Specific-Yield and Particle-Size Relations of Quaternary Alluvium Humboldt River Valley Nevada

By PHILIP COHEN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTENTS

Page
Abstract M1
Introduction 1
Hydrogeologic features 3
Field and laboratory methods 3
Laboratory data 5
    Porosity 5
    Specific retention 10
    Specific yield 10
    Summary of relations between specific yield, porosity, specific retention, sorting coefficient, and median particle-size diameter 20
Comparison of specific-yield values of the deposits of the Humboldt River valley with data published by others 21
Conclusions 23
References cited 24

ILLUSTRATIONS

Page
FIGURE 1. Map of Nevada showing location of Humboldt River Research Project area M2
2–4. Relation between porosity and sorting-coefficient values—
    2. Silt- and very fine sand-size ranges 6
    3. Fine- and medium-sand-size ranges 7
    4. Coarse- and very coarse sand- and gravel-size ranges 8
5. Relation between median particle-size-diameter and porosity values 9
6–8. Relation between sorting-coefficient and specific-retention values—
    6. Silt- and very fine sand-size ranges 11
    7. Fine- and medium-sand-size ranges 12
    8. Coarse- and very coarse sand- and gravel-size ranges 13
9. Relation between median particle-size-diameter and specific-retention values 14
10. Histogram showing frequency distribution of specific-yield values 15
11–13. Relation between sorting-coefficient and specific-yield values—
    11. Silt- and very fine sand-size ranges 16
    12. Fine- and medium-sand-size ranges 17
    13. Coarse- and very coarse sand- and gravel-size ranges 18

TABLES

Page

TABLE 1. Summary of specific-yield values of samples from the Humboldt River valley, Humboldt County, Nev. M19

2. Estimated specific yield, in percent, of sediments in the South Coastal Basin, southern California 21

3. Average specific yield, in percent, of sediments in the Mokelumne area, California 22

4. Specific yields used to estimate ground-water storage capacity in the San Joaquin Valley, Calif 22

5. Specific yield used to estimate total ground-water storage capacity in the Putah area, California 22

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

SPECIFIC-YIELD AND PARTICLE-SIZE RELATIONS OF QUATERNARY ALLUVIUM, HUMBOLDT RIVER VALLEY, NEVADA

By Philip Cohen

ABSTRACT

As part of a study to determine changes of ground water in storage, 323 samples of unconsolidated alluvium from the Humboldt River valley, Humboldt County, Nev., were analyzed for specific yield and particle-size distribution. Specific-yield values of the fine-grained deposits are considerably higher than previously reported by other writers. These high specific-yield values are partly related to the high primary and secondary porosity of the fine-grained deposits, and may be due partly to compaction of the samples in the centrifuge.

There are complex interrelations between porosity, specific retention, sorting coefficient, and median particle-size diameter in the deposits of the study area. Because of these interrelations, specific yield cannot readily be estimated from any one or a combination of the aforementioned parameters.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Nevada Department of Conservation and Natural Resources and other State and Federal agencies, is participating in a comprehensive interagency hydrologic study known as the Humboldt River Research Project. The study area is shown in figure 1. One of the major objectives of this study is to determine a hydrologic budget for the study area. To help meet this objective, the U.S. Geological Survey is studying changes of ground water in storage in the shallow aquifers. As part of this study, 323 sediment samples were collected from the Humboldt River valley in the fall of 1959 and the summer of 1960; and these samples were analyzed for specific yield and particle-size distribution in the Hydrologic Laboratory, U.S. Geological Survey, Denver, Colo. The purpose of this report is to analyze these data and describe the interrelations between them.

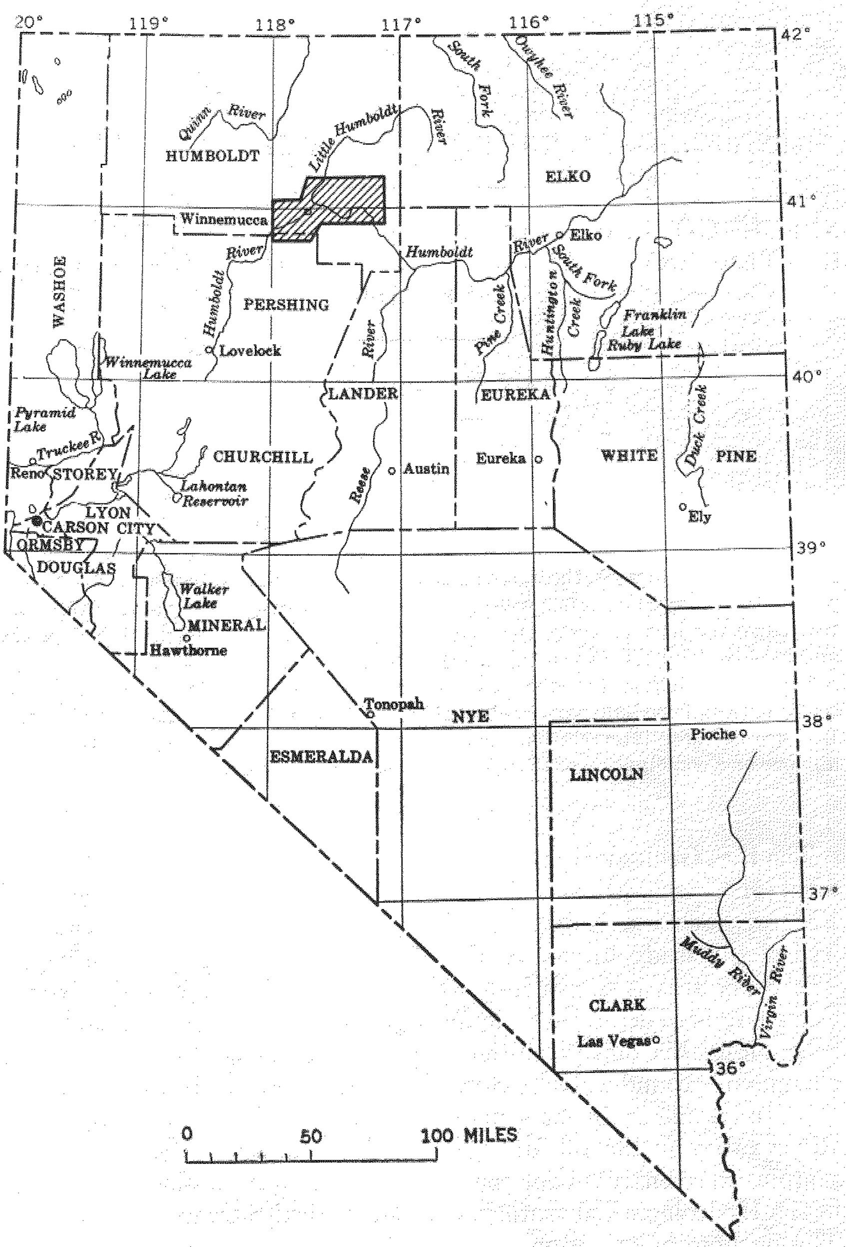


FIGURE 1.—Map of Nevada showing the location of the Humboldt River Research Project area.

This study was under the immediate supervision of O. J. Loeltz, district engineer in charge of ground-water investigations in Nevada. The writer is indebted to the personnel of the Nevada Department of Conservation and Natural Resources, who were valuable coworkers in the field.

HYDROGEOLOGIC FEATURES

The mountain ranges in the study area are composed of dense sedimentary, igneous, and metamorphic rocks that range in age from Paleozoic to Quaternary. These rocks generally have low interstitial porosity and do not transmit appreciable amounts of water except, perhaps, through fractured zones.

Significant changes of ground water in storage occur only in Quaternary alluvium. The alluvium includes lacustrine deposits of Pleistocene Lake Lahontan age and fluviatile and subaerial flood-plain deposits of Recent age. The Lake Lahontan deposits include three stratigraphic units: the so-called lower silt and clay, medial gravel, and upper silt and clay; the lower two units are recognized only in the subsurface. The lower silt and clay unit, whose thickness has not been determined, and the upper silt and clay unit, which is about 55 feet thick, consist largely of dense relatively impermeable silt, clayey silt, and clay. The medial gravel, whose maximum thickness is about 100 feet, consists of well-sorted highly permeable sand and gravel. The flood-plain deposits range from highly permeable stringers of sand and gravel to relatively impermeable lenses of silty clay and clay. Locally, the porosity of the silty and clayey deposits has been increased by plants and burrowing invertebrate animals. Also, most of the fine-grained flood-plain deposits are moderately porous, because they have been subjected to little or no compaction.

The flow of the Humboldt River tends to increase markedly in the spring and to diminish in midsummer. Ground-water levels respond to the increased stage and flow of the river and tend to reach their maximum altitudes in May. Levels decline in the summer in response to the decrease in flow of the river, evapotranspiration, and, to a lesser extent, pumpage for irrigation. Ground-water levels recover somewhat in the winter because of the virtual cessation of evapotranspiration.

FIELD AND LABORATORY METHODS

Test holes were augered with a power auger at approximately 175 sites on and adjacent to the flood plain of the Humboldt River in a 40-mile reach centered about the city of Winnemucca in north-central Nevada. The usual procedure was to auger two holes at each site. The first hole commonly was augered to a depth of about 5 to 10 feet below the water table. Casing was installed upon completion of the augering, and after about 30 minutes the water level in the well was measured. A second hole then was augered with the power auger to a depth of about 1 foot above the interval to be sampled. A hand auger was used to complete the augering to the desired sampling depth. Undisturbed samples were collected by means of a core barrel that consists of a 2-inch-diameter by 4-inch-long core barrel containing two brass liners. The barrel was driven into the sediments with the aid of a 25-pound slip hammer. The core in the upper brass liner was discarded to eliminate the possibility of contamination that may have resulted from material falling into the hole prior to and during the insertion of the core barrel. This procedure was repeated until all desired samples were collected at each augering site. As a general rule, an attempt was made to sample all the representative lithologic units within the zone of anticipated water-level fluctuations.

It was not possible to collect undisturbed core samples at some of the augering sites, especially where the sediments were coarse or very moist. Disturbed samples collected under these conditions were repacked in the laboratory in an attempt to reestablish as nearly as possible their original porosity.

Laboratory studies consisted of determining the particle-size distribution and the specific yield of 323 sediment samples. The particle-size distribution of each sample was obtained by the hydrometer-and-sieve method.

The size classification of sedimentary particles used by the Ground Water Branch, U.S. Geological Survey, is used in this report and is as follows:

Description	*Diameter (mm)*
Gravel	>2.0
Very coarse sand	1.0–2.0
Coarse sand	.5–1.0
Medium sand	.25–0.5
Fine sand	.125–0.25
Very fine sand	.0625–0.125
Silt	.004–0.0625
Clay	<.004

It was necessary to determine porosity and specific retention to calculate specific yield. Porosity was determined by the standard pycnometer method. The centrifuge-moisture-equivalent method was used to determine the specific-retention values of the sediment samples. Meinzer (1923, p. 28) defined the specific retention of a rock or sediment sample as "* * * the ratio of (1) the volume of water which, after being saturated, it will retain against the pull of gravity to (2) its own volume." Multiplying this ratio by 100 expresses specific retention as a percentage. Specific retention was not determined directly. Rather, centrifuge moisture equivalent, or the amount of water, expressed as a percentage of the total volume of a saturated sample, retained by the sample after having been subjected to a force equal to 1,000 times the force of gravity for 1 hour, was determined. The specific-retention data were derived from the centrifuge-moisture-equivalent data by a method based upon the work of Piper and others (1939, p. 118–119) in which specific retention obtained by drainage in the field was related to the centrifuge moisture equivalent of the same materials.

The specific yield of a rock or sediment sample was defined by Meinzer (1923, p. 28) as "* * * the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume." This ratio multiplied by 100 expresses specific yield as a percentage. Specific yield is equal to porosity (the percentage of the total volume of the rock or sediment sample occupied by interstices) minus specific retention. Thus, specific yield was calculated by subtracting specific retention from porosity.

LABORATORY DATA

Because specific yield is related to specific retention and porosity, porosity and specific-retention data are discussed before specific-yield data.

POROSITY

It is convenient to relate porosity to the sorting-coefficient and median particle-size-diameter values of the samples. Sorting coefficient and the median particle-size diameter are derived from a cumulative curve of the size distribution of the particles that constitute the sample. (See Pettijohn, 1949, p. 22, for method of constructing a cumulative curve.) Sorting coefficient may be expressed by the formula

$$So=\sqrt{\frac{Q_3}{Q_1}}$$

where So is the sorting coefficient, Q_3 is the 75-percent quartile, and Q_1 is the 25-percent quartile. The quartiles are derived from the cumulative curve and are the diameters of the particles associated with the intersection of the 75- and 25-percent values with the cumulative curve. The median particle-size diameter is the size value associated with the 50-percent quartile.

Figures 2–4 show six graphs illustrating the relation between porosity and sorting-coefficient values of samples from the Humboldt River valley. If all the points were plotted on one graph, there would

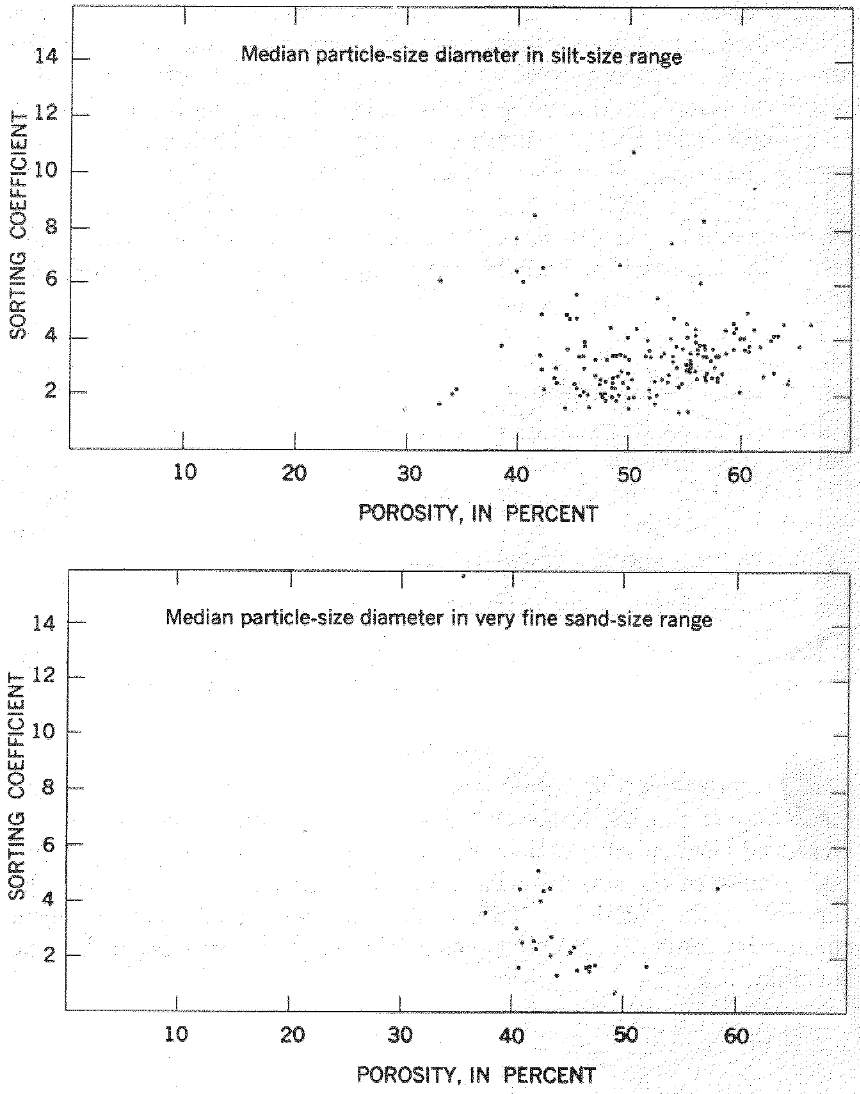


FIGURE 2.—Relation between porosity and sorting-coefficient values of samples from the Humboldt River valley, silt- and very fine sand-size ranges.

be little or no apparent relation between these parameters. There does seem to be a slight tendency for porosity to increase as sorting coefficient decreases for samples whose median particle-size diameters are in the sand-size ranges. The graphs also suggest that samples having coarser median particle-size diameters tend to have lower porosity values than samples having finer median particle-size diameters.

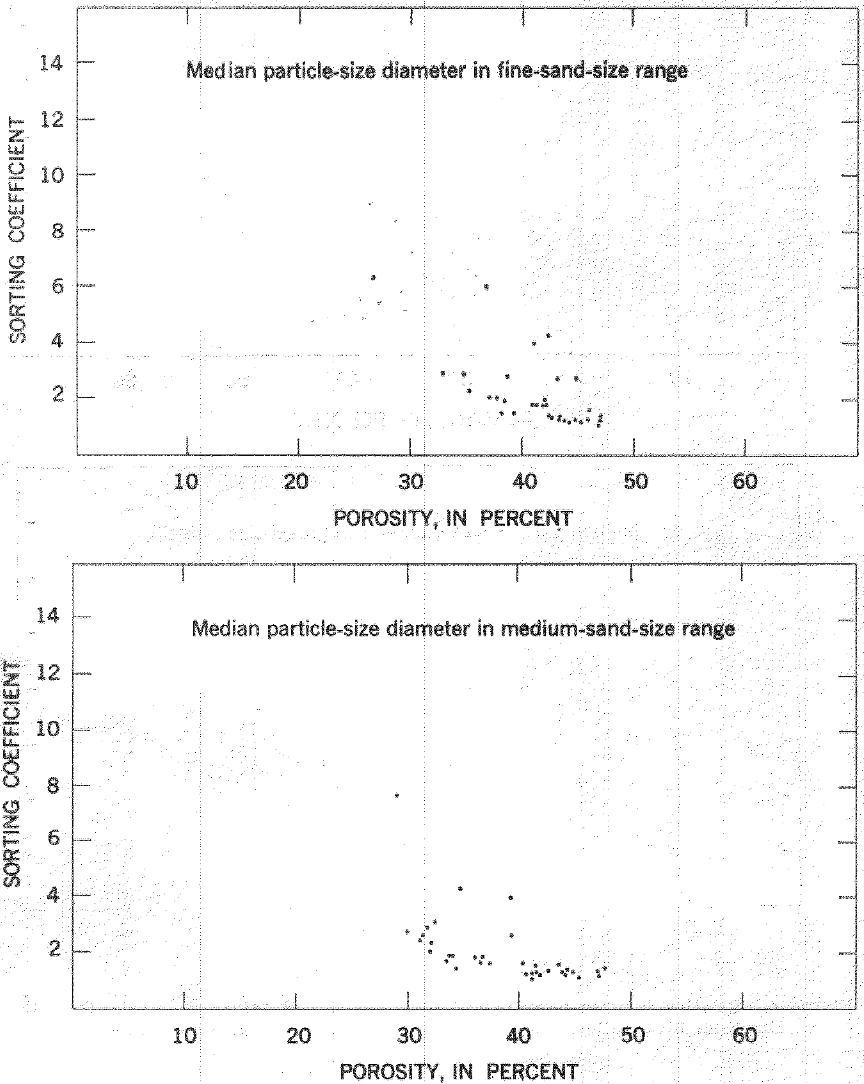


FIGURE 3.—Relation between porosity and sorting-coefficient values of samples from the Humboldt River valley, fine- and medium-sand-size ranges.

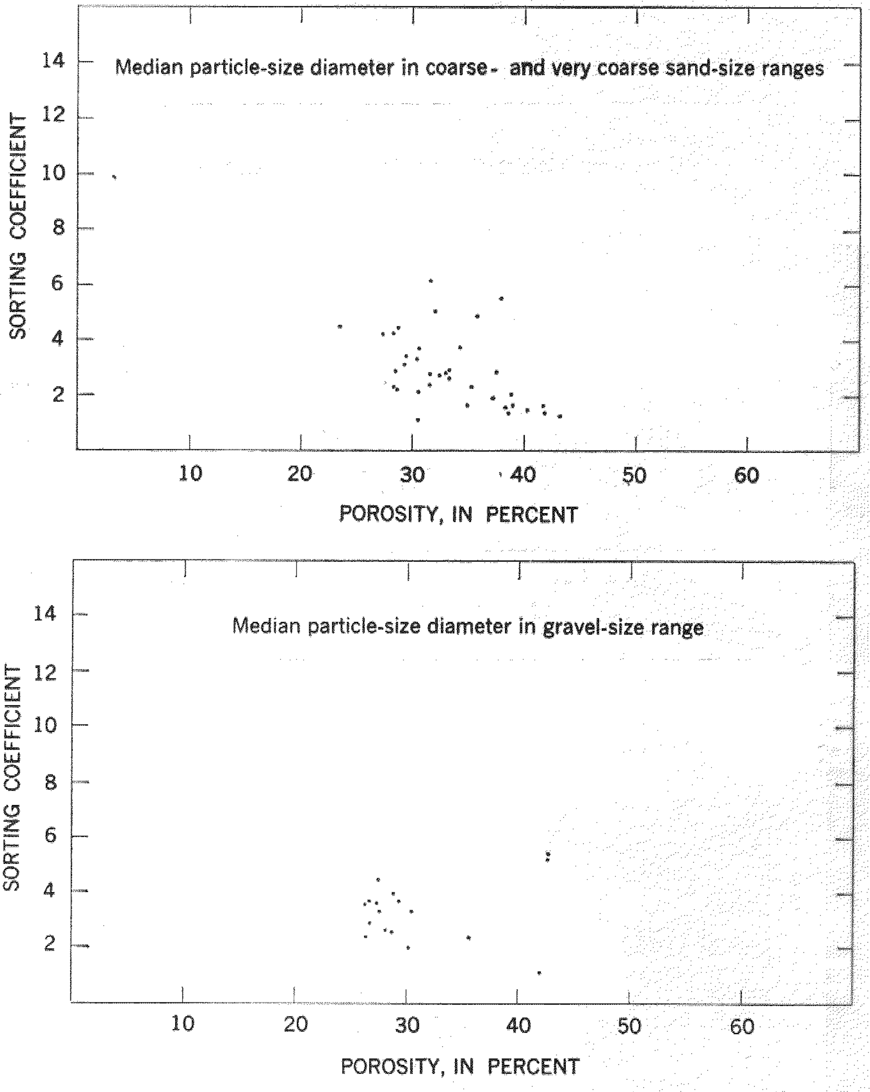


FIGURE 4.—Relation between porosity and sorting-coefficient values of samples from the Humboldt River valley, coarse- and very coarse sand- and gravel-size ranges.

Figure 5, a graph with median particle-size diameter as the abscissa and porosity as the ordinate, show more conclusively that porosity values tend to decrease as median particle-size-diameter values increase, at least for samples whose median particle-size diameters fall within the silt-through medium-sand-size ranges.

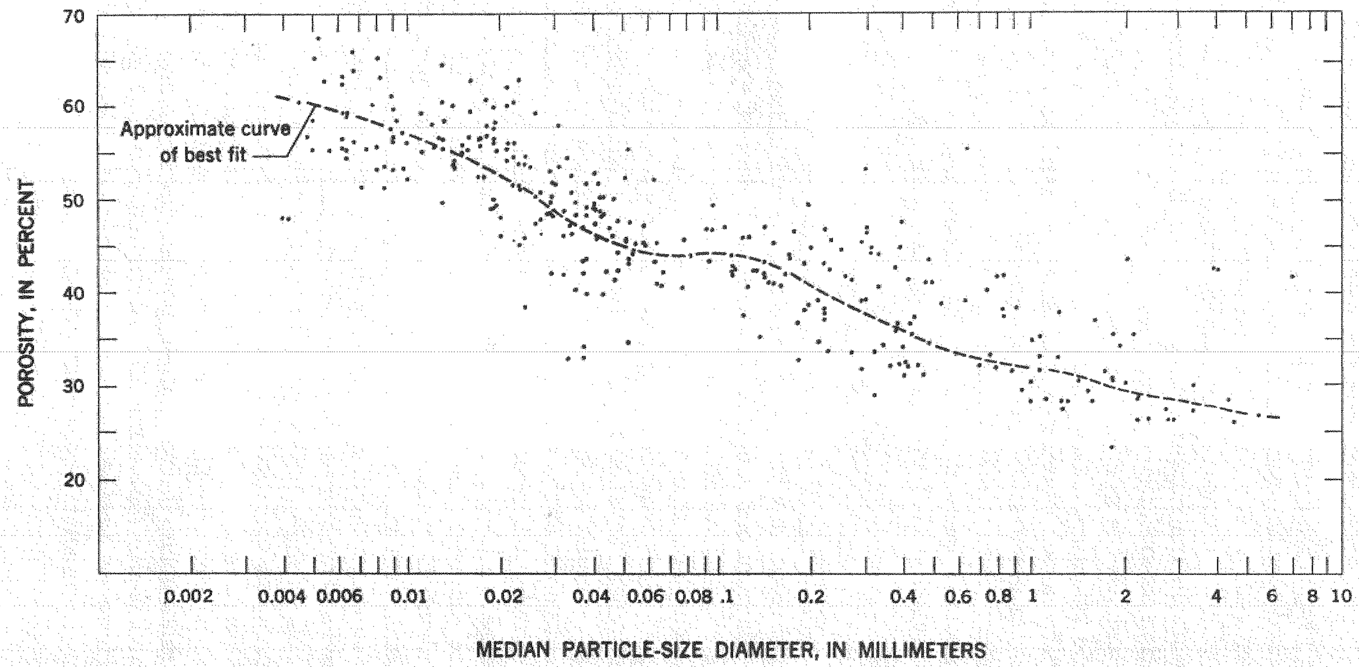


FIGURE 5.—Relations between median particle-size-diameter and porosity values of samples from the Humboldt River valley.

SPECIFIC RETENTION

The six graphs of figures 6–8 show the relation between sorting-coefficient and specific-retention values of the samples from the Humboldt River valley. Although specific retention tends to decrease as sorting coefficient decreases for samples whose median particle-size diameters are in the sand-size ranges, for most samples there is no exact relation between these parameters.

Figure 9 shows the relation between median particle-size diameter and specific retention. The points on the graph tend to define an elongate "S" curve. Specific-retention values tend to approach an upper limit of about 40 percent for samples whose median particle-size diameters are in the silt-size range, and tend to approach a lower limit of about 8 percent for samples whose median particle-size diameters are in the medium- and coarse-sand-size ranges.

SPECIFIC YIELD

Figure 10 is a histogram showing the frequency distribution of specific-yield values for 323 samples as determined in the laboratory. From the diagram one can see that the modal class of specific-yield values, the class of values that occur most frequently, is between 20 and 22 percent, and that the range of specific-yield values is large.

Table 1, which is a summary of the laboratory specific-yield data, shows that the mean specific-yield value and median specific-yield value of all samples is about 21 percent. The mean and median specific-yield values of the various classes increase from about 19 percent for samples whose median particle-size diameters are in the silt-size range to a high of about 29 percent for samples whose median particle-size diameters are in the fine-sand-size range, and then decrease to about 19 percent for samples whose median particle-size diameters are in the gravel-size range. The data thus further suggest that, as is to be expected, there is very little direct relation between specific yield and median particle-size diameters alone.

Figures 11–13 show six graphs illustrating the relation between sorting coefficient and specific yield. If all the data were plotted on one graph, there would be no apparent relation between specific yield and median particle-size diameter. The graphs show that there is no apparent relationship between these parameters for samples whose median particle-size diameters fall within the silt- and gravel-size classes. However, in the intervening classes, specific-yield values tend to increase as sorting-coefficient values decrease.

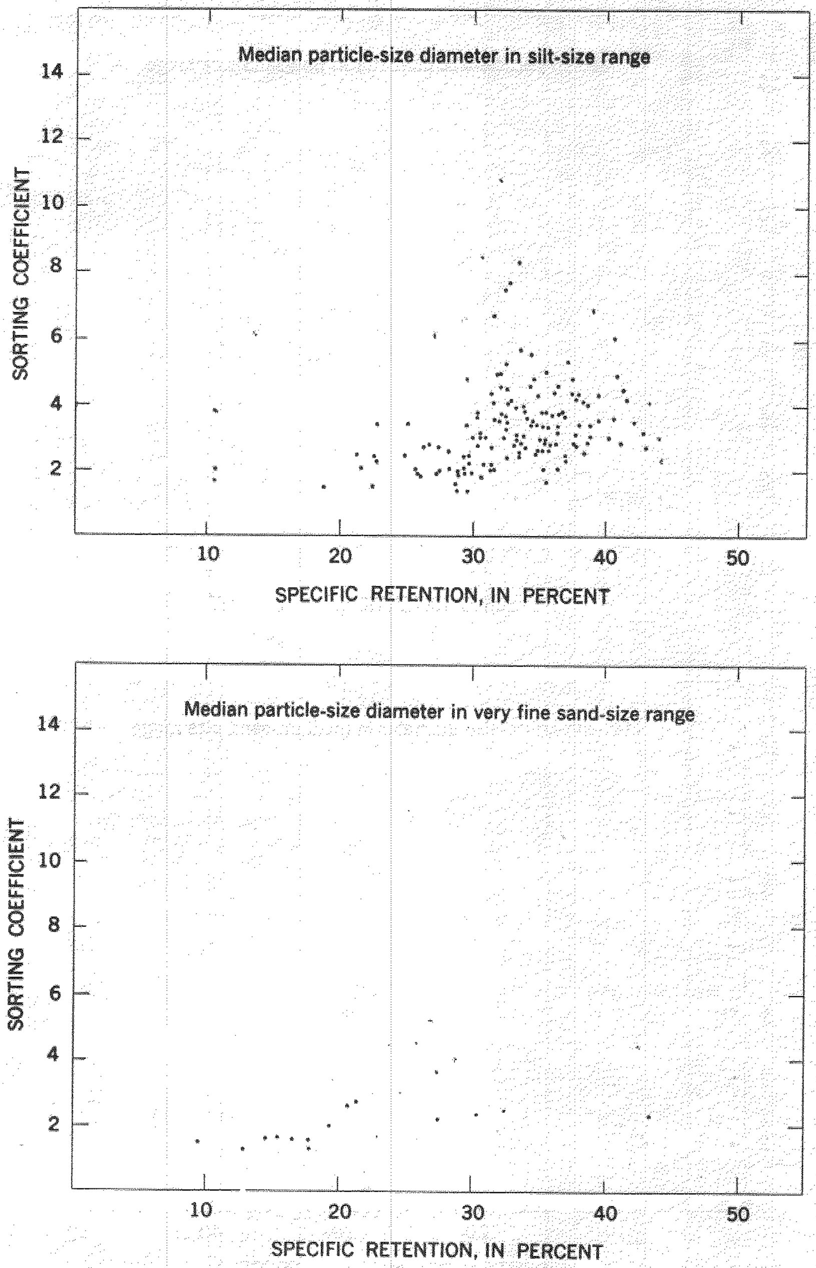


FIGURE 6.—Relation between sorting-coefficient and specific-retention values of samples from the Humboldt River valley, silt- and very fine sand-size ranges.

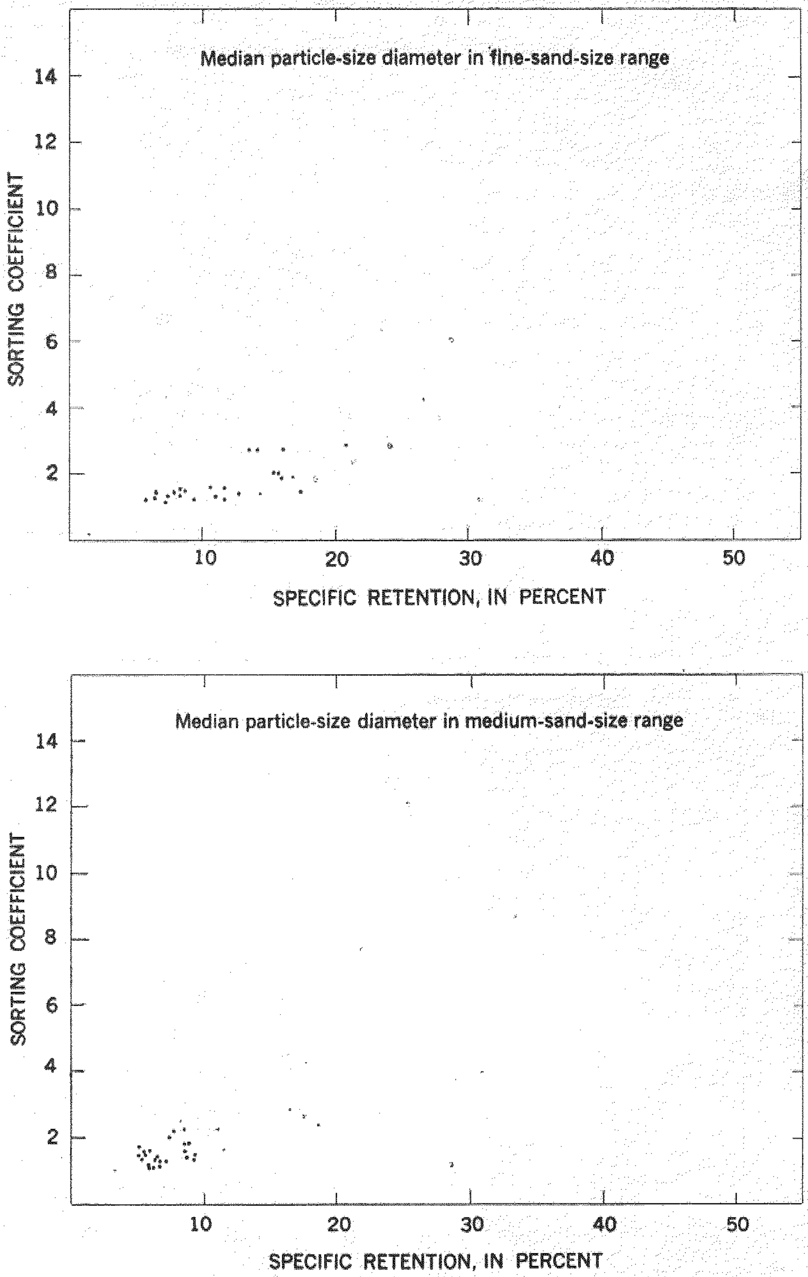


FIGURE 7.—Relation between sorting-coefficient and specific-retention values of samples from the Humboldt River valley, fine- and medium- sand-size ranges.

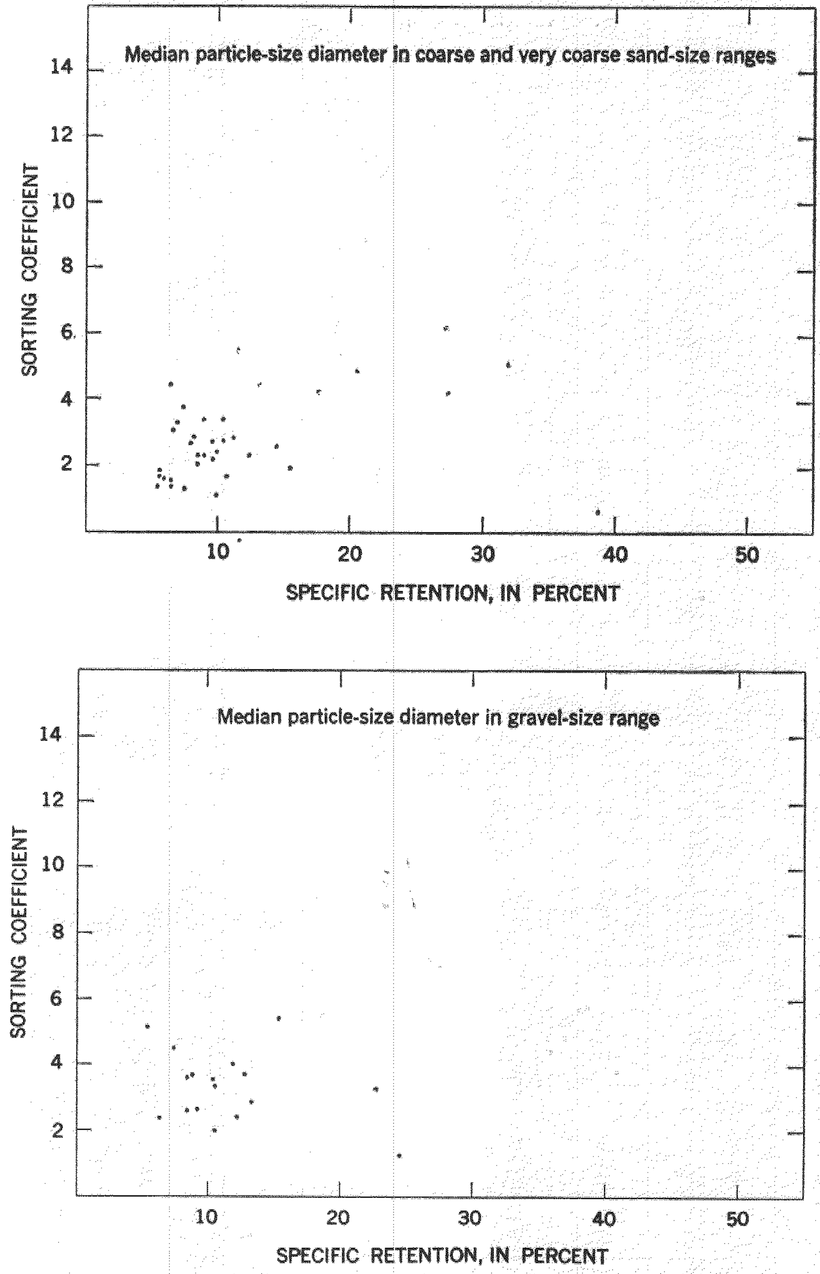


FIGURE 8.—Relation between sorting-coefficient and specific-retention values of samples from the Humboldt River valley, coarse- and very coarse sand- and gravel-size ranges.

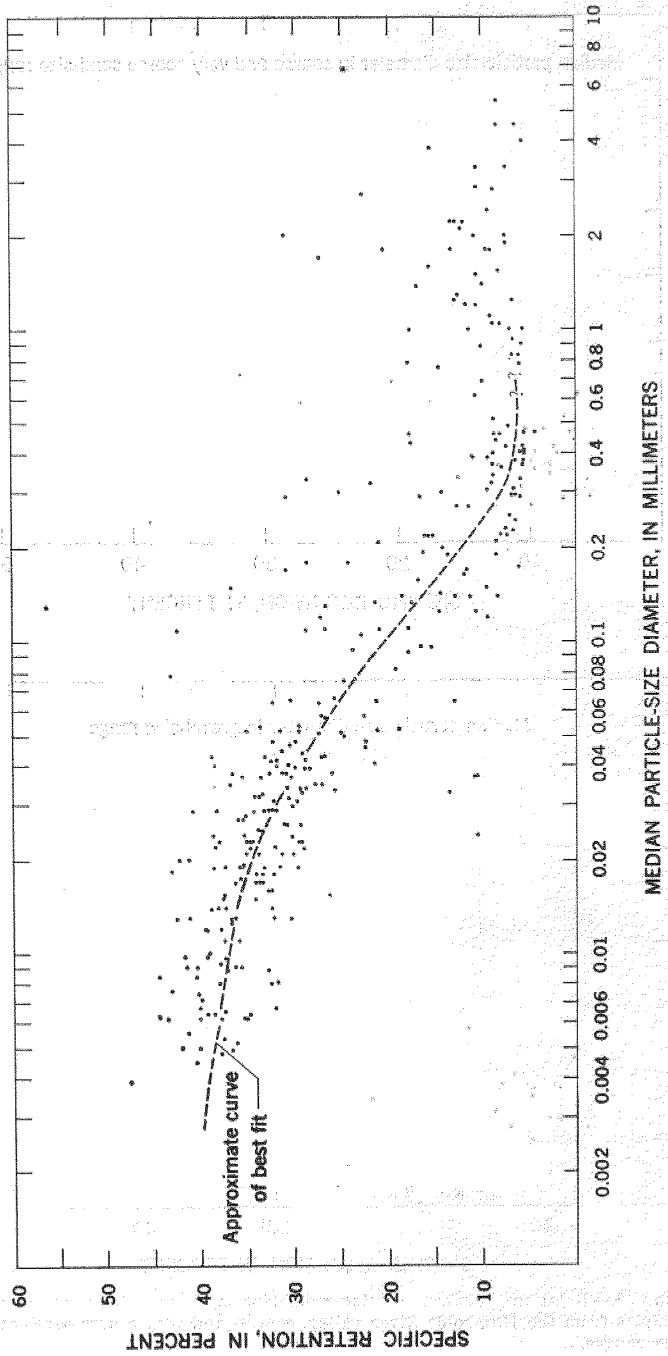


FIGURE 9.—Relation between median particle-size-diameter and specific-retention values of samples from the Humboldt River valley.

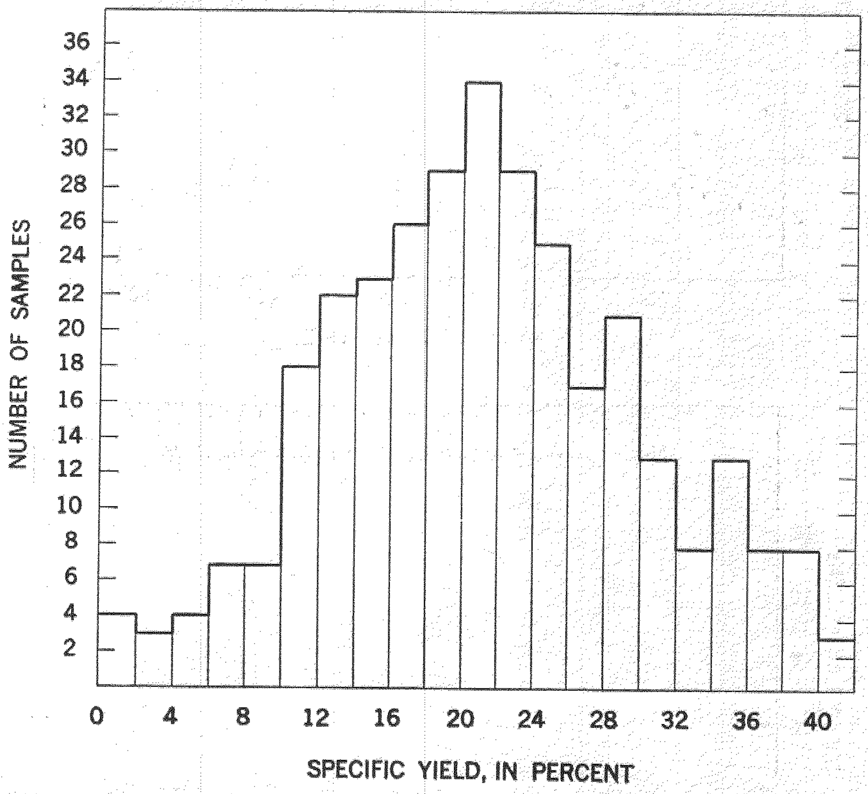
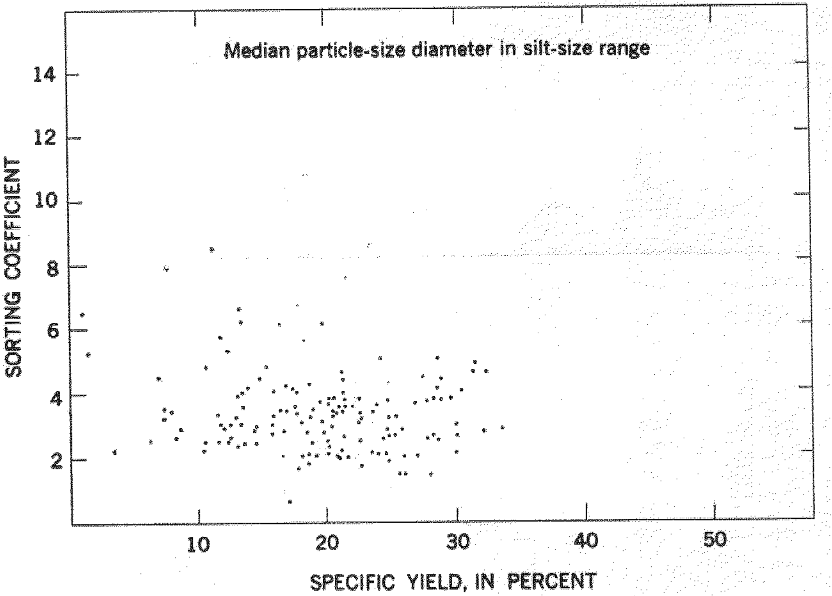


FIGURE 10.—Histogram showing the frequency distribution of the specific-yield values of samples from the Humboldt River valley.



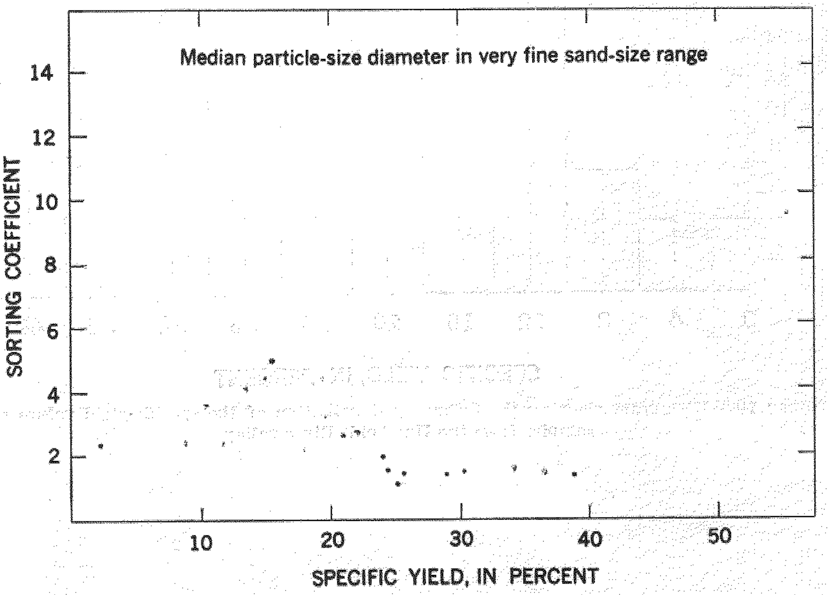


FIGURE 11.—Relation between sorting-coefficient and specific-yield values of samples from the Humboldt River valley, silt- and very fine sand-size ranges.

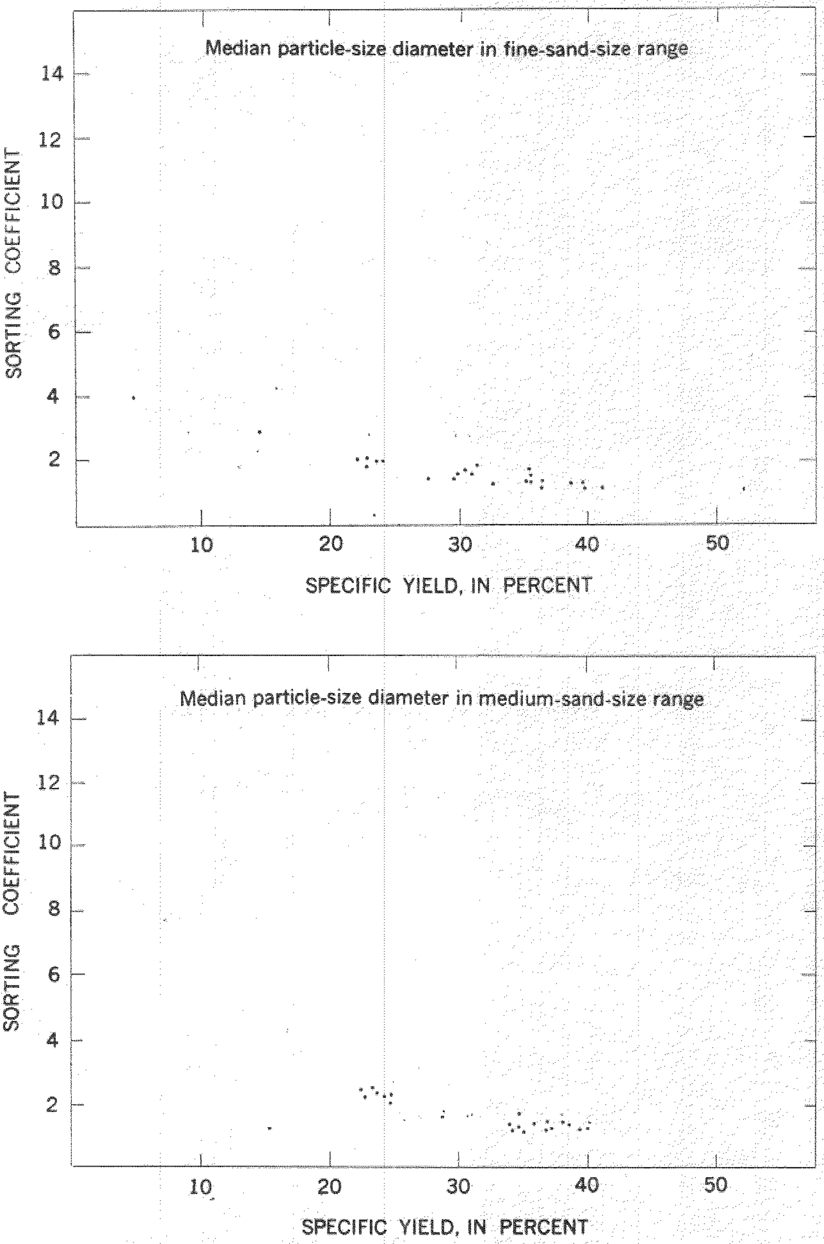


FIGURE 12.—Relation between sorting-coefficient and specific-yield values of samples from the Humboldt River valley, fine- and medium-sand-size ranges.

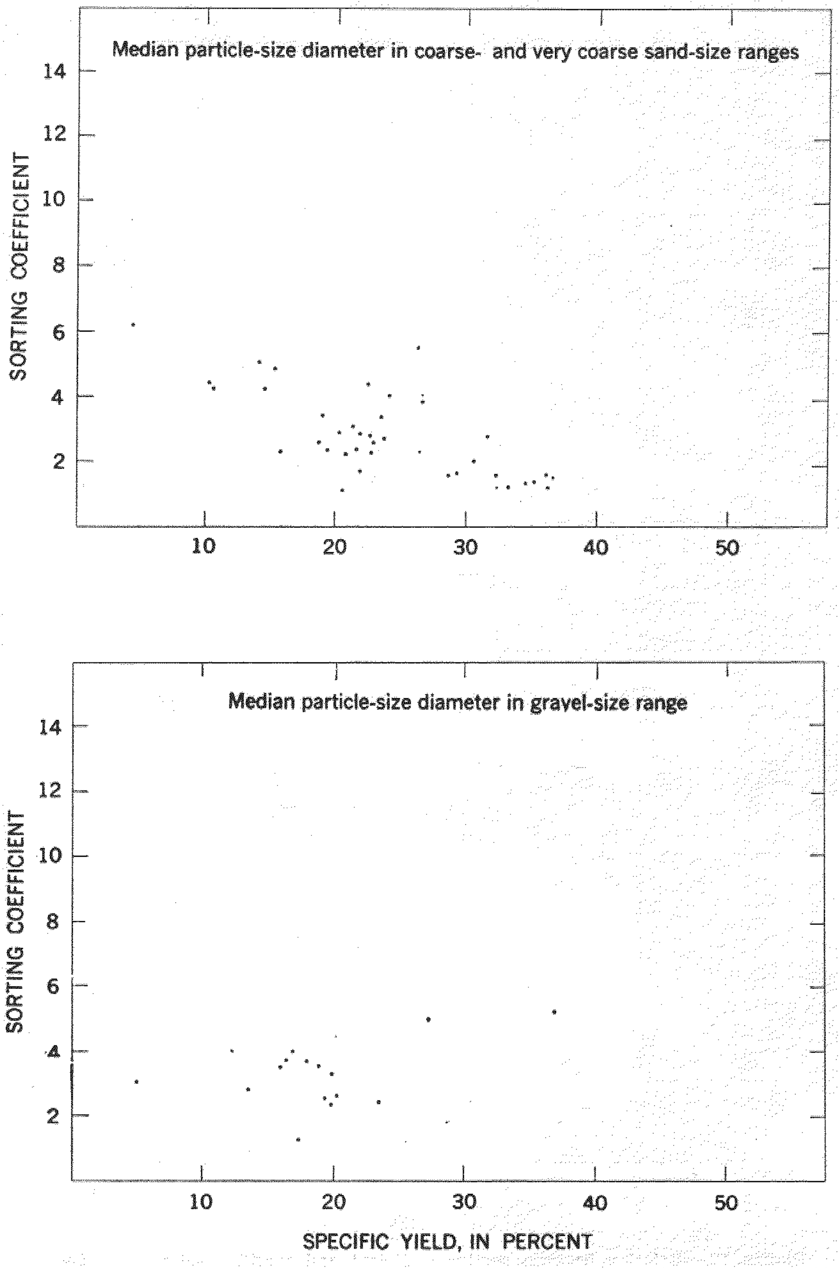


FIGURE 13.—Relation between sorting-coefficient and specific-yield values of samples from the Humboldt River valley, coarse- and very coarse sand- and gravel-size ranges.

TABLE 1.—*Summary of specific-yield values of samples from the Humboldt River Valley, Humboldt County, Nev.*

	Particle-size diameter, in millimeters											All samples
	Clay	Silt	Sand					Gravel				
	<0.004	0.004–0.0625	Very fine 0.0625–0.125	Fine 0.125–0.25	Medium 0.25–0.5	Coarse 0.5–1	Very coarse 1–2	Very fine 2–4	Fine 4–8	Medium 8–16	Coarse 16–32	
Number of samples whose median-particle-size-diameter values fall within the size range indicated	1	174	22	33	38	14	23	12	6	0	0	323
Mean specific yield, in percent	0.5	19.1	20.2	26.0	28.3	26.5	20.5	18.0	19.2	------	------	21.3
Median specific yield, in percent	------	19.1	20.3	29.2	28.4	29.3	21.4	18.8	19.5	------	------	20.9
Range of specific yield, in percent	------	1.0–34.1	0.3–39.2	4.3–40.9	7.2–40.6	10.7–35.9	4.6–36.2	4.9–27.4	0.7–37.3	------	------	0.3–40.9

SUMMARY OF RELATIONS BETWEEN SPECIFIC YIELD, POROSITY, SPECIFIC RETENTION, SORTING COEFFICIENT, AND MEDIAN PARTICLE-SIZE DIAMETER

The data and graphs presented thus far show the relations, or lack of relations, that seem to exist between specific-yield, porosity, specific-retention, sorting-coefficient, and median particle-size-diameter values of 323 samples from the Humboldt River valley. In summary, these apparent relations are:

1. For most samples, porosity values are virtually independent of softing-coefficient values alone.
2. Porosity values tend to increase as median particle-size-diameter values decrease.
3. For most samples, specific-retention values do not correlate with sorting-coefficient values alone.
4. Specific-retention values tend to increase as median particle-size-diameter values decrease.
5. Specific-yield values do not correlate with sorting-coefficient values of samples whose median particle-size-diameter values fall within the silt- and gravel-size ranges but tend to increase as sorting coefficient values decrease in the intervening ranges.
6. There is a poor correlation between specific-yield values and median particle-size diameter values.

Theoretically, all other factors being equal, porosity should be a function of the degree of assortment and should be independent of particle size. Thus, relations 1 and 2 seem to be contrary to theoretical considerations. These apparently anomalous relationships probably can best be explained as being related to the fact that other factors—such as shape of the particles, compaction, cementation, and primary and secondary sedimentary structures—are not equal.

Relation 3 is not entirely contrary to expected theoretical relationships because specific retention also is related to median particle-size diameter, especially in the clay- and silt-size ranges. There is very little literature describing the relation between specific retention and sorting coefficient, but it seems reasonable to assume that if all other factors are equal, specific-retention values should increase as the sorting-coefficient values increase for samples having the same median particle-size diameters. The poor relation between sorting coefficient and specific retention undoubtedly is due to the fact that all the other factors are not equal. This is especially true for the samples whose median particle-size diameters are in the silt-size range. The degree of compaction and secondary porosity of these samples is extremely variable.

Relation 5 and figures 11–13 show that specific-yield values tend to be independent of sorting-coefficient values alone for most of the samples. Relation 5 is a consequence of relations 1 and 3. If porosity and specific-retention values tend to be independent of sorting-coefficient values alone, then it is reasonable to assume that the difference between porosity and specific retention, or specific yield, also will tend to be independent of sorting-coefficient values alone.

Relation 6 is a consequence of relations 2 and 4. The approximate curves of best fit in the graphs of figures 5 and 9 have roughly about the same negative slope. Therefore, the difference between porosity and specific retention, or specific yield, tends to remain about constant for most of the size ranges shown in table 1; and this results in the poor correlation between the specific-yield values and median particle-size diameters of the samples.

COMPARISON OF SPECIFIC-YIELD VALUES OF THE DEPOSITS OF THE HUMBOLDT RIVER VALLEY WITH DATA PUBLISHED BY OTHERS

The laboratory specific-yield values of the deposits of the Humboldt River valley differ considerably from specific-yield values determined in other areas. Eckis and Gross (1934) studied the water-holding capacity of sedimentary deposits in the South Coastal Basin of the Los Angeles area, and the results of their study are summarized in table 2.

TABLE 2.—*Estimated specific yield, in percent, of sediments in the South Coastal Basin, southern California*

[After Eckis and Gross, 1934, p. 109, table 5]

Degree of alteration	Gravel				Sand		Clay	
	Boulders >256 mm	Coarse 64–256 mm	Medium 16–64 mm	Fine 8–16 mm	Coarse 1/2–8 mm	Fine 1/8–1/2 mm	Sandy	Clay
Unweathered:								
Surface alluvium	13.6	14.2	20.5	26.5	30.9	21.2	10	1
Subsurface alluvium	13	14	20	25	28	16	5	1
Weathered subsurface alluvial:								
Tight [1]	9	9	13	17	16		------	----
Clayey [2]	4	5	7	8	5		------	----
Residual clay [3]	1	1	1	1	1		1	

[1] Lime-cemented gravels are included in tight gravels.

[2] Lime-cemented sands are included in clayey sand.

[3] The specific yield of 1 percent makes allowance for small sandy or gravelly streaks; pure clay would have a specific yield near zero.

Piper and others (1939) studied the specific yield of sedimentary deposits in the Mokelumne area, California. They used two methods to determine the specific yield of 13 and 16 samples, respectively. By the first method, the volumes of undisturbed samples, saturated or unsaturated in response to the addition or withdrawal of known volumes of water, were determined. This is a direct method of determining specific yield and is referred to as the volumetric method. By the second method, referred to as the drainage method, they determined the difference between porosity and specific retention of undisturbed samples for periods of drainage ranging from 96 to 390 days. The results of the studies by the two methods are summarized in table 3.

TABLE 3.—*Average specific yield, in percent, of sediments in the Mokelumne area, California*

[From Piper and others (1939, p. 121)]

Material	Volumetric method	Drainage method	Average
Gravel and coarse sand	34.5	35	34.8
Medium and fine sand	22.6	26	24.2
Very fine sand, silt, and clay	5.0	3.5	4.2

Davis, Green, Olmsted, and Brown (1959); Thomasson, Olmsted, and LeRoux (1960); and Olmsted and Davis (1961) estimated the specific yield of sedimentary deposits in parts of the San Joaquin and Sacramento Valleys. Their estimates, based in large part upon the specific-yield investigations summarized in tables 2 and 3, are shown in tables 4 and 5.

TABLE 4.—*Specific yields used to estimate ground-water storage capacity in the San Joaquin Valley, Calif.*

[From Davis, Green, Olmsted, and Brown (1959, p. 209)]

Group	Material	Assigned specific yield (percent)
G	Gravel; sand and gravel; and related coarse gravelly deposits	25
S	Sand, medium- to coarse-grained, loose, and well-sorted	25
F	Fine sand; tight sand; tight gravel; and related deposits	10
Cg	Silt; gravelly clay; sandy clay; sandstone; conglomerate; and related deposits	5
C	Clay and related very fine grained deposits	3
X	Crystalline bedrock (fresh)	0

TABLE 5.—*Specific yield used to estimate total ground-water storage capacity in the Putah area, Calif.*

[From Thomasson, Olmsted, and LeRoux (1960, p. 286) and Olmsted and Davis (1961, p. 150)]

Material	Specific yield (percent)
Gravel	25
Sand, including sand and gravel, and gravel and sand	20
Tight sand, hard sand, fine sand, sandstone, and related deposits	10
Clay and gravel, gravel and clay, cemented gravel, and related deposits	5
"Clay," silt, sandy clay, lava, and related fine-grained deposits	3

A summary of the specific-yield values of the samples from the Humboldt River valley is shown in table 1 (p. 19). The samples are arranged according to the range of their medium particle-size diameters. Admittedly, size ranges based on the median particle-size diameter of the samples are not precisely comparable to the textural classifications used by the writers cited on pages 21 and 22. However, the classification used by any one of these writers also is not precisely comparable to the classification used by any of the others. In spite of the somewhat different classifications, it might be expected that the specific-yield values should be comparable. The specific-yield values shown by the other writers are roughly comparable for most of the textural ranges; however, the specific-yield values of the samples from the Humboldt River valley differ markedly from those shown by the other writers. The most striking difference is the tendency for samples from the Humboldt River valley to have considerably higher mean specific-yield values for samples whose median particle-size diameters fall within the silt-size range.

The relatively high specific-yield values of the samples whose median diameters are in the silt-size range probably partly is a result of the relatively high porosity of this material (p. 3). In addition, the specific-yield values of these samples in part may be high because of compaction of the material in the centrifuge (Terzaghi, 1949, p. 353). Smith (1961, p. A–11) showed that specific-yield values obtained from centrifuge-moisture-equivalent data, especially for fine-grained material, may be too high because the centrifuge tends to expel more water than would drain by gravity.

CONCLUSIONS

The relations between specific yield, based upon centrifuge-moisture-equivalent data, and median diameters and sorting coefficients of samples from the Humboldt River valley are complex. Partly because of these complexities, the specific-yield data can be used to obtain only a rough approximation of the total ground water avialable from storage, and they have little practical value for computing short-term changes of ground water in storage. Also, it seems that it would be extremely difficult, if not impossible, to estimate the specific yield of the alluvium of the Humboldt River valley by determining or estimating such parameters as sorting coefficient and medium particle-size diameter.

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