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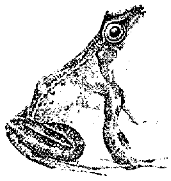

REPORT No. <>

SITE INVESTIGATION OF
CHANGES IN CONVEYED
WATER QUALITY AFTER LINING
WATER MAINS WITH BLAST
FURNACE SLAG CEMENT MORTAR

GLASGOW FIELD TRIALS

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SITE INVESTIGATION OF CHANGES IN CONVEYED WATER QUALITY AFTER LINING WATER MAINS WITH BLAST FURNACE SLAG CEMENT MORTAR

GLASGOW FIELD TRIALS

CONFIDENTIAL TO DoE AND STRATHCLYDE REGIONAL COUNCIL WATER DEPARTMENT

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CONTENTS

SUMMARY

I OBJECT

To investigate the effect on water quality of lining two dead end mains with blast furnace slag cement mortar in low and moderately low alkalinity waters.

II REASON

Cement mortar is widely used to internally renovate corroded iron water mains throughout the UK. In some cases the pH levels of the water passing through newly lined mains can be elevated above the EC directive maximum advisable values. To alleviate this, WRc has developed a modified mortar replacing 65% of the ordinary Portland cement with blast furnace slag (BFS). The new BFS mortar, during laboratory and field trials has been found to reduce the pH in the conveyed water by up to one pH unit in comparison to OPC. The trials in Glasgow have been conducted as a final part of a series of field trials to investigate the effect on pH of using BFS mortar in waters of varying alkalinity. Two sites were chosen, one at Millerston where the alkalinity of the water was approximately 14mg/l as $CaCO_3$, a level not previously examined and at Howwood where the alkalinity was approximately 22mg/l as $CaCO_3$.

III CONCLUSIONS

(1) At a water alkalinity of approximately 19-23mg/l as $CaCO_3$ (Howwood trial) the pH of the conveyed water in contact with the blast furnace slag cement mortar for 1 hour remained above the EC directive MAV of 9.5 for a period of 9 weeks. For a contact time of 6 hours the conveyed water pH remained above 9.5 beyond the duration of the trial 15 weeks after first returning the length to service.

(2) At a water alkalinity of approximately 12-16mg/l as $CaCO_3$ (Millerston trial) the pH of the conveyed water in contact with the blast furnace slag cement mortar for 1 hour remained above the EC directive MAV of 9.5

for a period of 12 weeks. For a contact time of 6 hours the conveyed water pH reached a value of 9.5 units, 15 weeks after returning the length to service.

(3) Initial pH values at Millerston may have been artifically low compared to the Howwood trial as high flows were maintained over the trial length due to consumer supply problems. However on rectifying the flow, pH values stabilised rather than increased.

(4) The concentrations of aluminium, calcium, potassium and sodium within the conveyed water was initially high, with aluminium above its EC directive MAV at both sites and potassium above its respective limit at Millerston. Potassium concentrations had fallen sufficiently by the eighth day but aluminium remained above the EC directive MAV, 9 weeks after lining at Millerston and 5 weeks after lining at Howwood.

The high concentrations of aluminium measured at the Howwood site was aggravated by the high source water levels of aluminium.

IV RECOMMENDATIONS

(1) Although the conveyed water pH values remained above the EC directive MAV for a significant period of time after lining, the use of blast furnace slag cement "Mainline" shows benefits in terms of pH when compared to Ordinary Portland cement. Therefore, if no alternative renovation or renewal technique is available for critical condition mains the use of blast furnace slag mortar is currently the best option and should be continued to be used.

(2) With the high levels of pH and metals occurring within the conveyed water the first few days after lining, a flushing programme could be initiated to alleviate water quality problems during this period.

(3) Cement mortar lining of dead ends or long rural lengths where little or no flow exist should be avoided. However, in certain circumstances flows could be artifically created through the mains by joining overland dead ends or by having controlled wastages.

(4) Source water to proposed relining areas should be monitored and if feasible controlled to reduce potential water quality problems over a short period, especially pH and aluminium.

(5) Further field measurements should be taken at both Howwood and Millerston 6 months after the initial return to service. Values after a 1 year period would also provide useful information.

SECTION 1 - INTRODUCTION

Cement mortar lining has been used for more than 50 years in the UK to provide protection against the corrosion of cast iron water mains. In recent years the use of this method of water mains renovation has increased, with most of the renovation being carried out on mains of 150mm diameter and less. Cement mortar is also applied as a factory lining to protect new ductile iron pipes from corrosion.

Cement mortar actively prevents corrosion of the cast iron substrate by creating a highly alkaline environment at the iron surface. One problem experienced with cement mortar lining has been its effect on the conveyed water quality. The mortar is alkaline and in situations where there is long contact periods between the lining and the water, the pH of the water is elevated. This elevation in conveyed water pH is strongly influenced by the chemistry of the conveyed water.

To alleviate these pH increases, WRc developed a modified mortar with 65% of the ordinary Portland cement replaced by a pozzolanic material blast furnace slag. This new mortar under laboratory conditions gave a reduction in pH of about one unit over a standard OPC mortar.

Having established the practical suitability of the new mortar by undertaking experimental lining with several contractors, it was then tested in various areas having water qualities with alkalinities of 8, 22, 35 and 55mg/l as $CaCO_3$. The results of these trials in dead end mains showed that a BFS lining resulted in a reduction of the pH in all water qualities when compared to OPC. In the harder waters (> 50mg/l as $CaCO_3$) the pH of the conveyed water was elevated for a few days above the EC MAV for pH of 9.5. However, in very low alkalinity waters (< 10mg/l as $CaCO_3$) the conveyed water failed to achieve compliance with the EC Directive and the pH exceeded 9.5 for several months. Due to the significantly different results obtained between alkalinities of 8 to 22mg/l as $CaCO_3$ and 22 to 35mg/l as $CaCO_3$ further trial sites were selected with alkalinities between these values.

This report details field trials carried out in two areas of Strathclyde, Howwood and Millerston which have conveyed water alkalinities of approximately 26 and 14mg/l as $CaCO_3$ respectively.

SECTION 2 - DESCRIPTION OF FIELD TRIAL

2.1 OBJECTIVES

To investigate the effect of blast furnace slag cement mortar lining on water quality in two separate 100mm diameter dead end water mains with a specific water chemistry.

2.2 LOCATION

2.2.1 Site 1 - Howwood

The length of main chosen for the trial at an alkalinity of approximately 26mg/l as $CaCO_3$, was situated on Midton Road Howwood, approximately 15 miles south west of Glasgow City Centre, within the Renfrew Division of Strathclyde Regional Council Water Department. There were no service connections along the selected length only two short lengths from Tee's for hydrants, the layout of the site is shown in Figure 1. For the duration of the trial the length was effectively removed from service. As this length was lined separate from the renovation contract no lengths of pipe upstream had been or were intended to be relined. The source water was supplied from the Muirdykes reservoirs with the treatment works situated only 2km from the site but undergoing reconstruction.

2.2.2 Site 2 - Millerston

The length of main selected for the trial at an alkalinity of approximately 14mg/l as $CaCO_3$ was situated in a pavement adjacent to the A80 Cumbernauld Road, Millerston 5 miles east of Glasgow city centre, within the Lanark Division of Strathclyde Regional Council Water Department. Although there were seven service connections off of the proposed 100m trial length these were re-routed prior to renovation work leaving the test length as detailed in Figure 2. This effectively removed the trial length from service for the duration of the trial period. As the supply for this trial length came direct from a 10" main along the centre of the Cumbernauld Road, renovation work carried out during the trial period should not have affected the obtained results. The source water for this area was from Loch Lomond.

2.3 METHOD

Both trial lengths were cleaned using rack feed boring machines situated at one of the excavation pits at either end of the trial lengths. Conventional lining techniques were used by the contractors, Centriline Limited*[1], as they lined both lengths with the blast furnace slag cement mortar (trade name 'Mainline' produced by Pozament Ltd*[2]). The Millerston lining was completed 7 days after the Howwood lining.

After a cure period of 24 hours a sample piece was exhumed from the centre of the Howwood trial length. Inspection of the condition of the cement mortar lining indicated excessive ridging but total coverage of the internal surface of the pipe was obtained. The Howwood trial length was pieced up as shown in Figure 1 but not chlorinated and flushed until five days later, the same day as the Millerston section was lined. The Millerston cement mortar trial length was inspected using CCTV 18 hours after lining, this showed a good uniform coverage of the entire 100m. Reconnection, chlorination and flushing of this site was carried out after CCTV inspection.

After reconnection of both trial lengths a nominal flow of 7 litres/minute was allowed through the lined sections to waste from the dead end hydrant overnight prior to sampling. This gave an overnight water contact time of approximately 1½ hours.

*[1] Centriline Ltd
Unit 481
Walton Summit Centre
Bamber Bridge
Preston
Lancs
PR58AX

*[2] Pozament Ltd
Swains Park Industrial Estate
Overseal
Burton-on-Trent
Staffordshire

Water quality was monitored at each of the dead ends after various contact times ranging from 0.5 to 6 hours. This was carried out by flushing the test length to waste to ensure a new supply of water within the main, stopping flow and sampling from the dead end for contact times of 0.5, 1, 2, 3, 4, 5 and 6 hours. Water quality prior to the inlet of the test lengths was also monitored.

2.4 MONITORING EQUIPMENT

2.4.1 pH

The pH of the conveyed water was monitored during the tests using a pHox series 47 pH recorder. The meter records both the pH and the temperature of the conveyed water using a combined glass and reference type pH electrode, held in a flow cell. The flow cell was fed from the hydrant via a pressure reducing valve, allowing a low flow to continuously pass through the flow cell during the test.

2.4.2 Water Analysis

Water samples were taken during the trials from the dead end hydrants after 0.5, 1, 2, 3, 4, 5 and 6 hours of stagnation. Conductivity and pH measurements were carried out in-situ, total alkalinity was analysed for by SRC Water Department, Balmore Road, Glasgow and metals by WRc Environment at Medmenham. The analytical technique used for the samples are shown in Table 1.

SECTION 3 - RESULTS

A summary of the information obtained during the trials is detailed in Tables 2 and 3 for Howwood and Millerston respectively.

The measured values of pH, alkalinity, conductivity, calcium, aluminium, sodium and potassium have been plotted against the duration of time after the lined lengths had been returned to water contact. These are shown in Figures 3-18. Contact times of 1 and 6 hours have been plotted to indicate the difference in concentration of the determinand within the conveyed water between these two stagnation periods.

3.1 DISCUSSION OF RESULTS

3.1.1 Howwood Trial pH

Figure 3 shows the pH of the water conveyed through the Howwood trial length over a 16 week period after blast furnace slag cement mortar lining. High values were observed for the first day after returning supply to the trial length as the hydroxides are released from the newly applied lining. After 8 days there is a reduction of just 0.1 pH units to 10.4 for the 1 hour contact sample, however there is a significant rise in source water pH from 8.65 to 9.2 units. This increase in the inlet water pH to the trial length would effect the final readings so figure 4 has been plotted subtracting the inlet pH from that measured after 1 and 6 hours plus the EC directive maximum allowable value (MAV)[1]. This now shows there is an appreciable drop in pH over the first week as both the 1 and 6 hour contact time samples begin to approach the inlet value.

Nine weeks after lining, the pH of the conveyed water observed after a contact time of 1 hour had reduced to below the EC MAV of 9.5. The 6 hour contact time value remained at 10.4 pH units. Fifteen weeks after lining the conveyed water pH values obtained from the test length remained below the EC MAV for 1 hour contact time but at 9.9 for 6 hours.

The pH values obtained from the Howwood trial (alkalinity 19-24mg/l as $CaCO_3$) compared well with a previous trial carried out at a similar source water alkalinity[2].

3.1.2 Millerston Trial pH

The change in conveyed water pH observed at Millerston over a 16 week period after blast furnace slag cement mortar lining is shown in figure 5. High values are observed for the first day after returning supply to the trial length. After eight days however, the value of conveyed water pH had reduced to 9.8 for 1 hour contact times and 10.5 for 6 hour contact. These values were less than those obtained from the Howwood site despite being at a lower inlet water alkalinity. This, on investigation is explained by the flow that remained on the two trial lengths over the intervening period of a week. The Howwood site had been left as a dead end with little or no flow across the lining. The Millerston site however, had, due to a local burst, the dead end valve opened to supply a large number of consumers. This created an unknown but high flow across the trial length for this initial period. After taking the two week sample, the dead end valve was able to be closed, removing the test length from service. These actions are reflected in the pH values obtained over the initial nine week period where little reduction in pH is seen when the high flows are removed. However, it must also be noted there is no evident increase in pH when stabilising testing conditions.

Fifteen weeks after returning the Millerston trial length to supply the conveyed water pH values are on or below the EC MAV of 9.5. On interpolating figure 5 it can be assumed that the 1 hour contact time pH would have reached 9.5 at or around 12 weeks.

The inlet water pH value supplying the Millerston trial length rose from 8.6 to 9.05 over the first week but remained constant at around 8.8 for the remainder of the trial period.

3.1.3 Alkalinity and Conductivity

The effects of the blast furnace slag cement mortar lining on total alkalinity and conductivity of the conveyed water at both sites is presented in figures 7 to 10. Values, on the first day after returning water supply to the trial lengths, are very high but drop significantly over the first week. Again there is a more rapid decline of the Millerston values as the high flows 'flush' the main.

By nine weeks both alkalinity and conductivity values have almost reached that of the inlet especially at Millerston and by fifteen weeks increases are negligible.

The inlet water alkalinities varied at times for both trials. The Howwood supply ranged from 14 to 24mg/l as $CaCO_3$ averaging at 20mg/l as $CaCO_3$. The Millerston source water ranged from 12 to 16mg/l as $CaCO_3$ with an average of 14mg/l as $CaCO_3$.

3.1.4 Metals

The metals concentrations shown in figures 11 to 18 (aluminium, calcium, potassium and sodium) were all increased initially due to leaching of the soluble metal compounds from the linings. At the Howwood trial only aluminium was detected in concentrations greater than its EC directive MAV after the first day. The concentrations of aluminium remained high throughout the trial only falling to below the EC limits by 65 days after lining. These high values however, have been governed by the high concentrations of aluminium in the source water supplying the trial length. SRC are currently constructing new treatment works which should alleviate this problem.

The Millerston trial length had concentrations of aluminium and potassium above their respective EC directive MAV's one day after resuming water supply. By the eighth day potassium had reduced sufficiently to comply but aluminium especially at the longer contact times of 5 and 6 hours remained above its EC limit up to 64 days after starting the trial.

SECTION 4 - CONCLUSIONS

(1) At a water alkalinity of approximately 19-23mg/l as $CaCO_3$ (Howwood trial) the pH of the conveyed water in contact with the blast furnace slag cement mortar for 1 hour remained above the EC directive MAV of 9.5 for a period of 9 weeks. For a contact time of 6 hours the conveyed water pH remained above 9.5 beyond the duration of the trial 15 weeks after first returning the length to service.

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(3) Initial pH values at Millerston may have been artifically low compared to the Howwood trial as high flows were maintained over the trial length due to consumer supply problems. However on rectifying the flow, pH values stabilised rather than increased.

(4) The concentrations of aluminium, calcium, potassium and sodium within the conveyed water was initially high, with aluminium above its EC directive MAV at both sites and potassium above its respective limit at Millerston. Potassium concentrations had fallen sufficiently by the eighth day but aluminium remained above the EC directive MAV, 9 weeks after lining at Millerston and 5 weeks after lining at Howwood.

The high concentrations of aluminium measured at the Howwood site was aggravated by the high source water levels of aluminium.

SECTION 5 - RECOMMENDATIONS

(1) Although the conveyed water pH values remained above the EC directive MAV for a significant period of time after lining, the use of blast furnace slag cement "Mainline" shows benefits in terms of pH when compared to ordinary Portland cement. Therefore, if no alternative renovation or renewal technique is available for critical condition mains the use of blast furnace slag mortar is currently the best option and should be continued to be used.

(2) With the high levels of pH and metals occurring within the conveyed water the first few days after lining, a flushing programme could be initiated to alleviate water quality problems during this period.

(3) Cement mortar lining of dead ends or long rural lengths where little or no flow exist should be avoided. However, in certain circumstances flows could be artifically created through the mains by joining overland dead ends or by having controlled wastages.

(4) Source water to proposed relining areas should be monitored and if feasible controlled to reduce potential water quality problems over a short period, especially pH and aluminium.

(5) Further field measurements should be taken at both Howwood and Millerston 6 months after the initial return to service. Values after a 1 year period would also provide useful information.

ACKNOWLEDGEMENTS

The author is grateful for the provision of the field sites by Strathclyde Regional Council Water Department plus assistance of the staff of Renfrew and Lanark Divisions in running the trials. A special thanks to E McCabe for coordinating the trials.

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2. MASON S. Site investigation of changes in conveyed water quality after lining water mains with blast furnace slag cement mortar - Kirk Merrington field trial. Report No. 362E, WRc Swindon. 1988.

Table 1 - Analytical Methods

DETERMINAND	METHOD	LABORATORY
Alkalinity to pH 4.5	Titration	SRC Water Department, Glasgow
Aluminium	ICP OES	WRc Medmenham
Calcium	ICP OES	WRc Medmenham
Potassium	ICP OES	WRc Medmenham
Sodium	ICP OES	WRc Medmenham
Iron	ICP OES	WRc Medmenham
Magnesium	ICP OES	WRc Medmenham

TABLE No. 2 ANALYSIS OF WATER FROM MIDTON RD HOWWOOD

Days after Return to Service	Contact Time (Hrs)	In-situ pH (units)	Cond-uctivity (us/cm)	Water Temp (deg C)	Alkal-inity (mg/l)	Calcium (mg/l)	Alumin-ium (mg/l)	Sodium (mg/l)	Potas-ium (mg/l)	Iron (mg/l)	Magnes-ium (mg/l)
1	0.5	10.3	215	6.0	40	18.6	0.471	7.73	2.22	0.076	0.007
1	1.0	10.5	228	5.5	49	22.3	0.504	8.46	2.84	0.099	0.007
1	2.0	10.8	286	5.5	67	28.6	0.509	9.19	3.99	0.073	0.006
1	3.0	11.05	399	6.0	87	32.0	0.541	9.63	5.07	0.171	0.007
1	4.0	11.25	456	6.0	97	33.9	0.579	9.97	6.67	0.089	0.007
1	5.0	11.45	643	6.0	128	43.7	0.559	11.10	11.50	0.012	0.002
1	6.0	11.50	605	6.0	123	41.2	0.733	10.90	11.90	0.110	0.009
1	INLET	8.65	134	5.5	20	12.1	0.170	7.22	0.631	0.072	0.007
9	0.5	10.2	166	6.5	33	17.2	0.595	8.07	1.24	0.124	0.009
9	1.0	10.4	181	6.5	38	19.2	0.361	8.03	1.45	0.089	0.006
9	2.0	10.9	354	6.5	58	26.6	0.511	11.90	5.11	0.125	0.008
9	3.0	10.7	341	6.5	67	31.3	0.680	15.30	6.91	0.313	0.020
9	4.0	10.9	349	6.5	72	33.1	0.570	12.90	5.19	0.187	0.011
9	5.0	11.05	362	6.5	74	33.8	0.485	11.20	4.38	0.072	0.002
9	6.0	11.05	365	6.5	70	35.4	0.595	9.43	3.42	0.331	0.025
9	INLET	9.2	134	6.5	24	13.5	0.247	7.47	0.653	0.034	0.005
16	0.5	9.6	129	6.0	29	15.8	0.290	7.72	0.841	0.213	0.021
16	1.0	9.8	146	6.0	31	16.9	0.392	7.70	0.782	0.653	0.030
16	2.0	10.1	152	6.0	34	18.2	0.268	7.86	0.913	0.414	0.015
16	3.0	10.25	166	6.0	39	19.6	0.285	7.97	1.05	0.346	0.015
16	4.0	10.35	177	6.0	45	21.6	0.278	8.22	1.25	0.198	0.013
16	5.0	10.55	188	6.0	46	23.0	0.318	8.28	1.40	0.295	0.017
16	6.0	10.55	216	6.0	50	23.8	0.397	8.04	1.56	0.661	0.033
16	INLET	9.25	129	6.0	22	13.7	0.193	7.63	0.712	0.106	0.014
32	0.5	9.45	132	6.5	23	13.9	0.230	7.93	0.667	0.432	0.017
32	1.0	9.80	132	6.5	23	13.9	0.163	7.98	0.686	0.118	0.007
32	2.0	10.05	133	6.5	24	14.6	0.169	8.03	0.758	0.087	0.006
32	3.0	10.25	136	6.5	27	14.1	0.148	7.18	0.707	0.089	0.004
32	4.0	10.35	145	6.5	28	16.3	0.194	7.95	0.872	0.125	0.006
32	5.0	10.45	152	6.5	30	16.7	0.180	7.94	0.932	0.066	0.004
32	6.0	10.50	161	6.5	33	18.4	0.210	8.18	1.04	0.105	0.005
32	INLET	9.30	121	6.0	19	12.5	0.210	7.96	0.677	0.045	0.004
65	0.5	9.15	125	10.0	16	10.8	0.086	8.14	0.634	0.046	0.004
65	1.0	9.40	134	10.0	18	11.4	0.108	8.14	0.657	0.195	0.007
65	2.0	9.60	137	10.0	19	11.7	0.110	7.91	0.679	0.155	0.006
65	3.0	9.85	133	10.0	21	13.3	0.117	8.16	0.707	0.203	0.006
65	4.0	10.00	135	10.0	25	14.1	0.123	8.14	0.763	0.148	0.006
65	5.0	10.15	143	10.0	26	14.1	0.120	7.78	0.693	0.057	0.003
65	6.0	10.30	156	10.0	28	15.9	0.147	8.20	0.865	0.112	0.005
65	INLET	8.80	126	10.0	14	9.0	0.068	7.71	0.555	0.029	0.003
108	0.5	9.05	137	15.0	23	12.8	0.110	8.54	0.739	0.095	0.050
108	1.0	9.20	138	15.0	23	12.7	0.110	8.27	0.723	0.053	0.046
108	6.0	9.90	152	15.5	23	17.9	0.200	8.91	1.090	0.246	0.067
108	INLET	8.65	129	15.0	23	12.4	0.120	8.53	0.762	0.034	0.057

TABLE No. 3 ANALYSIS OF WATER FROM CUMBERNAULD RD MILLERSTON

Days after Return to Service	Contact Time (Hrs)	In-situ pH (units)	Cond-uctivity (us/cm)	Water Temp (deg c)	Alkal-inity (mg/l)	Calcium (mg/l)	Alumin-ium (mg/l)	Sodium (mg/l)	Potas-ium (mg/l)	Iron (mg/l)	Magnes-ium (mg/l)
1	0.5	11.05	244	6.0	51	21.1	0.128	5.15	2.16	0.075	0.004
1	1.0	11.25	305	6.0	68	27.6	0.091	5.59	3.53	0.038	0.002
1	2.0	11.45	439	6.0	96	37.0	0.186	6.03	5.58	0.076	0.004
1	3.0	11.55	555	7.0	131	52.6	0.233	7.02	8.79	0.065	0.003
1	4.0	11.60	627	7.0	155	53.0	0.171	7.36	9.68	0.024	0.002
1	5.0	11.55	808	7.0	191	60.1	0.109	8.08	12.30	0.011	0.002
1	6.0	11.65	1035	7.0	205	64.5	0.225	8.24	12.80	0.025	0.002
1	INLET	8.60	93	6.5	14	7.48	0.051	4.76	0.558	0.074	0.005
8	0.5	9.55	75	7.0	17	8.29	0.085	4.78	0.648	0.099	0.007
8	1.0	9.75	83	7.0	20	9.29	0.106	4.84	0.710	0.092	0.006
8	2.0	10.00	100	7.0	24	10.60	0.144	4.94	0.835	0.102	0.007
8	3.0	10.15	107	7.0	30	12.10	0.179	5.08	1.050	0.095	0.007
8	4.0	10.25	129	7.0	32	13.60	0.232	5.17	1.26	0.124	0.006
8	5.0	10.40	137	7.0	35	15.30	0.560	5.90	1.49	0.129	0.007
8	6.0	10.45	145	7.0	44	16.20	0.319	5.52	1.60	0.085	0.005
8	INLET	9.05	72	6.5	16	7.72	0.053	4.76	0.541	0.073	0.005
15	0.5	9.55	87	6.0	17	8.87	0.080	4.86	0.716	0.099	0.005
15	1.0	9.60	92	6.0	18	9.17	0.099	4.90	0.728	0.085	0.004
15	2.0	9.80	102	6.0	20	10.10	0.154	5.01	0.904	0.086	0.005
15	3.0	10.00	104	6.0	22	10.70	0.152	5.06	0.930	0.100	0.006
15	4.0	10.10	105	6.0	26	11.30	0.163	5.09	0.992	0.090	0.005
15	5.0	10.20	114	6.0	28	11.50	0.179	4.96	1.01	0.117	0.005
15	6.0	*	*	*	*	*	*	*	*	*	
15	INLET	8.80	82	6.0	14	7.63	0.040	4.84	0.632	0.073	0.005
29	0.5	9.55	82	6.5	14	8.26	0.087	4.98	0.577	0.083	0.004
29	1.0	9.60	84	6.5	16	8.29	0.124	4.84	0.557	0.314	0.029
29	2.0	9.80	86	6.5	16	8.92	0.113	5.04	0.628	0.120	0.010
29	3.0	10.00	92	6.5	18	9.42	0.121	5.11	0.673	0.090	0.006
29	4.0	10.20	97	6.5	20	9.92	0.154	5.11	0.738	0.118	0.005
29	5.0	10.30	99	6.5	22	9.37	0.148	4.64	0.669	0.121	0.011
29	6.0	10.30	103	6.5	23	10.90	0.200	5.24	0.826	0.135	0.007
29	INLET	8.32	78	6.5	13	7.43	0.067	4.95	0.543	0.090	0.005
64	0.5	9.50	90	11.0	15	8.11	0.091	4.76	0.530	0.091	0.005
64	1.0	9.60	93	11.0	14	8.68	0.107	5.03	0.612	0.145	0.006
64	2.0	9.70	91	11.0	15	8.77	0.112	4.98	0.600	0.105	0.005
64	3.0	9.85	92	11.0	17	9.67	0.172	5.03	0.658	0.130	0.011
64	4.0	9.95	95	11.0	17	9.99	0.166	5.02	0.653	0.076	0.005
64	5.0	10.10	107	11.0	21	10.20	0.209	4.84	0.634	0.124	0.005
64	6.0	10.10	106	11.0	17	10.60	0.211	4.92	0.669	0.074	0.005
64	INLET	8.80	82	11.0	12	7.21	0.040	4.85	0.542	0.053	0.004
106	0.5	9.30	86	15.5	19						
106	1.0	9.40	87	15.5	16						
106	6.0	9.50	92	15.5	19						
106	INLET	8.85	80	15.5	16						

Figure 1 Layout of Trial Length – Howwood

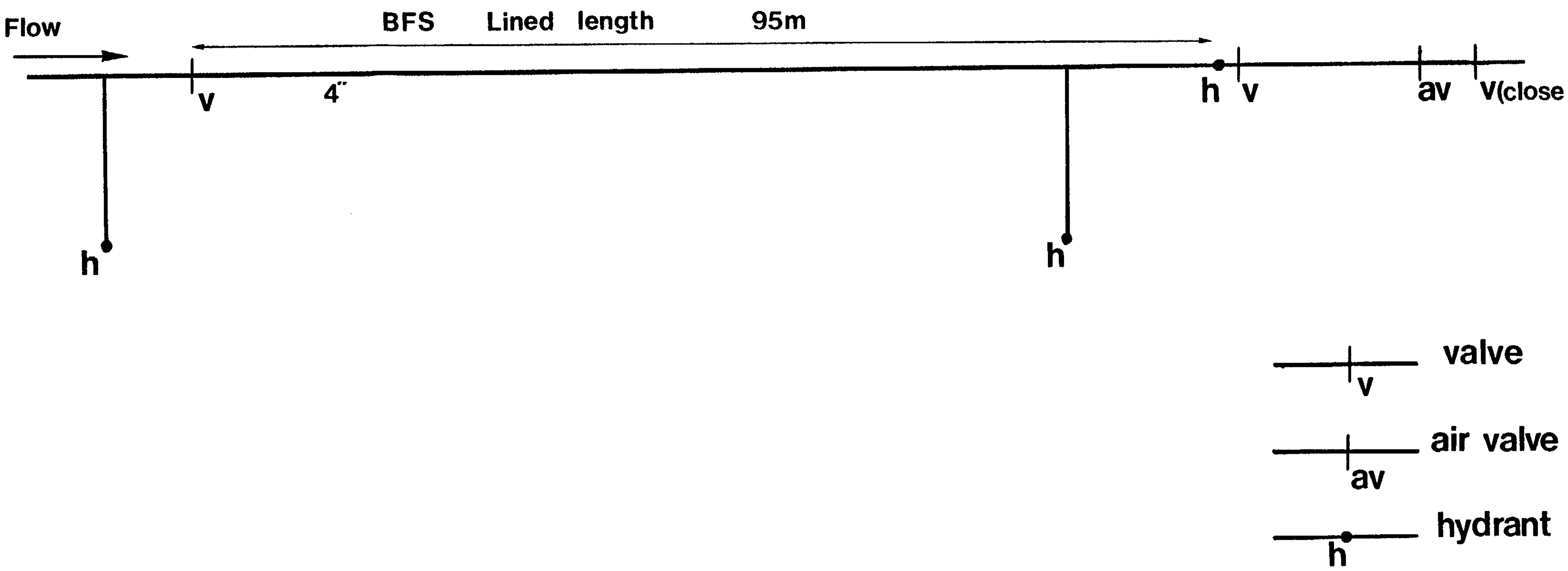

Figure 2 Layout of Trial Length – Millerston

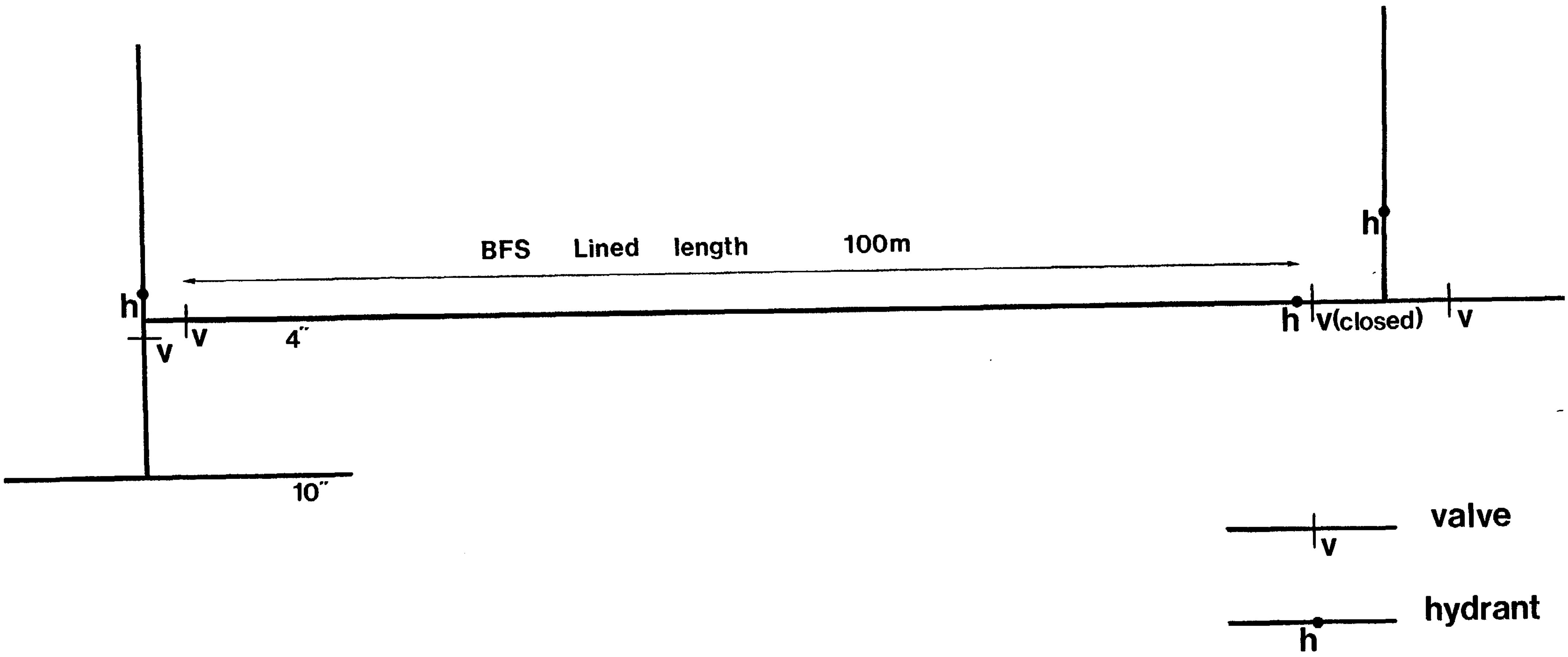

FIGURE 3 pH OF CONVEYED WATER FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

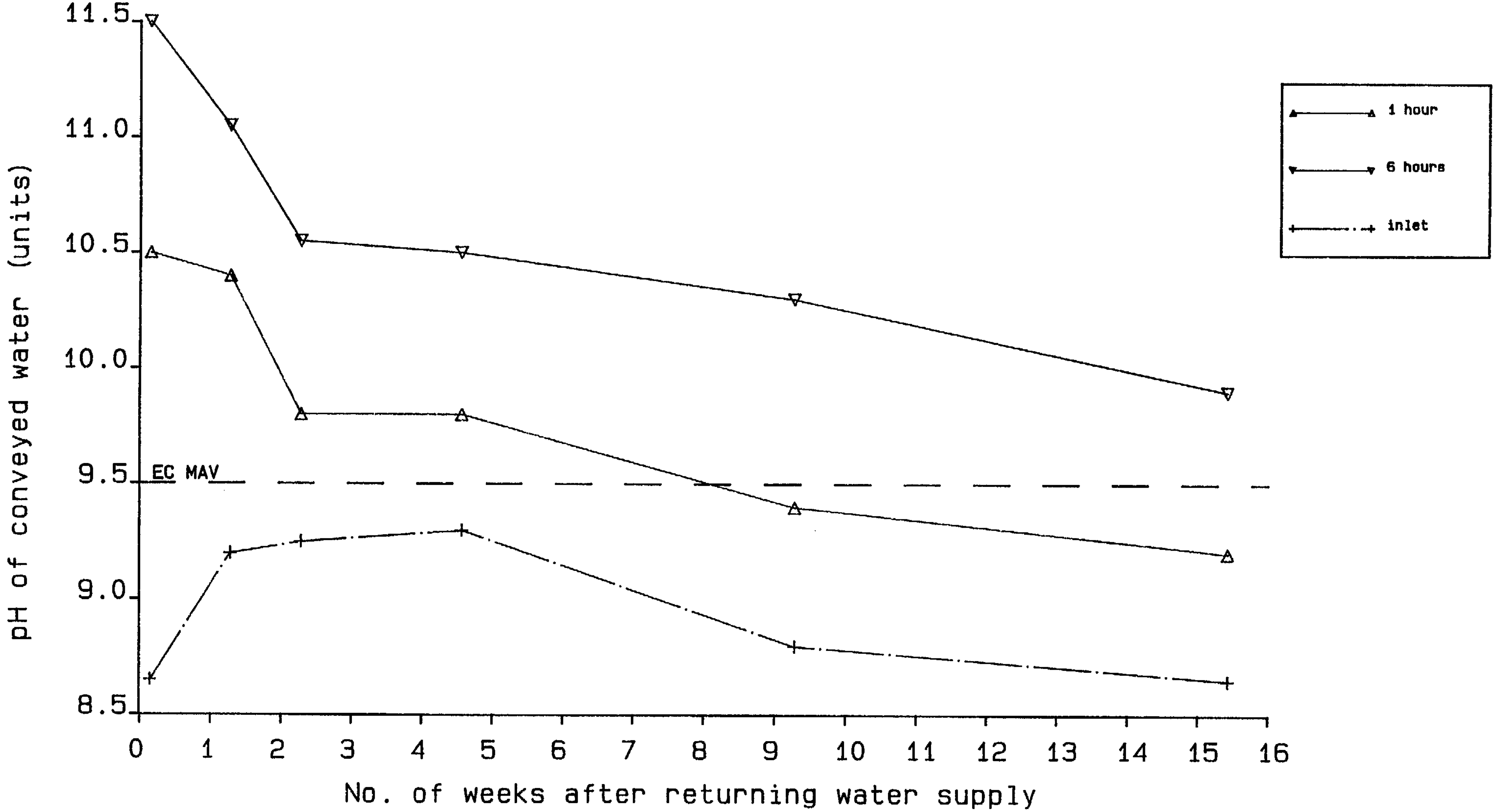

FIGURE 4 DIFFERENCE IN INLET pH VALUES WITH THOSE OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

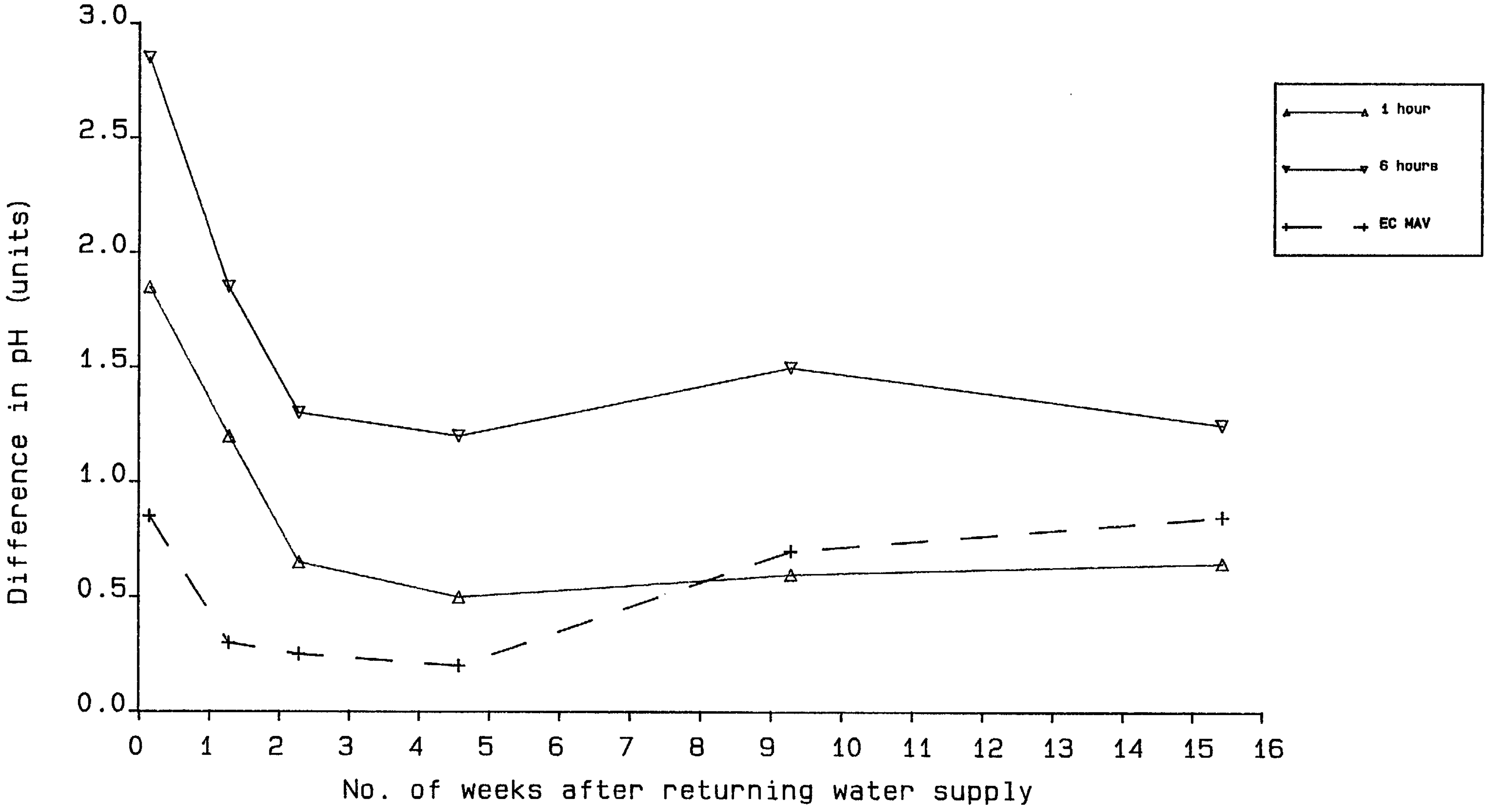

FIGURE 5 *pH OF CONVEYED WATER FOR CONTACT TIMES OF 1 & 6 HOURS MILLERSTON TRIAL LENGTH*

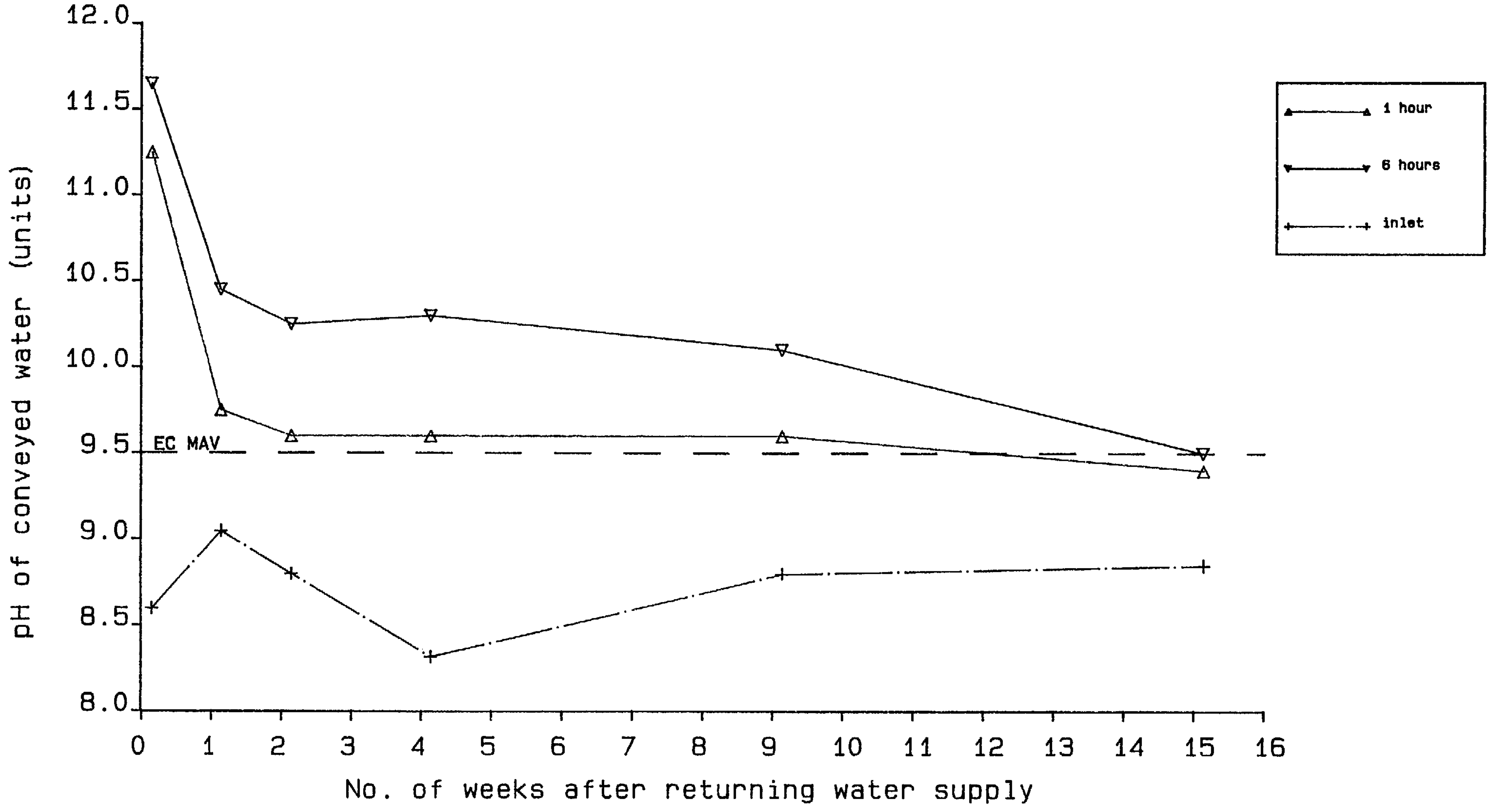

FIGURE 6 DIFFERENCE IN INLET pH VALUES WITH THOSE OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH

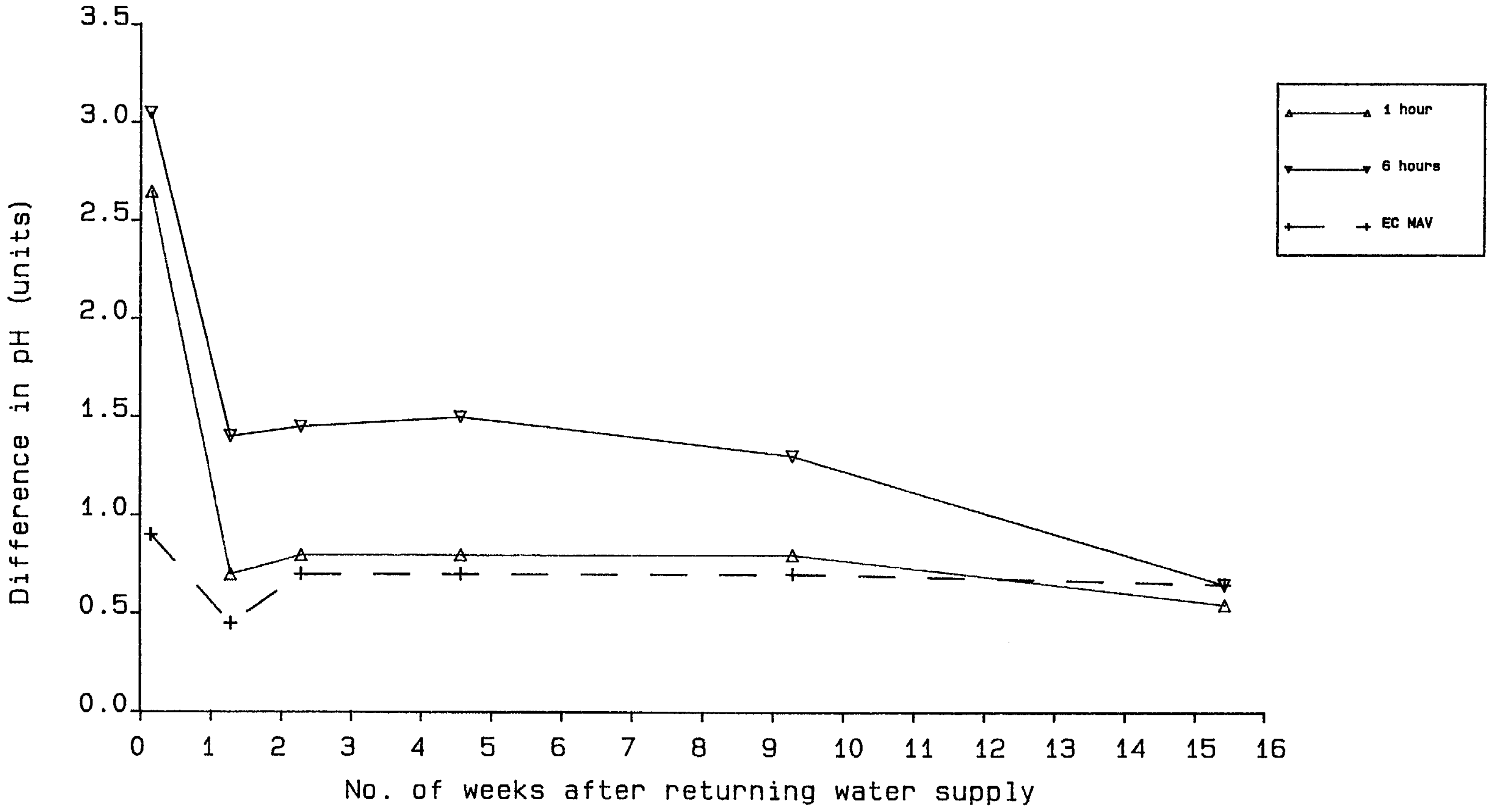

FIGURE 7 ALKALINITY OF WATER FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

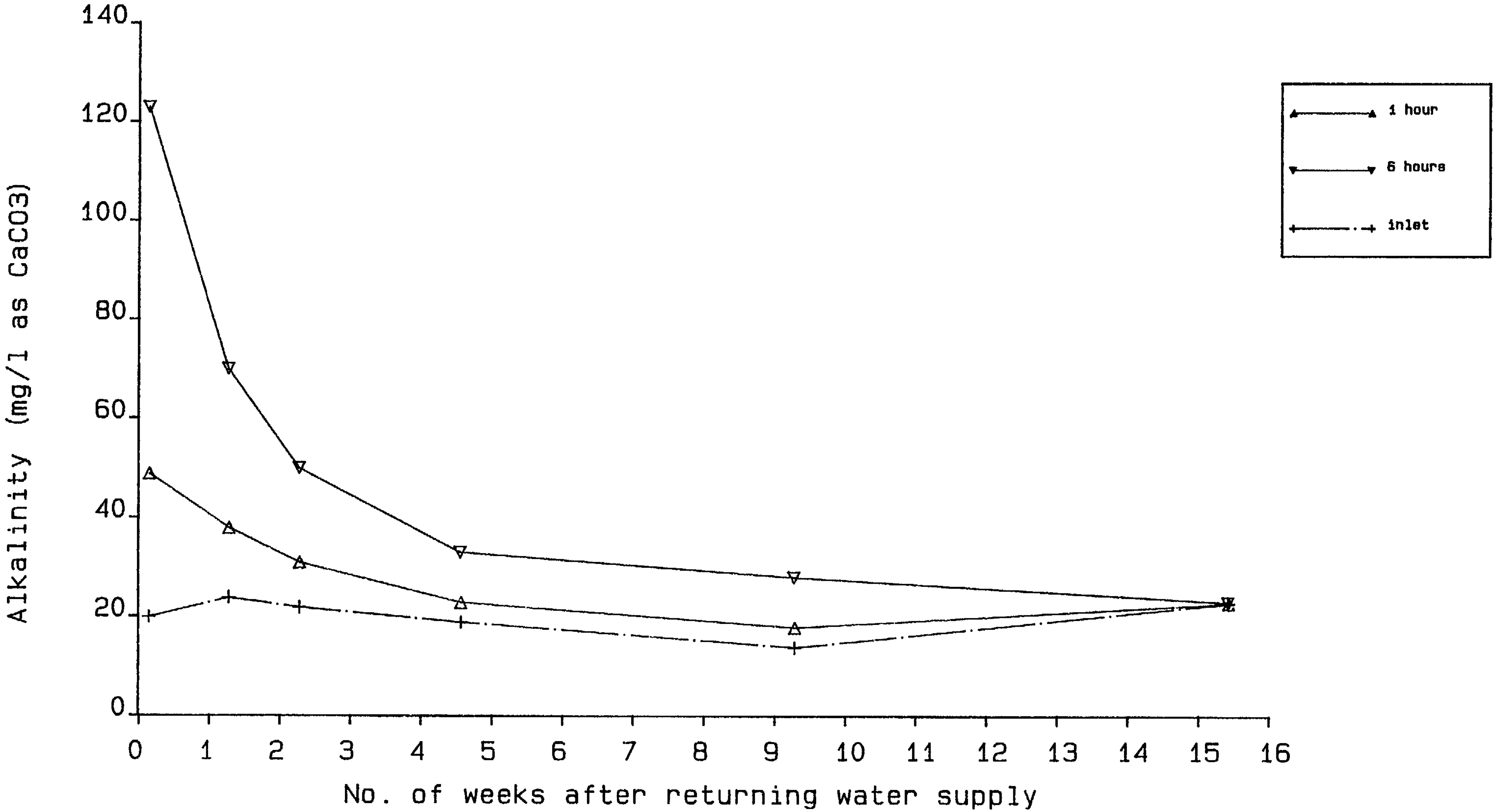

FIGURE 8 CONDUCTIVITY OF WATER FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

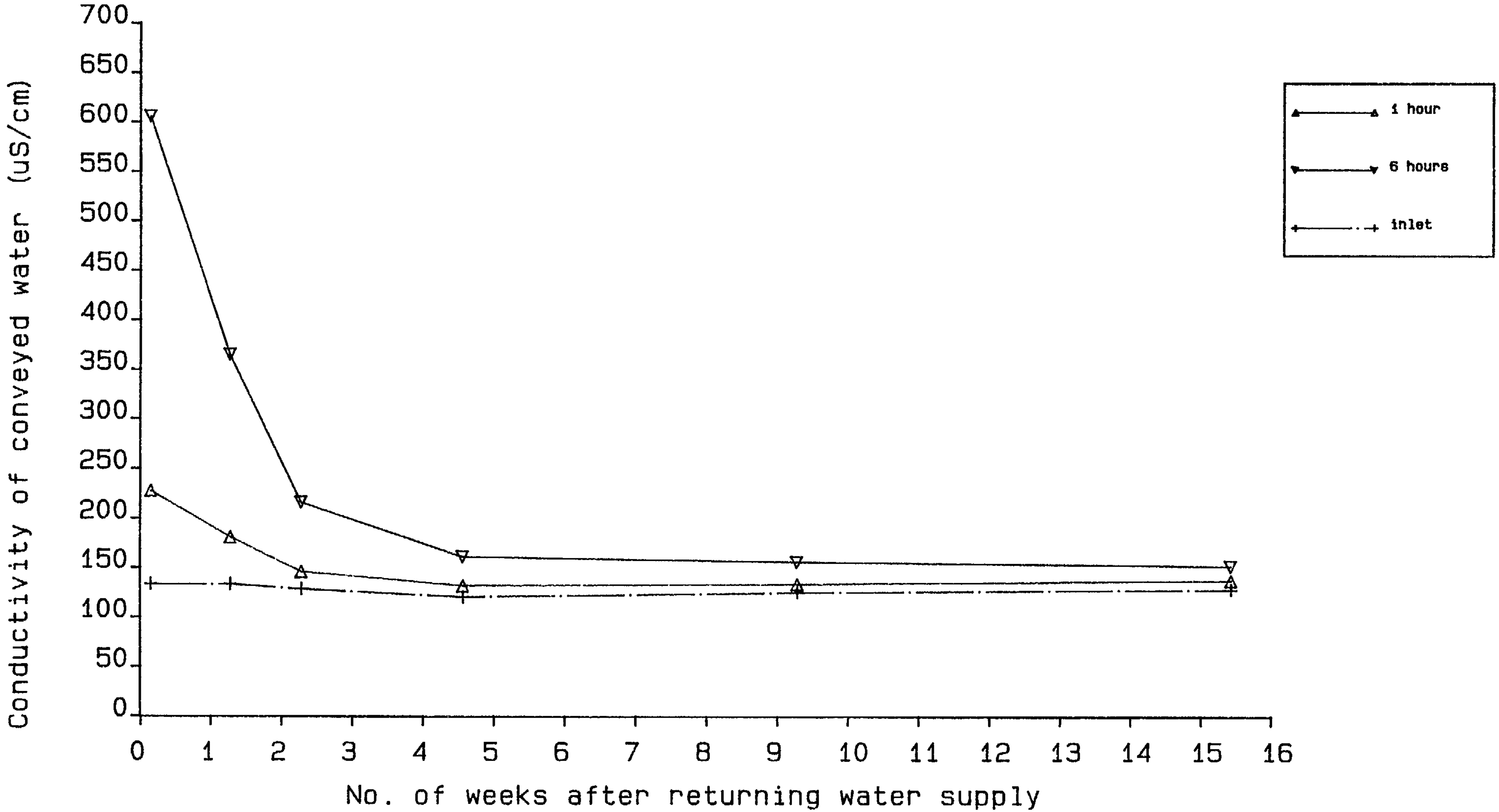

FIGURE 9 ALKALINITY OF WATER FOR CONTACT TIMES OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH

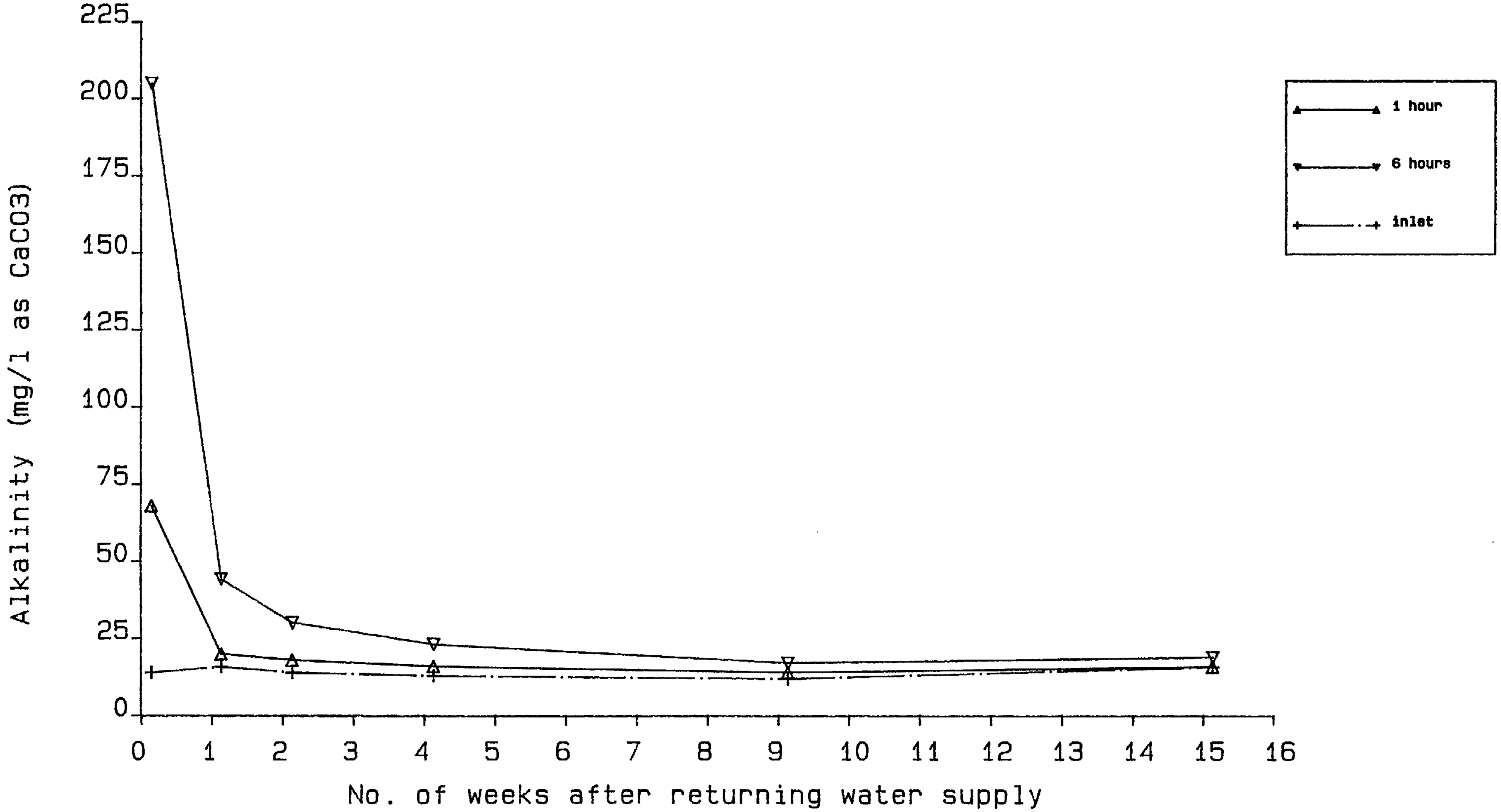

FIGURE 10 CONDUCTIVITY OF WATER FOR CONTACT TIMES OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH

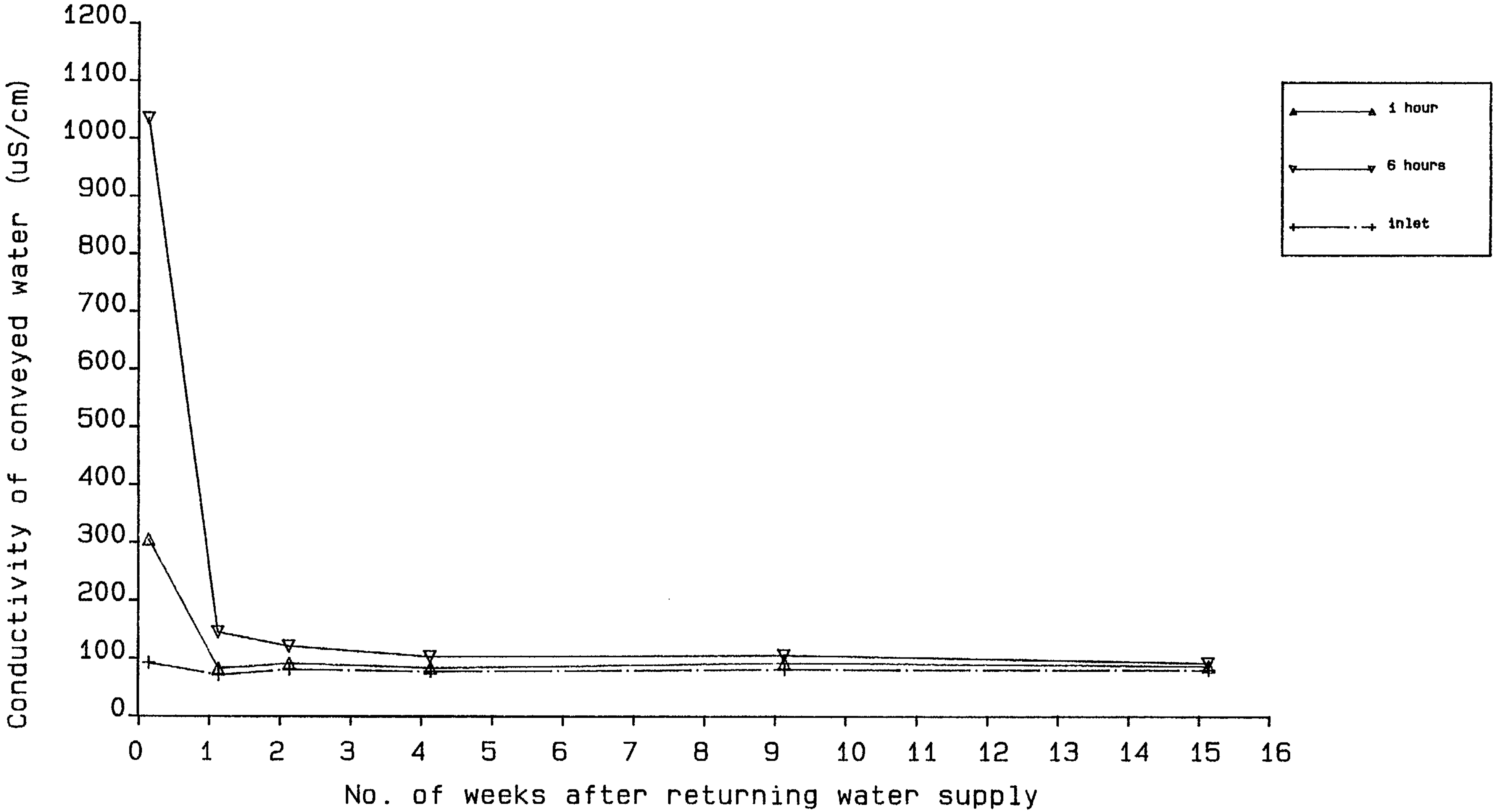

FIGURE 11 ALUMINIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

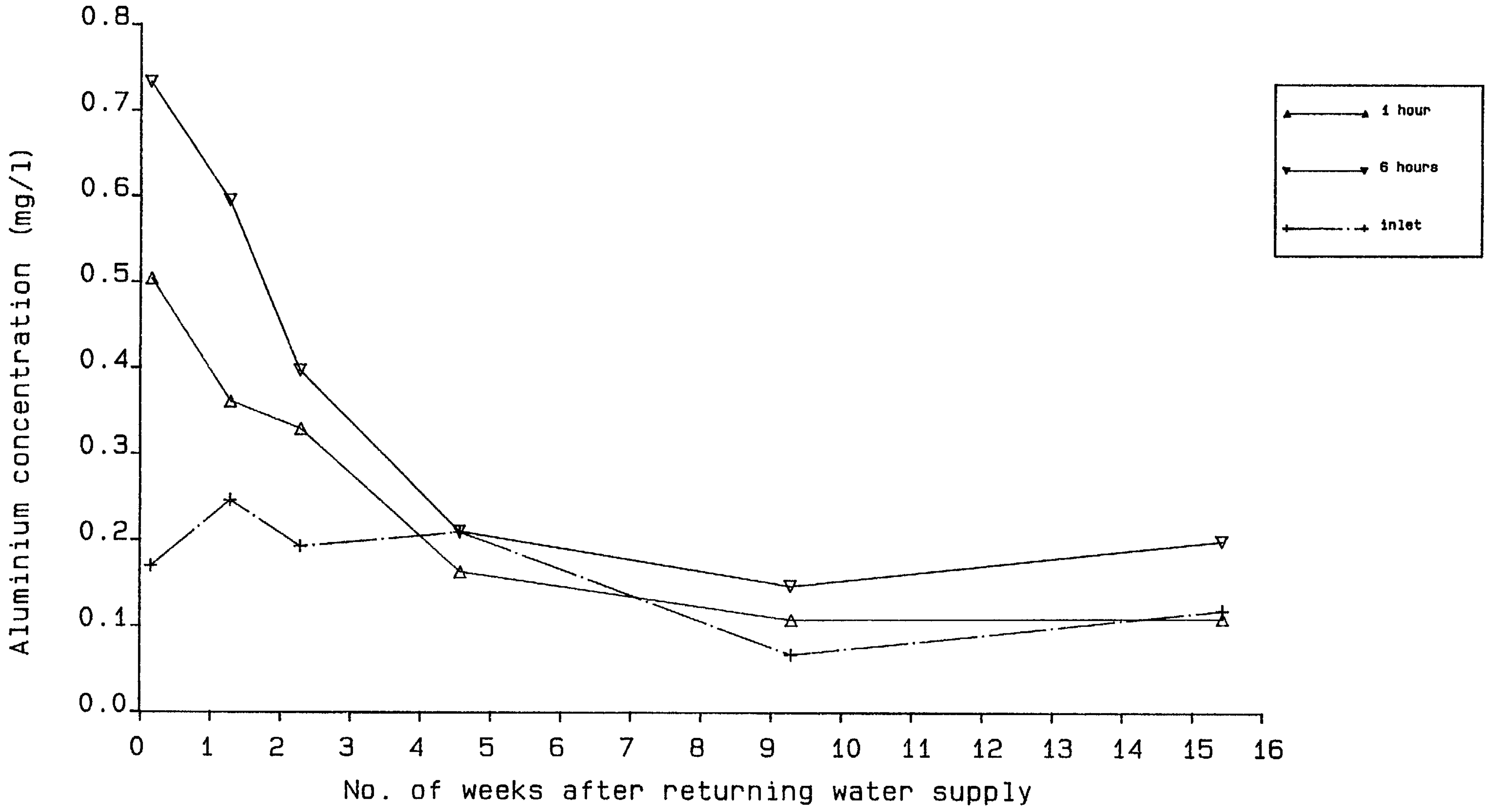

FIGURE 12 CALCIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

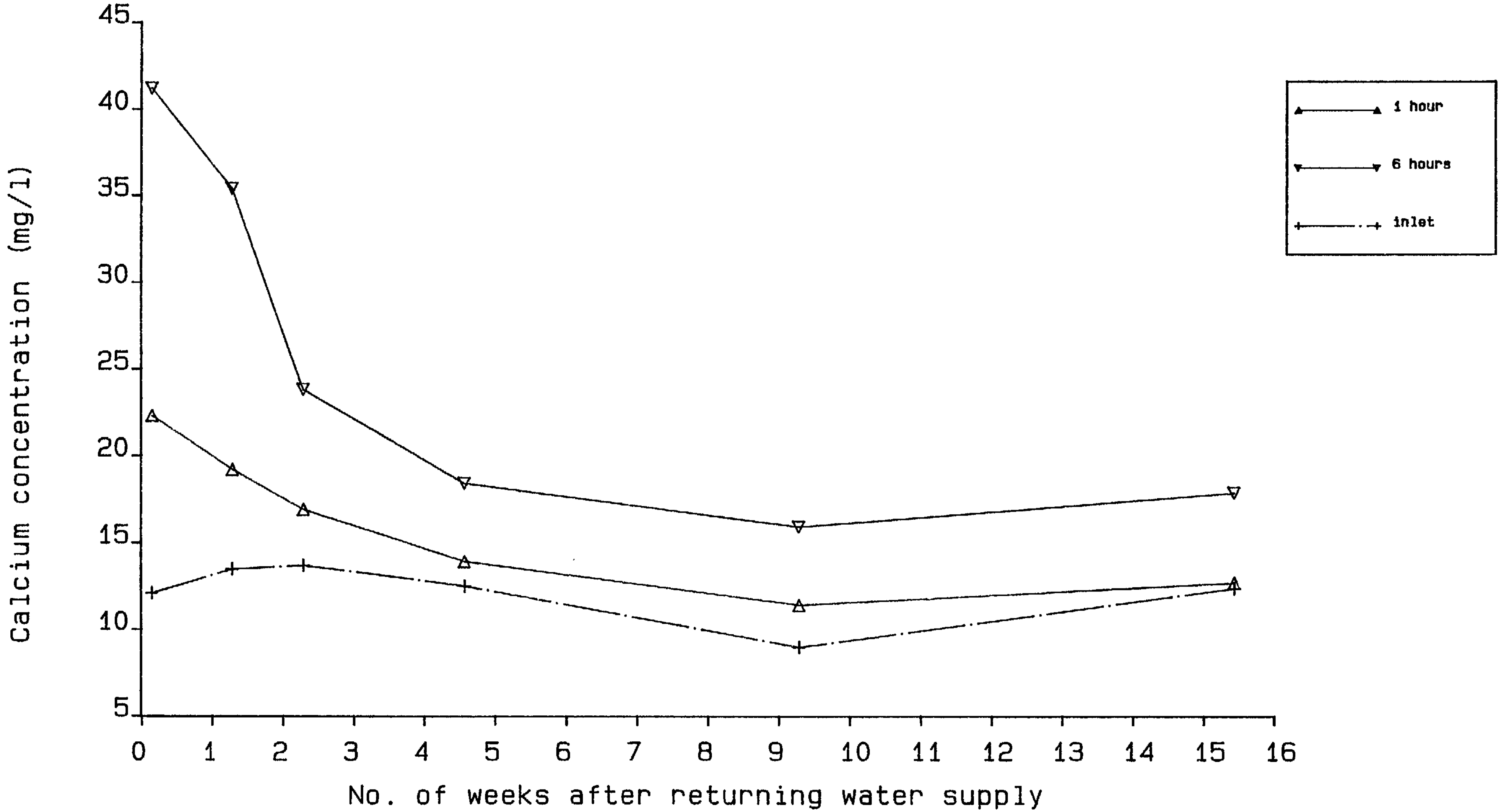

FIGURE 13 POTASSIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

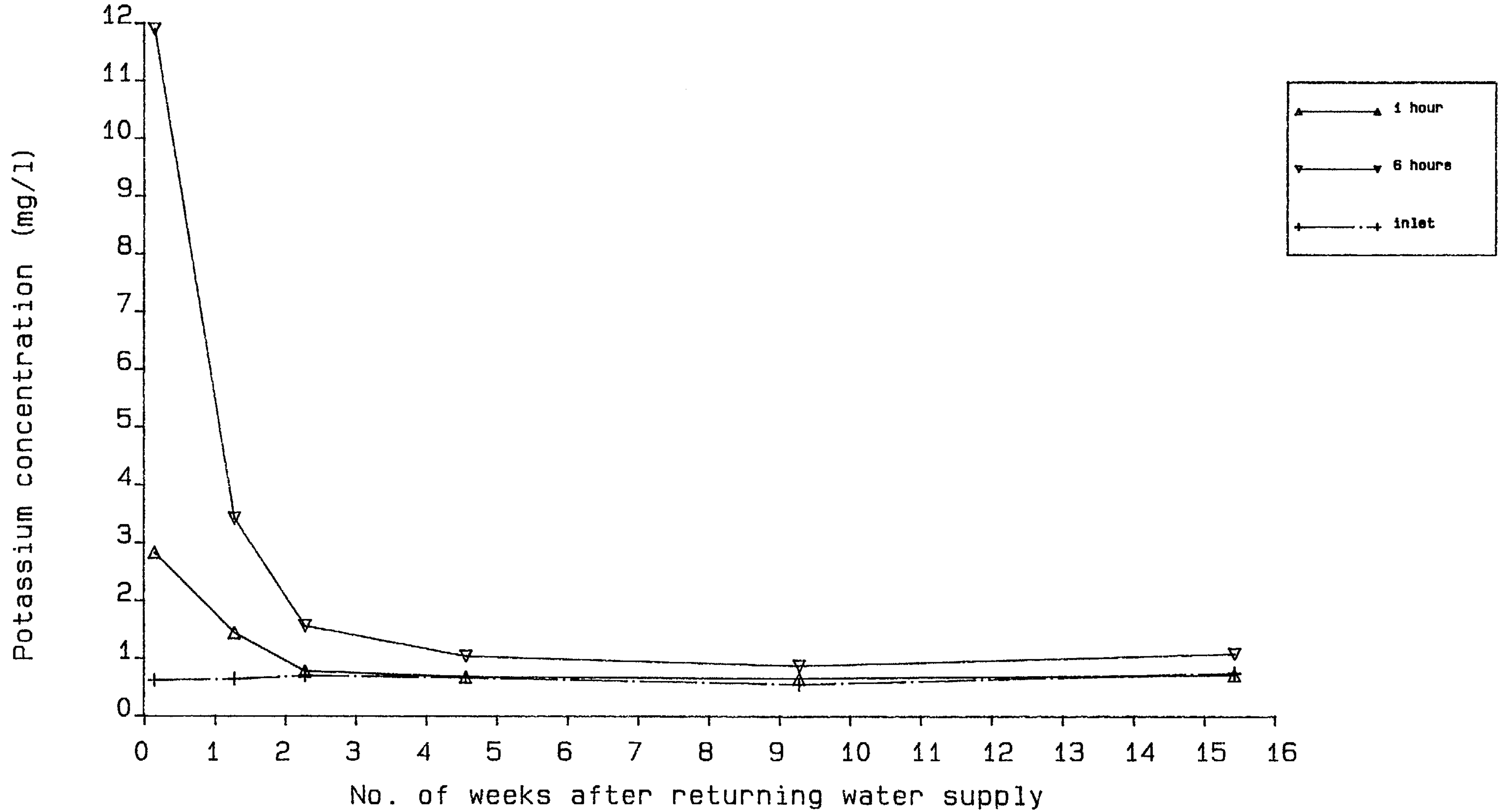

FIGURE 14 SODIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
HOWWOOD TRIAL LENGTH

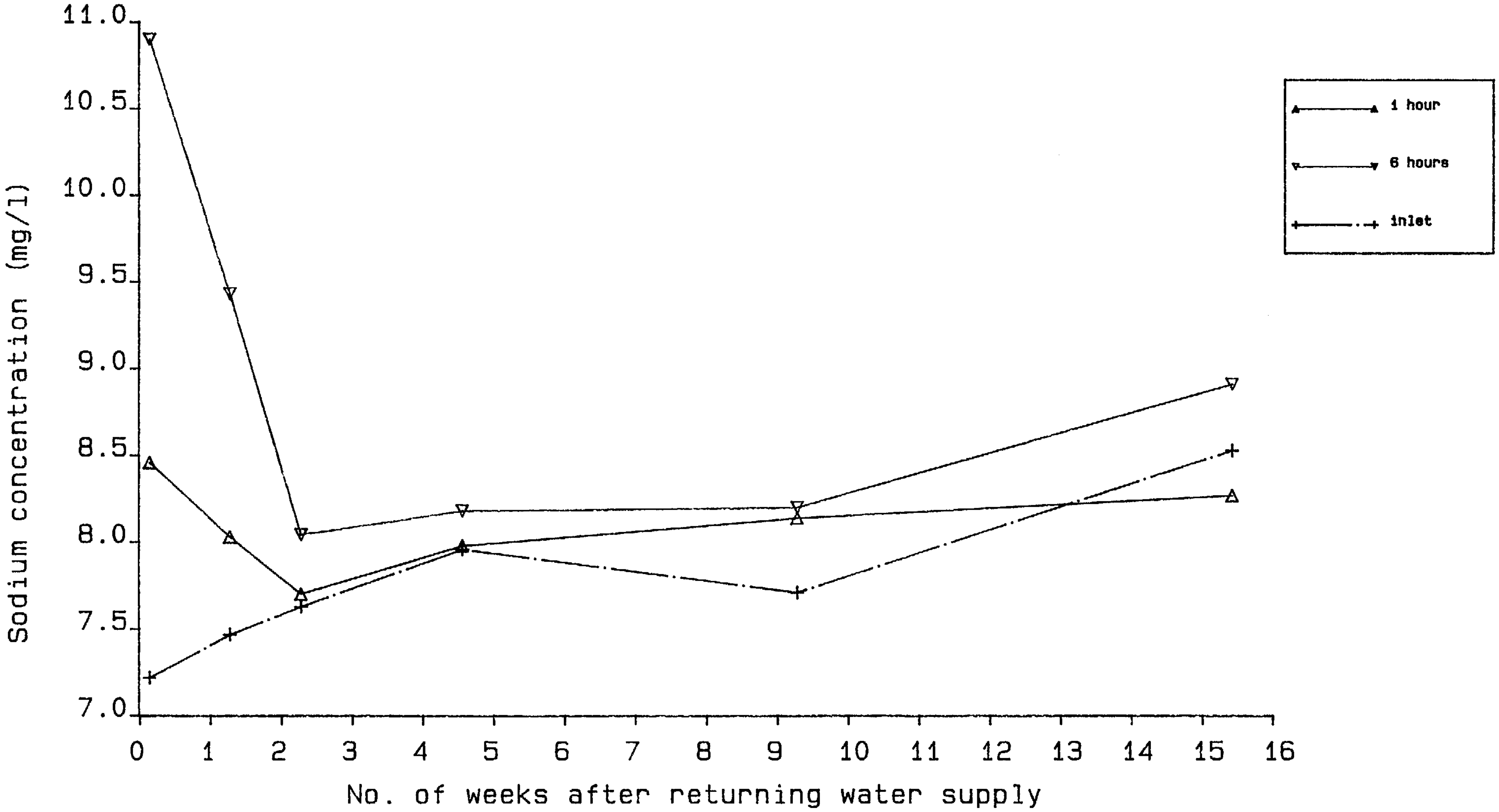

FIGURE 15 ALUMINIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH

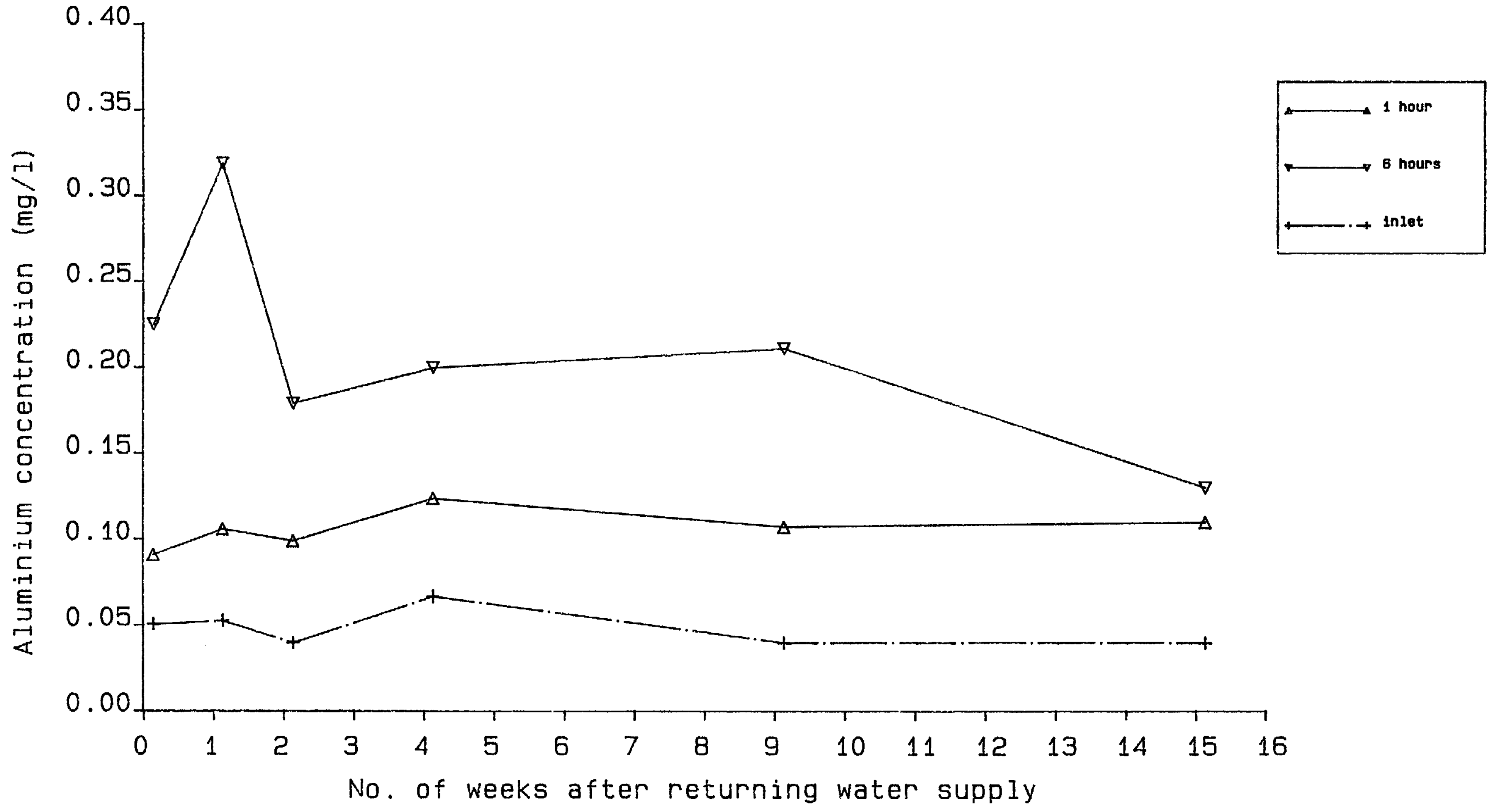

FIGURE 16 CALCIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH

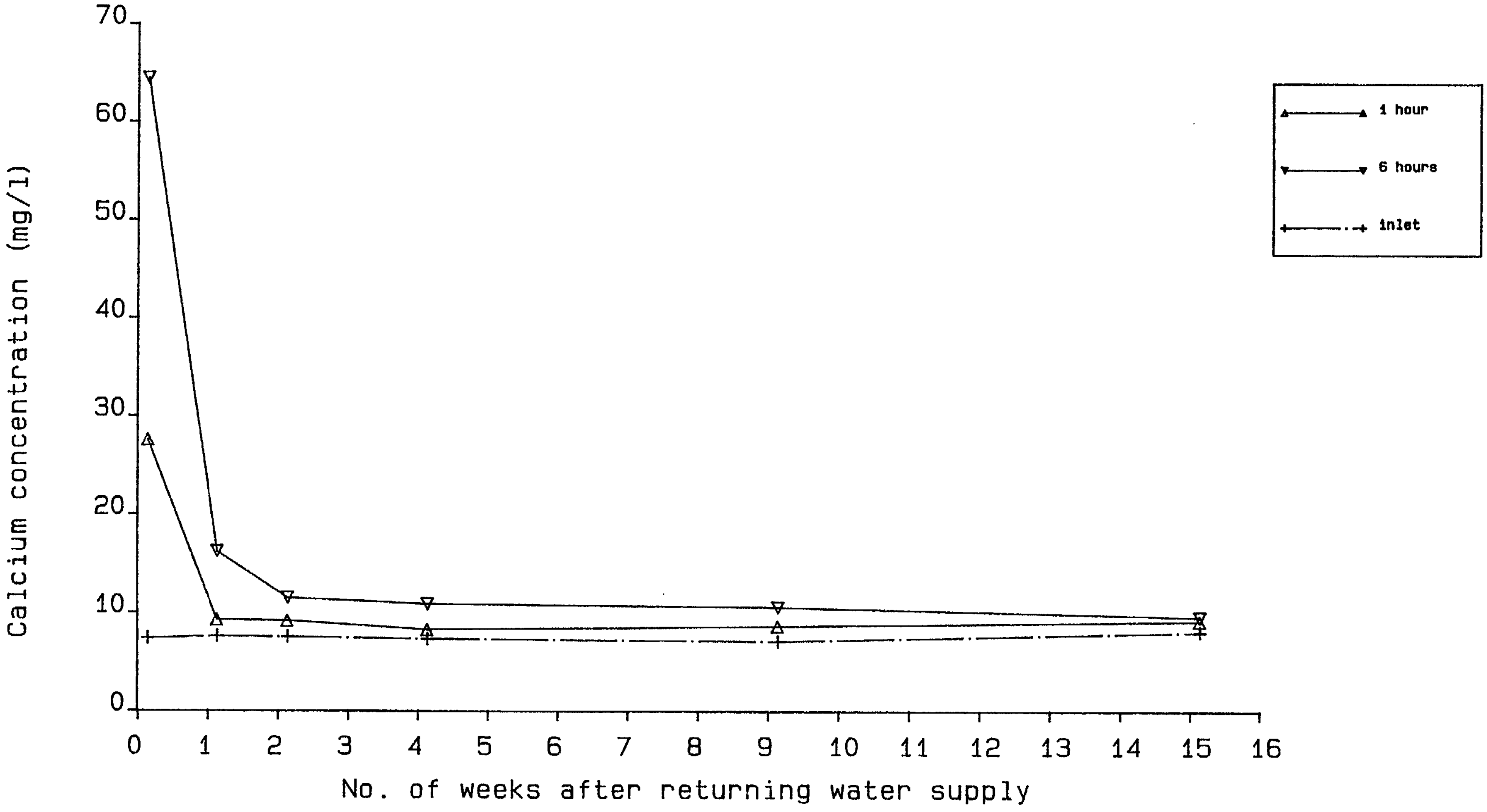

FIGURE 17 POTASSIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS MILLERSTON TRIAL LENGTH

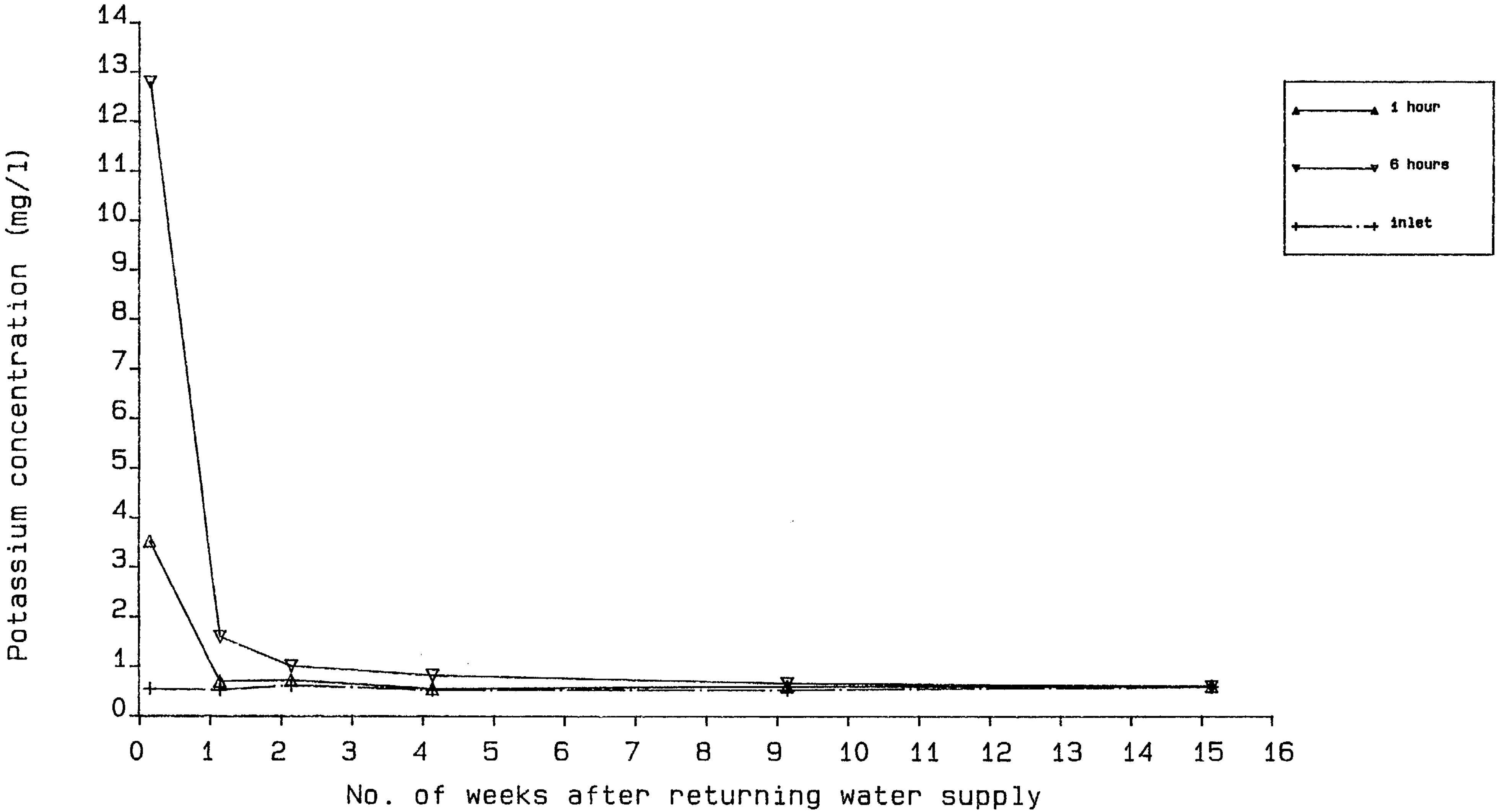

FIGURE 18 SODIUM CONCENTRATIONS FOR CONTACT TIMES OF 1 & 6 HOURS
MILLERSTON TRIAL LENGTH