UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Total and Water Extractable Boron in Sediments from Nine Sites of the Western United States

By

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INTRODUCTION

Boron is an essential element for plant growth, but if present at high levels in the growth medium can cause damage to shoots and leaves and reduce crop yields (Eaton, 1944; Glaubig and Bingham, 1985; Maas, 1986; Wilcox and Durum, 1967). Because of low moisture and high alkalinity in soils of the western United States, accumulated boron may limit the types of plants that can be used for cultivation or revegetation. Sediments may also accummulate boron and affect the quality of irrigation water which contacts them.

A survey study was undertaken to assess boron extractability from sediments at nine sites in the western United States as part of the phase one investigation conducted by the Department of Interior's selenium irrigation task force (DOISITF), an interagency program designed to identify and evaluate areas of potential irrigation problems in the West. A separate study examines the relationship between extractable and total boron to determine if extractable boron can be used as an indicator of boron reserves which would affect long-term quality of water exposed to soils or sediments. Finally, results obtained at different sample to water extraction ratios are discussed and recommendations are made for the comparison of data obtained from different studies.

MATERIALS AND METHODS

Samples collected from nine locations in the western United States (fig. 1, table 2, Severson and others, 1987) were air dried at room temperature and ground to pass a 2mm sieve using a Bico model 6R vertical grinder.

A total of 69 samples were extracted according to a modified method of Berger and Troug (Berger and Troug, 1940; Crock and Severson, 1980). For the survey study, an extraction ratio of one part sediment to two parts water (1:2) was used. Ten grams of sample were weighed into tared 50-ml polypropylene tubes and 20 grams of deionized water added. In other tests, amounts of soil were varied to achieve the desired extraction ratio. Tubes were capped, shaken to wet the entire sample and placed in a boiling water bath for 1 hour. After removal from the bath, tubes were allowed to cool and centrifuged at 1500X G for 15 minutes. Tared polypropylene tubes containing 10 µl of concentrated HNO_3 and 15 µg lutetium oxide as internal standard were brought to a final mass of 3 grams with supernatant. The final concentration of lutetium was 5 ppm. Precision of the method was evaluated by extracting four of the sediments five separate times at each ratio. Relative standard deviation for duplicate measurements on the same supernatant was < 1%.

Samples for total boron analysis were prepared by mixing 0.1 grams of sample with 0.3 grams of sodium peroxide in a zirconium crucible and sintering for 20 minutes at 420°C. The sinter cake was placed in a teflon beaker with 14 mL de-ionized water, disaggregated by stirring, and dissolved by addition of 6 mL of 6 N HCl. Lutetium was adjusted for a final concentration of 5 ppm and the sample brought to a final mass of 20 grams with deionized water.

All boron analyses were performed using a Jarrell Ash model 1160 Inductively Coupled Argon Plasma--Atomic Emission Spectrometer (ICAP-AES) (Lichte and others, 1987). In the survey study using the extraction ratio of 1:2, the determination limit was 0.4 ppm dry weight in sample. The determination limit for total boron was 20 ppm in sample.

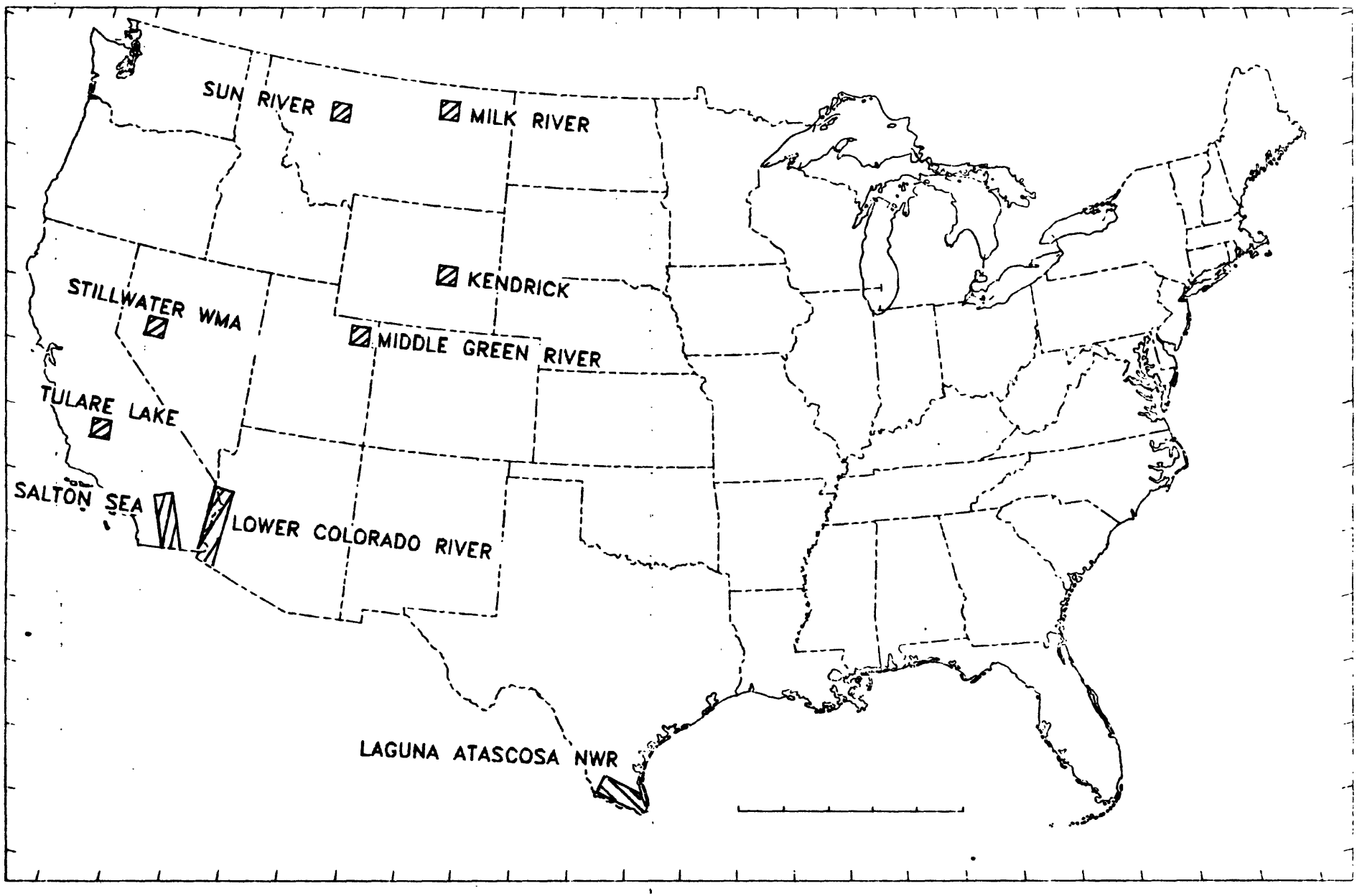

Figure 1. Map showing the general locations of the nine western United States field-screening project areas.

RESULTS AND DISCUSSION

Total Boron

Table 1 presents the raw data for 69 samples analyzed for total boron. Sample location is indicated by the first two letters in each identification number (eg. TL07U861 from Tulare Lake). Concentrations range from <20 ppm to 263 ppm (fig. 2) with a geometric mean of 48 ppm. No data were found in the literature on total boron in sediments for comparison with this study. The range for these sediments, however, is similar to that found in previous studies on western soils of <20ppm to 300 ppm (Conner and Shaklette, 1975; Ebens and Shaklette, 1982; Whetstone and others, 1942). The mean is higher than the 32 ppm found in B horizon soils of the eastern US (Conner and Shaklette, 1975). At individual sites (table 2), geometric means for total boron range from 20 ppm at Stillwater to 76 ppm at Tulare Lake. The distribution is positively skewed due to four high-boron samples from Tulare Lake. These samples were obtained from ponds where significant evaporation has occurred resulting in boron build up in the water and subsequently in the underlying sediments. Their uniqueness is evident in the extraction studies as well.

Extractable boron

An extraction ratio of 1 part soil to 2 parts water was chosen for the survey study for two reasons: 1) previous USGS studies have used this ratio (Crock and Severson, 1980, Severson and Gough, 1983); and 2) to lower the determination limit. At this ratio, extractable boron ranges from 0.5 ppm to 130 ppm (table 1) with a geometric mean of 3.8 ppm (fig.3). In contrast to total boron, this mean is higher than observed for many western soils extracted by the same method (Ebens and Shaklette, 1982; Haas, 1944; Parker and Gardner, 1982; Whetstone and others, 1942). The distribution is positively skewed--similar to that for total boron. The skewness is influenced by the same four samples from Tulare Lake which affect the total boron distribution. At individual sites (table 2), geometric means range from 1 ppm at Green River to 12 ppm at Tulare Lake. As with total boron, the mean extractable boron is highest at Tulare Lake--more than twice that of the next highest site at Milk River. Five of the nine sites in this study contain sufficient extractable boron to be toxic to many crops if present in the soil at these levels (Eaton, 1944; Glaubig and Bingham, 1985; Maas, 1986; Wilcox and Durum, 1967).

A plot of extractable boron versus total boron (fig. 4) shows the four samples high in total and extractable boron from Tulare Lake are separated from the rest. Thirty-eight to fifty percent of the total boron is extractable at a 1:2 ratio. This is further evidence of the unique conditions of this closed system. Since these sediments are high in extractable boron, waters coming in contact with them will become unsuitable for irrigation purposes unless diluted with fresh low-boron waters. In addition, the large amount of total boron means there may be sufficient reserve to affect water quality for a long time.

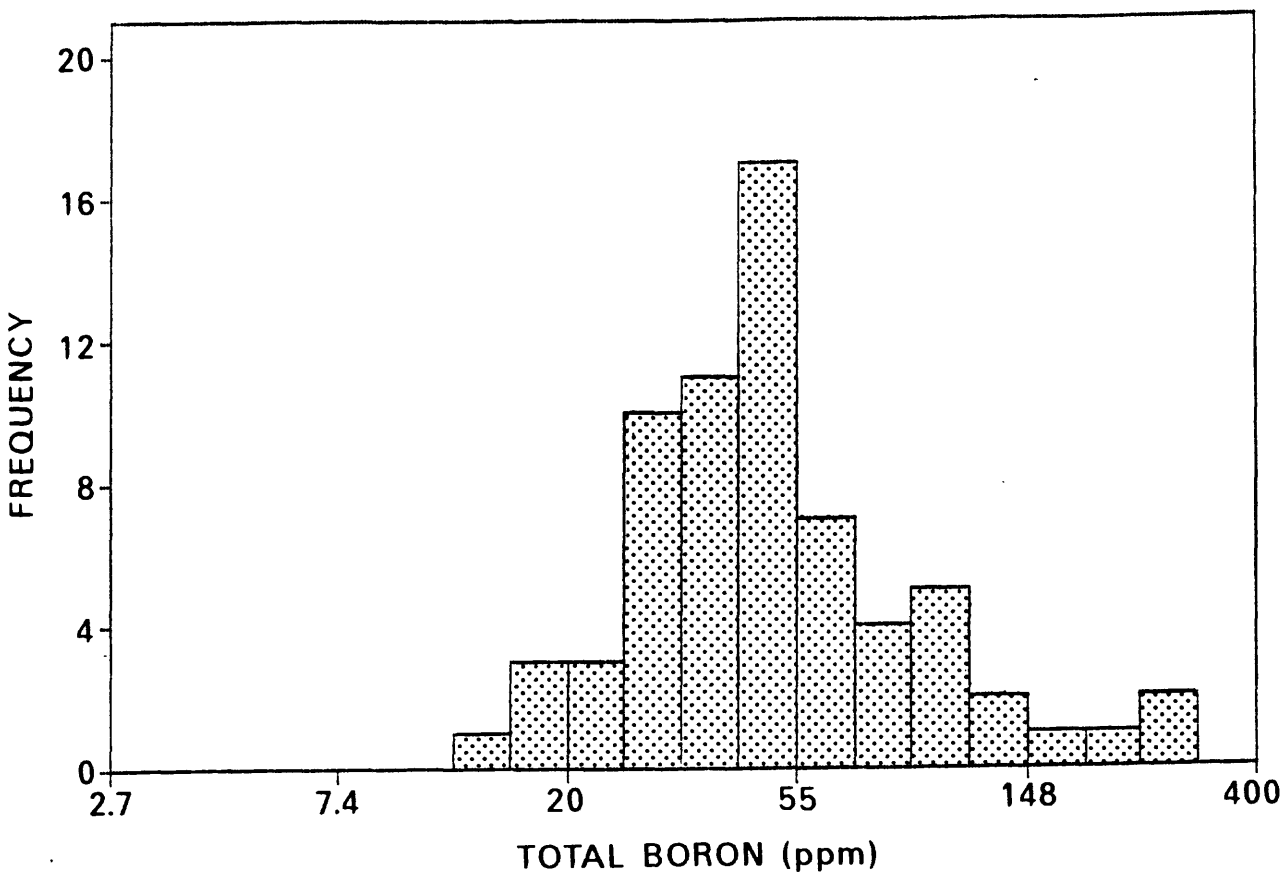

Figure 2. Frequency distribution for log total boron. Log class interval = .11

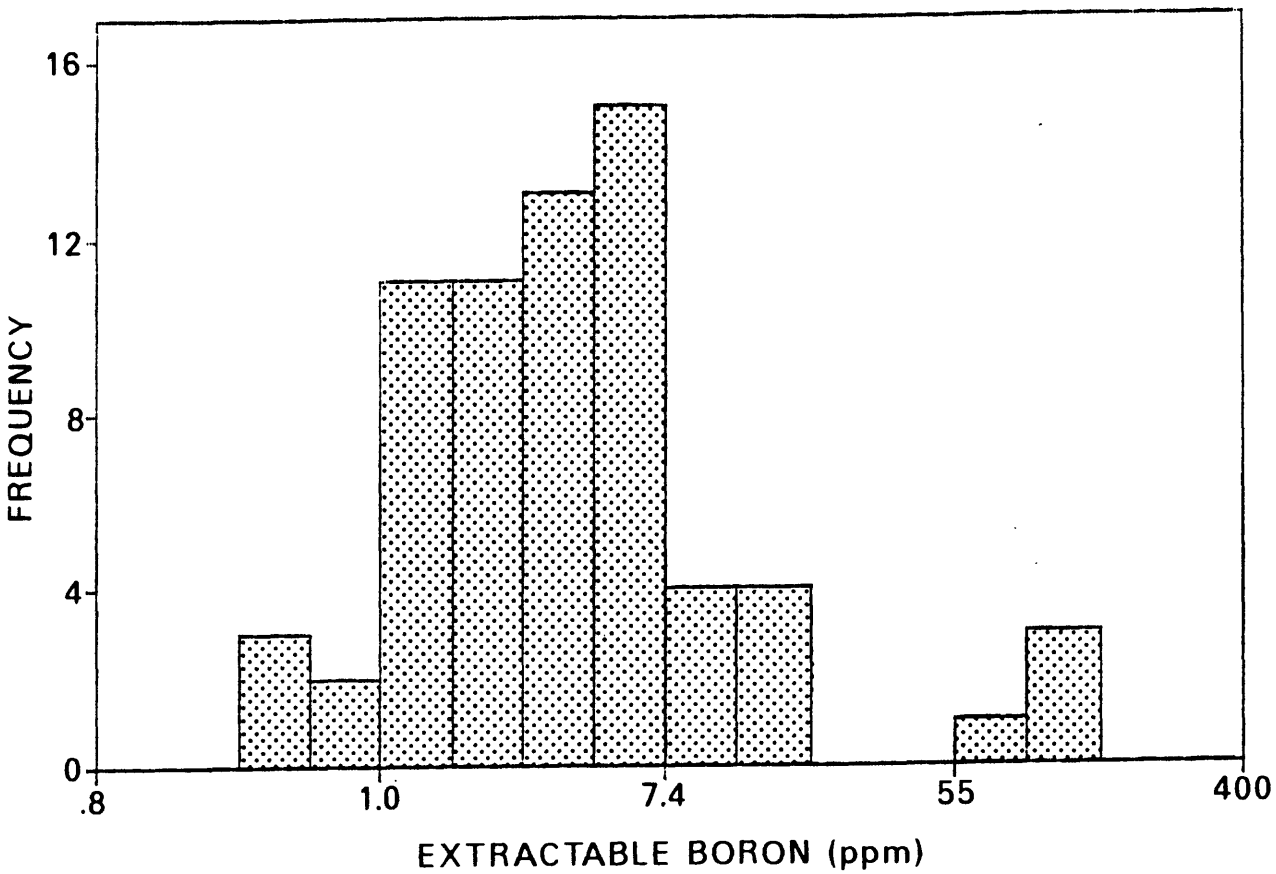

Figure 3. Frequency distribution for log water extractable boron at 1:2 extraction ratio. Log class interval = .87.

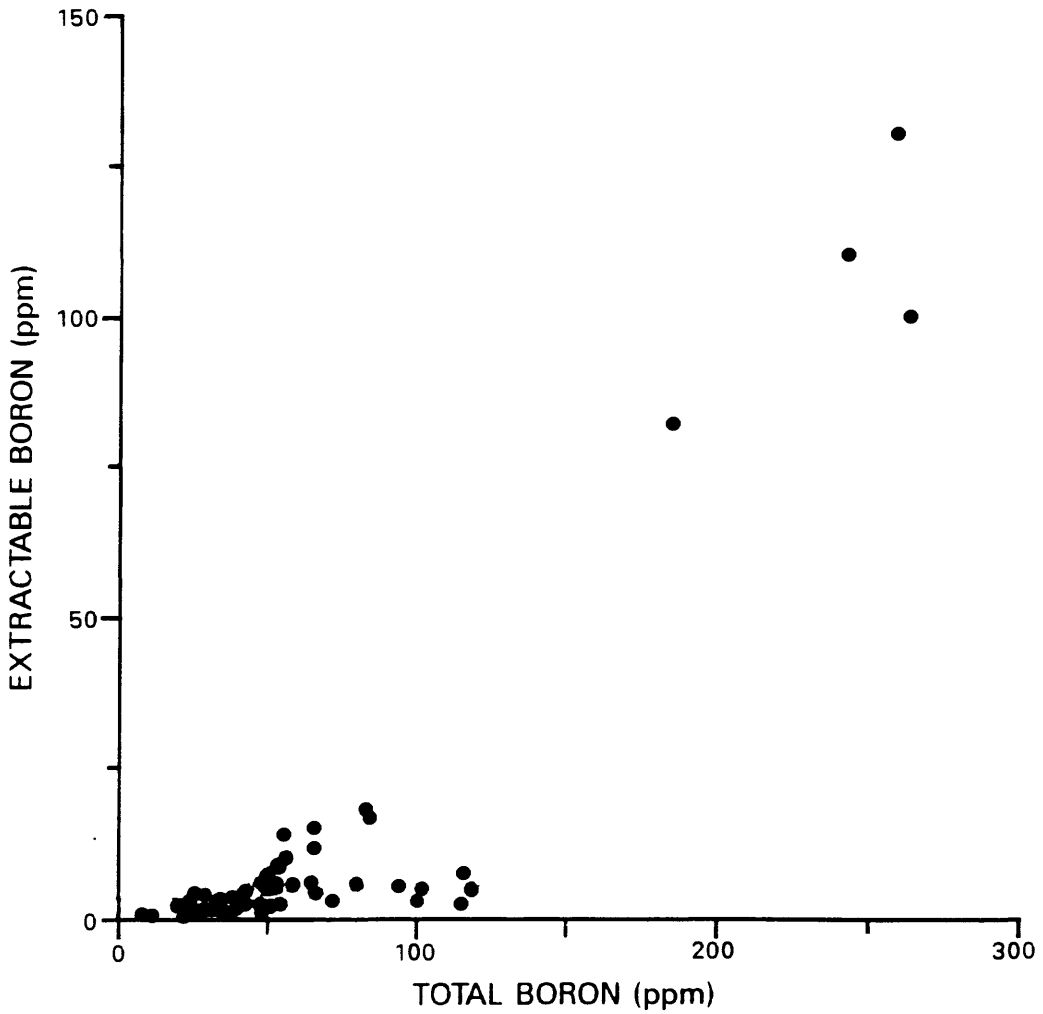

Figure 4. Water extractable boron versus total boron in stream sediments.

Effect of sediment to water ratio

The second part of this study examined the effect of different sample to water ratios on boron extraction. A 1:10 ratio was selected for comparison with data obtained at 1:2. The frequency distribution for these results is shown in figure 5. Compared to the distribution obtained at 1:2 (fig. 2), the skewness is reduced and a more normal distribution is observed. In addition, an average of 20% more boron can be extracted at the higher ratio. If the four high samples from Tulare Lake discussed earlier are removed from the data set and the results plotted, the mean difference between the two ratios is even greater (fig. 6). Extractable boron at the higher ratio is 1.7 times that extractable at 1:2.

To more fully characterize the behavior of extractable boron, four samples from three different sample sites were tested by a series of soil to water ratios--1:2, 1:10, 1:20 and 1:50. For this test, samples were selected from the upper end of the 1:2 frequency distribution in order to detect boron at the higher extraction ratios, and since sediments with higher extractable boron concentrations are more likely to adversely affect water quality. Figure 7 shows that as the extraction ratio increases from 1:2 to 1:50, more boron is extracted, but the amount varies for the different samples. Sample 09 from Tulare Lake shows the greatest absolute increase between the 1:2 and 1:10 extraction ratios. Using a paired t-test the differences for all four samples were found to be statistically significant at a 95% confidence level between the 1:2 and 1:10 extraction ratios. At higher extraction ratios only the Tulare Lake samples continue to show significantly more extractable boron. This suggests that boron in the Tulare Lake sediments is associated with either a readily exchangeable or solubility-limited phase.

CONCLUSIONS

There are two principle conclusions from this study. First, the data show that total boron levels in sediments are not very different from soils, but extractable levels are higher. Sediments, therefore, probably contain phases with water extractable boron which are not found in soils. The same phases may determine the short or long term release of boron to irrigation water in these systems. The second conclusion is that different extraction ratios will obtain different data from the same sample. Similar differences have been observed in soil extraction studies (Okazaki and Chao, 1968; Parker and Gardner, 1982) and other soil data compiled in the literature (Swaine, 1955). This means that studies may be difficult to compare unless the extraction methods are also evaluated and relationships between data sets are determined.

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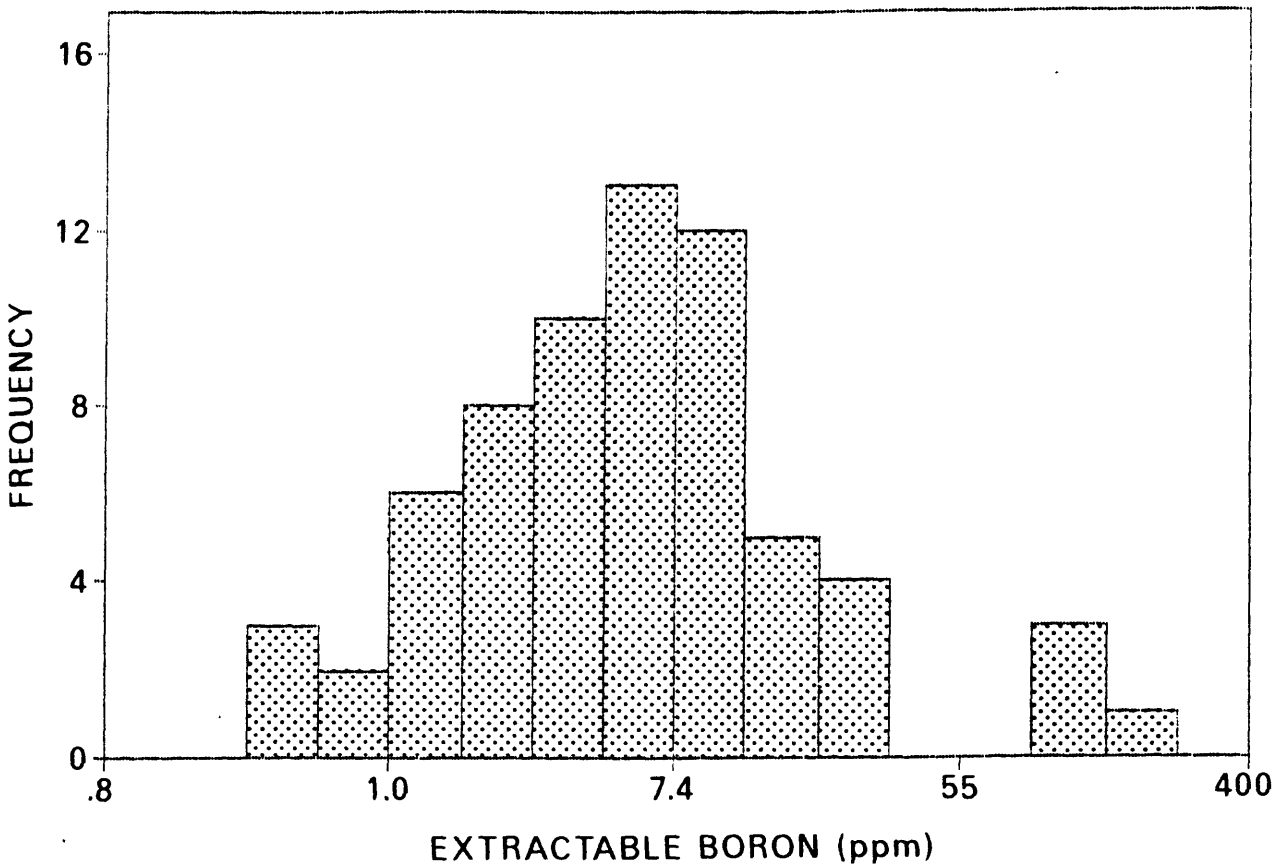

Figure 5. Frequency distribution for log water extractable boron at 1:10 extraction ratio. Log class interval = .87.

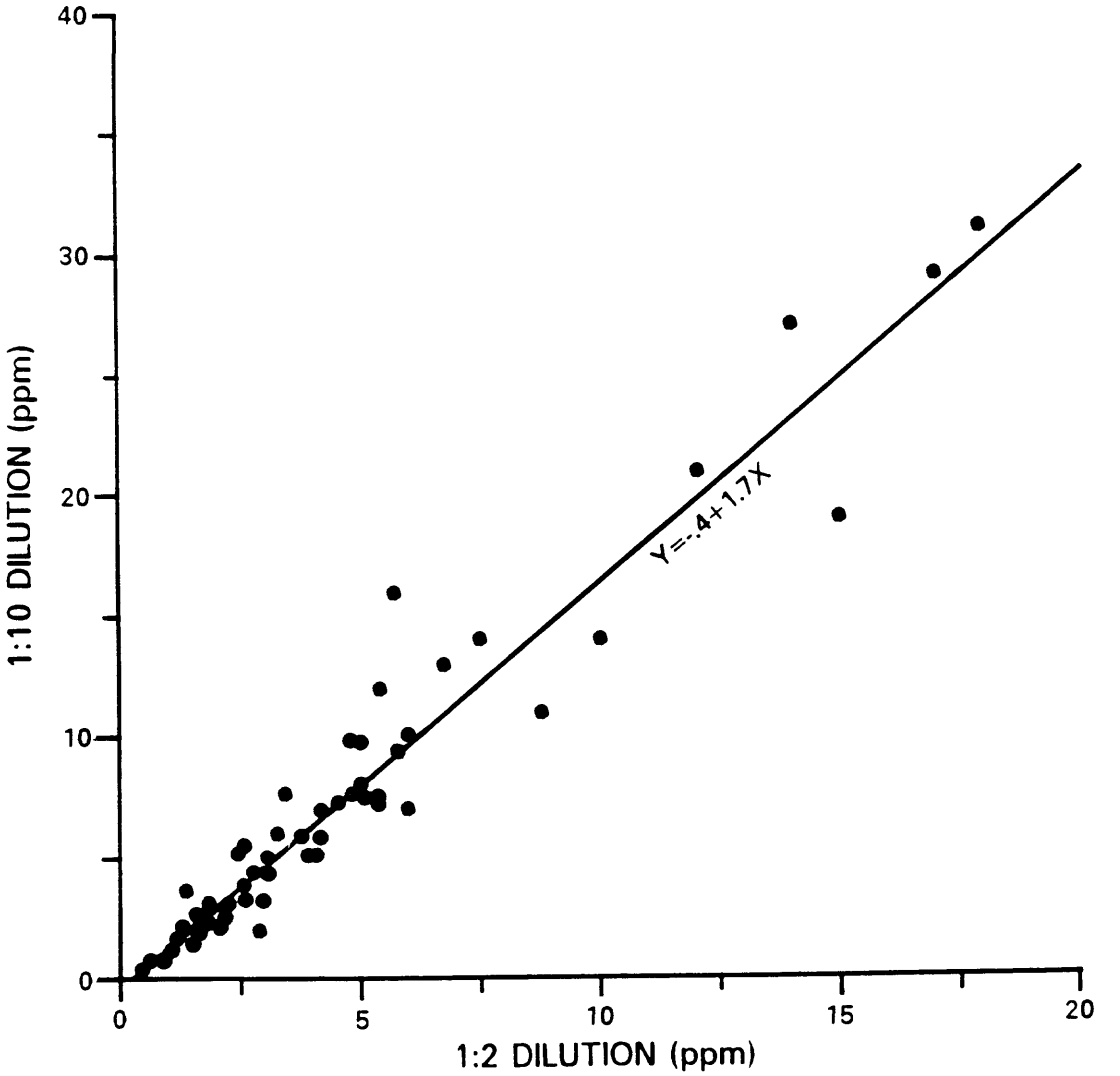

Figure 6. Extractable boron at 1:10 versus 1:2 extraction ratios without four high boron samples from Tulare Lake.

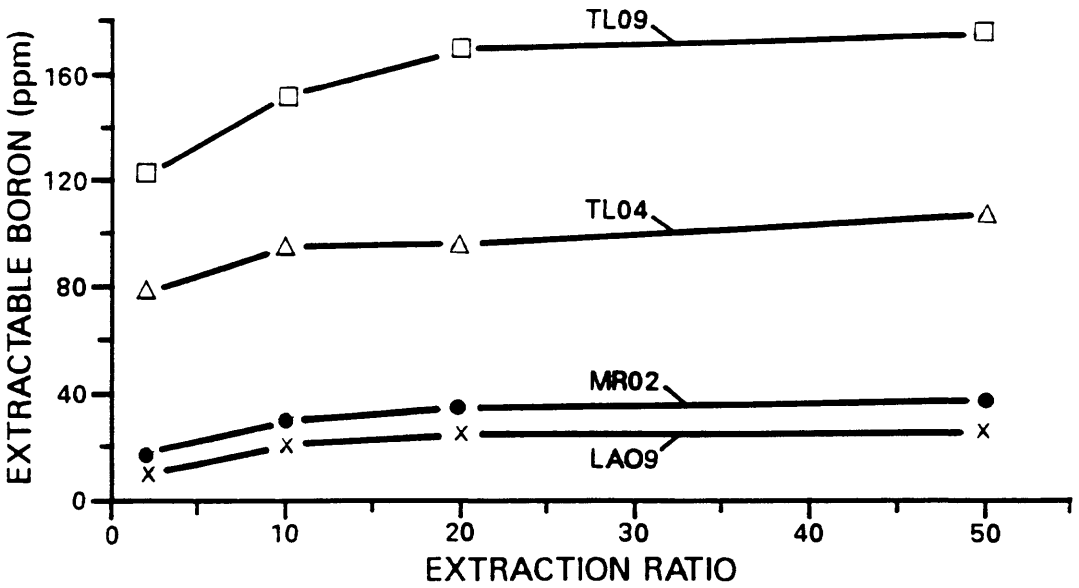

Figure 7. Extractable boron for several samples at various extraction ratios.

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Table 1. Boron data for sediments from nine areas in western U.S.

Sample ID	ppm extractable 1:2	ppm total	percent extractable 1:2	ppm extractable 1:10
SR01U861	4.2	102	4	6.9
SR02U861	5.0	102	5	9.8
SR03U861	2.6	115	2	3.9
SR04U861	7.5	116	7	14
SR05U861	4.8	118	4	9.8
SR06U861	4.5	66	7	7.2
SR07U861	5.2	51	10	7.4
SR07U862	5.4	51	11	7.2
SR08U861	3.0	100	3	3.3
SR09U861	3.1	72	4	4.4
SR10U861	2.1	40	5	2.2
SR11U861	2.6	53	5	5.5
SR12U861	4.2	44	10	5.8
SR13U861	5.4	49	11	7.5
SR14U861	1.3	29	4	< 2
MR01U861	4.9	43	11	7.7
MR02U861	17	84	21	29
MR02U862*	18	83	22	31
MR03U861	4.0	26	15	5
MR04U861	5.0	51	10	8
MR05U861	5.4	94	5	12
MR06U861	1.1	26	4	< 2
LA01U861	5.7	80	7	16
LA02U861	5.8	59	10	9.4
LA03U861	3.4	49	7	7.6
LA04U861	2.5	42	6	5.2
LA05U861	4.7	46	9	7.4
LA06U861	3.1	36	9	4.8
LA07U861	14	56	25	27
LA08U861	6.0	65	9	7
LA10U861	1.2	27	4	< 2
LA11U861	1.9	33	6	3
LA12U861	3.3	39	8	6
LA13U861	4.1	29	14	5.1
LA14U861	1.6	34	5	2.7
LA15U861	6.0	48	13	10
LA09U861	12	66	15	21
LC01U861	1.2	30	4	< 2
LC02U861	.8	20	4	< 2
LC03U861	1.0	33	3	< 2
TL01U861	3.1	41	8	4.8
TL02U861	10	56	18	14
TL03U861	1.8	29	6	2.5
TL04U861	82	185	42	94
TL05U861	.5	21	2	< 2
TL06U861	2.2	20	11	2.5
TL07U861	110	243	45	140
TL08U861	100	263	38	110
TL09U861	130	259	47	150
SS02U861	.6	< 20	-	< 2
SS03U861	.5	< 20	-	< 2
SS04U861	.7	< 20	-	< 2
SS05U861	1.3	48	3	2.1
SS06U861	1.6	36	4	< 2
SS07U861	1.1	24	5	< 2
SS08U861	2.6	48	5	3.3
SS09U861	1.5	34	4	< 2
SS10U861	2.2	48	5	3.1
SS11U861	15	66	24	19
SS12U861	.5	22	2	< 2
SS13U861	8.8	54	16	11
SS14U861	1.1	36	3	< 2
SS15U861	1.4	34	4	3.6
SS15U862*	2.9	34	9	2.0
SS16U861	2.4	51	5	3.2
KW07U861	1.0	38	3	< 2
SN01U861	.8	< 20	-	< 2
SN02U861	2.8	24	12	4.4
GR01U861	2.2	26	8	3.1
GR02U861	3.8	51	7	5.9
GR03U861	6.8	50	14	13

* Duplicate.

Table 2. Water soluble, total and % extractable boron of 69 sediment samples based on dry weight

Site	number of samples	Geometric Means		
		water extractable 1:2 ppm	total ppm	% extractable
Tulare Lake (TL)	9	12	76	16
Milk River* (MR)	6	5.6	52	10
Laguna Atascosa (LA)	15	4.0	45	9
Green River (GR)	3	3.8	40	9
Sun River (SR)	14	3.7	67	5
Salton Sea* (SS)	15	1.6	31	5
Stillwater (SN)	2	1.5	20	8
Lower Colorado (LC)	3	1.0	27	4
Kendrick** (KW)	1	1.0	38	3

*One sample duplicated from this site.
**Values for one sample only.