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EFFICIENT DESIGN AND UTILIZATION OF RAINFALL NETWORKS

by

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and

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ABSTRACT

Historical monthly rainfall data were analyzed by methods of multivariate statistics. The analysis was designed to separate complex patterns of rainfall variability in winter and in summer into simpler independent patterns. The independent components of rainfall pattern were studied in an attempt to detect relationships with network size and configuration, with orientation of the gages to landsurface slope, and with gage elevation.

The intent of the study was to follow up the analysis and interpretation of rainfall data with methods of estimation of rainfall amounts and of estimation of rainfall patterns in any geographic area. Such methods of prediction, based on established relationships between rainfall characteristics and terrain characteristics, would lead to precise estimation of available water resource in any area, and to principles of efficient network design to monitor rainfall in the area.

The study was only nominally successful in accomplishment of the stated objectives. It has been clearly demonstrated that multivariate statistics provides a powerful and efficient tool in rainfall data analysis. It has also been clearly demonstrated that rainfall patterns can be broken up into simpler, independent patterns. However, the definition of relationships between rainfall and network physical characteristics could not be brought to useful form. Sufficient data from networks large enough for such determinations were not available.

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INTRODUCTION

Efficient development of the water resources of the Nation can only be carried out when there is information about water on which to base planning and design. If the supply of water is large enough to satisfy all demands no problems or conflicts arise. Such supplies of water are seldom found to-day, and even these few remaining regions of plenty will experience increased demands because of population growth and increased water usage.

Concern with water resources is partly a concern with distribution of water in space and time. A thorough knowledge of these distributions can only be gained by continuous measurements. Traditionally, water resources have been monitored at two different points in the hydrologic cycle. Networks of stream gages monitor the flow of water in surface streams. Networks of raingages monitor the flow of water from the atmosphere to the surface of the earth. Other portions of the hydrologic cycle are monitored, obviously. Depths of water can be measured in ground-water wells. Soil moisture is measured in a few locations. Atmospheric humidity measures the water content of the air over the earth. But the bulk of working information to-day comes from the massive data collection networks of raingages and streamgages.

If every stream had been monitored by a line of stream gages spaced along it's entire length for the past, say, 100 years, there would be little need for additional information. Such an extensive network would be an adequate space-time sample from the past with which we could estimate with a certain degree of confidence information about future supplies. But streams with 100-year records are rare. Lines of gages along the lengths of streams are limited to the major river systems. Many smaller streams have only one gage with less than 25 years of record. Some streams have no streamgages.

The number of stream gages is increasing, and of course, the record length on existing gages is constantly increasing. It is doubtful, however, whether it will be possible in any forseeable future to work only with stream flow information and ignore rainfall information. Obviously, any water resources development to-day must be planned and designed on information available to-day. A relationship between space and time distribution of rainfall and space and time distribution of streamflow still appears one of the more feasible schemes to establish firm bases of information for planning. Rainfall data have a peculiar advantage over streamflow data. Water measured as it impacts the surface of the earth has not been modified in quantity or distribution by the earth itself. Certainly mountains affect precipitation, and the proximity of a maritime supply of moisture has an influence on the hydroclimate in a locality. But these are essentially constant effects.

The modification of the quantity and distribution of water by the earth is not constant and it is not simple. The amount of water that the soil can absorb depends upon how much it already holds. The rate at which it can be absorbed depends upon the surface character of the earth. The release of water to the stream channels and it's passage downstream depend upon geological characteristics and the hydraulic properties of the system of stream channels. The amount of water in the soil varies from day to day. Man uses the surface of the earth in different ways at different times, sometimes covering it with impervious surfaces so that no water can infiltrate. He builds large dams to interrupt the flow of water in the rivers. The geology of one basin differs radically from the drainage basin next to it.

We may re-iterate, then, that our water supply monitored by our raingage nets offers a relatively simple and constant bulk of information. It is stochastic information, certainly. But the very variability of rainfall is reasonably constant. Rainfall amount and variability are not modified presently to any degree by man's activities nor by the earth itself.

The potential utility of the rainfall information is not realized until this information can be applied to the specific problem. Intelligent application requires an understanding of the determination of average rainfall on a drainage area. An ideal network of raingages would have many times the density of present day networks. The density of gages would be uniform, regardless of terrain. Density would be the same in urban and rural areas. The gages would all continue to operate in the same location, never changing their exposure to a potential rainfall catch.

Actual raingage networks are far from ideal. The number of gages is often very limited. The density of gages is nonuniform, mountainous terrain being especially deficient in gages. Networks change continuously. Observers who read and service the gages move or die, and gages must be moved to a new observers residence. Gages must be moved away from construction. An urban community sprawls over the countryside, and the home owner in a new development has no desire to see a raingage in the center of his neatly clipped lawn. Sometimes extra money is appropriated, allowing installation of a few more gages. The person responsible for operation of the network, in effect faces a responsibility for continuous re-design of his network. If a gage should be moved in which direction should it be moved? If an extra gage is to be installed where should it be placed? The answer to both of these questions should be "Where it will provide the most information."

The specific answer to the question above may be difficult of achievement. A brief mention of average rainfall determination is pertinent here. One raingage provides one point of measurement of rainfall. A network of gages provides a point of measurment for each gage in the net. To compute the total volume of water falling on an area it is necessary to multiply the average depth of rainfall by the area. In more sophisticated terminology, it is necessary to integrate some rainfall function over the area. In any event, it is necessary to interpolate for the amount of rainfall between the gages. The determination of such an interpolation method should be based on the processes which cause rainfall to vary from point to point. If the interpolating function were known one could get the most information from measurement of rainfall on the present networks. But, additionally, one could decide where to place a gage when the network is changed because the interpolating function would indicate regions of large variability of rainfall. In such regions the gages should be spaced closely. In regions of comparatively uniform rainfall, spacing of gages could be relaxed.

As a starting point in developing methods for efficient design or utilization of networks it is necessary to analyze present networks. How do patterns of rainfall observed in present networks reflect the location of that network? What are the quantitative effects of mountain barriers? What is the effect of east-west versus a north-south orientation when the net is not circular? What is the effect of direction of slope of the land surrounding the gages? If these and other effects can be detected and measured in actual recorded data, they can be used as a basis for systematic rainfall determination, and a more precise determination of volumes of water resource replenished from the atmosphere.

Background

Many investigators have reported on analyses of rainfall variability over the area covered by a raingage network as well as the variability of the rainfall with time. Such studies reflect many different objectives, which are, however, usually in one or the other of two broad categories. The investigator usually wishes to document the expected error between "real" rainfall and the "sample" rainfall provided by the gages, or else he wishes to "explain" the variability in rainfall by introducing some physiographic or climatological characteristics of the raingage site. Most investigators recognize the lack of independence of the two approaches. Such studies have been continuing over a comparatively long period of time, but the method of attacking the problem has gradually changed. With the advent of the electronic computer as an every-day working tool it has been possible to introduce sophisticated analytical and mathematical methods. Large sets of data can also now be handled efficiently and quickly.

Linsley and Kohler [1951] analyzed daily precipitation for each of 55 stations in an intensively gaged area in Ohio. The basic data were the 55-station averages for 68 storms. Among other findings they reported a linear relationship between the distance of the gage from the center of the area and the deviation of the gage rainfall amount from the areal average rainfall. McGuinness [1963] developed an empirical relationship between daily rainfall amounts for selected storm periods, the gage ratio in square miles per gage, and the absolute difference between a 64-gage network and selected subnetworks. McGuinness used data from the Coshocton Watersheds in Ohio. James [1964] studied variability of rainfall catch with respect to topography. He reported on differential rainfall amounts measured on the windward and leeward sides of a small hill. The windward side gage recieved only 92 per cent of the leeward gage amount. However, James pointed out that other investigators have found that windward gages receive larger catches. The excessive precipitation on the windward sides of high mountain barriers, and the deficient rainfall in the lee of such mountain barriers are well known.

Hershfield [1965] studied correlations in rainfall amount among raingages for 15 major storms on 15 different watersheds. The basic method was the establishment of isocorrelation lines based on the correlation coefficients between a key gage and all other gages of the network. Hershfield developed empirical relationships between the average distance from the key gage to the 0.9 isocorrelation line and storm rainfall parameters. Caffey [1965] studied annual precipitation and annual effective precipitation. His method, like Hershfields, is based on the analysis of the distribution of correlation coefficients between a control gage and all other gages in a regional "block" of gages surrounding the control gage. Caffey worked with large climatic networks in western United States rather than with intensive networks. He fitted an ellipitcal response surface to the isocorrelation lines, and noted the effect of topography, general wind circulation, and frontal activity on the orientation of the major axis of the elliptic response surface. Nicks [1965] has reported preliminary analysis on a network of 175 raingages in an area of 1130 square miles in the Washita River Watershed in Oklahoma. The basic design of the network is a 3- by 3-square mile grid oriented north-south and east-west. The preliminary analysis indicated that the number of gages could be radically reduced if only a Thiessen weighted (area-weighted) mean daily rainfall was desired. Nicks pointed out that other considerations may control, such as a requirement for information of specific rainfall amounts on sub-portions of the network. He also mentions particularly the possibility of variation of rain catch with direction of storm travel across the net.

Amorocho and Brandstetter [1967] have published probably the most mathematically oriented study of precipitation patterms for storms. They generated the storm patterns by smoothing rainfall data by curve- and surface-fitting techniques. They found that the parameters of a three-parameter gamma function, representing the smoothed rainfall record at each station could be represented by trend surfaces, or fields, across the networks.

The only study found in which eigenvector analysis was used to analyze patterns in rainfall data was the recent publication by Stidd [1966].

A copy of this publication was received after initiation of the study reported here, and to that extend the two reports represent independent approaches. Stidd used as basic data a 12 x 60 matrix, consisting of the 12 monthly average precipitation amounts for 60 stations in Nevada. A 12 x 12 matrix was generated by premultiplication by the transpose of the original matrix. He found that three eigenvectors accounted for 93 percent of the variance, or information, in the 12 x 12 matrix. These eigenvectors were interpreted in terms of 1) Annual cycle of winter storms, 2) Annual cycle of summer time convective precipitation, and 3) Late spring and early fall rainfall. The vector elements varied linearly with elevation. These elements were adjusted for the elevation relationship and then plotted to the respective raingage location. Consistent patterns of the three vectors resulted.

Objectives

The primary objectives in the study of bases for "Efficient Design and Utilization of Rainfall Networks" is the systematic analysis of what has already been measured. The form of the analysis is controlled by the intended subsequent application of the results of analysis. Stated more directly, rainfall data collected over many years by networks of gages will be treated statistically. Rainfall is not constant over an area, however, certain average "patterns" of rainfall can always be found. The statistical analysis is designed to separate these "patterns" into more basic components. Hopefully, these basic components can be related to certain features of land and climate where the raingage net is located. If such pattern components are found to exhibit a consistent relationship, network to network, then again hopefully, a dominant influence of the land and climate, the "domain" of the particular networks analyzed, will have been found.

Following a successful analysis it is always possible to synthesize. If the analysis has produced consistent and identifiable relationships such as mentioned above, then elements of land and climate of a new and different "domain" can be used with the relation to estimate the pattern components in the new domain. And, lastly, compositing the components will produce an estimate of the rainfall pattern for the new domain. Obviously, such analytical and synthetical procedures must be based on quantitative relationships. This required quantification is the reason for use of statistical procedures.

The final goal of the study is a practical and workable procedure for estimating average rainfall on an area. Such averaging is possible, and conventionally carried out, from an assumptive basis of simple linear interpolation between raingages. Alternatively, an assumed simple area-weighting of each raingage has been practiced. Such initial assumptions will be avoided in this study. At the same time, a theoretically "correct" solution based on atmospheric physical and mechanical principles is not presently possible. Hence the compromise solution is proposed. This compromise solution, as explained, is based on a rational, statistical interpretation of the variabilty of rainfall data and the properties of the network in which the rain was measured.

This study was limited to presently available data. The research effort did not involve installation and operation of new networks. The so-called "experimental" features of the study are therefore essentially uncontrolled. The land and climate features incidental to the present networks are the only expression of these features which can be analyzed. Since past dense networks of gages were installed to measure rainfall on an area such as a watershed rather than to "sample" the land and climate features, a definite chance for bias exists. There is no alternative if one wishes to analyze data now. Long records are required. Data from new networks would only reach sufficient volume after a waiting period of, say, ten years.

Procedure

The analysis of historical rainfall data was based on multivariate statistics. Several advantages derive from this approach. The catch of rain at each gage can be treated as the statistical variate it truly is. There is no need to reduce the rainfall amounts to the fixed variate concept of the multiple regression predictor equation. The method of principle components, essentially an eigenvalue-eigenvector analysis, will produce components of the rainfall pattern. These components are orthogonal, each is mathematically independent of every other. If it can be shown that components, additionally, relate to some physical characteristic of the site of the network, then an "independent" measure of the effect of that characteristic on the rainfall pattern will have been found. In synthesis, compositing of several effects is reduced to simple addition if the separate component effects are orthogonal.

The total study was to proceed through three phases.

Phase I was component analysis of rainfall amounts.

Phase II was a re-analysis of the components of Phase I in association with parameters which describe the network physiographic and environmental characteristics. This phase was an attempt to develop the relationships between rainfall pattern components and the network properties.

Phase III was to be an analysis of the changes in the Phase II relationships from network to network. This phase would provide information on the variability of the functional relationships and perhaps also provide some clue as to the precision of any scheme for synthesis of rainfall data which might be devised.

Varying definitions of rainfall might be used. For example, the rain catch in a gage for one year could be considered a statistical variate. The rain which fell in a day, or a week could be used. Alternatively, rainfall during some natural time period, normally called a storm, might be the basic statistical variate. In this study monthly rain catches at the several gages of the network were used as the statistical variates. Data were broken into summer and winter, and each of these two sets were analyzed separately. The summer and winter periods were each of four months duration. The intent was to separate summer convective high intensity precipitation for the more uniform low intensity wintertime precipitation. With separate analysis of the two predominating types of precipitation separate development of functional dependence of rainfall patterns upon network characteristics should be possible. This separation does reject one third of recorded data, two months with transitional types of rainfall in the spring of the year, and two months in the fall of the year. This rejection is justified, however, on the basis of the stated objectives of the study. No attempt is being made to determine the most precise time-average of precipitation. The study is uniquely aimed at identification of effects, and in this concept simplification at the expense of some data rejection is justifiable in initial investigation.

RAINFALL NETWORKS AND DATA

The first major step in this study of rainfall networks was the solicitation of data. Letters of request were addressed to likely sources, explaining briefly the intent of the proposed study and the need for historical data. Initially, it was anticipated that research watersheds with their special instrumentation for rainfall-runoff studies would be fruitful sources of data from networks with large numbers of raingages. Of extreme value in preparation of these requests was a recent publication by the American Geophysical Union (1965). Letters of request were sent to all likely watershed projects in the eastern United States.

Research Watershed Networks

The following specific data were requested from each watershed research project:

1. Monthly or daily totals of rainfall for each raingage in the network for the period of simultaneous record of all gages. Minimums were set at 5 gages and 5 years of record.
2. Elevation of each station.
3. Station locations plotted on a topographic map.

The data sets obtained are listed with pertinent basic data in the first portion of Table 1. All data in this table are self-evident except for "Network Area". This characteristic was determined as the product of major and minor axes of the net. It is intended to be a descriptive and not a precisely defined charactistic.

Data were obtained from only 9 different research watersheds. Only 3 networks with more than 20 stations were found. This limited amount of historical data was an extreme disappointment and affected the entire study and the progress toward the stated objectives. The above statements are in no way intented to imply lack of cooperation on the part of project leaders to whom inquiries were addressed. Some project leaders even cooperated to the extent of copying to useful tabular form from worksheets in their files.

Georgia Networks

In addition to the "intensely" gaged research watersheds a portion of the Georgia State Climatic Network was also analyzed. This network

TABLE 1

RAINGAGE NETWORKS ANALYZED

Network	Network Area (sq.mi.)	No. of Stations	Area per Station (sq.mi.)	Season	Record Used	No. of Months
Coshocton, Ohio	0.971	7	0.139	Summer	May 64-Aug 64	76
				Winter	Nov 64-Feb 65	76
Coweeta "A", N. C.	1.513	6	0.252	Summer	May 37-Aug 56	80
				Winter	Nov 36-Feb 56	80
Coweeta "Active", N. C.	4.743	11	0.431	Summer	May 43-Aug 56	56
				Winter	Nov 42-Feb 56	56
Coweeta "B", N. C.	3.796	7	0.542	Summer	May 43-Aug 56	56
				Winter	Nov 42-Feb 56	56
Coweeta "C", N. C.	6.282	38	0.161	Summer	May 37-Aug 56	80
				Winter	Nov 37-Feb 56	76
Deer-Sloan, Mich., 16 Stn.	2.456	16	0.154	Summer	May 56-Aug 65	40
				Winter	Nov 56-Feb 65	36
Deer-Sloan, Mich., 22 Stn.	3.835	22	0.174	Summer	May 58-Aug 65	32
				Winter	Nov 58-Feb 65	28
Fernow, W. Va.	1.334	13	0.103	Summer	May 57-Aug 65	36
				Winter	Nov 56-Feb 64	36
Hubbard Brook, N. H., 5 Stn.	0.065	5	0.013	Summer	May 58-Aug 64	28
				Winter	Nov 57-Feb 64	28
Hubbard Brook, N. H., 8 Stn.	0.108	8	0.014	Summer	May 60-Aug 64	16
				Winter	Nov 60-Feb 64	16
Pigeon Roost Creek, Miss.	158.7	30	5.291	Summer	May 57-Aug 65	36
				Winter	Nov 57-Feb 65	32
Ralston Creek, Iowa	2.449	5	0.490	Summer	May 45-Aug 55	44
				Winter	Nov 44-Feb 55	44
Sleepers River, Vt.	49.89	13	3.838	Summer	May 60-Aug 65	24
				Winter	Nov 59-Feb 65	24
Tallahatchie River, Miss.	0.149	5	0.030	Summer	May 58-Aug 65	32
				Winter	Nov 57-Feb 65	32
Georgia, 4 Stn.	163.2	4	40.82	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 8 Stn.	822.8	8	102.9	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 12 Stn.	1972	12	164.4	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 16 Stn.	4326	16	270.4	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 20 Stn.	4729	20	236.5	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 24 Stn.	5759	24	240.0	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 28 Stn.	7405	28	264.5	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40
Georgia, 31 Stn.	8434	31	272.1	Summer	May 53-Aug 62	40
				Winter	Nov 53-Feb 63	40

of gages, located in northern Georgia was included to provide a completely different geographical scale, and to study certain "growth" effects which will be discussed later. Characteristics of the Georgia networks are shown in the last portion of Table 1.

The raingage networks studied within the state of Georgia differ in several important aspects from the research watershed networks described above. Perhaps the most important difference is that each successively larger network contains within it all the stations used in the smaller nets. A base network was selected and other stations were added to produce a "growth" effect, the entire new net being analyzed after each addition. A second difference is that the Georgia nets are not limited to a particular watershed area, but are much larger in area and encompass more of a variety of topographic features. Finally, the stations making up the nets are more subject to relocation than the stations set up specifically for research, with the consequent effect of introducing more error into their records.

As mentioned, there was no attempt to limit the Georgia networks to a particular watershed area. All official U.S. Weather Bureau raingaging stations in the State were considered in the beginning for inclusion. Then, to reduce data error resulting primarily from station relocations during the period of record used, all stations that could not meet the following arbitrary criteria were dropped from consideration:

a. Continuous record of rainfall available during the period of record.
b. Not more than two relocations during the period of record.
c. No single relocation exceeding two miles in distance from the original gage site.

The stations meeting these criteria were then located on a map of the State and, because of the more favorable density of stations in the northwest portion of the State, thirty-one stations in that area were selected for analysis as a net.

The network represented by the 31 stations selected extends over an area of approximately 8350 square miles (Figure B 10, Appendix B). Near the centroid of this area four stations were selected as a base network upon which to build. Subsequent networks were formed by adding stations in groups of four to the previous net, additions being made arbitrarily but roughly in order of their proximity to the center. In this way, networks of 4,8,12,16,20,24,28,31 stations were formulated and analyzed, each subsequent analysis showing the effect of adding four more stations to the previous net.

Selection of summer and winter months

Since the primary concern of this study was to try to identify basic physiographic features that consistently affect the pattern of rainfall over a network area, it was necessary from the very outset to reduce as much as possible variability in the data brought about by basic meteorological patterns. Analyzing rainfall patterns on the 12-month basis would have had the effect of combining the widespread cyclonic rainfall of the winter months with the limited, intermittent, convective thunderstorms of the summer months. By analyzing predominatly thunderstorm rainfall separately from predominantly cyclonic rainfall one of the principal meteorologic variables in the rainfall pattern should be eliminated.

To determine which particular months should be considered to have predominantly cyclonic, or "winter", precipitation and which convective, or "summer", precipitation, the following rainfall data were used as indicators; a) normal monthly precipitation; b) 5-year average, monthly number of days with .01 or more rainfall; c) 5-year average, monthly number of thunderstorm days. These data are all available in the standard U.S. Weather Bureau "Climatological Data" publication. Plots of these indicators versus month were made and were studied to determine the months for "summer" analysis and those for "winter" analysis.

As might be expected from general considerations, in each case studied the months of May, June, July, and August tended to have the same values in all three indicators and thus were indicated as being "summer" months. Likewise, the months of November, December, January, and February showed the least number of thunderstorm days, but had an increased amount of normal precipitation and number of days of rain; these months were definitely cyclonic, or "winter" months. The months of March, April, September, and October were consistently lower in all indicators and were not used in the analyses, since apparently their rainfall was the result of both convective and cyclonic events.

Therefore, for each network being studied, the separate summer and winter analyses were performed on the months May through August and November through February, respectively.

Definition of Network Characteristics

Over the years a considerable amount of research has been directed toward answering the questions: 1) What topographic features directly affect the rainfall over an area? - and 2) To what extent does each particular feature affect the rainfall amounts? The pattern of rainfall over an area is directly related to the major topographic features of that area. The problem has been to identify and to quantify the effects of the seemingly limitless number of physiographic land features that could contribute to the rainfall pattern.

Since the objective of this study was to identify rainfall patterns and to investigate the existence of a relationship between those patterns and the physical properties of the raingage network, it was necessary to define explicitly a number of physical properties that might produce the strongest effects on the rainfall pattern. In keeping with the purposes of the study, the physical features had to be readily identifiable from material and data readily available. Thus, the physical characteristics of the network area were defined in such a way that they could be measured from standard topographic maps or obtained from individual station location data.

A brief discussion of the physical properties used to describe each station follows:

1. Of foremost importance in describing a particular network and in considering the rainfall patterns over it is the overall size of the network area. The pattern of rainfall over a network within a research watershed of a few hundred acres would differ substantially from that over a state-wide or regional network. As a measure of the network size and the distribution of the individual stations within the net, latitude and departure distances of each station from the centroid of the net were measured and used as separate physical properties.

Property 1 - Station latitude - north-south distance from the network centroid to a station

Property 2 - Station departure - east-west distance from the network centroid to a station

2. In addition to describing the gross area of the network, a means of describing its general shape and orientation was desired. Rainfall patterns over long, narrow network areas should be substantially different from patterns over areas roughly circular in shape. Similarly a network lying "broadside" to the prevailing weather track could experience rainfall patterns differing from a network running parallel to it. In an attempt to describe the location of each station with respect to the general shape or orientation of the network, two properties were used:

Property 3 - Distance to Centroid - the straight line distance from the network centroid to the station

Property 4 - Orientation to Centroid - the octant within which the station lay with respect to the network centroid. Octants were designated NNE, ENE, ESE, SSE, SSW, WSW, WNW, and NNW

3. Perhaps the most readily available information for a station other than its location is its elevation above sea level.

Property 5 - Elevation - elevation of the station above sea level

4. Other factors generally considered to affect the rainfall pattern over a particular station are the topographic characteristics of the area immediately surrounding the station. The question arises, however, how near must a topographic feature be to a station to materially affect the rainfall over it? No one answer would be suitable for all networks; features within a mile of a station in a small intensively gaged area would have a relatively greater affect on the micro-pattern of rainfall over that area than they would on the pattern over a more open state-wide climatic network. For this reason the properties used in this study to describe the topography surrounding a station were defined in relation to the overall network size. The gross area of each network was computed by multiplying the length of its principal axis, L, by the corresponding maximum width, W. The average area per station was then determined by dividing the number of stations, n, in the network and a distance, D, was computed as the square root of the average station area, or

$$D = \frac{L \times W}{n}$$

To determine a slope property for its immediate surrounding area, a circle of diameter D and octant divisions as in Property 4, above, was first circumscribed around each station location on a topographic map. Readings were then taken along the circumference of the circle to determine the three adjoining octants containing the highest elevation readings and the corresponding opposite three adjoining octants containing the lowest elevation readings. The difference between the median high reading and the median low reading was then divided by D to give the slope property for each station the direction designation of the middle of the three high-elevation octants. In most instances separate areas of high and low readings were clearly decernible; however, for a few stations, the choice of the three high or of the three low octants was simply a matter of judgment.

Property 6 - Slope - the measure of the maximum change in elevation across a distance D in the area immediately surrounding the station.

Property 7 - Aspect - the octant toward which the area immediately surrounding the station generally falls.

MULTIVARIATE ANALYSIS OF DATA

The basic unit of input data in this statistical approach to rainfall network analysis was the rainfall during one calendar month. This monthly rainfall was tabulated for every gage for four months each summer and for four months each winter, and of course for every year of the raingage record.

Other units of base time could be used for basic data definition. For example considering other arbitrary units of time for definition of a unit of data, years, weeks or days are possibilities. A natural unit, the rain recorded during a specific storm event could also be used. Each system of data definition has advantages and disadvantages. Annual data are least variable, but result in small statistical samples and provide no possibility for inquiry into "within season" effect. Daily rainfall data do provide large statistical samples, but an extra degree of variability is introduced because storm rain amounts quite frequently fall in adjacent days, rather than within any one day. The storm is probably the best unit to use in searching for detailed information concerning the fall of rain unto a network of gages. However, basic data processing and publication of data do not normally include determination of storm rainfall amounts. This is especially true for state-wide climatological networks. Preparation of such basic storm rainfall data would therefore represent an expensive addition to the study.

Weekly and monthly rainfall data seemingly represent a compromise between the desirability of detail provided by the natural unit of occurrence, the storm, and the desirability of low cost of data processing. These arbitrary periods should provide rainfall data which are the sum of several storm events. The "carry-over" of rain of a particular storm into adjacent periods is lessened. It was decided to use monthly rainfall amounts on the basis that data are normally tabulated in this manner, and therefore, these data should represent minimum cost in data acquisition for the study.

Steps in Data Processing

Table 1, referred to earlier, shows the period of record and the number of months in the statistical sample for every network for both summer and winter. These data, punched on cards, were the input for 44 separate runs of a computer program, or 44 separate multivariate statistical analyses. The computer program accomplishes a component analysis of the rainfall data using the method of principal components.

The first step in this method of multivariate statistical analysis is the computation of a matrix of simple correlation coefficients. Each element of the matrix is the simple correlation of the monthly rainfall at the two gages given by the intersection of the row and column that locates the element. The matrix is square with dimension equal to the number of gages in the net. It shows all possible between-gage relationships. The main diagonal contains all "ones", showing the self-correlation of each gage.

Table 2 is an example of such a correlation matrix. It is the correlation matrix for summer months for Coweeta Network "A" consisting of six raingages. The lowest correlation coefficient is 0.858 between gages 8 and 36. Such high values of the correlation coefficients mean, obviously, that rain does not fall independently at each gage, but rather, within some limits, like amounts fall at every gage. Wintertime correlation coefficients are always higher than summertime coefficients. This difference is due to uniform rainfall occurring over large areas during wintertime cyclonic rainfall conditions, and more variable rainfall over an area during summertime, convective, showery, rainfall.

Since the correlations between all gages are very high, any gage could be used to estimate with some reliability the rain at any other gage in the network. Stated another way, this correlation means that each gage does not represent an independent item of information about the rainfall. All the gages, compositely, represent some number of items of information, this number being less than the number of gages if all minor or trivial variations are discounted.

Component Analysis of Data

It is possible to isolate and define numerically the items of information which are present in the correlation matrix. An eigenvalue-eigenvector analysis of the correlation matrix will produce such results. In multivariate

Table 2

Correlation Matrix

Coweeta Network "A" - Summer

		Gage Number					
		8	10	35	36	50	54
Gage Number	8	1.000	0.920	0.874	0.858	0.873	0.908
	10	0.920	1.000	0.959	0.935	0.958	0.991
	35	0.874	0.959	1.000	0.978	0.989	0.969
	36	0.858	0.935	0.978	1.000	0.971	0.942
	50	0.873	0.958	0.989	0.971	1.000	0.972
	54	0.908	0.991	0.969	0.942	0.972	1.000

statistics such a process of analysis is called component analysis; each derived item of information is called a component. Mathematically, the process is the solution of a set of linear simultaneous equations shown in Equation 1.

$$\begin{array}{l} r_1 = a_{11}p_1 + a_{12}p_2 + a_{13}p_3 \quad \ldots + a_{1N}p_N \\ r_2 = a_{21}p_1 + a_{22}p_2 + a_{23}p_3 \quad \ldots + a_{2N}p_N \\ r_3 = a_{31}p_1 + a_{32}p_2 + a_{33}p_3 \quad \ldots + a_{3N}p_N \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ r_N = a_{N1}p_1 + a_{N2}p_2 + a_{N3}p_3 \quad \ldots + a_{NN}p_N \end{array} \qquad (1)$$

In this system of equations "r" is the standardized rainfall at each of N gages, the p's are components, and the a's are elements of eigenvectors which serve to transform the p's into the r's. The reverse is also true. That is, using p_1 as an example:

$$p_1 = a_{11}r_1 + a_{21}r_2 + a_{31}r_3 + \ldots + a_{N1}r_N \qquad (2)$$

Equation 2 can be considered a definition of the components. Theoretically, by this definition, there are always as many components as there are gages. But if the trivial components are discarded the number of p's will be less than the number of r's. The reversability holds true under the reduced number of components.

A particular method of solution is available, known as the method of principal components. This is an iterative method of eigenvector-eigenvalue analysis. The method of principal components cause the most important eigenvectors, (informationwise) to be located first. After this eigenvector is factored from the correlation matrix and the method repeated, the remaining most important vector is found. This process can be continued through N steps for a matrix based on N gages. However, as the number of vectors found approaches N the information content approaches zero, and the vectors may be poorly defined numerically because of the growth of rounding errors.

Since the eigenvectors are ordered in importance by the order of their appearance in the solution, the process can be stopped at any point with the assurance that only the more trivial elements remain hidden. Some method of judgement is needed to define this stopping point in a systematic manner. So far in this discussion the function of the eigenvalues has not been mentioned. Eigenvalues of a matrix correspond to the more familiar roots of a polynomial equation. One finds the roots of such an equation because each root is a solution of the equation, a definable point. The eigenvalues are the roots of the characteristic equation of the determinant of the correlation matrix, and for each such root there is an associated eigenvector, or solution vector. The solution is a definable vector of relationship across the N rainfall amounts, as opposed to the definable single point of the simple polynomial.

The method of principal components determines that solution first which is associated with the largest eigenvalue. The eigenvalues can be shown to be the variance of the associated eigenvectors. For the purposes of application here, the statistical variance of a quantity may be thought of as the information in that quantity. It is further known that the sum of the eigenvalues is equal to the dimension of the matrix, which is in turn N, the number of gages in the network. Then as vector after vector is found, the sum of the associated eigenvalues approaches N. This accumulating total with a known upper limit provides a convenient method for estimating the separation of the important and the trivial eigenvectors. Note that the ratio, I, in Equation 3 will approach unity as the number of eigenvalues, E, approachesN.

$$\frac{\Sigma E}{N} = I \qquad (3)$$

Then a ratio of $\Sigma E/N$ less than unity may be thought of as a simple percentage of the information in the total correlation matrix that is contained in the eigenvalues making up the total ΣE.

Eigenvalue Summary of Network Data

The computer program used in this analysis to process rainfall data contains a control parameter corresponding to the ratio I in Equation 3. This value was set high, about 0.99 for all 44 runs of the program. Inspection of the first results showed that most of the information, or variance, in the correlation matrix could be explained by the first four components. Consequently, it was decided to systematize the analyses by examining the first four eigenvectors of each data set. A few re-runs had to be made to bring the number of found vectors to four. For a few small networks only three vectors could be found.

Table 3 summarizes the 44 eignvalues. The separate eignvalues, E, and the ratio, I, based on the first four components are listed. For the research watersheds values of I range upward from 0.988 for winter data. Essentially all of the information in the winter data is therefore explainable by the first four components. The values of I for the summer data range upward from 0.973, only one and one-half percentage points lower than the wintertime ratios. The difference between summer and winter ratios is in the direction expected, but is very small. Values of I for the Georgia climatic network range much more widely than for the research watersheds. Values of I for wintertime range upward from 0.956 for the largest net of 31 gages to the limit of 1.000 for four gages transformed to four components. Only about five percent of information is lost therefore, in transforming the wintertime data from varying sized nets to four components. For summer data the ratios are much lower. Only about 77.3 percent of the information in the 31-gage net is included in four components. This summertime value of I also ranges upward to 1.000 for the four-gage net.

Inspection of Table 3 shows that most of the information is contained in the first eigenvector. The first component might be thought of as a measure of the average precipitation at each gage. The remaining components would then be indicative of departures from this average value at each raingage. Eigenvalue Number one for all 44 data sets has been plotted in Figure 1. The values for the research watersheds lie close to the 45-degree line defined by $\Sigma E = N$. Wintertime values are particularly close to this 45-degree line.

The eigenvalues for the Georgia network lie well below those for the research watersheds, with summer values far below. These points for the various sizes of the Georgia net have been connected by dashed lines in order to bring out the startling uniformity of the variation of the first eigenvalue with network size.

Figure 2 is an additional plot of data in Table 3. The ratio I for the first four eigenvalues has been plotted against the number of gages. Again most of the research watersheds lie close to the limiting value, 1.000. The Georgia net exhibits the same uniformity of variation as was found for the first eigenvalue. Some differences among the research watersheds, and between the research watersheds and the Georgia networks are possible of further explanation. Figure 3 is a plot of residual information, 1.000 - I, against the gage density parameter given in Table 1. This density was plotted on a logarithmic scale simply to spread the small values of the research watersheds. The number of gages in the net are shown near each plotted point, and some curved lines have been added to show the empirical dependence on gage number. It can be seen that for networks with gages more closely spaced than about one for each 0.5 square miles the residual information amounts to only 1.5 percent or less. For gages spaced more closely than about 0.1 square miles per gage the differences between summer and winter residual become insignificant. Above 1.0 square mile per gage the residual information appears to increase rapidly.

Components of Rainfall

In a previous section "Component Analysis of Data" the relationships of eigenvalues and eigenvectors of the matrix of correlation coefficients was described. The eigenvalues are the roots of the characteristic equations and the eigenvectors are the solutions corresponding to the roots. The elements of the eigenvectors are the coefficients of the set of linear transforming equations, Equation 1. The eigenvalues were additionally described as measuring the variance of the correlation matrix which is associated with each eigenvector. The four principal eigenvalues for each data set were summarized in the immediately preceding section. This section will present

TABLE 3

EIGENVALUES FROM RAINFALL ANALYSIS

Network	Season	Eigenvalues 1	2	3	4	Sum of Eigenvalues ÷ No. Gages
Coshocton, Ohio	Summer	6.874	0.084	0.020	0.011	0.998
	Winter	6.931	0.037	0.016		0.998
Coweeta "A", N.C.	Summer	5.701	0.189	0.068	0.025	0.997
	Winter	5.881	0.062	0.027	0.019	0.998
Coweeta "Active", N.C.	Summer	10.294	0.260	0.179	0.110	0.986
	Winter	10.890	0.053	0.023	0.011	0.998
Coweeta "B", N.C.	Summer	6.591	0.221	0.103	0.041	0.994
	Winter	6.923	0.050	0.011	0.007	0.999
Coweeta "C", N.C.	Summer	36.229	0.596	0.350	0.178	0.983
	Winter	36.825	0.427	0.156	0.124	0.988
Deer-Sloan, Mich., 16 Stn.	Summer	14.452	0.732	0.324	0.179	0.980
	Winter	15.553	0.153	0.080	0.045	0.989
Deer-Sloan, Mich., 22 Stn.	Summer	19.471	1.077	0.704	0.186	0.974
	Winter	21.375	0.153	0.133	0.076	0.988
Fernow, W. Va.	Summer	12.868	0.073	0.023	0.019	0.999
	Winter	12.900	0.026	0.023	0.015	0.997
Hubbard Brook, N.H., 5 Stn.	Summer	4.971	0.015	0.010		0.999
	Winter	4.964	0.019	0.009		0.998
Hubbard Brook, N.H., 8 Stn.	Summer	7.939	0.031	0.017		0.998
	Winter	7.913	0.042	0.027	0.009	0.999
Pigeon Roost Creek, Miss.	Summer	23.576	1.626	1.349	0.711	0.909
	Winter	29.362	0.280	0.094	0.062	0.993
Ralston Creek, Iowa	Summer	4.924	0.036	0.019	0.014	0.999
	Winter	4.922	0.045	0.015	0.013	0.999
Sleepers River, Vt.	Summer	11.474	0.658	0.339	0.174	0.973
	Winter	12.216	0.443	0.100	0.081	0.988
Tallahatchie River, Miss.	Summer	4.987	0.007			0.999
	Winter	4.993	0.006			1.000
Georgia, 4 Stn.	Summer	3.162	0.390	0.294	0.154	1.000
	Winter	3.843	0.108	0.035		0.996
Georgia, 8 Stn.	Summer	5.916	0.613	0.393	0.335	0.907
	Winter	7.383	0.383	0.082	0.048	0.987
Georgia, 12 Stn.	Summer	8.299	0.861	0.663	0.478	0.858
	Winter	11.020	0.507	0.120	0.087	0.978
Georgia, 16 Stn.	Summer	10.781	0.926	0.786	0.701	0.825
	Winter	14.472	0.824	0.151	0.123	0.973
Georgia, 20 Stn.	Summer	13.285	1.092	1.059	0.809	0.812
	Winter	17.825	1.071	0.212	0.174	0.964
Georgia, 24 Stn.	Summer	15.691	1.335	1.165	0.843	0.793
	Winter	21.338	1.219	0.310	0.226	0.962
Georgia, 28 Stn.	Summer	17.698	1.859	1.234	1.026	0.779
	Winter	24.697	1.557	0.340	0.248	0.959
Georgia, 31 Stn.	Summer	19.120	2.452	1.268	1.133	0.773
	Winter	27.261	1.664	0.421	0.302	0.956

more detail on the eigenvectors as components of rainfall.

Component to Rainfall Relationships

The basic component to rainfall relationship was presented in Equation 2 which described the reversability of the linear transformation brought about by the operation of the eigenvectors. Statistically, the a_{ij} of Equation 2, the elements of the eigenvectors, may be thought of as regression coefficients. Each such element shows one functional linear relation between one raingage and one component. Such linear functions are necessary to express or to compute the actual numerical transformation from rainfall variables to component variables. These regression coefficients have a disadvantage in that they are scale-dependent. This dependency means that the value of the coefficient depends on the units of measurement of the variables. In order to measure the degree of relationship the regression coefficients should be converted to correlation coefficients. Each such coefficient would measure the degree of relationship between one raingage and one component.

The conversion from regression to correlation coefficients in component analysis is simple. It is only necessary to multiply each element of an eigenvector by the square root of the associated eigenvalue, as in Equation 4.

$$\alpha_{ij} = a_{ij} \sqrt{E_j} \qquad (4)$$

The computer program used in this multivariate analysis of rainfall data provides output listings of all the component-raingage correlations. Tables A-1 through A-19, Appendix A, show these correlation coefficients for the first four components for all data sets. Table A-2, for example, contains the coefficients for Coweeta, North Carolina, Network "A". Table 2 gave as illustration the initial matrix of correlation coefficients between all raingages of the network. Table 2 shows that rainfall at every gage is highly related to rainfall at every other gage. The correlation coefficients in Table A-2 are quite different. Gage Number 8, for example, has correlations of approximately 0.928, 0.358, 0.102, and 0.019 with the four components. The squares of these coefficients total 0.999, meaning that substantially all of the variation in the data for raingage Number 8 is transferred into the four components. The information transferred from the other gages to the four components is likewise very high. This, obviously, is the measure in terms of individual gages, of the same transference of information measured in total by the eigenvalues of Table 3.

A great advantage of the transformation from gages to components is that the component correlation coefficients are additive. The geometrical meaning of this property is that the components are orthogonal, a general property of eigenvectors. One may now speculate that the orthogonal components can be more easily interpreted than the original inter-gage relationships. It is known that the components found are principal components. The complex mutual correlations of the natural rainfall have been separated into four independent components. If strong influences are at work, causing patterns in the natural correlations, the components may identify with these influences in recognizable manner.

Component Maps

Most of the component-rainfall correlations in Tables A-1 to A-19 were plotted on maps of the gage networks. One map is necessary for each component; four summer maps and four winter maps yielding a total of eight maps for each data set. The component-rainfall correlation coefficient is simply plotted at the site of the raingage with which it is associated. Figures B-11 to B-18 show the component maps for the Coweeta Network "C". Figures B-19 to B-26 show the component maps for the 31-gage Georgia network. Iso-correlation lines are readily drawn. The correlation patterns do not break down into random values at each gage. In the previous section it was shown that most of the information at an individual gage is transferred to the four components. The correlation maps show that the coefficients defining this transference form fields in the network space. This opens the possibility that the identification of the components can proceed by attempting to match the correlation fields with other fields of information, such as elevation or slope at each raingage.

Stability of Components

One additional property of the components should be investigated prior to any attempt to identify or to relate the components to the raingage network characteristics. This property concerns the stability of the components. Specifically, do the eigenvectors change radically in configuration from network to network? The analysis of the Georgia State Network in increments of four raingages was undertaken partly to answer this question.

Figures 4 through 7 are plots of the component-rainfall correlations for the Georgia Network. The correlation coefficients for the initial four-gage net are plotted against the number of gages in the initial and subsequent runs. Thus the correlations with the components can be traced as these initial four gages become part of the larger nets. The second and third four-gage increments are also traced.

Figure 4 shows that the relationship between the gages and component Number 1 changes very little as the network grows. Summer and winter relationships are both fairly stable. Component Number 1 should be a comparatively invariant characteristic of the networks. Figure 5 shows that component Number 2 is quite invariant for wintertime but not for summertime data. Figures 6 and 7 show that the components 3 and 4 are variable. It is noteworthy, however, that for networks of 20 gages and larger summer and winter relationships both stabilize. Perhaps gages must number four to five times the number of components in order to produce a statistical averaging which stabilizes the gage to component relationship.

Figure 8 has been included to show in some detail the instability evident in Figures 4 through 7. Figure 8 is a plot of the four component correlations for station Number 1, one of the initial four-gage network. It is evident in this illustration that components 2 and 3 have tended to invert their relative positions. Component 1 is stable. Component 4 is somewhat indeterminate in position, but tends to lie between components 2 and 3. Plots of other gages, not included in the report, show other patterns of inversion of components.

In summary, it must be stated that components 2, 3, and 4 cannot be considered invariant in relationship to the raingages. While this is bothersome, it is not necessarily insurmountable. It does mean that any physical characteristic at work in causation of rainfall patterns might find expression in different components, particularly in small networks. Since the first four principal components contain nearly all of the information in the small networks there is little chance that any meaningful physical effect would be excluded by the analysis.

RAINFALL COMPONENTS VS PHYSICAL CHARACTERISTICS

In the previous sections of this report it has been shown that inter-gage relationships for both summer and winter monthly rainfall amounts could be reduced to four othogonal components with little loss of information. These components, being independent, are additive. Therefore, the rainfall inter-gage patterns are predictable by simple summation of the components. What remains to be done is the establishment of relationships between the components and the physical properties of the geographical location of the raingage network. Such relationships can be used to predict the independent components of rainfall, based solely on the location of the net, and the total pattern of rainfall is simply the weighted sum of the components.

The various elements that were devised and evaluated in order to describe each network are listed and defined in the section "Definition of Network Characteristics". Additional information is given in the network base maps in the appendix, Figures B-1 through B-10.

Second Phase Component Analysis

The original intent in this study was to perform a second-phase component analysis. Numerically, this analysis would be similar to the rainfall component analysis. However, the rainfall component elements, the eigenvector elements, would have been statistically matched to the network characteristics by the second-phase analysis. The result would be second-order components, hopefully showing how each of the rainfall components is caused by some such physical element as land-surface slope or elevation, or combinations of such physical elements since they are not statistically independent.

It was not possible to perform the second-phase component analysis. The returns to the requests for existing information produced very few network data-sets of sufficient length and sufficient size to allow a reliable statistical analysis. Most networks had too few gages to form an adequate statistical sample. Consequently, simple graphical studies were undertaken as a first crude attempt to discover how the rainfall components might possibly be related to network physical characteristics.

Third-Phase Component Analysis

A third-phase component analysis had also been tentatively listed as the last stage in the network analysis. This third-phase analysis would have attempted the determination of differences in rainfall components between networks as opposed to the earlier discussion relating to within-networks variability of rainfall patterns. Such between-networks analysis is necessary to bring out component variations due to differing topographic and climatic conditions in which the various networks are located. This analysis could not be carried out because of the paucity of adequate and available rainfall data.

Graphical Relationships

Approximately 600 charts of rainfall components elements versus network characteristics were plotted. These charts are exemplified by Figures C-1 through C-7. Each chart represents one component, summer or winter, plotted against one of seven physical properties. The charts serve as first estimates whether a relationship exists between the gage-element of each rainfall component and some property such as elevation of the raingage.

It was not considered worth the cost and effort to establish models for complete statistical regression-type analyses of each of the charts. The initial need is to identify possible component-characteristic relations, not to establish precisely quantified relationships. Consequently each of the charts was rated subjectively by three persons. This rating noted simply whether a relation was evident in the scattering of points in the chart, whether there was no relation, or whether the situation was indefinite.

The difficulty in attempting complete statistical analysis of the charts is shown in some of those included in this report for illustration of possible relationships. Figure C-3, Appendix C, shows Component 3 vs elevation for Coweeta Network C. The winter component exhibits a definite positively sloped relation which is possible of testing for significance with straightforward simple linear regression study. However, the summer component is much more complex. The relation is still positively sloped, but appears to lie in separate bands. Figure C-6 shows Component 3 vs longitudinal distance from the centroid for the Georgia Network. The winter component shows a definite positively sloped relationship. Again, the summer component shows a complex relationship. Little slope is evident in the scattering of points, but the points do divide into two bands, one with a mean value of the component element near 0.16, the other with a mean near -0.16. Because of such variability in the 600 charts, no simple adequate statistical test, capable of unvarying application to all charts, could be devised.

Relationship Summary

The results of subjective rating of relationships are shown in Tables 4 and 5. In the preparation of these tables the scores on each chart were totalled for the three raters for all the networks. The ratings were totalled separately for no relation, indefinite relation, and apparent relation. These three subtotals were then converted to proportionate parts of the grand total. These proportionate parts are the information presented in Tables 4 and 5. Component totals and characteristic totals were also computed, converted to proportionate parts, and included in the tables.

The summer and winter result summaries are remarkably consistent. Two differences are evident and worth noting. Component 4 for the summertime seems to exhibit slightly more tendency toward apparent relationship than does wintertime Component 4. This is probably the result of greater variability of summer rainfall patterns and a consequent alignment of real information in the pattern with physical characteristics. Wintertime rainfall patterns are flat, and the wintertime Component 4 may tend to contain random rather than meaningful elements of the pattern.

The second noteworthy difference in the summertime and wintertime tables concerns the characteristic "distance from Centroid". In the summertime the total for this characteristic across all components indicates a reasonable possibility of relationship. A good portion of this possible relationship is to be found in the Component 1 and the Component 4 subtotals. The wintertime components on the other hand seem to offer only weak possibility of relationship with the distance characteristic.

In both the summer and winter summary tables it is evident that Components 2 and 3 provide the most consistent relationship with the network characteristics. Fairly strong relationships are evident for longitude, latitude, azimuth from centroid, and elevation. Component 1, which implies the average value of rainfall, relates only to latitudinal distance in the wintertime, and to distance from the centroid in the summer. As pointed out earlier, Component 4 is weak except for the relation to "Distance from the Centroid" in the summertime.

Examination of the total relationship exhibited across all components shows that "Slope Direction" is not a meaningful characteristic. The direction of slope of the land surface as defined in this study does not relate to any component, summer or winter. The second weakest characteristic is slope. This is also an almost meaningless characteristic except for the wintertime Component 2 possibility. The reason for the possible difference in wintertime and summertime effect of slope is not clear, one might speculate that more numerous occurrences of conditional atmospheric instability in the summertime should cause a relation between slope and summer components.

The summary Tables 4 and 5 must be considered very tentative. The seven physical characteristics listed are not independent; latitude, longitude, and distance being obviously related. Also, component relations to these characteristics are only other forms of the component fields exemplified by the component maps Figures B 11 through B 26. Slope and elevation of a point on the land surface are also usually correlated. The second-phase component analysis had been intended to overcome some of these non-independencies. This second-phase analysis was not possible due to the lack of data mentioned earlier.

TABLE 4

SUMMER RAINFALL COMPONENTS VS NETWORK CHARACTERISTICS

(FIGURES ARE PROPORTIONATE NUMBER OF RELATIONSHIPS IN EACH CATEGORY)

Component	Longitude			Latitude			Distance from Centroid			Azimuth from Centroid			Slope Direction			Slope			Elevation			Total		
	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A
1	.83	.11	.06	.70	.19	.11	.32	.27	.41	.57	.33	.10	.90	.07	.03	.72	.11	.17	.63	.23	.14	.66	.19	.15
2	.33	.17	.50	.28	.22	.50	.65	.22	.14	.30	.17	.53	.80	.13	.07	.56	.33	.11	.29	.32	.38	.45	.23	.32
3	.44	.17	.39	.33	.42	.25	.46	.31	.23	.27	.30	.43	.83	.10	.07	.66	.20	.14	.56	.14	.30	.50	.24	.26
4	.61	.21	.18	.69	.13	.08	.48	.27	.24	.64	.14	.22	.83	.14	.03	.73	.15	.12	.63	.10	.27	.66	.17	.17
All	.55	.16	.28	.51	.25	.24	.47	.28	.25	.44	.24	.32	.84	.11	.05	.66	.20	.14	.52	.20	.28			

N- No Relation I- Indefinite A- Apparent Relation

TABLE 5

WINTER RAINFALL COMPONENTS VS NETWORK CHARACTERISTICS

(FIGURES ARE PROPORTIONATE NUMBER OF RELATIONSHIPS IN EACH CATEGORY)

Component	Longitude			Latitude			Distance from Centroid			Azimuth from Centroid			Slope Direction			Slope			Elevation			Total		
	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A	N	I	A
1	.90	0	.06	.53	.17	.30	.54	.26	.20	.72	.14	.14	.86	.10	.04	.69	.28	.03	.69	.08	.23	.70	.15	.15
2	.20	.26	.54	.31	.17	.51	.82	.12	.06	.14	.17	.69	.76	.17	.07	.49	.20	.31	.38	.31	.31	.44	.20	.36
3	.63	.20	.17	.37	.23	.40	.43	.37	.20	.45	.21	.34	.76	.24	0	.72	.11	.17	.36	.44	.20	.53	.26	.21
4	.67	.21	.12	.69	.25	.06	.73	.15	.12	.67	.15	.18	.81	.15	.04	.85	.15	0	.70	.15	.15	.73	.17	.10
All	.61	.17	.22	.47	.20	.33	.63	.23	.14	.49	.17	.34	.80	.17	.03	.68	.19	.13	.52	.25	.23			

N- No Relation I- Indefinite A- Apparent Relation

RAINFALL INTERPOLATION

The design and utilization of rainfall networks depends ultimately upon the ability to interpolate for rainfall amounts between gages. The original intent in this study was to accomplish this interpolation by first estimating the elements of the four independent components at the point of interest from the physical characteristics at that point. These component elements multiplied by the numerical values of the components and summed would be a value of rainfall at the point in terms of a standardized variate.

While it has not been possible to accomplish the stated objective because of lack of data, it is felt that enough progress was made so that the computational process of interpolation by components should be reported and illustrated. One point value of rainfall will be interpolated for the Coweeta Network A for summertime.

Table 6 provides a guide for rainfall interpolation using components. Standardized rainfall values are taken from Table 2. Any vector in this matrix of correlation coefficients could serve as a set of possible rainfall amounts converted to standardized form. The vector used represents a situation with Gage Number 8 as a rainfall base with other gage amounts computed from it. It is necessary to use some such system of definition of the network rainfall. Since amounts at the gages are highly correlated independent gage amounts cannot be used.

The transforming coefficients in Table 6 are computed from the eigenvector elements in Table A-2 and the eigenvalues in Table 3. Equation 3 shows that the transforming coefficients are simply the eigenvector elements divided by the square root of the associated eigenvalue. Also Equation 2 shows that the numerical values of the components can be computed as the sum of the product of the transforming coefficients and rainfall. The four numerical values of the components for the given numerical values of network rainfall are shown in Table 6.

The four numerical components are actually the six rainfall values transformed into a coordinate space in such a manner that the four values are not related. For the simple illustration presented here the four numerical components are assumed to be fixed transforms of the given rainfall and that their values hold anywhere within the network space.

The maps of the component elements show that these elements form fields of information in the network space. From the maps one can read values of the elements anywhere in the network space. One value was read from each of the component maps for the Coweeta Network A. The point selected for this illustration was midway on the line connecting gages 50 and 54. The four values are noted in Table 6. Immediately below these values are shown the associated transforming coefficients.

The interpolated standardized rainfall at the selected point can now be computed as indicated by Equations 1. The product-summation of the transforming coefficients and the numerical components is the interpolated value, and is 0.897 for the selected point. Simple linear interpolation between the standardized values at the two points gives a lower value of 0.891.

What this simple illustration may fail to make clear are the potentialities of such a method of interpolation. First, the separate component values are independent. Therefore, the product 0.415 x 2.215 = 0.919 is the portion of the rainfall at the selected point due to the first component. Likewise, the product -0.104 x 0.153 = -0.016 is the portion of the total rainfall due to the second component. The effect of the two components is the sum of the two products: 0.919 + (-0.016) = 0.903. Component 2, as well as Components 3 and 4, thus tend to act as deviations from the mean standardized value given by Component 1.

The second point to emphasize is that it is not necessary to read the component elements from component maps as was done in this simple illustration. If it had been possible to define the component elements through relations to the physical characteristics, then the component elements would be directly and specifically determined by the physical characteristics at the point of interest.

The standardized value of rainfall interpolated as in this simple illustration can be converted to dimensions of real rainfall by multiplication by an appropriate standard deviation followed by addition of an appropriate mean value of rainfall. Such values of mean and standard deviation would need to be pertinent to the selected point at which interpolation is being made. However, the mean and standard deviation of the rainfall at the base gage, Gage Number 8 in the example could serve as first estimates. Opposed to the idea of de-standardization is the concept that criteria for network design are not dependent on rainfall values per se, but rather on variability of rainfall. The standardized values can serve to indicate patterns of rainfall which must be adequately sampled by raingages. Also, the separate contributions to the standardized total by the individual components could show the effect of local site characteristics.

TABLE 6

COWEETA NETWORK A - SUMMER RAINFALL INTERPOLATION

Gage Number	Standardized Rainfall	Transforming Coefficients for Components			
		1	2	3	4
8	1.000	.3886	.8245	.3902	-.1229
10	.920	.4127	.1342	-.5214	.4162
35	.874	.4133	-.2935	.1107	-.3014
36	.858	.4071	-.3674	.5474	.5897
50	.873	.4129	-.2834	.0154	-.6100
54	.908	.4142	.0270	-.5136	.0293
Numerical Component		2.215	0.153	0.024	-0.003
Component Element From Map		0.993	-0.045	-0.102	-0.043
Trans. Coef.		0.416	-0.104	-0.390	-0.272

CONCLUSIONS

Data analysis by methods of multivariate statistics has been shown to be a feasible initial step in rainfall network analysis. By means of one of the multivariate techniques, component analysis, most of the information contained in rainfall measured at up to 30 gages can be transformed into about 4 components which are independent of each other. Briefly, many inter-related measurements of rainfall can be reduced to a much smaller number of non-related numerical values. These orthogonal values are simply mathematical abstractions until their subsequent identification by association with other information.

The identification of components was only partially successful. It was found that the linear transforming system which converts rainfall values to component values formed "fields" when plotted on the network maps. Therefore, the components must bear a relation to the average inter-gage rainfall relationships, which are also "fields" in the network space. All component analyses in this study produced such "fields" of transforming coefficients for the four most important components derived. Not one analysis degenerated into random pattern. This very consistency of results lends weight to the feasibility of the multivariate techniques in rainfall analysis. The consistency provides strong assurance of stability of the derived intermediate information, the components, as subsequent attempts are made to achieve a higher level of information in the identification of the components.

The lack of full success was experienced in identification of the components. Some relationships between components and physical characteristics of the raingage network were found, but many potential relationships could not be supported. Study at this phase was seriously restricted by lack of data. It was not possible to obtain data from networks of many gages with long, stable records. Only such information could form a sound basis for second-phase analysis of the components and the isolation of clear component-characteristics relationships.

Optimum utilization of raingage network information, and efficiency in design of new networks had been postulated on the basis of identified components and the establishment of component characteristic relationships.

Rainfall could be interpolated for any point for which the physical characteristics were known and for which the component characteristics relations applied. Since identification failed, the end objectives of the project were not realized.

Difficulties encountered in this study were limitations of data and limitations of time. No results of analysis point to rejection of the basic concepts or the techniques employed. More study of the derived components would probably yield much more information than it was possible to bring out in this report.

It is hoped that the trial analysis of this study will be of value to other workers responsible for network evaluation. Specifically, it is hoped that the project leaders who supplied data for this study will find the initial results of value in possible better understanding of rainfall variability within their own networks.

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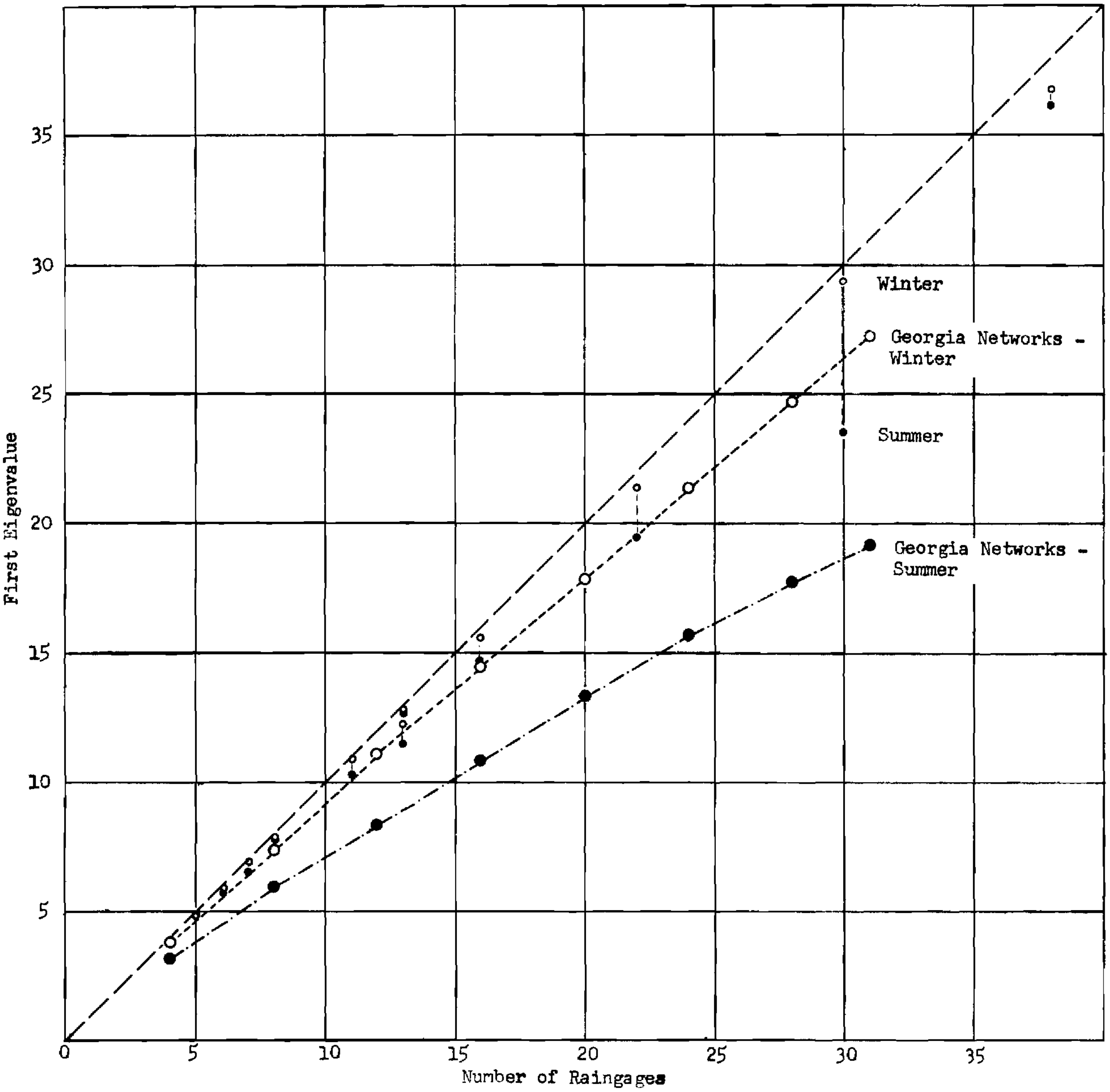


Figure 1. First Eigenvalue vs. Number of Raingages

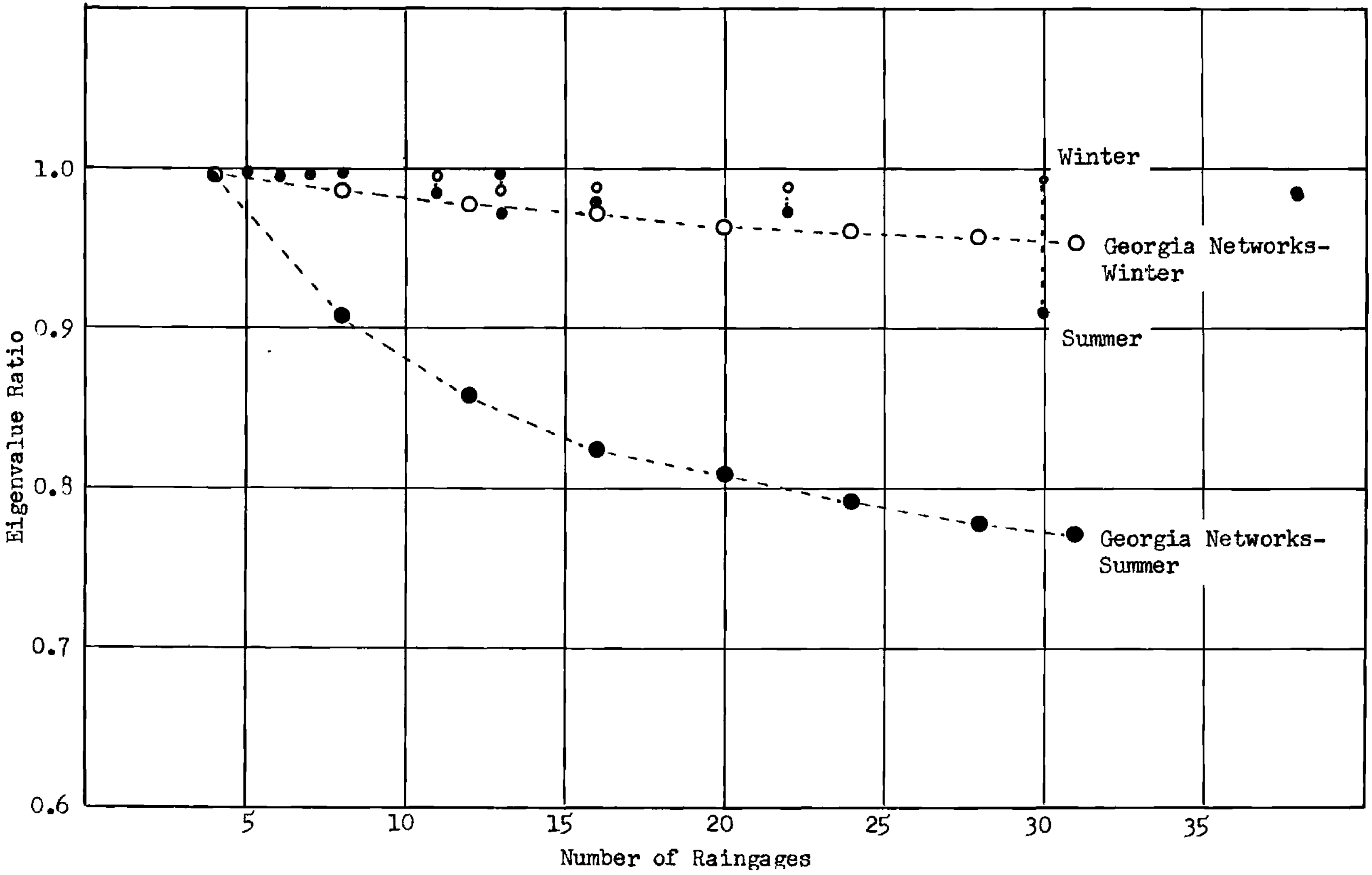


Figure 2. Ratio of Sum of First Four Eigenvalues to Number of Raingages

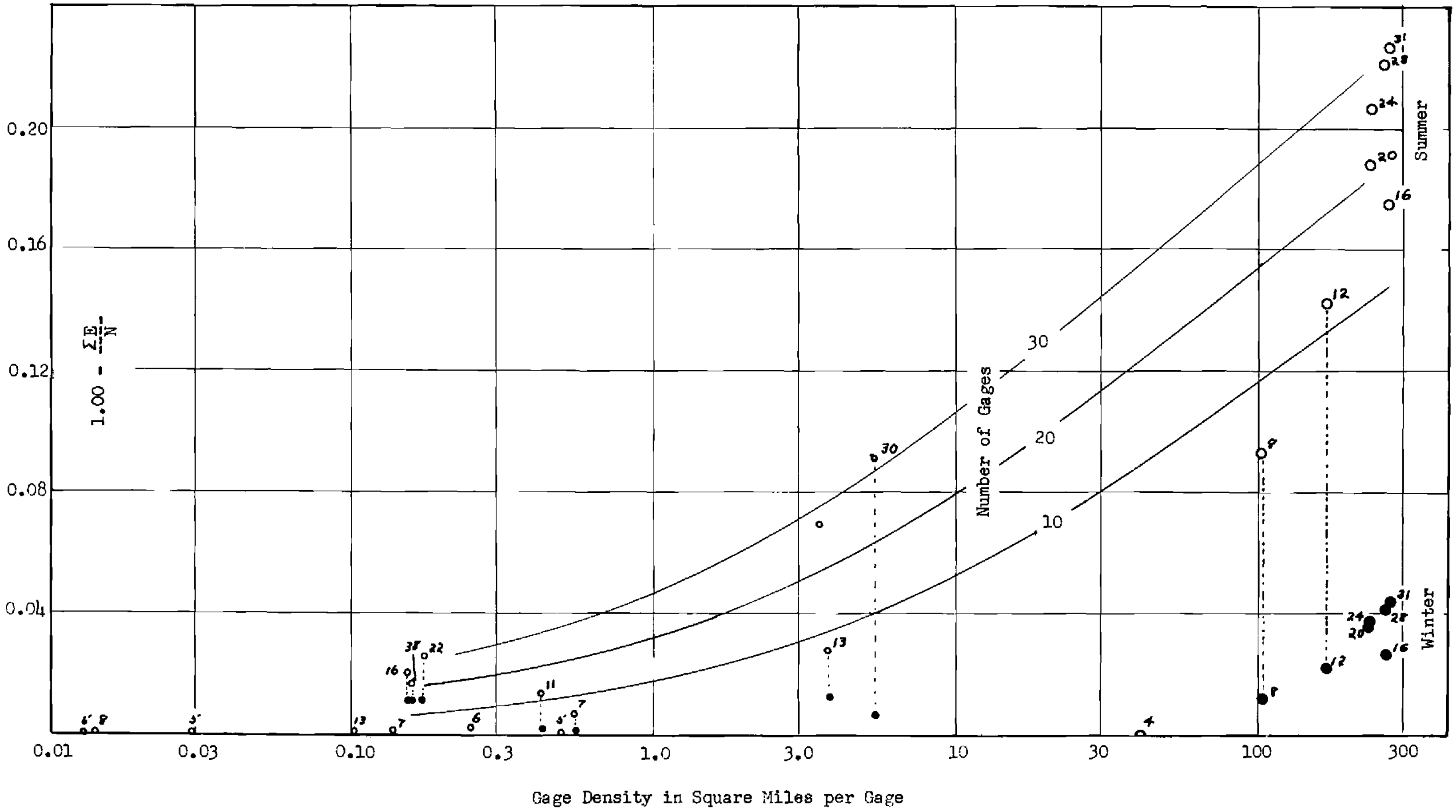


Figure 3. Residual Variance versus Gage Density

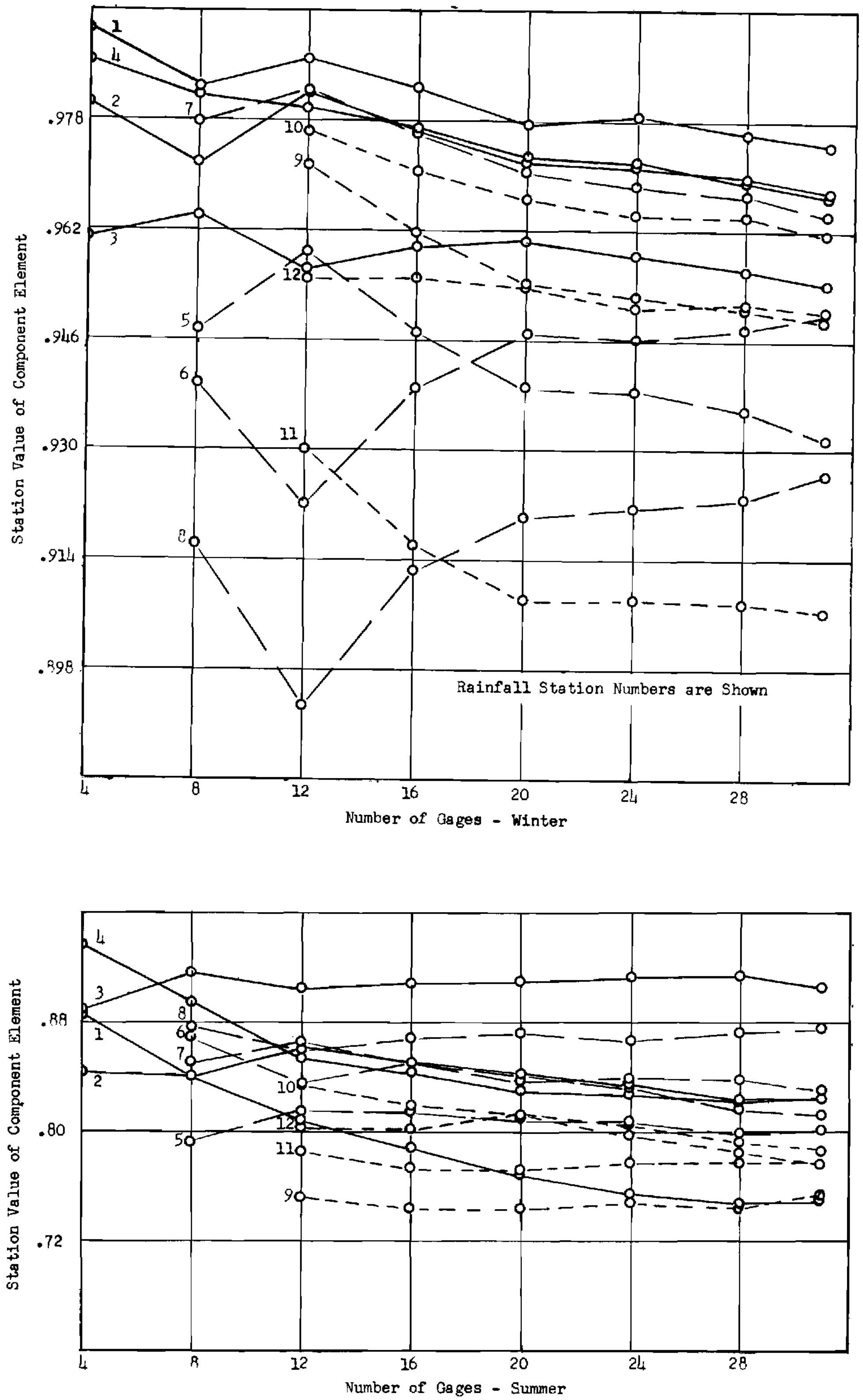


Figure 4. Values of Component 1 vs. Number of Stations in Georgia Net

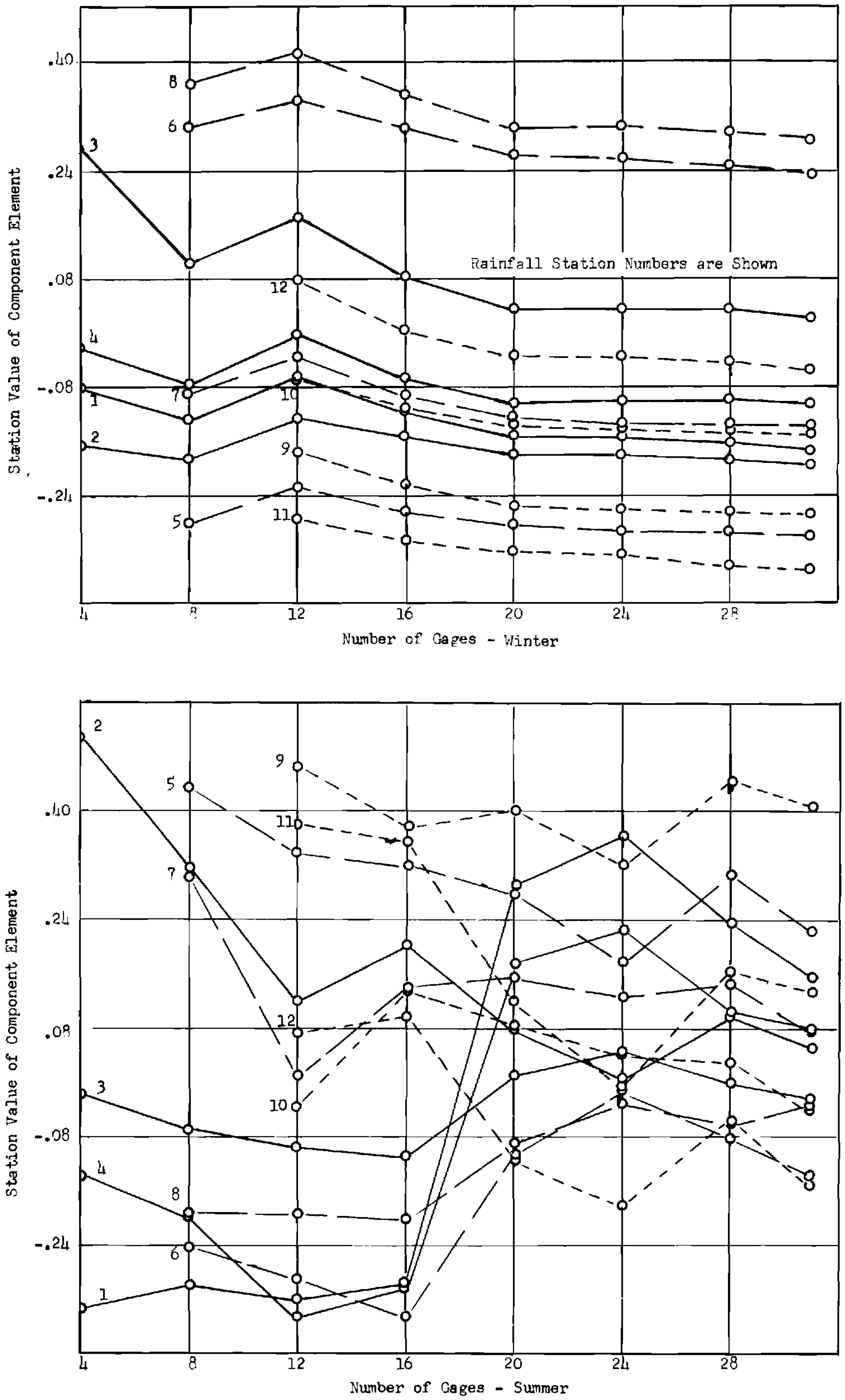


Figure 5. Values of Component 2 vs. Number of Stations in Georgia Net

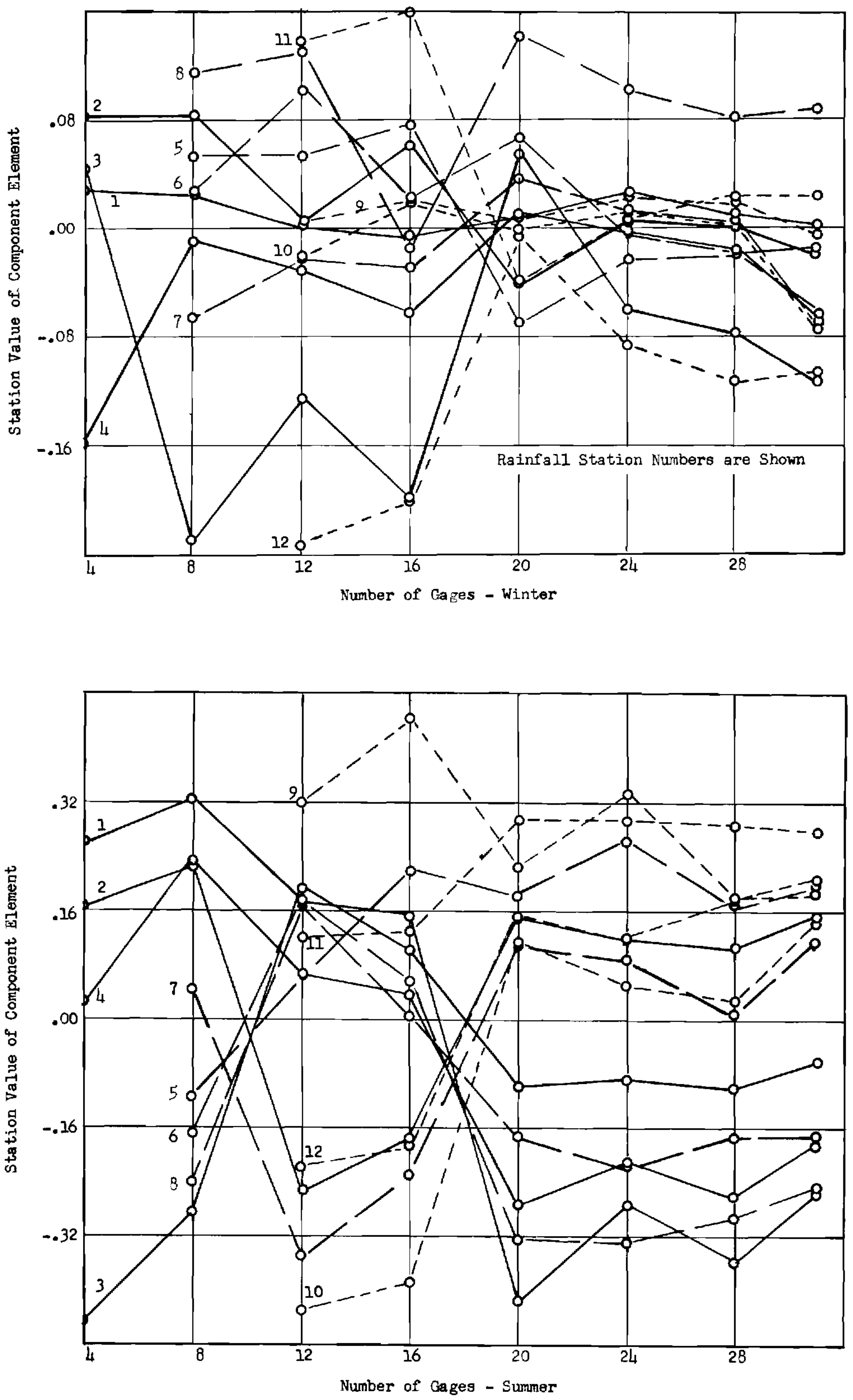


Figure 6. Values of Component 3 vs. Number of Stations in Georgia Net

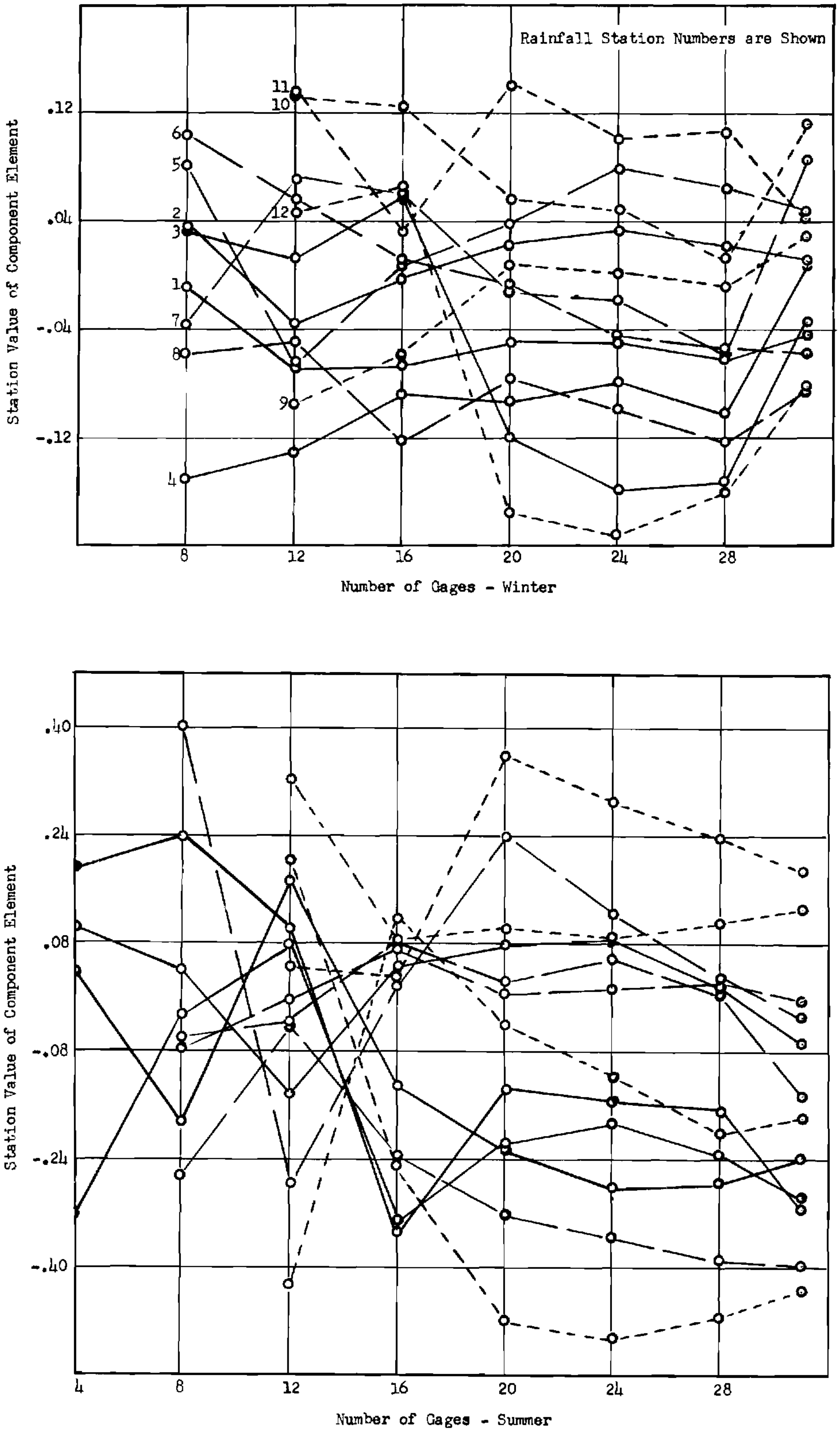


Figure 7. Values of Component 4 vs. Number of Stations in Georgia Net

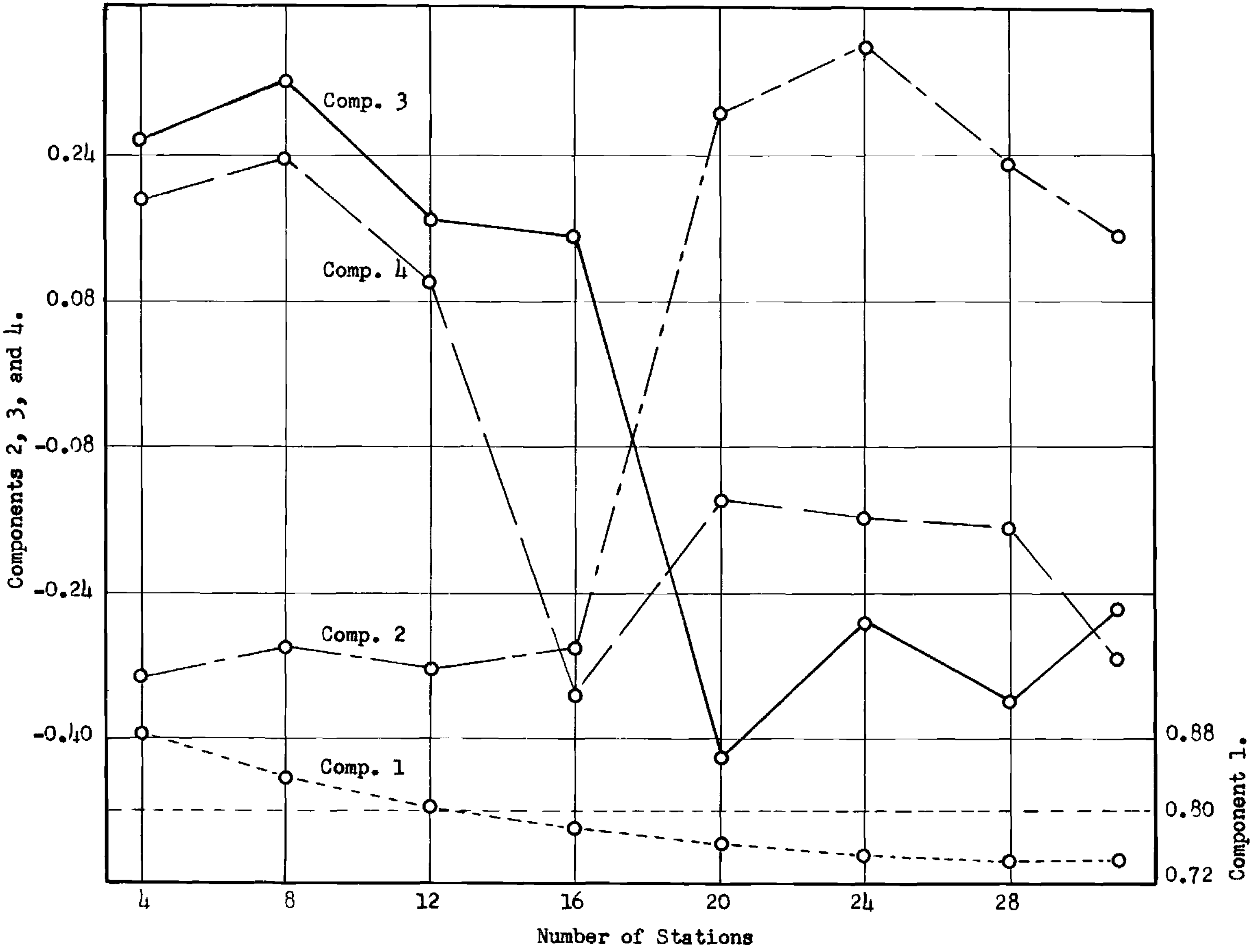


Figure 8. Components of Station Number 1 vs. Number of Stations in Net.

APPENDIX A

Tables of Component Elements

TABLE A-1

COSHOCTON, OHIO, NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
Y101	0.991535	-0.118076	-0.030509	0.020767	0.996615	0.055300	-0.024024	Not computed
Y102	0.995725	-0.072529	-0.005616	-0.016119	0.996085	0.036843	-0.067220	
Y103	0.993846	-0.072761	-0.072550	0.024395	0.997494	0.023136	-0.038144	
103	0.989397	-0.084836	0.115478	0.014950	0.995893	0.040723	0.058647	
108	0.993796	0.078968	0.008093	-0.066897	0.996241	0.011522	0.073587	
109	0.995442	0.067678	-0.020902	-0.036156	0.998133	0.006123	0.005462	
119	0.977093	0.203927	0.006293	0.059119	0.984852	-0.172578	-0.008213	

TABLE A-2

COWEETA, N. C., NETWORK "A"

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
8	0,927885	0.358162	0.101823	-0,019397	0,988639	-0,049875	0,134224	0,044711
10	0,985533	0.058300	-0.136039	0.065705	0,993834	-0,028610	0,017336	-0,089557
35	0,986971	-0.127487	0,028879	-0,047570	0,995763	-0,048861	-0,055355	0,033590
36	0,972098	-0.159594	0.142816	0.093085	0,993615	-0,056404	-0,067568	0,061747
50	0,985926	-0.123108	0,004007	-0,096287	0,994490	-0,040220	-0,026409	-0,060596
54	0,988938	0,011723	-0.134011	0,004633	0,973659	0,227763	-0,001702	0,010338

NETWORK "B"

Station	Summer 1	Summer 2	Summer 3	Summer 4	Winter 1	Winter 2	Winter 3	Winter 4
19	0,980166	-0,155382	0,070917	-0,075259	0,985687	-0.158969	-0.052608	-0,014729
101	0,985592	-0,102808	0,003351	0,041630	0,998263	-0.002776	0.013917	0,038494
45	0,917532	0,359154	0,170287	0,011416	0,997008	0.061253	0.002556	0,008571
29	0,975309	0,096741	-0,154093	-0,098801	0,993693	0.091951	-0.038810	0.035299
31	0,971163	0,099288	-0,191406	0,049096	0,993338	0.093172	-0.016102	-0,062630
69	0,981243	-0,121013	0,020852	0,133073	0,996009	-0.032500	0.075666	-0,015981
41	0,979588	-0,152223	0,087810	-0,060916	0.997543	-0.051930	0.018205	0.013273

TABLE A-3

COWEETA, N. C., NETWORK "ACTIVE"

Station	Summer Components 1	2	3	4	Winter Components 1	2	3	4
2	0,975311	0,076706	0,107138	-0,048425	0,995214	0,032237	0,060521	-0,022367
15	0,983204	-0,134473	-0,048202	0,043018	0,997443	-0,036823	0,031933	0,015870
19	0,983530	-0,137673	-0,059667	0,049485	0,985186	-0,150608	-0,060519	-0,054005
20	0,982697	-0,123942	0,008188	0,062818	0,995873	-0,039583	0,068823	0,008750
29	0,971450	0,140667	-0,028765	-0,144271	0,993457	0,097095	-0,003669	-0,041936
31	0,960776	0,151487	-0,102932	-0,175976	0,991408	0,099741	-0,069579	-0,001863
40	0,925927	-0,027998	0,366612	-0,010588	0,998045	0,008494	0,050386	-0,006442
41	0,980615	-0,126732	-0,072585	0,058223	0,997683	-0,047980	-0,016813	0,016129
45	0,907748	0,361693	-0,029663	0,209201	0,996090	0,066027	-0,031317	0,006758
69	0,978875	-0,080317	-0,090736	-0,010815	0,995390	-0,025901	-0,038132	0,069913
101	0,987596	-0,068362	-0,032848	-0,023365	0,998970	-0,002134	0,011461	0,014499

TABLE A-4

COWEETA, N. C., NETWORK "C"

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
6	0,935221	0,166477	0.167135	0,016498	0,991832	-0,032774	0.057462	0,021373
7	0,974025	0,162784	0.116567	0,001880	0,987826	-0,042666	0.090508	0,051124
8	0,934318	0,197271	0.059420	0,039258	0,989429	-0,034626	0.098561	-0,002100
9	0,980744	0,163008	0.051447	0,003519	0,992942	-0,041402	0.085978	-0,011255
10	0,977611	0,166739	-0.021668	0,007094	0,960324	-0,030034	0.052755	-0,016465
12	0,969112	-0,134629	0.132341	-0,067032	0,992751	0,011540	-0.076796	-0,015280
13	0,985035	-0,126157	-0.073124	0,038641	0,996314	-0,003433	-0.053662	0,005392
14	0,986699	-0,082620	-0.097598	-0,002715	0,997630	-0,005410	-0.024404	0,000072
15	0,987191	-0,116495	0.012239	-0,011173	0,997211	-0,001957	-0.042268	0,001169
16	0,983224	-0,110505	0.085540	-0,080817	0,995772	0,002557	-0.043896	0,000615
17	0,985752	-0,137632	0.041790	-0,004965	0,995731	0,003431	-0.063251	-0,005866
18	0,983854	-0,135928	0.052654	-0,034703	0,995911	0,006981	-0.071795	0,006017
19	0,984422	-0,126131	-0.044247	0,019847	0,988459	0,060971	-0.072462	-0,007434
20	0,979115	-0,143191	0.044686	-0,056661	0,996358	-0,000049	-0.049565	0,010408
21	0,974059	-0,140378	0.124632	-0,086745	0,768692	0,635994	0.066023	0,003615
22	0,986639	-0,101043	0.021239	-0,064910	0,941837	-0,027864	0.035324	0,303583
23	0,984875	-0,131880	0.017666	0,019929	0,993347	0,009117	-0.079681	-0,001378
24	0,985113	-0,109287	0.039693	-0,071287	0,996771	-0,009806	-0.025704	0,010645
29	0,969820	0,155455	0.135048	-0,010809	0,990306	-0,036692	0.100361	0,019132
31	0,962067	0,211796	0.075054	0,031005	0,989065	-0,045490	0.104733	-0,024965
32	0,895188	-0,140479	0.215905	0,334144	0,977283	0,018423	-0.135034	-0,007164
33	0,981658	0,129125	-0.079186	0,005438	0,995598	-0,021751	0.010995	-0,021017
34	0,980179	0,083746	-0.128090	0,012355	0,995353	-0,024480	-0.017537	0,008499
35	0,982842	-0,028625	-0.133168	0,016285	0,993345	-0,005716	-0.051804	-0,019240
36	0,971714	-0,100722	-0.092339	0,048875	0,991765	-0,001761	-0.058399	-0,027934
39	0,987036	-0,062276	-0.109661	0,015225	0,996057	-0,004802	-0.026136	-0,011143
40	0,970781	-0,034352	0.131936	-0,120131	0,992891	-0,010103	-0.001493	-0,001224
41	0,983257	-0,113764	-0.091642	0,054219	0,997721	-0,003285	-0.043493	-0,005443
42	0,980719	-0,118793	-0.096310	0,057406	0,997646	-0,005847	-0.040118	0,000940
45	0,989375	0,086976	0.054839	-0,028866	0,996309	-0,033765	0.062854	0,004002
47	0,989853	-0,016181	-0.034924	-0,059334	0,996642	-0,014605	0.011990	-0,013310
49	0,984016	0,071824	-0.118152	0,000658	0,998005	-0,018161	0.008378	-0,012351
50	0,985294	-0,029713	-0.134771	0,025524	0,995794	-0,010019	-0.031596	-0,002394
53	0,975991	0,094426	-0.139398	0,001913	0,998475	-0,023251	0.013471	-0,010873
54	0,982383	0,139232	-0.075967	-0,004832	0,958911	-0,025166	-0.021756	-0,074718
55	0,985023	0,134355	-0.025144	0,001255	0,996511	-0,029877	0.059155	-0,014091
56	0,987967	0,118744	0.028899	-0,012936	0,995482	-0,030837	0.054518	0,002896
60	0,975277	0,138885	-0.077594	-0,003687	0,947657	-0,037881	0.140496	-0,137087

TABLE A-5

DEER-SLOAN, MICH., 16-GAGE NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
1	0.910001	0.221174	0.262692	-0.175931	0.962241	0.253158	-0.034021	0.037735
2	0.923217	0.256384	0.262912	-0.042024	0.987553	0.068423	0.050109	0.067220
3	0.947426	0.238943	0.117372	0.061785	0.979106	0.151785	0.012688	-0.082577
4	0.940814	0.275799	0.007597	0.145148	0.973249	-0.033733	0.218634	-0.024297
5	0.941430	0.239548	-0.169378	0.116027	0.989671	0.037916	0.032291	-0.058561
6	0.932639	0.274430	-0.175779	0.096461	0.984902	0.043169	0.059755	0.117864
7	0.969859	0.011807	-0.200454	-0.078636	0.993067	0.019909	-0.050541	-0.033177
8	0.977599	-0.005106	-0.111877	-0.095411	0.991078	0.043235	-0.061040	-0.026084
9	0.982672	-0.084302	-0.045480	-0.110538	0.987771	-0.091814	0.029918	-0.060974
10	0.976566	-0.142313	-0.008729	-0.004654	0.990887	0.023044	-0.077310	-0.043292
11	0.936394	-0.274378	0.102690	0.128705	0.990597	-0.118892	-0.000965	-0.013183
12	0.917618	-0.256058	0.124003	0.158455	0.988294	-0.078178	-0.039205	-0.024566
13	0.944511	-0.287937	0.006525	0.070903	0.988550	-0.084992	-0.051962	0.041609
14	0.964989	-0.232313	0.010322	-0.059934	0.986369	-0.087913	-0.079860	0.054150
15	0.967130	-0.215579	0.022919	-0.065791	0.991568	-0.082761	-0.001382	0.022364
16	0.969186	0.005529	-0.175606	-0.129887	0.989758	-0.055848	-0.004858	0.026109

TABLE A-6

DEER-SLOAN BASINS, MICH., 22-GAGE NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
1	0.919686	0.230640	0.267324	0.111548	0.966512	0.198197	-0.125447	-0.020988
2	0.922756	0.248069	0.246547	-0.082748	0.987519	0.081331	0.006723	-0.086210
3	0.950604	0.239196	0.045122	-0.140437	0.984443	0.125376	-0.015972	-0.002462
4	0.953113	0.212390	-0.080299	-0.063127	0.974934	-0.028782	0.158250	-0.101600
5	0.934968	0.156336	-0.289894	0.018128	0.989772	0.062549	-0.017245	0.051667
6	0.929272	0.161552	-0.309342	0.022814	0.987500	0.011333	0.033821	-0.024435
7	0.960597	-0.055644	-0.214615	0.035724	0.991599	0.015553	-0.100990	0.013664
8	0.970236	-0.065122	-0.122456	0.036515	0.988065	0.019044	-0.106548	0.023901
9	0.980223	-0.124503	-0.012751	0.027872	0.986602	-0.082325	0.057450	0.049002
10	0.958423	-0.233118	0.011803	0.069644	0.988647	0.031341	-0.054197	0.110903
11	0.928741	-0.314101	0.130071	-0.036114	0.990833	-0.115656	0.005489	0.023605
12	0.910939	-0.250307	0.140630	-0.128943	0.989582	-0.069700	-0.032970	0.044334
13	0.927596	-0.335731	0.041020	0.018333	0.991604	-0.083927	-0.057442	-0.023494
14	0.954402	-0.262873	0.062800	-0.017031	0.984991	-0.097819	-0.036399	0.082042
15	0.954765	-0.242375	0.076524	0.007571	0.988751	-0.109221	-0.021352	-0.007034
16	0.964948	-0.032810	-0.176288	0.053269	0.986729	-0.079200	-0.069587	-0.086089
17	0.891823	0.197771	0.245619	0.298460	0.980860	0.086547	0.042106	-0.062086
18	0.924304	0.235867	0.275277	-0.036794	0.984715	0.049624	0.037333	-0.014066
19	0.938817	0.295512	0.064714	-0.135197	0.989941	0.011300	0.118750	0.009679
20	0.947349	0.235772	-0.126365	-0.024675	0.968678	0.087013	0.183780	0.115037
21	0.939333	0.026400	-0.288806	0.024127	0.995431	-0.028592	0.012981	-0.035147
22	0.929187	-0.302274	0.053363	-0.052195	0.987211	-0.078509	-0.015905	-0.060199

TABLE A-7

FERNOW, W. VA., NETWORK

Station	Summer Components 1	Summer Components 2	Summer Components 3	Summer Components 4	Winter Components 1	Winter Components 2	Winter Components 3	Winter Components 4
1	0.987490	-0.132968	-0.078144	-0.006862	0.997217	0.010054	0.019342	0.015453
3	0.992668	-0.113312	-0.000844	-0.021492	0.996705	0.045582	-0.010209	0.025347
5	0.995179	-0.037226	0.077966	-0.032872	0.995030	0.047152	0.016377	0.038714
7	0.997427	0.002602	0.063181	-0.017171	0.994364	0.070321	-0.068579	0.013649
10	0.997771	-0.048255	0.007696	0.014240	0.999005	0.002032	-0.012009	-0.003911
11	0.996522	0.007687	0.011886	0.076763	0.994382	-0.070729	-0.057105	-0.018176
12	0.997691	0.005789	0.036681	0.042924	0.995834	-0.026817	-0.037451	-0.066781
14	0.994774	0.060444	-0.025739	0.070429	0.994767	-0.077425	-0.024305	0.041687
15	0.996258	-0.081254	-0.007506	-0.007147	0.998081	0.013861	-0.005925	0.022977
18	0.994788	0.091173	-0.033073	-0.010278	0.997079	-0.034230	0.023552	0.025084
19	0.995288	0.088511	-0.009842	-0.018828	0.996461	-0.034349	0.067159	-0.001276
20	0.994590	0.081473	0.015136	-0.043583	0.995519	0.051316	0.006481	-0.065256
22	0.993181	0.075759	-0.053872	-0.044371	0.995432	0.003394	0.083393	-0.027065

TABLE A-8

HUBBARD BROOK, N. H., 8- AND 5-GAGE NETWORKS

Station	Summer Components 1	2	3	4	Winter Components 1	2	3	4
1	0.995894	-0.070941	0.041675	Not computed	0.994927	0.075508	0.026751	-0.029418
2	0.996435	0.056064	0.042309		0.994521	0.087156	0.005242	-0.028544
3	0.996960	0.023939	-0.048339		0.993911	-0.090567	0.010149	-0.054758
4	0.996466	-0.070494	0.032568		0.998149	0.047775	0.021208	0.005151
5	0.994842	-0.088969	-0.045176		0.989379	0.027855	-0.140836	0.019550
6	0.995259	0.035516	-0.077257		0.992302	-0.117472	-0.024312	0.005947
7	0.996299	0.080086	0.015699		0.996532	-0.053885	0.051005	0.029730
8	0.997202	0.036464	0.041254		0.996511	0.023811	0.052255	0.052905

Station	Summer Components 1	2	3	4	Winter Components 1	2	3	4
1	0.997397	0.039038	0.049967	Not computed	0.997494	0.058779	-0.009691	Not computed
2	0.995807	-0.083117	0.032837		0.997804	0.014159	0.005079	
3	0.996834	-0.047186	-0.058843		0.995270	-0.067741	0.068216	
4	0.998450	0.034264	0.025126		0.996503	0.070489	0.003451	
5	0.996848	0.059063	-0.048411		0.995039	-0.072943	-0.066827	

TABLE A-9

PIGEON ROOST CREEK, MISS., NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
1	0.811033	0.407484	-0.194106	0.134524	0.982605	0.140708	-0.051520	-0.090685
2	0.845004	0.417115	-0.141554	0.143408	0.986795	0.123106	-0.011180	-0.042764
3	0.837853	0.094025	0.295393	-0.249437	0.996845	0.002738	-0.005099	-0.023897
4	0.889140	-0.143456	-0.319012	-0.003595	0.991093	-0.010802	0.074781	-0.052594
5	0.901992	-0.178702	-0.156298	-0.241014	0.989985	-0.109394	0.008200	-0.033072
6	0.902163	-0.234245	-0.154699	-0.239054	0.988720	-0.108579	-0.002240	-0.055408
7	0.902023	-0.254390	-0.126806	-0.132989	0.992151	-0.088187	0.023343	-0.046253
8	0.939324	-0.112424	-0.007717	-0.046123	0.992758	-0.105624	-0.002856	-0.020030
9	0.870797	-0.182700	0.192048	0.311210	0.994158	-0.073993	-0.046817	-0.031975
10	0.848929	-0.331130	0.277557	0.239395	0.990380	-0.059806	-0.106153	-0.040744
11	0.897875	-0.188997	0.187508	-0.087008	0.992069	-0.063114	-0.059090	-0.013549
12	0.825929	0.332886	0.323942	-0.190268	0.990287	0.088017	0.049167	-0.051252
13	0.929623	-0.093922	0.122177	-0.012222	0.986303	-0.079299	0.094337	-0.012390
14	0.902600	0.207977	0.052691	0.053222	0.994340	0.015873	0.004485	-0.011154
15	0.910446	0.185133	-0.104611	0.167970	0.984414	-0.043313	0.141815	-0.039933
16	0.850414	0.372847	0.181266	0.011127	0.983838	0.133088	0.066770	0.040550
17	0.895886	0.317366	0.002872	0.103807	0.989090	0.127323	-0.000412	0.051160
18	0.899645	-0.217871	-0.262828	-0.030428	0.989917	-0.101529	-0.004194	0.045949
19	0.946982	-0.120403	0.044023	-0.020777	0.994595	-0.070232	0.001660	0.019920
20	0.906639	-0.216353	0.191740	0.243170	0.992999	-0.072527	-0.070850	0.040582
21	0.878128	-0.311110	0.230199	0.165158	0.990081	-0.040050	-0.103928	0.015152
22	0.861194	0.123352	-0.308161	0.157452	0.987051	0.129417	-0.004171	0.045724
23	0.853647	0.271153	0.206687	-0.284257	0.981874	0.151433	0.050598	0.023518
24	0.914024	-0.173528	0.195557	0.049614	0.991368	-0.014132	-0.078354	0.020816
25	0.932860	-0.033224	-0.015146	-0.136223	0.984318	-0.100287	0.005803	0.125566
26	0.923092	0.057830	0.200769	-0.105555	0.993788	-0.014204	0.017584	0.022851
27	0.800804	0.296076	0.090751	0.079493	0.973332	0.205132	-0.060727	-0.013082
28	0.847290	0.147953	-0.433823	0.018514	0.986672	0.136285	-0.014774	0.037053
29	0.939938	-0.101524	-0.223436	-0.037513	0.994557	-0.077839	0.042072	0.026753
30	0.903973	-0.168410	-0.313660	-0.032402	0.992437	-0.013228	0.042106	0.063211

TABLE A-10

RALSTON CREEK, IOWA, NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
1	0.991114	-0.071078	-0.110944	-0.016785	0.995699	-0.052546	0.042677	0.038667
2	0.990685	-0.095963	0.079305	-0.054927	0.993152	-0.061429	-0.087472	0.044339
3	0.994428	-0.027959	0.019940	0.096084	0.991569	-0.097693	0.011712	-0.083822
4	0.995162	0.067532	0.020466	0.012848	0.995091	0.049438	0.066229	0.033170
5	0.990267	0.127488	-0.008636	-0.036437	0.985549	0.162323	-0.032427	-0.031255

TABLE A-11

TALLAHATCHIE RIVER, MISS., NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
S-1	0.998330	-0.040279	Not computed	Not computed	0.999056	-0.039153	Not computed	Not computed
S-7	0.998043	-0.050834			0.998922	-0.043478		
S-11	0.999109	0.019134			0.999448	0.028737		
S-12	0.999201	0.031888			0.999496	0.028654		
S-13	0.998760	0.042127			0.999348	0.032861		

TABLE A-12

SLEEPERS RIVER, VT., NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
R-1	0.942136	-0.206013	-0.212609	-0.014949	0.864419	0.479342	0.011505	0.135548
R-2	0.942079	0.096742	-0.284306	0.028946	0.934742	0.319439	0.009051	-0.108618
R-7	0.967194	-0.200990	-0.030348	0.111227	0.983904	-0.071602	-0.046157	0.123961
R-10	0.961125	-0.131489	0.157136	-0.109744	0.987803	-0.123478	-0.031643	0.007441
R-11	0.868183	0.370964	0.237205	0.071607	0.976838	-0.118372	0.015539	-0.006170
R-12	0.961950	0.148241	0.080006	-0.134025	0.983997	-0.032003	-0.018788	-0.124663
R-15	0.963136	-0.044794	-0.088548	-0.150546	0.983565	0.089576	-0.037865	-0.094098
R-16	0.948768	-0.236636	-0.046606	-0.068553	0.983619	-0.056744	-0.110331	0.038375
R-17	0.929836	-0.171993	0.091215	0.272818	0.988880	-0.106455	-0.029404	0.057813
R-18	0.859540	0.459432	-0.138759	0.100125	0.957964	-0.038227	0.271943	-0.003978
R-19	0.971615	0.119493	-0.130478	-0.027113	0.988650	0.043398	-0.062072	-0.048162
R-23	0.951713	0.115602	0.197480	-0.101149	0.985017	-0.140429	-0.020213	-0.020825
R-24	0.938009	-0.250393	0.177278	0.046970	0.974822	-0.173404	0.058418	0.054374

TABLE A-13

GEORGIA 4- AND 8-GAGE NETWORKS

	Summer Components				Winter Components			
Station	1	2	3	4	1	2	3	4
0603	0.886377	-0.331176	0.259929	0.192596	0.991440	-0.080690	0.029510	
1585	0.841966	0.512127	0.164365	0.042490	0.980824	-0.163063	0.083574	
3295	0.888826	-0.013004	-0.445335	0.107217	0.961100	0.272072	0.045956	
9077	0.936571	-0.134725	0.028855	-0.322261	0.987032	-0.022228	-0.157660	
0603	0.838886	-0.296023	0.323301	0.238903	0.983052	-0.127339	0.026631	-0.008388
1585	0.838933	0.319673	0.225772	-0.186261	0.971894	-0.181486	0.085146	0.037872
3295	0.915635	-0.066951	-0.284728	0.001363	0.964329	0.104918	-0.228564	0.031813
9077	0.894364	-0.199465	0.235430	-0.024707	0.981437	-0.074739	-0.008415	-0.149972
9524	0.791373	0.436633	-0.113584	0.403910	0.947818	-0.280096	0.054057	0.081949
1675	0.868374	-0.241146	-0.167837	-0.057547	0.940024	0.308090	0.028157	0.105894
0181	0.850203	0.301549	0.042781	-0.265362	0.977986	-0.091353	-0.066036	-0.036607
3115	0.875591	-0.197422	-0.241277	-0.077034	0.916481	0.368697	0.115593	-0.059013

TABLE A-14

GEORGIA 12-GAGE NETWORK

	Summer Components				Winter Components			
Station	1	2	3	4	1	2	3	4
0603	0.808788	-0.320925	0.174555	0.105615	0.986956	-0.065891	0.002140	-0.069806
1585	0.861214	0.118537	-0.253004	0.174139	0.981933	-0.126150	0.006124	-0.034842
3295	0.901905	-0.097912	0.192245	-0.142489	0.956491	0.171970	-0.123706	0.013148
9077	0.852357	-0.350469	0.066048	0.077270	0.980190	-0.002038	-0.029206	-0.130141
9524	0.815806	0.339924	0.063119	-0.274397	0.958933	-0.223456	0.055008	-0.076083
1657	0.835271	-0.292813	0.175729	-0.036393	0.921892	0.346633	0.103401	0.057603
0181	0.863776	0.006899	-0.349197	-0.042765	0.982201	-0.032839	-0.022129	0.071841
3115	0.858484	-0.199211	0.169889	-0.005097	0.892526	0.412649	0.130857	-0.048256
2408	0.751036	0.467875	0.317399	0.045767	0.971662	-0.175079	0.008346	-0.093934
1670	0.834071	-0.037020	-0.424660	0.206492	0.976804	-0.069407	-0.022219	0.132390
6407	0.784670	0.381327	0.118872	0.326840	0.930273	-0.272685	0.138712	0.136616
4854	0.800648	0.070878	-0.216153	-0.424987	0.954956	0.079866	-0.230471	0.047308

TABLE A-15

GEORGIA 16-GAGE NETWORK

	Summer Components				Winter Components			
Station	1	2	3	4	1	2	3	4
0603	0.787379	-0.298515	0.153689	-0.347636	0.982858	-0.119487	-0.004979	-0.066147
1585	0.851116	0.200739	-0.175386	-0.130066	0.976688	-0.152900	0.063101	-0.003424
3295	0.907162	-0.112853	0.102349	0.046262	0.959603	0.080677	-0.197280	0.058055
9077	0.840339	-0.265257	0.033510	-0.333912	0.976838	-0.066886	-0.061914	-0.087931
9524	0.814021	0.317172	0.219147	0.017830	0.947121	-0.261341	0.077135	0.008771
1657	0.850290	-0.352046	0.054835	0.079892	0.938821	0.306672	0.023031	0.012760
0181	0.850343	0.139270	-0.229026	-0.233811	0.976636	-0.094840	-0.028087	0.060132
3115	0.867800	-0.207024	0.004465	0.071419	0.912276	0.352095	-0.015077	-0.122349
2408	0.741761	0.375204	0.442390	0.028811	0.961745	-0.224304	0.020197	-0.058229
1670	0.817856	0.131828	-0.386728	-0.254020	0.970865	-0.113219	0.019799	0.127014
6407	0.772343	0.350894	0.128415	0.080644	0.916337	-0.304252	0.160232	0.032556
4854	0.803021	0.091502	-0.189758	0.115270	0.955294	0.001919	-0.202457	0.066072
7430	0.812897	-0.266863	0.024744	0.331958	0.920964	0.329516	0.049274	0.093916
2475	0.846080	-0.047212	0.304350	-0.026072	0.967090	0.002020	-0.013267	-0.220456
8600	0.781058	0.187859	-0.325406	0.222853	0.979122	-0.110636	-0.026950	0.067668
2493	0.773607	-0.166823	-0.141052	0.370897	0.866665	0.450752	0.162590	0.036052

TABLE A-16

GEORGIA 20-GAGE NETWORK

	Summer Components				Winter Components			
Station	1	2	3	4	1	2	3	4
0603	0.768216	0.289079	-0.416456	-0.133896	0.977445	-0.154294	0.009728	-0.048415
1585	0.840381	0.072159	0.149486	-0.226473	0.971763	-0.177384	-0.042623	0.022916
3295	0.909466	0.009540	-0.096628	0.077436	0.960755	0.035813	0.056988	-0.119902
9077	0.829522	0.175212	-0.271701	-0.217223	0.972721	-0.101008	0.010927	-0.090617
9524	0.807367	0.275429	0.185242	0.238229	0.938962	-0.285300	-0.068404	0.039451
1657	0.840324	-0.112769	-0.322213	0.022509	0.946956	0.264812	0.069639	-0.006149
0181	0.835524	0.150623	0.109579	-0.325141	0.970582	-0.126316	0.037833	-0.010328
3115	0.871852	-0.901099	-0.170807	0.005140	0.920185	0.303889	0.142276	-0.075198
2408	0.741423	0.400073	0.224414	0.359414	0.954200	-0.257849	0.008680	0.009084
1670	0.807630	0.077357	0.112020	-0.479169	0.966439	-0.139682	-0.001489	0.058492
6407	0.770463	0.114335	0.295848	0.101817	0.908380	-0.323071	-0.041417	0.142599
4854	0.808945	-0.117442	0.151796	-0.040572	0.953578	-0.036522	-0.005188	-0.174932
7430	0.822412	-0.280782	-0.247248	0.162245	0.933022	0.307518	-0.108063	-0.018666
2475	0.832878	0.216967	-0.179268	0.204675	0.960529	-0.046056	0.142102	-0.120605
8600	0.794953	-0.192193	0.316009	-0.108914	0.975649	-0.137884	-0.060683	-0.031159
2493	0.790768	-0.315555	-0.087416	0.100129	0.882289	0.432253	0.039007	0.108891
2429	0.847978	-0.266472	0.207594	0.208393	0.929665	0.235253	-0.223448	-0.045522
3621	0.805593	0.236741	0.210108	0.015560	0.911541	-0.226917	0.150094	0.151553
0746	0.829079	-0.133990	-0.304811	0.118911	0.902966	0.347805	0.115291	0.172688
7600	0.723950	-0.502973	0.215491	-0.069974	0.935807	0.150073	-0.225761	0.068001

TABLE A-17

GEORGIA 24-GAGE NETWORK

	Summer Components				Winter Components			
Station	1	2	3	4	1	2	3	4
0603	0.754734	0.361860	-0.268975	-0.154506	0.978630	-0.153191	0.027673	-0.049934
1585	0.834742	0.000468	0.115006	-0.281309	0.971109	-0.180701	0.005751	0.032891
3295	0.912137	0.044187	-0.087493	0.084468	0.958390	0.035985	-0.058903	-0.158863
9077	0.827735	0.224085	-0.207143	-0.184066	0.971942	-0.100525	-0.002055	-0.079175
9524	0.807466	0.175707	0.265265	0.123938	0.938572	-0.292685	-0.022323	0.079485
1657	0.839227	-0.015376	-0.329466	0.057849	0.946032	0.258483	-0.002519	-0.045163
0181	0.832990	0.126973	0.089884	-0.354215	0.968658	-0.133296	0.013880	-0.018379
3115	0.867185	-0.033544	-0.215311	0.011781	0.921518	0.308460	0.102208	-0.099366
2408	0.747381	0.319299	0.334814	0.291365	0.952575	-0.261362	0.023827	0.001835
1670	0.797897	0.039106	0.051159	-0.504205	0.964399	-0.144440	0.011288	0.050133
6407	0.777957	-0.013657	0.297368	0.083272	0.908574	-0.328070	0.006135	0.101254
4854	0.805130	-0.182222	0.114913	-0.116277	0.950688	-0.037648	-0.085559	-0.190787
7430	0.815238	-0.162789	-0.330685	0.151740	0.931762	0.297416	-0.133351	0.011896
2475	0.831617	0.306368	-0.114483	0.170263	0.961428	-0.039813	0.137861	-0.152039
8600	0.782642	-0.271634	0.176355	-0.188404	0.975551	-0.142008	-0.058745	-0.010168
2493	0.783615	-0.218878	-0.223630	0.066765	0.883698	0.427298	0.053617	0.099111
2429	0.851553	-0.324145	0.123555	0.164499	0.930635	0.223115	-0.221714	0.029041
3621	0.809143	0.198589	0.286709	-0.007236	0.911593	-0.220055	0.107496	0.034145
0746	0.820370	0.025332	-0.352223	0.105961	0.904382	0.347335	0.116504	0.122376
7600	0.738652	-0.523934	0.033211	0.009322	0.936238	0.140202	-0.198521	0.134369
7610	0.816069	-0.373988	0.152217	0.055490	0.956399	0.092111	-0.192428	-0.065395
3147	0.756398	0.033221	0.316149	0.150338	0.934243	-0.270598	-0.037107	0.176847
0969	0.802123	-0.115931	-0.170086	0.148047	0.902367	0.272171	0.239938	0.113419
2006	0.770444	0.388304	0.024941	0.130124	0.961964	-0.027134	0.183044	-0.083171

TABLE A-18

GEORGIA 28-GAGE NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
0603	0.749185	0.231806	-0.358092	-0.167072	0.976169	-0.163585	0.012029	-0.062317
1585	0.822116	0.096172	0.108777	-0.271362	0.969638	-0.187323	-0.000610	0.020835
3295	0.913534	-0.002460	-0.099690	0.015428	0.956488	0.035453	-0.075600	-0.150626
9077	0.820738	0.096287	-0.259777	-0.231177	0.969287	-0.099295	-0.013771	-0.101556
9524	0.798787	0.309118	0.165423	0.029475	0.935720	-0.293018	-0.019262	0.065972
1657	0.838026	-0.082748	-0.291709	0.004284	0.947406	0.247674	-0.015605	-0.054114
0181	0.816669	0.146590	0.006599	-0.388118	0.967408	-0.133054	0.007749	-0.058253
3115	0.872496	-0.065256	-0.170403	0.026874	0.922769	0.297466	0.083225	-0.123308
2408	0.745565	0.444378	0.177278	0.236678	0.950669	-0.261832	0.018319	-0.008274
1670	0.785001	0.030365	0.027980	-0.473603	0.964290	-0.147415	0.004158	0.010399
6407	0.777732	0.161330	0.283684	0.110123	0.908002	-0.344061	0.025393	0.108061
4854	0.792846	-0.059718	0.173688	-0.200750	0.951168	-0.044686	-0.110818	-0.160335
7430	0.817760	-0.173970	-0.245748	0.128760	0.933158	0.289183	-0.144014	0.025683
2475	0.825339	0.228997	-0.230028	0.027812	0.959913	-0.049698	0.099215	-0.187989
8600	0.782302	-0.195075	0.281252	-0.214578	0.974711	-0.148660	-0.063503	-0.002626
2493	0.793010	-0.253903	-0.156242	0.079576	0.888272	0.420901	0.055632	0.073673
2429	0.856041	-0.202445	0.225887	0.107463	0.932085	0.210161	-0.219016	0.076066
3621	0.803701	0.257246	0.208463	-0.065518	0.912131	-0.219856	0.136339	0.070754
0746	0.827472	-0.040155	-0.327087	0.123524	0.908960	0.350029	0.144482	0.090223
7600	0.753051	-0.447937	0.224164	0.076650	0.935867	0.139263	-0.174352	0.128712
7610	0.824662	-0.248120	0.266933	0.078299	0.955125	0.080720	-0.189879	-0.026511
3147	0.759120	0.130398	0.314277	0.090604	0.933416	-0.272372	-0.012426	0.163678
0969	0.812189	-0.142103	-0.109734	0.161936	0.903466	0.263386	0.239456	0.055584
2006	0.761638	0.354940	-0.127797	0.030358	0.959936	-0.046059	0.155356	-0.120800
7489	0.781964	-0.275073	-0.123154	0.183747	0.896571	0.333539	0.160145	0.081598
1732	0.781430	-0.201283	0.191347	0.086961	0.941691	-0.167790	-0.022767	-0.040244
8436	0.800116	-0.409283	-0.099386	0.200242	0.925345	0.314406	-0.104916	0.046390
5633	0.445902	0.653606	0.026923	0.395651	0.907644	-0.331438	0.054133	0.121115

TABLE A-19

GEORGIA 31-GAGE NETWORK

Station	Summer Components				Winter Components			
	1	2	3	4	1	2	3	4
0603	0.750480	0.154655	-0.253689	-0.309150	0.974309	-0.174766	0.001203	-0.041964
1585	0.822185	0.049730	0.156518	-0.236785	0.967676	-0.195067	-0.020378	0.012661
3295	0.906930	-0.021231	-0.057484	-0.064010	0.954123	0.025128	-0.113291	-0.033676
9077	0.823356	0.076855	-0.182712	-0.294300	0.966308	-0.106911	-0.066790	0.008165
9524	0.800345	0.224943	0.199477	-0.029189	0.931577	-0.300223	-0.061826	0.047241
1657	0.829754	-0.138292	-0.245907	-0.141889	0.949492	0.237274	-0.013777	-0.057754
0181	0.811360	0.076992	0.118986	-0.398114	0.964322	-0.137837	-0.068788	0.086813
3115	0.875239	-0.037332	-0.170084	-0.005549	0.926530	0.284553	0.088780	-0.085090
2408	0.754588	0.404790	0.185263	0.187425	0.948732	-0.268041	-0.004779	0.029228
1670	0.776335	-0.040154	0.146670	-0.431798	0.961173	-0.150782	-0.072737	0.113493
6407	0.775480	0.128148	0.279212	0.133808	0.906208	-0.349494	0.023131	0.041094
4854	0.785775	-0.154495	0.212794	-0.175295	0.949661	-0.053138	-0.103817	-0.081011
7430	0.813233	-0.191917	-0.253785	0.033617	0.933281	0.276991	-0.135307	-0.089038
2475	0.834167	0.228242	-0.196104	-0.081296	0.961503	-0.060278	0.111303	-0.091809
8600	0.771391	-0.232001	0.314981	-0.101095	0.972417	-0.159516	-0.069237	-0.029438
2493	0.788500	-0.256942	-0.177447	0.052381	0.892983	0.415215	0.042711	0.020987
2429	0.851917	-0.246517	0.179448	0.154605	0.931693	0.195880	-0.167615	-0.156690
3621	0.803834	0.238960	0.272120	-0.029201	0.912438	-0.219027	0.093968	0.141295
0746	0.835316	-0.024447	-0.351187	0.043143	0.912416	0.350704	0.060430	0.172193
7600	0.748792	-0.396437	0.137124	0.223341	0.933300	0.131694	-0.214990	0.028113
7610	0.815015	-0.296121	0.226764	0.135976	0.953768	0.067743	-0.155848	-0.139804
3147	0.755444	0.075371	0.330817	0.110714	0.930670	-0.276732	-0.049186	0.095643
0969	0.812619	-0.116300	-0.149448	0.130425	0.908371	0.254937	0.205682	0.051942
2006	0.769756	0.363791	-0.079593	-0.052694	0.962496	-0.059456	0.175295	-0.084326
7489	0.779574	-0.262404	-0.169204	0.160667	0.900366	0.337973	0.066934	0.205724
1732	0.777444	-0.196995	0.164986	0.168191	0.939639	-0.170999	-0.057296	0.050866
8436	0.797793	-0.380333	-0.180020	0.219266	0.926863	0.305391	-0.099380	-0.047050
5633	0.471630	0.663669	-0.026642	0.290812	0.907457	-0.340474	0.088701	-0.009295
2283	0.645035	0.597042	-0.069224	0.262108	0.921701	0.020547	0.232113	-0.166141
4802	0.768542	-0.324839	-0.152683	0.175172	0.925197	0.306117	0.058950	0.171844
8746	0.679462	0.507707	-0.178797	0.084373	0.935401	-0.125526	0.251676	-0.143842

APPENDIX B

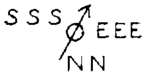
Base Network Maps

Coweeta Network "C" Component Maps

Georgia Component Maps

APPENDIX B
(Con't)

Georgia Component Maps



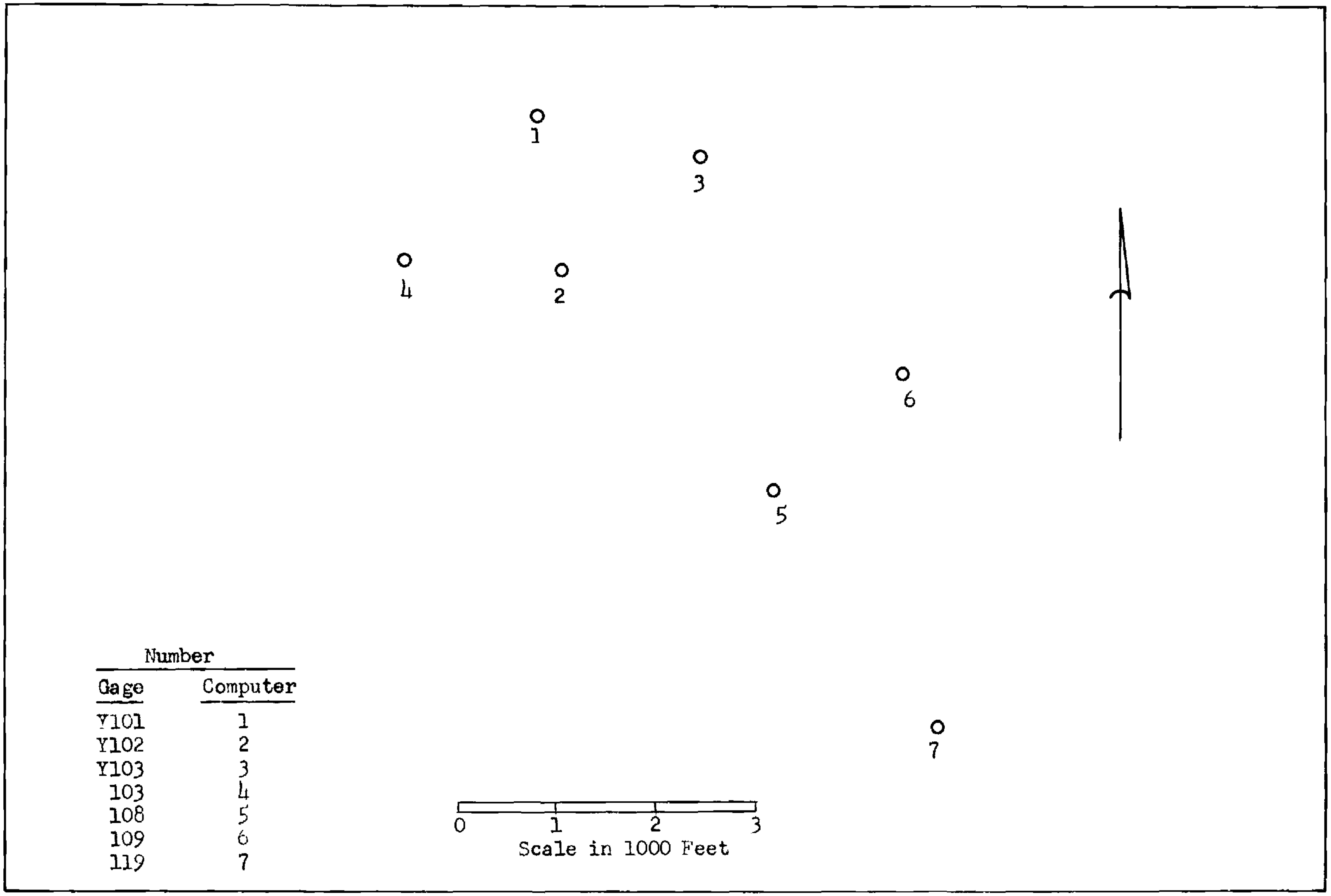
⌀ — STATION LOCATION AND DOWNSLOPE DIRECTION

NN — STATION NUMBER

EEE — ELEVATION ABOVE SEA LEVEL IN FEET

SSS — SLOPE IN FEET PER MILE

LEGEND FOR BASE MAPS OF NETWORKS



Number	
Gage	Computer
Y101	1
Y102	2
Y103	3
103	4
108	5
109	6
119	7

Figure B1. Coshocton, Ohio Network

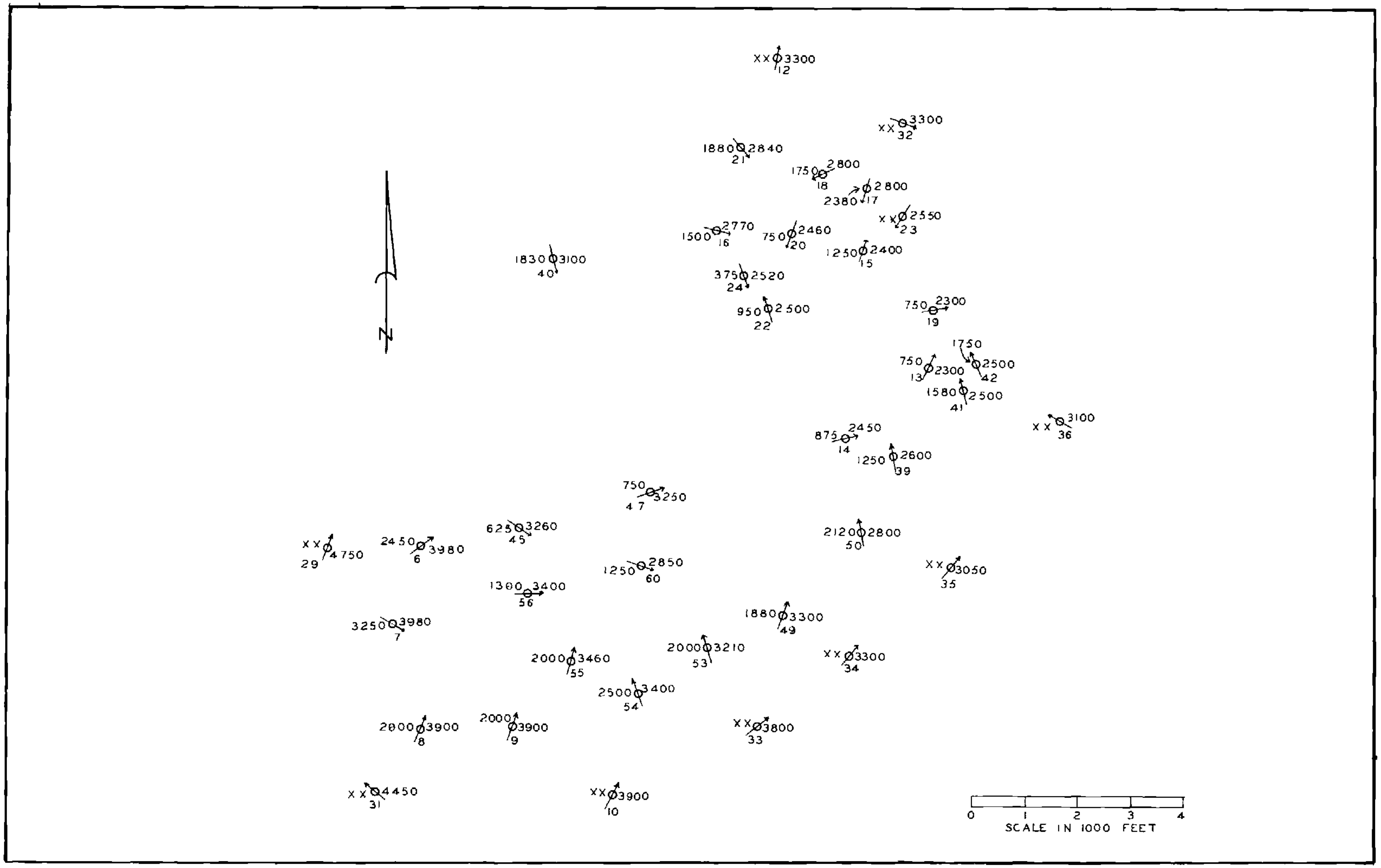
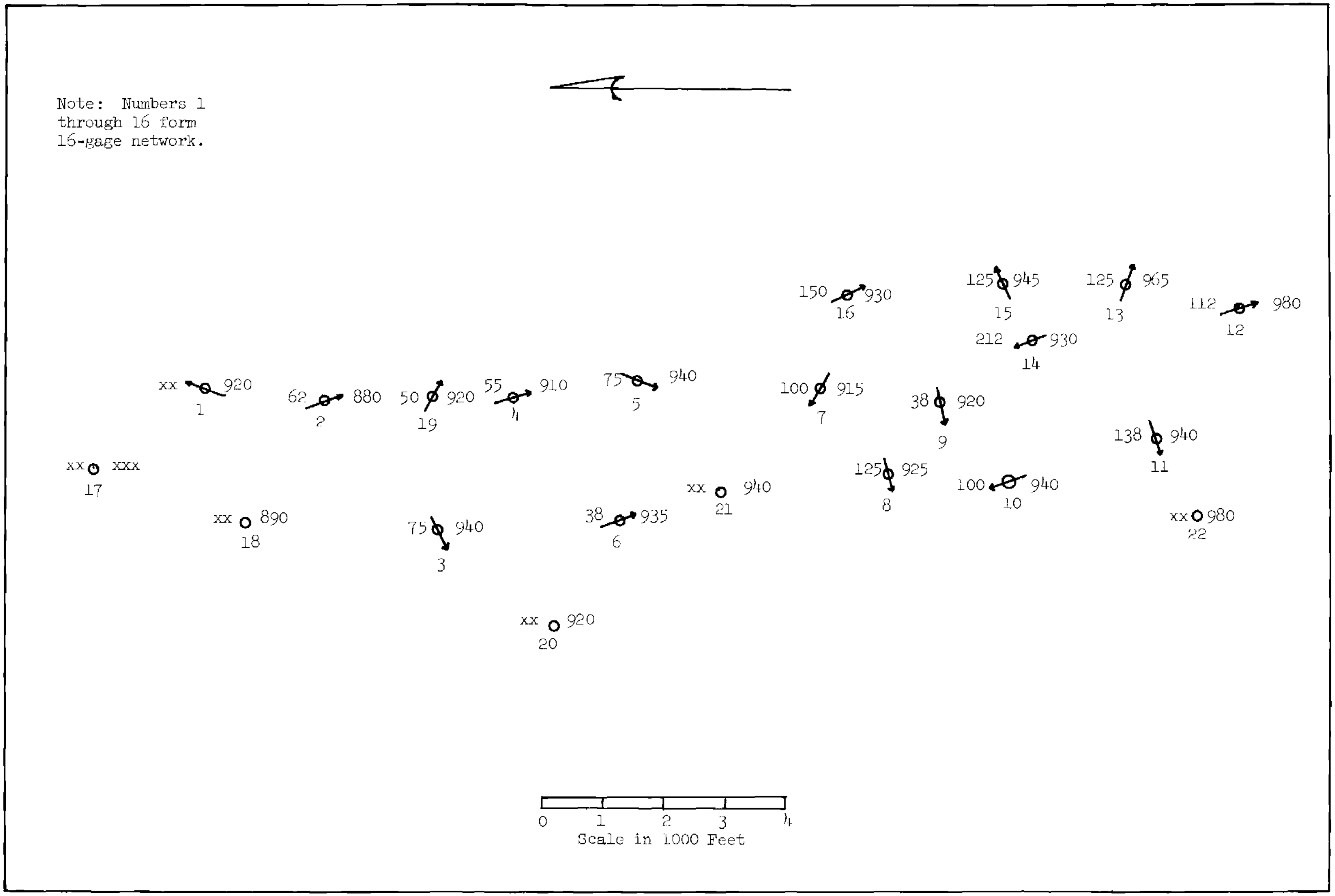


Figure B2. Coweeta, North Carolina Network



Note: Numbers 1 through 16 form 16-gage network.

Figure B3. Deer-Sloan, Michigan Network

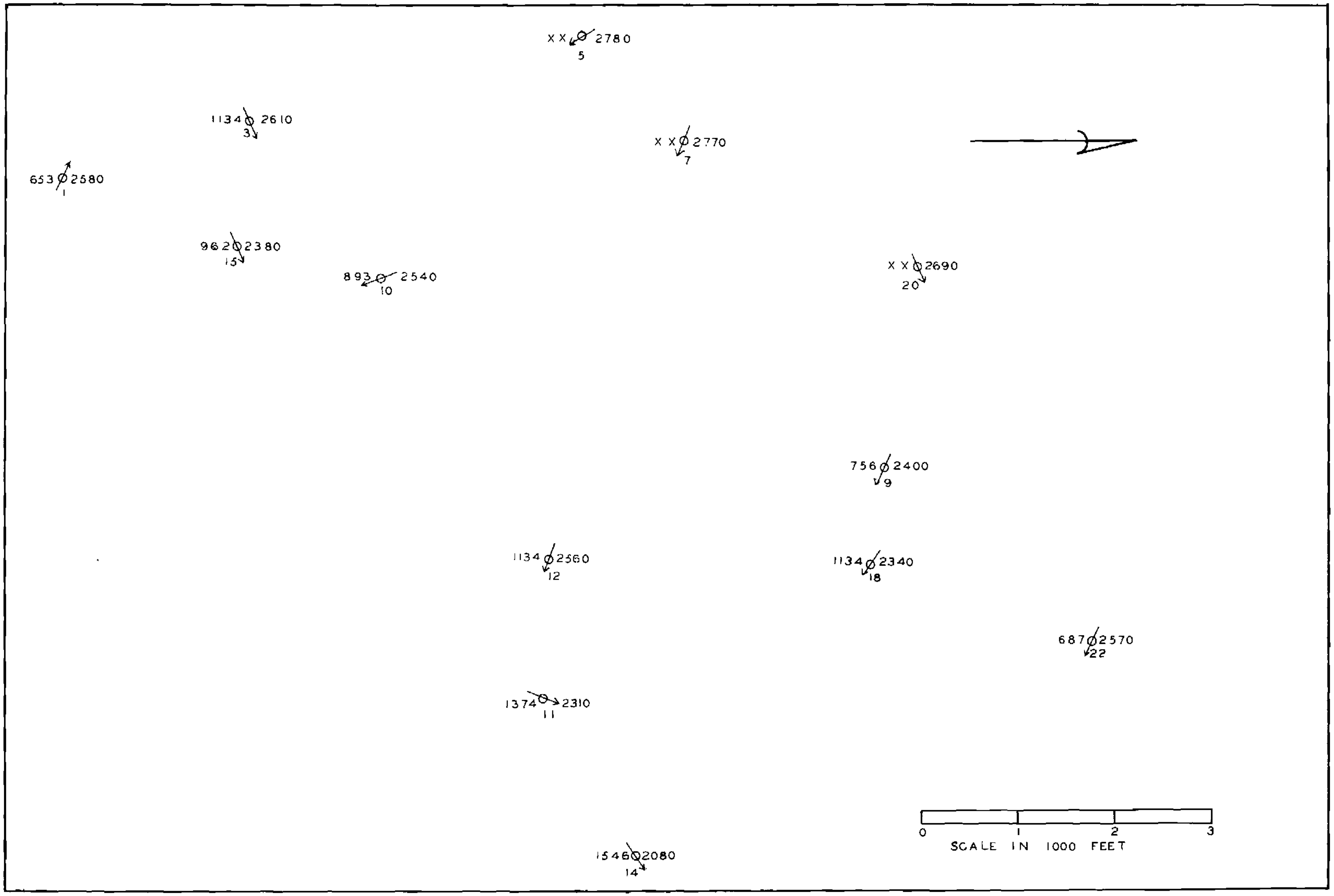


Figure B4. Fernow, West Virginia Network

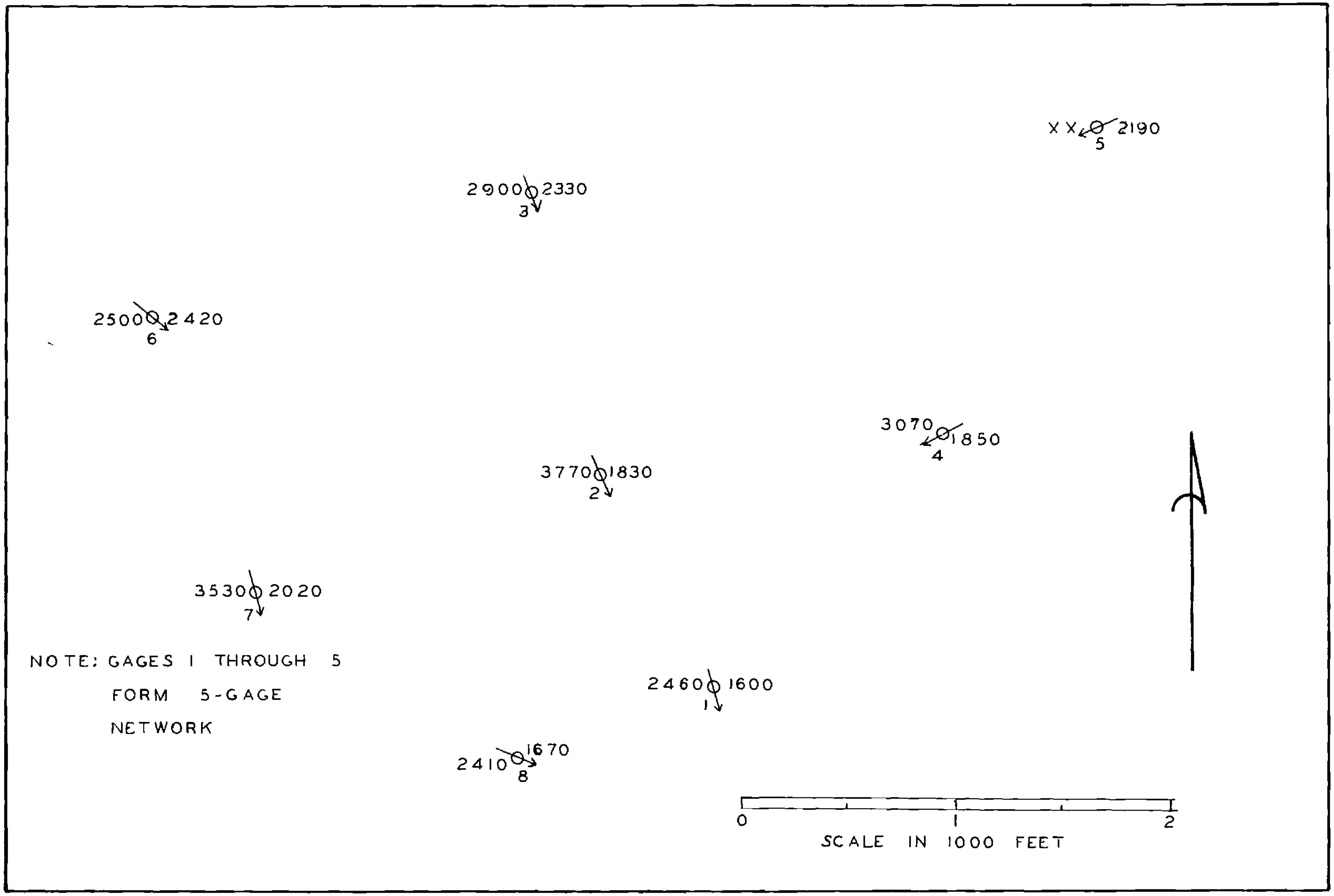


Figure B5. Hubbard Brook, New Hampshire Network

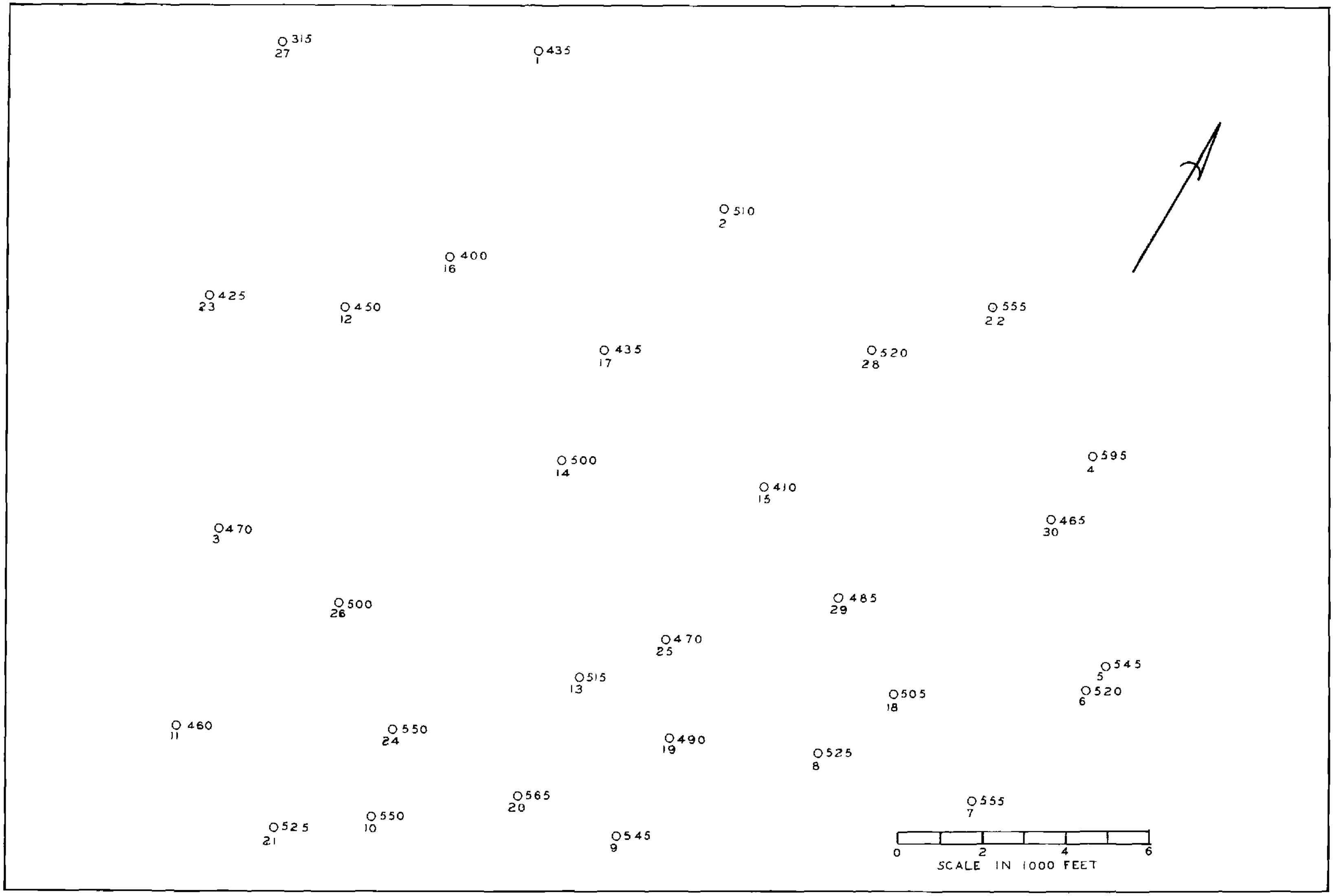


Figure B6. Pigeon Roost Creek, Mississippi Network

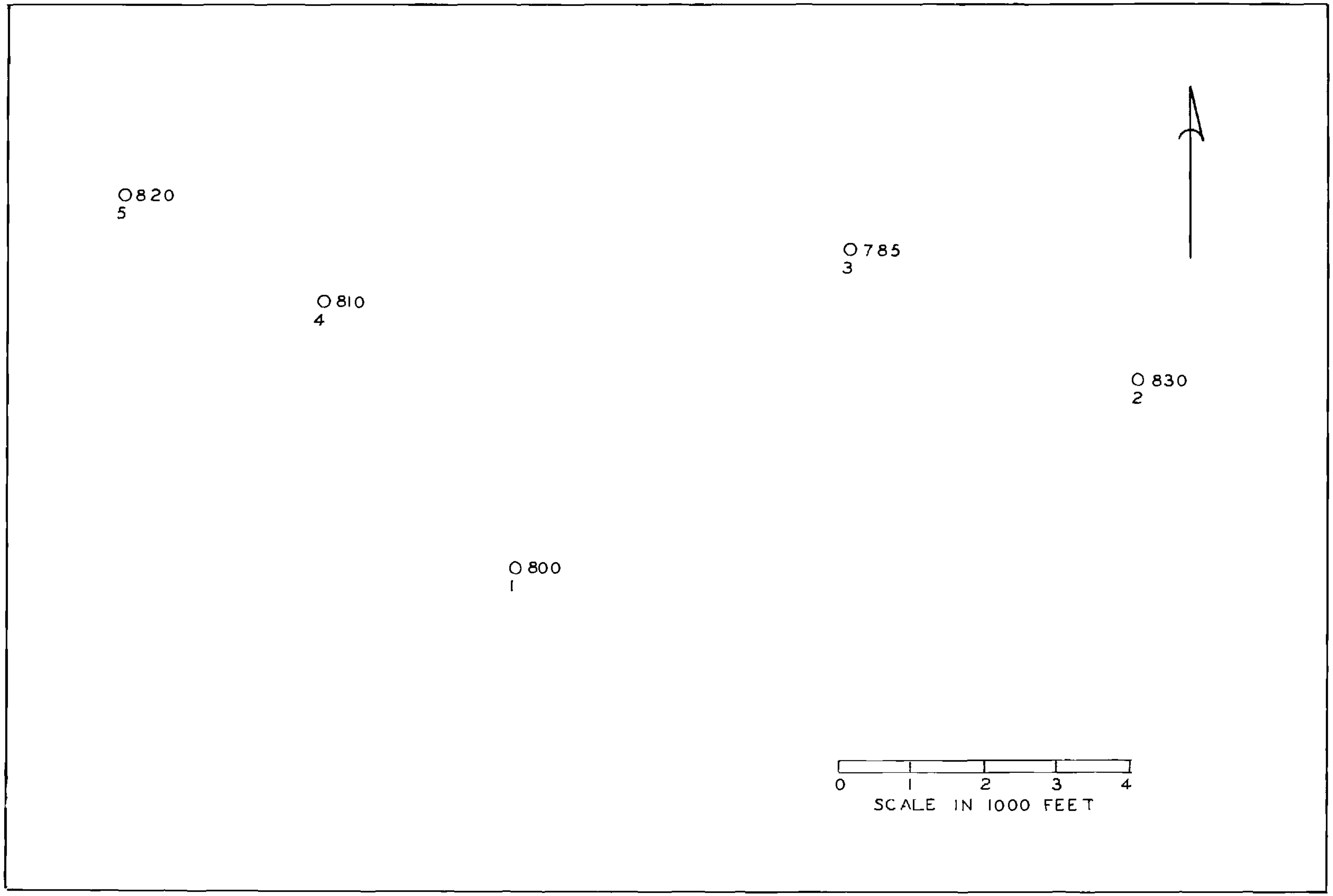


Figure B7. Ralston Creek, Iowa Network

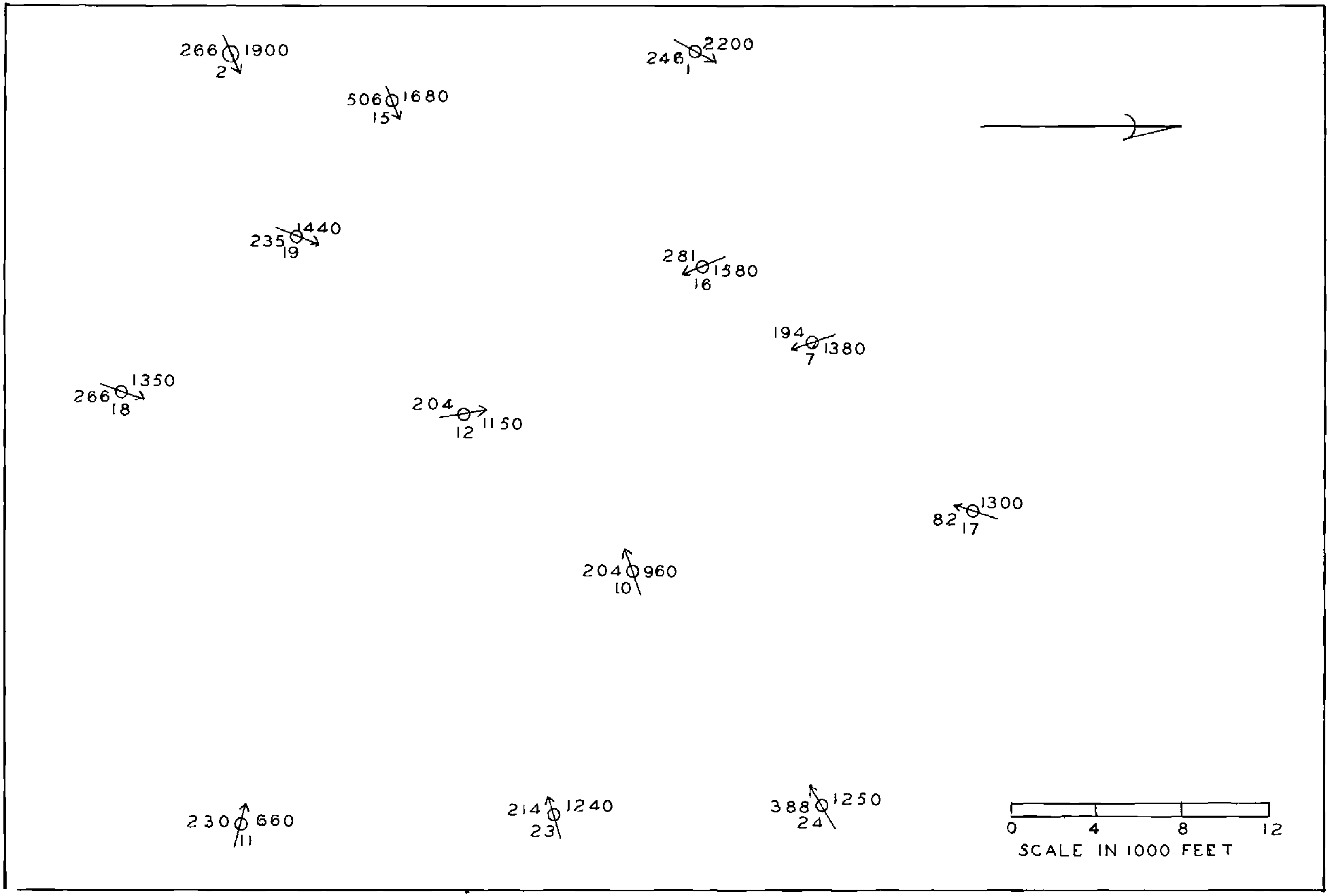


Figure B8. Sleepers River, Vermont Network

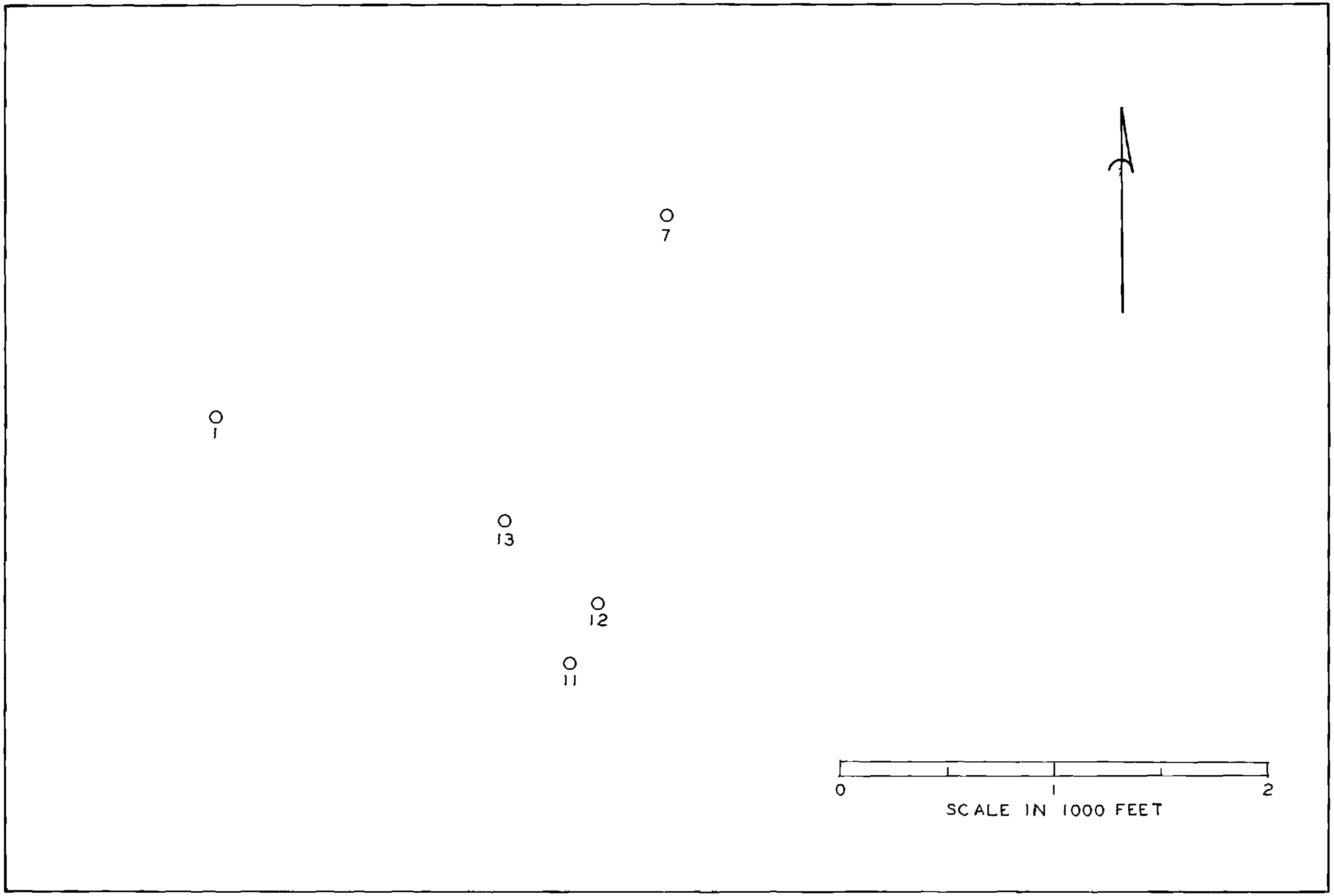


Figure B9. Tallahatchie River, Mississippi Network

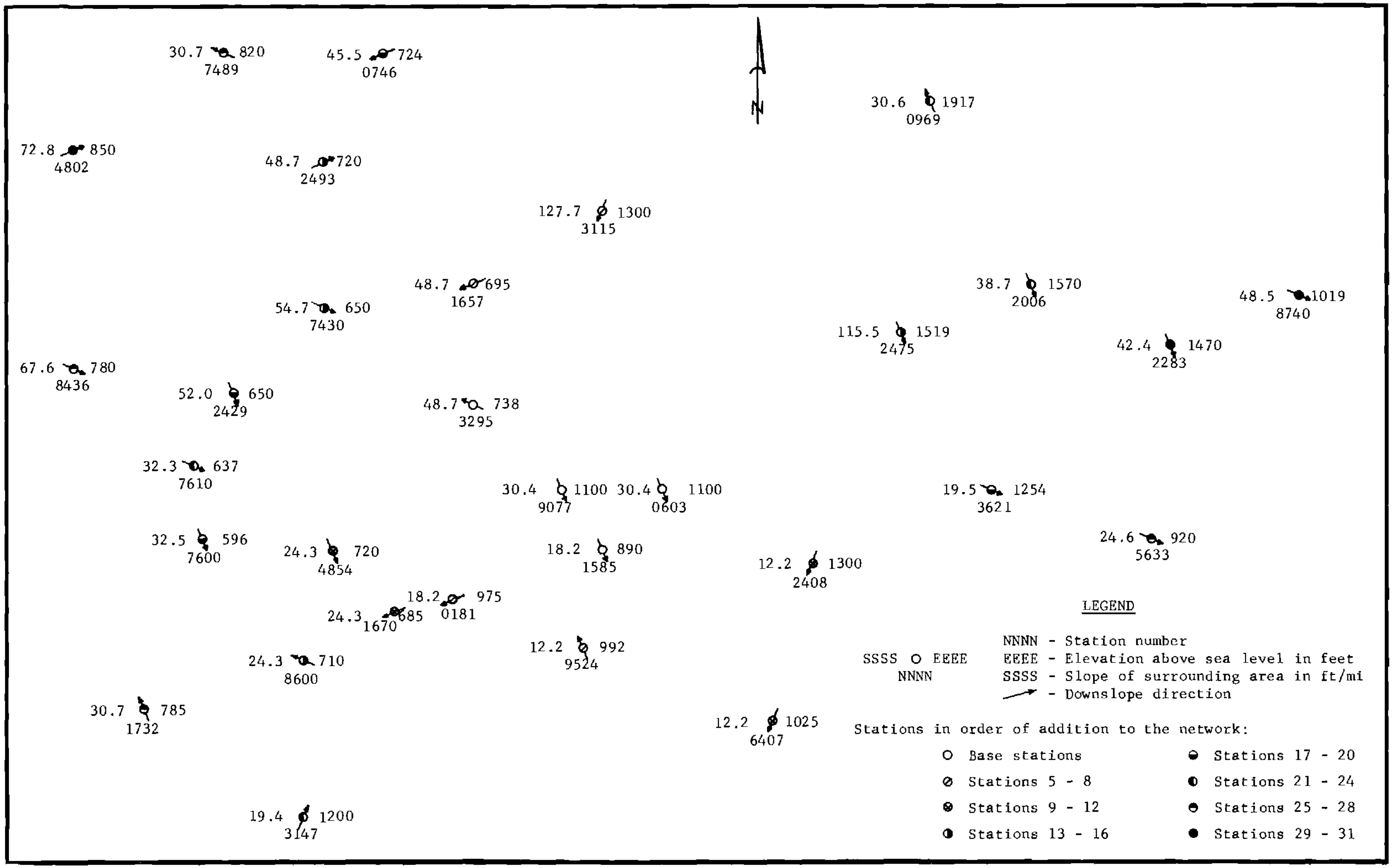


Figure B10. North Georgia Network

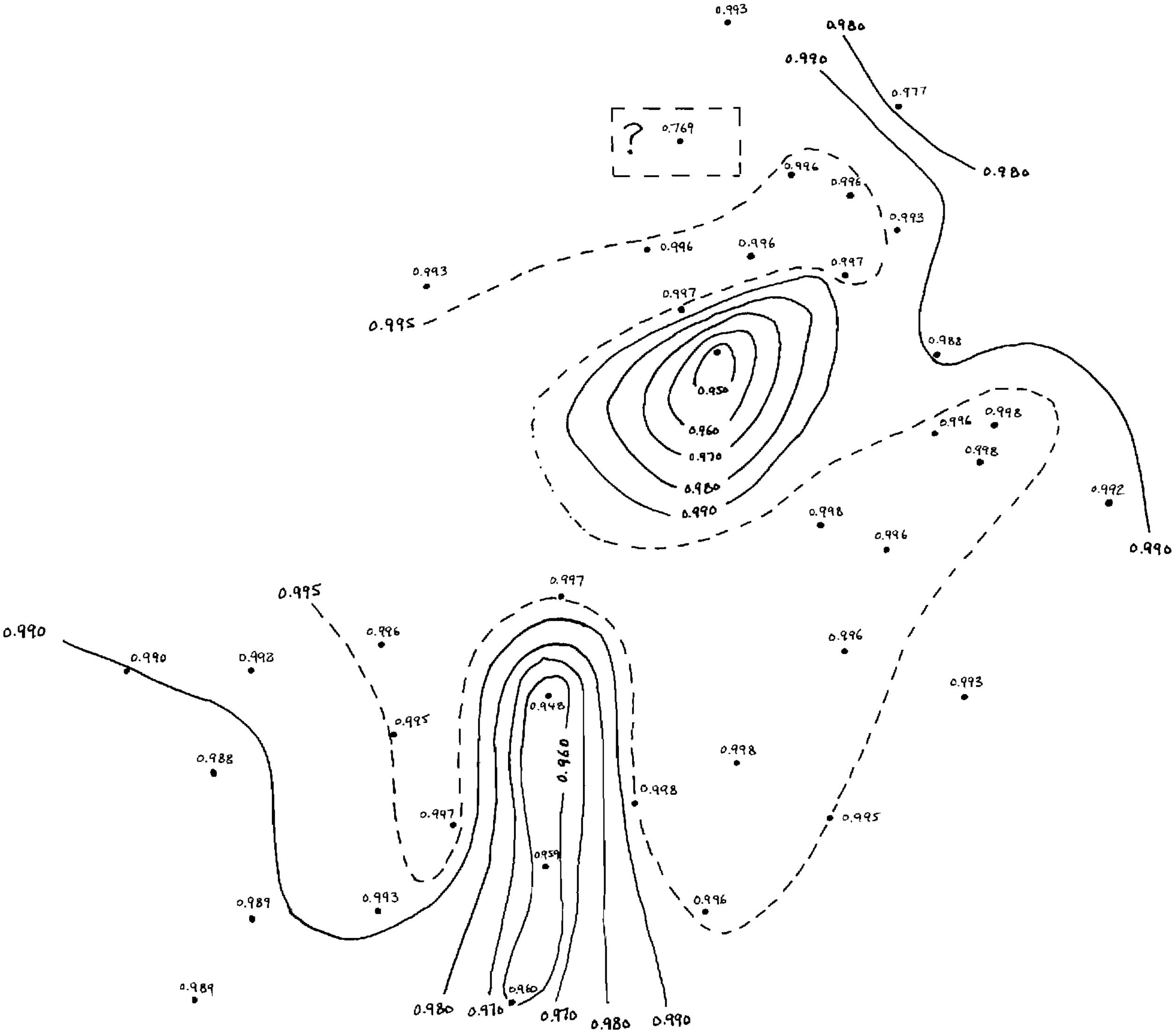


Figure B-11 Coweeta Network C. Component 1 Winter

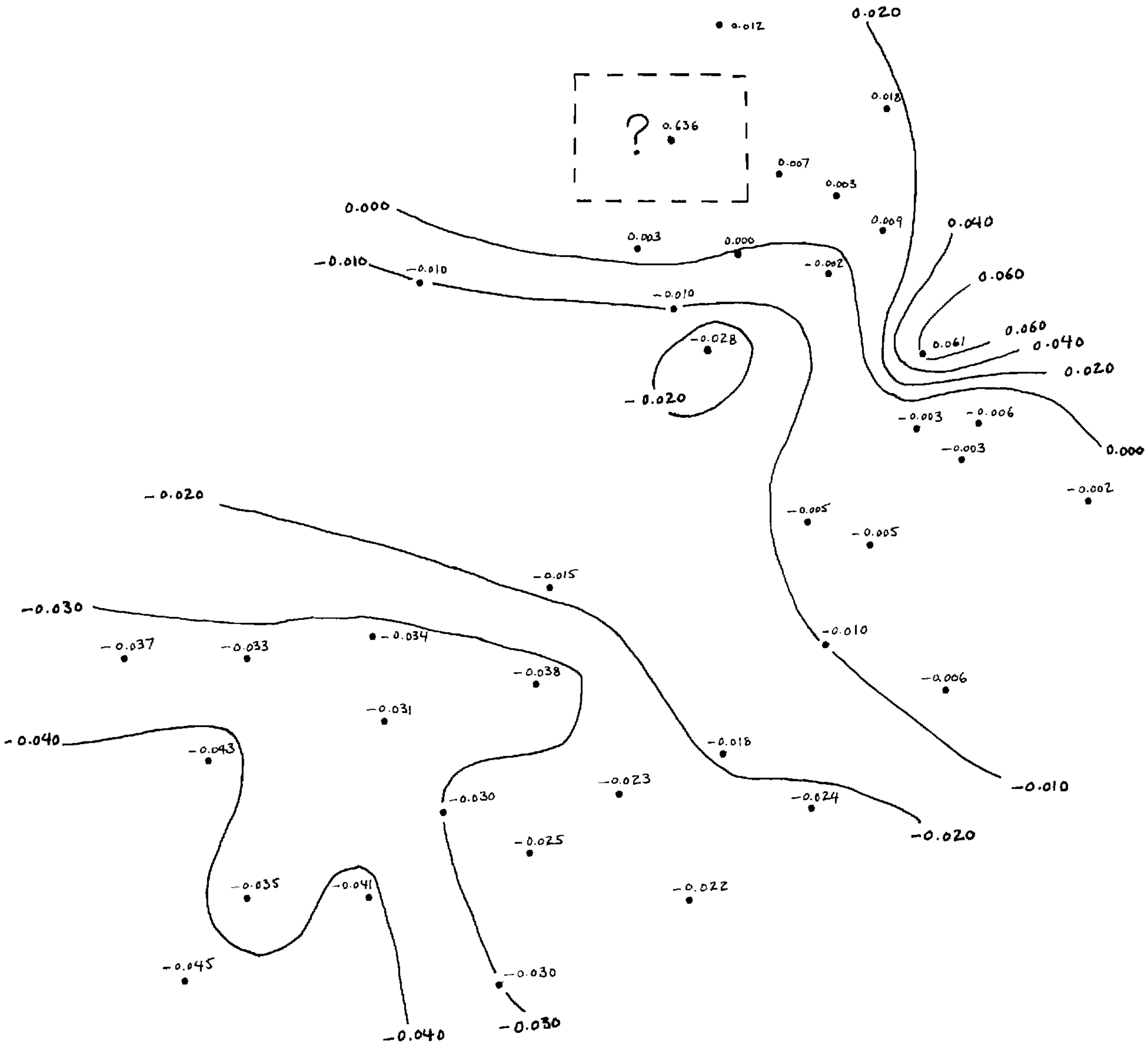


Figure B-12 Coweeta Network C. Component 2 Winter

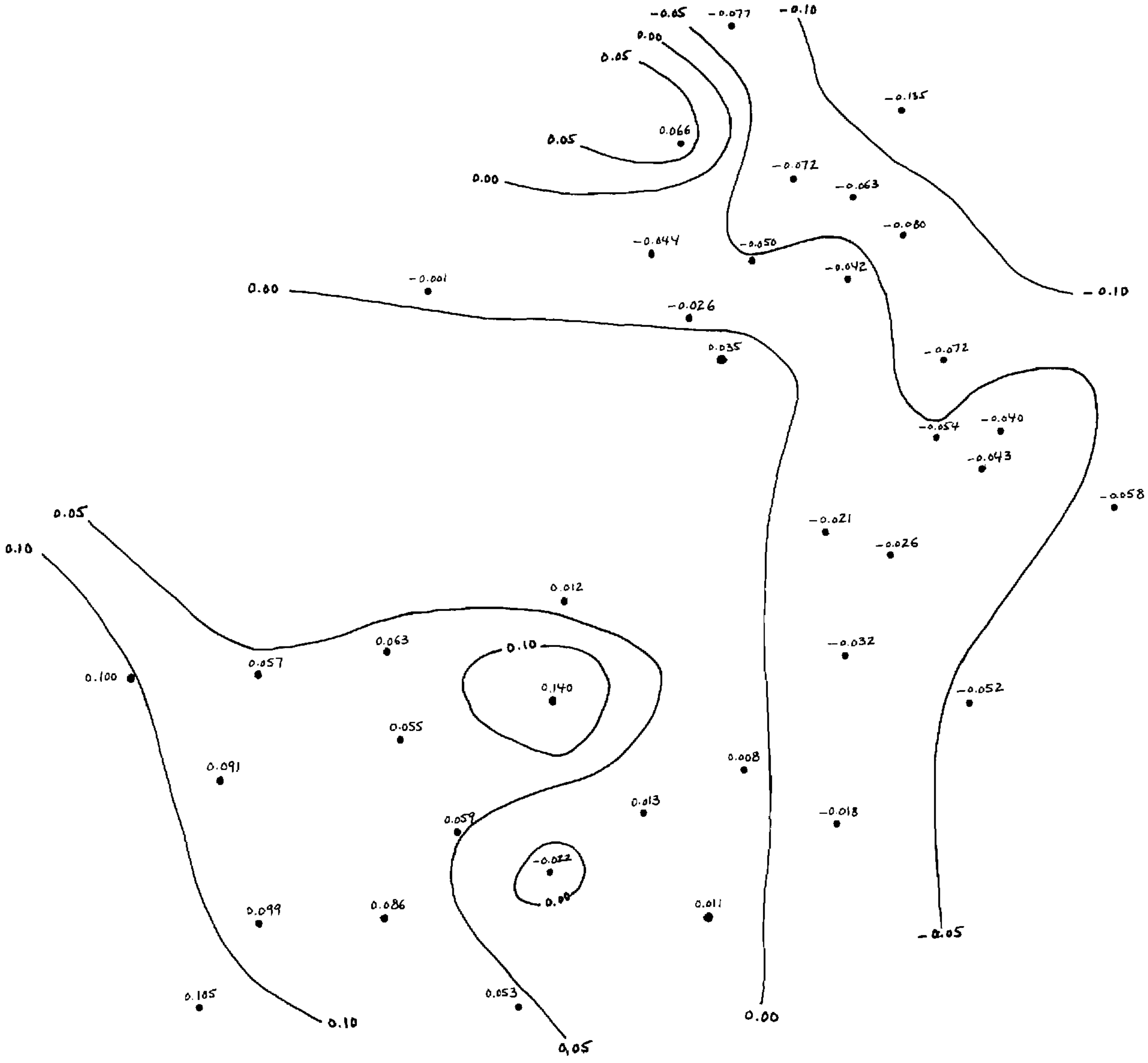


Figure B-13 Coweeta Network C. Component 3 Winter

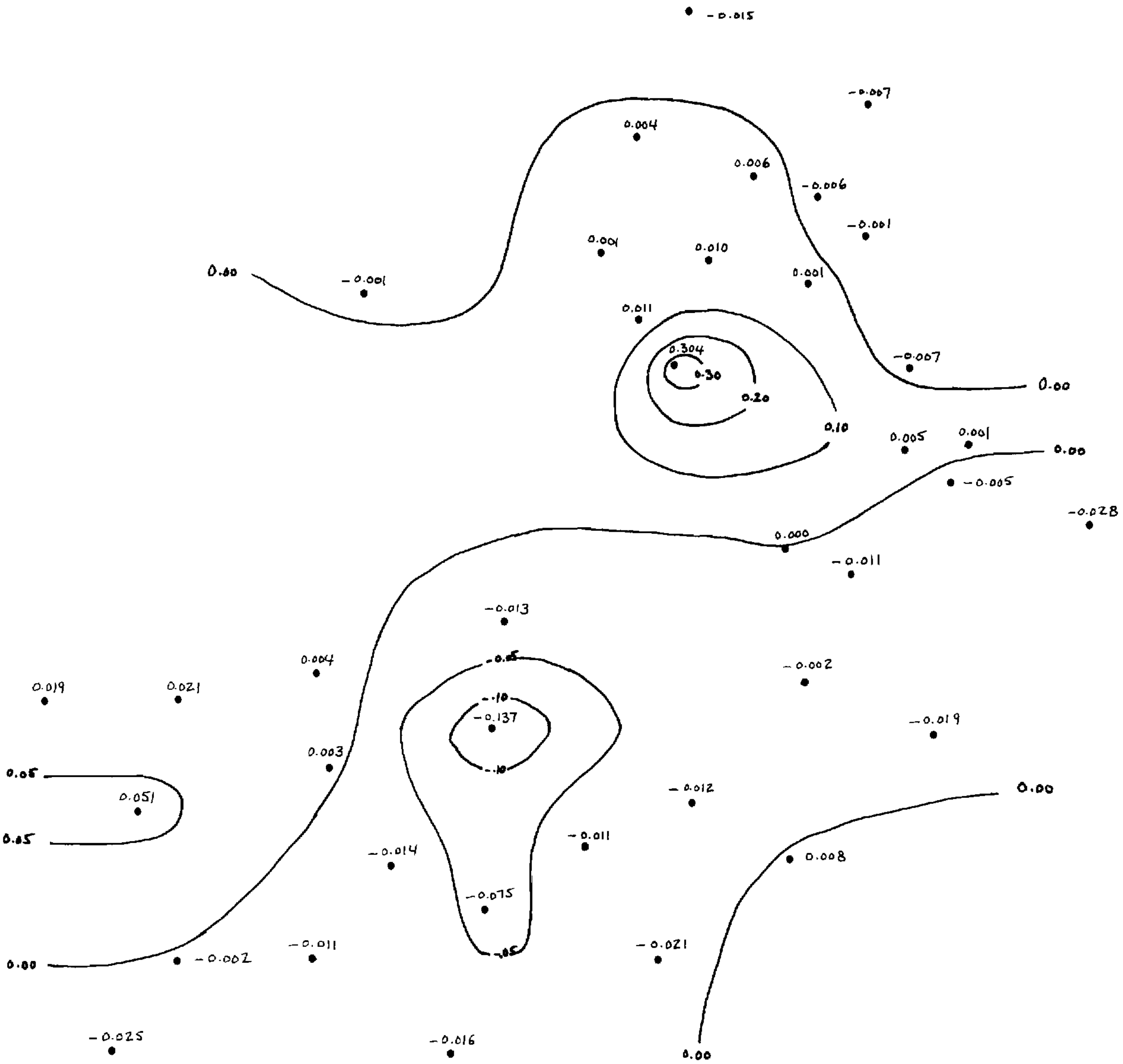


Figure B-14 Coweeta Network C. Component 4 Winter

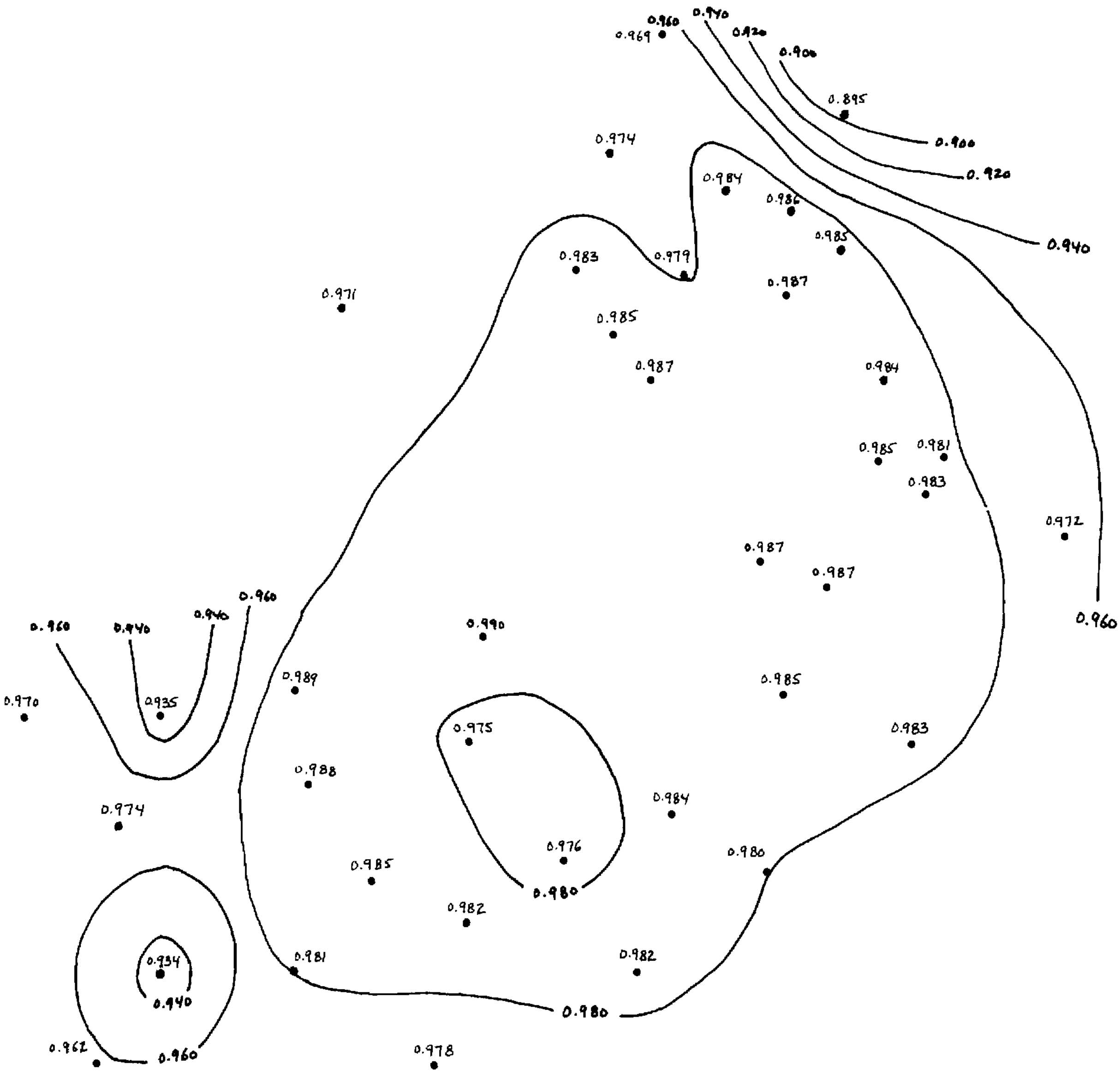


Figure B-15 Coweeta Network C. Component 1 Summer

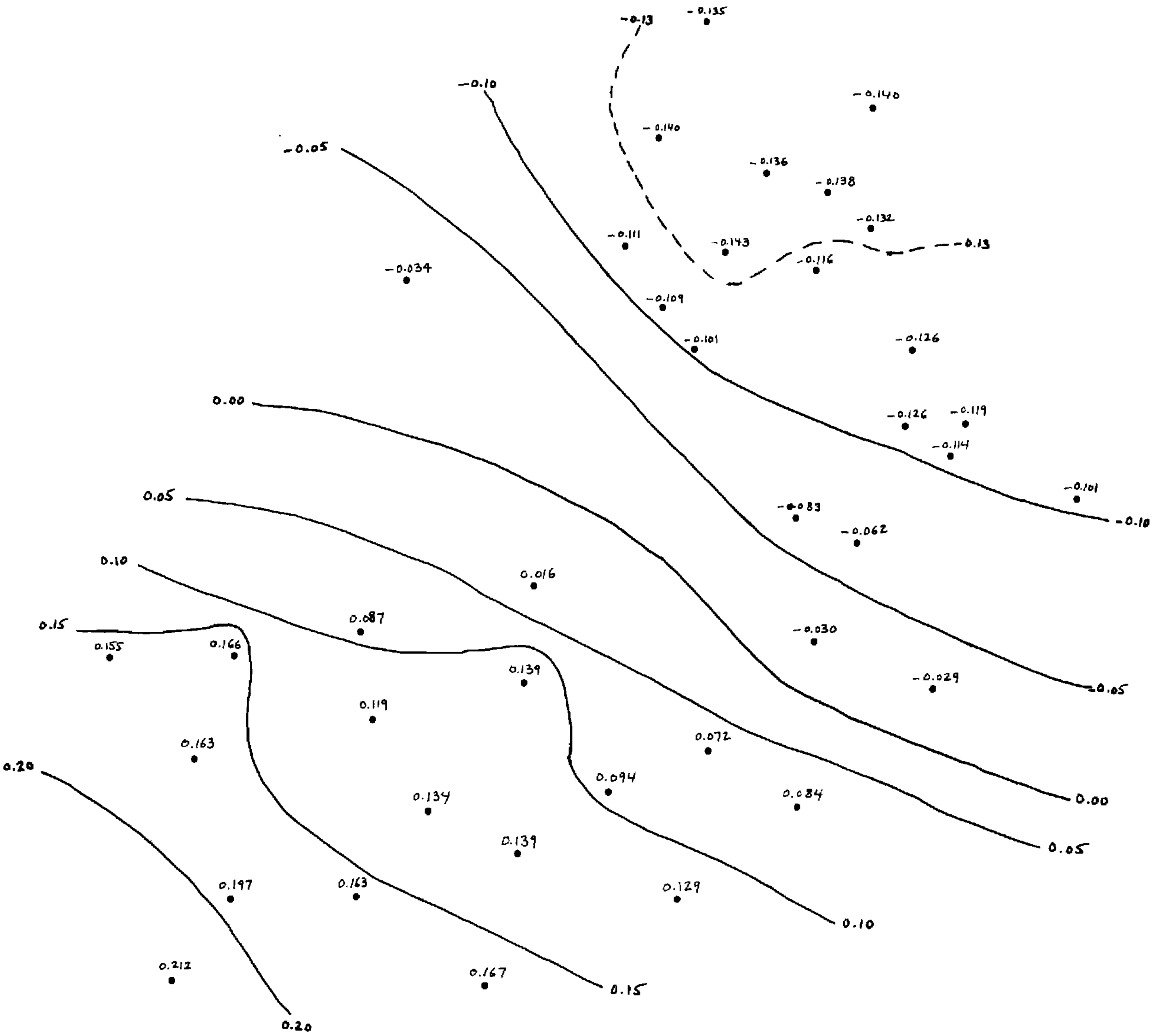


Figure B-16 Coweeta Network C. Component 2 Summer

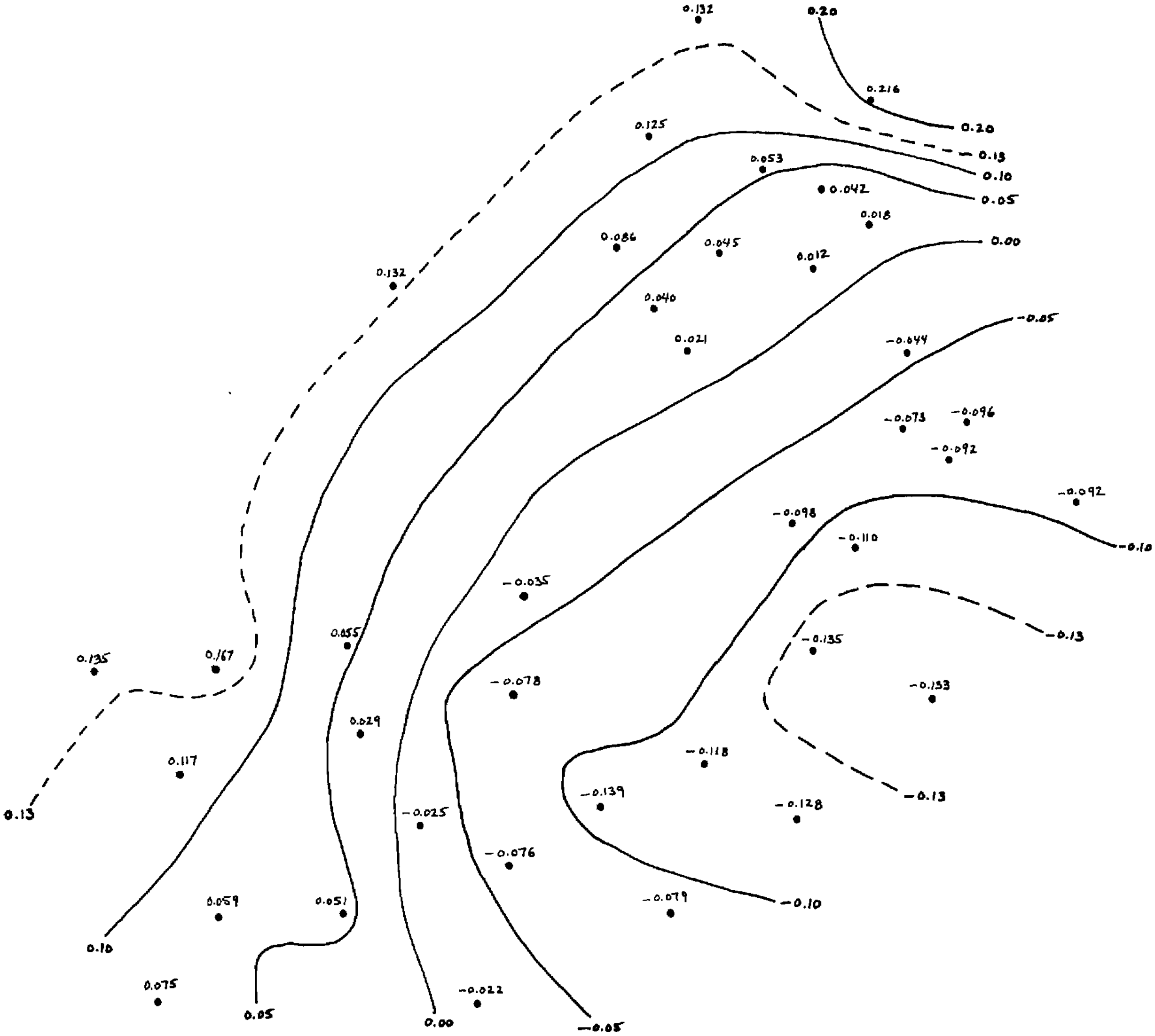


Figure B-17 Coweeta Network C. Component 3 Summer

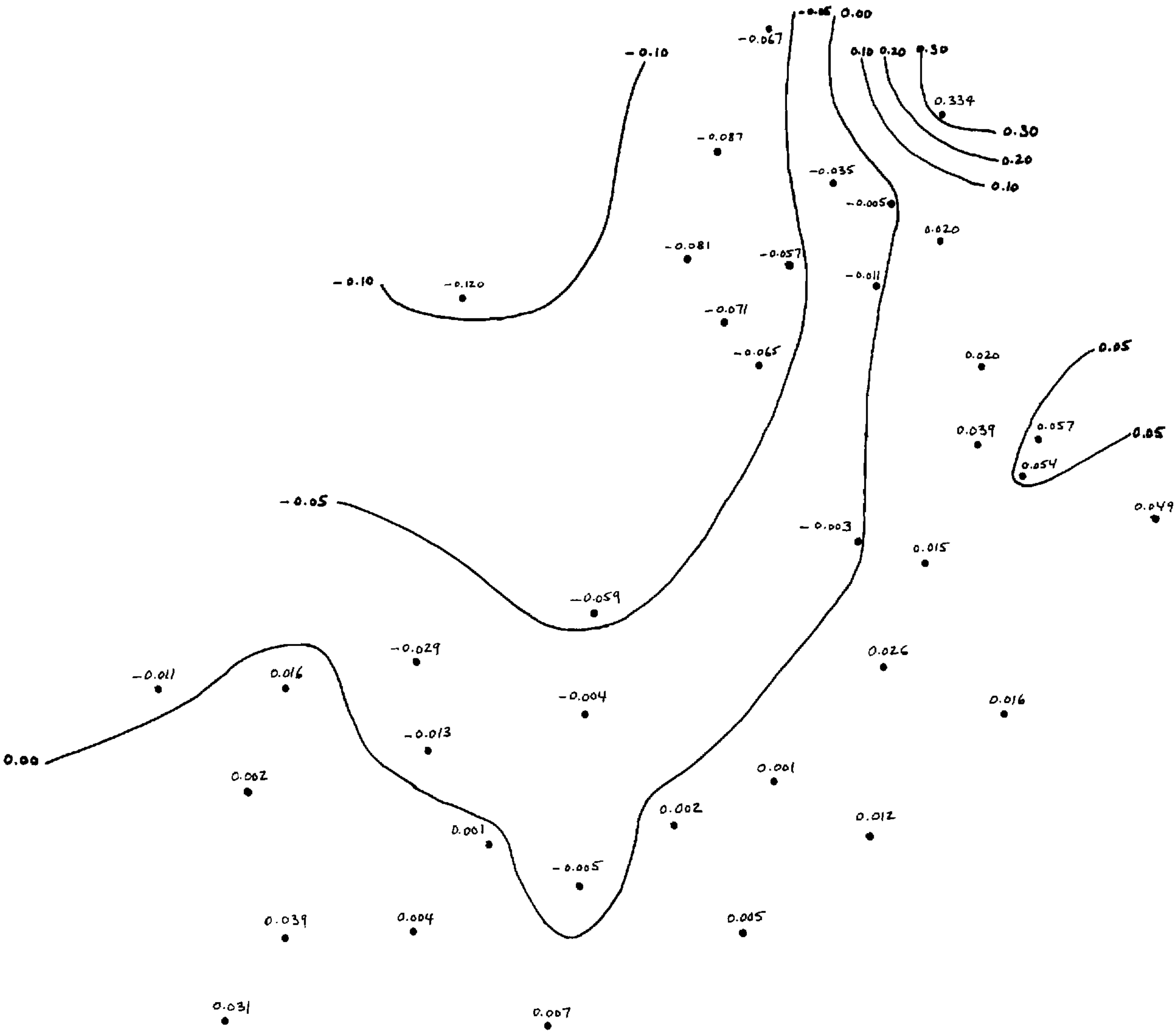


Figure B-18 Coweeta Network C. Component 4 Summer

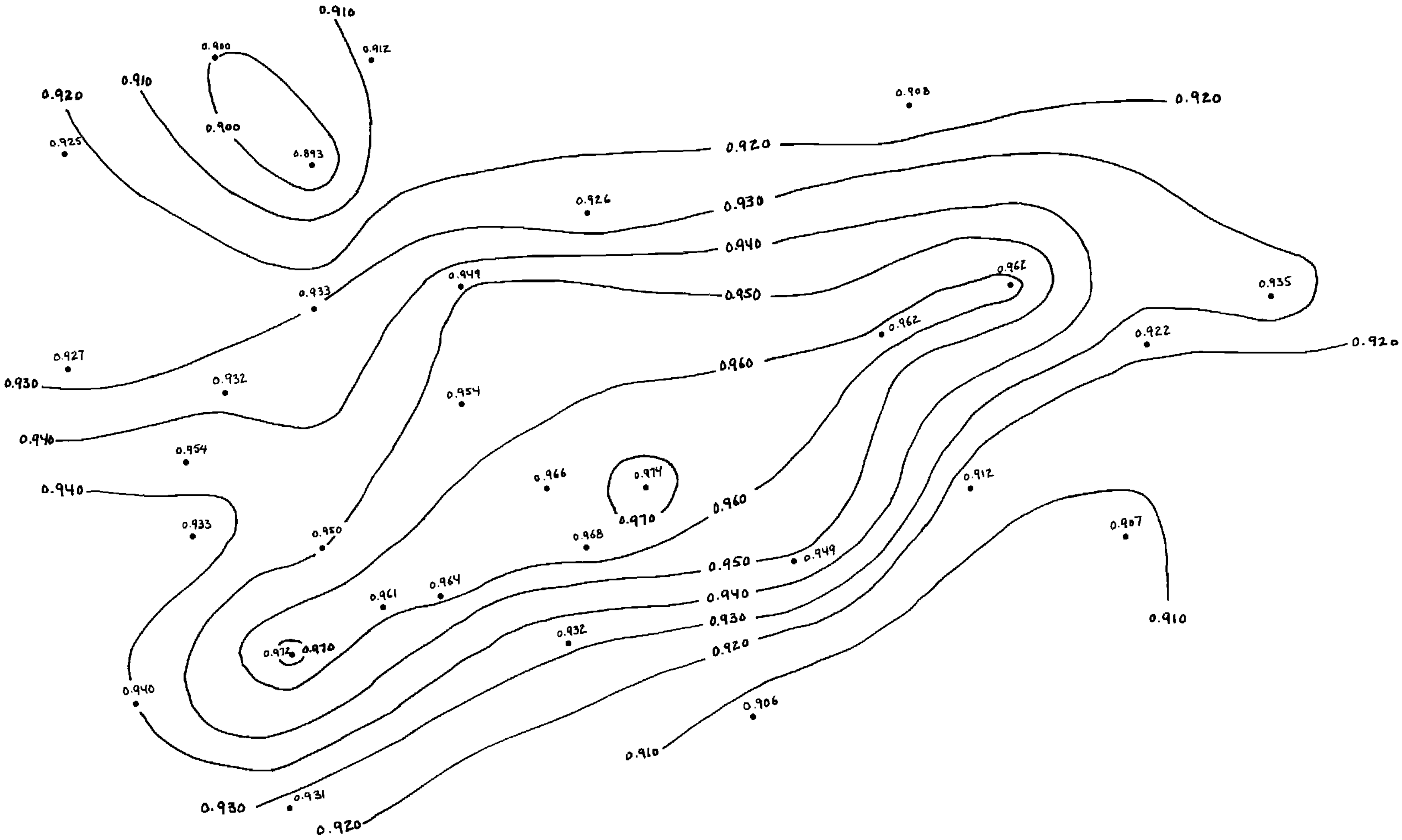


Figure B-19 Georgia Network Component 1 Winter

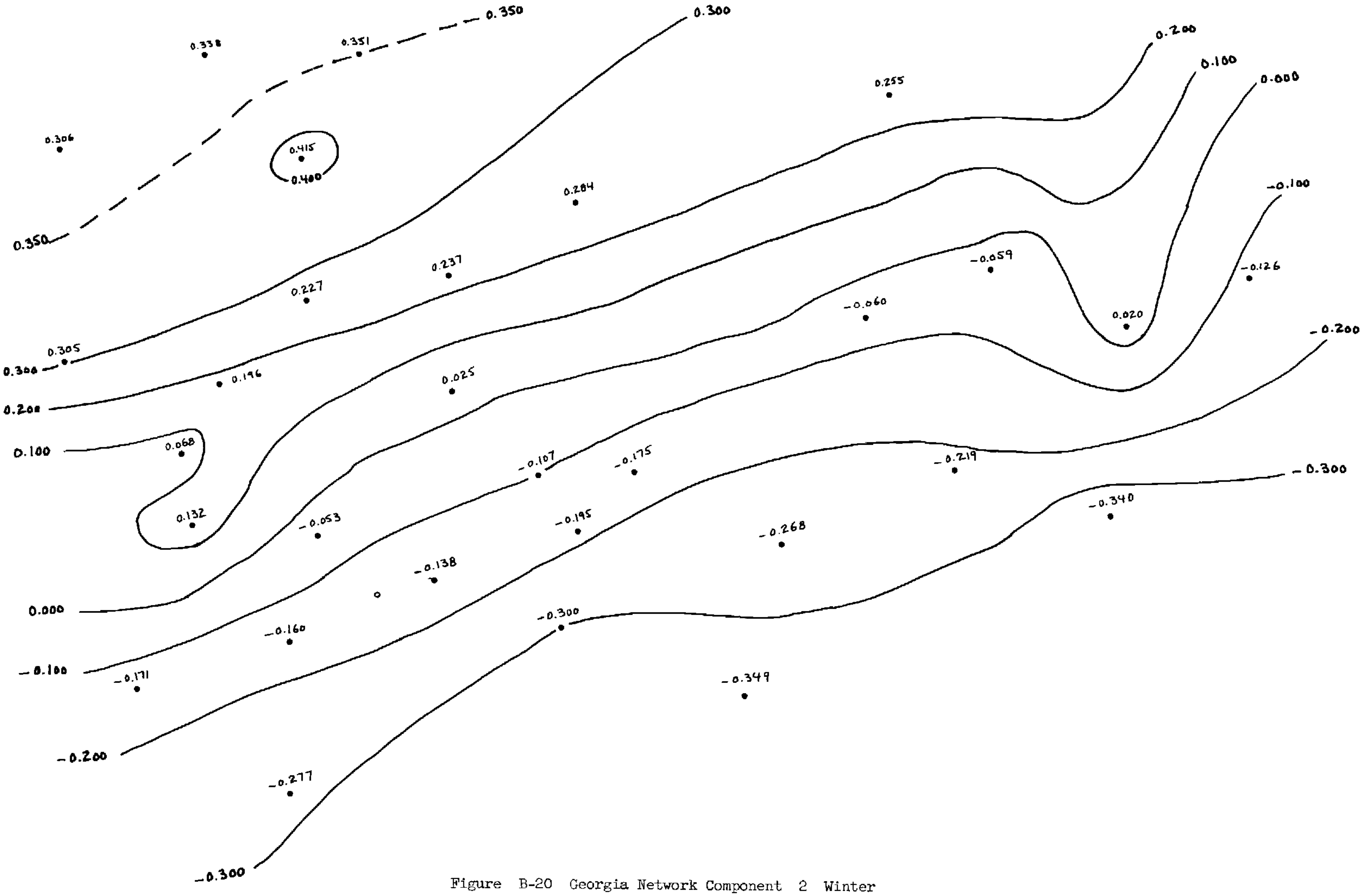


Figure B-20 Georgia Network Component 2 Winter

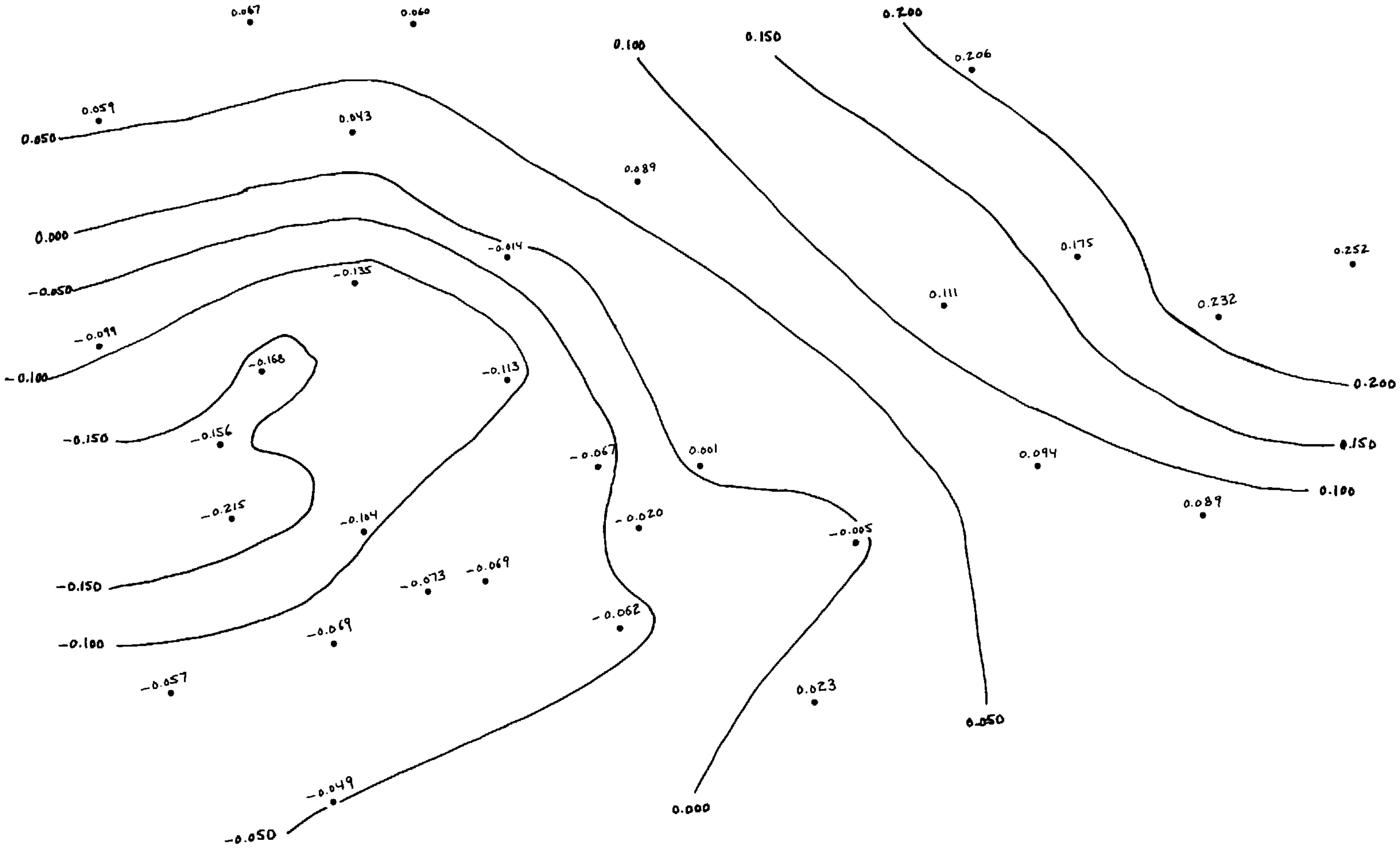


Figure B-21 Georgia Network Component 3 Winter

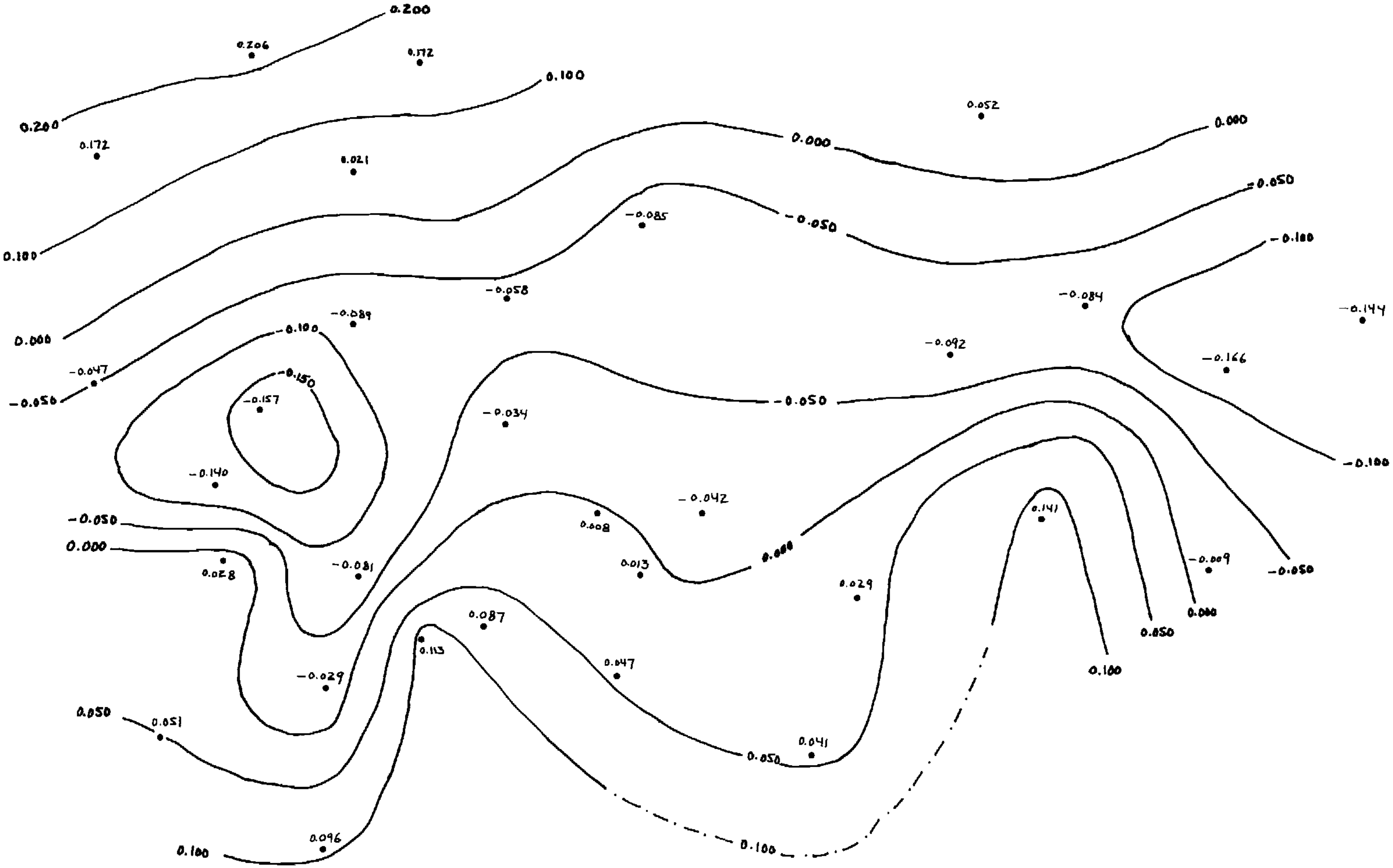


Figure B-22 Georgia Network Component 4 Winter

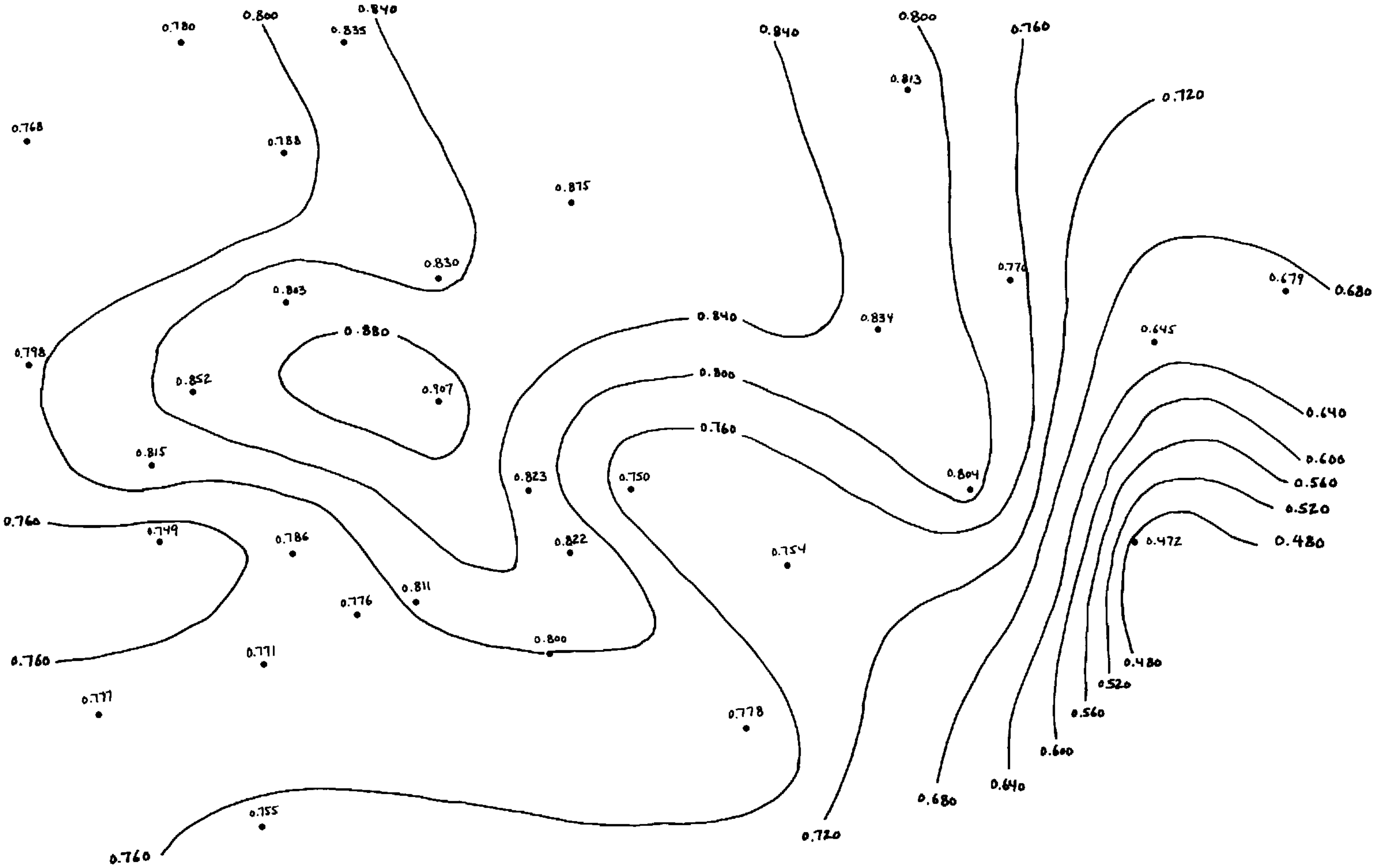


Figure B-23 Georgia Network Component 1 Summer

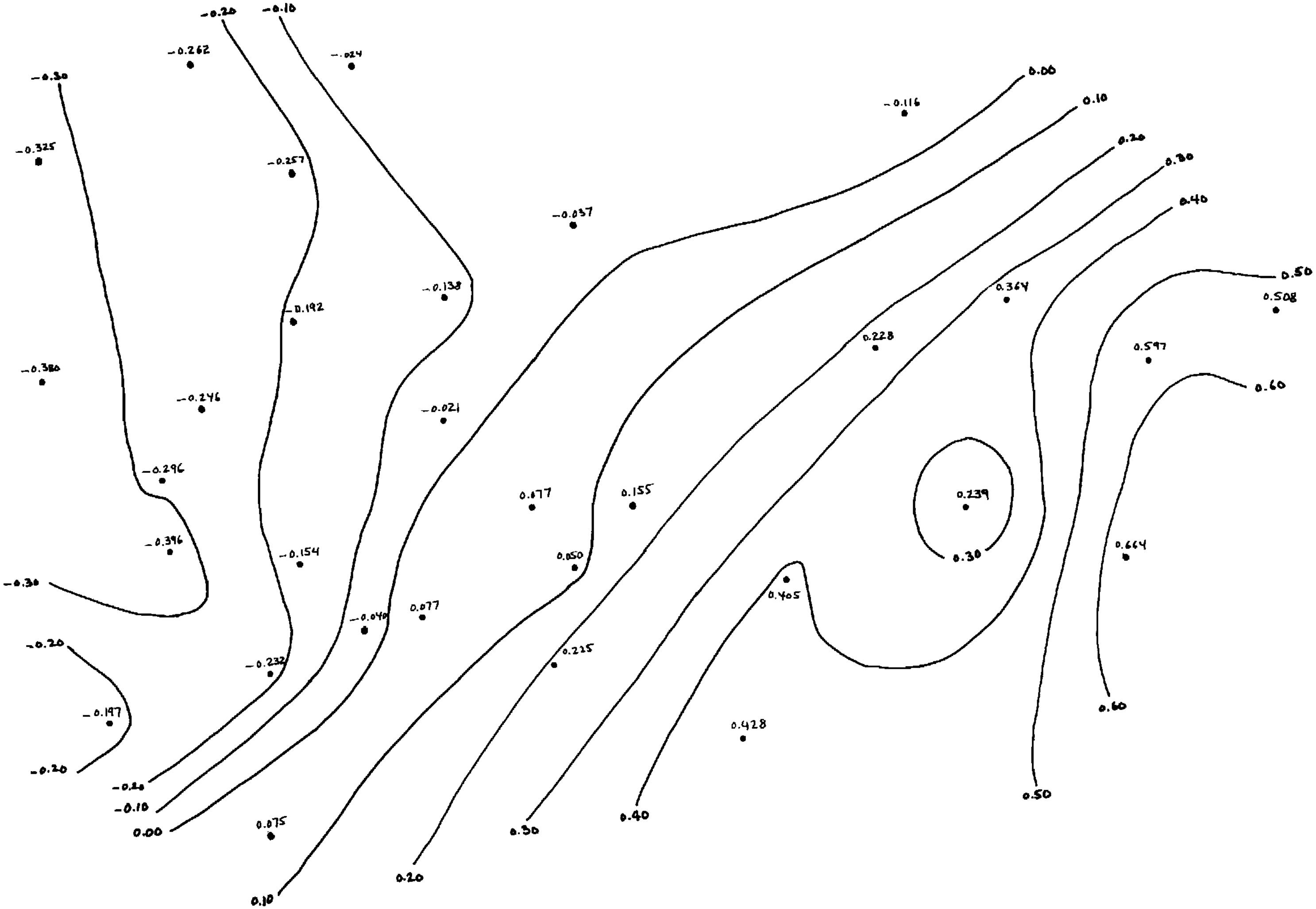


Figure B-24 Georgia Network Component 2 Summer

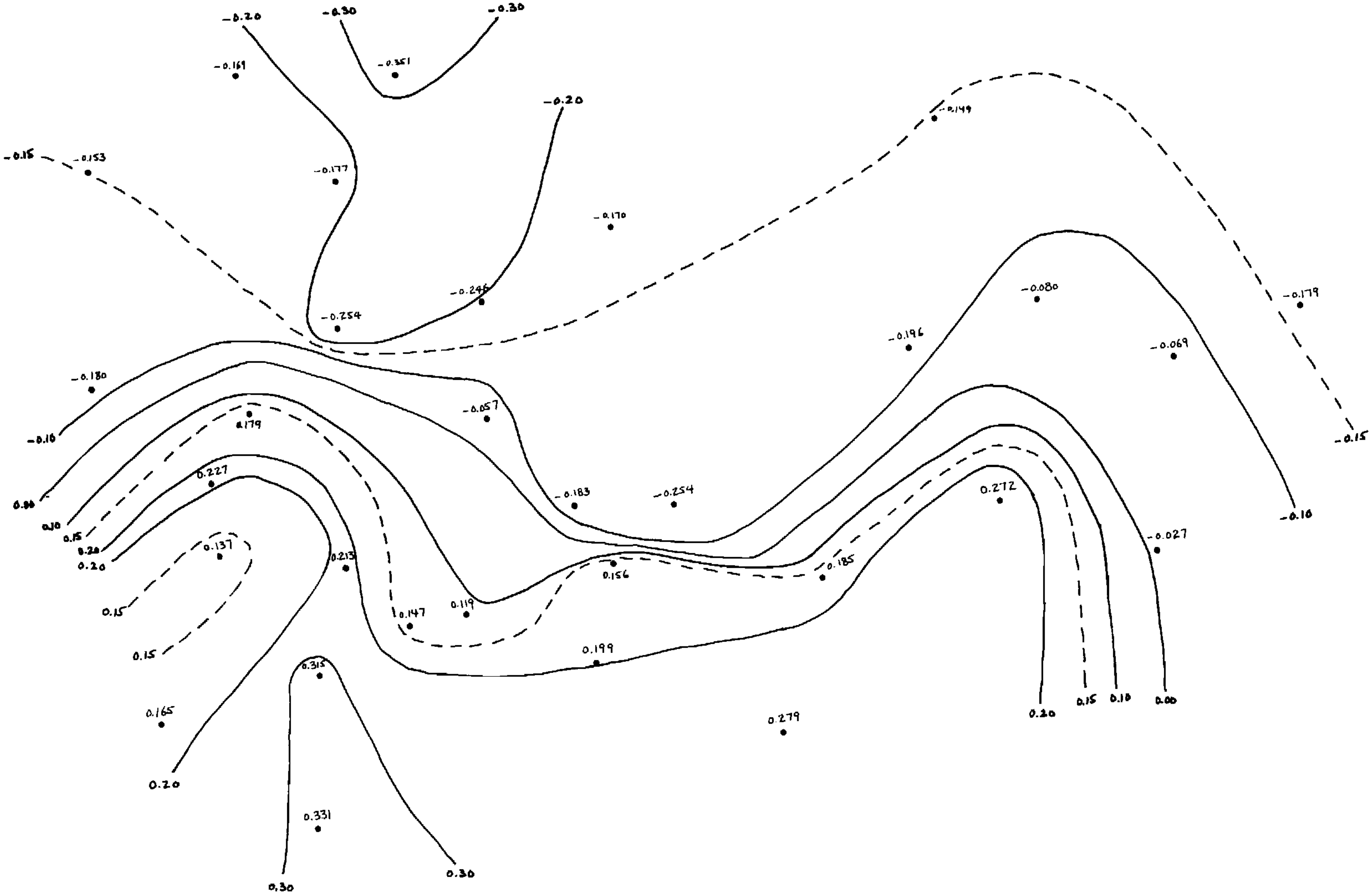


Figure B-25 Georgia Network Component 3 Summer

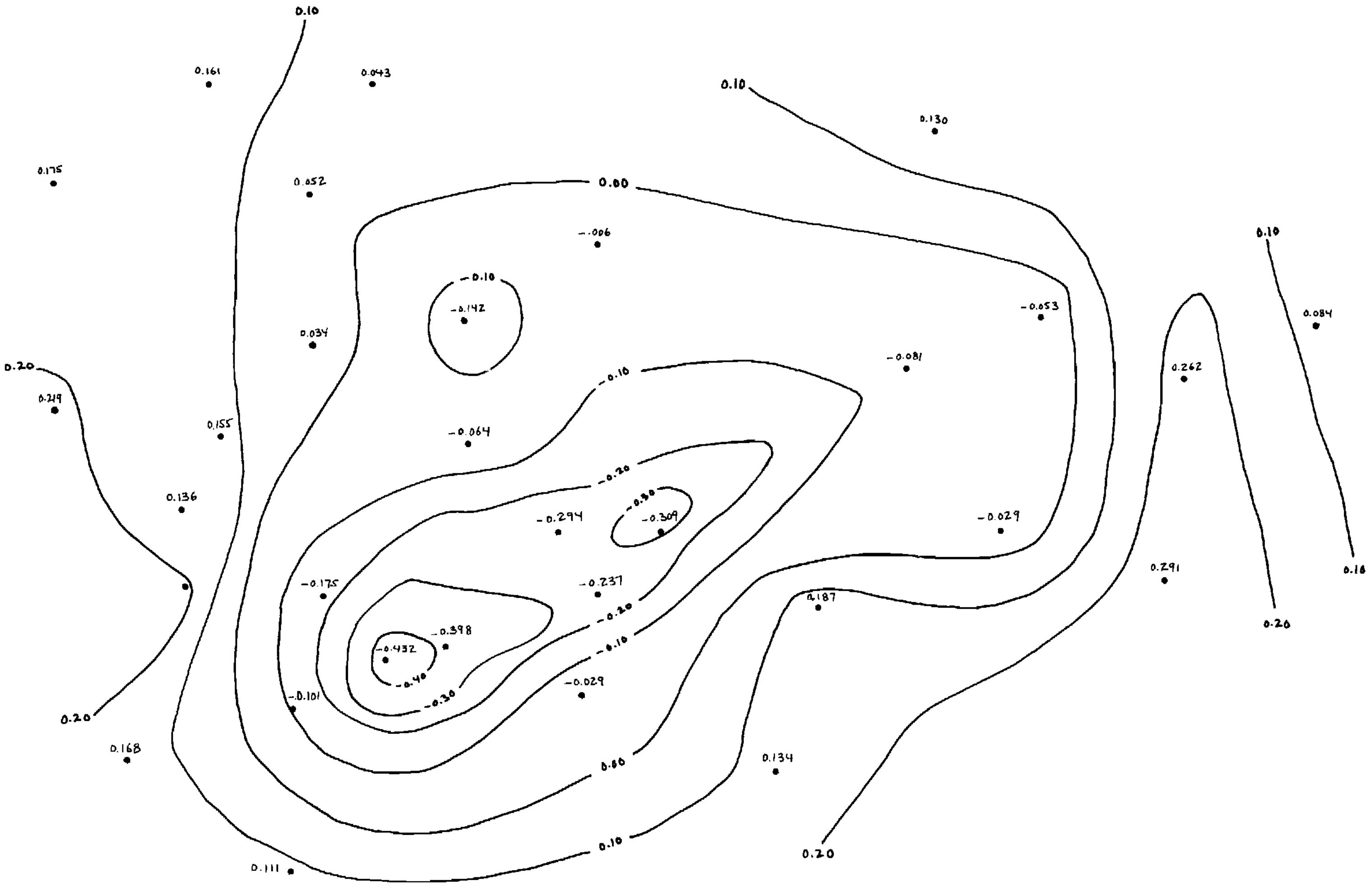


Figure B-26 Georgia Network Component 4 Summer

APPENDIX C

Component vs Characteristic Charts

Coweeta Network C

Figure

Georgia Network

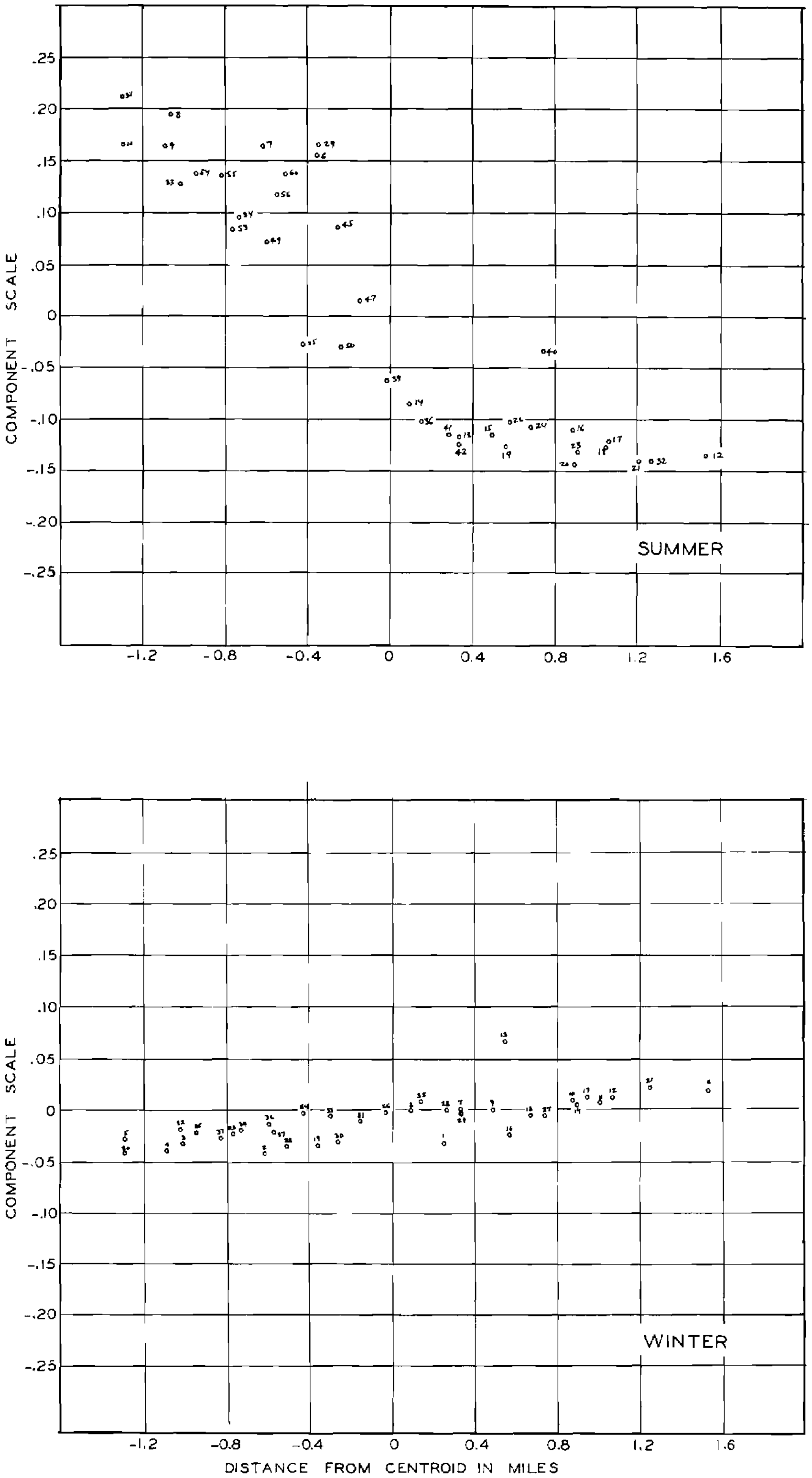


FIGURE C-1. COMPONENT 2 VS. LONGITUDE - COWEETA

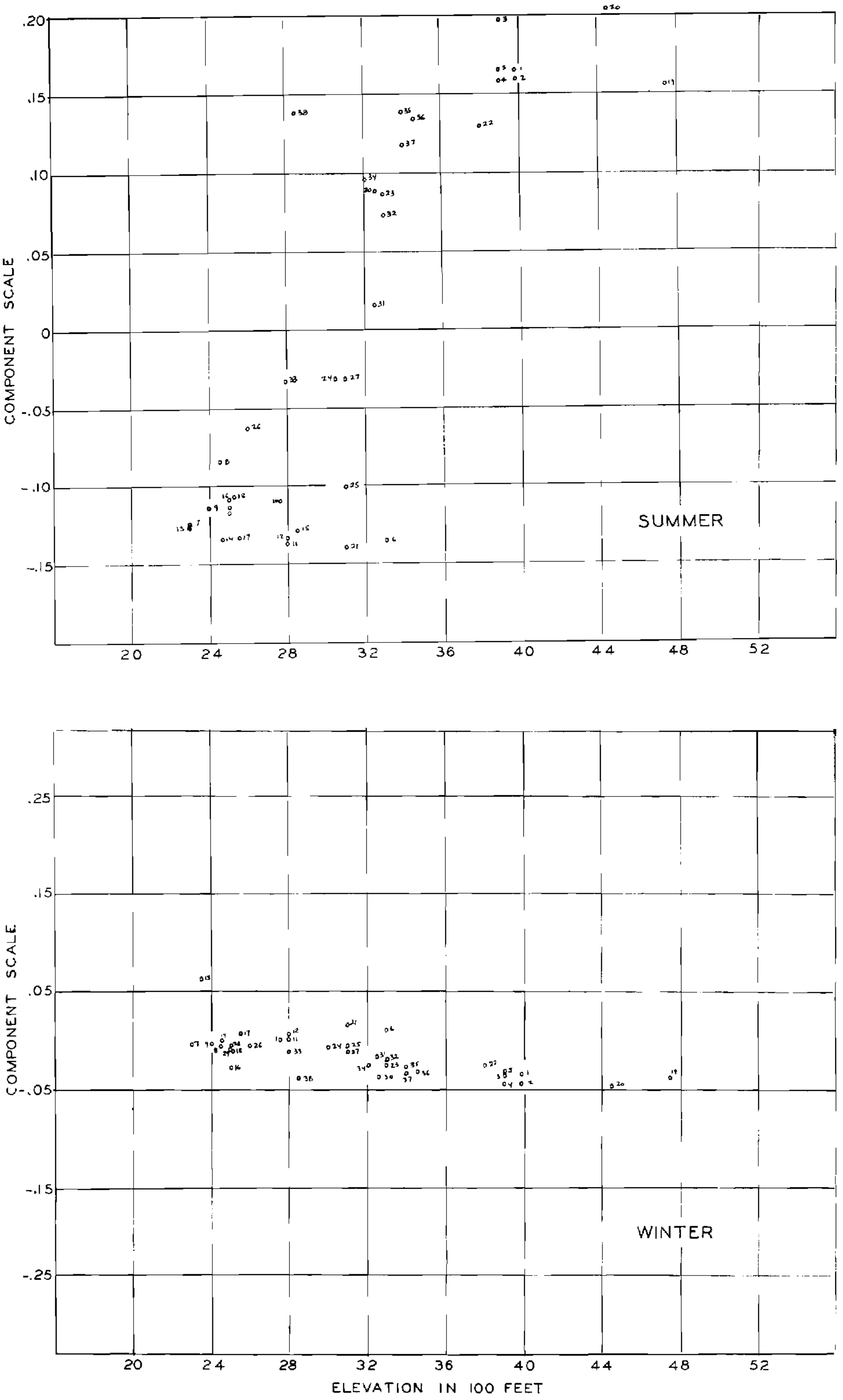


FIGURE C-2. COMPONENT 2 VS. ELEVATION - COWEETA

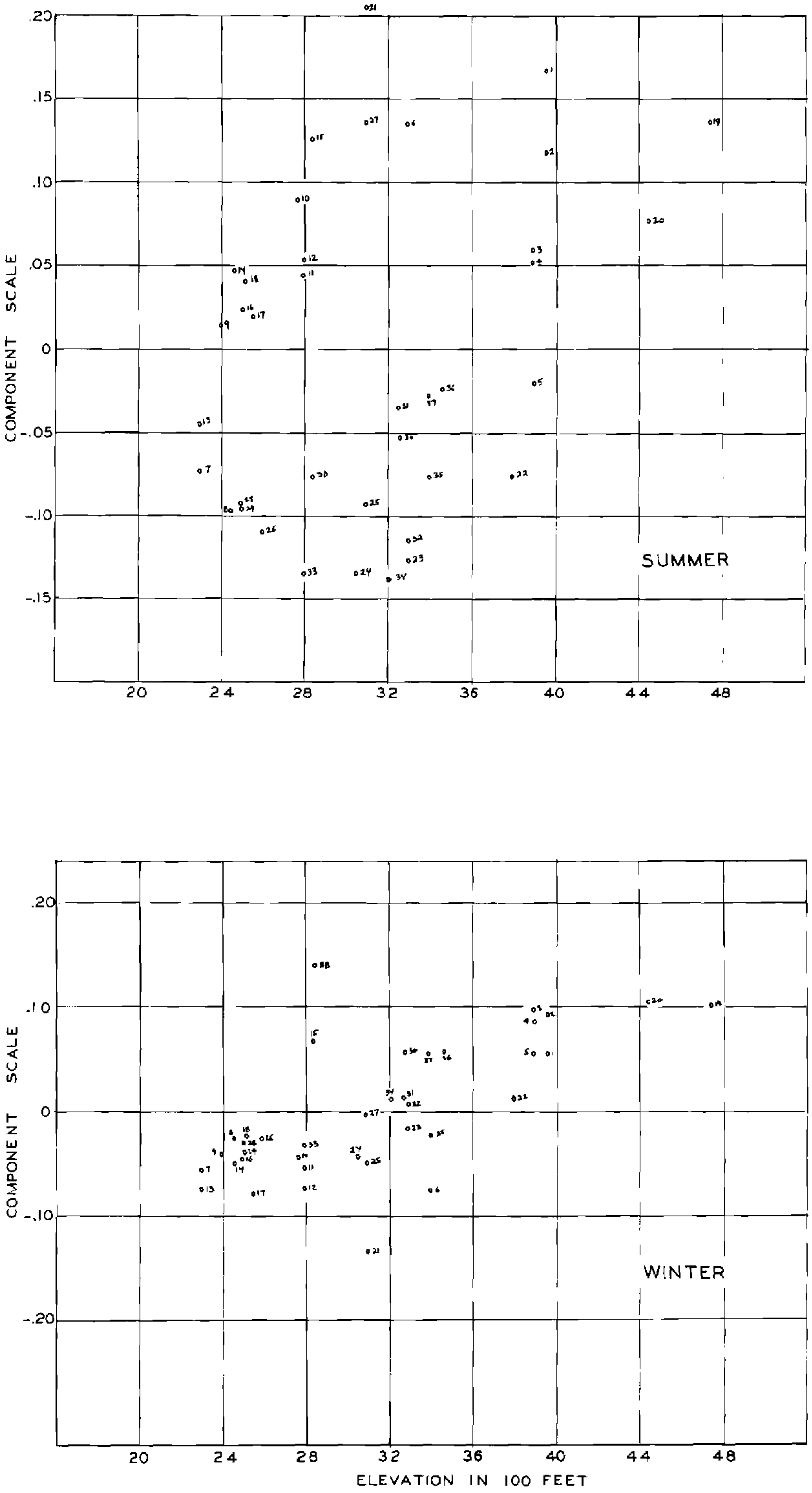


FIGURE C-3. COMPONENT 3 VS. ELEVATION - COWEETA

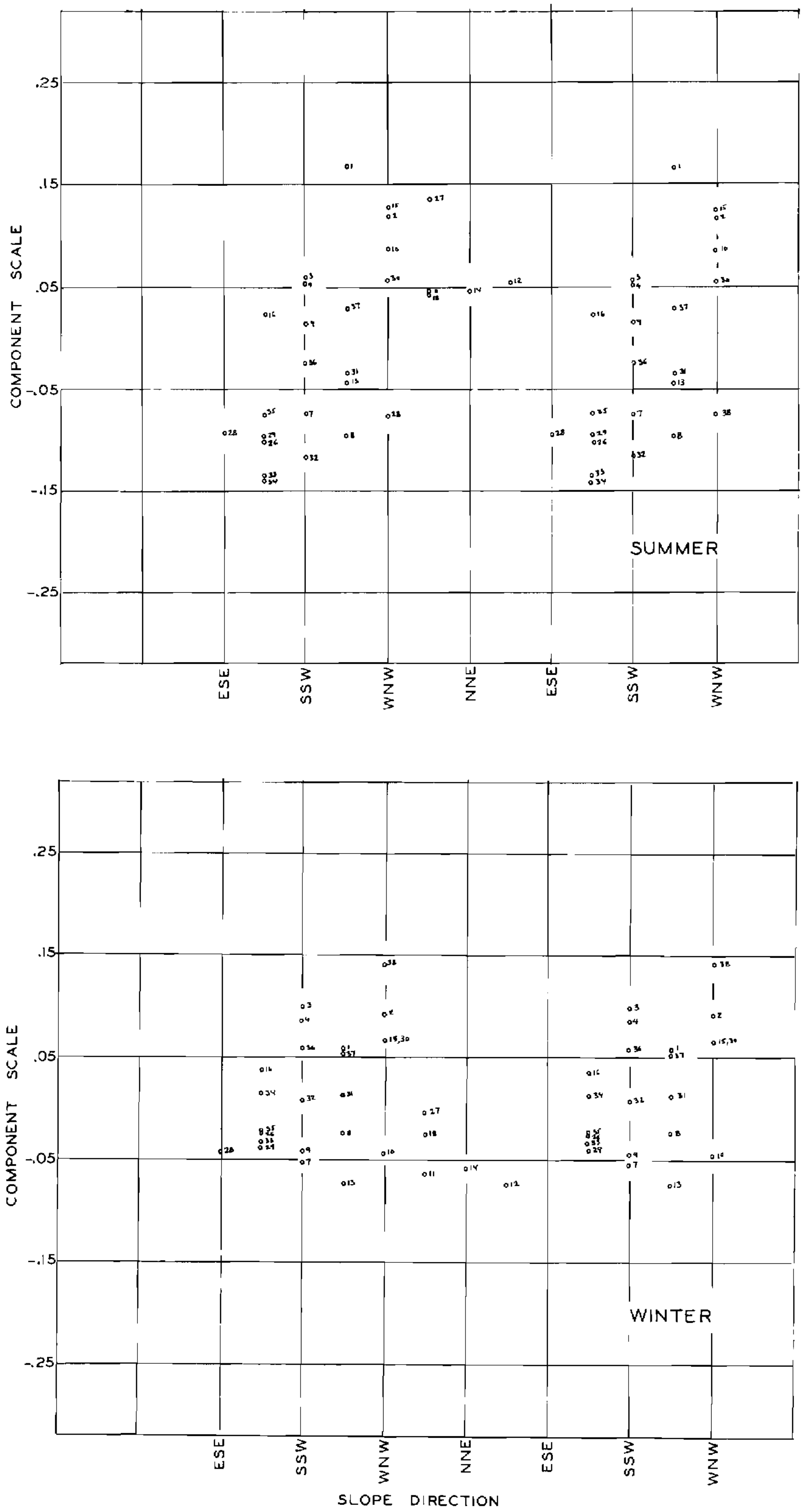


FIGURE C-4. COMPONENT 3 VS. SLOPE DIRECTION - COWEETA

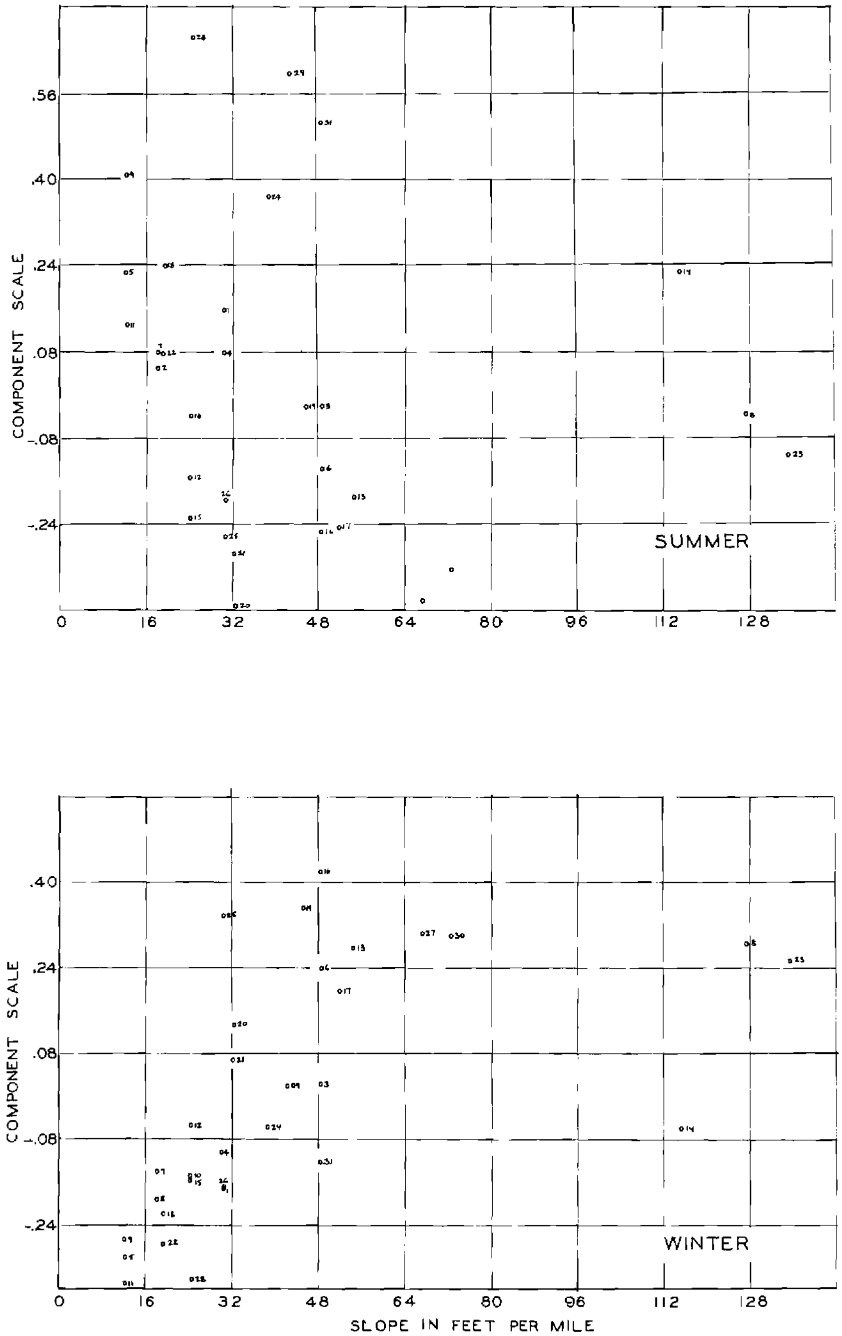


FIGURE C-5. COMPONENT 2 VS. SLOPE - GEORGIA

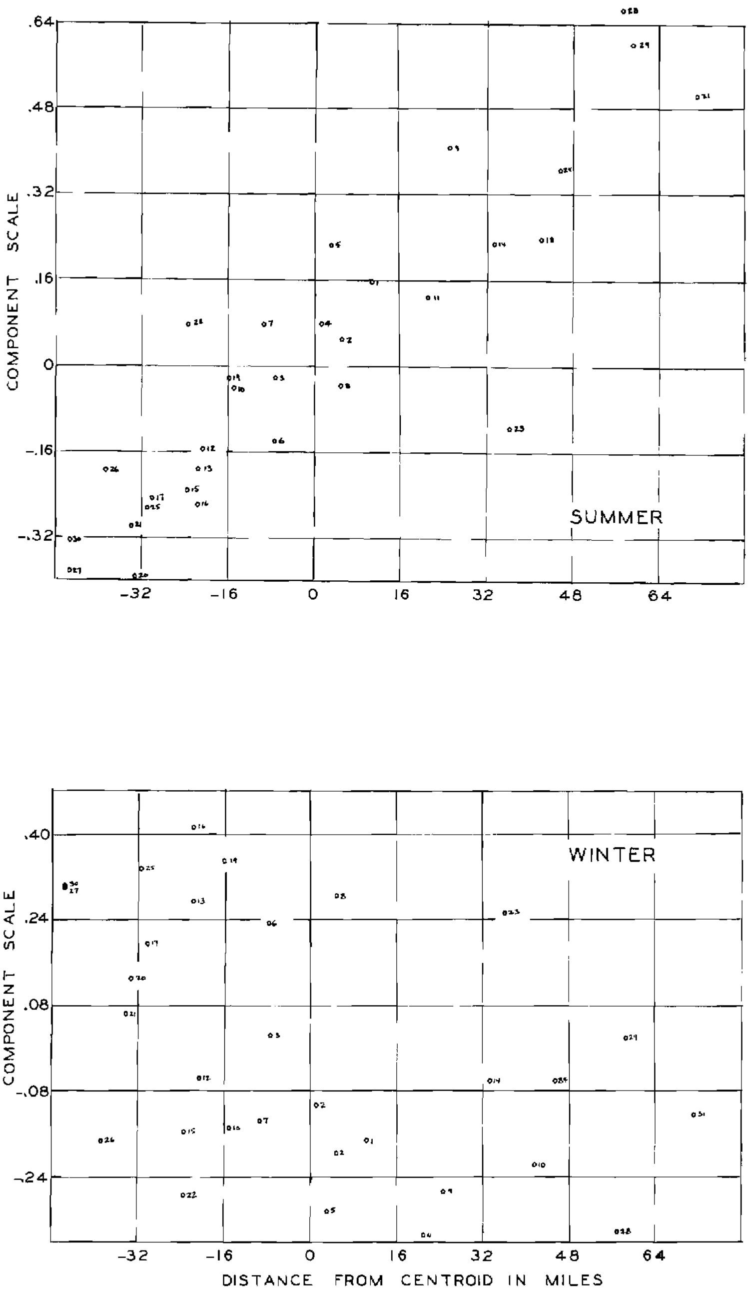


FIGURE C-6. COMPONENT 2 VS. LONGITUDE-GEORGIA

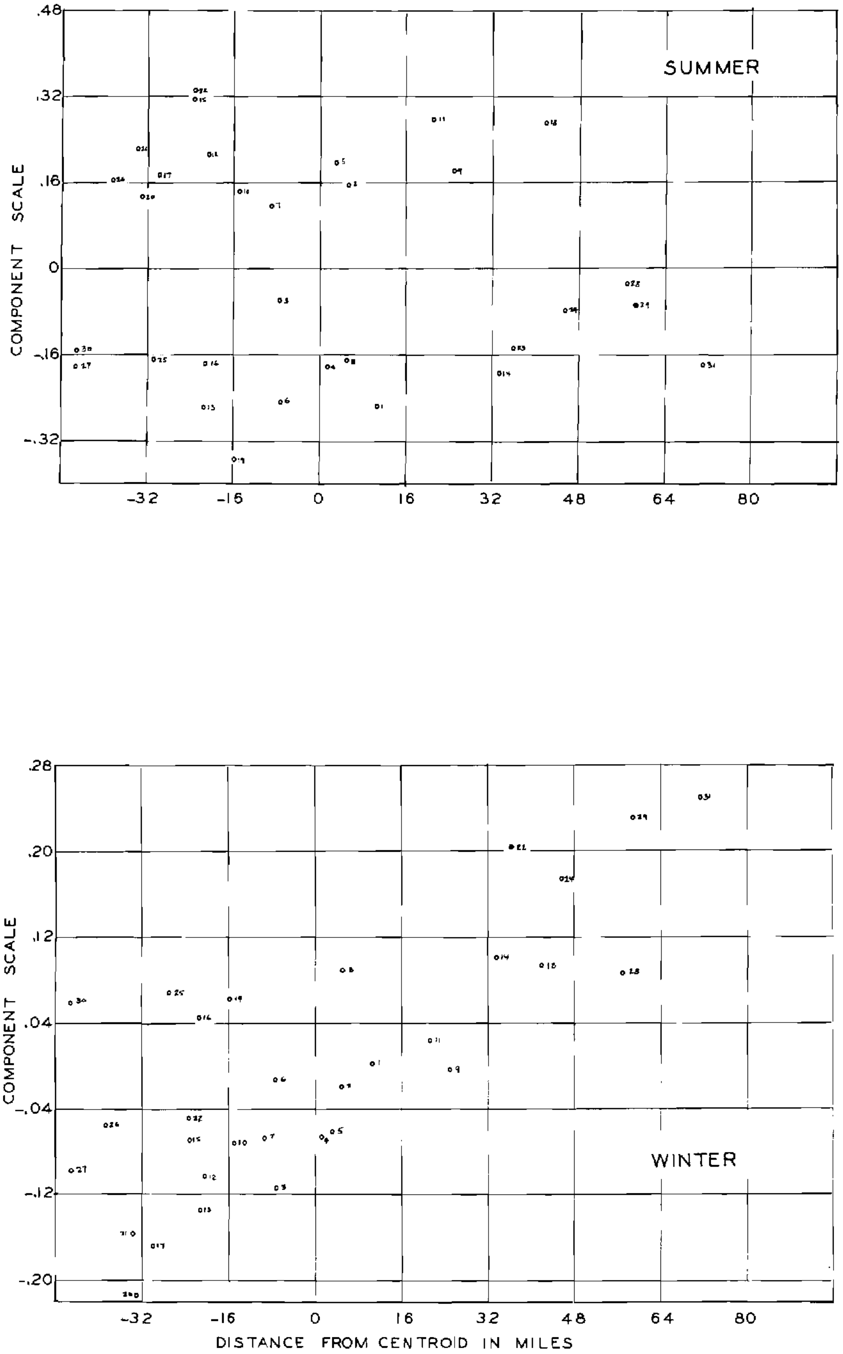


FIGURE C-7. COMPONENT 3 VS. LONGITUDE - GEORGIA