ESTIMATING AVERAGE DISSOLVED-SOLIDS YIELD FROM BASINS DRAINED BY EPHEMERAL AND INTERMITTENT STREAMS--GREEN RIVER BASIN, WYOMING

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, conversion factors for inch-pound units used in this report are listed as follows:

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.59	square kilometer
cubic foot per second	0.02832	cubic meter per second
ton per day	0.9072	megagram per day
ton per day per square mile	0.3503	megagram per day per square kilometer

STATION NUMBERS

Routine surface-water sampling stations are identified by 8-digit numbers; for example, 09216527. The first two digits (09) refer to the major drainage basin. The remaining six digits (216527) refer to individual station location; increasing numerical values of the six digits indicate that stations are located progressively further downstream.

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ABSTRACT

This report describes a method developed to determine the average dissolved-solids yield contributed by small basins characterized by ephemeral and intermittent streams in the Green River basin in Wyoming. Methods routinely applied to perennial streams generally do not provide accurate estimates when applied to ephemeral and intermittent streams. To provide more accurate estimates, dissolved-solids loads were determined from streamflow records and discrete samples of specific conductance. Arithmetic means were determined from geometric means and standard deviations of the loads. The arithmetic means were adjusted for no-flow days, and the results were divided by the amount of drainage area to estimate dissolved-solids yields.

The dissolved-solids yields from drainage areas encompassed by pairs of sampling sites on a stream system were estimated from the slope of the line connecting the paired points on a plot of average dissolved-solids discharge versus drainage area. Variations of average yield among sites were 10 times smaller than variation of average dissolved-solids discharge. The estimated yields for greater than 50 percent of the drainage area represented by the stations analyzed had a range of less than 15 percent.

Estimates of dissolved-solids discharge at eight water-quality sampling stations range from less than 2 to 95 tons per day. The dissolved-solids yields upstream from the sampling stations range from about 0.023 to 0.107 ton per day per square mile. However, estimates of dissolved-solids yields contributed by drainage areas between the paired stations on Bitter Creek, Salt Wells Creek, and Little Muddy and Muddy Creeks ranged only from 0.081 to 0.092 ton per day per square mile.

INTRODUCTION

Water quality, specifically dissolved solids, is an important factor in determining suitability of water for certain uses and in assessing possible downstream effects of those uses over time. Quantitative description of dissolved solids is useful in evaluating existing water quality as well as in projecting effects of proposed or on-going development. Salinity, as dissolved solids is sometimes called, has been described quantitatively for the major perennial streams of the Green River basin in Wyoming (DeLong, 1977, 1986a). Much of the Green River basin in Wyoming (fig. 1), however, is characterized by ephemeral and intermittent streams.

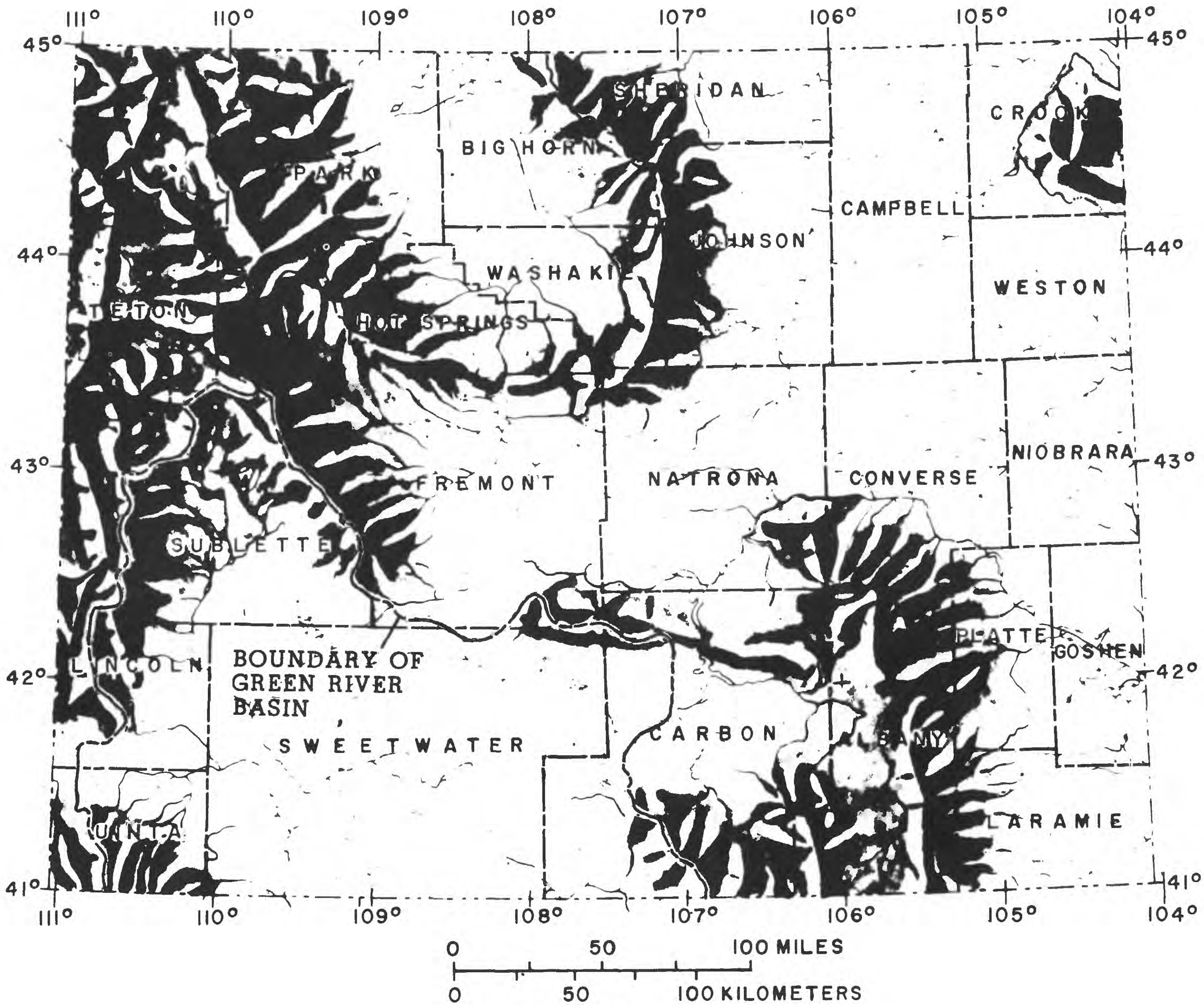

Figure 1.--Location of Green River basin in Wyoming.

Because of the sporadic nature of precipitation and streamflow in these areas, water quality is highly variable and difficult to measure or predict. Without adequate knowledge of sources and processes involved in the transport of dissolved and sorbed constituents within a basin, the expected effects on water quality resulting from proposed development or mitigation are difficult to determine.

A study of the water quality of runoff from small basins characterized by ephemeral and intermittent streams was conducted by the U.S. Geological Survey during water years 1980 and 1981 in cooperation with the U.S. Bureau of Land Management. One part of the study involved the numerical modeling of flow and transport to help identify processes dominant in the divestment and transport of dissolved solids from the small basins. Typically, the small streams at low flow are only a few feet wide, meandering through wider flood plains. During a runoff event, streams inundate the adjacent flood plains, short-circuiting meanders and significantly shortening the effective stream length. Existing flow equations and flow models did not account for this dominant effect. Extension of the flow equations and subsequent development of numericai solution techniques initiated in the study of small basins are summarized in a report by DeLong (1986b).

The second part of the study involved estimating the dissolved-solids yields contributed by small basins characterized by ephemeral or intermittent streams. This report describes the method developed and estimates made at eight water-quality sampling stations (table 1; fig. 2).

Table 1.--*Water-quality sampling stations*

Station number	Station name
09216527	Separation Creek near Riner, Wyoming
09216545	Bitter Creek near Bitter Creek, Wyoming
09216562	Bitter Creek above Salt Wells Creek, near Salt Wells, Wyoming
09216565	Salt Wells Creek near South Baxter, Wyoming
09216750	Salt Wells Creek near Salt Wells, Wyoming
09222300	Little Muddy Creek near Glencoe, Wyoming
09222400	Muddy Creek near Hampton, Wyoming
09235300	Vermillion Creek near Hiawatha, Colorado

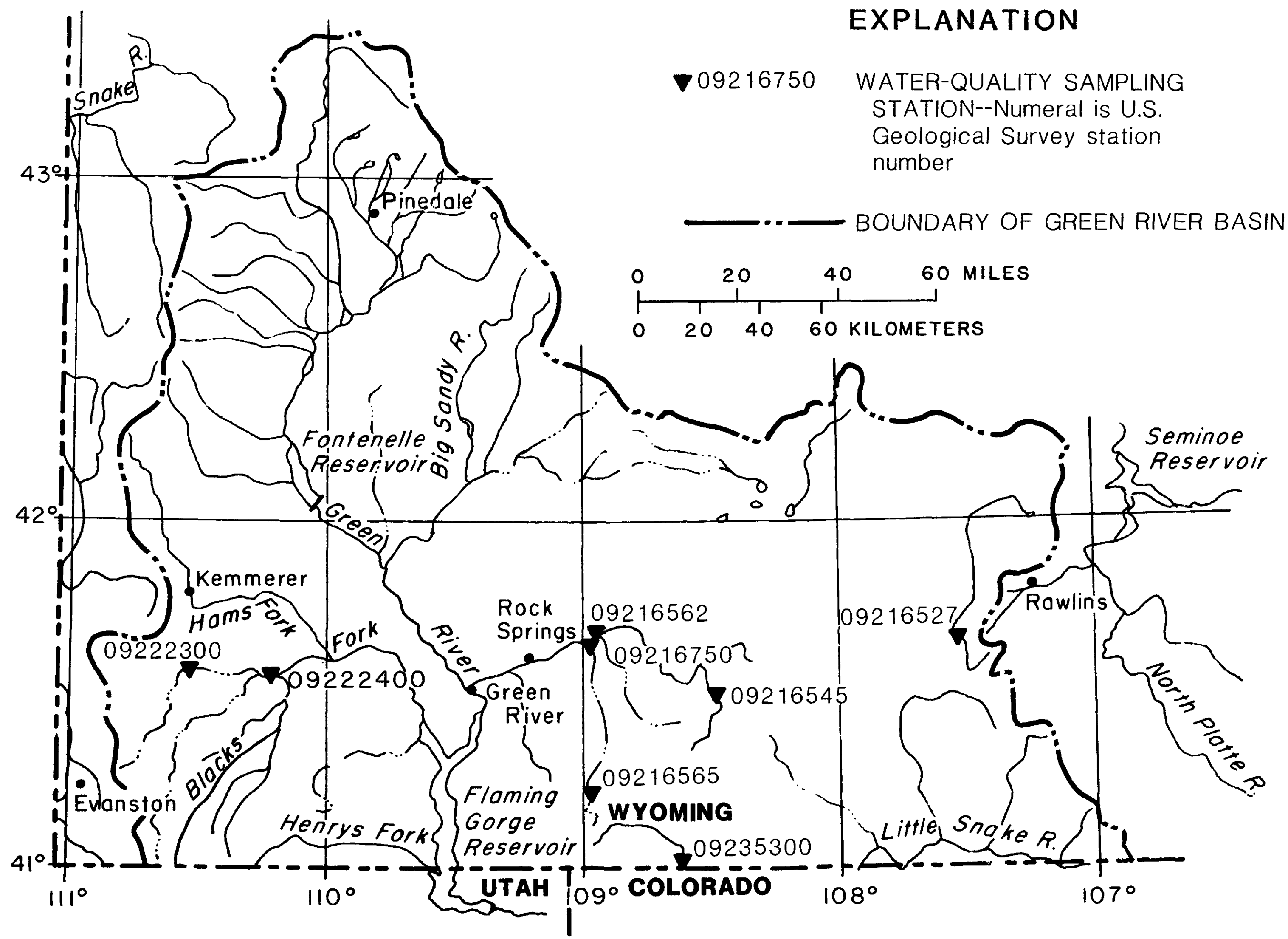

Figure 2.--Location of water-quality sampling stations.

RELATION OF DISSOLVED-SOLIDS DISCHARGE TO STREAMFLOW

Salts dissolved and entrained by runoff from snowmelt and precipitation are a major part of the dissolved-solids discharge carried by most Wyoming streams. Any increase in streamflow must result in an increase in dissolved-solids discharge unless the additional water contains no dissolved solids. DeLong (1977) and Rucker and DeLong (1987) reported a relation of dissolved-solids concentration to streamflow in the major perennial streams of Wyoming as:

$$C = AQ^B$$

where C = dissolved-solids concentration, in milligrams per liter;

Q = streamflow, in cubic feet per second; and

A and B = regression coefficients.

The dissolved-solids discharge (D) can be estimated by multiplying concentration by streamflow:

$$D = QC = AQ^{B+1}.$$

This relation shows that when B is greater than -1, the dissolved-solids discharge increases with increasing streamflow. Because sources of additional water to the stream vary, the additional dissolved-solids discharge may vary and the coefficients A and B may not be constant. DeLong (1977) and Rucker and DeLong (1987) represented A and B with harmonic functions of the day of the year. Rucker and DeLong were able to effectively relate the variation in sources of streamflow and dissolved-solids discharge of the major streams to seasonal trends. This relation is not feasible for ephemeral and intermittent streams.

Dissolved-solids concentration and discharge generally cannot be estimated directly from streamflow in ephemeral or intermittent streams as in the perennial streams. The highly variable runoff and dissolved-solids discharge of the ephemeral and intermittent streams are very sporadic and are not easily described by smooth harmonic functions. Variation that may occur throughout a season in the perennial streams may occur within hours in an ephemeral or intermittent stream.

Washing of Salts from Inundated Basin Surfaces

The washing of readily available salts from basin surfaces during runoff is a dominant process by which salt loading of ephemeral and intermittent streams occurs. Obviously, when there is no runoff in a channel there is also no salt load. Salts accumulating between runoff events are stored on basin surfaces and remain available to subsequent precipitation and runoff. The effect of washing or "flushing" of salts by rainfall and runoff in Salt Wells Creek is shown on figure 3 and was documented by Lowham and others (1982).

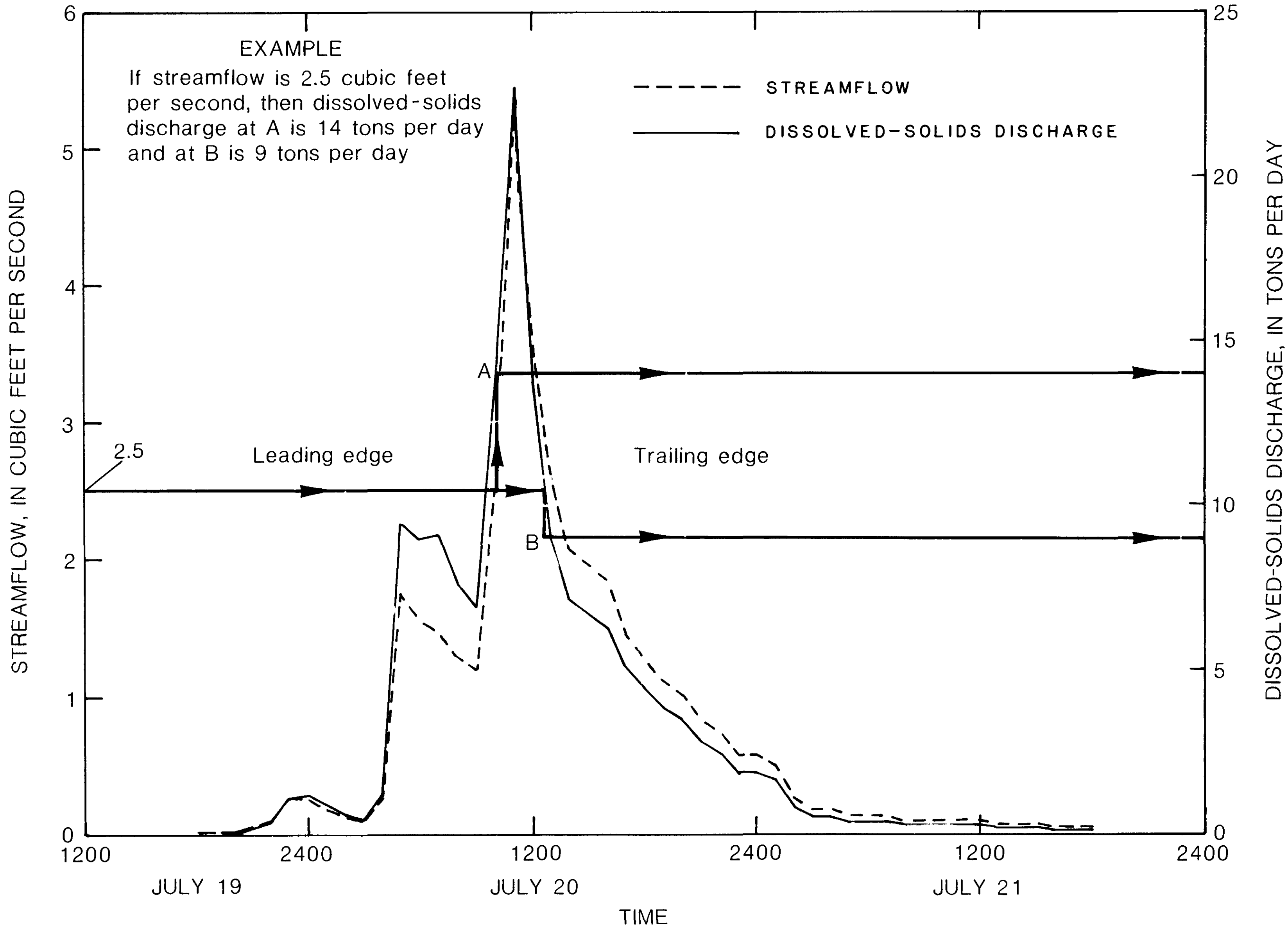

Figure 3.--Streamflow and dissolved-solids discharge at station 09216565, Salt Wells Creek near South Baxter, Wyoming, July 19-21, 1977.

A finite quantity of salts are stored on basin surfaces and are readily available for flushing during runoff. After the readily available supply of salts is exhausted, salt loading of the stream then becomes dependent on the rate at which salts are produced at the inundated surfaces. Evidence of this may be seen in dissolved-solids discharge and streamflow hydrographs shown in figure 3. There are about 50 square miles of drainage area upstream from the water-quality sampling station. About 7 miles upstream from the station, Salt Wells Creek is joined by Alkali Creek. Because measurements were not made upstream from the station during runoff, the cause of the multiple peaks in figure 3 is not known. Perhaps they result from the combination of Alkali Creek and Salt Wells Creek upstream from the sampling station. It is clear, however, that the dissolved-solids discharge hydrograph is shifted forward in time when compared to the streamflow hydrograph. Note that the dissolved-solids discharge at equal streamflow is greater on the leading edge of the hydrographs than on the trailing edge (fig. 3). At a streamflow of 2.5 cubic feet per second, the leading edge has a dissolved-solids discharge of about 14 tons per day, and the trailing edge has a discharge of about 9 tons per day. The relative forward shift of the dissolved-solids discharge hydrograph is a result of the depletion of the readily available salts.

Ground-Water Contribution

Salt load contributed by ground water in a basin characterized by ephemeral and intermittent streams cannot be simply determined from dissolved-solids discharge during base flow. Base flow may be intermittent or nonexistent (by definition, ephemeral streams have no base flow). Salts brought to the surfaces of the basin by ground water may not reach the stream channel or be transported until there is sufficient runoff. These deposits contribute to the readily available salts discussed earlier. Less obvious is the fact that the ephemeral and intermittent streams may contribute their streamflow and salt load to the perennial streams that do have sustained periods of measurable base flow. Estimates of ground-water contribution to salt loads based on base flows in the perennial streams may be in error when a significant part of the salt load is contributed by ephemeral and intermittent streams.

ESTIMATING AVERAGE DISSOLVED-SOLIDS DISCHARGE

The quantity of salts contributed by a basin can be estimated from continuous records of specific conductance and streamflow collected on perennial streams (DeLong, 1977, 1986a; Rucker and DeLong, 1987). Dissolved-solids concentration is estimated from a relation with specific conductance and then multiplied by the appropriate streamflow to estimate the dissolved-solids discharge. However, there are disadvantages to this method when attempting to estimate dissolved-solids discharge in ephemeral and intermittent streams. Specific-conductance monitors are not usually operated on ephemeral or intermittent streams, and when the attempt is made, operation is more difficult than on major perennial streams because the low- or no-flow periods are routinely punctuated by abrupt floods of water and sediment.

Continuous Specific-Conductance Monitors

Annual or average dissolved-solids discharges cannot be computed directly from continuous records of specific conductance and streamflow obtained from monitors operated on Salt Wells Creek (station 09216565), even though the attempt to continuously monitor specific conductance at the station was one of the more successful attempts made on an intermittent stream in Wyoming. A significant part of the specific conductance record is missing, preferentially during periods of early spring runoff. Another complication in using published records from this station is that daily-mean specific conductance and streamflow are computed from the hourly or continuous record and are the only data readily available to users.

A daily-mean dissolved-solids concentration can be estimated directly from the daily-mean specific conductance because they are linearly related. However, estimates of daily-mean dissolved-solids discharge made from multiplication of daily-mean streamflow and dissolved-solids concentration may be inaccurate during periods when concentration and streamflow are changing abruptly. Typically, the most abrupt changes in concentration and streamflow occur during periods of greatest load. A more accurate estimate of daily-mean dissolved-solids discharge would require multiplication of streamflow and concentration averaged individually over shorter periods of time.

Discrete Specific-Conductance Samples

Average dissolved-solids discharge in this report is estimated from discrete measurements of specific conductance and streamflow. During water years 1977-81, 183 such measurements were made at the monitor station on Salt Wells Creek (station 09216565). Dissolved-solids concentration was estimated from specific conductance and multiplied by streamflow to give an estimate of instantaneous dissolved-solids discharge:

$$C = aK + b,$$

$$\text{and } D = 0.0027QC,$$

where C = dissolved-solids concentration, in milligrams per liter;

K = specific conductance in microsiemens per centimeter at 25° Celsius;

a and b = regression coefficients;

D = dissolved-solids discharge, in tons per day; and

Q = streamflow, in cubic feet per second.

As shown in figure 4, the instantaneous dissolved-solids discharges fit a log-normal distribution as do similarly estimated discharges at other selected stations in the southern part of the Green River basin in Wyoming. The averages or arithmetic means (table 2) of the distribution were estimated from the geometric means and standard deviations by methods presented by Sichel (1952) and adapted by DeLong (1986a).

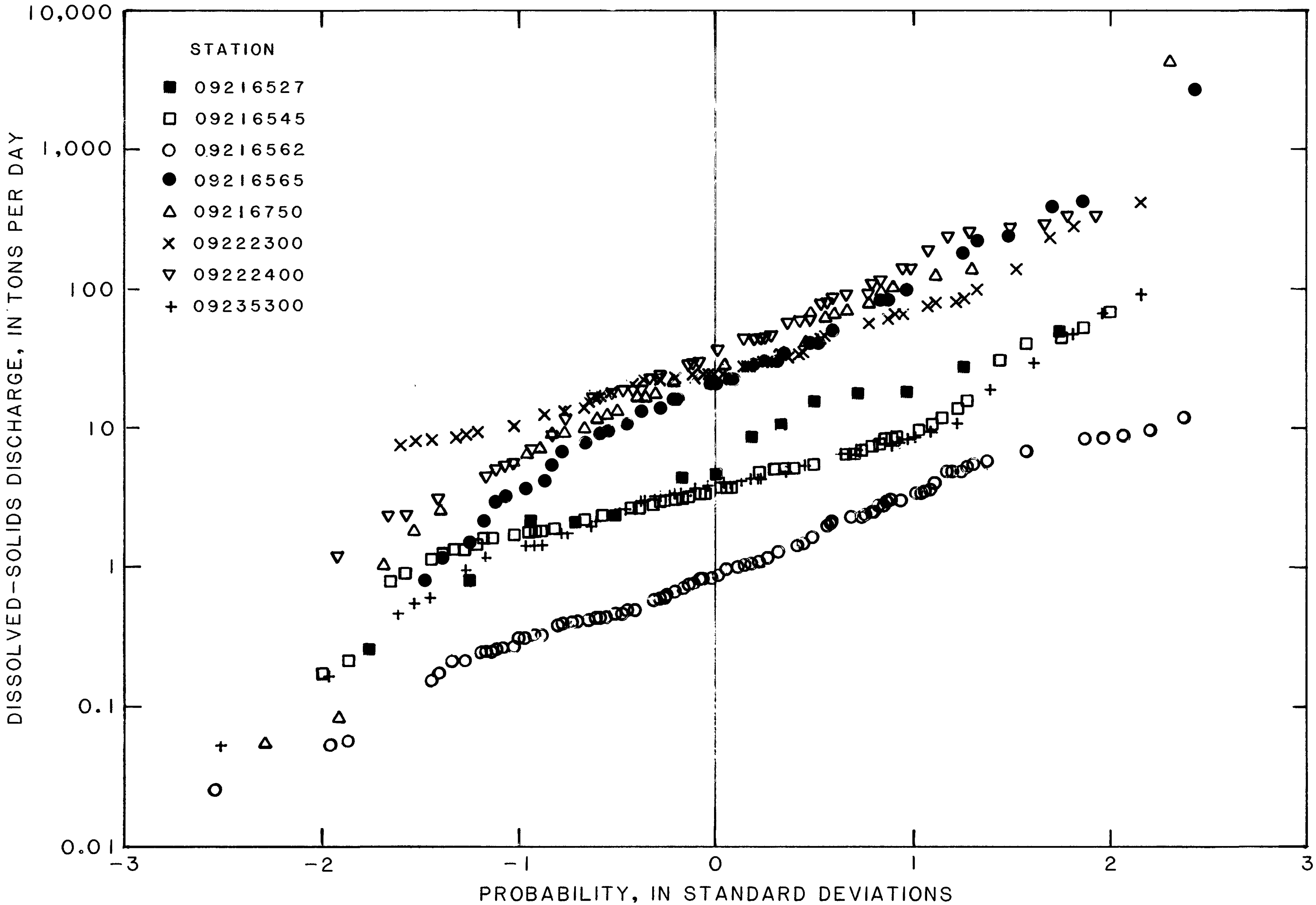

Figure 4.--Dissolved-solids discharges computed from samples collected at selected water-quality sampling stations.

Table 2.--*Average dissolved-solids discharges and yields, water years 1977-81*

Station number	Drainage area (square miles)	Number of samples	Ratio of flow days to total days	Dissolved-solids discharge: Mean $\log_{10}$	Dissolved-solids discharge: Standard deviation $\log_{10}$	Dissolved-solids discharge: Average for flow days (tons per day)	Number of no-flow days during given water year: 1977	1978	1979	1980	1981	Total	Average discharge (tons per day)	Average yield (tons per day per square mile)
09216527	55.3	14	0.240	0.7300785	0.6363647	14.7	293	267	281	271	226	1,388	3.53	0.0638
09216545	308	113	.957	.5942515	.5025848	7.65	38	0	40	0	0	78	7.32	.0238
09216562	836	90	.714	1.0241735	.8545902	70.5	192	118	90	52	71	523	50.3	.0602
09216565	34.7	182	.951	-.0550438	.5532501	1.98	46	0	32	0	11	89	1.88	.0542
09216750	526	56	.370	1.3939457	.7904325	124.0	243	238	231	227	211	1,150	45.9	.0873
[1]09222300	416	101	1.000	1.4444079	.4232476	44.6	0	0	0	0	--	0	44.6	.107
09222400	963	95	.952	1.4744596	.6792141	99.8	1	21	48	0	17	87	95.0	.0987
09235300	196	103	.606	.5482761	.5349597	7.50	76	41	31	0	57	719	4.55	.0232

[1] Averages for station 09222300 (discontinued September 30, 1980) are for water years 1977-80.

Adjusting Estimates for No-Flow Days

The average values of dissolved-solids discharge represent periods during which streams were flowing and must be adjusted by a theorem of conditional probability to estimate overall averages. Zero estimates of dissolved-solids discharge, resulting from periods when streams were not flowing, were not included in the log-normal distributions. Jennings and Benson (1969) similarly applied a theorem of conditional probability to distributions of annual flood peak data. Simply stated, to adjust estimates from the distribution drawn only from the period when there is flow, the estimates are multiplied by the probability that there will be flow. For example, daily streamflow records indicate there were 89 days at station 09216565 in which no flow occurred during the 5 years analyzed. The ratio of days on which flow occurred to the total number of days is an estimate of the probability of flow occurring during the analyzed period:

$$0.95 = (1825-89)/(1825).$$

The estimated average dissolved-solids discharge during the flow period (table 2) is 1.98 tons per day. Consequently the overall average for the 5-year period is:

$$(1.98)(0.95) = 1.88 \text{ tons per day.}$$

ESTIMATES OF AVERAGE DISSOLVED-SOLIDS DISCHARGES AND YIELDS

The estimates of average dissolved-solids discharges at the eight stations (table 2) range from less than 2 to 95 tons per day; the largest discharge is about 50 times greater than the smallest discharge. As might be expected, much of this variation is related to the drainage area upstream from the sampling stations (fig. 5). Dissolved-solids yields range from about 0.023 to 0.107 ton per day per square mile; the ratio of largest to smallest yield is about 4.6.

The slopes of lines in figure 6 indicate the average rates at which dissolved-solids discharges increase between stations. The slope of the three lines range from 0.081 to 0.092 ton per day per square mile, a variation of less than 15 percent. Thus, on the average, the drainage areas contributing to the streams between the six paired water-quality stations yield dissolved solids at similar rates (tons per day per square mile). The drainage area encompassed by the six paired sites is more than two-thirds of the area represented by the three downstream-most sites and more than one-half of the total area represented by all of the studied sites. Presumably, if more sites were sampled upstream from the upstream-most sites, the common rate of dissolved-solids yield could be extended to an even greater part of the studied area.

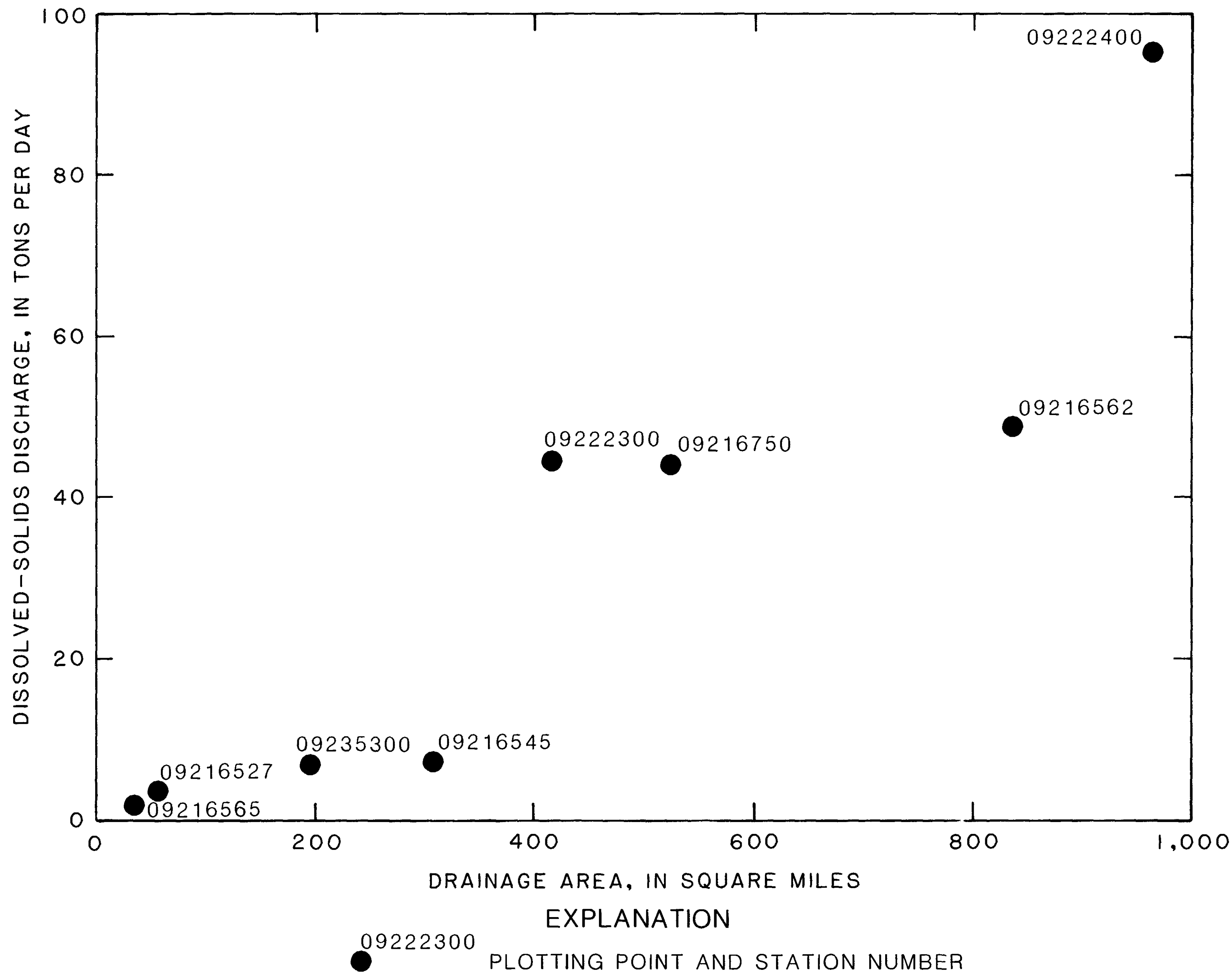

Figure 5.--Relation of average dissolved-solids discharge to drainage area at selected water-quality sampling stations, water years 1977-81 (station 09222300, water years 1977-80).

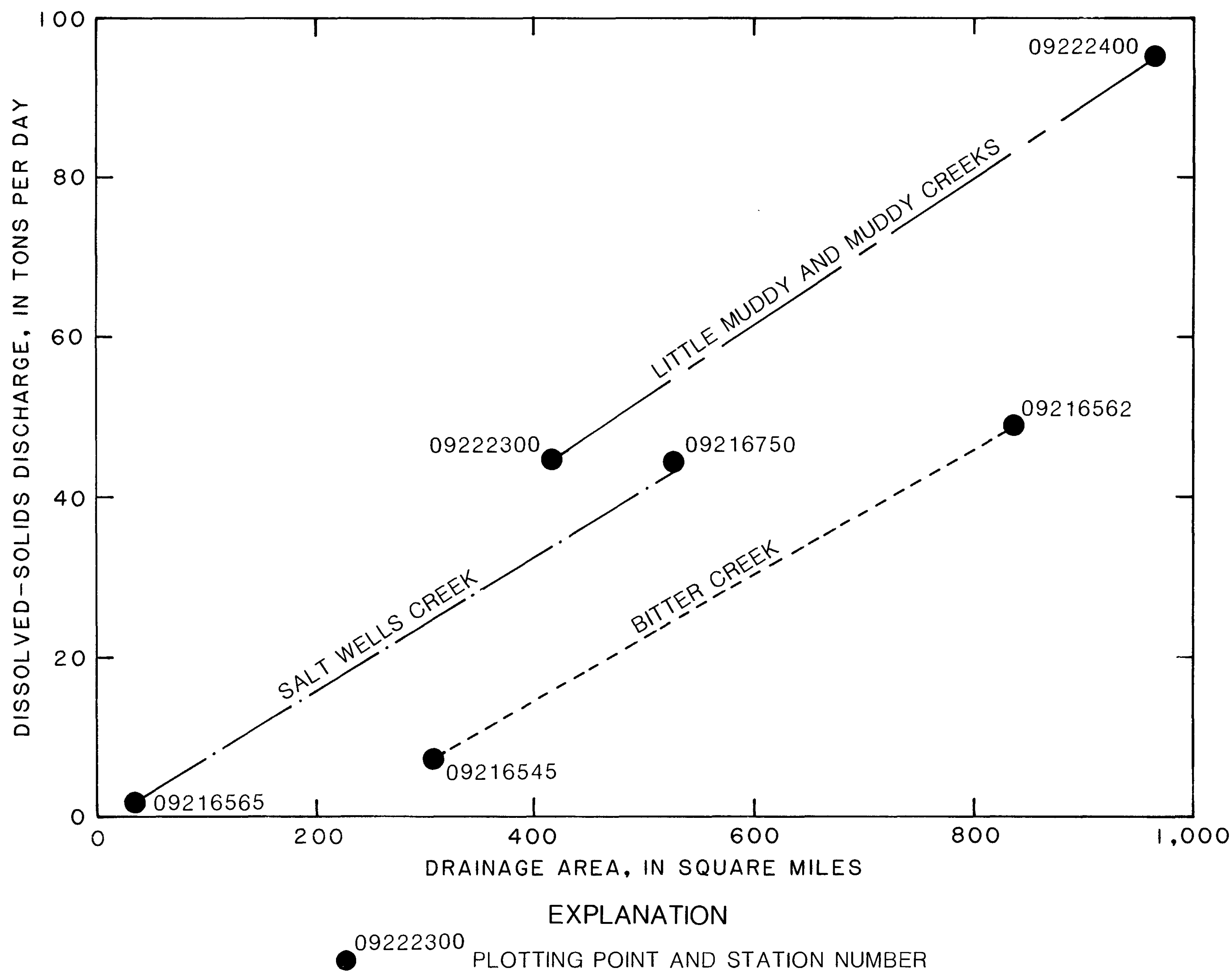

Figure 6.--Rate of dissolved-solids contribution between paired water-quality sampling stations.

CONCLUSIONS

Average dissolved-solids discharge for ephemeral and intermittent streams in the Green River basin, Wyoming, may be computed from discrete samples of specific conductance and streamflow. The method presented requires that the relation between specific conductance and streamflow, as well as the probability of the occurrence of flow be known. Instantaneous dissolved-solids discharges computed at selected stations fit log-normal distributions from which arithmetic means subsequently may be computed. The arithmetic means may be adjusted for no-flow days (which were not included in the distribution) by using a theorem of conditional probability.

Estimates of dissolved-solids yields for eight stations analyzed range from 0.023 to 0.107 ton per day per square mile of drainage area. The dissolved-solids yield from a drainage area encompassed by two sampling sites on a stream system may be estimated from the slope of the dissolved-solids discharge versus drainage area line. Estimates of dissolved-solids yields contributed by drainage areas between the six paired water-quality stations on Bitter Creek, Salt Wells Creek, and Little Muddy and Muddy Creeks ranged from 0.081 to 0.092 ton per day per square mile or less than 15 percent variation. This indicates that more than two-thirds of the drainage area represented by the three downstream-most sites yields dissolved solids at nearly the same rate.

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