BASE FLOW AND GROUND WATER IN UPPER SWEETWATER VALLEY, TENNESSEE

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ILLUSTRATIONS

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FACTORS FOR CONVERTING INCH-POUND UNITS TO

INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply	by	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ft (foot)	0.3048	meter (m)
inch (in)	25.4	millimeter (mm)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	0.06308	cubic meter per second (m^3/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	cubic meter per second per meter [(m^3/s)/m]

Base Flow and Ground Water in Upper Sweetwater Valley, Tennessee

by

Ronald D. Evaldi and James G. Lewis

ABSTRACT

The upper Sweetwater Valley area has a flow system with complex interaction between surface and ground water. A water budget study indicated that during dry years approximately three-fourths of the annual flow to Sweetwater Creek may be derived from ground-water sources. Hydrograph analysis showed seasonal variation of recharge to the ground-water flow system. Streamflow records were analyzed to estimate the frequency of low flow of Sweetwater Creek at river mile 16.7, and indicated the lowest average flow for 1 day in 20 years to be about 5.1 cubic feet per second. Two periods of base-flow measurements of Sweetwater Creek identified channel reaches with significant gains and losses of streamflow.

Base flow measurements also showed interbasin transfer of water among sub-basins of the valley. Major flow surpluses were associated with areas in which the majority of flow originated at a spring. Topographically low areas adjacent to the main stem of Sweetwater Creek generally have surplus flow. Topographically higher areas generally have deficient surface outflow unless significant spring flow occurs in the basin.

Ground-water recharge occurs by water draining into sinkholes, faults, and fractures. Ground-water flow is regionally diffused across formation strikes from the topographically low areas unless the water is exposed to highly permeable formations or impervious formations. Ground water infiltrates the highly permeable formations and flows along strike. Ground water encountering impervious formations may discharge at small springs at the contact, or may reroute along the contact if the upgradient rock is sufficiently permeable or has well developed secondary porosity. Ground-water discharges to streams at innumerable seeps and at a few large springs. Areas of ground-water flow up-gradient of large springs are hypothesized as likely areas of significant ground-water reservoirs.

INTRODUCTION

This report is the third in a series by the U.S. Geological Survey whose aim is to gain better knowledge of ground-water flow and ground-water-surface-water relations in the folded and faulted Valley and Ridge province of Tennessee. The others were studies of the Dandridge area by Hollyday and Goddard (1979) and of Savannah Valley by Rima (1974). The objective of the upper Sweetwater Valley study was to determine base streamflow and ground-water availability and to develop concepts of ground-water occurrence and movement.

The study was restricted in general to the 33 mi^2 of the upper Sweetwater Creek Valley, an area within 4 miles of the city of Sweetwater that included parts of Loudon, McMinn, and Monroe Counties (fig. 1). The 1-year study began in the fall of 1981 and included well and spring inventories, base-flow stream measurements, study of aerial photography and geologic data, and analyses of streamflow data.

The authors thank Lewis W. Roach, General Manager, Board of Public Utilities, City of Sweetwater, for his cooperation and support of this study. Frank Perchalski, Donald Malone, and Daniel Sapp, of TVA, Mapping Services Branch, provided the expertise for aerial photograph interpretation and graphics preparation.

HYDROGEOLOGIC FRAMEWORK

Physiography

Upper Sweetwater Valley is in the Valley and Ridge physiographic province (fig. 1). The Valley and Ridge province is characterized by parallel northeast-trending ridges and valleys (Sun and others, 1963). The average width of the province is about 40 miles in the study area. It is a region of complex geologic structure where the topography is controlled by faults and folds. Local topographic relief consists of ridges underlain by resistant sandstone or cherty limestone and dolomite, and valleys underlain by shale and soluble limestone. Sinkholes are numerous and overlapping sinkholes or large areas with interior drainage are common.

Major thrust faults have caused a general repetition of formations resulting in a repeating sequence of prominent ridges and valleys from northwest to southeast. The contacts between formations strike northeast and the beds dip to the southeast. The Knoxville thrust fault crosses the study area from northeast to southwest. The area is drained by Sweetwater Creek which flows northeast.

Hydrogeology

Sweetwater Valley is underlain by a folded and faulted sequence of approximately 5,000 feet of dolomite, limestone, and shale that range in

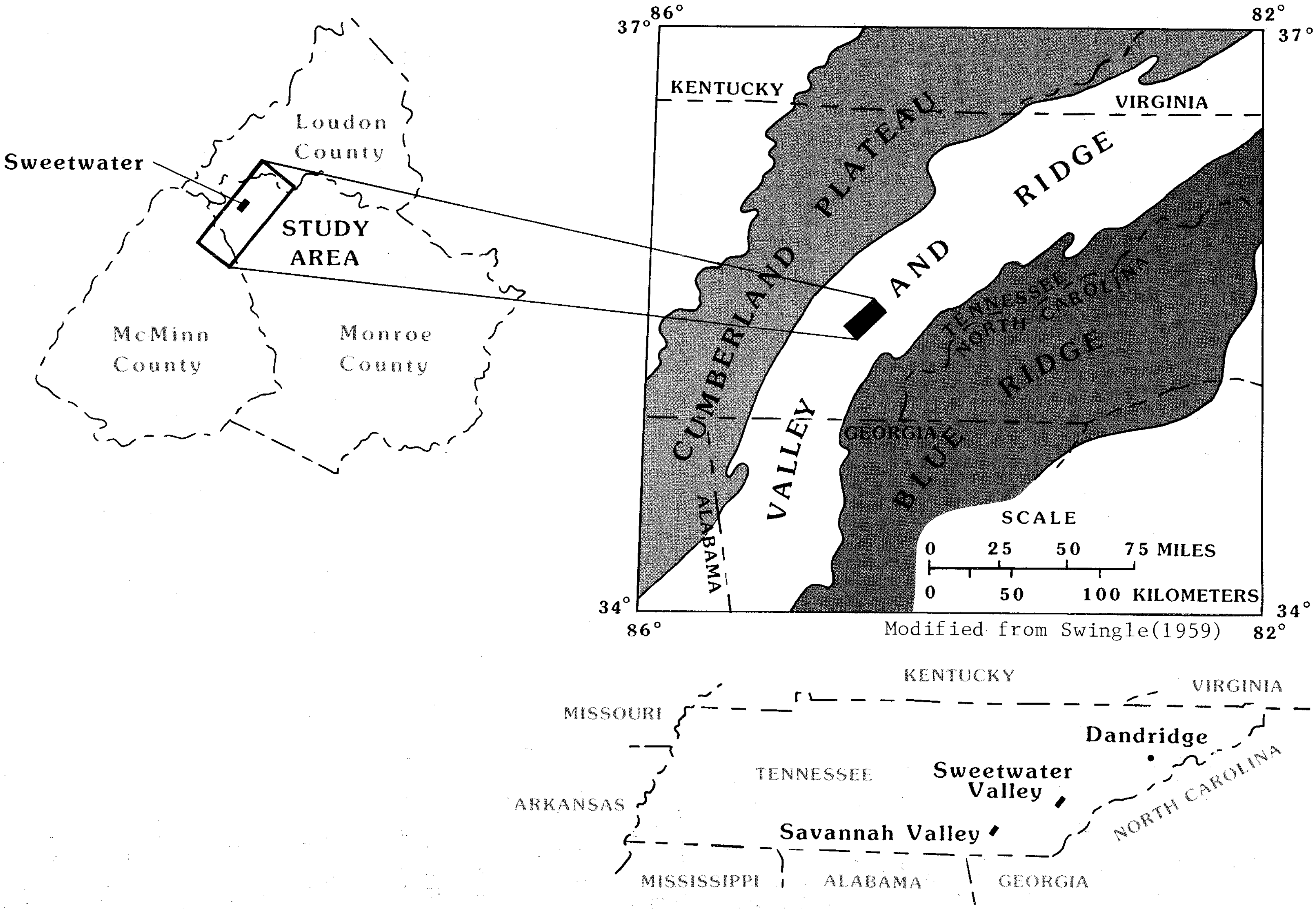


Figure 1.--Location of the upper Sweetwater Valley study area and relation to physiographic subdivisions of the Appalachian Mountains.

age from Middle Cambrian through Middle Ordovician. The distribution of each formation is shown in figure 2. Bedrock exposures in Sweetwater Valley are mostly small and widely scattered. Almost everywhere the bedrock is covered with weathered rock, slope wash, and soil. Geologic descriptions of the formations in Sweetwater Valley and the water-bearing characteristics are listed in table 1. Discussions of individual formations are excerpted from reports by Hollyday and Goddard (1979) and Swingle (1959). The hydrologic characterisitics of each formation vary with chemical composition, texture, structure, topographic setting, and degree of weathering.

Weathered material, or residuum, is the most widespread unconsolidated formation in the area. The infiltration rate of the soil formed on the residuum in the Sweetwater area is generally 0.6 to 2.0 inches per hour (Hall and others, 1981). Residuum that contains large amounts of rock fragments has a higher permeability than that composed mostly of clay, and will yield and transmit larger quantities of water. Residuum from formations of the Knox Group, such as Copper Ridge Dolomite and Longview Dolomite (former usage), normally yields as much as 5 gal/min of water to wells. Residuum with less rock fragments, such as that above the Kingsport Formation and Mascot Dolomite (both of former usage), yields lesser quantities (Swingle, 1959).

Slope wash, or colluvium, is abundant but not as widespread as residuum in the area. Water-bearing properties of the colluvium are generally the same as those of the residuum.

Stream deposits, or alluvium, are composed principally of clay, silt, and gravel-size rock fragments. The rock fragments occur at various depths in the alluvium, unlike those in the residuum which occur near the top of bedrock. The spaces between rock fragments are filled with silt and clay of low permeability which makes the alluvium a poor aquifer.

The limestone was formed from deposits of calcareous mud, fragments of the skeletons of marine organisms, and minor amounts of quartz sand grains. These deposits were solidified by heat and pressure over a period of many years. Some limestones have been recrystallized; rocks that were composed principally of calcite have been replaced by dolomite. These rocks have few pores or primary openings in which water can occur or move.

Secondary openings, formed after the sediments were solidified and recrystallized, occur in the rocks along bedding planes, joints, and numerous fractures in the rocks. Many of these secondary openings have been enlarged by solution along the walls of the openings. These solution formed openings give the dense rock secondary porosity and permeability in which water can occur or move. However, the frequency and size of these openings probably decrease with depth below land surface.

Formations that behave as structurally competent units, such as the Copper Ridge Dolomite, are brittle and tend to fracture cleanly when stressed. The fractures thus produced are numerous and closely spaced,

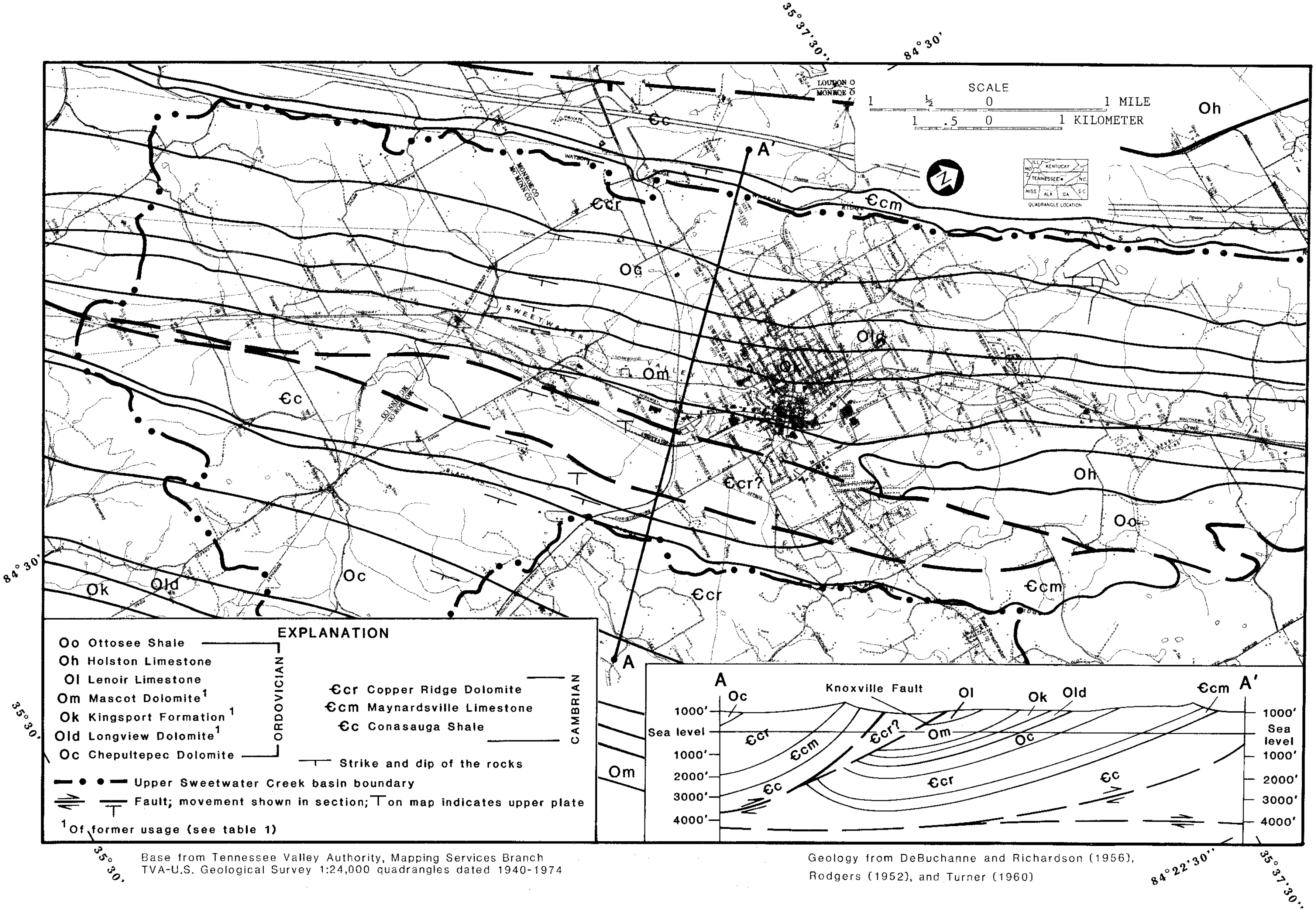


Figure 2.--Geologic map and cross section of upper Sweetwater Valley, Tennessee.

Table 1.--Description and water-bearing characateristics of formations in upper Sweetwater Valley, Tennessee

Group	Geologic formation	Approximate thickness, in feet	Physical character	Water-bearing characteristics
	Ottosee Shale (Oo)	250	Yellow-weathering, bluish, calcareous shale and very shaley limestone; lenses of blue and red crystalline limestone present in shale.	Water occurs in joints, faults, bedding planes, and in solution channels in limestone lenses. Smaller yields and shallower wells than in limestone formations.
	Holston Limestone (Oh)	200	Red, coarsely crystalline limestone ("marble"). Quartzose at top; layers of blue, medium to finely crystalline limestone at bottom. Some very cherty, blue, aphanitic limestone.	Water occurs in fractures and solution openings in coarse crystalline limestone.
	Lenoir Limestone (Ol)	150 to 400	Dark, bluish-weathering, clayey and nodular limestone.	Very limited in areal extent. In east Tennessee, 3 of 8 springs inventoried in Lenoir Limestone flow at least 450 gal/min.
KNOX GROUP	Mascot Dolomite (Om)[a]	500 to 600	Siliceous and cherty, medium dark-gray, cryptocrystalline dolomite. May contain chert, some cryptocrystalline limestone, and some sandstone.	In general, water occurs in joints and bedding-plane solution openings. Yields small to large supplies to wells. In east Tennessee, 11 of 37 springs inventoried in Mascot Dolomite flow at least 450 gal/min.
KNOX GROUP	Kingsport Formation (Ok)[a]	200 to 250	Dolomite that is either white or light gray; well-bedded to massive with a few thin layers of sandstone or limestone; basal 50 feet all bluish-weathering limestone.	In east Tennessee, 2 out of 8 springs inventoried in the Kingsport Formation flow at least 450 gal/min.
KNOX GROUP	Longview Dolomite (Old)[a]	250 to 300	Gray, well-bedded dolomite with a few layers of bluish-weathering limestone; contains massive chert.	Water occurs in solution openings.

Table 1.--Description and water-bearing characateristics of formations in upper Sweetwater Valley, Tennessee--Continued

	Geologic formation	Approximate thickness, in feet	Physical character	Water-bearing characteristics
KNOX GROUP	Chepultepec Dolomite (Oc)	750	Cherty, light-gray, fine-grained thick-bedded to massive dolomite with silty laminae. Basal member contains layers of sandstone with dolomitic cement. More sinkholes than any other formation except the Copper Ridge Dolomite.	In east Tennessee, 2 out of 30 springs inventoried in Chepultepec Dolomite flow at least 450 gal/min.
KNOX GROUP	Copper Ridge Dolomite (€cr)	1,000	Upper 1/4 is light-gray, very fine grained dolomite with interbeds of chert, siliceous oolite and calcareous sandstone. Lower 3/4 of formation is dark, purplish-gray, coarsely crystalline, dolomitic limestone. The most sinkholes of any formation.	In east Tennessee 16 out of 96 springs inventoried in the Copper Ridge Dolomite flow at least 450 gal/min.
	Maynardville Limestone (€cm)[b]	200 to 400	Upper half is blue limestone and gray finely laminated dolomite; limestone may be interbedded with dolomite; also limestone conglomerates are present; very little chert. Lower half is gray, thickbedded limestone that is chert-free. A thin shale layer occurs near base.	Springs occur at contact with underlying Conasauga Shale. In east Tennessee, 3 out of 5 springs inventoried in the Maynardville Limestone flow at least 450 gal/min.
	Conasauga Shale (€c)	2,000	Greenish-gray noncalcareous shale with layers and lenses of limestone weathered to orange clay; may contain thin siltstone layers and dull purplish and brown shale. The basal member has greenish and purplish silty shale containing thin layers of siltstone; no limestone.	Smaller yields and shallower wells than in limestone formations

a. Current usage by the U.S.Geological Survey assigns the upper part of the Kingsport Formation to the Mascot Dolomite, the Longview Dolomite is assigned to the lower part of the Kingsport Formation, and the Longview Dolomite is restricted from Tennessee. Former usage has been maintained in this report to coincide with spring inventory and previous investigations.

b. May be considered upper member of Conasauga Shale.

and provide passages for the flow of water. Formations such as the Lenoir Limestone and Conasauga Shale behave as structurally incompetent units and deform more or less plastically when stressed. The fractures produced in such rocks are few and provide limited passageways for water.

Water occurs in secondary openings in calcareous shale containing limestone lenses, such as the Ottosee Shale and upper part of the Conasauga Shale, in joints, faults, and along bedding planes and solution channels. The limestone lenses are thin and relatively rare, and the water-carrying openings are small. The shale tends to fold under stress rather than fracture, and the openings through which the water can move are less numerous than in limestone formations. Water occurs in noncalcareous shale, such as the Conasauga Shale, in much the same manner as in the calcareous group. However, the weathering process does not appreciably increase storage capacity and permeability.

ANALYSIS OF STREAMFLOW RECORDS

Streamflow records are available for Sweetwater Creek, which is the surface drainage system of the study area. The streamflow records were analyzed to estimate low-flow frequency of Sweetwater Creek and a water budget for 1980. Figure 3 shows the drainage network of upper Sweetwater Creek and locations of the stream gaging stations and major springs in the study area.

Discharge Data

The flow of Sweetwater Creek was gaged August 1964 to September 1981 by TVA. The gage was 2.9 miles northeast of downtown Sweetwater at river mile 16.7 (fig. 3) from August 1964 to April 1970. The gage was relocated May 1970 to a site 2.0 miles northeast of downtown Sweetwater at river mile 17.6 (fig. 3). The drainage area at river mile 16.7 is 28.2 mi^2, and 26.4 mi^2 at river mile 17.6. The annual maximum, minimum, and mean of the daily mean discharges are listed in table 2. The average discharge for 1965-80 is 50.2 ft^3/s. The streamflow was probably affected during low flow by releases or withdrawals of several industries, and the city of Sweetwater filtration plant (river mile 21.8, fig. 3) and sewage disposal plant (river mile 19.6, fig. 3).

Low-Flow Estimates

Streamflow data for Sweetwater Creek below Sweetwater were analyzed to estimate the frequency of low-flow of the creek (table 3). Because only 11 years of data are available, the low-flow discharges for the corresponding recurrence intervals listed in table 3 should be considered approximations. Those values are expected to change with the collection of additional discharge data at the site.

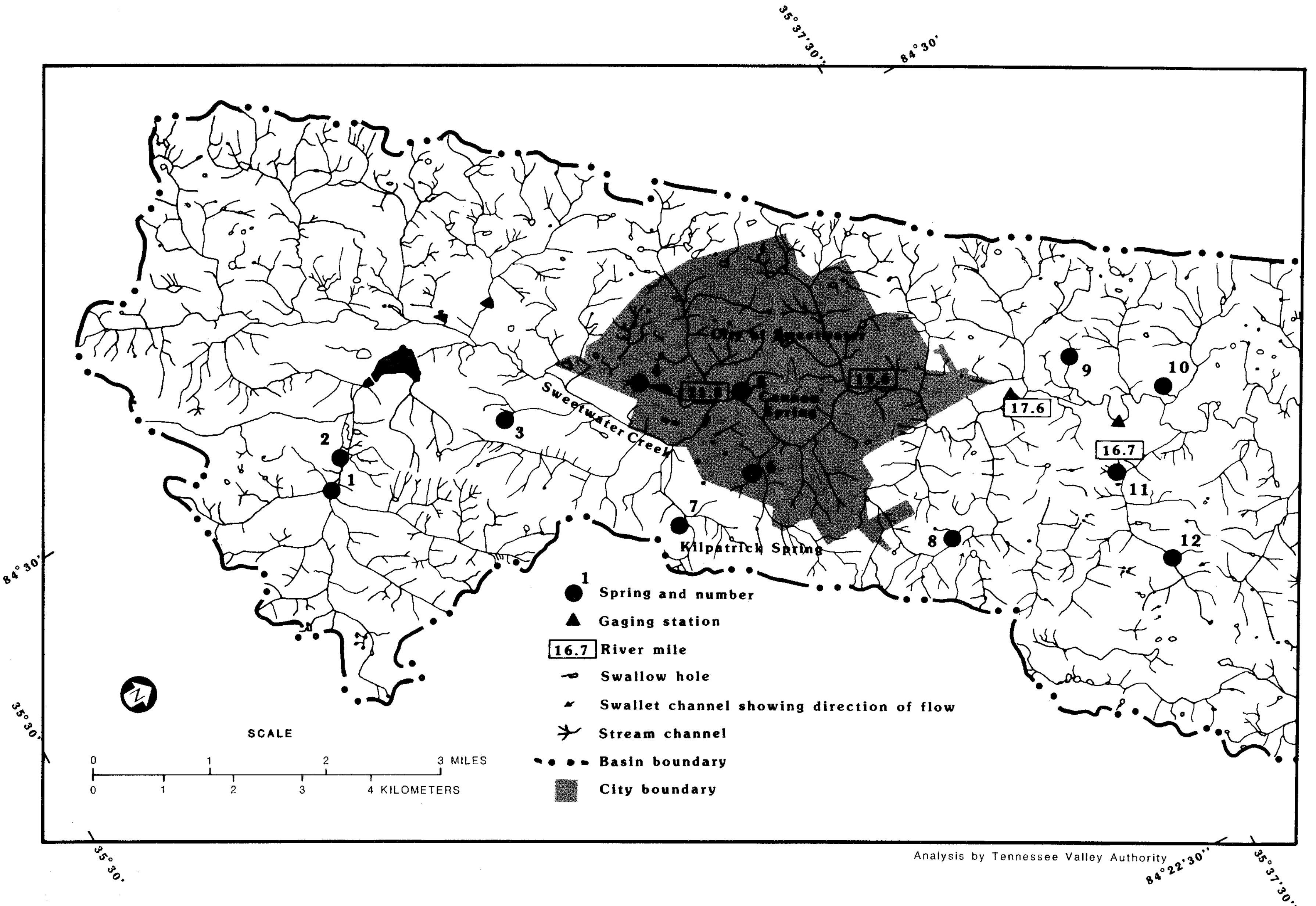


Figure 3.--Drainage network of upper Sweetwater Creek showing major spring locations.

Table 2.--Streamflow of Sweetwater Creek

Year	Daily discharge, in cubic feet per second		
	Maximum	Minimum	Mean
03520050 Sweetwater Creek near Sweetwater, Tenn.			
1965	618	8.0	45
1966	428	10	42
1967	637	18	83
1968	453	10	44
1969	767	7.9	36
03520045 Sweetwater Creek below Sweetwater, Tenn.			
1970	384	7.4	45
1971	234	10	51
1972	448	9.3	61
1973	887	9.5	64
1974	833	10	67
1975	536	9.0	53
1976	176	9.6	39
1977	349	8.7	43
1978	212	9.1	40
1979	226	14	55
1980	366	4.3	35

Table 3.--Low flow frequency estimates of Sweetwater Creek below Sweetwater, Tennessee

Number of consecutive days	Lowest average flow, in cubic feet per second for recurrence interval indicated, in years			
	2	5	10	20
1	9.5	7.3	6.1	5.1
3	9.9	7.7	6.4	5.4
7	10	8.0	6.7	5.7
14	11	8.3	7.0	6.0

The city of Sweetwater obtains most of its water from Sweetwater Creek at river mile 21.8 (fig. 3). The creek at that point has a drainage area of 17.1 mi^2. The Sweetwater Creek gaging station is located 4.2 miles below the city filtration plant and the gage records do not directly represent water availability at the filtration plant. The gage is 2.0 miles downstream of the sewage treatment plant and thus measures most of the water utilized by the city. However, the lowest daily streamflow (4.3 ft^3/s) for the period of record at the gage occurred during the summer of 1980 when the Sweetwater Utility District reported mild water-supply problems. The recurrence frequency suggests that the city may have a water-supply problem, at current usage rates, less frequently than once in 20 years.

Water Budget

Streamflow is maintained by discharge from ground-water sources after all water (overland flow) has drained off the land surface following precipitation. Streamflow from ground-water sources is referred to as base flow. The source of this water is from storage in the ground-water aquifers. In many ways, the ground-water reservoir is analogous to a surface-water impoundment. For example, on an annual or long-term basis, inflow to and outflow from an impoundment are approximately equal. The impoundment provides temporary storage to even out variations in streamflow throughout the year. Likewise, the ground-water reservoir stores water during wet periods of the year and releases it gradually throughout the year.

Because ground-water discharge provides the base flow of streams, surface-water hydrographs can be analyzed to estimate recharge to the ground-water system from individual storms and to estimate ground-water evapotranspiration. The methods are described in reports by Rorabaugh (1964) and Daniel (1976). Results of analyses of hydrographs for Sweetwater Creek below Sweetwater for 1980, a dry year in which the minimum recorded flow occurred, are given in table 4. Some base flow in January was derived from recharge during December 1979. These analyses showed that approximately three-fourths of the annual flow of Sweetwater Creek in 1980 was derived from ground-water sources.

The total runoff of Sweetwater Creek in 1980 was compared to the totals for Tennessee River stations above and below the Sweetwater Creek confluence. The runoff from Sweetwater Creek is considered to agree reasonably with the Tennessee River stations and implies that ground-water underflow must be insignificant:

03497000 Tennessee River at Knoxville = 18.2 inches.
03520045 Sweetwater Creek below Sweetwater = 18.1 inches.
03543005 Tennessee River at Watts Bar Dam = 20.6 inches.

INVENTORY OF SPRINGS, WELLS, AND WATER QUALITY

Springs

A spring is a natural discharge of ground water. The rate of discharge from a spring fluctuates in response to changes in the amount of ground water available above spring level. In the study area, the greatest annual flow from a spring generally occurs during the winter or early spring when water levels are highest following winter recharge.

Springs are important sources of water in Sweetwater Valley. They occur throughout the area under diverse topographic and geologic conditions. The water supply for the city of Sweetwater is augmented from Cannon Spring (spring no. 5, fig. 3). Water from springs is also used for crop irrigation and for livestock watering. Springs feed Sweetwater Creek, but the amounts of water supplies obtained directly or indirectly from springs are unknown.

Table 4.--Estimated 1980 water budget of upper Sweetwater Valley above Sweetwater Creek mile 17.6. (Expressed as the depth to which the surface drainage area (26.4 mi^2) would be uniformly covered)

	1980 Monthly calculations, in inches			
Month	Precipitation[a]	Streamflow[b]	Recharge to saturation zone	Losses to aeration zone
January	6.1	2.7	4.0	0
February	2.0	2.1	1.2	0
March	10.9	5.2	4.1	0
April	4.1	3.1	1.5	0
May	3.7	1.6	.9	0
June	1.6	.9	.2	0
July	3.2	.4	.1	.1
August	4.6	.2	.3	.1
September	1.3	.3	.3	0
October	3.2	.4	.2	0
November	4.7	.6	.7	0
December	1.3	.6	.5	0

1980 SUMMARY: Precipitation, 46.7 inches; stream discharge, 18.1 inches; baseflow[c], 13.8 inches (76 percent); overland runoff, 4.3 inches (24 percent); ground-water underflow, 0; and evapotranspiration, 28.6 inches.

[a] Average of Athens and Lenoir City reports (National Oceanic and Atmospheric Administration, 1980).
[b] Includes overland runoff and base flow.
[c] (Recharge to saturation zone) minus (Losses to aeration zone).

Wells

Driller's reports for 90 wells in the Sweetwater Valley study area indicate that yield to wells is highly variable. However, most wells in Sweetwater Valley probably are not located at sites hydrologically favorable for obtaining maximum yields. The characteristics of the well that had the maximum reported yield from each geologic formation have been described (table 5). These wells probably do not penetrate the full thickness of the ground-water reservoir and may not define the maximum production of wells in each geologic formation.

Water Quality

Sweetwater Creek water-quality data were collected by TVA from October 1968 to September 1972. Data were obtained at river mile 16.7 from October 1968 to May 1970, and at river mile 17.6 for the remainder of the period. The results are summarized in table 6. The samples were collected from the open channel and represent untreated stream water. The analyses undoubtedly reflect sewage effluent from the city of Sweetwater. The maximum value for color, chloride, and dissolved solids exceeded the U.S. Environmental Protection Agency (1979) recommended limits for drinking water. However, most values were within those limits.

Table 5.--Description of wells in upper Sweetwater Valley with maximum reported yield from indicated geologic formation

Geologic formation	Yield (gal/min)	Specific capacity[a]	Regolith (ft)	Well depth (ft)
Ottosee Shale	118	20	30	124
Holston Limestone	12	.3	103	110
Lenoir Limestone	17	---	26	330
Lenoir/Mascot contact	1,360	34	27	178
Mascot Dolomite[b]	23	---	80	225
Kingsport Formation[b]	14	---	115	298
Longview Dolomite[b]	15	---	21	125
Chepultepec Dolomite	110	4.2	73	155
Copper Ridge Dolomite	100	---	5	105
Maynardville Limestone	20	---	63	105
Conasauga Shale	20	.4	90	95

[a] Yield per foot of drawdown in the pumped well.
[b] Former usage, see table 1.

BASE-FLOW ANALYSIS

Base-Flow Measurements

Streams in carbonate terrane can lose flow to the ground-water system along some reaches through solution openings in the stream channel when the stream level is above ground-water level. This water can return to the stream system by springs and seeps downstream from the area of water loss or in an adjacent stream basin where the ground-water level is above stream level. Through this process, various reaches of a stream channel lose or gain water. A stream can be deficient in flow or completely dry if ground-water levels are below stream level and solution openings beneath the stream are large and extensive enough to divert streamflow underground, thus draining the area by subsurface routes.

Low base-flow measurements and high base-flow measurements of Sweetwater Creek and tributaries were made during the study. Significant changes in flow per mile of channel were detected by both periods of measurements. Gains or losses of flow along the channel can be attributed to one or more of the following: measurement error, evaporation, unmeasured tributary inflow, diversions, or interaction with the ground-water system. No diversion of flow by the city of Sweetwater occurred during either period of measurements. Amounts of flow diversion by industry or other users are unknown. Most, if not all, of the flow changes are assumed to have been caused by water leaving or entering the stream through solution openings in the bedrock. The magnitude of the flow change is indicative of the relative interaction between the surface and the ground-water systems under base-flow conditions.

Table 6.--Range in water-quality parameters from Sweetwater Creek; samples obtained October 1968 to September 1972 (analyses by Tennessee Valley Authority)

Constituent	Number of Determinations	Minimum value	Maximum value	Median value	EPA limit
Alkalinity (mg/L as $CaCO_3$)	25	78	151	130	---
Bicarbonate (mg/L as HCO_3)	25	95	184	158	---
Calcium, dissolved (mg/L as Ca)	25	24	44	35	---
Carbon dioxide, dissolved (mg/L as CO_2)	4	6.5	13	10	---
Chloride, dissolved (mg/L as Cl)	25	4.0	260	36	[a]250
Color (platinum-cobalt units)	25	2	60	6	[a]15
Hardness, noncarbonate (mg/L as $CaCO_3$)	25	1	17	10	---
Hardness (mg/L as $CaCO_3$)	25	91	158	134	---
Iron, total recoverable (µg/L as Fe)	25	60	360	150	[a]300
Magnesium, dissolved (mg/L as Mg)	25	6.9	16	12	---
Nitrogen, ammonia dissolved (mg/L as N)	18	.03	1.9	.17	---
Nitrogen, nitrate dissolved (mg/L as N)	18	.24	1.8	1.1	[b]10
Nitrogen, nitrite dissolved (mg/L as N)	18	.01	.14	.05	---
Nitrogen, organic total (mg/L as N)	17	.10	1.1	.41	---
pH (units)	24	6.9	7.8	7.3	[a]6.5-8.5
Phosphorus, total (mg/L as P)	18	.06	1.2	.28	---
Potassium, dissolved (mg/L as K)	25	1.2	7.1	2.1	---
Silica, dissolved (mg/L as SiO_2)	25	5.3	7.6	6.3	---
Sodium, dissolved (mg/L as Na)	25	1.6	180	22	---
Sodium adsorption ratio	25	.1	6.3	.9	---
Sodium percent	25	3	71	29	---
Solids, dissolved residue @ 180°C (mg/L)	24	117	628	198	[a]500
Specific conductance (µmho)	25	175	1110	315	---
Sulfate, dissolved (mg/L as SO_4)	25	2.7	26	8.2	[a]250
Temperature (°C)	24	1.0	23.5	16	---

[a] Secondary maximum contaminant level (U.S. Environmental Protection Agency, 1979).
[b] Primary maximum contaminant level (U.S. Environmental Protection Agency, 1976).

A preliminary reconnaissance of the stream system was made on September 28, 29, 1981, at which time many observations of dry channel were made. The first set of measurements of Sweetwater Creek (flow, temperature, and specific conductance) was made by the U.S. Geological Survey October 15, 1981, during low base flow (table 7 and fig. 4). Additional flow measurements were obtained October 20, 1981, to better define parts of the flow system. Streamflow was measured at 42 sites on Sweetwater Creek and its

Table 7.--Low base-flow data (October 15 and 20, 1981)

Site No.[a]	Station No.	Date	Time	Temperature (°C)	Streamflow, instantaneous (ft^3/s)	Specific conductance (μmho)
[b]1	03520040	Oct.15,1981	1620	15.0	0.78	280
2	03520041	Oct.15,1981	0910	15.5	4.3	260
3	03520043	Oct.15,1981	0950	14.5	7.2	305
4	03520044	Oct.15,1981	0830	15.5	7.2	332
[c]5	03520045	Oct.15,1981	1055	14.5	7.1	345
[c]6	03520050	Oct.15,1981	1015	15.5	9.0	321
7	03520053	Oct.15,1981	1330	15.5	2.1	285
[b]9	353247084291400	Oct.15,1981	1115	15.0	.17	232
12	353250084291400	Oct.15,1981	1250	15.5	.15	230
14	353256084291900	Oct.15,1981	1405	15.5	.74	232
15	353258084292600	Oct.15,1981	1500	14.0	.33	245
18	353302084304700	Oct.15,1981	1235	14.0	.00	345
23	353324084305900	Oct.15,1981	1330	14.0	.02	250
25	353355084301500	Oct.15,1981	1415	15.0	.17	300
26	353358084295300	Oct.20,1981	1115	15.0	1.2	183
27	353409084300000	Oct.15,1981	1615	16.5	.85	270
		Oct.20,1981	1150	--	.94	--
[b]28	353416084290100	Oct.15,1981	1515	15.5	.06	345
30	353431084291300	Oct.15,1981	1430	16.0	3.0	255
		Oct.20,1981	1315	--	2.9	--
31	353448084284300	Oct.15,1981	1330	14.5	.05	340
32	353503084281400	Oct.15,1981	1215	14.0	.11	405
33	353503084281600	Oct.15,1981	1140	15.0	3.4	260
34	353508084275700	Oct.15,1981	1615	15.5	.68	290
35	353525084282200	Oct.15,1981	1650	17.0	1.0	320
36	353536084281200	Oct.15,1981	0905	15.5	1.0	292
37	353539084272900	Oct.15,1981	1435	15.5	.21	370
39	353544084290100	Oct.15,1981	1635	20.5	.02	281
42	353546084292200	Oct.15,1981	1600	20.0	.08	350
43	353546084292300	Oct.15,1981	1600	20.5	.04	344
44	353549084280800	Oct.15,1981	0730	14.5	5.7	290
45	353550084280500	Oct.15,1981	0845	14.5	6.5	280
46	353551084274700	Oct.15,1981	0750	15.0	6.3	300
47	353553084273500	Oct.15,1981	1305	16.0	.24	370
48	353555084273200	Oct.15,1981	1105	14.5	.10	420
49	353601084272600	Oct.15,1981	0850	14.5	8.0	300
51	353653084270100	Oct.15,1981	0915	14.5	.19	365
53	353714084265100	Oct.15,1981	1005	14.0	.04	290
54	353750084251600	Oct.15,1981	1445	15.0	.23	295
57	353800084263300	Oct.15,1981	1830	15.0	1.2	250
58	353828084255100	Oct.15,1981	1145	15.0	2.4	290
59	353830084261100	Oct.15,1981	0830	15.0	8.4	315
60	353831084260900	Oct.15,1981	0915	14.0	.65	320
62	353858084254100	Oct.15,1981	1040	15.0	11	320

[a] Site numbers are referenced to figure 4.
[b] Spring.
[c] Stream gaging station.

tributaries. Stream channels were dry at 43 other sites. The flow at the gage on Sweetwater Creek below Sweetwater was 7.1 ft^3/s, which roughly corresponds to the lowest average daily flow (7.3 ft^3/s) expected once in 5 years (table 3).

The second set of measurements was made by the Survey February 23, 24, 1982, during high base flow (table 8 and fig. 5). The flow at the gage on Sweetwater Creek below Sweetwater was 68 ft^3/s, which is roughly 10 times more than the flow on October 15 and about 36 percent greater than the average discharge for the period of gaging record. Streamflow was measured at 58 sites on Sweetwater Creek and its tributaries. Stream channels were dry at 12 other sites.

The gains and losses per mile of channel reach for both sets of measurements were computed and plotted on maps (figs. 4 and 5). The gaining and losing channel reaches defined by low base-flow measurements showed the difficulty in locating optimum streamflow diversion sites in the carbonate terrane of the Valley and Ridge. Combined stream and spring flow for October 15, 1981, was 6.5 ft^3/s at river mile 21.5 (fig. 4). Slightly farther downstream at river mile 20.7, 8.0 ft^3/s (an increase of 23 percent) was available. However, no further flow increases were detected until river mile 16.7 where 9.0 ft^3/s was measured. Significant tributary inflow originating at major springs resulted in flow increase to 11.4 ft^3/s at river mile 15.1.

Areas of Surplus and Deficient Flow

Although there is little or no interbasin transfer of water out of the Sweetwater Valley, the discharge measurements showed interbasin transfer among the sub-basins of the valley. The discharge data were analyzed in the following manner:

- The average flow per unit area of surface drainage for the entire study area was computed based on the total basin flow and basin area at the most downstream site.
- The surface drainage divides between all streamflow measurement sites were delineated, and the surface area of each sub-basin was computed.
- The area of each sub-basin was multiplied by the average flow per unit area of surface drainage to determine the outflow expected from each sub-basin.
- The actual outflow from each sub-basin was calculated then compared to the expected outflow to define areas with surplus or deficient flow.

The areas of surplus and deficient flow as derived by this procedure were identified and plotted on maps (figs. 6 and 7). In general, topographically higher areas have deficient outflow unless significant springflow occurs in the basin. Topographically lower areas adjacent to the main channel of Sweetwater Creek generally have surplus flow. Major flow surpluses were generally associated with basins in which the majority of flow originated at springs.

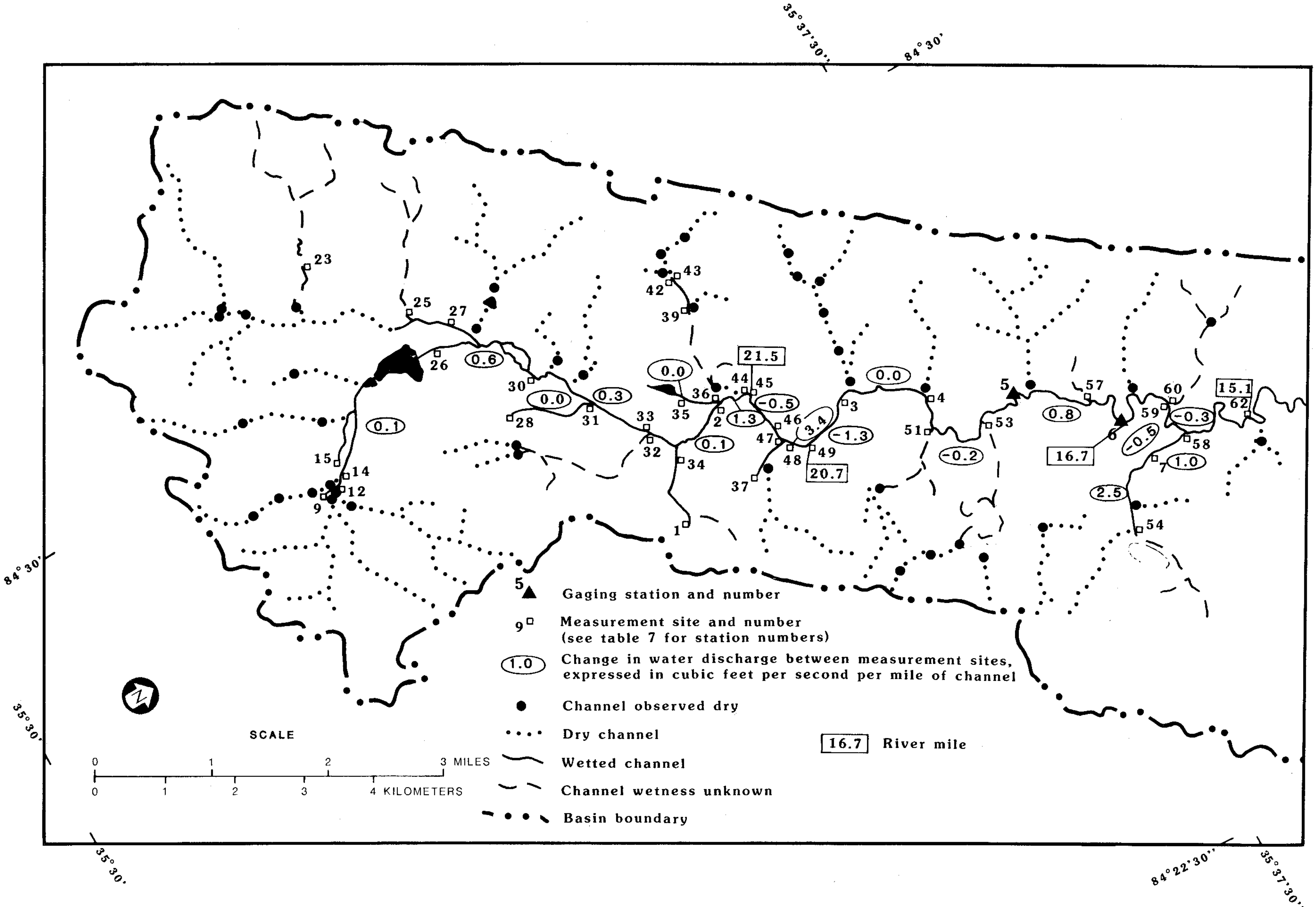


Figure 4.--Low base-flow measurement site locations, and change in water discharge between sites, October 15-20, 1981.

Table 8.--High base-flow data
(February 23-24, 1982)

Site No.[a]	Station No.	Date	Time	Temperature (°C)	Streamflow, instantaneous (ft^3/s)	Specific conductance (μmho)
[b]1	03520040	Feb.23,1982	1305	14.0	5.5	200
2	03520041	Feb.23,1982	0825	9.0	39	203
3	03520043	Feb.23,1982	1010	9.5	55	228
4	03520044	Feb.23,1982	0830	8.5	59	240
[c]5	03520045	Feb.23,1982	1020	9.5	68	230
7	03520053	Feb.24,1982	0945	13.0	10	265
8	353244084310500	Feb.24,1982	1215	12.5	1.0	200
[b]9	353247084291400	Feb.24,1982	1000	14.0	.83	180
10	353249084291200	Feb.24,1982	0900	11.5	.04	166
11	353249084291300	Feb.24,1982	0905	13.0	4.2	163
13	353250084291600	Feb.24,1982	0915	--	.01	172
[b]15	353258084292600	Feb.24,1982	1220	13.0	1.5	126
16	353300084294800	Feb.24,1982	1140	14.5	.73	172
17	353300084301800	Feb.24,1982	1145	14.0	.04	145
18	353302084304700	Feb.24,1982	0800	11.0	4.0	210
19	353314084294500	Feb.24,1982	1315	14.5	2.5	182
20	353315084294400	Feb.24,1982	1350	15.0	8.1	186
21	353315084305100	Feb.24,1982	0845	10.0	3.5	130
22	353322084295700	Feb.24,1982	1420	16.0	.14	170
24	353339084302800	Feb.24,1982	0940	11.0	8.5	190
25	353355084301500	Feb.24,1982	1045	--	2.0	--
26	353358084295300	Feb.23,1982	1410	11.5	11	160
27	353409084300000	Feb.23,1982	1235	11.0	13	198
[b]28	353416084290100	Feb.23,1982	1320	14.5	.55	295
29	353420084295100	Feb.23,1982	1500	10.5	1.5	122
30	353431084291300	Feb.23,1982	1200	9.5	29	200
31	353448084284300	Feb.23,1982	1235	12.0	.87	285
32	353503084281400	Feb.23,1982	1120	13.0	1.5	315
33	353503084281600	Feb.23,1982	1030	9.0	32	195

See footnotes at end of table.

Table 8.--High base-flow data--Continued
(February 23-24, 1982)

Site No.[a]	Station No.	Date	Time	Temperature (°C)	Streamflow, instantaneous (ft^3/s)	Specific conductance (µmho)
34	353508084275700		1215	15.0	6.3	216
35	353525084282200	Feb.23,1982	1455	17.0	5.0	242
36	353536084281200		0900	8.5	4.6	272
38	353539084282000		1405	14.0	3.3	178
39	353544084290100		0805	11.5	2.3	160
[b]40	353544084292500		1020	10.5	.05	38
41	353545084290100	Feb.24,1982	0720	11.0	.39	220
42	353546084292200		0950	11.0	.57	146
43	353546084292300		0900	10.5	.60	97
44	353549084280800		0800	8.5	51	208
45	353550084280500		0850	8.5	51	208
46	353551084274700		0735	9.5	54	215
47	353553084273500	Feb.23,1982	1220	15.5	1.6	270
48	353555084273200		1245	13.5	.43	340
49	353601084272600		0900	9.0	54	220
50	353631084274300		1115	10.0	1.2	124
51	353653084270100		0920	12.5	1.5	395
52	353713084263200	Feb.24,1982	1415	--	4.6	--
53	353714084265100	Feb.23,1982	1020	11.5	4.2	285
		Feb.24,1982	1345	15.5	4.2	290
54	353750084251600	Feb.24,1982	1025	13.5	1.8	302
55	353757084264300	Feb.23,1982	1500	14.0	5.8	200
56	353759084245500	Feb.24,1982	1100	14.0	1.3	300
57	353800084263300		1530	14.0	5.9	207
58	353828084255100		1335	14.5	9.0	255
59	353830084261100	Feb.23,1982	0905	9.0	74	240
60	353831084260900		0945	12.0	1.9	203
61	353858084252800		1410	16.5	.24	310
62	353858084254100		1205	10.0	84	240
63	353900084270100	Feb.24,1982	1200	--	.05	--

[a] Site numbers are referenced to figure 5.
[b] Spring.
[c] Stream gaging station.

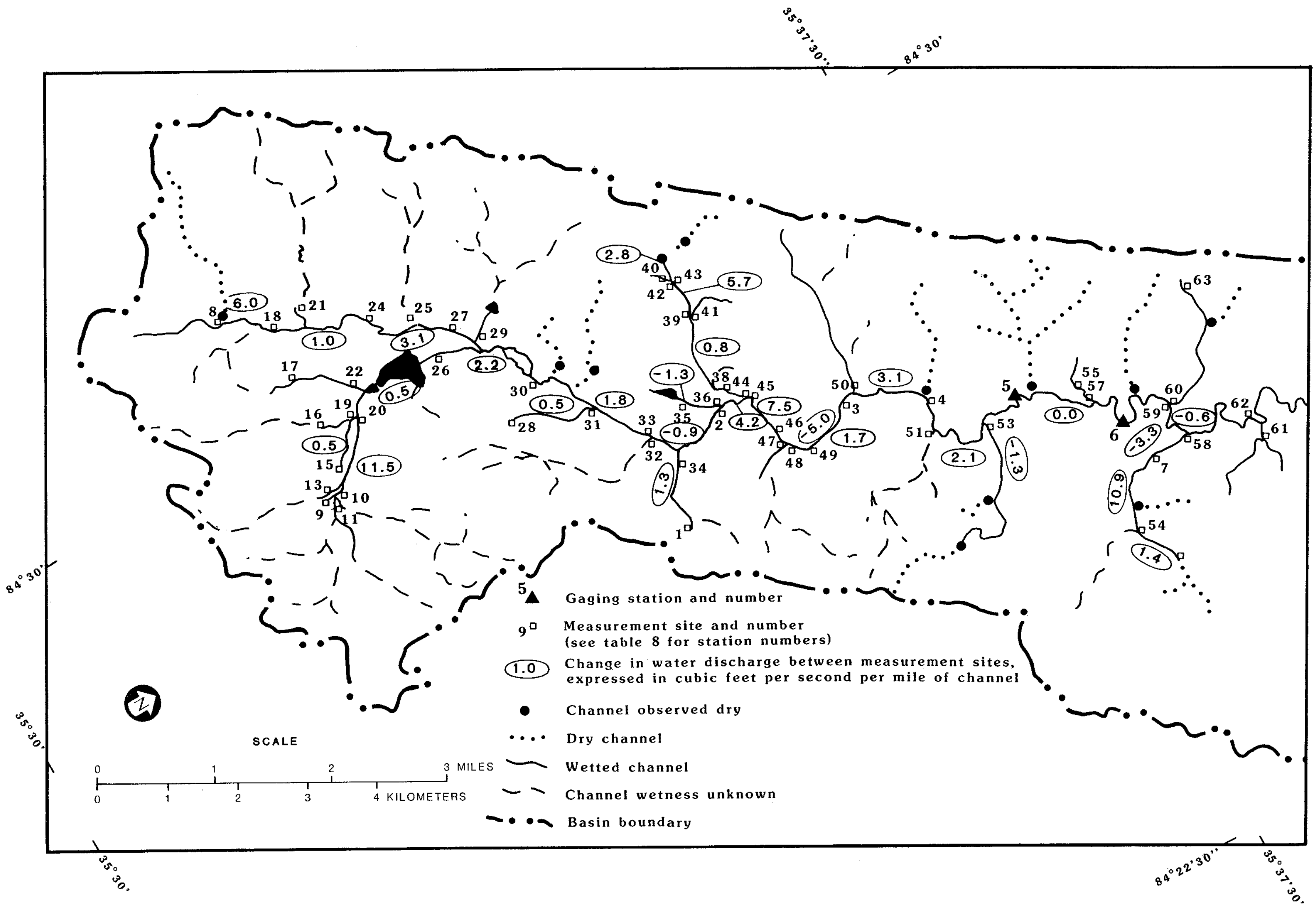


Figure 5.--High base-flow measurement site locations, and change in water discharge between sites, February 23-24, 1982.

CONCEPTS OF GROUND-WATER FLOW

Previous Investigations

The distribution of streamflow in upper Sweetwater Valley indicates a ground-water flow network which has many similarities to two other areas previously studied by the U.S. Geological Survey. The two areas, Dandridge and Savannah Valley, are both in the Valley and Ridge physiographic province. Sweetwater Valley is about midway between the two areas. Results and conclusions from both reports were used as guides for development of a ground-water flow concept for the Sweetwater Valley.

In Dandridge, Tennessee, the concept of the ground-water flow system proposes that there is regionally diffuse flow across the strike of the beds towards topographically low areas. This flow may be intercepted by high permeability beds adjacent to the Copper Ridge Dolomite-Chepultepec Dolomite contact and then routed along the strike to springs.

In Savannah Valley, Tennessee, the most productive aquifers were near the top of the Knox Group. Wells with the greatest yields were located on linear features formed by southeasterly trending stream valleys. The linear features are probably the surficial expression of zones or lines of rock fracture or jointing; perhaps fault traces. Being less resistant to subaerial erosion, these zones are prone to form stream valleys which concentrate both surface and underground drainage.

Upper Sweetwater Valley System

The gaining and losing channel reaches and areas of surplus and deficient flows, determined from discharge measurements (February 23, 24, 1982), were related to the geologic framework. The objective of this analysis was to relate probable ground-water recharge areas to approximate paths of flow to discharge areas. A theoretical ground-water flow concept of the Upper Sweetwater Valley is presented in figure 8.

Regionally, there is probably diffuse flow of ground water across the strike of the formations to topographically low areas. The diffuse flow is evidenced by surface-flow deficiencies in the topographically higher valley perimeter and by surplus surface-flow along the topographically lower central axis of the valley (see figs. 6 and 7). Ground-water flow is generally perpendicular to the strike of the formations and follows irregular flow paths provided by bedding planes, fractures in the rock, and solution-enlarged passages.

The flow of the major springs in the upper Sweetwater Valley (springs 4, 5, 7, 9, and 11, fig. 8) is supplied by diffuse flow which enters areas of high permeability and reroutes along the strike toward the northeast.

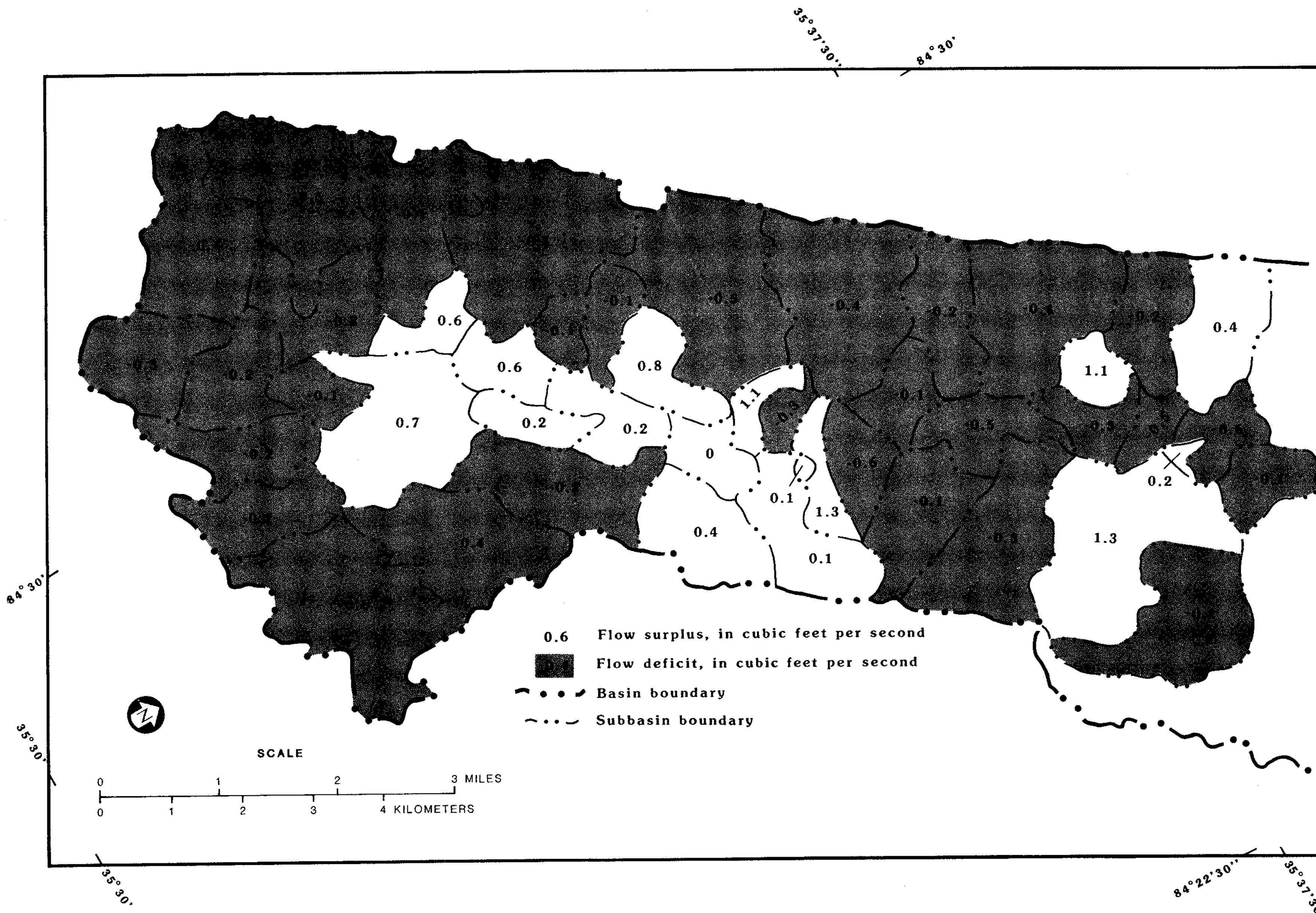


Figure 6.--Areas of surplus and deficient flows in upper Sweetwater Valley, October 15-20, 1981.

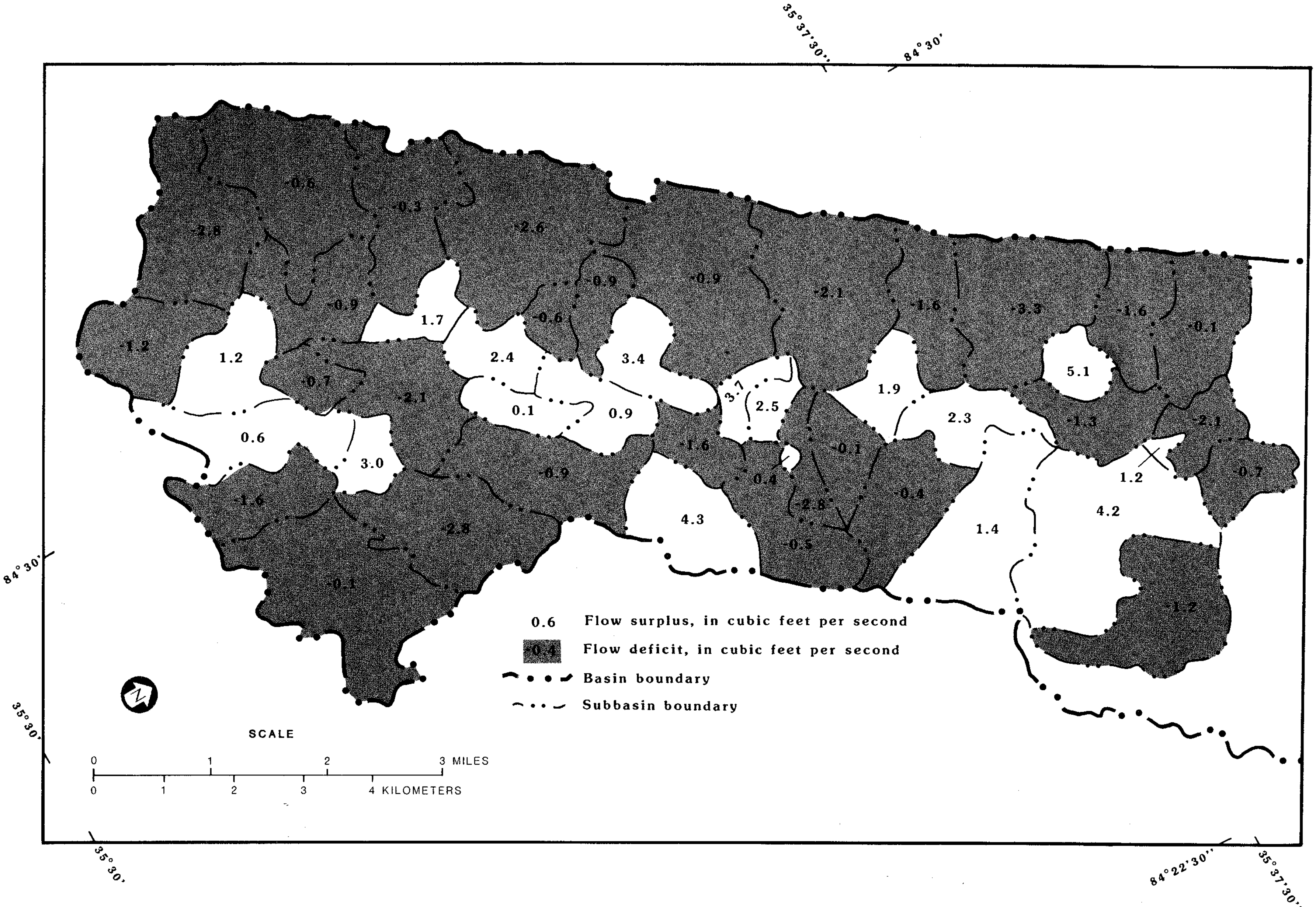


Figure 7.--Areas of surplus and deficient flows in upper Sweetwater Valley, February 23-24, 1982.

The major ground-water discharge for the northwestern half of the upper Sweetwater Valley occurs at springs in the Knox Group. As in Savannah Valley, the Knox Group is considered to have favorable water producing units. These units (Mascot Dolomite and Longview Dolomite, of former usage) collect the flow, forming systems somewhat comparable to surface-stream systems, and route the ground-water drainage parallel to strike to major springs (springs 4, 5, and 9, fig. 8).

Ground water in the southeastern half of the upper Sweetwater Valley encounters shale as it flows perpendicular to strike toward topographic lows. Shale is relatively impervious and acts as a barrier to water movement. The upgradient rock is usually a carbonate which may or may not have developed increased permeability by solutioning. If the upgradient rock does not have high permeability or secondary porosity, the flow will discharge at relatively small springs at the contact (for example, springs 2 and 12, fig. 8). If the upgradient rock has high permeability or secondary porosity along the shale contact, the ground water moves along the shale contacts to major discharge sites such as Kilpatrick Spring (spring 7, fig. 8). In areas where the shale formations pinch-out, the water is able to continue flowing across strike. Where this occurs, the flow may be collected by higher permeability formations and routed parallel to strike to major discharge sites. This situation may occur at the unnamed spring (spring 11) in the northeastern-most part of the valley.

Although little interbasin ground-water transfer was indicated by runoff comparison, the volume of surplus flow at Kilpatrick Spring indicates that some recharge may be coming from the Copper Ridge Dolomite southeast of the surface-water divide. This is probably an insignificant contribution to total valley outflow.

POTENTIAL SOURCES OF WATER SUPPLY

Site Selection

A large perennial spring or actively gaining channel reach is a point of major ground-water discharge and may indicate extensive solutioning in the area. These areas of solution act as water-collection systems comprising underground reservoirs (Hollyday and Goddard, 1979). The most productive ground-water reservoirs are probably in the areas up-gradient of the natural ground-water discharge areas. Potential ground-water supply areas in the upper Sweetwater Valley were located on this basis (fig. 9).

Areas have a greater probability for successful development of high-yielding ground-water supplies if selected on the basis of hydrologic and geologic criteria. The criteria for selection of high-yielding ground-water areas in the upper Sweetwater Valley are similar to those used in Dandridge and Savannah Valley. In Dandridge, site-selection criteria developed for locating successful ground-water supplies were (1) near a large spring, (2) near a creek that is intermittant, and (3) on or near the contact between the Copper Ridge Dolomite and Chepultepec Dolomite

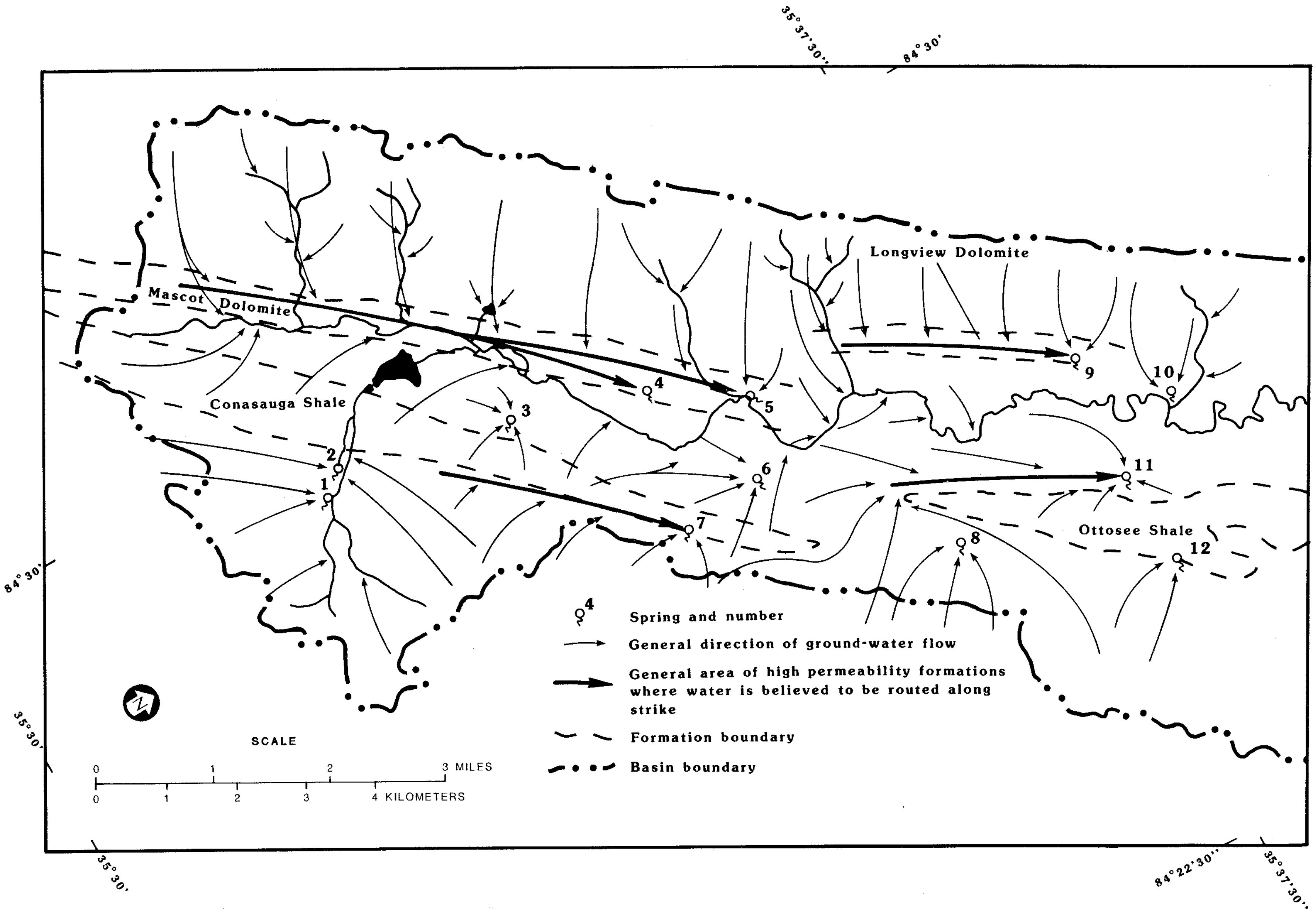
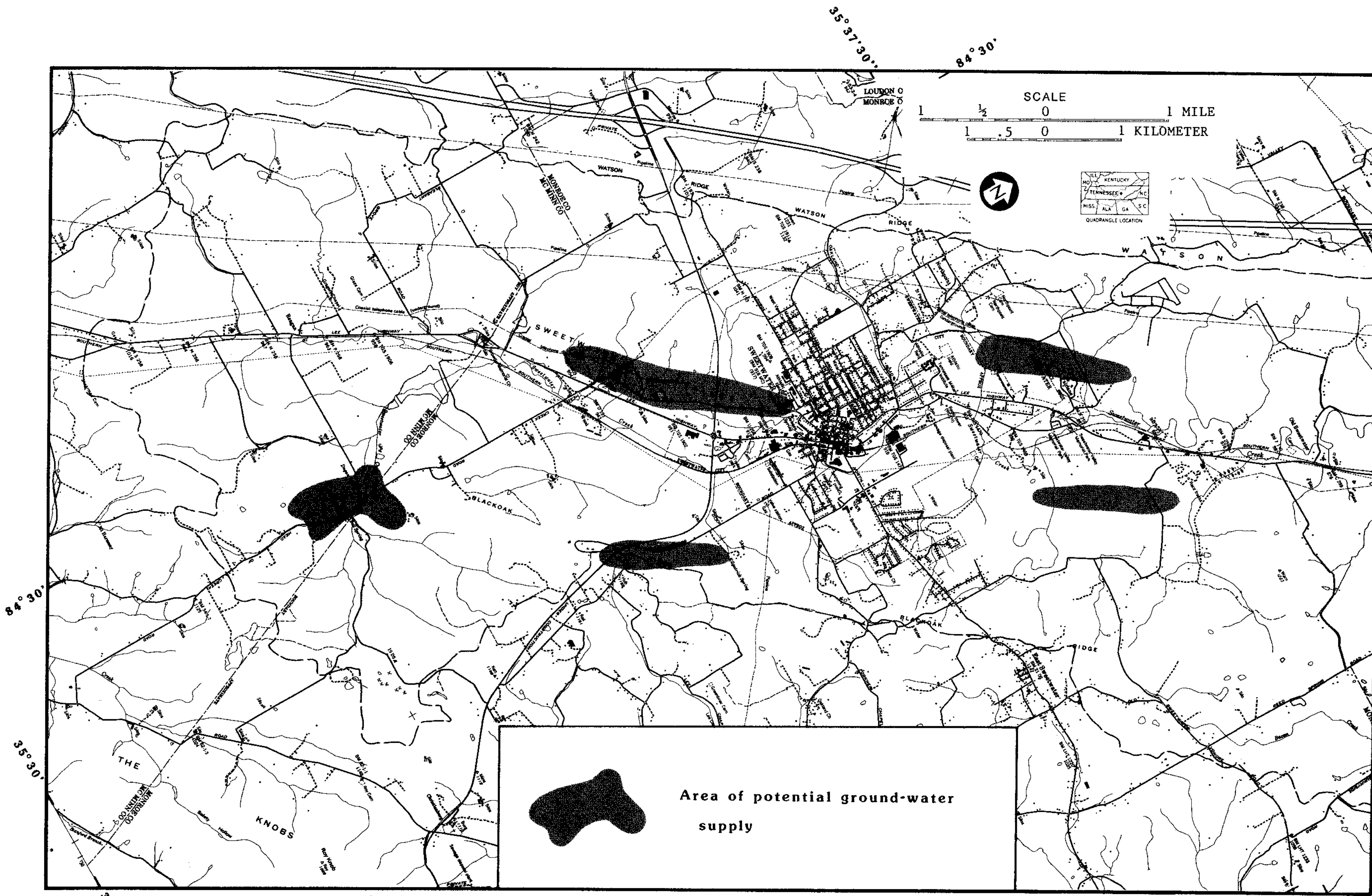


Figure 8.--Theoretical ground-water flow network of upper Sweetwater Valley, February 23-24, 1982.



Base from Tennessee Valley Authority, Mapping Services Branch
TVA-U.S. Geological Survey 1:24,000 quadrangles dated 1940-1974

Figure 9.--Potential groundwater supply areas in upper Sweetwater Valley.

(Hollyday and Goddard, 1979). In Savannah Valley, the principal criterion for locating successful ground-water supplies was the presence of a linear feature formed by a stream valley observable on low-altitude areal photography (Rima, 1974).

As stated previously, the areas which probably have the greatest potential for high ground-water yield are near large perennial springs. Within these areas, the water-bearing characteristics of the rock formations should be considered. Major ground-water flow occurs mainly in underground channel systems which parallel formations of higher permeability, as opposed to lesser diffused flow which traverses formations of different permeabilities. The chance of intercepting one of the underground channel systems increases if a formation with high permeability is tapped.

Sites on or near linear features observable on low-altitude areal photography would have a greater possibility of intercepting a high yielding water zone. These linear features may indicate fractures in the bedrock or solution channels that concentrate ground-water flow. The intersection of two or more linear features would probably be most favorable. Linear trends of topographic features, soil tone, and vegetation from aerial photography were used to identify areas most favorable for ground-water exploration (fig. 10).

Resource Protection

Some water in carbonate terrane moves through open conduits and may not receive the natural filtration such as is associated with sand and gravel aquifers, for example. The water quality in carbonate terrane may be susceptible to pollution and chemical degradation and much of the recharge area may need protection, otherwise the water may need treatment before consumption. Sinkholes, faults, and fractures that may be associated with areas of greater secondary permeability are the major paths by which the ground-water system is recharged and can also be polluted. Sinkholes and linear features of the upper Sweetwater Valley were detected from aerial photography (fig. 10).

SUMMARY AND CONCLUSIONS

Sweetwater Valley is in the Valley and Ridge physiographic province of east Tennessee. The area is underlain by a folded and faulted sequence of approximately 5,000 feet of limestone, dolomite, and shale. The limestone and dolomite are highly soluble and form numerous sinkholes. Most ground water occurs in solution openings rather than in primary pore spaces which are essentially nonexistent in the bedrock.

Hydrograph analysis of Sweetwater Creek showed seasonal variation of recharge to the ground-water flow system. A water budget study indicated that during dry years approximately three-fourths of the annual flow to Sweetwater Creek may be derived from ground-water sources.

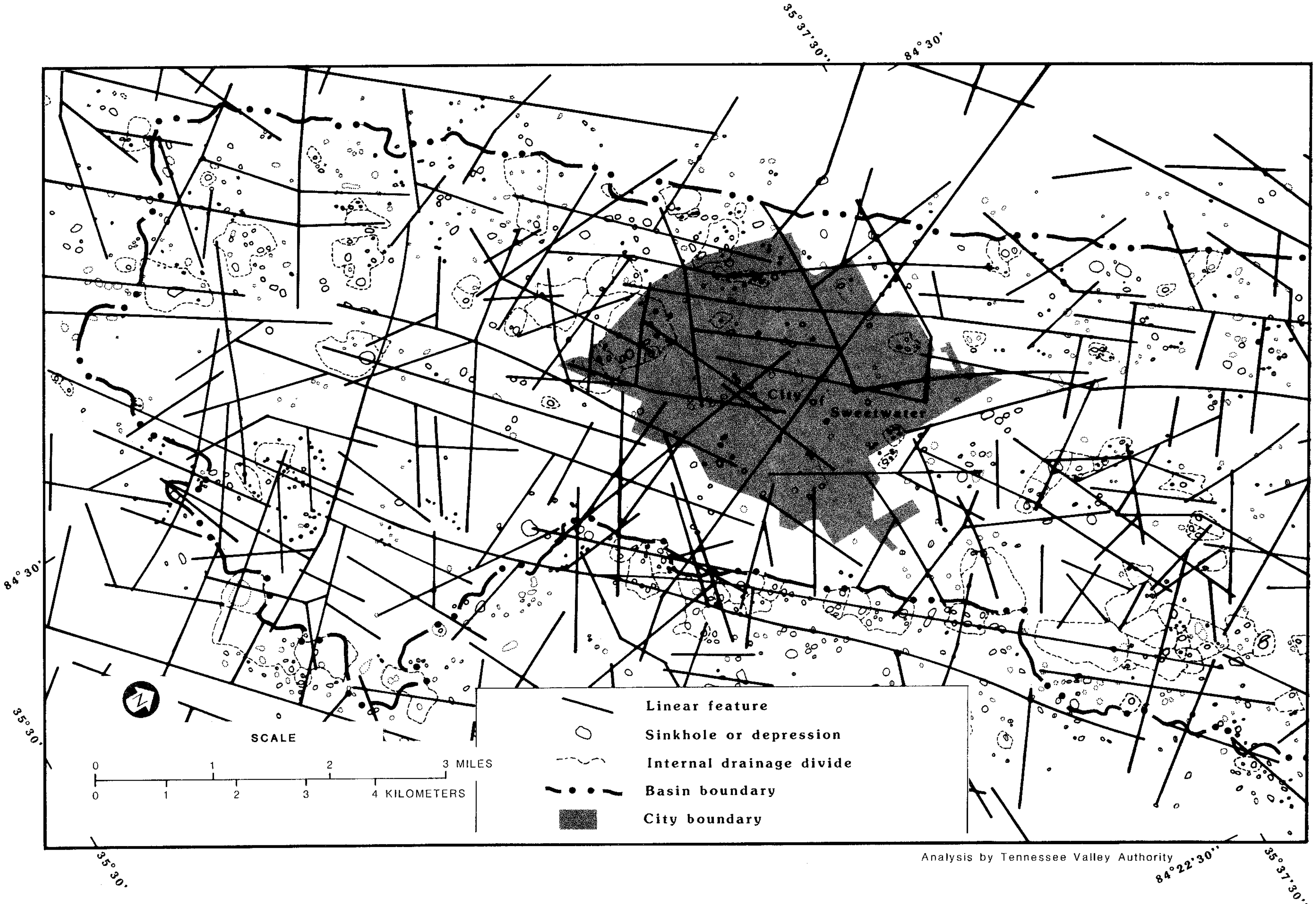


Figure 10.--Locations of sinkholes and linear features from aerial photographic interpretation.

Two periods of base-flow measurements of Sweetwater Creek identified channel reaches with significant gains and losses of streamflow which indicate an interchange of water between the ground-water and surface-water flow system. Low base-flow stream and spring measurements demonstrated the difficulty in locating optimum streamflow diversion sites in the carbonate terrane of the Valley and Ridge province.

The two periods of base-flow measurements identified areas within the basin having surplus or deficient outflow of ground water. Ground-water flow in upper Sweetwater Valley is believed to be regionally diffuse across formation strikes from the topographically high valley perimeter to the topographically lower areas adjacent to the main stem of Sweetwater Creek. This diffused flow may be interrupted if the water is exposed to a high permeability formation or to an impervious formation. Ground water encountering an impervious formation may discharge at small springs at the contact, or the water may reroute along the contact if the upgradient formation has well developed secondary porosity. Ground water infiltrates the high permeability formations and flows along strike to a major discharge area such as a large perennial spring or actively gaining channel reach. Areas of ground-water flow up-gradient from natural ground-water discharge sites were hypothesized as likely areas for finding significant ground-water reservoirs. The most productive areas are likely to be in the most permeable formations and located on a linear feature.

Ground water in carbonate terrane may be susceptible to degradation unless the recharge area is defined and much of it protected, otherwise the water may require treatment before consumption.

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