KANSAS GEOLOGICAL SURVEY
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GEOLOGIC CONTROLS ON DRAINAGE DENSITIES AND ORIENTATIONS, NORTH-CENTRAL KANSAS

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Abstract

Comparison of 4426 stream link orientation measurements with geologic structural trends, paleoslope surfaces, and solar insolation angle for a large area of north-central Kansas indicates that the orientations of a majority of these streams were apparently influenced by one or more of these factors. The strongest correlation is with solar insolation angle, particularly on smaller order streams and in easily erodable strata. The strongest correlation with geologic controls is for regional joint trends within smaller order basins, and with regional fold axes for rivers and major streams. High drainage densities are correlated at all scales with areas of Permian bedrock subjected to Pleistocene glaciation; however, the differences may not be significant.

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A fine study – worthy of publication as an article in a [illegible] journal [illegible] the [illegible]. I am very [illegible] amazed [illegible] [illegible] interesting findings!

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Introduction

Background Information

The drainage pattern of Kansas and its origin represents an interesting aspect of Kansas geology that has received rather sporatic attention over the years, but little detailed study. At first glance, the drainage network of much of Kansas appears to demonstrate a "textbook example" of the basic dendritic pattern of fairly uniform density. However, on closer inspection it is apparent that certain stream orientations are more prevalent than others, producing a distinctly subdendritic to rectangular appearence (Howard, 1967). Drainage density also appears to vary somewhat from place to place. This paper will focus primarily on these two aspects of Kansas drainage patterns and attempt to asccount for any distinct trends.

In his pioneering work on the relationships between drainage and structure in southern Kansas and central Oklahoma, Melton (1959) found that stream orientations were most strongly correlated with solar insolation angle (i.e. oriented preferentially north-south) and secondarily with regional joint patterns. The solar influence on drainage was most pronounced in lower order basins, whereas joint effects were strongest in higher order streams. This conclusion disagrees somewhat with the findings of Baehr (1954) who studied drainage and rock structure in three small basins in the south half of the Junction City 30-minute quadrangle of Geary and Riley counties, Kansas. Baehr stated (p. 57) that bedding and joints acted as the primary controls on headward migration of tributaries cutting the thick Permian limestones of his study area. He did not attribute any componants to nongeologic (i.e. solar) effects. Merriam (1955, p. 82) remarked on the angularity of drainage in western Kansas, and later (Merriam, 1963, p. 254) suggested a bedrock fracture control. Kirk (1968) noted a rectilinear pattern existed for much of the drainage pattern of eastern Kansas. He correlated the stream trends with surface fractures, basement faults, earthquake epicenter distribution, geophysical anomaly trends, and the locations of igneous intrusions, but offered no quantitative data in support. Ward (1968) measured 5,777 joints in Pennsylvanian and Permian limestones in south-central Kansas. He also remarked (p. 15) on an apparent influence of the joints on both the overall drainage pattern, and the location of minor drainage ways. Chelikowsky (1972, p. 7) mentioned an "angular pattern" to the drainage of Riley County which he attributed the regional joint pattern, but offered no data to support this view. McCauley and others (1975) utilized an optical Fourier transform of Landsat satellite imagery to define dominant stream trends for several portions of north-central Kansas. They argued that tectonic influences had produced zones of weakness along which streams would tend to prefferentially downcut. Berendsen, and others (1978) utilized the linear trends of eastern Kansas rivers to define structural lineaments in the Precambrian basement, although they did not suggest why this relationship should be true. Most recently, Hoppie (1980) evaluated geologic influences on the morphology, including orientation, of the Solomon River in north-central Kansas. He concluded that the orientation of a portion of the river flowing over the Cretaceous Greenhorn Limestone may have been influenced by a well-developed set of joints in this unit, but the evidence for other portions of the river was inconclusive.

Each of the foregoing studies has either addressed a certain aspect of Kansas Geology only indirectly related to the origin of drainage patterns or has addressed the question directly, but only for a very limited area of Kansas. In addition, the writer was unable to locate any references to drainage density studies in the regional literature. What is lacking is a comprehensive analysis of drainage densities and orientations for a large area of Kansas in light of the considerable amount of baseline geologic data that has become available after years of study. The following study was undertaken as an attempt at this.

Drainage densities and stream-segment orientations were measured on standard topographic map products at 3 scales (1:1,000,000; 1:250,000; 1:24,000) for that portion of north-central Kansas between 38 and 40 degrees north latitude and between 96 and 98 degrees west longitude (Fig. 1). The orientations of 4426 stream links representing 9510.8 linear kilometers of drainage were compiled in the form of rose diagrams and compared with known geologic structures (joints, faults, bedding, flexures) and other factors (regional slope, glacial history, solar insolation angle) to ascertain the possible controls acting on drainage orientations. Stream link densities provided a only a fairly crude measure of drainage density and were considered of limited utility for geologic analysis.

Study Area

The study area comprises about 38,000 square kilometers of north-central Kansas. Although it is presently characterized by a sub-humid continental climate, the northeastern portion was glaciated at least twice during the Pleistocene and most of the present day drainage pattern is probably descended from ancestral drainage developed under alternating periods of interstadial and glacial/periglacial conditions (Frye and Leonard, 1952). Average annual precipitation ranges from about 60 centimeters in the northwestern corner to around 90 centimeters in the southeastern corner, but the amount received usually varies considerably from year to year. Prior to settlement in the late 1800's, native (climax) vegetation consisted of tall to mid-grass prairie on the uplands and hillsides, and narrow stands of deciduous trees along major watercourses. Modern land use includes primarily cereal grain production on tillable lands and livestock grazing on seminative pasture tracts (steeper slopes) within the Flint Hills and Smoky Hills.

Geologically, the study area lies in the Prairie Plains monocline

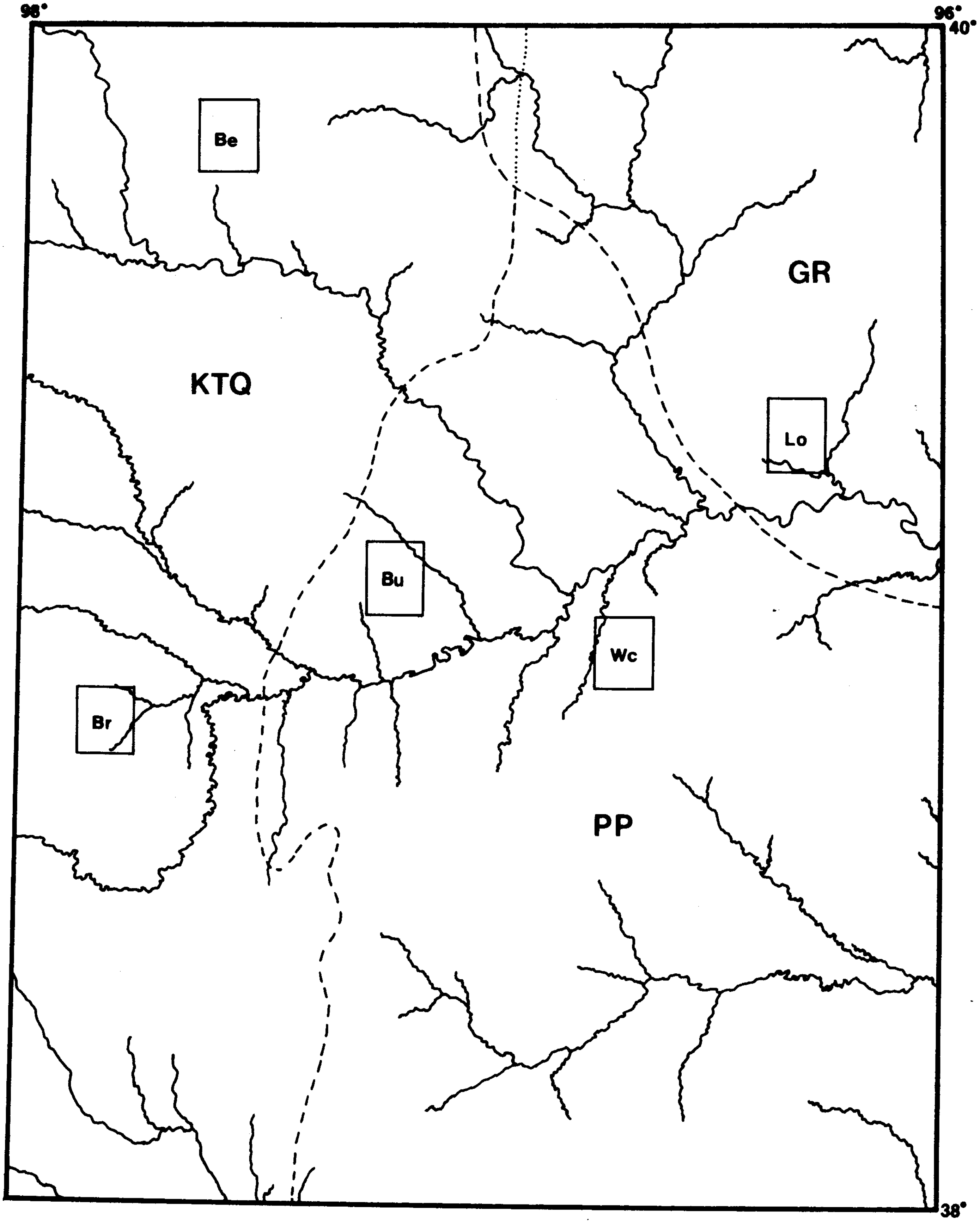


Figure 1. Map of study area showing rivers and major streams, generalized geology (PP = Pensylvanian-Permian bedrock, KTQ = Cretaceous-Tertiary-Quaternary deposits, GR = glaciated region), and locations of maps referred to in text. Scale 1:1,000,000.

structural province (Jewett, 1951). Regional dips of a few meters per kilometer or less (<1 degree) to the west are common, although local structures may reverse this general trend. The Precambrian surface is broken by the east-northeast trending Nemaha Uplift along the eastern edge of the study area. The largest structural feature in the basement is the Central North American Rift System (CNARS) of Keweenawn age, which parallels the Nemaha Uplift to the west. The CNARS is thought to have had a profound influence on all subsequent structural development in the area of the Salina Basin (Serpa, et al., 1984). Only a few significant faults are known to cut surface rocks within the study area (Coombs, 1948; Sternin, 1961; Merriam, 1963, p. 252), but quite a few basement faults have been infered from geophysical and borehole data (Geometrics, 1977; Berendsen, et al., 1978; Yarger, 1983).

Information on regional joint sets has been collected for Pennsylvanian and Permian rocks within Riley County by Neff (1949, Plate 1), Marshall County by Nelson (1952, Plate 2), Geary County by Baehr (1954, Plate 1), Chase County by Ward (1968, Plate 1), Morris County by Macfarlane (1979, Plate C), and for Cretaceous rocks in Ottawa and surrounding counties by Hoppie (1980, p. 53). Studies in Kansas outside the study area provide additional information on regional joint trends (Wagner, 1961, Wilson County; Stewart, 1967, Douglas and Jefferson counties; Neuhauser, 1983, Ellis County). The joint-trend data utilized in this study come from these sources. Joints within the Paleozoic units show a remarkable consistancy of orientation throughout much of the Mid-continent (Ward, 1968). Only locally do sets deviate much from the regional trends, probably in response to local structures (Chelikowsky, 1972). In fact, this apparent tendency lead Baehr (1954, pp. 57-58) to propose structural mapping for petroleum exploration in this area of Kansas on the basis of analysis of stream orientations.

The Phanerozoic section ranges in thickness from less than 170 meters in

Marshall County above the Nemaha Uplift to about 1300 meters in Saline County. Consolidated outcropping strata (Fig. 1) consist of Pennsylvanian and Permian shales and limestones, sandstones and shales of the Cretaceous Dakota Group, and limestones and shales of the Cretaceous Colorado Group. Unconsolidated deposits include the Tertiary "Equus Beds" of the McPherson County area, similar deposits in northern Republic County, Pleistocene glacially-derived sediments in portions of the northeastern corner, and Quaternary alluvial fill in modern river and stream valleys. Lithologies of bedrock units exposed in the detailed study quadrangles are shown in Fig. 2.

The point in time during which modern streams began to erode in their present locations is difficult to estimate. The Pleistocene erosional history of major rivers in Kansas was outlined by Frye and Leonard (1952). Bayne and Fent (1963) stated (p. 363) that most, if not all, modern drainage probably post-dates the late Pliocene. Stewart (1973) agreed with this interpretation. Hoppie (1980, Plate 1) made an attempt at deriving the pre-erosional topographic surface. His reconstructed surface shows a gentle eastward slope about 30 degrees to the south of east with values of about 1.2 m/km for the Cretaceous Colorado strata, around 0.2 m/km for the Cretaceous Dakota and uppermost Permian shale units, and around 2.0 m/km for the more resistant Permian and Pennsylvanian rocks along the eastern margin (Flint Hills) of the study area. This paleosurface will be regarded as the surface upon which the major drainages under consideration here could have developed.

Methodology

Data Collection

The basic source of information on drainage in north-central Kansas consisted of a set of standard U.S. Geological Survey topographic map products at three scales. Areas analyized included the entire study area at a scale of

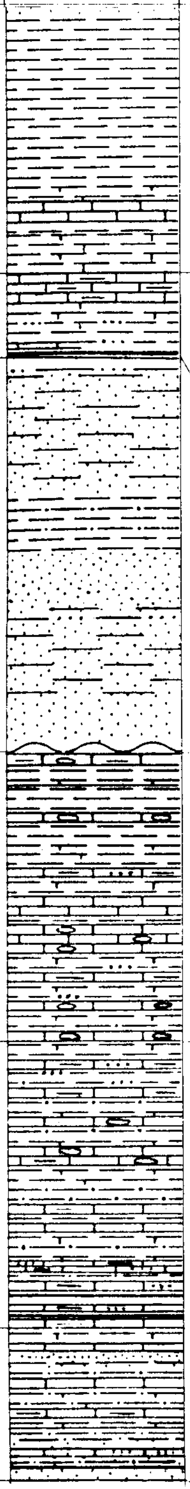
SYS	SERIES	GROUP OR FORMATION		LITHOLOGY	GENERALIZED DESCRIPTION
CRETACEOUS	Upper Cretaceous	Colorado Group	Carlile Shale		Shale, limestone, and sandstone. At top, locally about 5 feet thick, gray to pale-yellowish-brown siltstone or very fine grained sandstone. Shale, upper 200 feet, is dark gray to medium gray; locally contains ironstone concretions, and interbedded very thin siltstone layers. Shale, lower 80 feet, is medium gray, calcareous, and contains many very thin and thin bedded, fossiliferous, shaly limestone and calcareous shale layers.
			Greenhorn Limestone and Graneros Shale		Greenhorn Limestone is medium gray to light gray; contains interbedded argillaceous limestone, marl, and calcareous shale; fossiliferous. Upper and lower boundaries are both gradational and conformable. Thickness 0-30 feet. Graneros Shale is medium gray to dark gray, interbedded with thin layers of silt; upper part, about 40 feet thick, interbedded with thin limestone layers; lower part, about 25 feet thick, contains thin layers of carbonaceous material.
	Lower Cretaceous	Dakota Sandstone			Sandstone and interbedded sandy carbonaceous shale, lenses of sand cemented by iron oxide, and siltstone concretions; light gray, yellowish gray, brownish gray, and reddish brown; beds are lenticular, locally crossbedded; sandstone is fine to coarse grained, micaceous, and contains scattered chert pebbles. Equivalent to Dakota Group of the Nebraska Geological Survey, which includes (descending order): the Omadi Sandstone, Skull Creek Shale, Fall River Sandstone, Fuson Shale, and Lakota Sandstone.
		UNCONFORMITY			
PERMIAN	Lower Permian	Chase Group			Limestone and shale. Limestone is light gray to dark gray, yellowish gray to pale yellowish brown. Two limestones in the upper part are thin bedded to medium bedded, argillaceous, cherty and fossiliferous; two limestones in the lower part are medium bedded to massive bedded, very cherty, and fossiliferous. Shale is gray, green, red, reddish brown, calcareous, arenaceous, fossiliferous; locally fissile. Chase Group equivalent to upper part of Big Blue Series of the Nebraska Geological Survey, which includes (descending order): Nolans Limestone, Odell Shale, Winfield Limestone, Gage Shale, Towanda Limestone, Holmesville Shale, Barneston Limestone, Blue Springs Shale, Kinney Limestone, Wymore Shale, and Wreford Limestone.
		Council Grove Group			Shale and interbedded limestone. Shale is gray, green, red, reddish brown, or maroon, sandy, calcareous, fossiliferous; locally fissile; several fissile black shale beds are in lower 75 feet. Interbedded dark- to light-gray, medium- to thick-bedded, argillaceous, cherty limestone beds are very fossiliferous and locally contain shale partings. Council Grove Group equivalent to middle part of the Big Blue Series of Nebraska Geological Survey, which includes (descending order): Speiser Shale, Funston Limestone, Blue Rapids Shale, Crouse Limestone, Easly Creek Shale, Bader Limestone, Stearns Shale, Beattie Limestone, Eskridge Shale, Grenola Limestone, Roca Shale, Red Eagle Limestone, Johnson Shale, and Foraker Limestone.
		Admire Group			Shale and interbedded limestone. Shale is dark gray to light gray, brown, red, or green, sandy, calcareous, and fossiliferous. Interbedded dark- to light-gray, very thin to medium bedded, argillaceous very fossiliferous limestone beds. Near top of unit a fine-grained, micaceous sandstone bed underlies a stromatolite limestone bed which has distinctive lobate bedding. Admire Group equivalent t lower part of Big Blue Series of the Nebraska Geological Survey, which includes (descending order) Hamlin Shale, Five Point Limestone, West Branch Shale, Falls City Limestone, and Onaga Shale.

Figure 2. Generalized stratigraphic column of Permian and Cretaceous rock units exposed in detailed-study quadrangles (after Dreeszen, et al., 1973).

1:1,000,000; the three major geologic subdivisions of the study area (Fig. 1) at a scale of 1:250,000; and 5 much smaller "detailed-study" areas at a scale of 1:24,000. The general data collection technique followed that of Flarity (1978). It consisted of attaching a sheet of tracing paper to each map area and approximating all observable valley-center orientations and lengths by tracing straight line segments (links) onto the overlay. "Observable valleys" included all those with perminant or intermitant streams shown on the maps, and lines connecting all distinct contour-line crenulations in the manner recomended by Morisawa (1957). Stream link orientations and lengths on each completed overlay were measured and grouped into 18 different northern-hemisphere 10-degree interval classes. It was not deemed necessary to record actual streamflow direction (Cox and Harrison, 1979). These class data were subsequently tabulated for each map area. Previous studies have generally shown a high degree of positive correlation between link length and link frequency, and this relationship was found to hold for most of the current study area data. As a result, Flarity (1978) recommended link orientations be compiled into length-weighted percent-frequency rose diagrams for comparison with geologic data. The use of percent-frequency scaling produces diagrams of roughly the same scale and thus permits easy comparison between areas of markedly different length distribution characteristics. This approach was taken here and length scales on the resultant diagrams (Figs. 3 through 9) only range from 10 to 20 percent.

The 1:1,000,000 scale base map of Kansas was utilized for analyzing drainage basins exceeding 100 square kilometers in area. This includes all rivers and major streams within the study area, as portrayed on Fig. 1. Due to the limited sample size (108 links), the study area was not subdivided on the basis of bedrock type at this scale. It was hoped that analysis at this scale might yield information on drainage control by the very largest basement structures as suggested by Wise (1969).

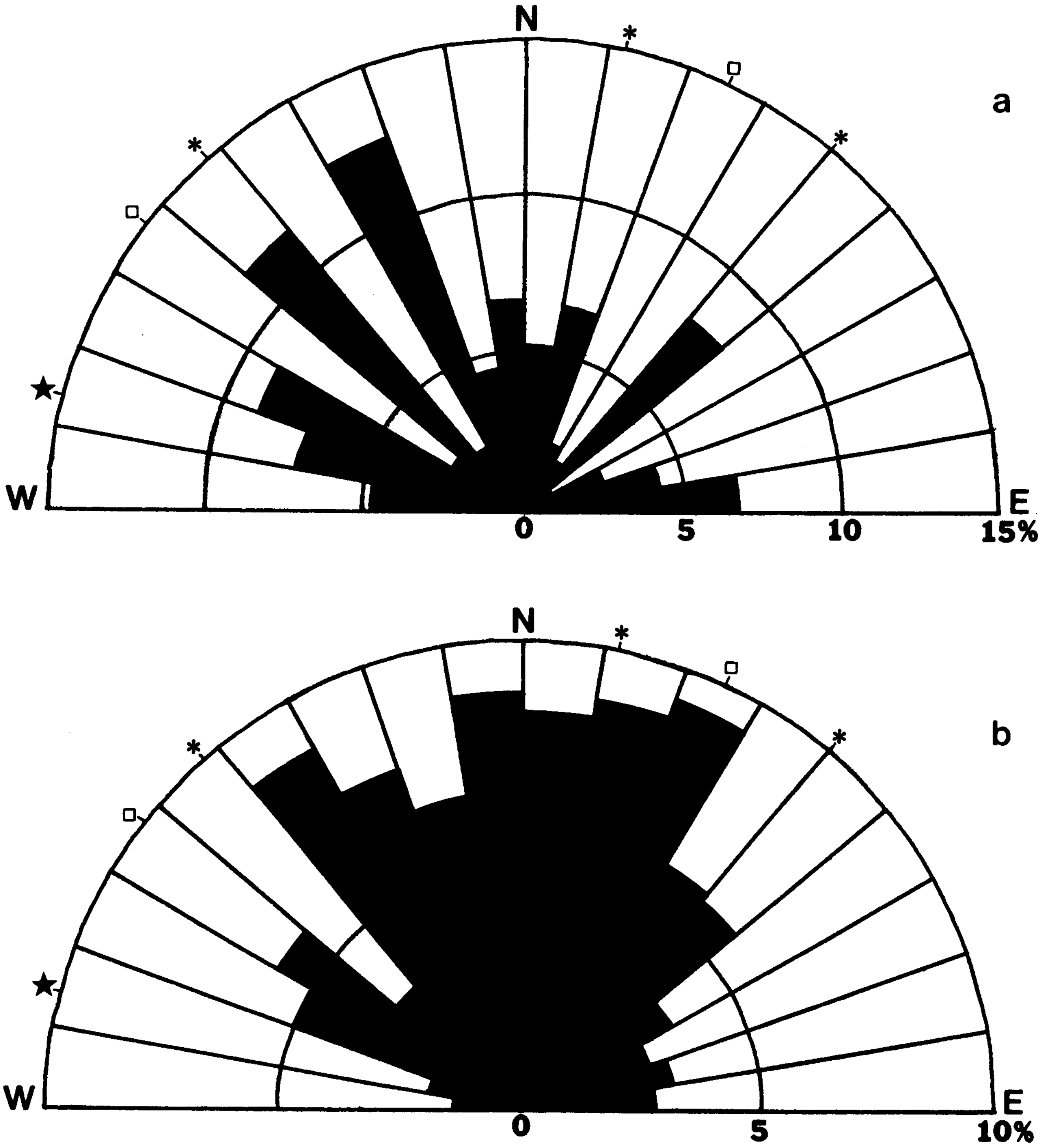


Figure 3. Rose diagrams for (a) rivers and major streams of entire study area, and (b) larger streams in Pennsylvanian-Permian bedrock portion of study area. Orientation of regional fault trends (open squares), fold axes (asterisks), and restored surface slope (star) also shown.

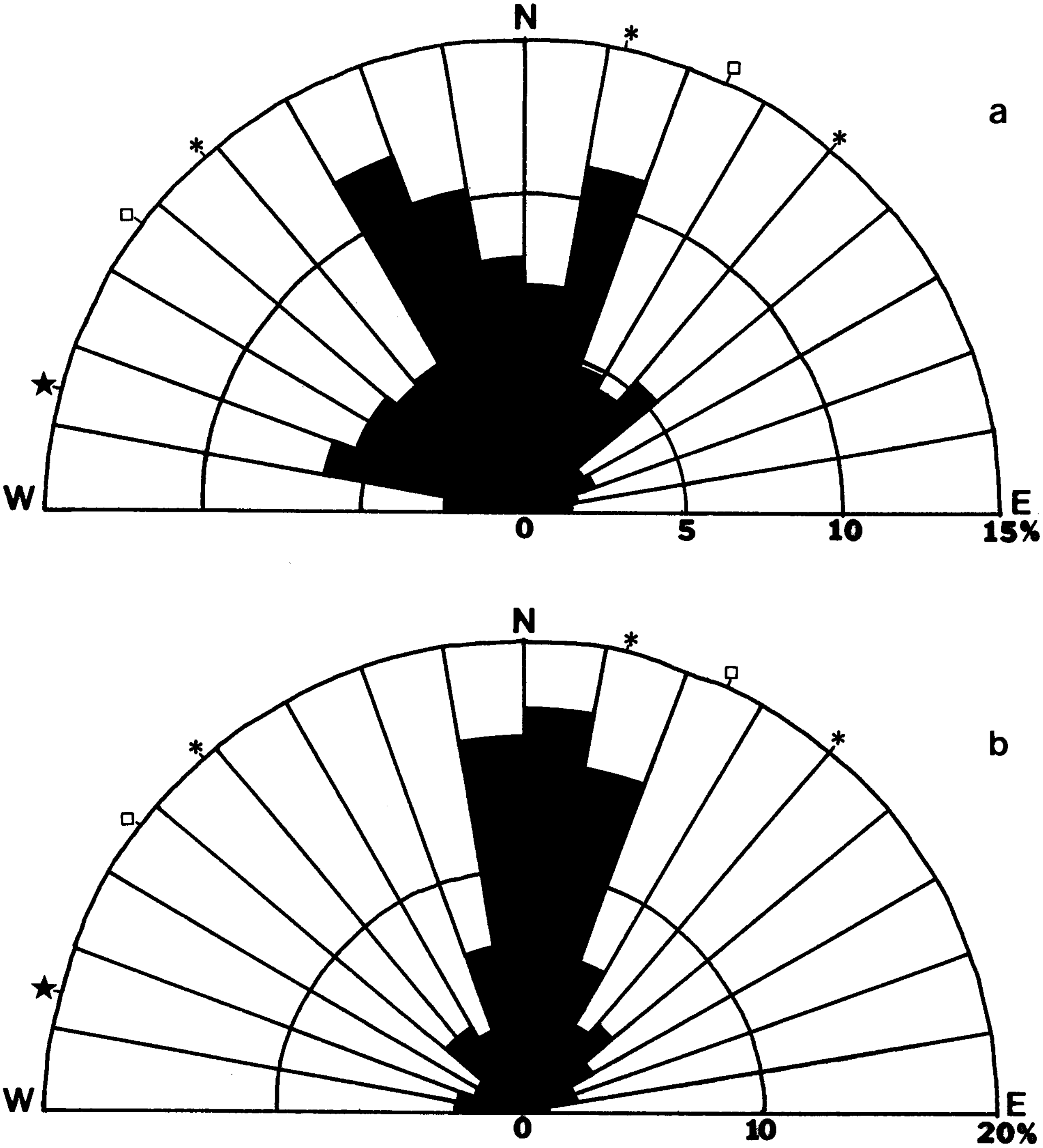


Figure 4. Rose diagrams for larger streams in (a) glaciated region and (b) Cretaceous-Tertiary-Quaternary portion of study area. Orientation of regional fault trends (open squares), fold axes (asterisks), and restored surface slope (star) also shown.

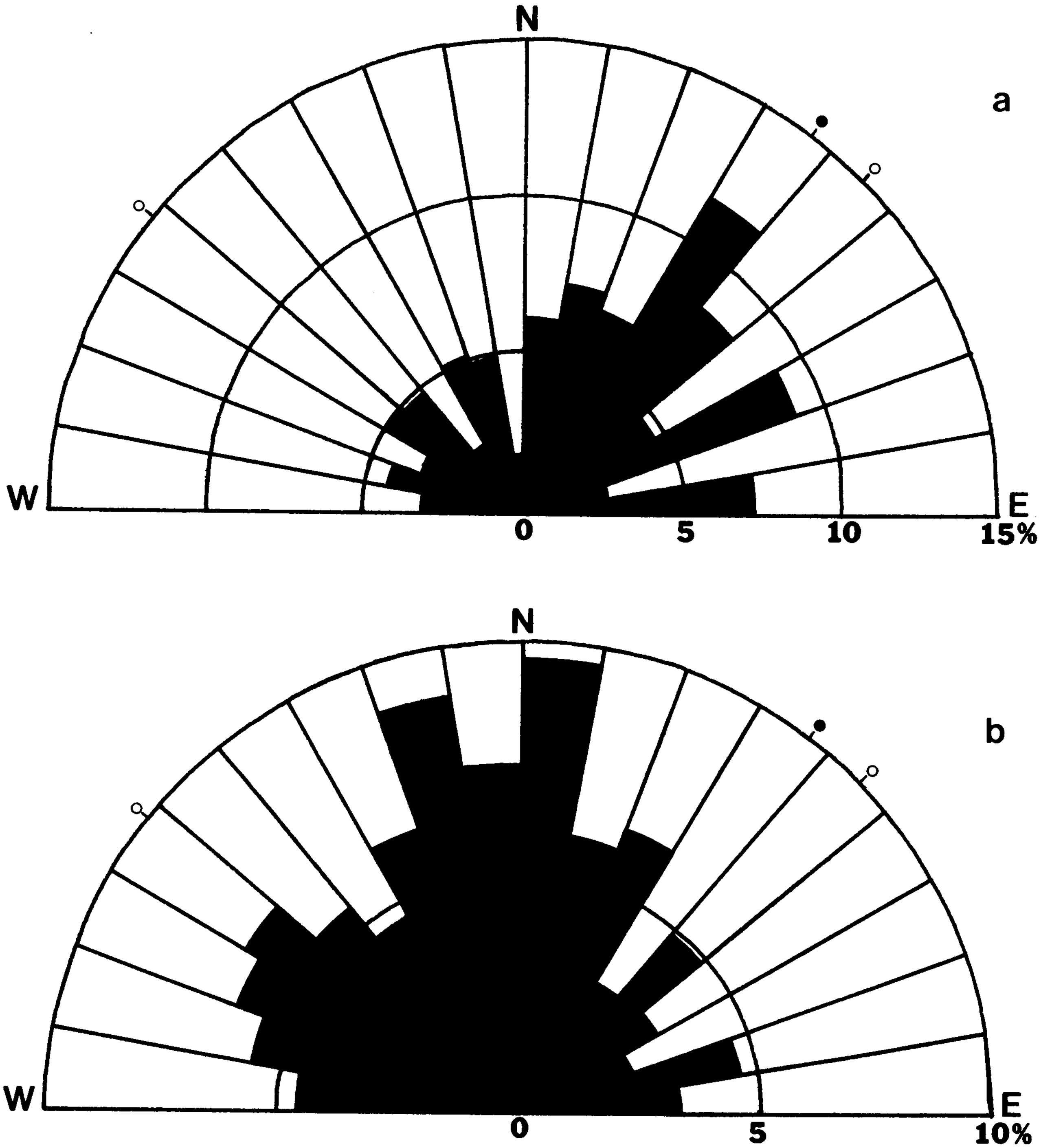
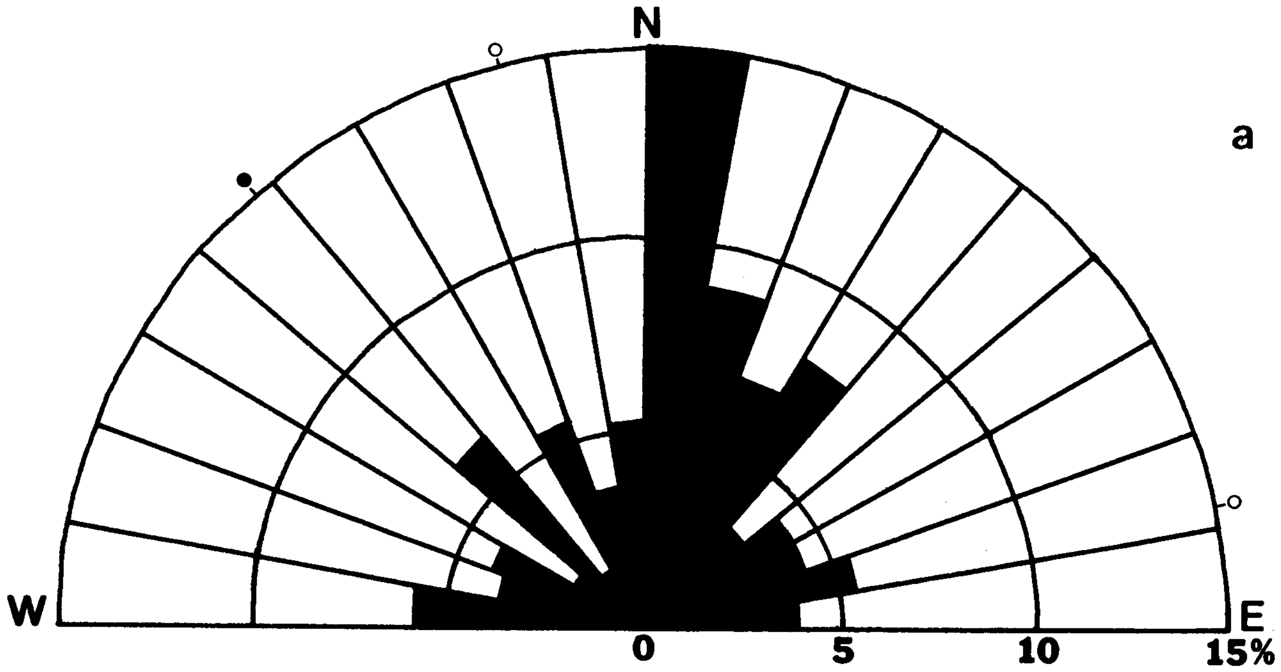


Figure 5. Rose diagrams for (a) minor streams, and (b) first order streams in White City quadrangle detailed-study area. Orientation of local joint trends (open circles) and bedding dip (solid circle) also shown.



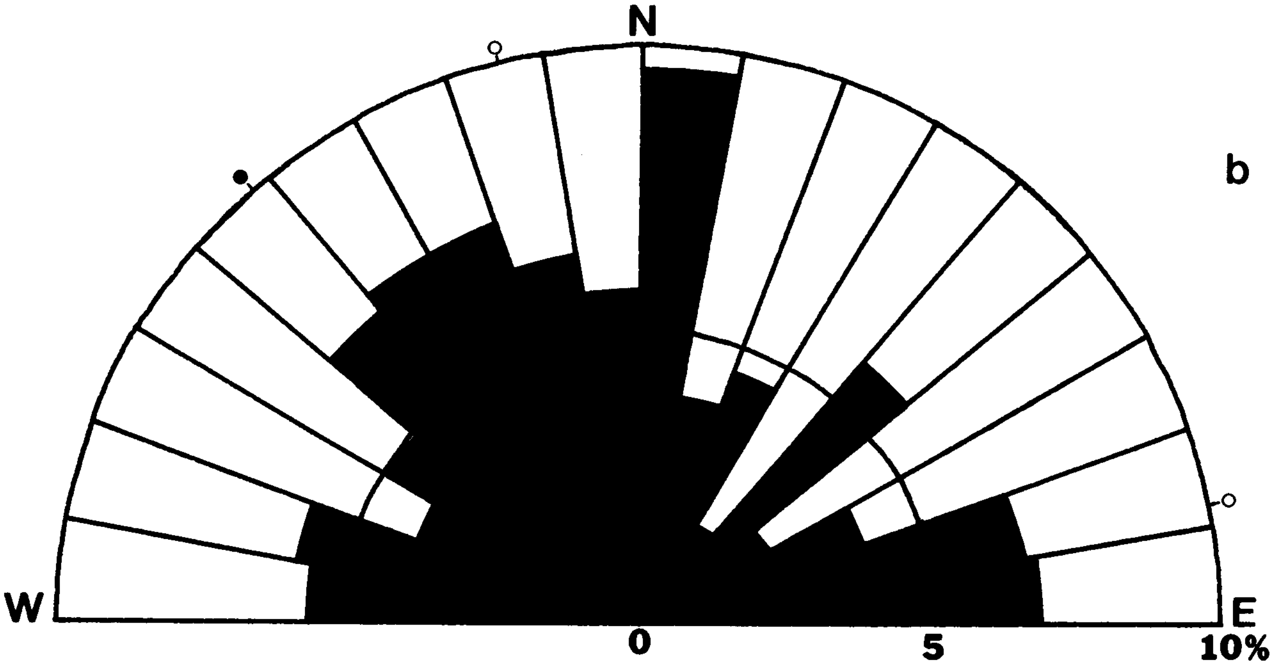
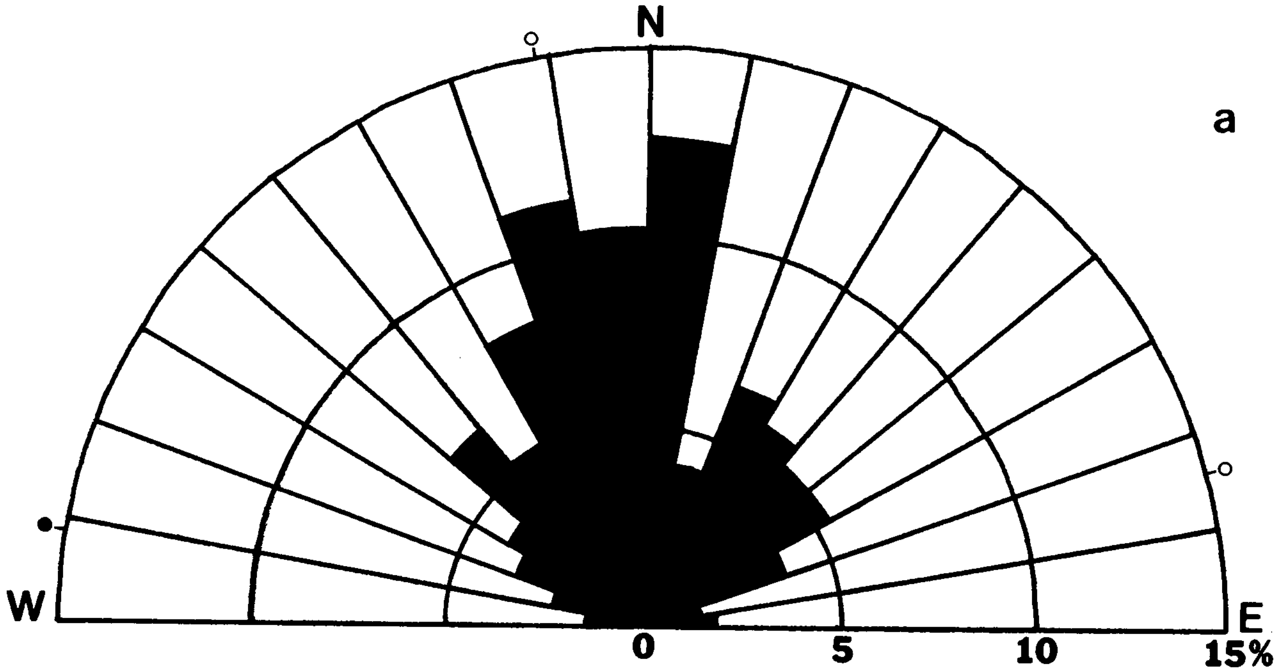


Figure 6. Rose diagrams for (a) minor streams, and (b) first order streams in Buckeye quadrangle detailed-study area. Orientation of local joint trends (open circles) and bedding dip (solid circle) also shown.



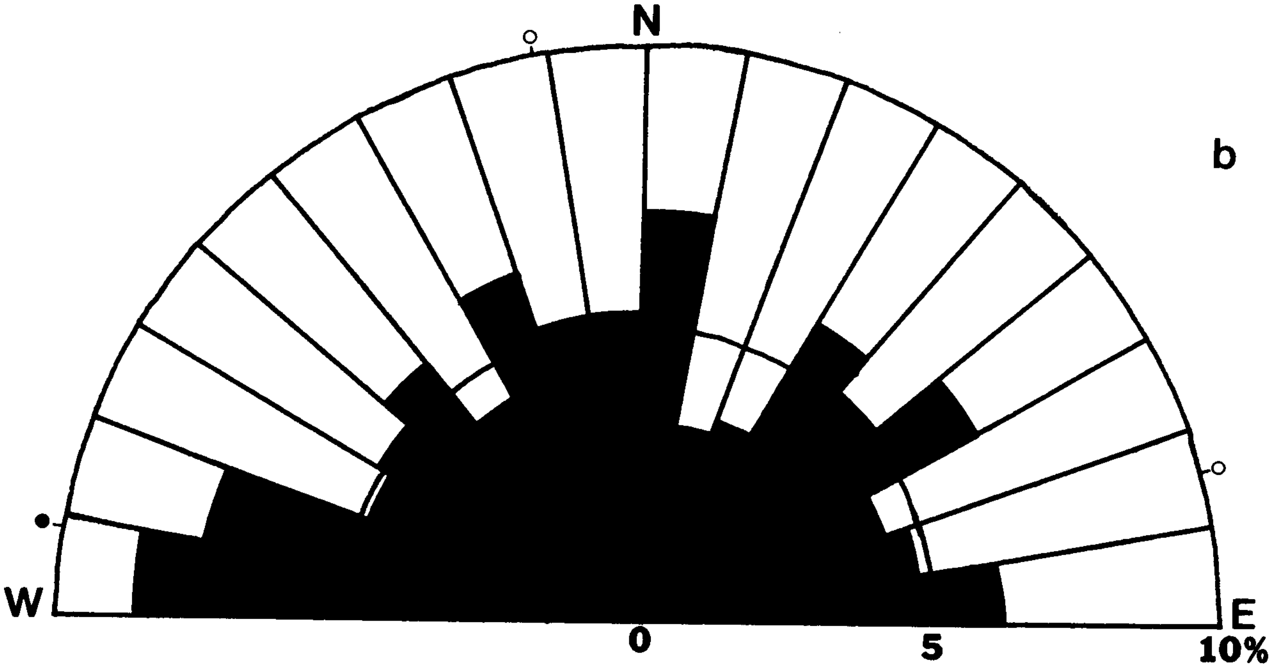
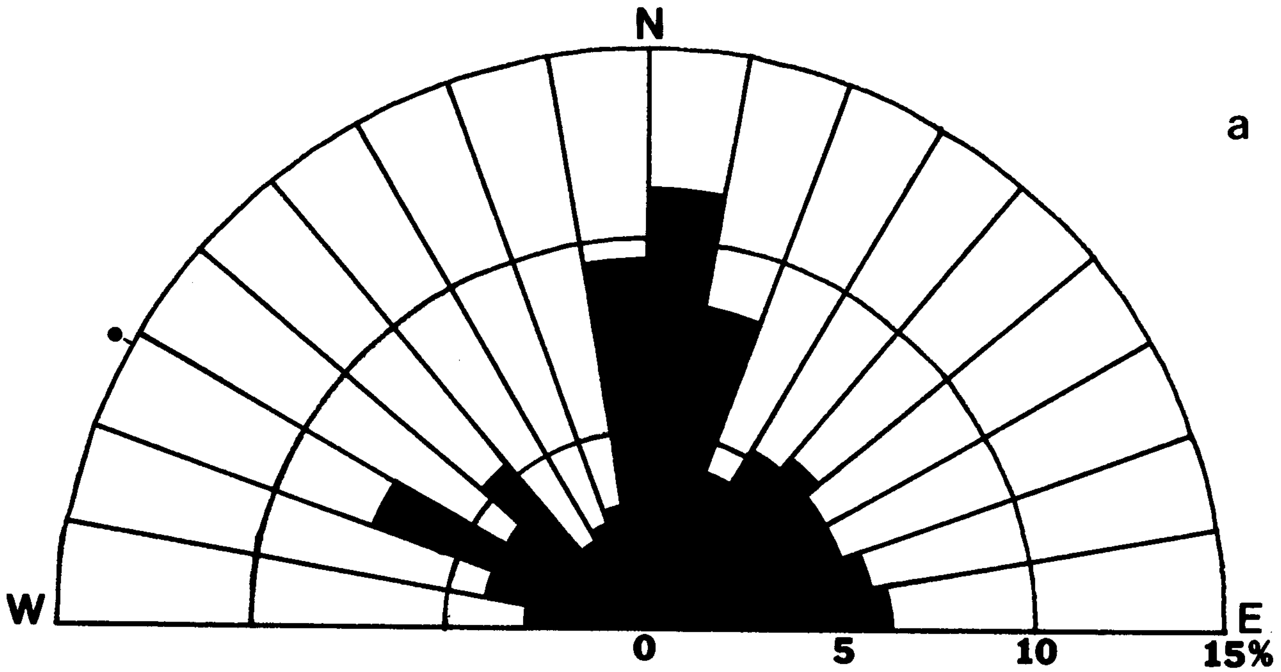


Figure 7. Rose diagrams for (a) minor streams, and (b) first order streams in Louisville quadrangle detailed-study area. Orientation of local joint trends (open circles) and bedding dip (solid circle) also shown.



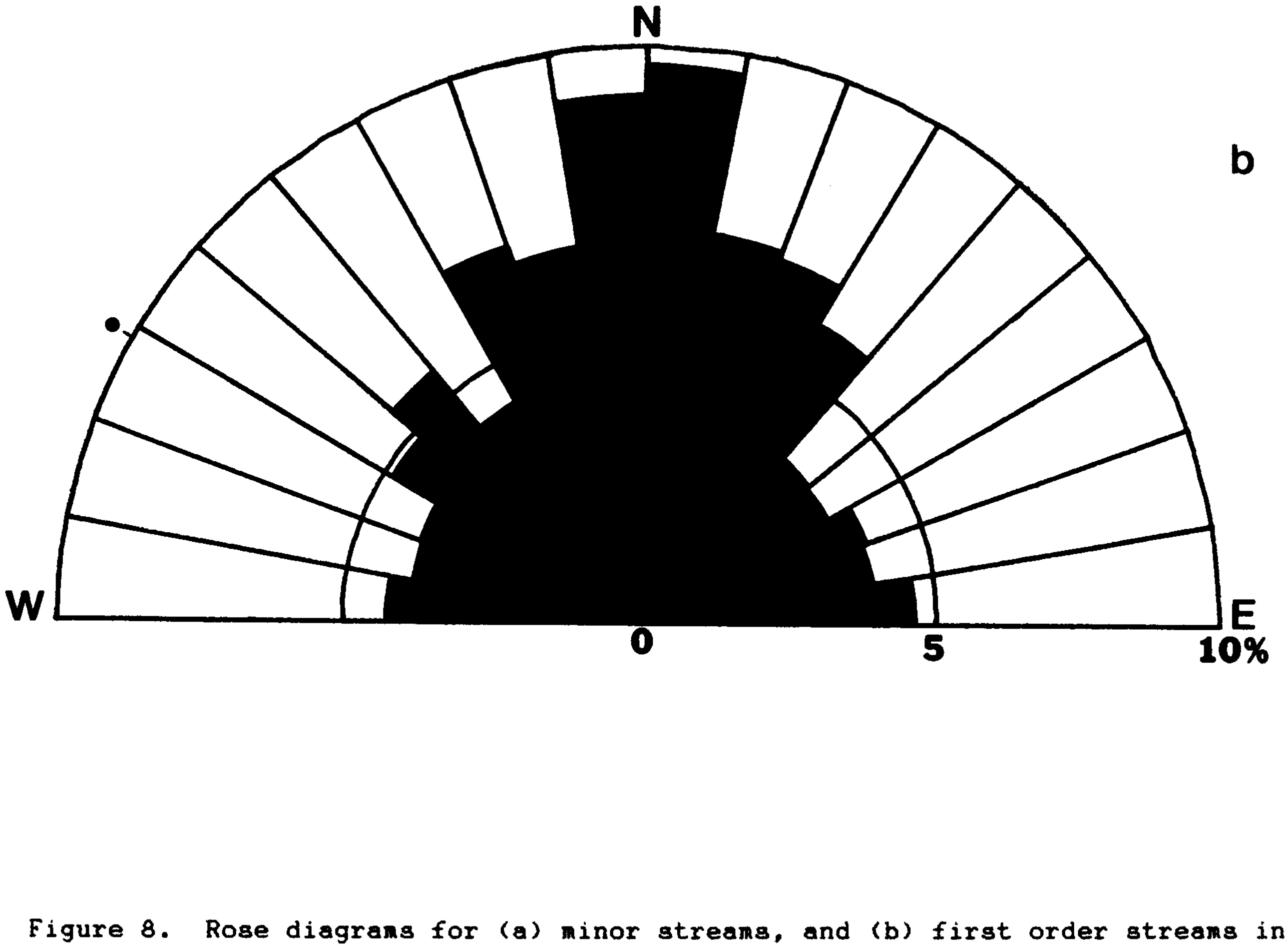
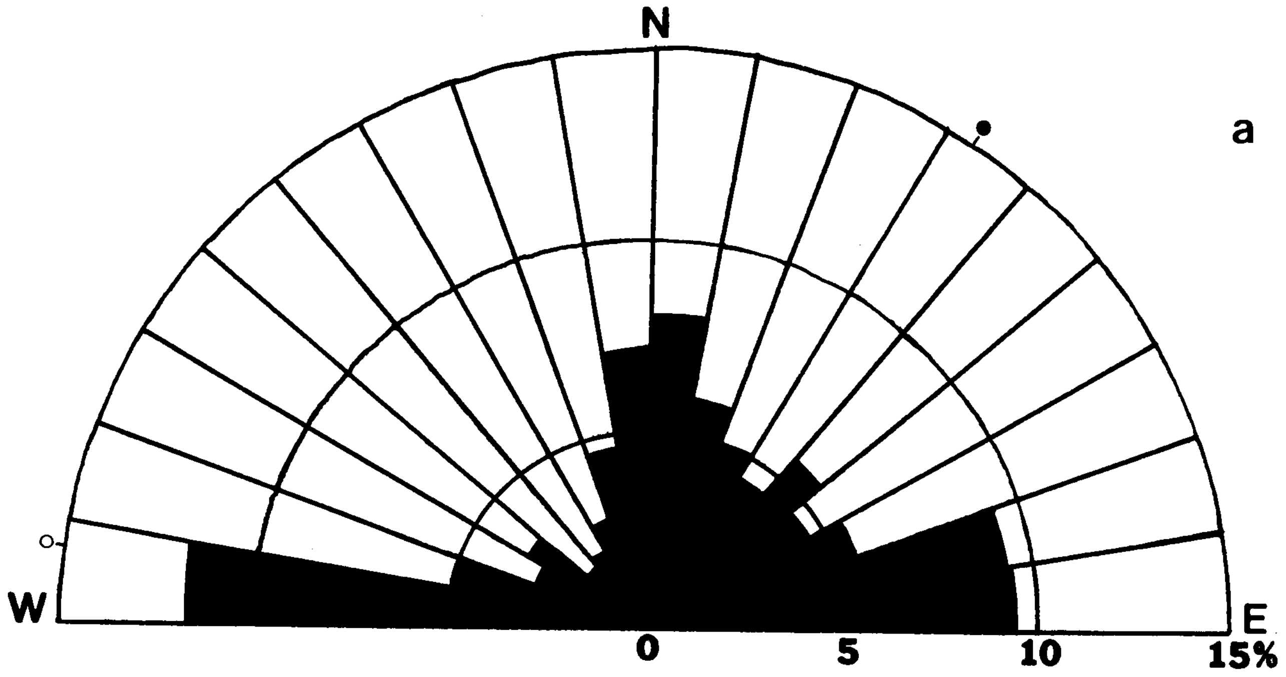


Figure 8. Rose diagrams for (a) minor streams, and (b) first order streams in Brookville quadrangle detailed-study area. Orientation of local bedding dip (solid circle) also shown.



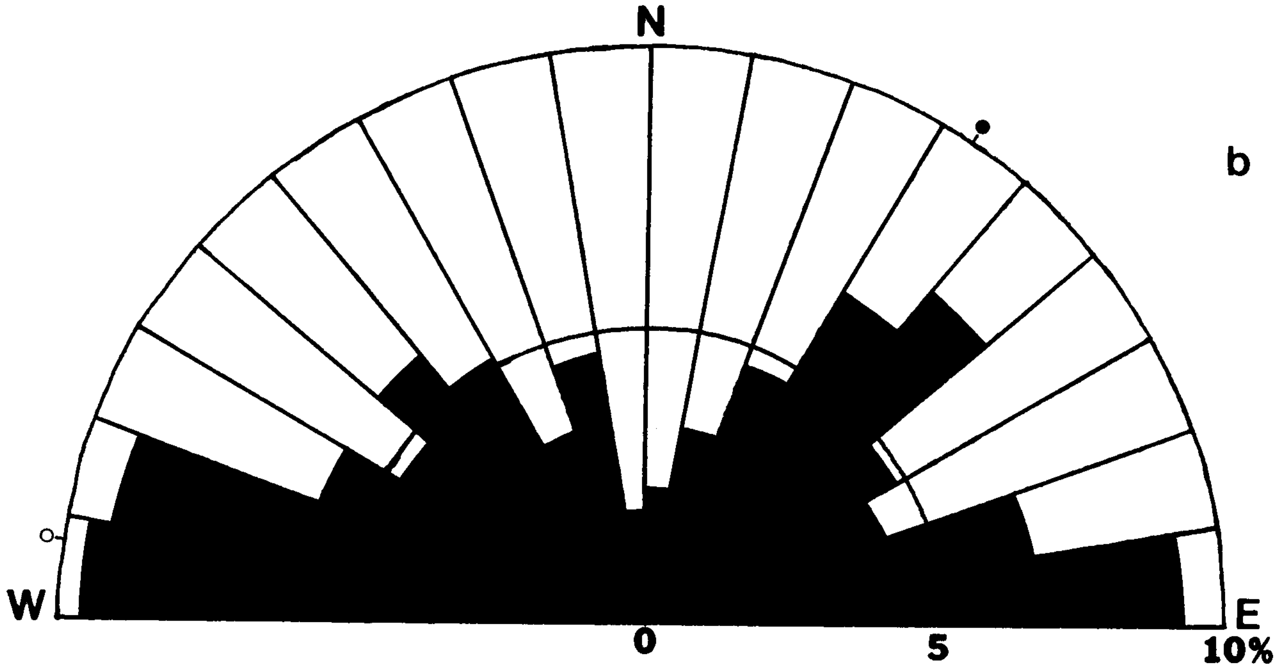


Figure 9. Rose diagrams for (a) minor streams, and (b) first order streams in Belleville SE quadrangle detailed-study area. Orientation of local joint trend (open circle) and bedding dip (solid circle) also shown.

Analysis of the two 1:250,000 scale topographic maps of the study area (Manhatten and Hutchison sheets) included subdivision on the basis of generalized bedrock age (Fig. 1). In this phase of the study, larger streams and creeks with basin drainage areas greater than about 10 square kilometers, but less than 100 square kilometers were included in the analysis. It was hoped that this approach might produce an understanding of any effects of Pleistocene glaciation and different structure ages on drainage.

Finally, a set of five quadrangle maps at a scale of 1:24,000 were selected on the basis of bedrock age, lithologic type, glaciation history, and availability of existing joint and bedding-dip orientation data. These maps (Fig. 1) included "Wc" White City, "Bu" Buckeye, "Lo" Louisville, "Br" Brookville, and "Be" Belleville SE quadrangles. Analysis was carried out on all stream basins less than 10 square kilometers in area for a "representitive" quarter of each map (37.6 square kilometers). Stream links were subdivided on the basis of Strahler's (1954) stream order into "first order" and "greater than first order". "First order" streams included primarily line segments conecting "V's" in contour lines. This multi-scale approach was considered necessary because numerous studies have shown marked sensitivity to geologic control on orientation at different levels of stream order (Melton, 1959; Flarity, 1978).

Data Analysis

Analysis of drainage orientation and density measurements was restricted to visual comparison of rose diagrams with known geologic trends after considering the complexity of statistical analysis of multimodal orientation data sets (Curray, 1956; Abdel-Rahman and Hay, 1978) and time constraints. Table 1 and Figs. 3 through 9 summarize stream link statistics for the study area and each subdivision of it. Note that not all of the various annotation symbols used on the rose diagrams are present on every diagram. Symbols in Figs. 3 and 4 represent factors that might be expected to operate on drainages at regional

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scales. Symbols on Figs. 5 through 9 include controls probably operating on only smaller tributaries.

Results and Discussion

Rivers and Major Streams

Examination of Fig. 3a reveals a very "spikey" and distinctly multimodal distribution of orientations for rivers and major streams in north-central Kansas. Individual orientations correlate well with known regional fold axes and Hoppie's (1980) paleosurface slope direction. One mode (N70-90E) does not appear to be explained by any known controls. Another rather suprising result is the distinct lack of correlation with regional fault trends. The "spikeyness" is probably caused by the small sample size (n=108) and thus greater influence of individual links on the cummulative percent length.

Large Streams

Fig. 3b shows a strongly unimodal distribution of large streams flowing on Pennsylvanian-Permian age bedrock areas. The primary mode appears to result from several combined factors. A possible minor mode at N50-70W may be due to regional fault trends. Fig. 4a represents streams draining glaciated bedrock in the northeastern corner of the study area. An apparent mode at N10-20E may be due to regional fold effects. The primary mode at N10-30W does not correspond with any known controls listed so far. It may reflect "let-down" Pleistocene drainages that developed as ice-marginal streams or perhaps recessional moraine effects such as those observable in southeastern Nebraska along Cedar Bluffs till ridges (Bill Wayne, 1984, pers. comm.). Fig. 4b is a remarably unimodal distribution, centered on N0-10E. Although it could reflect regional folding effects, this orientation is identical with the one that Melton (1959) ascribed to "solar insolation effects" (acting due north), with a overprinted "prevailing wind effect"(to account for the eastward shift), for streams draining Permian bedrock in northern Oklahoma.

Minor Streams

Minor streams exceeding first order in the White City quadrangle (Fig. 5a) show a multimodal distribution with the primary mode apparently due to the combined effects of joints and bedrock dip. These streams drain areas underlain by the thick-bedded, well-jointed Fort Riley and Florence limestones (Jewett, 1941) and one might expect these units to profoundly influence the drainage pattern developed on them. This conclusion supports Baehr's (1954) findings. First order stream links appear bimodally distributed (Fig. 5b). The primary mode is centered roughly on north and is probably related to solar effects. The secondary mode is fairly well correlated with one of the local joint sets, although the conjugate set does not show a very pronounced effect on drainage.

Fig. 6a portrays the drainage trends of minor streams greater than first order within an area of Wellington Shale outcrop. Again, a pronounced NO-10E maxima suggests primarily solar control for drainage in this area. A very minor mode at N70-80E may relate to the local joint set. First order basins (Fig. 6b) show a very good correlation with both joints and bedding, and again a solar-related NO-10E spike.

The Louisville quadrangle comprises an area Lower Permian shales and thin limestone beds subjected to continental glaciation during the Pleistocene (Scott, 1959). Drainage trends are decidedly bimodal at stream sizes greater than first order (Fig. 7a). Whereas the primary mode appears to reflect both joint and solar control, a secondary mode is of unknown origin. First order streams show a pronounced mode (Fig. 7b) corresponding to local bedding dip, and a minor spike at NO-10E. The origin of a possible secondary mode in the northeast quadrant is unknown.

The Cretaceous age Dakota Group consists primarily of sandstone and sandy shales. Although Hoppie (1980) was able to collect quite a few joint orientation measurements, they show no pronounced modes. Minor streams (Figs. 8a and 8b) show a prominant northerly mode, and possibly some bedrock dip control.

In the Bellville SE quadrangle, Createaceous Colorado Group limestones form a prominant east-west trending errosional scarpof fairly high relief. They contain a very well developed joint set that shows a high degree of correlation with the most prominant modes in Figs. 3a and 3b. A distinct secondary mode at NO-10E is present in the higher order minor streams, but lacking in first order drainages.

Drainage Density

Although it was originally set forth as one of the goals of this study, a rigorous analysis of drainage density variations was not undertaken. The method of stream link analysis did not lend itself directly to true measurement of drainage density, but an analogous measure of texture was derived using cummulative link lengths and areas drained (Table 1). Since the primary controls on drainage density are usually considered to be lithology, vegitative cover, and climatic variables (Morisawa, 1962), it is conceivable that useful information could be gained from such an analysis of Kansas Rivers and streams.

General Summary

A compilation of the foregoing statements appears in Table 2. It is immediately apparent after looking at the rose diagrams that a strong mode often occurs in the N10E vane. As a result it has received the highest "correlation" ranking of all factors listed on Table 2. Also high in this ranking of correlation with drainage are local joint trends and local bedding.

Conclusions

The following statements about this study are regarded as true:

1) A phenomenon that has been dubbed "solar insolation effect" by Melton (1959) appears to be the single most important control on drainage orientations in

north-central Kansas. It warrants further investigation to properly define it in terms of physical cause and effect, time of operation, and areal extent.

2) Analysis of drainage orientations alone does not lead to a unique interpretation of drainage origins. Structural analysis based purely on drainage characteristics would almost certainly meet with failure.

3) It appears several unknown factors may be operating on drainage orientations in north-central Kansas. Detailed work on each individual river or stream (eg. Hoppie's or Baehr's studies) may be required to resolve these uncertainties.

4) Measurement of stream link lengths and orientations is extremely time-consuming and tedious. I strongly recommend an increased level of automation for any future work of a similar nature.

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