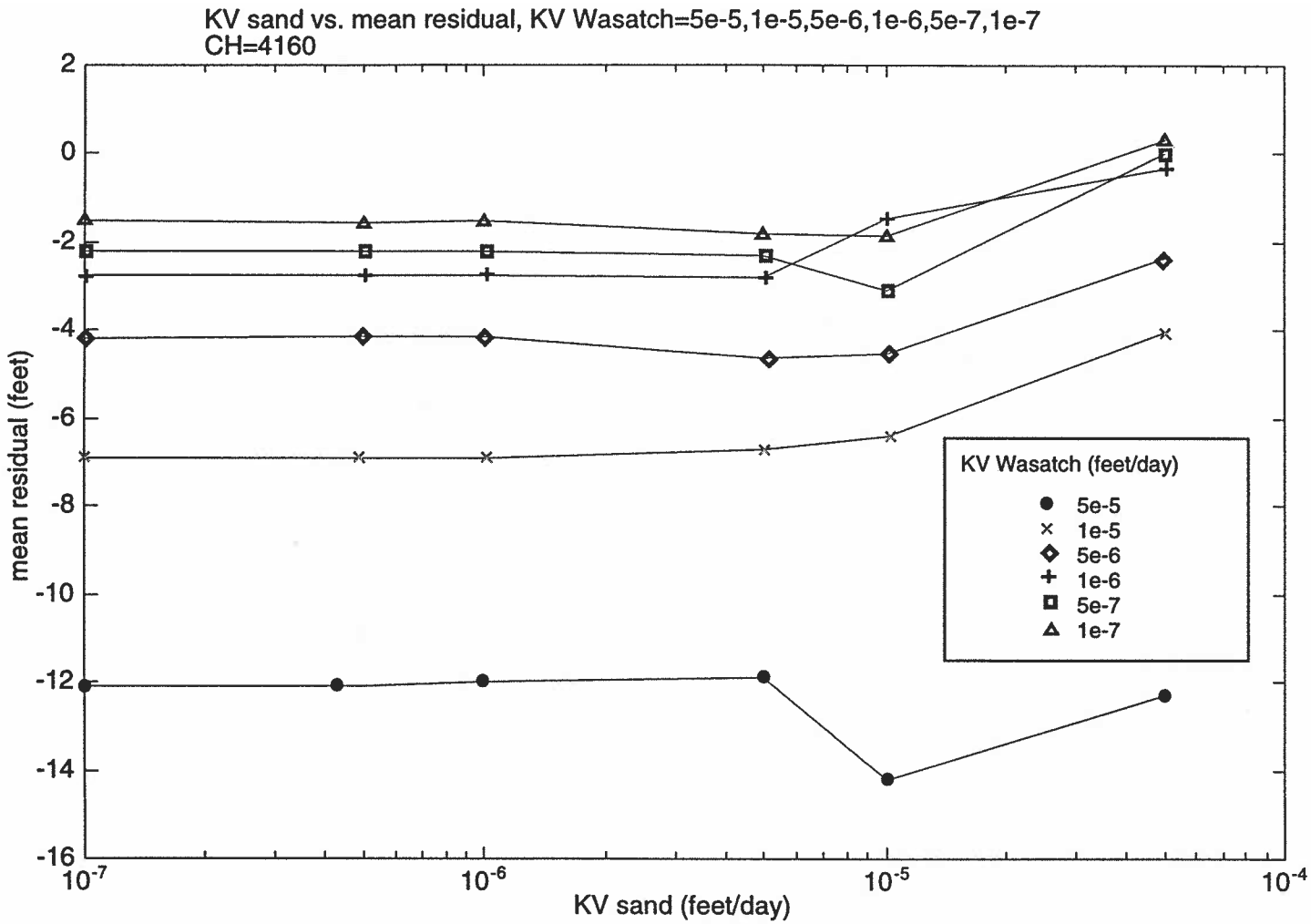


Figure 4-7. Case KV2. KV of the confining layer underlying the sand lens vs. mean residual. KV of the confining layer underlying the Wasatch, outside of the sand lens fixed at values shown in figure, CH fixed at 4160 feet.

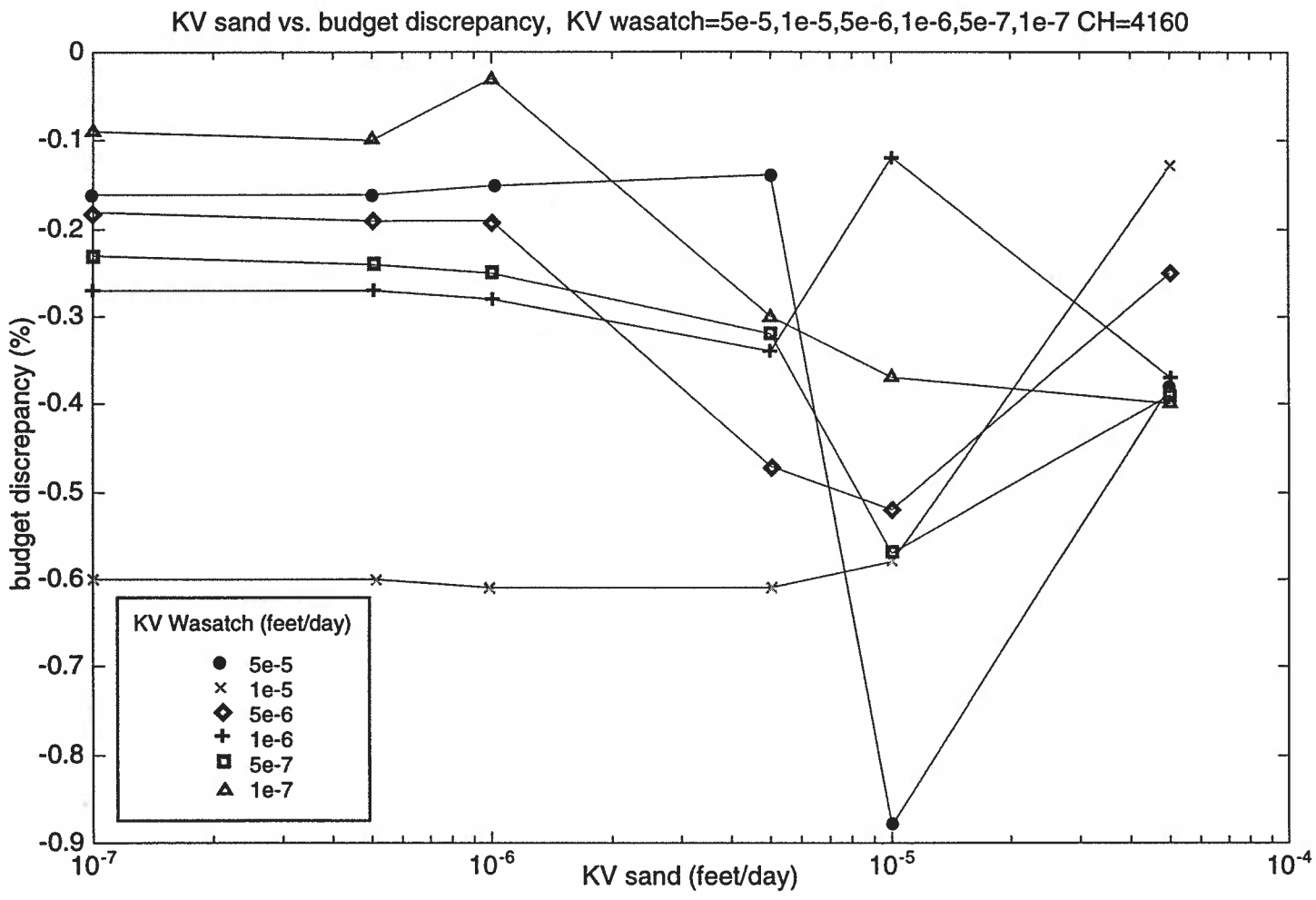


Figure 4-8. Case KV2. KV of the confining layer underlying the sand lens vs. budget discrepancy. KV of the confining layer underlying the Wasatch, outside of the sand lens fixed at values shown in figure, CH fixed at 4160 feet.

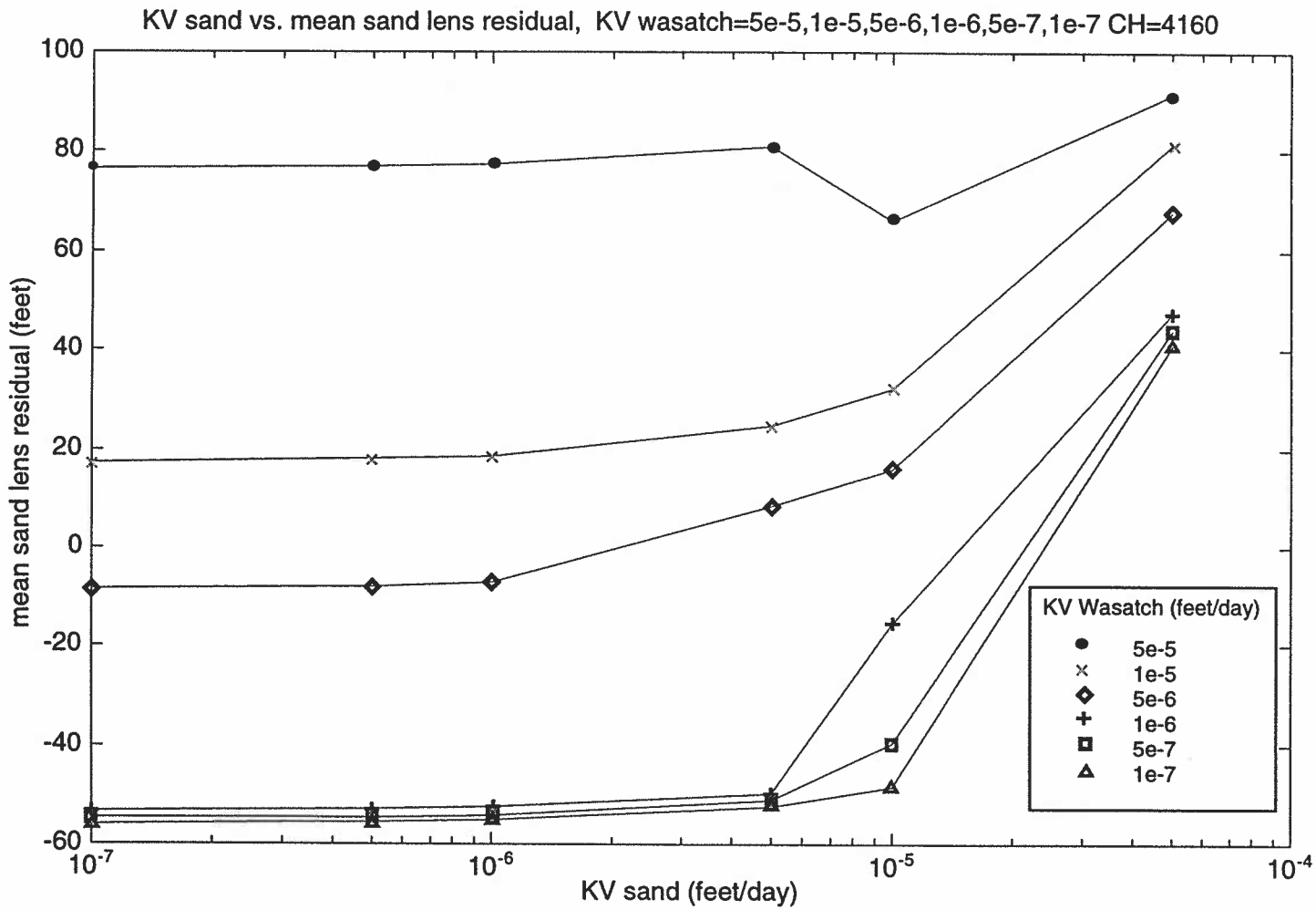


Figure 4-9. Case KV2. KV of the confining layer underlying the sand lens vs. mean sand lens residual. KV of the confining layer underlying the Wasatch, outside of the sand lens fixed at values shown in figure, CH fixed at 4160 feet.

Table 4-2. Results of chapter 4 case KV2

CH=4160 feet, KV zone 1 underlies the sand lens, KV zone 2 underlies the sand lens layer outside of the sand lens.

simulation no.	KV zone 1 (feet/day)	KV zone 2 (feet/day)	sum of the squared residuals	mean residual (feet)	budget discrepancy (%)	sand lens resid. #1	sand lens resid. #2	rmse (feet)
1	1.00E-05	1.00E-05	99620	-6.40	-0.58	37.3	27.1	41.8
2	1.00E-05	5.00E-06	100180	-4.53	-0.52	21.2	10.6	41.9
3	1.00E-05	1.00E-06	105480	-1.46	-0.12	-10.8	-20.2	43.0
4	1.00E-05	5.00E-07	108200	-3.11	-0.57	-33.5	-46.1	43.6
5	1.00E-05	1.00E-07	111290	-1.85	-0.37	-40.3	-57.1	44.2
6	1.00E-05	5.00E-05	107110	-14.20	-0.88	69.9	62.5	43.3
7	5.00E-05	5.00E-05	114850	-12.30	-0.38	94.3	88.8	44.9
8	5.00E-05	1.00E-05	111160	-4.01	-0.13	85.4	77.5	44.2
9	5.00E-05	5.00E-06	108520	-2.36	-0.25	71.8	63.9	43.6
10	5.00E-05	1.00E-06	107190	-0.31	-0.37	51.7	43.6	43.4
11	5.00E-05	5.00E-07	107190	0.03	-0.39	48.2	40.0	43.4
12	5.00E-05	1.00E-07	107250	0.34	-0.40	45.2	36.9	43.4
13	5.00E-06	5.00E-05	110490	-11.90	-0.14	85.9	76.2	44.0
14	5.00E-06	1.00E-05	98894	-6.70	-0.61	29.9	19.3	41.7
15	5.00E-06	5.00E-06	100180	-4.64	-0.47	13.9	3.2	41.9
16	5.00E-06	1.00E-06	110340	-2.78	-0.34	-41.0	-58.3	44.0
17	5.00E-06	5.00E-07	111610	-2.28	-0.32	-42.4	-60.0	44.3
18	5.00E-06	1.00E-07	112770	-1.82	-0.30	-43.6	-61.3	44.5
19	1.00E-06	5.00E-05	109370	-12.00	-0.15	82.5	72.8	43.8
20	1.00E-06	1.00E-05	98535	-6.89	-0.61	24.1	13.2	41.6
21	1.00E-06	5.00E-06	101350	-4.12	-0.19	-1.8	-12.2	42.2
22	1.00E-06	1.00E-06	111550	-2.75	-0.28	-43.7	-61.7	44.2
23	1.00E-06	5.00E-07	112910	-2.21	-0.25	-45.1	-63.3	44.5
24	1.00E-06	1.00E-07	114490	-1.49	-0.03	-47.0	-63.6	44.8
25	5.00E-07	5.00E-05	109230	-12.10	-0.16	82.0	72.3	43.8
26	5.00E-07	1.00E-05	98504	-6.91	-0.60	23.4	12.4	41.6
27	5.00E-07	5.00E-06	101400	-4.14	-0.19	-2.7	-13.1	42.2
28	5.00E-07	1.00E-06	111710	-2.74	-0.27	-44.1	-62.1	44.3
29	5.00E-07	5.00E-07	113080	-2.19	-0.24	-45.5	-63.7	44.5
30	5.00E-07	1.00E-07	114600	-1.54	-0.10	-47.4	-64.0	44.8
31	1.00E-07	5.00E-05	109110	-12.10	-0.16	81.7	71.9	43.8
32	1.00E-07	1.00E-05	98481	-6.92	-0.60	22.8	11.8	41.6
33	1.00E-07	5.00E-06	101440	-4.16	-0.18	-3.5	-13.8	42.2
34	1.00E-07	1.00E-06	111840	-2.73	-0.27	-44.3	-62.5	44.3
35	1.00E-07	5.00E-07	113230	-2.18	-0.23	-45.8	-64.0	44.6
36	1.00E-07	1.00E-07	114770	-1.53	-0.09	-47.7	-64.4	44.9

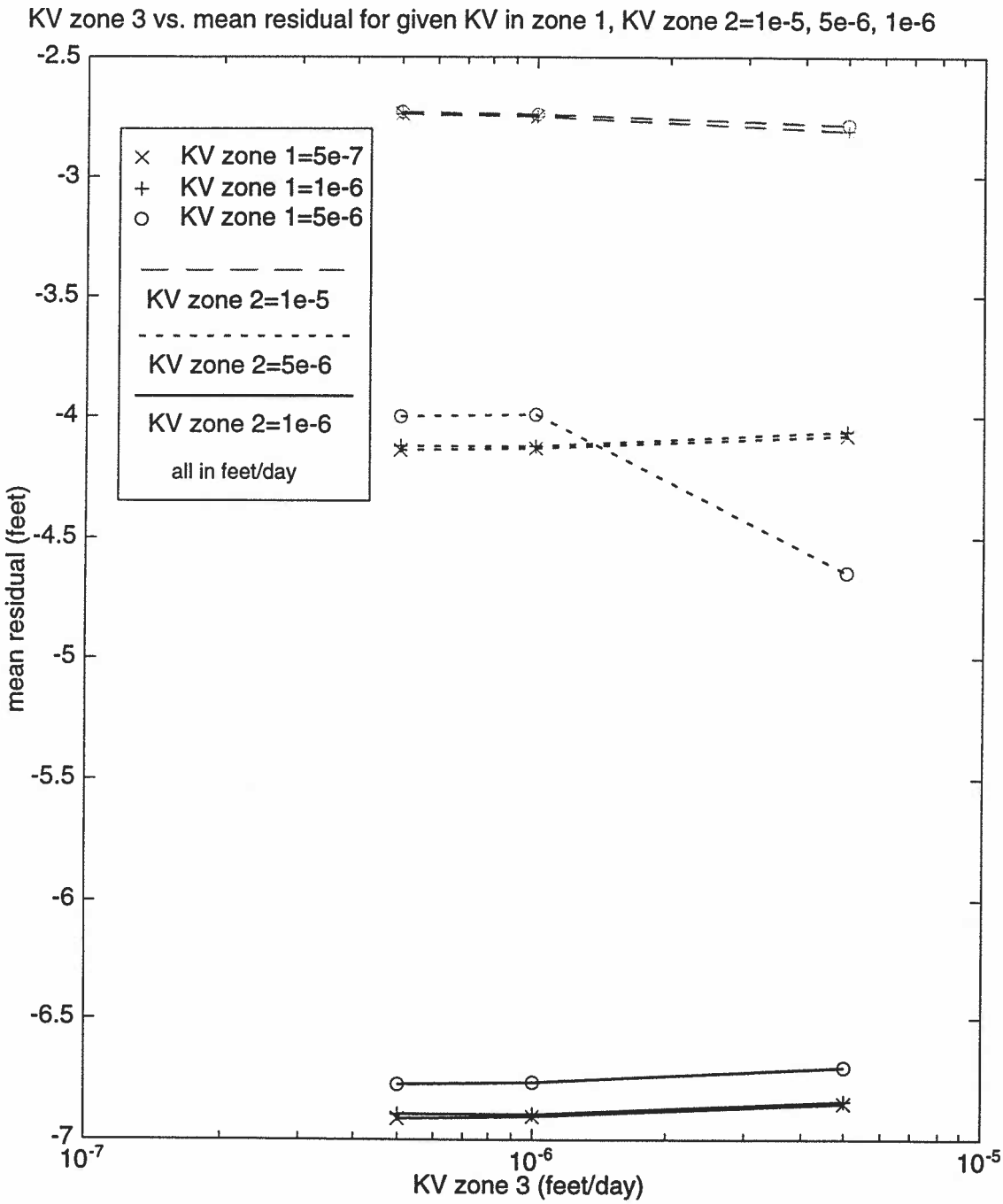


Figure 4-10. Case KV3. KV in zone 3 vs. mean residual . KV in zone 2 fixed as shown in figure, KV in zone 1 varies between 5e-7 and 5e-6. Zones 1 and 3 underlie the sand lens, zone 2 underlies the Wasatch outside of the sand lens.

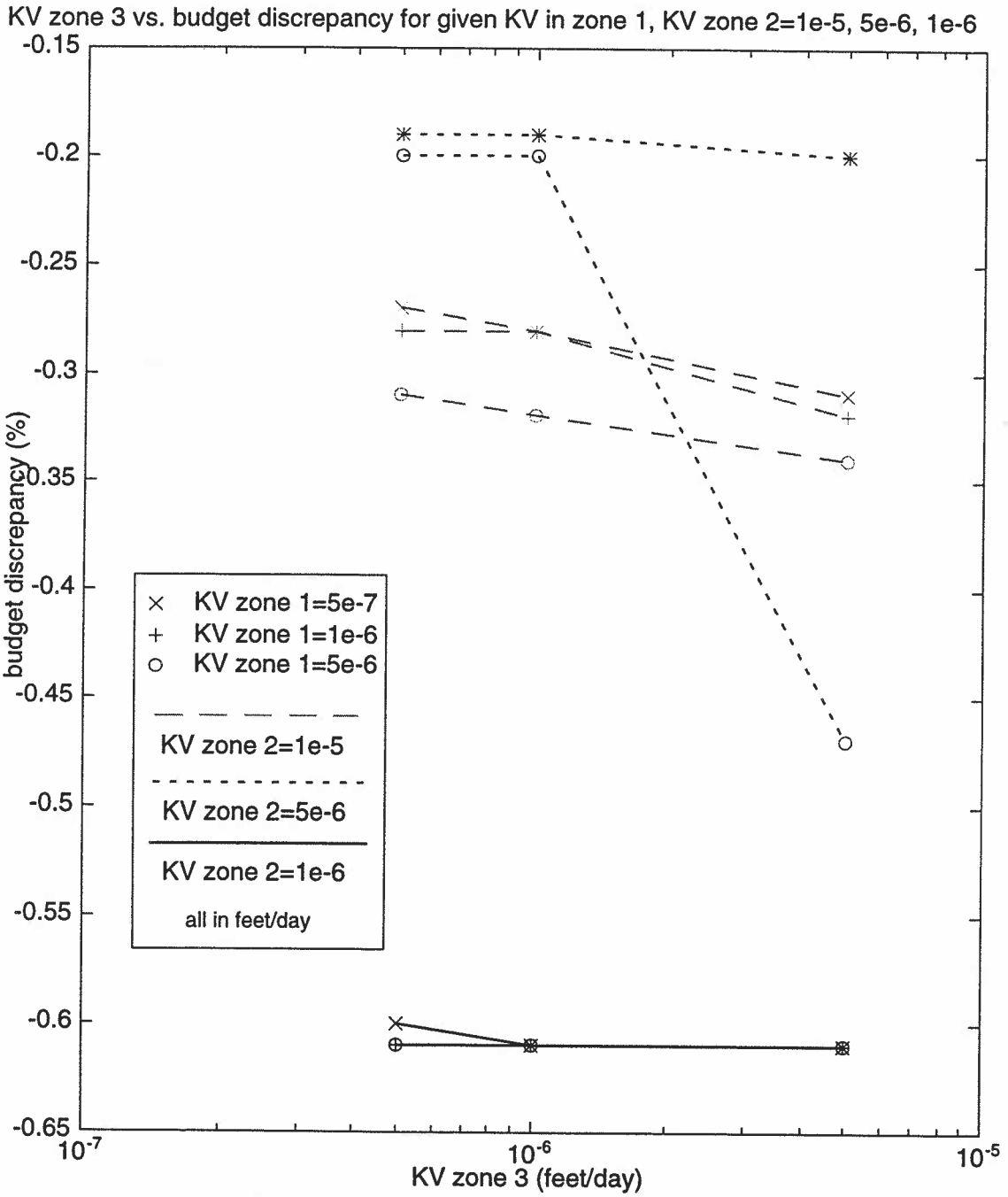


Figure 4-11. Case KV3. KV in zone 3 vs. budget discrepancy. KV in zone 2 fixed as shown in figure, KV in zone 1 varies between 5e-7 and 5e-6. Zones 1 and 3 underlie the sand lens, zone 2 underlies the Wasatch outside of the sand lens.

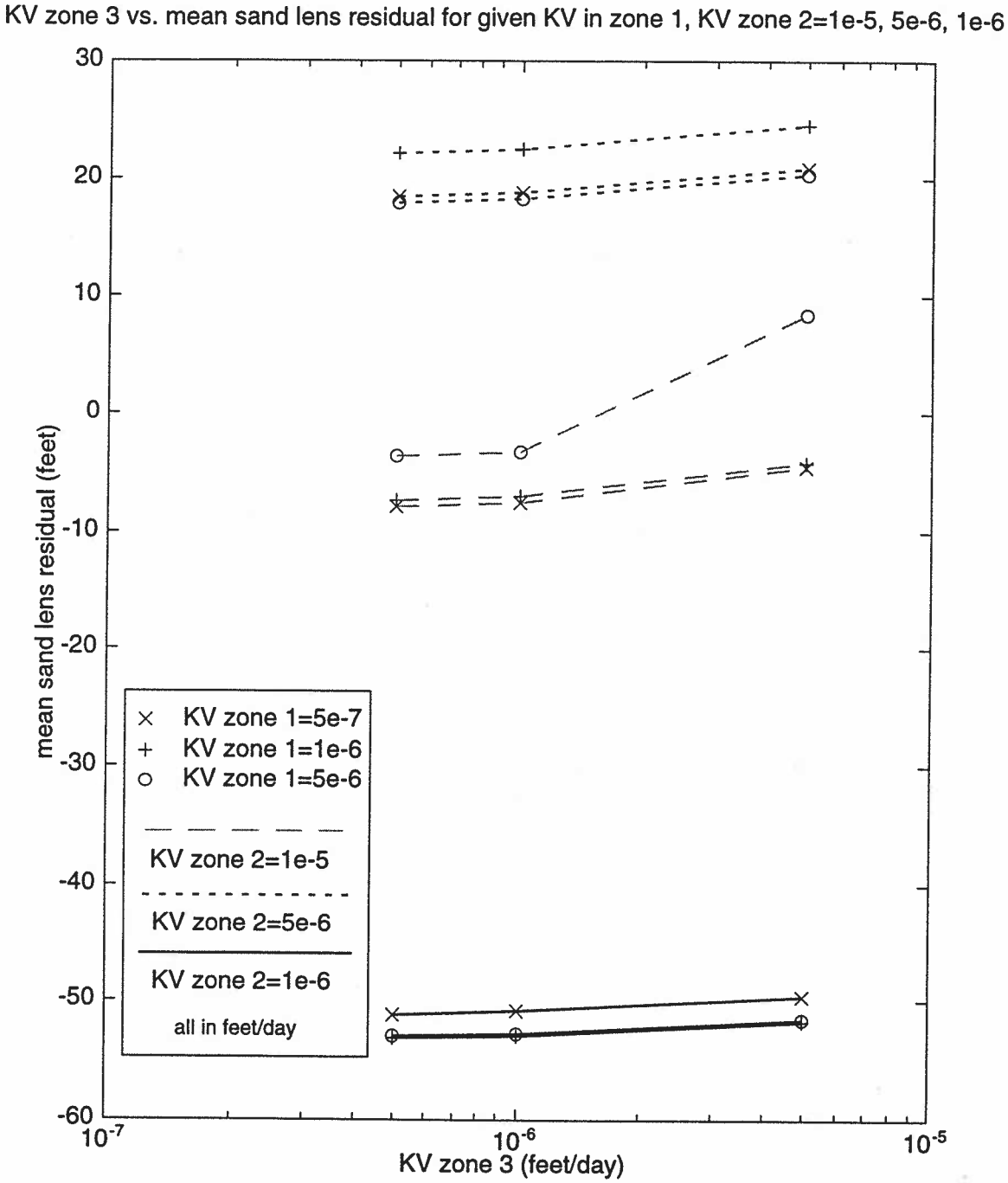


Figure 4-12. Case KV3. KV in zone 3 vs. mean sand lens residual. KV in zone 2 fixed as shown in figure, KV in zone 1 varies between 5e-7 and 5e-6. Zones 1 and 3 underlie the sand lens, zone 2 underlies the Wasatch outside of the sand lens.

Table 4-3 Results from chapter 4 case KV3

CH=4160

simulation no.	KV zone 1 (feet/day)	KV zone 2 (feet/day)	KV zone 3 (feet/day)	sum of the squared residuals	mean residual (feet)	budget discrep-ancy (%)	sand lens resid. #1	sand lens resid. #2	rmse (feet)
1	1.00E-05	5.00E-07	5.00E-07	98504	-6.91	-0.6	23.4	12.4	41.57091
2	1.00E-05	5.00E-07	1.00E-06	98518	-6.9	-0.61	23.7	12.6	41.57386
3	1.00E-05	5.00E-07	5.00E-06	98640	-6.85	-0.61	26.4	14.3	41.5996
4	1.00E-05	5.00E-06	5.00E-07	98701	-6.77	-0.61	26.9	17.3	41.61246
5	1.00E-05	5.00E-06	1.00E-06	98721	-6.76	-0.61	27.2	17.5	41.61667
6	1.00E-05	5.00E-06	5.00E-06	98894	-6.7	-0.61	29.9	19.3	41.65312
7	1.00E-05	1.00E-06	5.00E-07	98521	-6.89	-0.61	23.8	13	41.57449
8	1.00E-05	1.00E-06	1.00E-06	98535	-6.89	-0.61	24.1	13.2	41.57745
9	1.00E-05	1.00E-06	5.00E-06	98663	-6.84	-0.61	26.8	14.9	41.60444
10	5.00E-06	5.00E-06	5.00E-07	101180	-4	-0.2	0.954	-8.2	42.13179
11	5.00E-06	5.00E-06	1.00E-06	101170	-3.99	-0.2	1.39	-7.96	42.12971
12	5.00E-06	5.00E-06	5.00E-06	100180	-4.64	-0.47	13.9	3.17	41.92307
13	5.00E-06	1.00E-06	5.00E-07	101370	-4.12	-0.19	-2.28	-12.5	42.17133
14	5.00E-06	1.00E-06	1.00E-06	101350	-4.12	-0.19	-1.79	-12.2	42.16717
15	5.00E-06	1.00E-06	5.00E-06	101240	-4.06	-0.2	1.82	-10.2	42.14428
16	5.00E-06	5.00E-07	5.00E-07	98504	-4.14	-0.19	-2.71	-13.1	41.57091
17	5.00E-06	5.00E-07	1.00E-06	98518	-4.13	-0.19	-2.22	-12.8	41.57386
18	5.00E-06	5.00E-07	5.00E-06	98640	-4.08	-0.2	1.45	-10.7	41.5996
19	1.00E-06	5.00E-06	5.00E-07	110850	-2.73	-0.31	-43.3	-58.9	44.09917
20	1.00E-06	5.00E-06	1.00E-06	110790	-2.74	-0.32	-43	-58.8	44.08723
21	1.00E-06	5.00E-06	5.00E-06	110340	-2.78	-0.34	-41	-58.3	43.99761
22	1.00E-06	1.00E-06	5.00E-07	111610	-2.74	-0.28	-44	-61.8	44.25009
23	1.00E-06	1.00E-06	1.00E-06	111550	-2.75	-0.28	-43.7	-61.7	44.23819
24	1.00E-06	1.00E-06	5.00E-06	111070	-2.81	-0.32	-41.8	-61.2	44.14291
25	1.00E-06	5.00E-07	5.00E-07	111710	-2.74	-0.27	-44.1	-62.1	44.26991
26	1.00E-06	5.00E-07	1.00E-06	111650	-2.75	-0.28	-43.8	-62.1	44.25802
27	1.00E-06	5.00E-07	5.00E-06	111160	-2.81	-0.31	-41.8	-61.6	44.16079

layer. Although the mean sand lens residual jumps from one side of the decimal point to the other there is little change in it's magnitude. There is very little change in the mean residual, indicating about the same quality of fit. The only real improvement seems to be in the budget. The results indicate that mean residual and mean sand lens residual are not affected by KV of the confining layer below the sand lens with a KV in this zone below 1.0E-5 feet/day. This indicates that the model is not sensitive to KV of the confining layer under the sand and that subdivision of the confining layer is not reasonable. Above KV of zone 2=1E-5 feet/day, the budget discrepancy is sensitive to even minor alterations of the KV in zones 1 or 2, indicating that values of KV higher than this are unreasonable.

Case KV3

In comparison with the KV values for the sand lens in case KV2, the southern lobe of the sand lens has been lowered by a half order of magnitude while the northern lobe has been raised by a half order of magnitude. Figures 4-10 to 4-12 show that the model is sensitive only to the KV of zone 2. It is possible that the heterogeneity of the confining layer should be considered. However, the changes in the estimated KV resulting from zonation of the confining layer are limited to an order of magnitude between case KV1 and case KV3 and only in the southern lobe of the sand lens. Over the scale of the study domain, the estimate of 4.5e-6 feet/day arrived at in case KV1 is the most reasonable.