PROBLEMS IN ESTIMATING SELF-SUPPLIED INDUSTRIAL WATER USE BY INDIRECT METHODS -- THE CALIFORNIA EXAMPLE

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U. S. GEOLOGICAL SURVEY

Water Resources Investigations Report 83-4276

Menlo Park, California

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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I L L U S T R A T I O N S

T A B L E S

TERMS USED FREQUENTLY IN THIS REPORT

Several terms that are used frequently throughout this paper are intended to have the following meanings:

<u>fresh water</u> -- water that contains less than 1,000 milligrams per liter (mg/L) of dissolved solids; generally, more than 500 mg/L is undesirable for drinking and many industrial uses.

<u>water use</u> -- the supplies of water taken from a ground- or surface-water source for use by the various consumers.

<u>consumptive use or net water use</u> -- water consumed by evaporation in a manufacturing process or contained in the product; also, the difference between water intake and water discharge at an industrial plant.

<u>self-supplied industrial water use</u> -- the use of water by industry where the supply is developed by the industry rather than delivered through a public supply system.

<u>SIC (Standard Industrial Classification) number or code</u> -- the organizational code for industrial establishments from a Commerce Department classification system based on industrial activities and products. A particular number represents a group of industries with similar activities and products. The number of digits in the code represents the level of specificity of activities and products in the group. For example, there are 20 two-digit codes designating 20 generalized groups, about 150 three-digit codes designating 150 more-specific groups, and about 450 four-digit codes designating 450 even-more-specific groups.

<u>value added</u> -- the difference between the cost of materials and other inputs in manufacturing a product and the price received for the product that is shipped.

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ABSTRACT

Consumptive fresh-water use by industry in California is estimated at about 230 million gallons per day, or about one-half of one percent of agricultural withdrawals in the State, and only about 1 percent of agricultural consumptive use. Therefore, a significant State-wide realignment of the total water resources could not be made by industrial conservation measures. Nevertheless, considerable latitude for water conservation exists in industry -- fresh water consumed by self-supplied industry amounts to about 40 percent of its withdrawals in California, and only about 10 to 15 percent nationally (not including powerplant use). Furthermore, where firms withdraw and consume less water there is more for others <u>nearby</u> to use.

With this perspective, the central question of this study was whether accurate estimates of industrial water use could be made from coefficients of water use based on indicators such as production and employment. Apparently, the answer is no, because different data sets produced divergent coefficients of water use for similar industries.

The variability resulted from at least two problems: 1) unreliable data associated with responses to questionnaires, and 2) real differences in water use within industrial classifications where materials, products, and processes may differ widely among establishments. In addition, the amounts of water used in an individual firm, or within a narrow industrial category, simply may not be representative of others within a more general category because the classification system may lump more-water-use intensive industries with less-water-use intensive industries.

INTRODUCTION

The intent of this study was to develop a method of estimating overall self-supplied industrial water requirements using coefficients of water use for production and employment from five major-use industrial categories. Those categories included food and kindred products, lumber, pulp and paper, chemical and allied products, and petroleum industries.

The hypothesis was that existing industrial water-use data could be correlated accurately with either production or employment data as a means of estimating and projecting industrial water use. Emphasis shifted toward an analysis of the problems in developing accurate coefficients for projecting industrial water use when it became apparent that the existing data were not adequate to support the hypothesis.

Data used to test the hypothesis were from California Department of Water Resources (DWR) publications and from U. S. Bureau of the Census publications on manufacturing. The analysis was basically a comparison of water-use data from those two sets of information.

RELATION OF INDUSTRIAL WATER USE TO OTHER MAJOR USES

Although this paper is about industrial water use, an overview of water-use categories other than industrial, both in California and the U. S., gives perspective to the significance of self-supplied industrial use as a part of the overall framework of water use. Table 1, adapted from Solley, Chase, and Mann (1983) gives a summary of fresh-water withdrawals and consumptive use for offstream water-use categories nationally and in California for 1980. The major offstream water-use categories are public supply, rural use, irrigation, and self-supplied industrial use, including thermoelectric power generation. The estimated total national rate of withdrawal of fresh ground and surface water in 1980 was about 380 billion gallons per day (bgd), including about 150 bgd for thermoelectric power plants.

Table 1. -- Summary of fresh-water withdrawals and consumptive use for offstream water-use categories, in California and nationwide, in billion gallons per day, 1980 (Solley, Chase, and Mann, 1983, pp. 10, 14, 18, 22, 23).

	California		U. S.	
	withdrawal	consumptive use	withdrawal	consumptive use
Public supply	4.1	1.7	34.0*	7.1
Rural use	0.2	0.1	5.6	3.9
Irrigation	37.0	23.0	150.0	83.0
Self-supplied Industrial				
thermoelectric	2.0	0.04	150.0	3.2
other	0.5	0.2	39.0	5.0
Total (rounded)	44.0	25.0	380.0	100.0

* 12 bgd from public supplies goes to industrial categories other than thermoelectric.

Nationally, withdrawals for industry other than power plants were estimated at 39 bgd as self-supplied plus 12 bgd from public supplies. Thus, fresh-water withdrawals for industrial use (51 bgd not including withdrawals for power plants) comprise less than 15 percent of total fresh-water withdrawals. Industrial plants with an annual intake of 20 million gallons or more, which represent only about 3 percent of the total number of plants, account for about 95 percent of those withdrawals. In any given State such plants are generally represented by three to five 2-digit SIC industrial categories (see p. v, "Terms...."). In California, the industrial base is well-diversified, and the major water-using industries include five categories: food, petroleum, lumber, pulp and paper, and chemicals.

Industry is a major competitor for water nationally, but the biggest users by far are agriculture and thermoelectric power plants, which required fresh-water withdrawals of about 150 bgd each in 1980. Nationally, agriculture accounts for about 40 percent of all fresh-water withdrawals and 65 percent of freshwater withdrawals not including those for thermoelectric power. In the West, about 90 percent of consumptive water use is by irrigated agriculture (Bredehoeft, 1983). In the eastern states the percentage of industrial water use is higher, and accurate information about industrial withdrawals is relatively more important than in the West.

In California, withdrawals for industry are higher than for any other State west of the Mississippi River except Texas, and amount to about 0.5 bgd [180 billion gallons annually (bg/yr)] of fresh water, exclusive of power plants. About 0.2 bgd (70 bg/yr) are not returned and are considered as consumptive use. Withdrawals for irrigation of agricultural lands amount to about 37 bgd (13,500 bg/ yr), and about 23 bgd (8,400 bg/yr), are considered as consumptive use. In other words, industrial consumptive use in California is about one-half of one percent of agricultural withdrawals and only about 1 percent of agricultural consumptive use -- and agricultural withdrawals account for more than 80 percent of the total withdrawals, including those for thermoelectic power.

Fresh water consumed by self-supplied industry -- evaporated in the manufacturing process or incorporated in the product -- amounts to about 40 percent of withdrawals in California and 10 to 15 percent of withdrawals nationally (not including power-plant use). Thus, considerable opportunity exists for a plant to recycle water. However, economic incentives for withdrawing less water are not strong because the cost of water supplies is generally less than 2 percent of production costs (National Water Commission, 1973). Realistically, the economic incentive for conservation of water by industrial establishments is the cost of treating sewage effluent.

Where the cost of using water is small there will be little recycling. This was the case in the early 1950's when the average intake for all industries was about 55 percent of the gross water used. Recycling has grown since then so that now in the major water-using industries as shown in figure 1, the intake is about 30 percent of the gross water used. The "Clean Water Act" (Public Law 92-500, Federal Water Pollution Control Act Amendments of 1972) provided impetus to recycling by sharply increasing the cost of using water. Although the increased cost was not for water intake but was for water discharge, the effect was the same as if the cost of buying the water supply had risen. Industrial discharge must now be treated, and treatment is costly. Therefore, firms try to minimize their discharge both by using processes that are less water-intensive and by recycling as much water as possible. This has an added cost-saving aspect in that chemicals formerly discharged with the effluent can be recovered and also recycled. While the direct benefits of water conservation in industry are apparent, the benefit of the additional increment of water available for other uses resulting from this conservation may be small, except in localized situations, compared with the common indirect benefit of decreasing wastewater discharges.

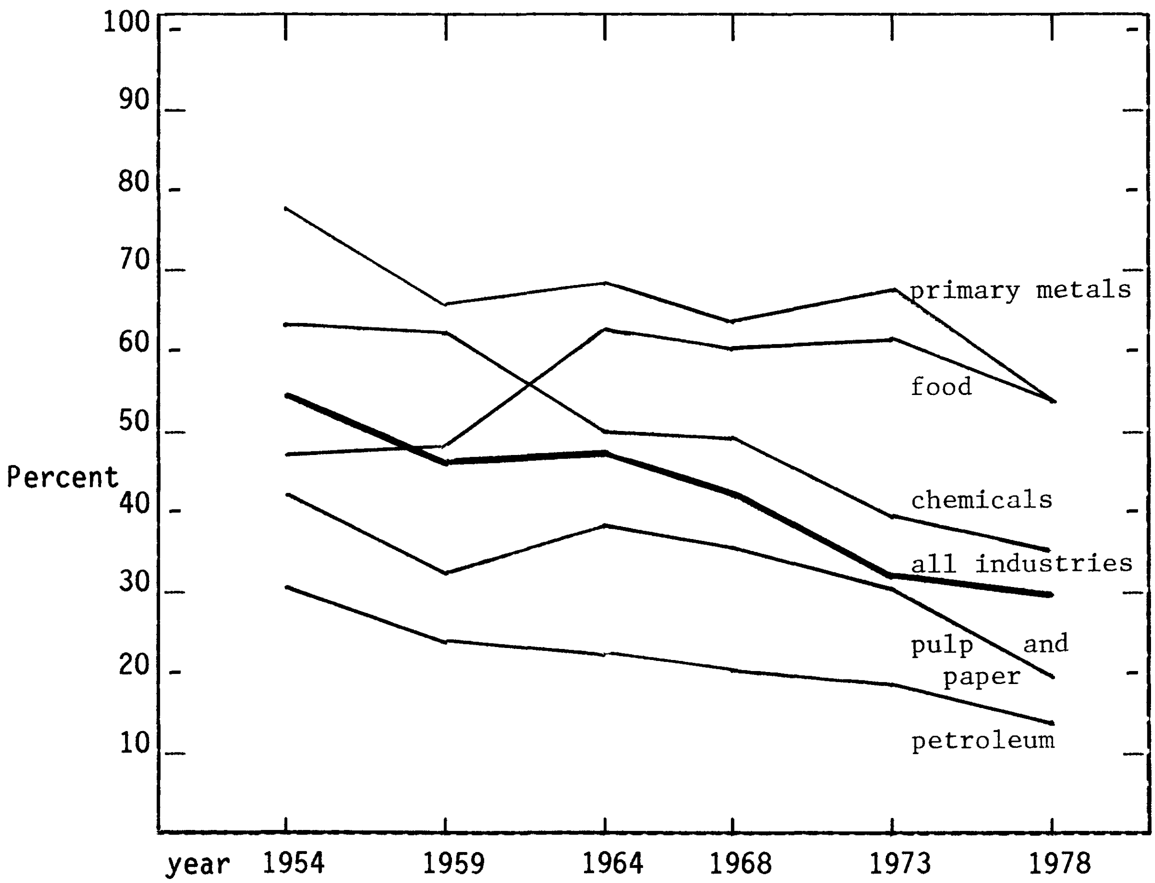

Figure 1.--Nationwide industrial water intake as a percentage of gross water used (David, Elizabeth, 1983, written commun.)

Two conclusions related to water conservation measures by industry can be drawn from the statements in the preceding paragraphs. First, very little realignment of the total water resources could be brought about by conservation measures by any but the major users representing the top three to five SIC groups indicated. Furthermore, overall water use would not be affected significantly, even by large industrial conservation measures. Second, where industrial use is a critical element in water management and planning, the important issue to be addressed will likely be the quality of the return flows rather than water consumption. Nevertheless, the availability of water at particular sites is and will continue to be affected by industrial withdrawals and consumption. When industries withdraw and consume less water there is more for others nearby to use.

DESCRIPTION OF THE DATA

Sources and Reliability of the Data

Two main sets of data were used in trying to develop a consistent (from one data set to another) and repeatable (from one year to the next) relation of either employment or production to water use for each of the 2- or 3-digit level SIC industrial manufacturing categories. One set is derived from several U. S. Census Bureau publications; the other is derived from two reports published by the State of California Department of Water Resources (DWR). Both sets of data are based on responses to questionnaires. A third set of generalized data is published in "Estimated Use of Water in the United States in 1980" (Solley, Chase, and Mann, 1983). The 1980 USGS report is the latest in a series published every five years since 1950. Forms for summarizing water use for each of six water-use categories (public supply, rural use, irrigation, thermoelectric, self-supplied industrial, and hydroelectric power) were completed by each of the U.S.G.S Water Resources Division District Offices and the compilations and report were prepared by the National Water-Use Information Program Office.

Methods for generating water-use data vary from one District Office to another, and from category to category. The data may be from on-site measurements or from estimates and extrapolation from similar, earlier reports. The accuracy of the estimates, therefore, ranges widely, and the data are not coded for accuracy. However, estimates for self-supplied industrial water withdrawals were considered generally reliable by the authors of the USGS report because many supplies are metered.

In spite of metering, however, estimates of water use in industry seem elusive because they depend on both an adequate number of returned questionnaires and the accuracy of written responses from establishments. In the absence of a means of checking the accuracy of responses, reported use may actually conform more closely with withdrawal and discharge permits than meter records, even if records are maintained. Furthermore, records of production levels and indirect indicators of production such as water use are often considered confidential by industrial establishments. Except when required by law, as for Census Bureau questionnaires, responses cannot be expected to be adequate, and even the accuracy of the obligatory responses in some cases can be questioned. Discrepancies from one year to the next within an industrial category are checked, but a mechanism for verifying the responses is not available.

Much of the information for California in the U.S.G.S. report was abstracted from studies made by the California Department of Water Resources (DWR). Those estimates were considered the best available. The latest DWR estimates of industrial use are contained in "Water Use by Manufacturing Industries in California, 1979" (State of California, May 1982). "Unit employee use" data in the DWR report, expressed in gallons per employee-working day, were averaged from replies from each 4-digit SIC level industry in every county.

Unit employee use data thus developed were assumed to be typical of an entire industrial group, presumably at the same SIC level. Where data were inadequate or absent, estimates from statewide averages were substituted. For some 3-digit SIC categories there was no response at all. Nevertheless, a value was given. Values from the latest survey were compared by the DWR authors with those of a previous 1970 survey (State of California, 1977) in order to detect large errors, and statewide averages for a particular industry were substituted in recent reports from the 1970 survey where the latest response to questionnaires was inadequate. It is uncertain how estimates were made if earlier responses were deficient. Because the response was partial, the employee unit-use value that was determined for a particular industrial group was used to expand the data to include an entire industrial group by multiplying it by the total number of employees in that group. Statistically, if there were errors in the coefficient based on a partial response, they were compounded by multiplying by the entire population of that group.

The other recent study by DWR in which industrial water use estimates are made is "Measuring Economic Impacts, the application of input-output analysis to California water resources problems" (State of California, March 1980). Except for the water-use data (also based on questionnaires), which were referenced to the DWR multiregional input-output model, this report stated that no primary research was conducted and all other data are from secondary sources.

Analysis and Manipulation of the Data

The present study uses the Census Bureau and DWR data to attempt a correlation of employment and water use, and production and water-use estimates. Data in the various Census Bureau publications are arranged by industry, water-use region, state, and county. The National study, "Water Use in Manufacturing, 1977 Census of Manufactures" (Bureau of the Census, 1981), contains water-use and employment information at the 4-digit level for the national averages. However, the State and regional compilations are at the 2-digit level. The Census Bureau State and county reports do not contain water-use information, and extrapolations were necessary to draw correlations between water and employment, and water and production. The DWR reports contain aggregated data on water use and employment at the 2- and 3-digit SIC level. Hence, comparisons are made of correlations based on 2- and 3-digit SIC level aggregates.

The primary assumptions for relating water use to employment and production were that 1) the number of employees is an indication of production, and the level of production will be directly related to water use, 2) the number of employees is also an indication (although indirect) of water use, and 3) water use per employee could be generalized for any particular industrial category. A secondary assumption was that water use per <u>production</u> employee is more directly related to the level of production than is water use per general employee, including those in supporting services. A ratio of production workers to total workers for the respective SIC categories was, in fact, determined from national Census Bureau estimates, and each was applied to total employment estimates in a matching SIC category in more recent Census Bureau County Business Patterns publications. It was further assumed that a coefficient for water use per production worker per day, determined from 5-year Census reports, could be multiplied by the annual employment estimates in County Business Patterns and State Manufacturers registers to determine a reasonable estimate of total use in each industrial category.

Estimates of water use made on the basis of the above assumptions are presented in table 2. This table shows a comparison of employee coefficients relative to industrial water use in the U. S., California, and Idaho by 2-digit level

SIC code	MAJOR INDUSTRY GROUP	U.S.		U.S.	U.S.	U.S.	U.S.	Calif.	Calif.		Idaho
	reference number(s)(date)	19, 20 (1977)		20 (78)	20(78)	5 (75)	10(63)	14(79)	18,20 (77)		* (78)
		intake 20 mil gal or more		intake 20 mil gal or more	all firms	all firms	all firms	all firms	all firms		all firms
		Employees all	Employees prod						Employees all	Employees prod	
20	Food and kindred products	2.0	2.8	5.0	2.4	2.8	1.4	2.0	1.3	1.7	4.9
21	Tobacco products	0.3	0.4	0.5	0.4	0.4	0.2	0.1	--	--	--
22	Textile mill products	0.8	0.9	1.9	1.0	0.8	0.6	--	0.3	0.4	--
24	Lumber and wood products	0.9	1.1	9.3	1.5	1.0	1.1	2.3	--	--	21.5
25	Furniture and fixtures	--	--	0.2	0.4	0.1	0.1	0.1	--	--	--
	261 Pulp mills	71.7	92.9					73.3			
26	Paper and allied products	13.2	17.1	37.1	14.0	11.6	9.8	3.5	4.2	5.4	0.2
28	Chemicals and allied products	17.3	28.0	35.5	22.0	15.2	14.6	1.4	0.9	1.7	9.2
29	Petroleum and coal products	21.0	30.5	53.6	35.7	25.5	25.2	9.4	6.4	10.3	--
30	Rubber, misc. plastic products	1.1	1.4	3.2	1.4	1.0	1.4	0.3	0.4	0.6	0.1
31	Leather and leather products	0.2	0.2	2.5	0.3	0.1	0.2	0.2	--	--	--
32	Stone, clay, glass products	1.3	1.7	4.1	1.9	1.5	1.4	1.1	--	--	3.6
33	Primary metal industries	11.9	15.0	20.6	13.6	11.9	11.2	0.8	--	--	0.5
34	Fabricated metal products	0.2	0.3	1.0	0.5	0.3	0.2	0.3	0.1	0.1	0.1
35	Machinery, except electrical	0.3	0.5	1.1	0.5	0.4	0.4	0.2	--	--	1.0
36	Electric, electronic equipment	0.3	0.4	0.7	0.4	0.3	0.3	0.2	0.1	0.2	0.5
37	Transportation equipment	0.6	0.8	0.9	0.7	0.6	0.6	0.2	0.1	0.2	--
38	Instruments, related products	0.3	0.5	0.7	0.4	0.3	0.4	0.2	--	--	0.1
39	Misc. manufacturing industries	0.1	0.1	0.7	0.4	0.2	0.2	0.1	--	--	--

*Britton, B. R., 1983, written commun.

Table 2. A comparison of fresh-water use per employee by major water-using industry groups as computed from numbered references (1,000 gallons per employee per working day; based on 225 working days except under references 7 and 12, where the number of days was not indicated; production workers separated where "prod" indicated).

SIC code industrial groups, as derived from the several reports mentioned above. Although the relative amount of water use in a particular category is similar, coefficients in the same category are mostly inconsistent. Considering the inconsistencies in the coefficients, refining the ratio of water use per employee to the nearest gallon or even 10 gallons per day as has been done in previous reports (apparently without comparative data), indicates a level of accuracy that is seriously misleading.

In the attempt to relate production to water use, production was defined as the value of shipments adjusted to inventory on hand, or "value added" plus the cost of materials. The value-added measure was chosen as the production element for which a water-use coefficient would be determined because it is commonly reported in economic studies of both the Census Bureau and other publications. Table 3 shows a comparison of the ratios of freshwater intake per unit value of output (shipments) for the various industrial sectors in California and nationwide. Again, although the relative amount of water use in a particular category is similar, most of the coefficients in the same category are inconsistent.

The range of estimates of the two preceeding water-use ratios made in the following five major water-use categories are shown in figures 2a - e : a) food and kindred products, SIC code 20, b) lumber industries, SIC code 24, c) pulp and paper, SIC code 26, d) chemicals and allied products, SIC code 28, and e) petroleum industries, SIC code 29.

The agreement of California and national-average coefficients in the food and kindred products group was the best among the major categories. The coefficient of employee use relative to intake per day in California (State of California, 1979) is 2.0 (thousand gallons per employee per day), and nationally (U. S. Bureau of the Census, 1980 and 1981) it is also 2.0 for all employees and 2.8 for production employees. These estimates were compiled from a relatively large sample of returned questionnaires, 1,005 out of 2,001 in California, and 2,208 out of 26,656 nationally.

Just a fair agreement among employee-use coefficients was found for lumber industries: the California estimate is 2.3, and national estimates (same references) are 0.9, all employees, and 1.1, production employees.

The water-use estimates for pulp mills, SIC code 261, compare well between the reports but not in the aggregate of pulp and paper, SIC code 26. In the same order as above, estimates for SIC code 26 derived from those reports are 3.5, 13.2, and 17.1, respectively.

In the chemicals and allied products group the differences between California and the rest of the nation are puzzling, and no explanation is offered. In the same order, the estimates are 1.4, 17.3, and 28.0. Similarly, in the petroleum group the water-use estimates are inconsistent. In the same order, they are 9.4, 21.0, and 30.5.

Comparing ratios of fresh-water intake per unit value of output in the same five categories points up more apparent differences between the California and national statistics. In the food and kindred products group the difference between the California and national coefficients (in million gallons per unit of net production expressed in millions of dollars) are significant but within reason.

SIC code	location / reference number	U. S.	U. S.	California	California
	reference number	19, 20	19, 20	13	18, 20
		Establishments			
	MAJOR INDUSTRY GROUP	all	>20 mil gals	all firms	all firms
	All industries	10.1	9.6	2.6	1.7
20	Food and kindred products	4.3	3.8	4.1	2.3
21	Tobacco products	-	-	-	-
22	Textile mill products	4.6	4.0	0.5	1.3
24	Lumber and wood products	5.7	3.9	5.8	8.3
25	Furniture and fixtures	2.5	1.4	0.8	-
26	Paper and allied products	38.1	37.7	19.5	10.2
28	Chemicals and allied products	36.9	36.6	3.6	1.8
29	Petroleum and coal products	12.1	12.0	4.2	2.1
30	Rubber, misc. plastic products	5.9	4.7	9.5	1.8
31	Leather and leather products	2.1	1.1	4.9	0.6
32	Stone, clay, glass products	7.3	5.8	5.4	6.0
33	Primary metal industries	33.1	32.9	1.7	4.6
34	Fabricated metal products	1.8	1.0	1.4	0.4
35	Machinery, except electrical	1.9	1.4	0.5	2.0
36	Electric, electronic equipment	1.7	1.3	0.6	0.5
37	Transportation equipment	1.6	1.4	0.6	0.3
38	Instruments, related products	1.7	1.2	0.4	0.3
39	Misc. manufacturing industries	1.8	0.4	0.8	0.1

Table 3. A comparison of ratios of fresh-water use to net production in major water-using industry groups for California and the U. S., 1977-78 (gallons per dollar of output).

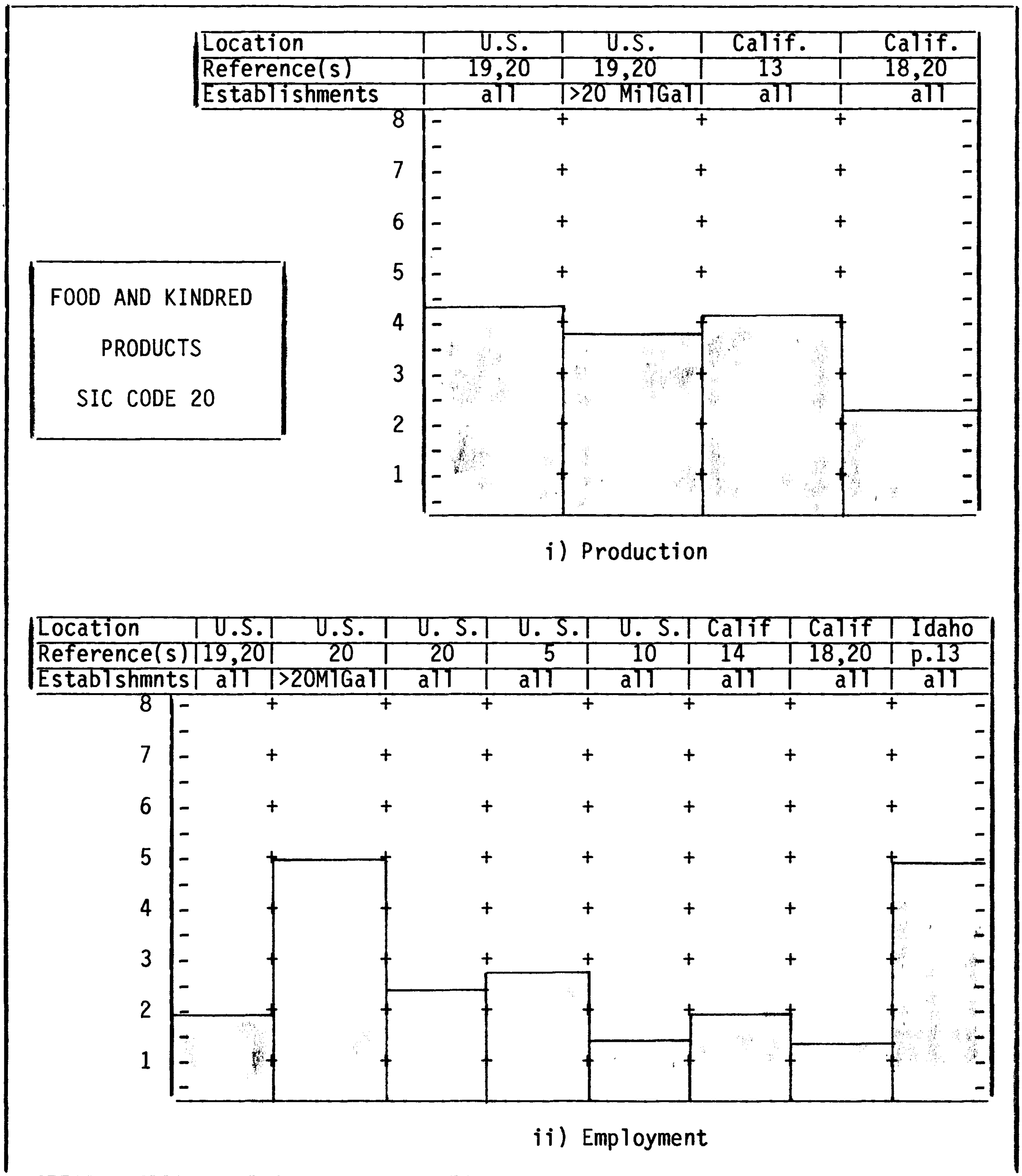

Figure 2a. -- Range in water-use coefficients based on i) production (gallons per dollar of output), and ii) employment (1,000 gallons per employee per working day) for food and kindred products, SIC code 20.

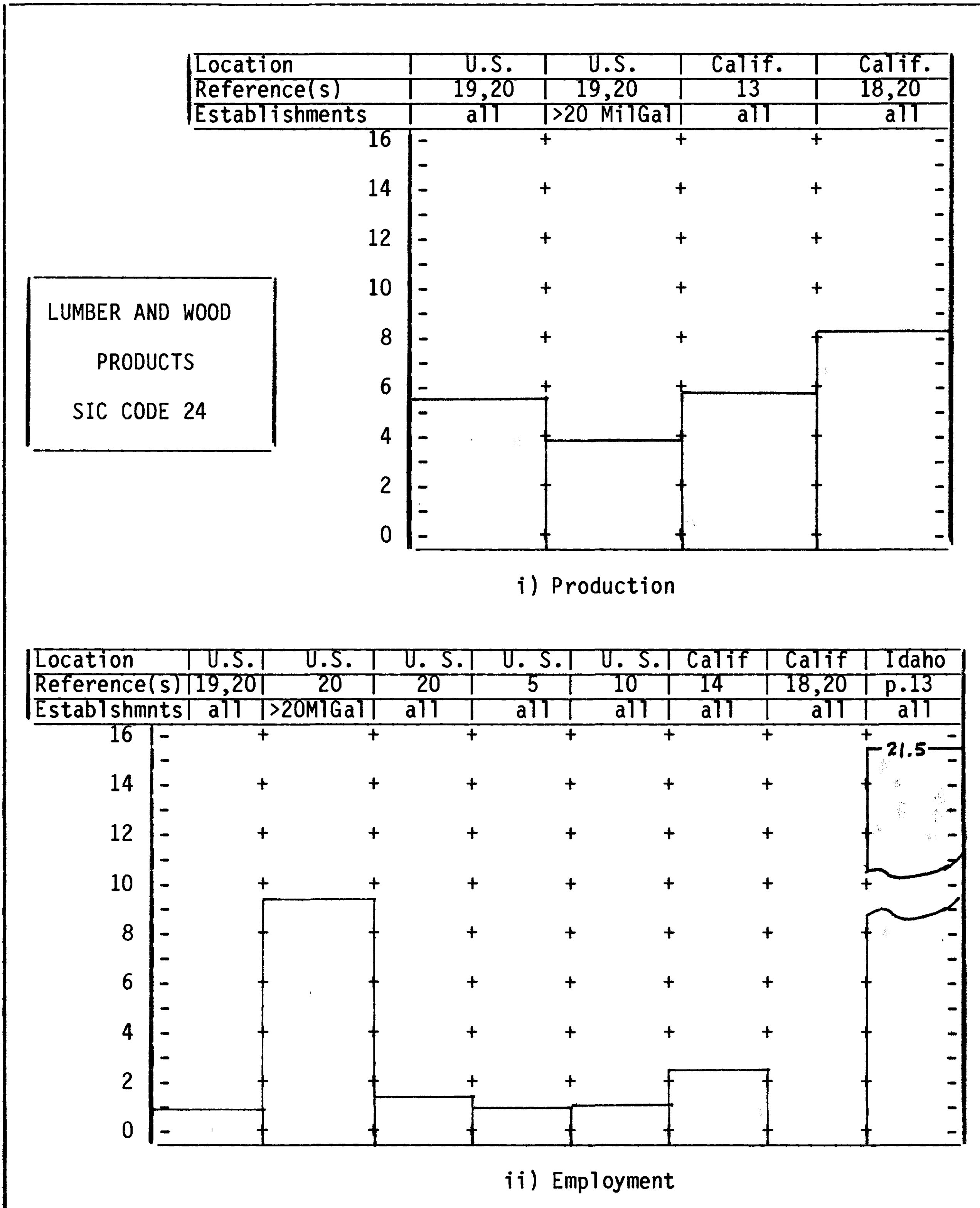

Figure 2b. -- Range in water-use coefficients based on i) production (gallons per dollar of output), and ii) employment (1,000 gallons per employee per working day) for lumber and wood products, SIC code 24.

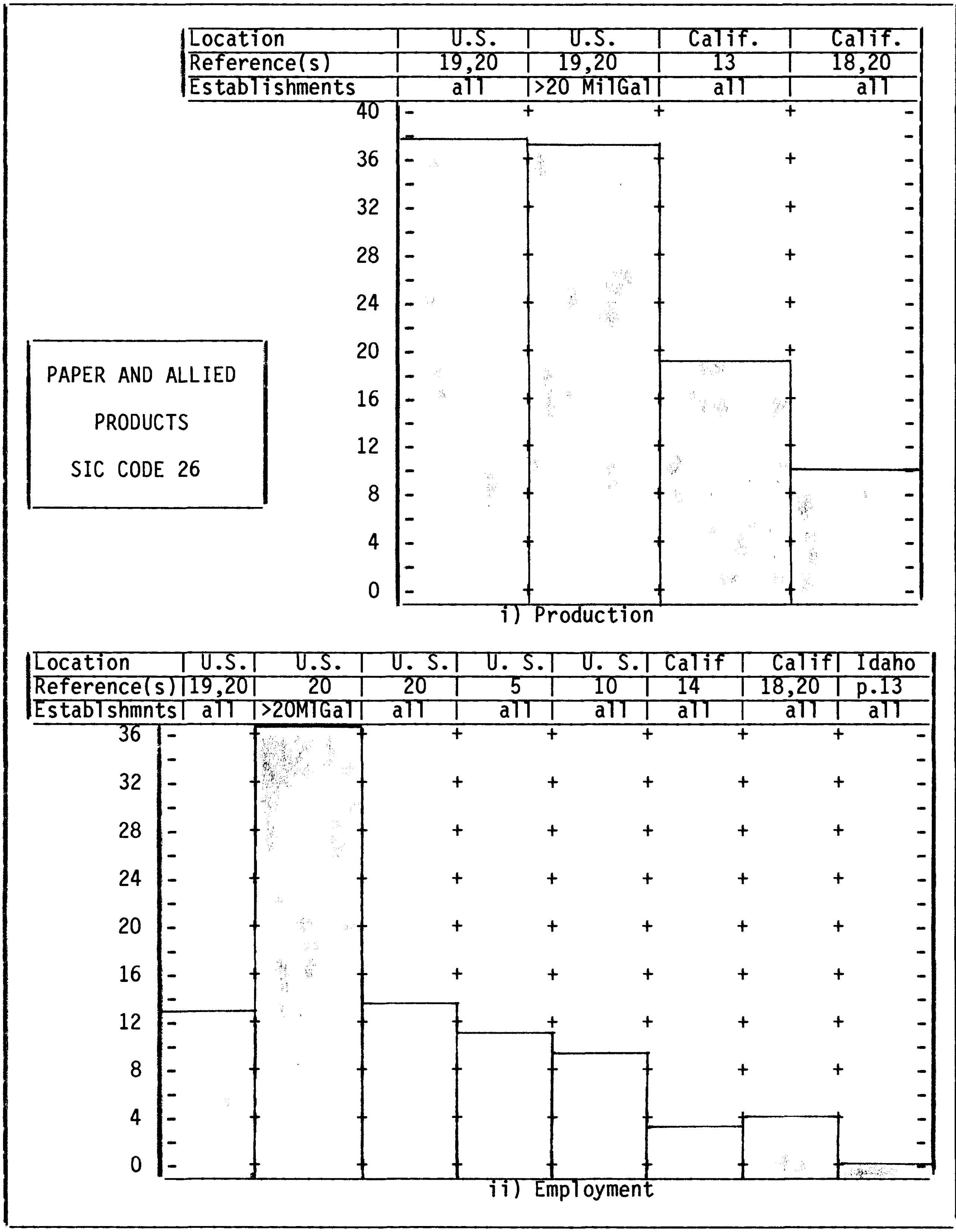

Figure 2c. -- Range in water-use coefficients based on i) production (gallons per dollar of output), and ii) employment (1,000 gallons per employee per working day) for paper and allied products, SIC code 26.

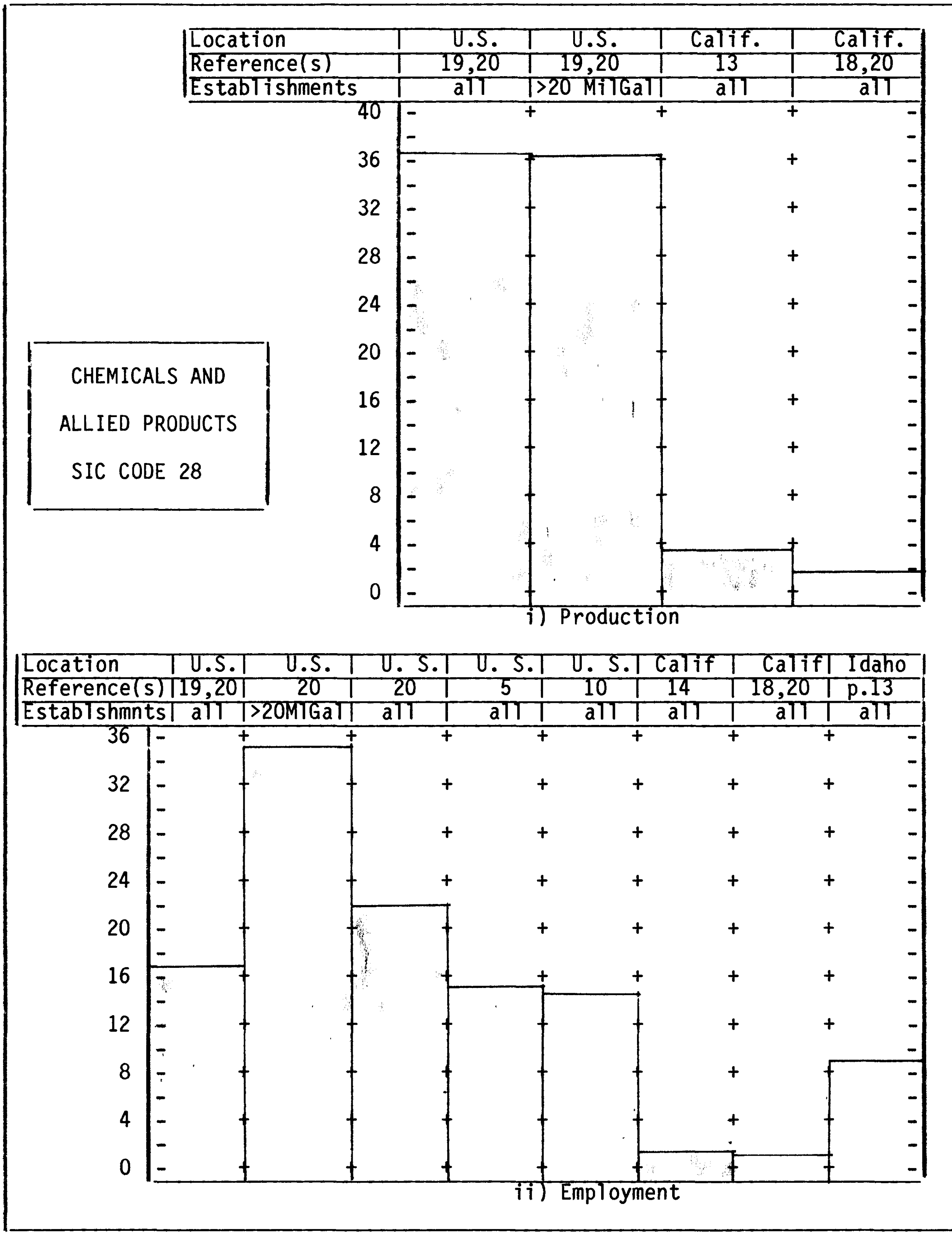

Figure 2d. -- Range in water-use coefficients based on i) production (gallons per dollar of output), and ii) employment (1,000 gallons per employee per working day) for chemicals and allied products, SIC code 28.

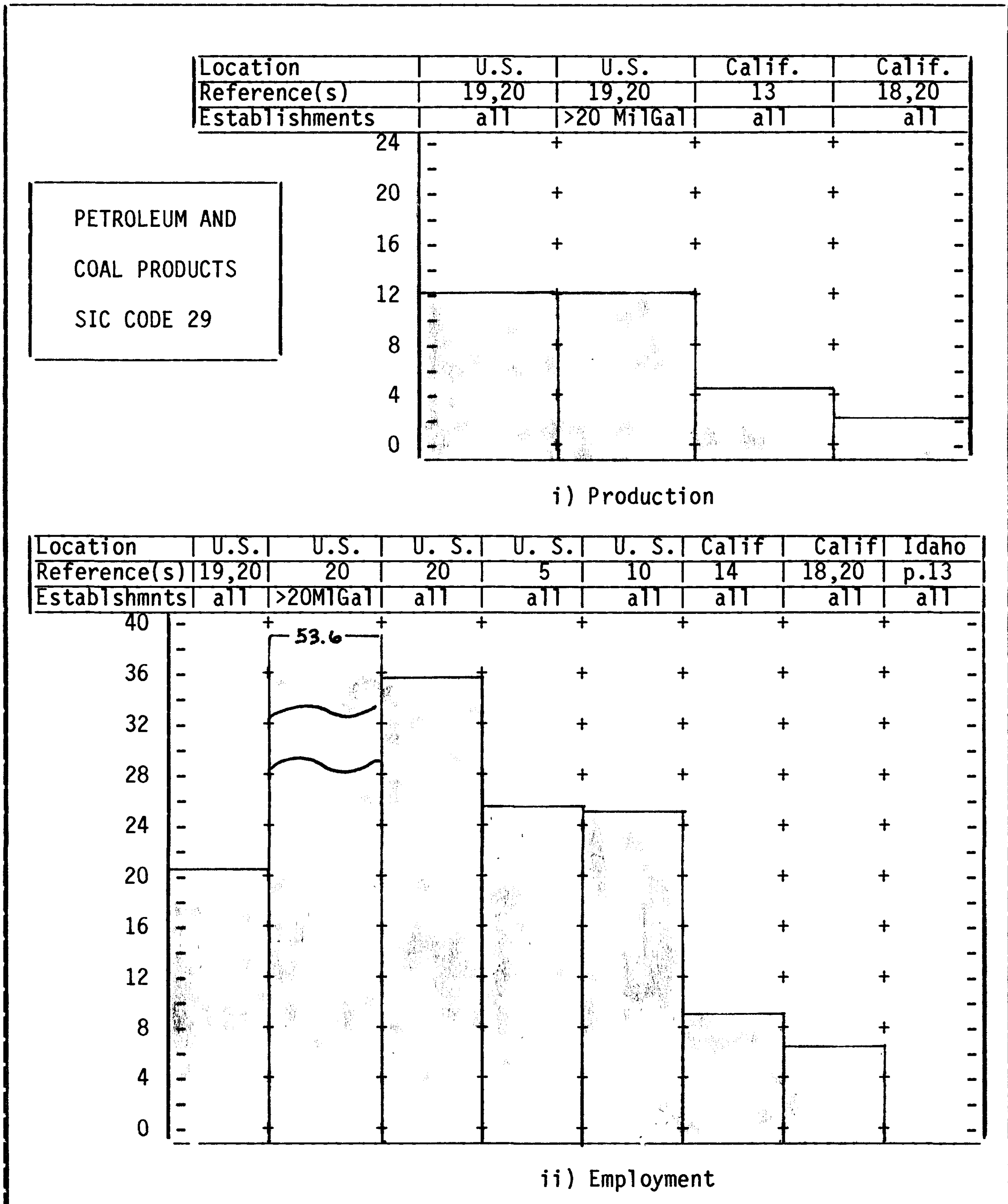

Figure 2e. -- Range in water-use coefficients based on i) production (gallons per dollar of output), and ii) employment (1,000 gallons per employee per working day) for petroleum and coal products, SIC code 29.

The California estimate, derived from the California input-output analysis (State of California, 1980) is 4.1, the California estimate from Census figures is 2.3, (U. S. Bureau of the Census, 1980 and 1981) and the national estimate derived from the Census Bureau's "Water Use in Manufacturing" (U.S. Bureau of the Census, 1981), is 4.3. The coefficients for the lumber group, in the same order, are 5.8, 8.3, and 5.7, respectively. The coefficients for pulp and paper, SIC code 26, have larger discrepancies: the estimates are 19.5, 10.2, and 38, respectively. Coefficients for chemicals and allied products are also varied, with estimates of 3.6 and 1.8, and 36.0, respectively. Finally, the coefficients in the petroleum group were not consistent, with estimates of 4.2 and 2.0, and 12.1, respectively.

PROBLEMS IN DEVELOPING ACCURATE COEFFICIENTS OF WATER USE

The ranges in water-use estimates for similar industries shown in figures 2a - e are the result of computations using inconsistent data. The differences of water-use coefficients based on production and employment data among firms that are in the same SIC industrial category may be apparent differences resulting from the question of reliability already mentioned (sparse or erroneous data associated with questionnaires) or they may be actual differences. Several problems are encountered in trying to arrive at common coefficients for any particular industrial group. These problems are in addition to naturally-occuring localized conditions affecting unit-production water-use characteristics of a plant such as the availability and quality, including temperature, of water supplies, and the air temperature, where air cooling is used in addition to water cooling.

Aggregated water-use coefficients at any of the SIC code levels may represent averages for an industry in which materials, products, and processes differ widely. One aspect of these differences is that modern plants may use more efficient processes than older plants, and even modern plants producing similar products differ in their processes. Hence, similar amounts of water may not correlate with similar production levels, even within the same 4-digit category, which includes about 450 classifications. A startling variety of values of water use per unit of product was reported by different manufacturers in "Water in Industry" (National Association of Manufacturers, 1965). For example, in the production of a ton of salt, the range was from 6 to 67,640 gallons; and in the production of a ton of sugar, the range was from 3,000 to 68,300 gallons.

Nevertheless, a detailed knowledge of the production process in each industrial group would help in developing a valid and consistent correlation of water use with production and employment. This information might be developed from data collected on production and employment, and from a determination, if possible, of the change in water use with changes in production levels in several establishments representing a specific industrial category. Although such information could provide a basis for making year-to-year estimates of water use within a particular category, the work required would represent more of an undertaking than directly developing water-use estimates. Estimating the change in water use relative to production levels in food processing industries, for example, would be particularly difficult because of both differing processes and practices, and because of seasonal and cyclic schedules for production, in which water use may or may not reflect variations in production.

Furthermore, whether or not production levels are changing, water-use coefficients may be shifting where changes in water use per unit of production are occuring because of more water-efficient practices. Wastewater treatment within some establishments is allowing more and more recycling, and the age of the firm or the modern character of the processes may be controlling the amount of water used in production. When this happens, value added per ton of production bears less and less relation to water use per ton of product, and water use estimates based on value added become increasingly inaccurate.

Another problem, aside from differing processes and local water and air conditions, is that the water use of an individual company or industry may not be representative of other companies in its SIC category -- the SIC classifications lump more-water-use intensive industries with less-water-use intensive industries. Water-use coefficients would be representative only if the differences in water use per unit of output were smaller within a particular classification than they were between same-level classifications. If the range in the amount of water use per ton of output within a particular classification were large, changes in production within such a classification might not be associated with apparent changes in water use, but might lie within the range of accuracy.

A ready example of this situation is in the paper industry, where it would seem plausible to develop a reliable estimate of water use per ton of product for a papermaking establishment. However, such a coefficient would not be valid within a classification or establishment that included papermaking and pulping, because pulping uses so much more water per ton of production than does papermaking. In actuality, the number of processes used by individual plants varies considerably. For example, one paper mill may perform several or all of the steps leading to a final paper product -- chipping, pulping, bleaching, papermaking, converting, and electric power generating -- while another plant may be involved in only chipping and pulping, or just papermaking. In "Water requirements of the pulp and paper industry," Mussey (1955) reported considerable variation between the maximum and minimum values of water used per ton even for similar end products. His study showed that the maximum amount of water used in producing a particular kind of pulp was 10 times the minimum, and the amounts of water used in bleaching pulp were more variable, with a maximum amount of water of more than 13 times the minimum. In paper manufacturing still more variability was found: the maximum water used to produce a unit value of similar paper product was 18 times the minimum. Obviously, water requirements vary considerably, and even plants having similar water requirements may have far different intakes because of differing recycling rates. Hence, the specificity of processes in some industries, in addition to localized conditions of water and air, implies that a coefficient of water use per unit of production determined for a particular industrial establishment may be practically unique.

Unfortunately, all of the problems associated with estimates of water use based on value added also bear upon estimates of water use relative to employment. The underlying reason is that the principal and direct measure of the amounts of water, employees, and other materials used by a firm is the production level of that firm. Value added, employment, and water use are not related in as a direct or causal way to each other as each is, respectively, to production. For the same reason, relating the two inputs -- water and numbers of employees -- to each other, compounds any data errors that may exist in either of those estimates. Dividing the ratios of water use to production and employment to production from the DWR input-output analysis (March 1980) to determine a water use/employment coefficient, produced coefficients that were consistently low. In this case, the unusually low figures apparently resulted from a combination of low water-use and high employment estimates. The water-use-per-employee figures thus determined were not compatible with those of the latest DWR study, "Water Use by Manufacturing Industries" (May, 1982).

Finally, an overall problem became apparent in attempting to develop coefficients where relatively few establishments withdraw a large proportion of the total water supply: a generalized water coefficient or multiplier based on a cross-section of establishments simply may not be appropriate to represent an average for a 2- or 3-digit level SIC industrial sector. Such a coefficient might produce erratic total water-use estimates when multiplied by the entire employment population of an industrial category, unless production levels, the numbers of employees, and water use were all in comparable ratios in both the larger and smaller plants.

SUMMARY AND FURTHER STUDY

This is an overview of problems encountered in attempting to estimate self-supplied industrial water use in California by indirect methods. An analysis of the available data answered some questions and raised others. The main question was whether accurate estimates of industrial water use could be made from data on surrogates such as production and employment. Apparently, the answer is no. A fundamental problem was that different data bases produced coefficients that differ widely for similar industries, in some cases by an order of magnitude. This raises questions about the accuracy of the production, employment, and water-use data bases. Much of the potential for error appeared to lie in the water data bases, because 1) the data are based on responses, if any, to questionnaires; and 2) the data are aggregated inappropriately for this kind of correlation. Industries that use different amounts of water, both because of differences in the product and because of differences in production processes even where the end-product is similar, are, in some cases, lumped together. In short, the data sets did not have the precision nor close connection with a product needed to obtain accurate correlations.

Considering the problems in determining industrial water use, and, further, recognizing that industrial use accounts for a very small percentage of the total withdrawals and consumptive use of the supply, a second question emerged: why bother at all with industrial water-use data at the local or even the State level in California? One answer is that even though the eventual long-term problem may be how to redistribute the total available water supply, on a short-term, local, and practical scale, the problem may actually be how to conserve a small amount of water. In specific situations, the quantity and timing of water used could have a significant effect on the distribution of supplies in the immediate vicinity of a plant and on the supply of water available for other uses. For example, where there is a temporary water shortage, or the cost of a new distribution system as well as sewage treatment might be postponed, the tangible and immediate benefits of local industrial conservation could be argued. More effective water utilization by industry need not affect the aggregate national, regional, or even State availability of water when specific local need is important. Identification of these situations would be of consequence to interested communities because statewide statistics regarding industrial use simply would not support pleas to conserve and to realign supplies. The geographic location of the demand for water is the critical concern, because supplies are not uniformly distributed.

Inasmuch as the approach taken for estimating industrial water use did not produce satisfactory results, a third question is: how can industrial water use be estimated with more confidence? A relatively small number of industrial establishments may withdraw as much as 90 percent of the total industrial needs over large geographic areas, and more in selected industrialized areas. Estimates of use, therefore, should be obtainable by gathering data from a manageable number of plants representing the largest users, and a more straightforward data-gathering method than has previously been employed is conceivable. Metering of industrial water use, for example, seems warranted considering the amount of work and the potential for error that can limit the value of other kinds of estimates such as those based on questionnaires. The data sets developed in this manner could be refined by sampling the large water-using plants from each of the five major water-use categories.

As a method of estimating industrial water use, metering appears to have been overlooked, perhaps because of political implications. Even though millions of households have been metered for decades, they are served through public supply systems, whereas most industrial water is self-supplied. Obviously, industry has concerns about confidentiality, privacy and freedom from public accounting; however, generalized water-use records probably would not disclose confidential plant processes. Addressing in depth the question of whether a critical resource of limited supply should become more publically accountable is beyond the scope of this paper.

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