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Impact Assessment of Coal Slurry Pipelines on Water Resources Utilization and Allocation

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IMPACT ASSESSMENT OF COAL SLURRY PIPELINES ON WATER RESOURCES UTILIZATION AND ALLOCATION

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ABSTRACT

Pike county, the largest coal producing and exporting county from the state of Kentucky was studied to assess the impact of a possible coal slurry pipeline project on the water resources allocation and utilization in the region. Potential coal slurry pipelines from the region were identified and water requirement for operating several hypothetical pipelines were computed by using a recently developed computer program . Climatological data for the county were collected and analyzed for a 29-year period of record with a view to determining the monthly net consumptive use in the region. Available groundwater data for the region was also collected in an effort to assess the groundwater situation of the region. Present urban demand was quantified and an estimate of urban demand in 2010 A.D. was made by using the population projections. Streamflow data from three flow gaging stations encompassing almost the entire drainage basin of the streams in Pike county were collected. On the assumption that the water required for coal slurry pipelines would be withdrawn from a location near Pikeville, only the streamflow records from the USGS gaging station No. 03209500 on the Levisa Fork at Pikeville were analyzed to determine the risks in meeting the total demand (urban demand and minimum baseflow requirement plus combined demand for operating all seven hypothetical coal slurry pipelines) in any month of the year. The allowable demand at 5 percent risk defined as sustainable withdrawal was also computed on a month by month basis.

DESCRIPTORS : Water Demand*, Slurry Pipelines*

IDENTIFIERS : Coal Slurry Pipeline, Monthly Mean Demand, Risks, Sustainable Withdrawal

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CHAPTER 1

INTRODUCTION

1.1 The Global Energy Picture : A Shift Towards Coal

The 1973 oil crisis unmistakably demonstrated the vulnerability of a nation too dependent upon foreign energy supplies. By the time the second oil crisis of 1979 was imminent, the equilibrium of energy sources had already started drifting from oil to coal. That shift was a direct outcome of a global concern for alternative energy supplies in the face of rising oil price and uncertain political situations in the major oil exporting countries. A global picture (Fig 1.1) of the evolution of energy sources over time shows that in the period 1960-1978, there was a clear decline in the use of coal (from 36% to 25%) and a corresponding growth in oil consumption (from 29% to 39%). But the scenario changed sharply after 1978, showing an increasing pattern for coal, concomitant with a decreasing trend for oil as energy source. According to the current projections, coal will assume the leading role in World's energy supply by the year 2000, growing steadily from 25 percent in 1978 to 28 percent in 2000 and 32 percent in 2020. On the contrary, the present day leader of energy sources, oil, will regress to

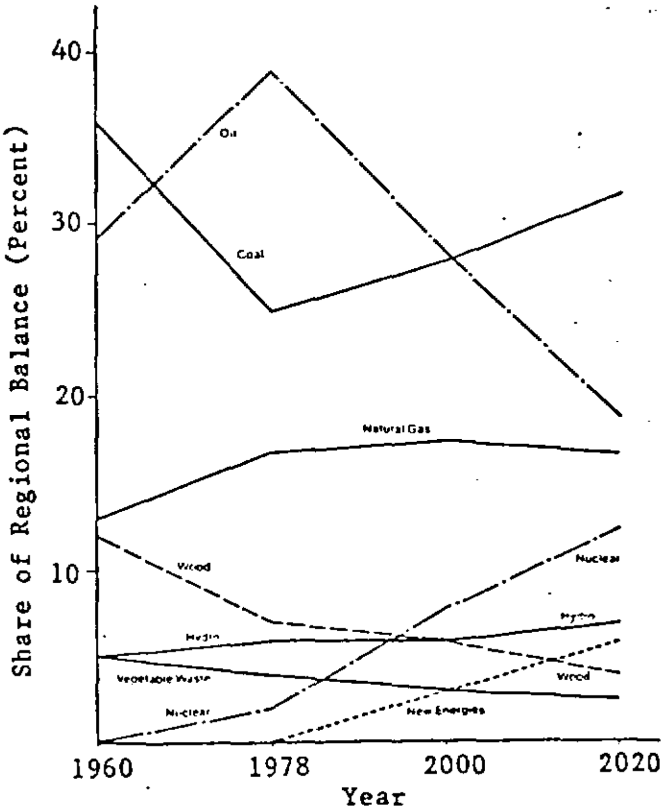


Fig. 1.1 World Energy Consumption : Evolution of Supplies.

Source: Energy 2000 - 2020 : World Prospects and Regional Stresses.

28-29 percent in 2000 A.D. from 39 percent in 1978 and further down to 18-20 percent in 2020 (Frisch, 1983).

1.2 The United States' Energy Consumption : A Surge to Coal

According to the World Energy Conference estimates (Frisch, 1983) the United States possesses about a quarter of total global coal reserves. By comparison, Saudi Arabia, the country having the largest share of crude oil reserves, has about 23 percent of the world's total petroleum reserves. On a thermal energy basis, the potential Btu of the United States' coal reserves is about 4.5 times the potential Btu of all the known oil reserves of the OPEC countries and about 3.5 times that of all the known oil reserves of the free world. The United States Geological Survey (USGS) has already identified 1.7 trillion tons of coal resources, while contingent resources may be as high as 4 trillion tons (taking into account as yet undiscovered coal). Of the 437 billion tons of demonstrated coal reserves, the Department of Energy has estimated that about 237 billion tons of coal can actually be economically recovered with existing technology.

United States' Department of Energy data (Table 1.1) indicate a trend similar to the global energy picture -- a shift towards increased prominence of coal.

Several energy projections show that the United States will be increasingly turning towards coal to meet its future energy demands. The Energy Information Administration, in its 1981 Annual Report to Congress, projected that the share of coal in the domestic energy supply will increase from 18.7 Quadrillion Btu in 1980 to 33.7 Quadrillion Btu in 1995 (an 80% increase in 15 years). The World Energy Conference (Frisch, 1983) predicted that in North America (United States, Canada and Puerto Rico), the share of coal in the energy supply will leap to 33-34 percent (as against 18% in 1978 and currently 19.1%), that of nuclear energy will increase from 4 percent to 11 percent and the share of oil will drop down to 21 percent (compared to 45 percent in 1978). The report further forecasts that this trend will continue through 2020 -- when coal will assume 48 to 49 percent of the region's total energy demand, while nuclear energy will meet 13 percent of the total demand and the share of oil will be as low as 7 percent. In fact, the size and the range of the coal resources in United States support the possibility of a gradual substitution of oil by coal as a source of energy.

Table 1.1 U.S. Domestic Energy Consumption

Coal Vs. Other Fuels, 1974-1983
(Trillion Btu)

		Percentage, Total Consumption					
Year	Total U.S. Consumption	% Coal	% Oil	% N. Gas	% Hydro	% Nuclear	% Others
1974	72,759	17.7	46.0	29.8	4.5	1.8	0.2
1975	70,707	18.1	46.3	28.2	4.6	2.7	0.1
1976	74,510	18.4	47.2	27.3	4.1	2.8	0.1
1977	76,332	18.3	48.6	26.0	3.3	3.5	0.1
1978	78,175	17.6	48.6	25.6	4.0	3.9	0.3
1979	78,910	19.1	47.0	26.2	3.9	3.4	0.4
1980	75,900	20.4	45.0	26.9	4.1	3.5	0.1
1981	73,940	21.7	43.3	27.0	4.0	3.9	0.1
1982	70,822	21.8	42.8	25.9	5.0	4.4	0.1
1983	70,454	22.5	42.6	24.7	5.5	4.6	0.2

The relative low cost of coal compared to oil provides the necessary impetus for the increased preponderance of coal as an energy source. The Department of Energy (DOE) reported that the 1979 ratio of the delivered price of residual fuel oil to the delivered price of industrial steam coal was 2.3 to 1. According to the DOE projections, coal's price advantage over competing fuels will increase beyond 1985. By 1995, the ratio of the projected price of the residual fuel oil to steam coal is expected to be 3.5 to 1 in a low oil price scenario, 4.4 to 1 in a midprice circumstance and 5.3 to 1 in a high price situation (National Coal Association, 1982).

1.3 Facing the Coal Challenge:

In this perspective, it is a truism to say that the time is ripe to begin building a compatible infrastructure and adequate facilities for future increased production, handling and transport of coal. The present US annual production of coal (780.7 million tons in 1983) is only a tiny portion of the huge recoverable reserves of 237 billion tons. Estimates show that US annual coal production will increase to 2 billion tons by the year 2000. There is also a strong surge in the demand for the US coal in the foreign market. However, the problem lurks in the transportation of this large amount of coal coast to coast, as the production sites and the market and distribution places are far away from one another. Railroads, which currently account for about 65% of total coal traffic, are already overburdened and are no less hazardous than any other mode. Other modes of current coal transportation and their shares in the total coal traffic are as follows:

Trucks and motor vehicles	-	12%
Barges	-	11%
Mine mouth generating plant consumption (moved by trucks or conveyor belts)	-	11%
Slurry pipelines and other modes	-	1%

(National Coal Association, 1982)

A special report (Hart, 1984) on coal exports for the Bureau of Intelligence and Research, U.S. State Department, communicated that internal transport costs now account for about one-half of the average price of steam coal delivered to Western Europe. The report cited the relatively high cost of transporting coal to US ports as one of the three major reasons for a 31 percent decline in US coal exports since 1981 (when it hit a record shipment of 102 million tons, a 38% share of the World's total coal shipment), while the lower priced coal exports by rival countries have substantially increased.

A potential alternative for an economic and efficient coal transportation is the coal slurry pipelines, especially in cases where large volumes of coal are to be transported over long distances. The slurry pipeline system involves pumping a constant flow of crushed coal mixed with water (or another liquid) through an underground pipeline from production sites to the market or distribution sites. One of the important features of the slurry pipelines is that the flow is to be maintained perennially, i.e. all the time, regardless of the seasonal variation of local water availability and demands. The physical and legal availability of sufficient quantitites of water at the initiation point is a key determining factor in the realization of coal slurry pipelines. Palmer et. al. (1978) claimed that compared to other methods of energy conversion and transport, coal slurry pipelines require about a third of the amount of water required for coal gasification, and a fifth of that required for onsite electrical generation. As regards to the economy in transportation costs, the United States Congress' Office of Technology Assessment report (OTA, 1978) on Coal Slurry Pipelines concluded that slurry pipelines are more economical than unit trains for some specific types of individual movements, especially for long distance transshipment. The OTA also showed ranges of rail and pipelines costs for a given volume of coal as they vary typically with distance (Fig. 1.2). A rail rate study completed by A. T. Kearnay, Inc. (Dorris,1981) on a proposed 'Coalstream Pipeline', which will gather in both the Appalachian and Illinois Basin coal fields and transport it to about 16 power plants in Georgia and Florida, documented a large amount of savings in coal transportation costs over time in favor of slurry pipelines as against rails (Fig. 1.3).

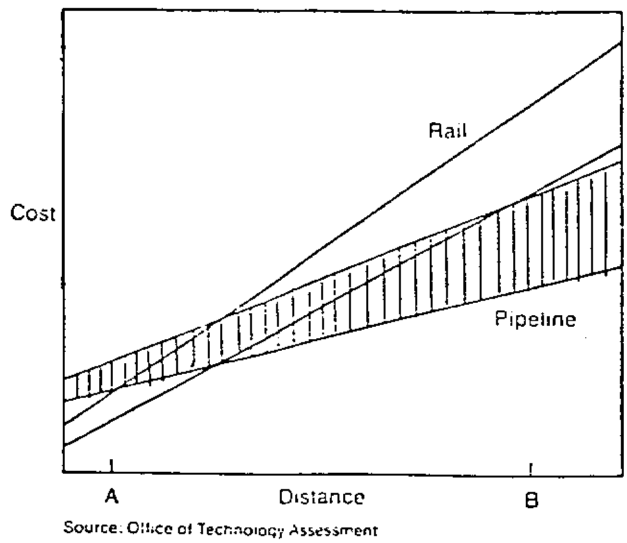


Fig 1.2 Form of Typical Rail and Pipeline Cost Ranges for a Given Annual Tonnage.

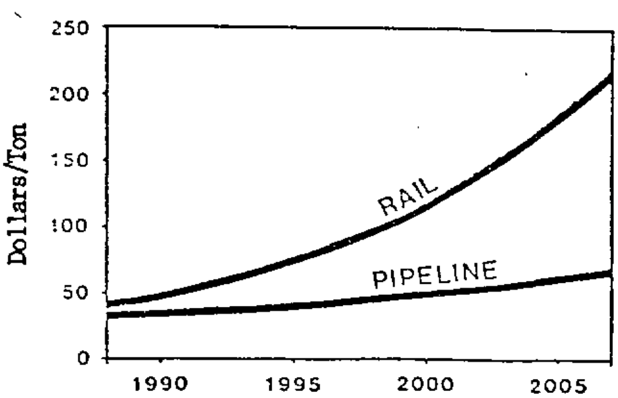


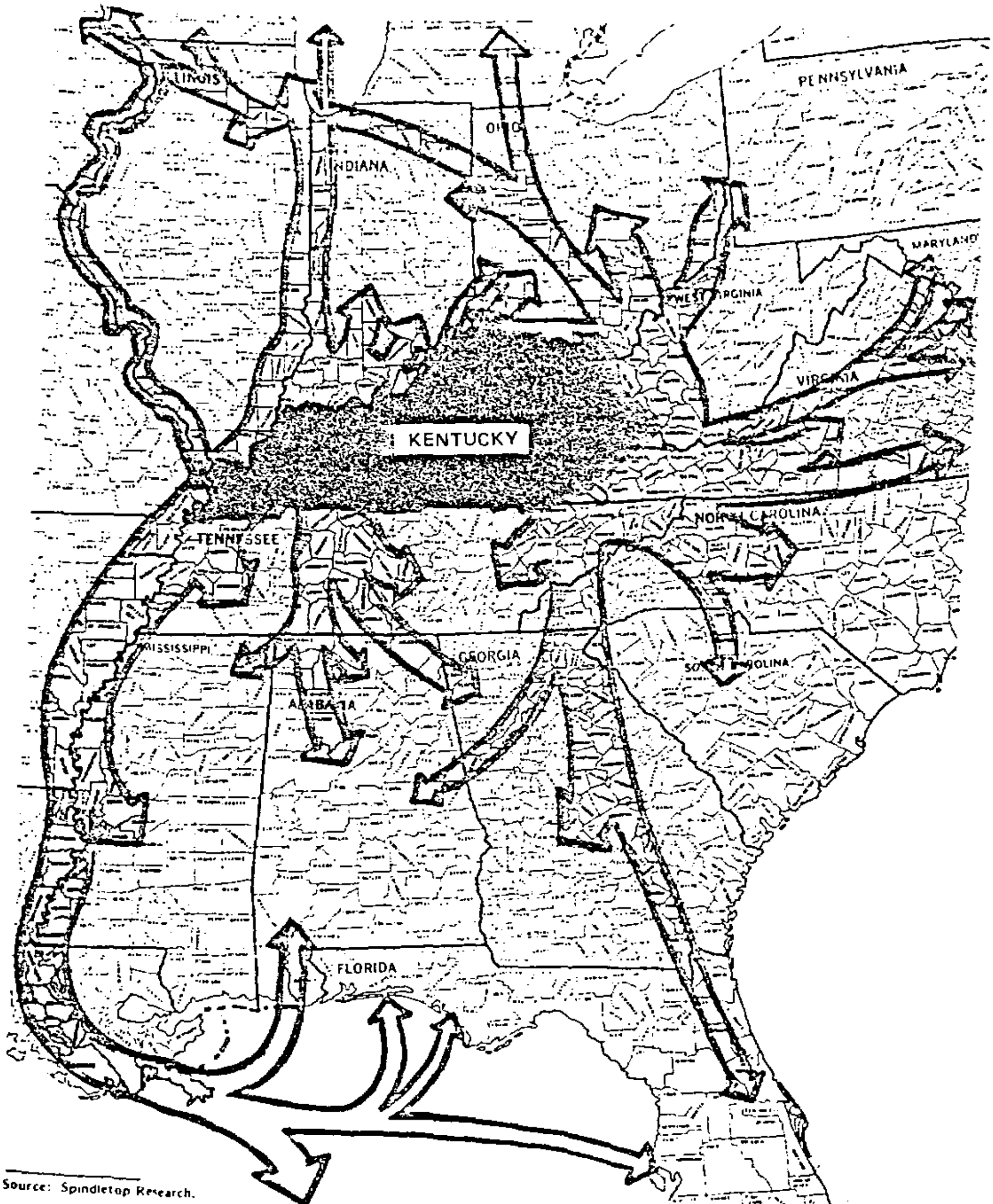
Fig. 1.3 Coal transportation Costs to Southeast.

Source: Proceedings of the Sixth International Technical Conference on Slurry Transportation, 1981.

Coal slurry pipelines, by their very nature, entail the least environmental hazard as compared to other modes of coal transportation because they are buried under the ground. Moreover, once completed, slurry pipelines are dustless, noiseless (except for pumping stations) and independent of weather conditions and traffic.

1.4 Kentucky's Coal: Its Prospects and Utilization

Kentucky is the number one coal producing state of the United States. The 1982 coal production in Kentucky was 149 million tons (18.3 percent of total US poduction), while the demonstrated coal reserves in the state amounts to about 40 billion tons (about 8.0 percent of the nation's total). Of its total annual coal production, Kentucky consumes about a quarter and the rest three quarter is exported out of the state. A pictorial depiction of movements of the Kentucky coal by all modes is presented in Fig. 1.4. The Energy Information Administration's Energy Data Reports (1978) showed that more than 115 million tons of Kentucky coal travelled by truck for some part of the journey from coal mine to consumer. During 1982, 1,419.28 million ton-miles of coal were reported in the state roadways. The average distance a ton of coal was shipped by truck from origin to destination in that year was 11.4 miles and 70 percent of all coal was hauled to rail-served tipples (Kentucky Transportation Cabinet, 1983). At present, over 90 million tons of Kentucky coal are transported by railroads.



Source: Spindletop Research.

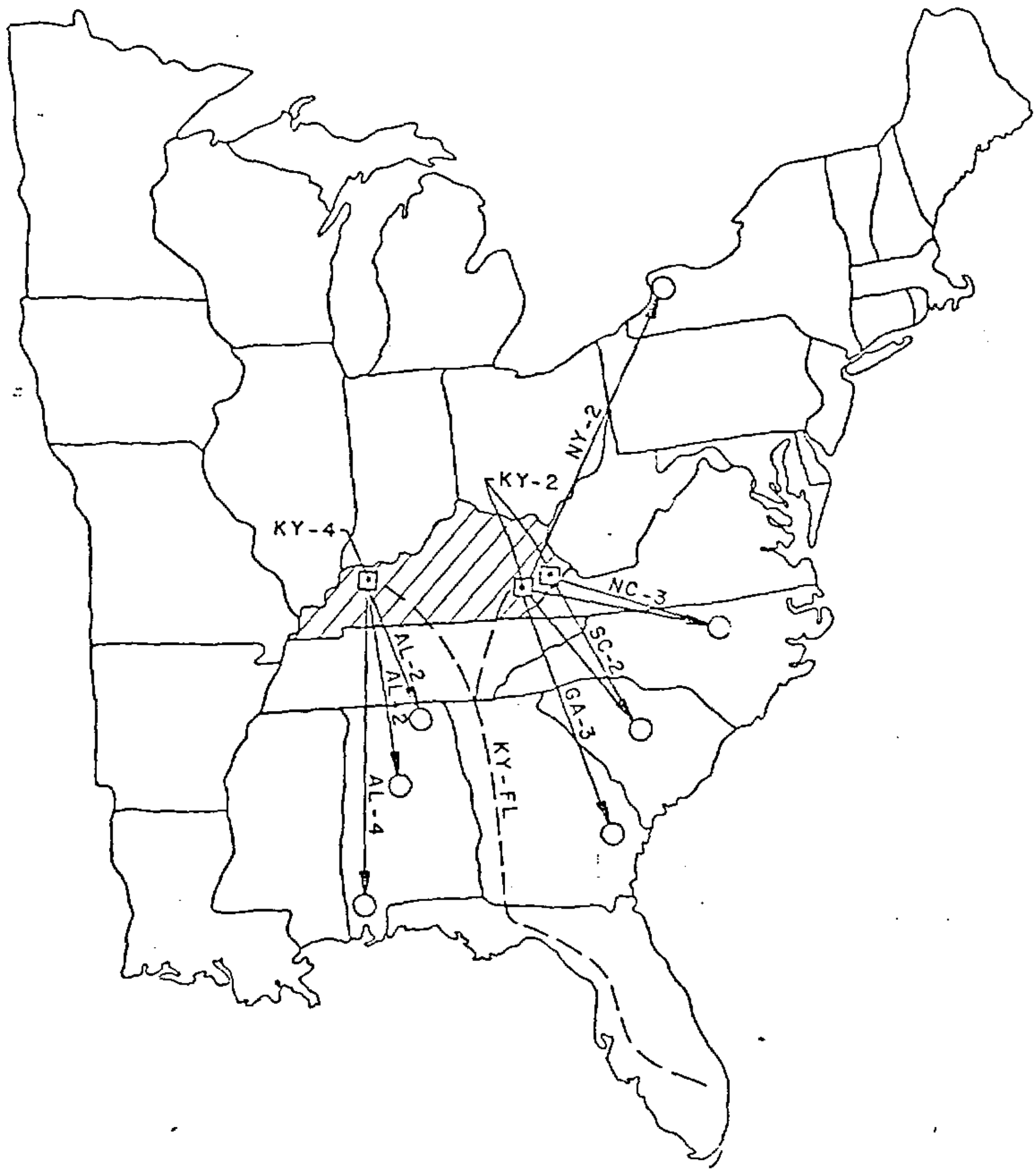
Fig. 1.4 Movements of Kentucky Coal by All Modes.

As a consequence, the existing coal transportation systems in and around the state are extensively utilized, almost overreaching the capacity. Furthermore, under a future scenario of large scale increase in the coal consumption, Kentucky is expected to play a significant role in meeting the future demands, nationwide and abroad. In the face of such a challenging situation there is an urgent need of substantial improvements in the currently overburdened coal transportation facilities in the state. This calls for a closer look into the potentiallly economic and efficient alternative modes of transportation, among which, slurry pipeline is very promising.

A coal slurry pipelines feasibility study (Mathtech, 1978) in the Appalachian Region made positive recommendations for the Appalachian Regional Commission (ARC) to support the implementation of coal slurry pipelines in the region. The Mathtech, Inc. examined a number of potential coal slurry transport routes and ranked those into highly probable, probable, possible and unlikely categories on the basis of their cost effectiveness in comparison to the other modes of transportation. A hypothetical coal slurry pipeline system was designated to be highly probable if it was found to be cost competitive with the conventional modes of transportation all the time and a probable system was defined as one which was found cost competitive at least 50 percent of the time. A possible application is cost competitive less than 50 percent of the time and an unlikely system is more costly than the conventional modes of tranportation. Of the ten coal slurry pipelines which Mathtech categorized as highly probable or probable application, seven are from the state of Kentucky, as shown in Fig. 1.5. Those seven coal slurry pipelines are expected to transport a total of estimated 53.0 million tons of coal from Kentucky each year. In addition, the proposed Kentucky-Florida 1500 mile pipeline will transport another 40 to 50 million tons of coal per year from Eastern and Western Kentucky.

1.5 Coal slurry Pipeline: Water Requirement:

The large volume of water demanded is the primary drawback of coal slurry pipelines. The actual quantity of water requirement varies with the amount and type of coal to be transported and the form of slurry (fine pulverized coal water slurry or coarse coal water mixture) to be employed. Until recently it was agreed upon that a 1:1 coal to water ratio, by weight, is adequate for slurry transportation. However, a study conducted by Kao and Rusher (1983) revealed that the coal to water ratio is primarily dependent on the particle size distribution of the coal in the slurry mix, as well as on other coal and pipeline characteristics. Kao and Rusher developed a computer program to determine the water requirement for any coal slurry pipeline, as a function of the amount of coal to be transported , coal



Source: Mathtech, Inc. (1978)

Fig. 1.5 Potential Slurry Pipelines From Kentucky.

Source: Mathtech, Inc. (1978)

properties and pipeline characteristics. In the present study, this program was used to calculate the water requirement for the hypothetical coal slurry pipelines under consideration. Although a 1:1 coal to water ratio by weight is practicable for long distance transportations, a coarse coal water mixture (i.e. higher than 1:1 coal to water ratio) may sometimes prove more energy efficient for short or medium distance (50 to 200 miles) coal slurry pipelines, because of savings in energy from the dewatering phase of the slurry coal (Kao and Li, 1982).

1.6 Objectives of the Present Study:

The specific objectives of the present study are :

1. To identify the availability of water resources at or near the coal field where the proposed coal slurry transport systems are to be initiated.

2. To assess the potential impact of a probable coal slurry transport system on the local and state water resources utilization programs.

1.7 Scope of the Present Study:

The focus of the present study is Pike county, a major coal producing region in the state of Kentucky. Attempts were made to assess the water resources availability in that zone and the demands for water under different hypothetical coal slurry pipelines were quantified. Precipitation and temperature data for a 29 year period were collected and consumptive use was computed for every month of the year. In an effort to evaluate the groundwater situation, available data on groundwater were collected and an approximate piezometric map of the region was drawn on the basis of collected data. Finally, a comprehensive risk analysis was made on the probability of meeting (or not meeting) the demand in any month of the year. The sustainable withdrawal at 5 percent risk was also computed on a month by month basis.

CHAPTER 2

RESEARCH PROCEDURE AND DATA

2.1 Selection of a Pilot Study Area:

The Mathtech (1978) study rated ten hypothetical coal slurry pipeline applications as highly probable or probable in the Appalachian Region. Five of those ten pipeline routes initiate from the Eastern Kentucky and two more originates from the Western Kentucky. Though the western and eastern parts of Kentucky have almost an equal share in the State's total coal reserve, the increasingly stringent regulations concerning surface mine reclamation and air quality have restricted the market for the high sulfur coal of Western Kentucky. As a consequence, the past decade has seen an overall decline in the Western Kentucky coal production concomitant with an increase in the production in Eastern Kentucky (Fig. 2.1).

The Eastern Kentucky coal now accounts for almost three quarters of the total amount of coal that is produced in Kentucky. During 1983, coal was produced in a total of 42 counties in Kentucky (of them, 28 are in Eastern Kentucky) and the total coal production in the state was 131.5 million tons. Eastern Kentucky coal

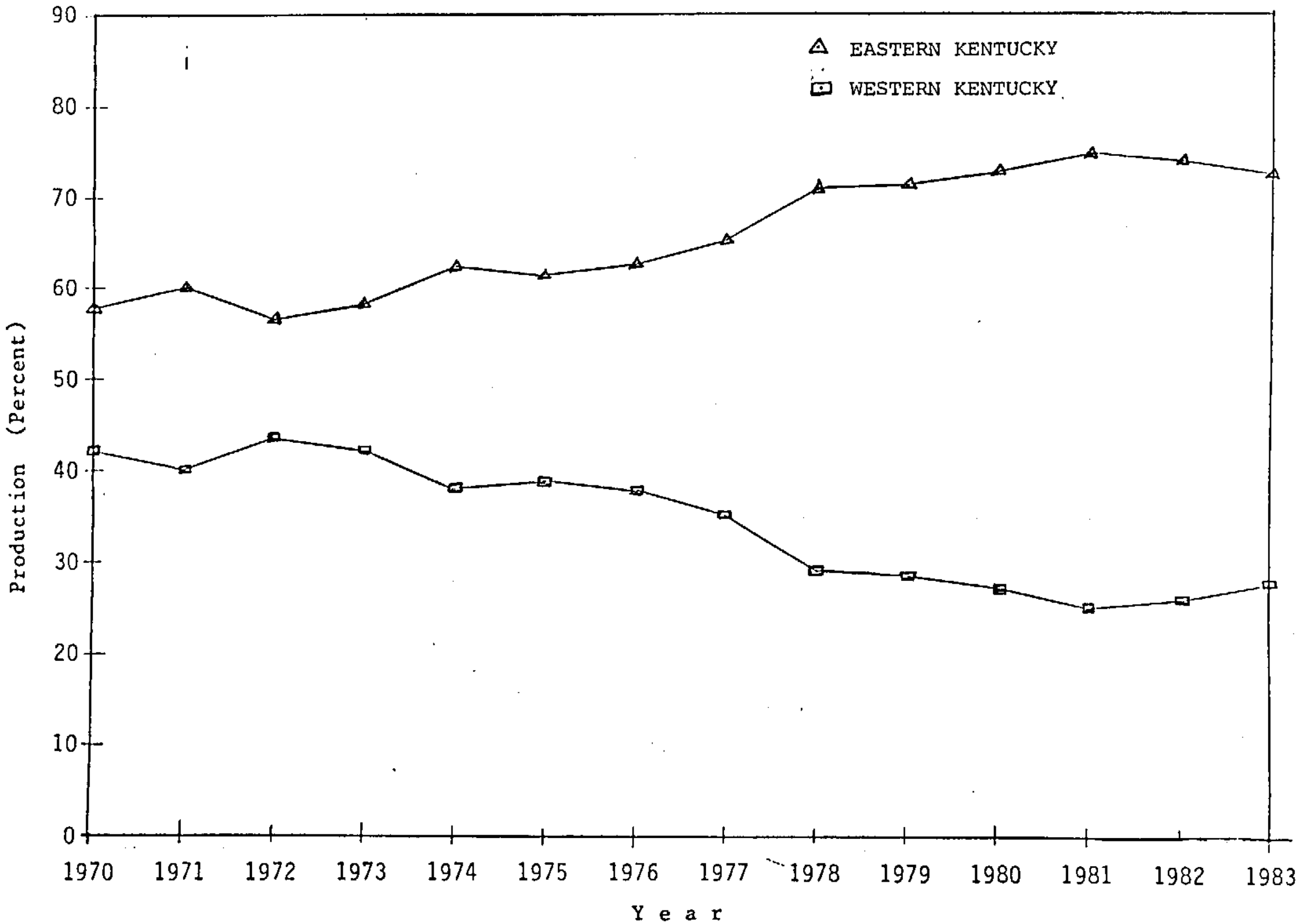


Fig. 2.1 Kentucky Coal Production by Region.

Source: Kentucky Department of Mines and Minerals, Annual Reports.

production in 1983 amounted to 95 million tons, while Western Kentucky produced 36.5 million tons. Moreover, fourteen counties in the Eastern Kentucky each have a coal reserve of more than one billion tons while only eight counties of the Western Kentucky have such a huge amount of coal reserve individually. Eastern Kentucky, therefore, is considered to have an important role as far as coal slurry pipelines in Kentucky are concerned. But, for the present study, the Eastern Kentucky Coal Field would be too large an area to be investigated. Under this pretext, the highest coal producing county in Eastern Kentucky Coal Field, Pike county, was chosen as the pilot study area for the purpose of the present investigation.

Pike county, the largest county in the state of Kentucky, produced over 21 million tons of coal in 1983 (about 16.5 percent of total coal production of the State). One of the greatest bituminous coal fields in the United States, most of which is still untapped, is located in Pike county. The estimated coal reserve in this county is about 6 billion tons, and for years it has distinguished itself as one of the largest coal producing counties in the United States. Pike county's enormous coal reserve and current production level together with its high potential for becoming a springboard for coal slurry pipeline applications in Kentucky justifies its selection as a pilot study area. One other important reason for this selection was that almost all of the origin points of the aforementioned Mathtech (1978) recommended hypothetical coal slurry pipeline applications from Eastern Kentucky were inside or around this county.

2.2 Location of the Study Area:

Pike county is located in the Big Sandy River valley in the extreme southeastern portion of Kentucky and is bordered by West Virginia to the northeast and by Virginia to the southeast. It lies 150 miles southeast of Lexington, Kentucky, 112 miles southeast of Huntington, West Virginia and 200 miles northeast of Knoxville, Tennessee. With an area of 782 square miles, it is the State's largest county. The Tug Fork of the Big Sandy River flows along the northeastern boundary and Russell and Levisa Forks of the Big Sandy run through the western half. Fishtrap Reservoir in the central area covers 15,000 acres. The land surface is broken and mountainous but there is some fertile land in the river valleys. A map of the Pike county is presented in Fig. 2.2.

2.3 Data Collection:

Sufficient information about the water resources of the chosen study area is a basic requirement in the assessment of the impact of coal slurry pipelines on water resources allocation and utilization in the county. As such, an extensive search was made to accumulate all the available

Fig. 2.2 Map of the Pike County.

Source: Kentucky Geologic Base Map
Kentucky Geologic Survey.

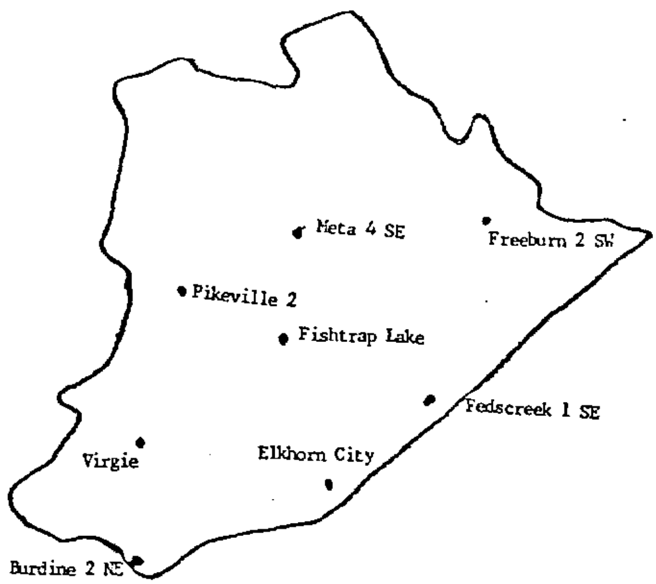
data on precipitation, surface water and groundwater resources of Pike county. Necessary adjustments were also made to the missing precipitation records in order to provide a more beneficial and consistent data base.

2.3.1 Climatological Data:

> " Most water of economic importance in the Eastern Kentucky Coal Field region comes from total precipitation. The precipitation falling on the ground evaporates, runs off in streams, or soaks into the soil." (Price, Mull and Killburn , 1962)

There are currently eight rain gaging stations in the Pike county. All these eight gaging stations have been operating since 1978. Previously there were fewer gaging stations in the county, as few as one in 1950. However, in the entire county there is only one station at Pikeville that reports the daily temperature. The aforementioned rain gaging stations and their geographic locations are shown in Fig. 2.3.

For the purpose of analysis, all the available mean monthly precipitation and temperature data recorded in the gaging stations inside Pike county were collected (see Appendix A). The period of available record extended to 29 years, from 1950 to 1967 and then from 1971 to 1981, with data for three years (1968-'70) not available during the



Station	Index No.	Latitude	Longitude	Elevation
Burdine 2 NE	1120	37°-13'	82°-35'	1560 ft
Elkhorn City	2520	37°-18'	82°-21'	815 ft
Fedscreek 1 SE	2812	37°-24'	82°-14'	850 ft
Fishtrap Lake	2825	37°-26'	82°-25'	718 ft
Freeburn 2 SW	3046	37°-33'	82°-10'	730 ft
Meta 4 SE	5370	37°-32'	82°-33'	800 ft
Pikeville 2	6355	37°-29'	82°-32'	1060 ft
Virgie	8348	37°-20'	82°-35'	920 ft

Fig. 2.3 Precipitation Gaging Stations in Pike county.

time the investigation was carried out.

2.3.1.1 Adjustment for Missing Climatological Data:

Many of these gaging stations have short breaks in their records from time to time, resulting in missing records. No estimation for those missing values were made. Instead, a number of Thiessen Polygons were drawn (Fig. 2.4) for different combinations of stations (e.g. 8-station Thiessen Polygon (TP), 7-station TP, ... up to 3-station TP) on the presumption that a missing record at a station in any month is equivalent to the situation that the station is nonexistent in that month. In this way, the area apportioned to each precipitation gaging station in the Pike county varied from month to month. The weighted average precipitation over the entire Pike county in any month of a year was computed by employing the following four steps:

1. An area was apportioned to each gaging station using the proper Thiessen Polygon (e.g. when records for a month were available in 7 stations, then a corresponding 7-station TP was used).
2. A weighting factor was assigned to each gaging station according to the percentage of area apportioned to the corresponding station.
3. The monthly mean precipitation values at each station were multiplied by the corresponding weighting factor.

4. The results from the step 3 were added together to obtain the average precipitation over the area for the corresponding month of the year.

As an illustration, the monthly mean precipitation values for the months of March, April and August through December, 1980, show records from eight stations while those for the remaining months of the year show records from seven stations , with the values from the station at Pikeville 2 missing for those months (see Appendix A). In order to compute the average monthly precipitation over the entire Pike county for the months of March, April and August through December, 1980, the stations were weighted by the corresponding percentage of areas assigned to them from the 8-station Thiessen Polygon (Fig. 2.4a). The monthly averages over the area for the remaining months of that year were computed by weighting the stations with percentage of areas taken from the 7-station Thiessen Polygon (Fig. 2.4b) which excludes the station Pikeville 2. Availability of a digitizer (a computerized planimetering device) and a digital computer made such rigorous analysis for every month of the year for a 29 year period of record possible.

This method was considered better than estimating the missing records at a gaging station either by arithmetic averaging over the stations for which the records were

8-Station TP
(B,E,FE,FI,FR,M,P,V)

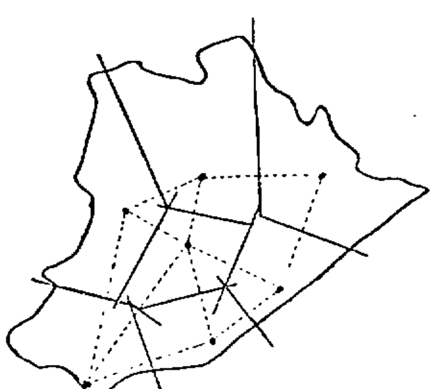
a

7-Station TP
(B,E,FE,FI,FR,M,V)

b

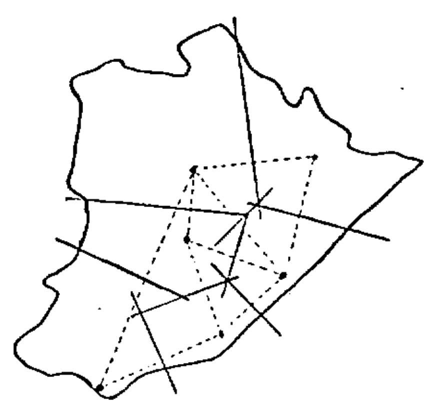
Station Index

Burdine 2 NE	B
Elkhorn City	E
Fedscreek 1 SE	FE
Fishtrap Lake	FI
Freeburn 2 SW	FR
Meta 4 SE	M
Pikeville 2	P
Virgie	V



7-Station TP
(B,E,FE,FI,FR,M,P)

c



6-Station TP
(B,E,FE,FI,FR,M)

d

Fig. 2.4 Thiessen Polygons.

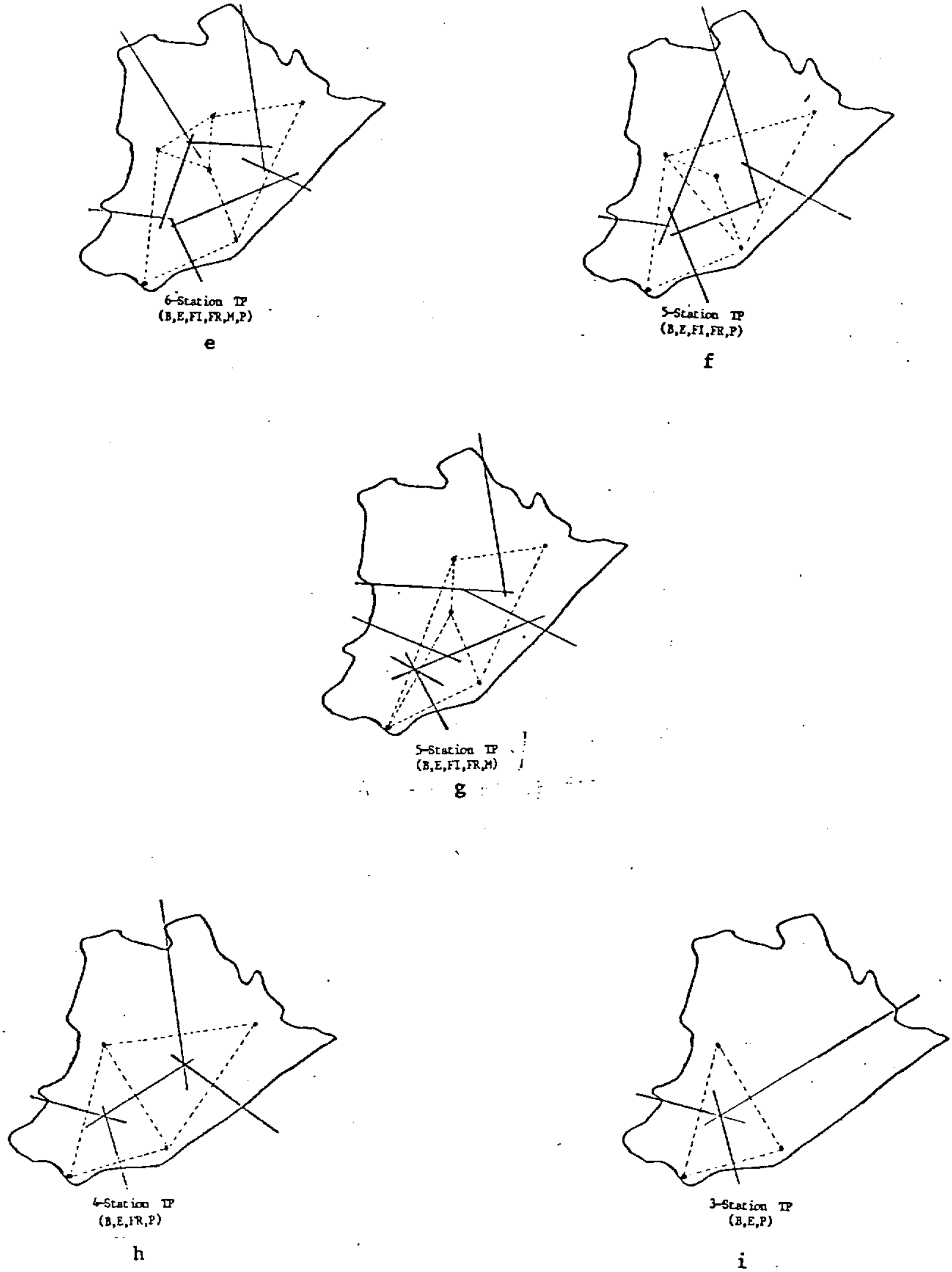


Fig. 2.4 Thiessen Polygons (Contd.)

available, or by Normal Ratio method, using records from three nearest stations; because, quite often, the annual mean values were found missing for more than one station. Variability in the number of gaging stations in different years changes the gaging network from time to time. In this regard, the method that was chosen to analyse the data was found capable of accounting for this variability.

The temperature record is available for only one station in the county, at Pikeville, and the mean monthly values recorded at that station during the period of record was taken to be the average monthly mean temperature over the entire county. Diagrammatic representations of the

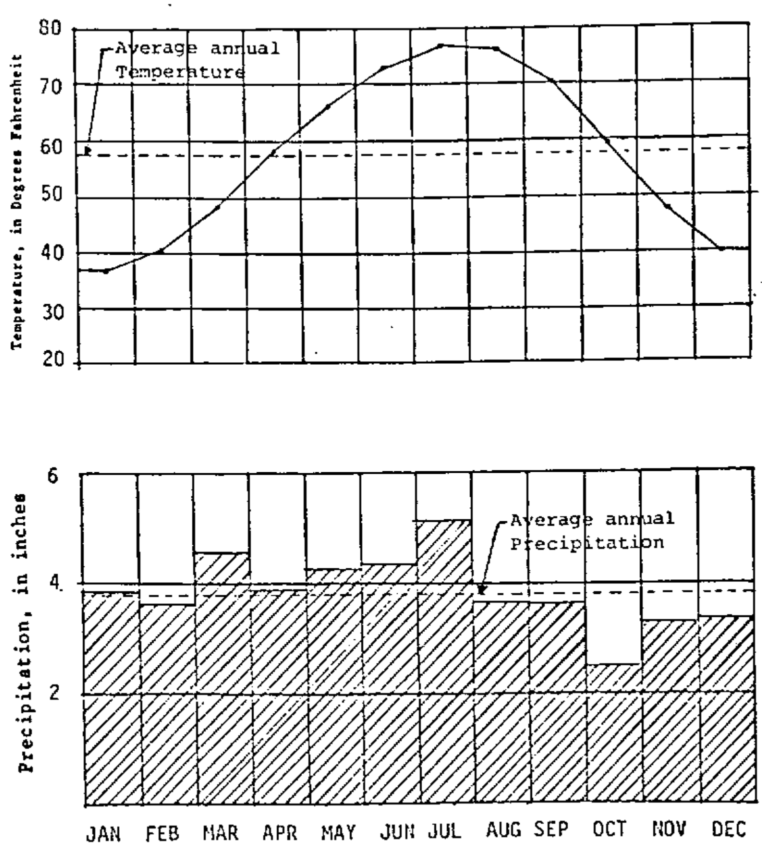


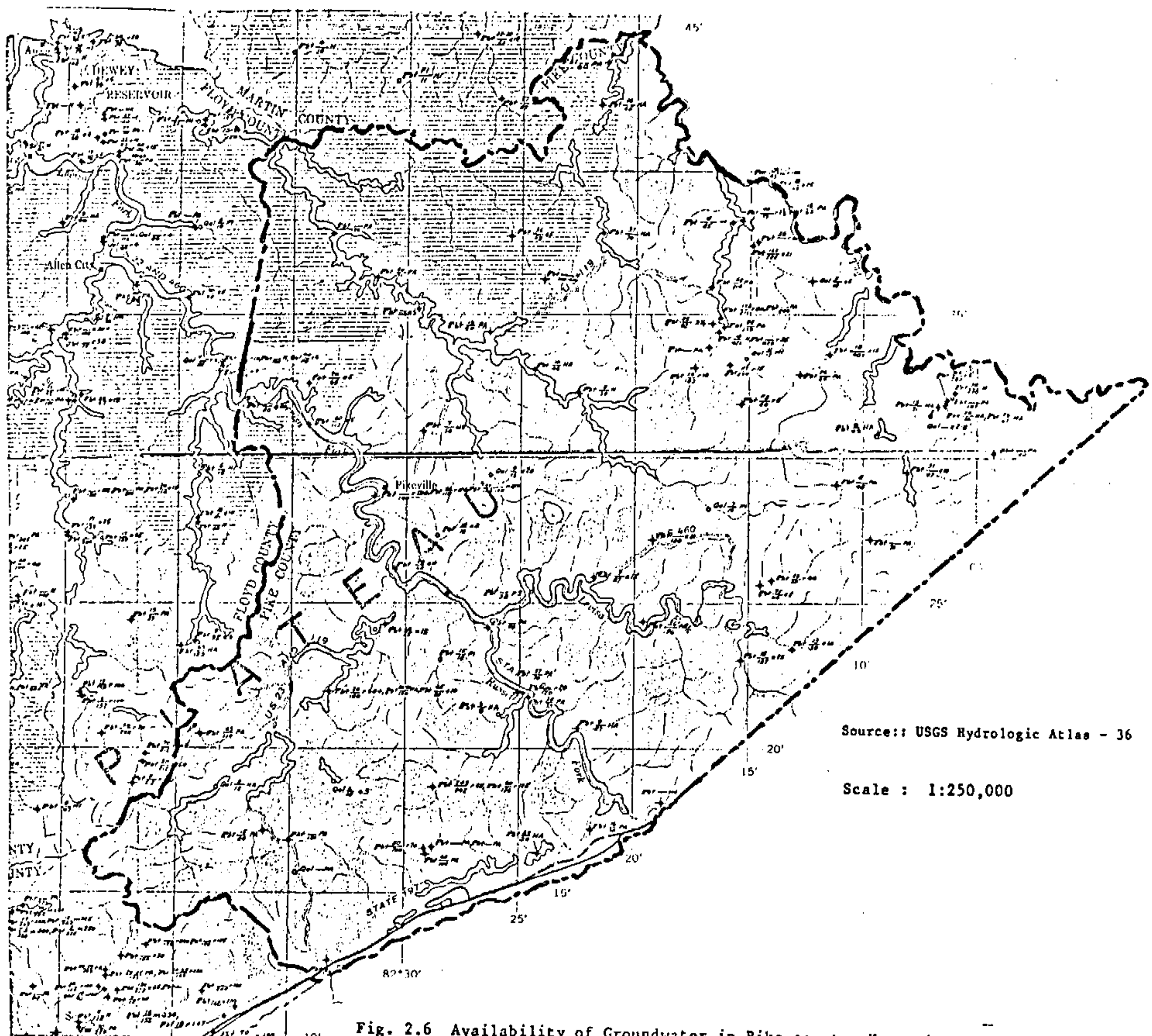
Fig. 2.5 Average monthly temperature at 1 station and average monthly precipitation at 8 stations in the Pike county.
Period of record: 1950-'67 and 1970-'81.

monthly mean precipitation and monthly mean temperature in the Pike county are given in Fig. 2.5.

2.3.2 Groundwater Availability:

A detailed investigation of the availability of groundwater in the Pike county is still lacking. Price, Kilburn and Mull (1962) inventoried the wells and springs in the area and published a hydrologic atlas (USGS Hydrologic Atlas - 36) showing the locations of the wells and springs, rock formation, yield and pump type, depth of water in the wells below the land surface and depth of well below the land surface etc. The Pike county portion of HA-36 is reproduced in Fig. 2.6. The Kentucky Department of Commerce (1981) reported that ground water availability in the Pike county ranges from 50 to 200 gpm in the major portion of the county and 5 to 50 gpm along the extreme south and northwest borders.

Pike county lies in the geological region known as the Kanawha Section of the Eastern Coal Field that contains rock formations of the Pennsylvanian age. Almost the entire county is underlain by shale, sandstone, and coal of Pennsylvanian age. The Kanawha Section is a much dissected plateau characterized by narrow crooked valleys and irregular steep sided ridges. Most of the inhabitants live along the streams and a great majority of the wells in the area are drilled in the valley bottoms. Rock strata in this



Source:: USGS Hydrologic Atlas - 36

Scale : 1:250,000

Fig. 2.6 Availability of Groundwater in Pike county, Kentucky.

region generally yield adequate supplies of water for domestic use. Ground water is used as a source of supply for the public water system serving approximately 3 percent of the total population in the Big Sandy Area Development District (ADD) which includes Pike county. 73 percent of the residents withdraw water from private wells located on their property, or from mine water (water which seeps from the sides of the coal mines) or from springs or creeks located on or near their property (Howard Bell,1973).

2.3.3 Surface Water Resources :

Pike county lies within the watersheds of Levisa and Tug Forks. Tug Fork of the Big Sandy River flows along the northeastern boundary and Levisa and Russell Forks run through the western half.

The Levisa Fork of the Big Sandy River rises in Buchanan county in southeast Virginia and flows in a northwesterly direction to Prestonburg, Kentucky, from where it flows almost due north to its junction with the Tug Fork at Louisa, Kentucky. The Levisa Fork and its tributaries drain 1279 square miles in the Big Sandy Area Development District. Among the major tributaries of the Levisa fork are Russel Fork, Shelby Creek, Mud Creek, Beaver Creek, Middle Creek, Abbott Creek, John's Creek, Paint Creek, Greasy Creek and Tom's Creek.

The Russell Fork is a minor river basin within the Big Sandy ADD and is the major tributary of the Levisa Fork. It rises in the southwest Virginia in Dickenson county and empties into the Levisa Fork at Nelsa in Pike county. Major tributaries of Russel Fork in Kentucky are Elkhorn Creek and Marrowbone Creek. Russell Fork drains 133 square miles in Pike county.

In the Levisa Fork drainage basin, stream flow data were collected from two gaging stations located on the Levisa Fork and one on its tributary -- Russel Fork (see Appendix B). These selected streamflow gaging stations are shown in Fig. 2.7. As mentioned earlier, Tug Fork flows along the northeastern boundary of the county and is, therefore, not pertinent to the drainage basin under consideration. As such, no flow records were collected anywhere on the Tug Fork.

USGS Gaging Station 03209500 on the Levisa Fork is located on the right bank, 20 feet downstream from the bridge on State Highway 1426, one mile (1.6 Km) south of Pikeville, 1.5 mile (2.4 Km) upstream from Harolds Branch, 0.75 mile (1.2 Km) downstream from Lanks Branch and at mile 90.5 (145.6 Km). Coordinates of the gaging station are latitude 37^{0}-27′-51″ and longitude 82^{0}-31′-35″. Drainage area of the Levisa Fork at this location is 1232 square miles. The gage is a water stage recorder and the datum is

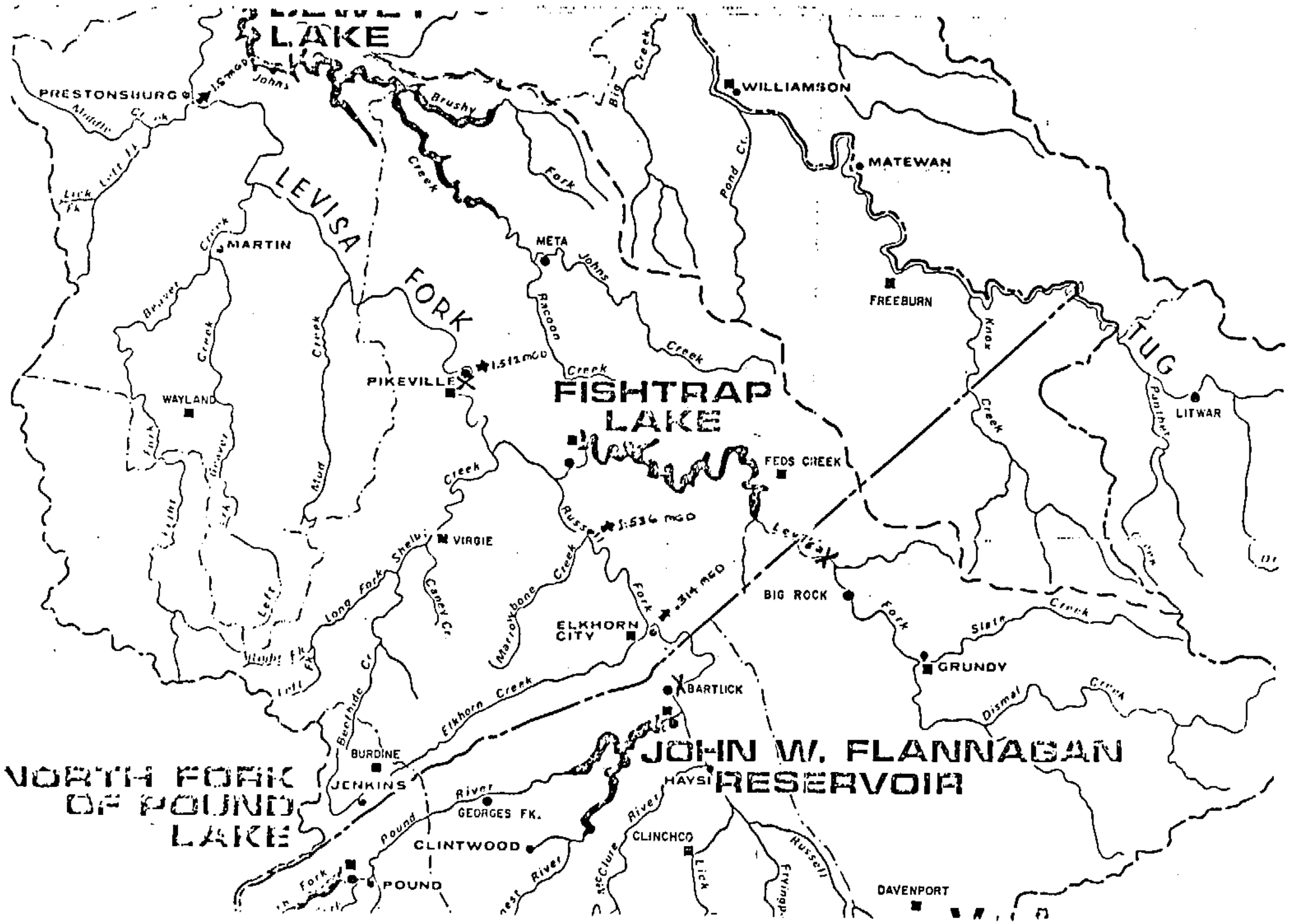


Fig. 2.7 Drainage Basin of Pike county.

X : Selected Streamflow Gaging Stations.

➡ : Water Treatment Plants.

Scale : 1: 250,000

631.28 feet above the Mean Sea Level. The period of record began in October, 1937. Average discharge during 45 years of record is 1478 cfs and the minimum recorded flow during the period of record was 1.5 cfs. There are facilities for low flow augmentation for this station from Fishtrap Lake, J.W. Flannagan Lake and North Fork Pound reservoirs.

USGS Gaging Station 03207800 on Levisa Fork is located on the Buchanan county, on the left bank at Big Rock, Virginia, 2000 feet downstream from Rocklick Creek, and 2500 feet downstream from bridge on the State Highway 645. Coordinates of the gaging station are latitude 37^{o}-21′-13″ and longitude 82^{o}-11′-45″. Drainage area of the Levisa Fork at this location is 297 square miles. The gage is a water stage recorder and the datum is 866.37 feet above Mean Sea Level. Average discharge during 9 years is 383 cfs and the minimum discharge over the period of record was 5.0 cfs.

USGS Gaging station 03209200 on Russell Fork is located on the Dickenson county, Virginia, on the left bank at Bartlick, just upstream from bridge on State Highway 611, 0.2 mile downstream from Pound River, and 1.1 mile upstream from Fall Branch. The coordinates of the gaging station are latitude 37^{o}-14′-45″ and longitude 82^{o}-19′-25″. The drainage area of Russell Fork at this location is 526 square miles and the gage is a water stage recorder and the datum of the gage is 1165.10 feet above MSL. The period of record began on October, 1962. The average discharge over 14 years is 687 cfs and the minimum discharge over the period of record was 5.5 cfs.

2.4 Urban Water Demand:

At present there are three major water treatment plants operating in the Pike county : one is at Pikeville, operating at a capacity of 1.512 million gallons per day, a second one is located near the confluence of the Marrowbone Creek and the Russell Fork having a capacity of 1.536 million gallons per day (mgd) and the third one is at Elkhorn City with a capacity of 0.30 mgd. Another treatment plant at Prestonburg, Kentucky , operating at a capacity of 1.8 mgd was also taken into account as it was found related to the drainage basin under consideration. The location of all the above four treatment plants in the drainage basin are shown in Fig. 2.7. However, from the standpoint that coal water demand is to be met by withdrawal from a location near Pikeville, it is evident from the Fig. 2.7 that the treatment plant at the Elkhorn City is of very little or no importance at all. The total demand from the remaining three water treatment plants of concern was found to be 4.848 million gallons per day. The Urban Studies Center at the University of Louisville forecasts that by the year 2010 A.D., there will be a 60 percent increase over the present population in the Pike county

(Price, 1983). On this basis, the total urban demand for water was computed by multiplying the sum total of the demands from the above three water treatment plants by 1.6 and thus the projected urban demand for 2010 A.D. was estimated to be 7.7568 million gallons per day.

2.5 Minimum Base Flow:

The minimum base flow that is to be maintained in the Levisa Fork beyond the withdrawal point at Pikeville was estimated from the flow records at a gaging station on the Levisa Fork near Prestonburg, Floyd county, Kentucky. The USGS gaging station 03209800 is located on the right bank 50 feet downstream from concrete highway bridge on State Highway 114 at Prestonburg, 150 feet downstream from the mouth of Trimble Branch, 450 feet upstream from Middle Creek and at mile 81.4. Coordinates of the station are latitude $37^{\circ}-40'-15''$ and longitude $82^{\circ}-46'-38''$. The minimum monthly mean flowrate over a 18 year period of record beginning on October, 1963 was found to be 32.9 cfs occurring in the month of October, 1963. This minimum monthly mean discharge was taken to be the minimum baseflow that should be maintained in the stream all the time.

2.6 Coal Transport Water Demand:

As was mentioned earlier, the water requirement for any coal slurry pipeline is a function of the amount of coal to be transported, the properties of coal and the pipeline characteristics. The computer program developed by Kao and Rusher (1983) was used to determine the water requirement for selected coal slurry pipelines originating from inside or around the Pike county. The selected hypothetical pipelines are those that initiate at the Eastern Kentucky and are recommended by Mathtech (1978) as highly probable or probable. Seven such routes were selected and analysed separately, though, according to Mathtech study, some routes were found unlikely as a single case but higly probable or probable when combined with some other route. In all subsequent analyses, total coal transport water demand is taken to be the sum total of individual demands for each of these seven hypothetical coal slurry pipelines. It was found that the amount of water requirement for a particular slurry pipeline depends on the top coal particle size. The amount of water required for a particular coal slurry pipeline is minimum when the top coal particle size is 1.19 mm and then the coal to water ratio in the slurry pielines is 1:1 by weight, as shown in Table 2.1.

Table 2.1 Water Requirement for Coal Slurry Pipelines with Different Top Coal Particle Size.

(All amounts in Thousand Metric Tons per Year)

Route	Amount of Coal to be Transported	Water Requirement for Difnt. Top Size 1.19 mm	3.125 mm
KY-2 TO NY-2	7730	7730	8350
KY-2 TO OH-4	3940	3940	4370
KY-2 TO SC-2	3700	3700	4180
KY-2 TO NC-3	6200	6200	6700
KY-2 TO NC-2	7340	7340	7930
KY-2 TO MI-2	3050	3050	3360
KY-2 TO GA-3	2700	2700	3045

The aim of the present investigation was to determine whether the minimum water demand for coal slurry pipelines could be met in all months of the year with the available water resources in the Pike county. Thus, a coal to water ratio of 1:1 by weight was used hereafter to determine the total demand of all the above seven hypothetical coal slurry pipelines. A sample computation for quantifying the water requirement for any particular slurry pipeline is presented hereafter:

ROUTE: KY-2 TO NY-2

Amount of Coal to be Transported = 7.73 MMTY

(1 MMTY = 1 Million Metric Ton per year)

Amount of Water Required

for Coal Slurry Pipeline = 7.73 MMTY

= 7.73 x 10 m^3 /year

Monthly Water Requirement = 644,166.67 cubic meter

<u>Computation of Required Flowrate in cfs</u> :

<u>31-day Month</u> (Jan., Mar., May, July, Aug., Oct. and Dec.):

Required Flowrate = 644,166.67 m^3/month

= 644,166.67 m^3/(month * 31 days /month * 24 hrs /day * 60 min/ hr *60 sec/min)

= 0.2405 m^3/sec

= 8.49 cfs (1 m^3 = 35.3147 ft^3)

<u>30-day Month</u> (Apr., June, Sept. and Nov.) :

Required Flowrate = 644,166.67 m^3/month

= 644,166.67 m^3/(30*24*60*60 sec)

= 0.24852 m^3/sec

= 8.78 cfs.

<u>28 day month</u> (February):

Required Flowrate = 644,166.67 m^3/month

= 644,166.67 m^3/(28*24*60*60 sec)

= 0.26627 m^3/sec

= 9.40 cfs

All the aforementioned hypothetical coal slurry pipeline routes were analysed in a similar fashion and the results are tabulated below :

Table. 2.2 Monthly Water Requirement for Different Coal Slurry Pipelines

Route	31-day Month	30-day Month	28-day Month
KY-2 TO NY-2	8.49 cfs	8.78 cfs	9.40 cfs
KY-2 TO OH-4	4.33 cfs	4.47 cfs	4.79 cfs
KY-2 TO SC-2	4.07 cfs	4.20 cfs	4.50 cfs
KY-2 TO NC-3	6.81 cfs	7.05 cfs	7.54 cfs
KY-2 TO NC-2	8.07 cfs	8.33 cfs	8.93 cfs
KY-2 TO MI-2	3.35 cfs	3.46 cfs	3.72 cfs
KY-2 TO GA-3	2.98 cfs	3.07 cfs	3.28 cfs
TOTAL	38.10 cfs	39.36 cfs	42.16 cfs

CHAPTER 3

ANALYSIS AND RESULTS

3.1 Analysis of Climatological Data:

The monthly consumptive use for each month of every year for the entire period of record was computed with the help of a computer. Agriculture in the Pike county is on a small scale subsistence basis and the Kentucky Department of Commerce (1975) reported that only 4 percent of the area in the Pike county was farm land. Under this situation, the monthly consumptive use coefficient was assumed to be 1.1 for the largely forested county. The percent sunshine in different months of the year for the Pikeville 2 station (latitude 37°-29′) was taken to be the average value for the county. The slight differences in the latitudes (the maximum difference is 1/3rd of a degree) of the gaging stations have very little or no effect on the value of the percent sunshine as found from a percent sunshine vs. latitude chart (Schulz, 1973). The monthwise percent sunshine values thus taken are as follows :

January	--	6.91%	May	--	9.89%	September	--	8.38%
February	--	6.80%	June	--	9.89%	October	--	7.82%
March	--	8.34%	July	--	10.06%	November	--	6.85%
April	--	8.89%	August	--	9.45%	December	--	6.70%

With these assumptions, the monthly consumptive use and the net monthly consumptive use for Pike county were computed for each month of every year in the period of record. Those values for different months of the year were averaged month by month over the 29 year record period and are pictorially shown in Fig. 3.1. The excess precipitation over the consumptive use was neglected.

3.2 Analysis of Groundwater Data:

The geographical coordinates (latitude and longitude) of the well locations from HA-36 were used in locating the corresponding points on USGS 7.5-Minute Geologic Quadrangle Maps of the Pike county in order to find the land surface elevations of the well locations from the Mean Sea Level. The elevations of the water level in the wells with reference to the Mean Sea Level (MSL) were computed by subtracting the depths of the water in the corresponding wells given in HA-36 from the land surface elevations of the well locations as obtained from the Quadrangle Maps. An attempt was made to prepare a piezometric map of the Pike county from the obtained elevations of the water level in the wells at different locations of the county (Fig. 3.2).

The key factors governing the amount of water that may be obtained from the wells in rocks of Pennsylvanian age in the Eastern Coal Field region are the depth of the well, the topographic position of the well and the lithography of the

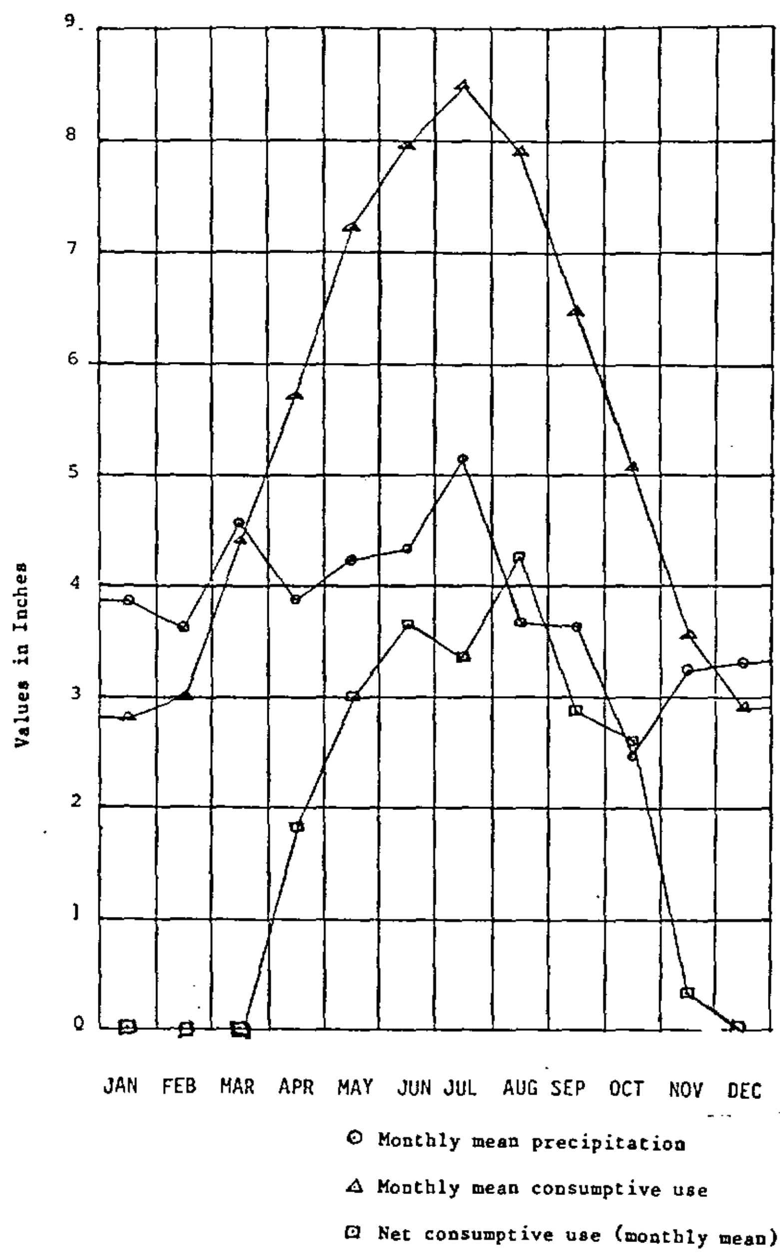
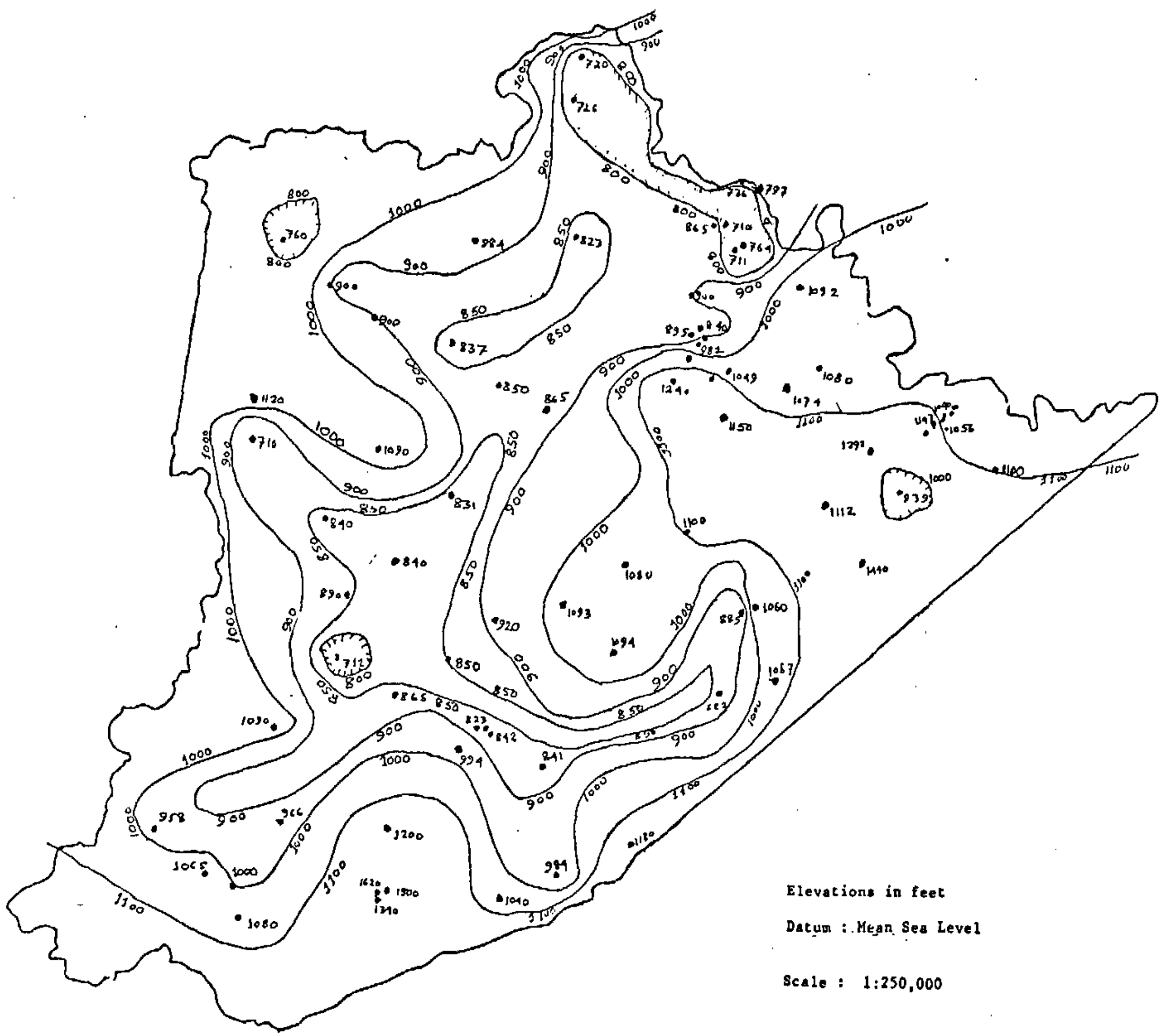


Fig. 3.1 Monthly consumptive use, monthly mean precipitation and Monthly net consumptive use in Pike county.



Elevations in feet

Datum : Mean Sea Level

Scale : 1:250,000

Fig. 3.2 Piezometric map of the Pike county.

rocks tapped. Wells drilled in topographic lows such as valleys are likely to yield more water than wells drilled on topographic highs such as hills. Precipitation, natural discharge, topography and rock characteristics are principal controlling factors in the amount of groundwater in storage. Also the drainage from the coal mines and pumping from the wells decrease the volume of groundwater in storage. Fluctuations of water levels in wells also may be caused by changes in the stage of nearby streams if the water in the well and in the stream is hydraulically connected. (Price, Mull and Kilburn, 1962)

3.3 Frequency Analysis of Stream Flow Records:

As mentioned before, the present study focused on the viability of meeting the water demands for the operation of hypothetical coal slurry pipelines through withdrawal of water from a location near Pikeville. On this assumption, it is evident from the diagram of the drainage basin (Fig. 2.7) that an analysis of stream flow records on Levisa Fork at Pikeville (USGS Station No. 03209500) would suffice to conclude whether demand for slurry pipelines can (or cannot) be met by withdrawing water from a point near Pikeville. Therefore, only the stream flow record from that station was analysed for the purpose of this study.

Observations for monthly mean discharge at the gaging station 03209500 on Levisa Fork at Pikeville in each month of a year over the 18 years period of record were grouped into a finite number of equal discharge intervals encompassing the entire range of mean flowrate values recorded for that month over the 18 year period. The number of times that the mean flowrate for a particular month fell in each interval was plotted as frequency on the left ordinate. Thus the frequency histograms of mean monthly flowrates at the station for each month of the year were obtained (Figs. 3.3 - 3.14). A close examination of the histograms of monthly mean discharge indicated that either an exponential or a gamma probability density curve would provide the best fit to the observed values. These probability densities can be mathematically expressed as :

Exponential: $$f_X(x) = \lambda e^{-\lambda x} \tag{3.1}$$

Gamma: $$f_X(x) = \frac{\lambda^p \, x^{p-1} \, e^{-\lambda x}}{\Gamma(p)} \tag{3.2}$$

It should be noted here that the monthly mean discharge for a month as shown in Figs. 3.3 - 3.14 were scaled in units of the width of the corresponding class interval, i.e. either in 1000 cfs or in 500 cfs. Under this transformation either an exponential or a gamma probability density function as defined above provides the best fit. For example, the histogram of the monthly mean discharge in the month of January (Fig. 3.3) indicated that a gamma probability density function might provide a reasonably good fit. However, as is evident from the figure, the random variable X having a gamma probability density function as defined by the equation (3.2) takes values in units of Kilo cfs, i.e. X takes a value 1 when the actual monthly mean discharge value is 1000 cfs, a value 2 when the actual monthly mean discharge value is 2000 cfs and so on. If Z be defined as the random variable denoting the actual monthly mean discharge in cfs, the relationship between the random variables Z and X can be expressed as follows:

$$Z = g(X) = 1000X$$

or

$$g^{-1}(z) = x = z/1000 \tag{3.3}$$

Under this transformation the probability density function of Z is given by

$$f_Z(z) = f_X\{g^{-1}(z)\}.\left|\frac{d}{dz}\{g^{-1}(z)\}\right|$$

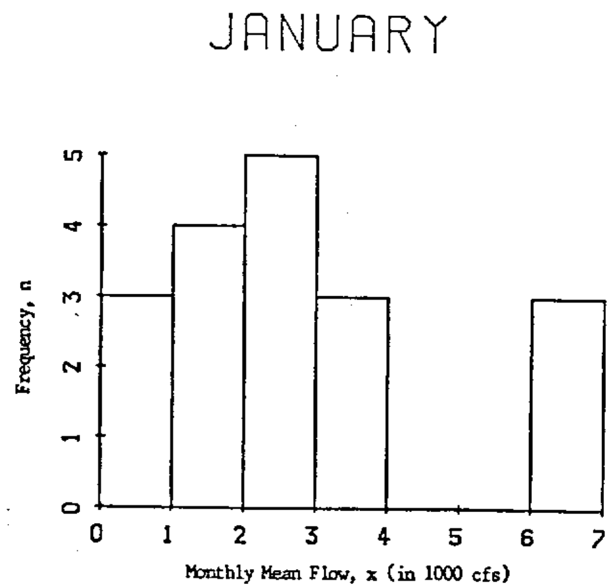
$$= f_X\left\{\frac{z}{1000}\right\}.\left|\frac{d}{dz}\left\{\frac{z}{1000}\right\}\right|$$

$$= \frac{\lambda^p\ (z/1000)^{p-1}\ e^{-\lambda(z/1000)}}{\Gamma(p)}.|(1/1000)|$$

$$= \frac{(\lambda/1000)^p\ z^{p-1}\ e^{-(\lambda/1000).z}}{\Gamma(p)}$$

$$= \frac{\beta^p\ z^{p-1}\ e^{-\beta z}}{\Gamma(p)} \tag{3.4}$$

where $\beta = \lambda/1000$



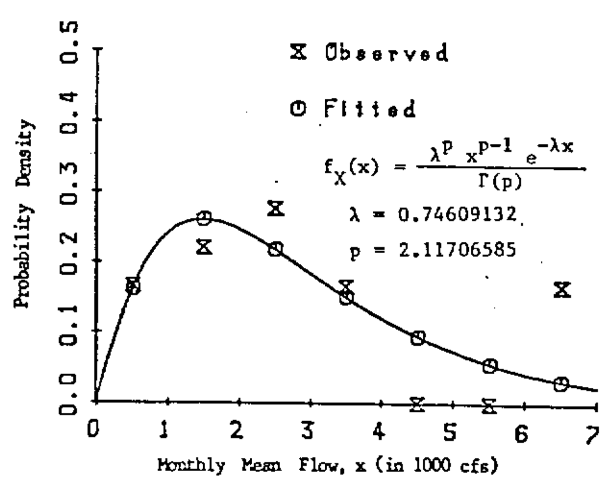


Fig. 3.3 Histogram and Fitted Probability Density Function

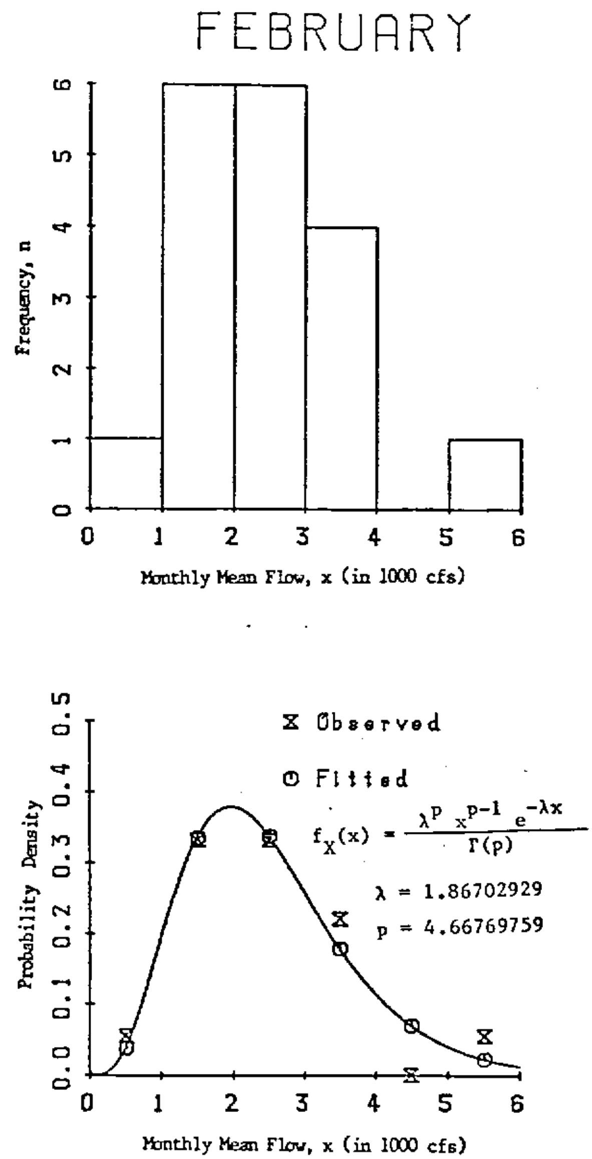


Fig. 3.4 Histogram and Fitted Probability Density Function

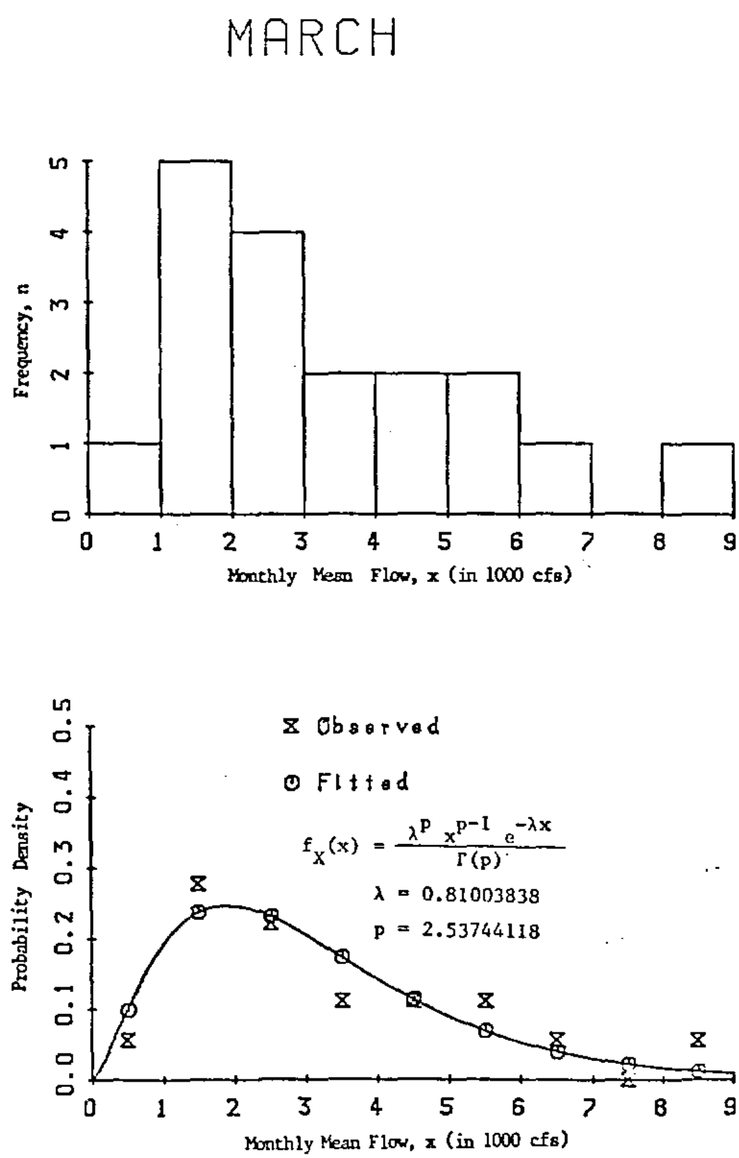


Fig. 3.5 Histogram and Fitted Probability Density Function

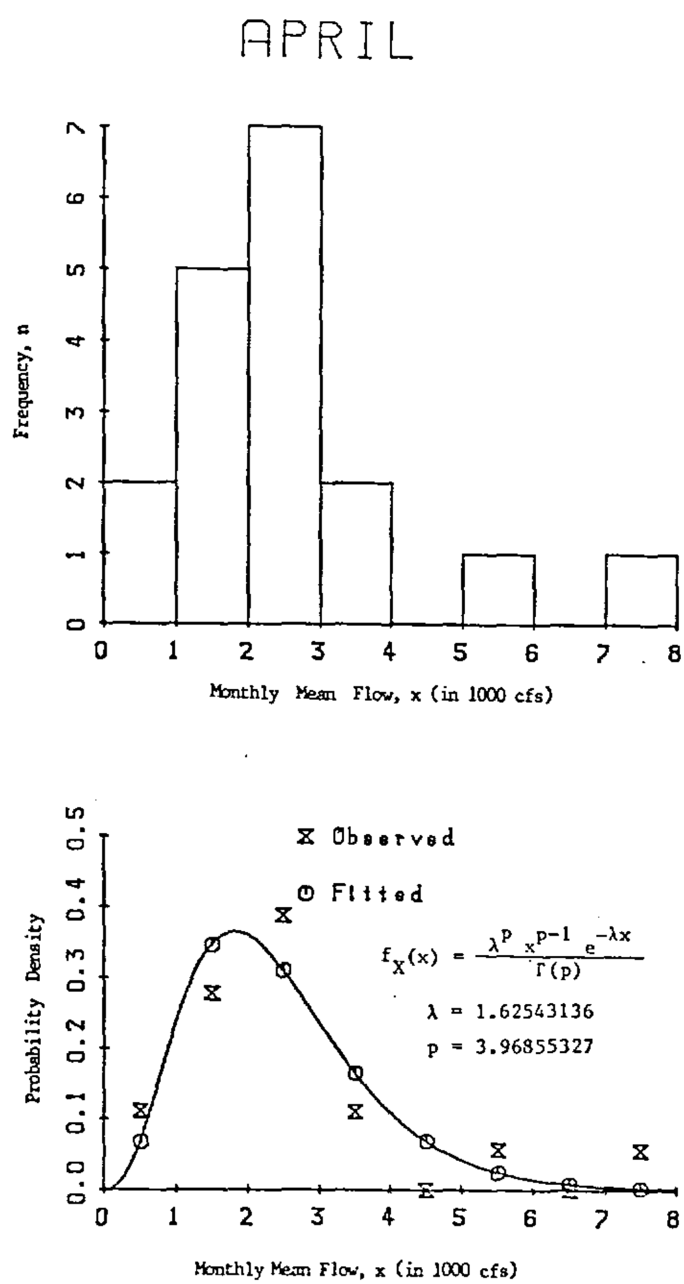
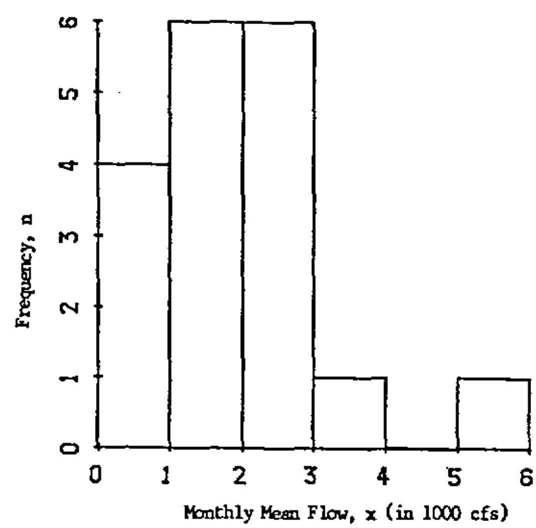


Fig. 3.6 Histogram and Fitted Probability Density Function

MAY



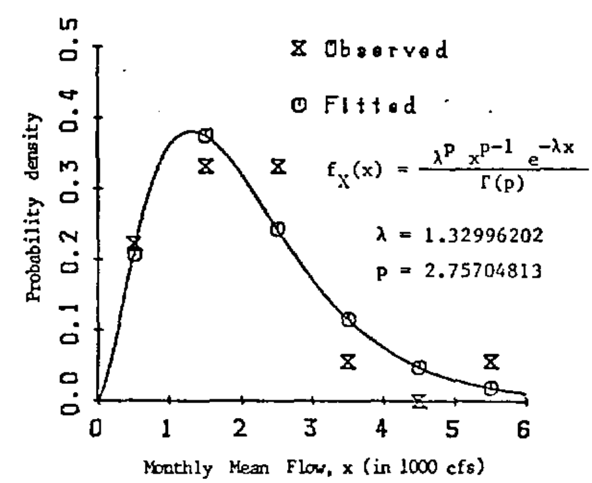
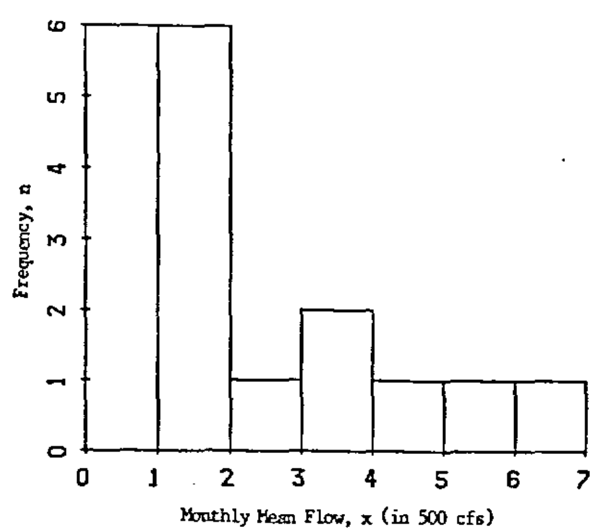


Fig. 3.7 Histogram and Fitted Probability Density Function

JUNE



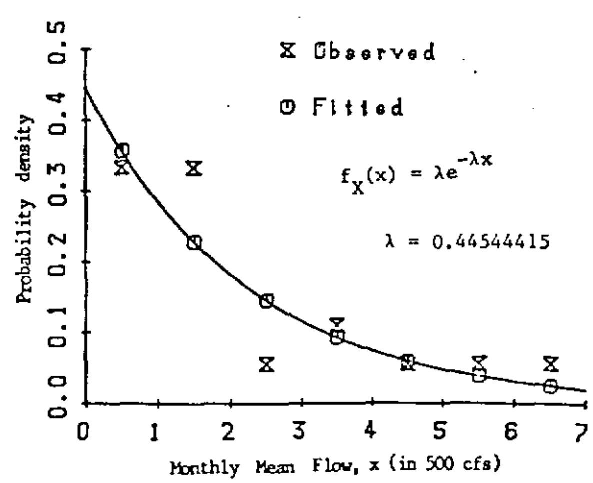


Fig. 3.8 Histogram and Fitted Probability Density Function

JULY

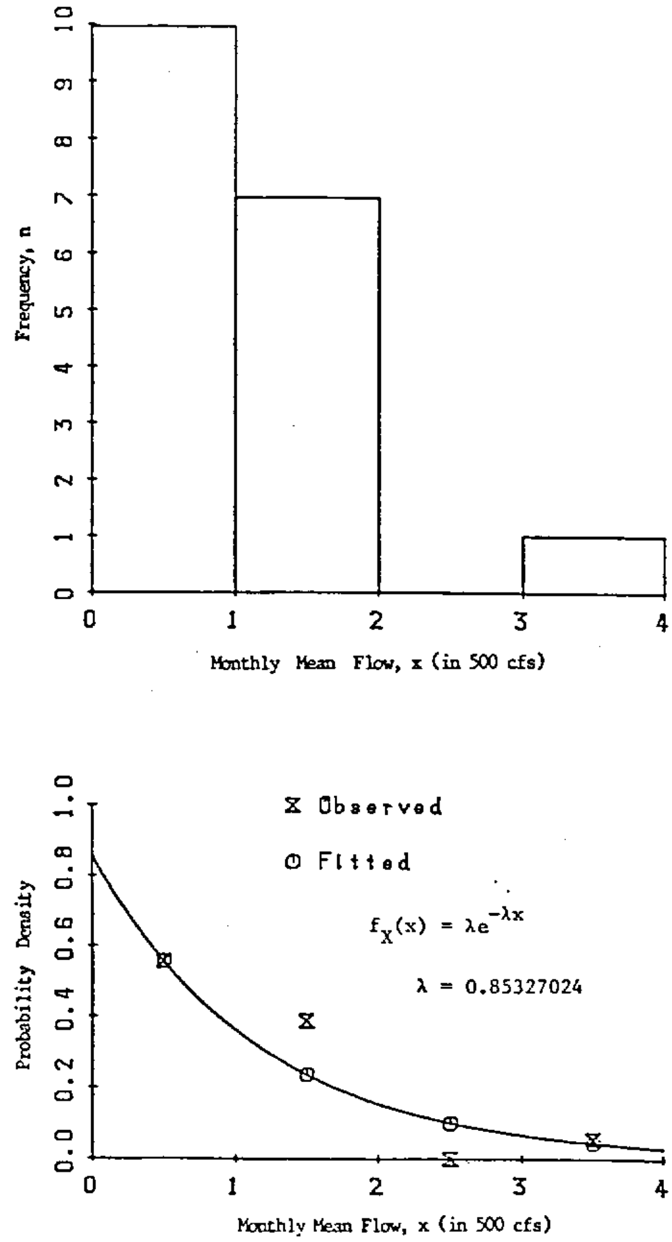
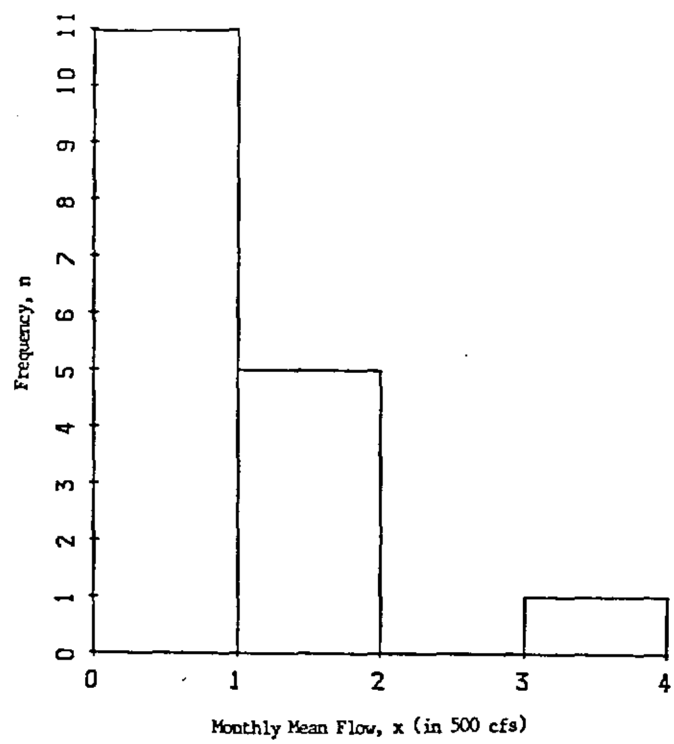


Fig. 3.9 Histogram and Fitted Probability Density Function

AUGUST



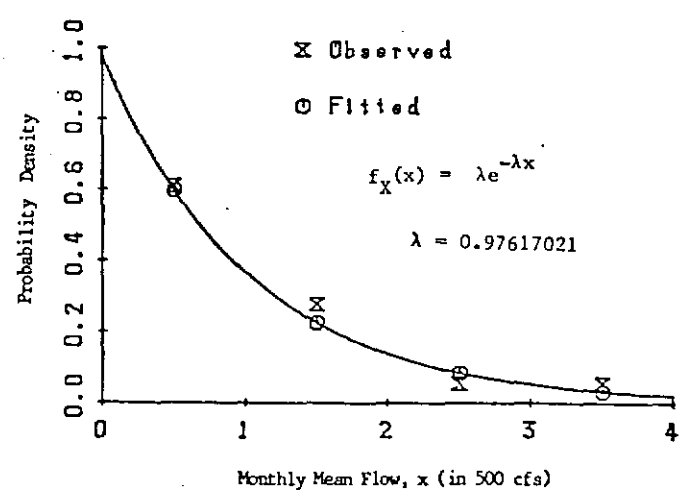


Fig. 3.10 Histogram and Fitted Probability Density Function

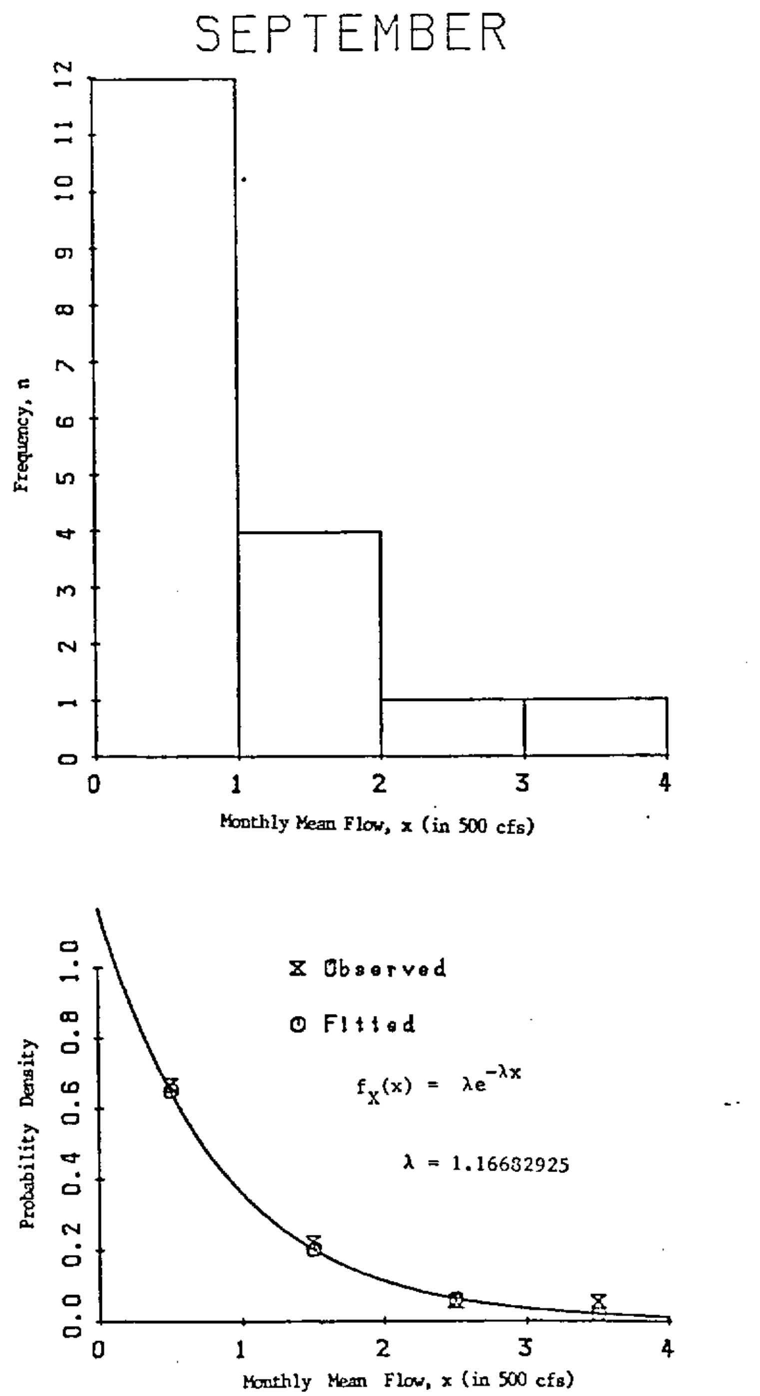


Fig. 3.11 Histogram and Fitted Probability Density Function

OCTOBER

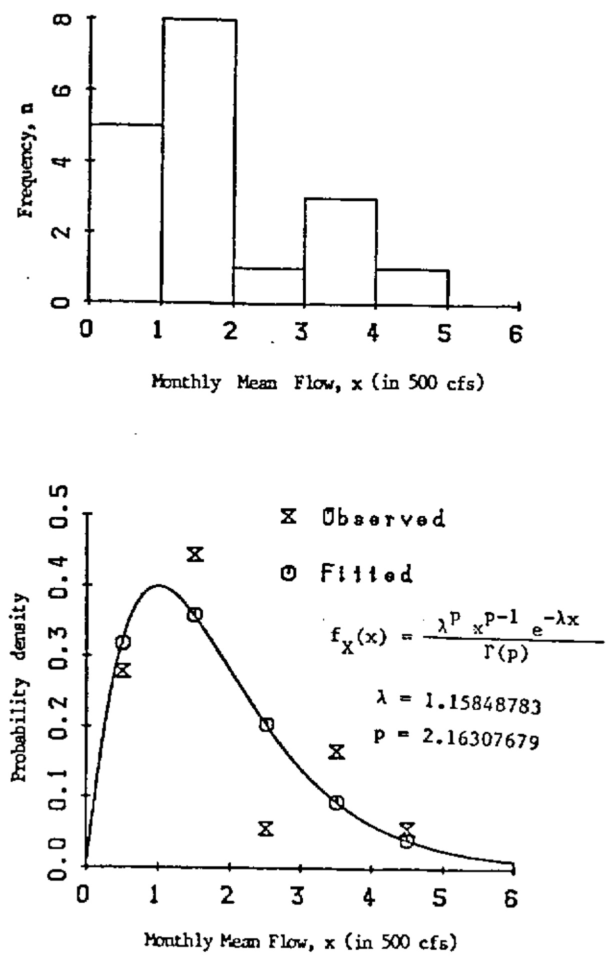
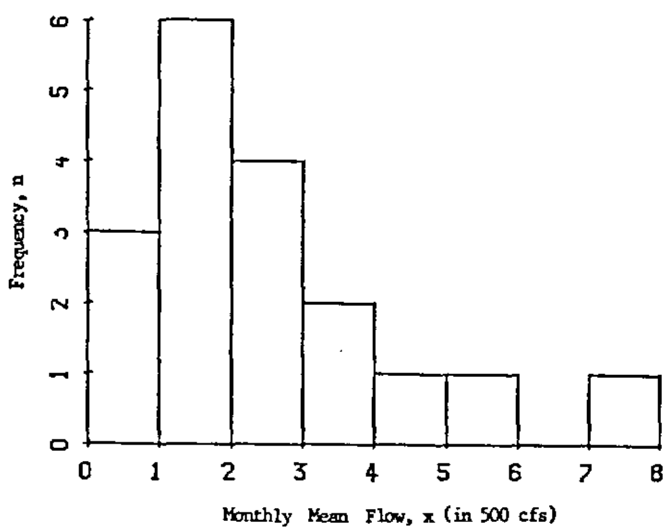


Fig. 3.12 Histogram and Fitted Probability Density Function

NØVEMBER



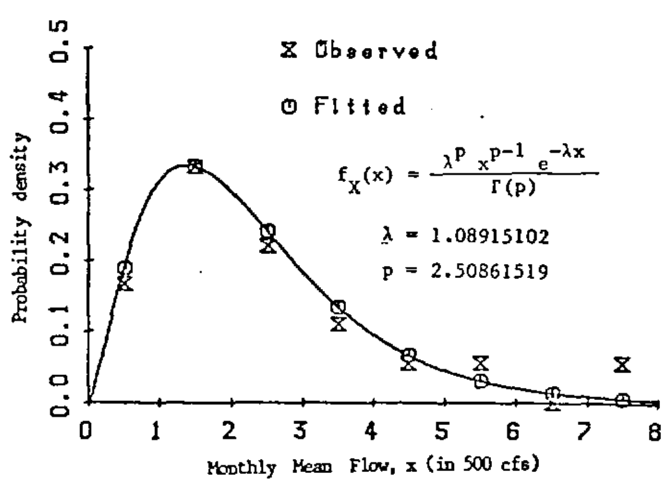
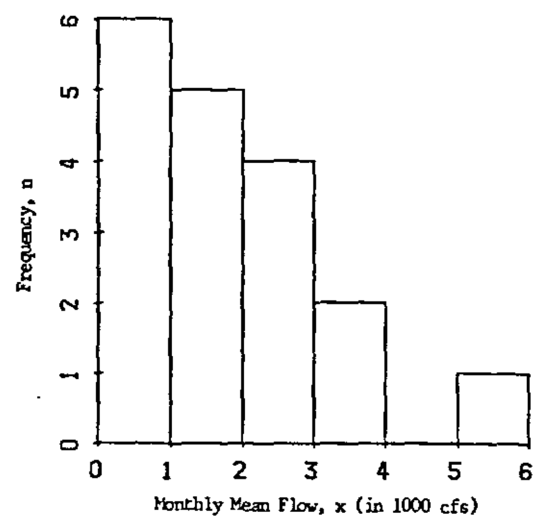


Fig. 3.13 Histogram and Fitted Probability Density Function

DECEMBER



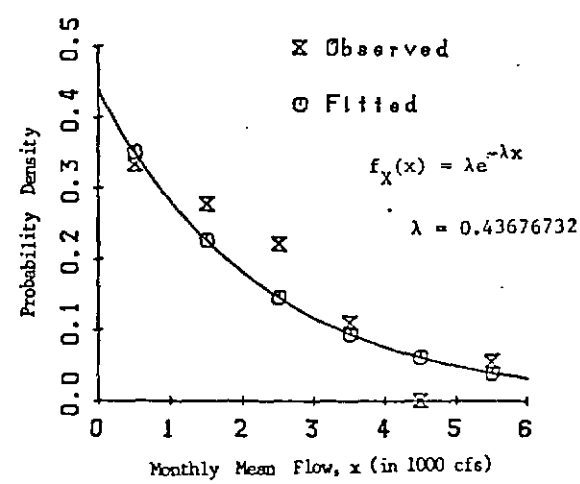


Fig. 3.14 Histogram and Fitted Probability Density Function

Thus the random variable Z, denoting the actual monthly mean discharge in cfs is also a gamma distributed random variable as X, but with a different parameter β, though the shape parameter p remains the same. This result of the similarity in the distribution of the random variable Z and the scaled random variable X is true for all other months. Since Z and X have the same form of probability distribution, any probability value obtained from the probability density function or the cumulative probability distribution function of X can be directly transformed to a corresponding value of Z. For example, in the instance of the month of January,

$$P\ (X \leq c) = P\ (Z/1000 \leq c) = P\ (Z \leq 1000c) \qquad (3.5)$$

Such a tranformation exists also for all other months in accordance to an appropriate relationship between Z and X. On this basis, the exponential or gamma probability density functions were fitted to the scaled random variable X.

Since relative frequency is synonymous with probability, the histograms as shown in Figs. 3.3 through 3.14 were transformed so that the area in each interval represented probability and the total area thus enveloped was unity. In order to achieve this transformation, the frequency n was divided by N, the sum of the frequencies, to obtain the relative frequency (n/N). The relative frequency or probability was then divided by the interval width, Δx , the value of which is unity in units of transformed random variable X. The ratio $n/(N \cdot \Delta x)$ is literally the probability per unit length in the interval and therefore represents the average density of probability. Since the probability densities thus fitted are continuous functions, the probability values could be read from the density or distribution curves for any value of x, integer or real.

A nonlinear regression computer program, in SAS, was used to produce least squares estimates of the parameters of these nonlinear models. The nonlinear regression program was based on Marquardt's algorithm (Marquardt,1963). A sample program for the case of a gamma distribution is listed below :

```
//JOB CARD
/*PASSWORD     ******
//STEP EXEC SAS
//SYSIN DD *
DATA A;
   INPUT X Y ;
   CARDS;
PROC NLIN    BEST=25 PLOT METHOD=MARQUARDT
             MAXITER=400 CONVERGE= 10.E-16;
   PARMS LAMBDA=1.10 TO 2.10 BY .25  P=1.50 TO 3.50 BY .50;
   G1=GAMMA(P);
   TERM=(LAMBDA**P)*EXP(-LAMBDA*X)*(X**(P-1));
   MODEL Y=TERM/G1;
```

```
   DER.LAMBDA=TERM*(P/LAMBDA-X)/G1;
   DER.P= TERM/G1 * (LOG(LAMBDA*X) + LOG(P) - 1./(2.*P)
     - 1./(12.*(P**2))+ 1./(120.*(P**4)) - 1./(252.*(P**6))
     + 1./(240.*(P**8)) - 5./(660.*(P**10))
     + 691./(32760.*(P**12)) - 7./(224.*(P**14))
     + 3617./(510.*16.*(P**16)) - 43867./(798.*18.*(P**18))
     +174611./(330.*20.*(P**20))-854513./(138.*22.*(P**22))
     + 236364091./(2730.*24.*(P**24))
     - 1425517.167/(26.*(P**26)) + 27298231.07/(28.*(P**28))
     - 601580873.9/(30.*(P**30) + 15116315770/(32.*(P**32))
     - 429614643100/(34.*(P**34)));
     OUTPUT OUT =B P=YHAT R=YRESID;
PROC PRINT DATA=B;
PROC MEANS DATA=B;
PROC PLOT DATA=B;
     PLOT Y*X='A'YHAT*X='P'/OVERLAY;
     PLOT YRESID*X/VREF=0;
/*
```

A computable expression for the term DER.P, the derivative of the gamma probability density function, $f_X(x)$ with respect to the shape parameter, p, which is an essential input to the computer program was obtained as follows:

$$\frac{\partial f(x)}{\partial p} = \frac{\partial}{\partial p}\left\{\frac{\lambda^p x^{p-1} e^{-\lambda x}}{\Gamma(p)}\right\}$$

$$= \frac{\lambda^p x^{p-1} e^{-\lambda x}}{\Gamma(p)} \cdot \{\ln(\lambda x) + \psi(p)\} \qquad (3.6)$$

Where $\psi(p)$ is the Psi (Digamma) function defined by

$$\psi(p) = \frac{d}{dp}\{\ell n\ \Gamma(p)\} = \frac{\Gamma'(p)}{\Gamma(p)} \qquad (3.7)$$

An asymptotic formula for Psi (Digamma) function is given by Abramowitz and Stegun (1965) :

$$\psi(p) \sim \ell n(p) - \frac{1}{2p} - \frac{B_{2n}}{2np^{2n}} \qquad (3.8)$$

where B_{2n}s are the Bernoulli numbers. The values of Bernoulli numbers up to n = 17 were taken from Davis (1935) and thus a computable, though approximate, expression was obtained for DER.P.

The fitted probability density curves to the transformed random variable X are presented along with their parameter values in Figs. 3.3 - 3.14.

3.4 <u>Risk Analysis</u>:

With these probability densities fitted to the monthly mean flowrate in the transformed units, a risk analysis was performed to determine the risks involved in meeting the total demand (the sum total of urban demand, minimum baseflow requirement and the demand for coal slurry pipelines) in any month of the year. The aim was to find for each month of the year, the probability that the monthly mean discharge in cfs is less than or equal to the total demand (monthly mean flowrate), mathematically expressed as

$$P\ (Z \leqslant b) \tag{3.9}$$

where, Z is a random variable denoting monthly mean discharge in cfs.

and b is the total demand (in terms of monthly mean flowrate) in cfs.

However,

$$P\ (Z \leqslant b) = P\ (kX \leqslant b)$$

$$= P\ (X \leqslant \frac{b}{k}) \tag{3.10}$$

where X is a transformed random variable, related to Z by $Z = kX$, k being a scaling factor (either 1000 or 500).

Thus the total demand, b, in any particular month is divided by the corresponding scaling factor, k and $P\ (X \leqslant \frac{b}{k})$ was evaluated as follows :

1. In case of an exponential probability distribution, the required probability is given by :

$$P\ (X \leqslant b/k) = F_X(x = b/k) = \int_0^{b/k} f_X(x)\ dx$$

$$= \int_0^{b/k} \lambda e^{-\lambda x}\ dx \quad = 1 - e^{-\lambda . b/k} \tag{3.11}$$

Substituting the values for total demand (monthly mean flowrate), b in cfs, and the scaling factor,k of the corresponding month in expresssion (3.11), the required probability was obtained in those cases. The risk, R is given by

$$R = 100.\ P\ (Z \leqslant b)$$

$$= 100.\ \ P\ (X \leqslant \frac{b}{k}) \qquad (3.12)$$

An example of the computation is given below :

Month : December

$f_X(x) = \lambda e^{-\lambda x}$ where λ =0.43676732

Urban Demand = 7.7568 Mgd

= 7.7568 x 3.7854 x 10^6 m^3/d

= 29,362.59 m^3/d

= 29,362.59 /86,400 m^3/sec

= 0.3398448 m^3/sec

= 0.3398448 x 35.3147 ft^3/sec

= 12.00 cfs

Coal Slurry Pipelines Demand = 38.1 cfs

Minimum Baseflow Requirement = 32.9 cfs

Total Demand, b = Urban Demand + Coal Slurry Pipelines Demand + Minimum Baseflow Requirement

= 83.00 cfs

Here, Z = 1000X and hence k = 1000 or b/k= 0.083

$$P\ (Z \leq 83) = P(\ 1000X \leq 83)$$
$$= P\ (X \leq .083)$$
$$= 1 - \exp(\ -0.42676732 \times .083)$$
$$= 0.0356$$

Risk, R = 100 x 0.0356 = 3.56%

2. In case of a gamma probability distribution, the required probability is given by :

$$P\ (X \leq b/k) = F_X(x = b/k) = \int_0^{b/k} f_X(x)\ dx$$
$$= \int_0^{b/k} \frac{\lambda^p\ x^{p-1}\ e^{-\lambda x}}{\Gamma(p)}\ dx \qquad (3.13)$$

The SAS function PROBGAM (y,p) computes the probability that a random variable Y, with a gamma distribution with shape parameter p, falls below the y value given. The probability density fuction that is evaluated by the SAS function PROBGAM is given by

$$f_Y(y) = \frac{y^{p-1}\ e^{-y}}{\Gamma(p)} \qquad (3.14)$$

or in other words,

$$\text{PROBGAM}\ (y,p) = P\ (Y \leq y) = \int_0^{y} \frac{u^{p-1}\ e^{-u}}{\Gamma(p)}\ du$$

Hence,

$$\text{PROBGAM}\ (\lambda y,p) = P\ (Y \leq \lambda y) = \int_0^{\lambda y} \frac{u^{p-1}\ e^{-u}}{\Gamma(p)}\ du$$

Substituting $u = \lambda v$

so that $du = \lambda dv$

and when $u = 0$, $v = 0$

$u = \lambda y$, $v = y$

the following expression was obtained :

$$\text{PROBGAM } (\lambda y, p) = P\ (Y \leqslant \lambda y)$$

$$= \int_0^y \frac{(\lambda v)^{p-1}\ e^{-\lambda v}\ \lambda\ dv}{\Gamma(p)}$$

$$= \int_0^y \frac{\lambda^p\ v^{p-1}\ e^{-\lambda v}}{\Gamma(p)}\ dv \qquad (3.15)$$

Similarly,

$$\text{PROBGAM } (\lambda b/k, p) = \int_0^{b/k} \frac{\lambda^p\ x^{p-1}\ e^{-\lambda x}}{\Gamma(p)}\ dx \qquad (3.16)$$

From the above expression it is evident that by the previous transformation, the SAS function PROBGAM can be modified to evaluate a two parameter gamma probability density function as defined in (3.2), instead of an one parameter p.d.f. defined by (3.14).

Thus the required probability for a particular month, as given by (3.13) in case of a gamma distribution was determined by performing the following steps:

1. The total demand (monthly mean flowrate) b in cfs was first divided by the scaling factor, k (either 1000 or 500). The result was then multiplied by the parameter λ of the fitted probability density curve for the corresponding month.

2. A computer program was executed to evaluate the SAS function PROBGAM ($\lambda b/k,p$)

A sample computation is given below :

Month : January

$$f_X(x) = \frac{\lambda^p \, x^{p-1} \, e^{-\lambda x}}{\Gamma(p)}$$

$$\lambda = 0.74609132$$
$$p = 2.11706585$$

Urban Demand	=	12.0	cfs
Coal Slurry Pipelines Demand	=	38.1	cfs
Minimum Baseflow Requirement	=	32.9	cfs
Total Demand	=	83.0	cfs

$$\begin{aligned} P\,(Z \leqslant 83) &= P\,(1000X \leqslant 83) \\ &= P\,(X \leqslant .083) \\ &= \text{PROBGAM}\,(0.083\,\lambda\,,p) \\ &= \text{PROBGAM}\,(0.0619255,p) \\ &= 0.0011885 \end{aligned}$$

Risk, R = 100 x 0.0011885 = 0.11885 %

The probability that the stream flow on the Levisa Fork at Pikeville may be less than the total demand in any month of the year was thus obtained for every month of the year and are tabulated in Table 3.1.

Next, the value x of the random variable X for which the probabilities as defined by equations (3.1) and (3.2), are equal to 0.05 (or 5%) was found as follows :

1. In case of an exponential distribution by solving the equation (3.17) for x,

$$P\ (X \leq x) = 0.05 = 1 - e^{-\lambda x} \tag{3.17}$$

and

2. In case of a gamma distribution by evaluating PROBGAM (λx,p) over a possible range of x values.

The corresponding value in cfs, z, for a particular month was obtained by multiplying x with the scaling factor k. These values of z are defined as the available water or the sustainable withdrawal at 5 percent risk. The results were tabulated in Table 3.1 and a comparative chart of the available water at 5 percent risk, the total demand and the surplus or deficit in each month of the year is presented in Fig. 3.15.

Table 3.1 Monthly Mean Water Demand, Risks in Meeting the Demand and Sustainable Withdrawal at 5 percent Risk.

Month	Urban Demand	Slurry Pipeline Demand	Minimum Baseflow Demand	Total Demand	Risk in meeting total demand	Sustainable Withdrawal at 5% Risk
	in cfs	in cfs	in cfs	in cfs	in %	in cfs
January	12.0	38.10	32.9	83.00	0.11885	541.0
February	12.0	42.16	32.9	87.06	0.00026	945.0
March	12.0	38.10	32.9	83.00	0.02914	729.0
April	12.0	39.36	32.9	84.26	0.00147	830.0
May	12.0	38.10	32.9	83.00	0.04752	523.0
June	12.0	39.36	32.9	84.26	7.23000	57.5
July	12.0	38.10	32.9	83.00	13.21000	30.0
August	12.0	38.10	32.9	83.00	14.96000	26.0
September	12.0	39.36	32.9	84.26	17.85000	21.0
October	12.0	38.10	32.9	83.00	1.06175	182.0
November	12.0	39.36	32.9	84.26	0.38125	263.0
December	12.0	38.10	32.9	83.00	3.56000	117.0

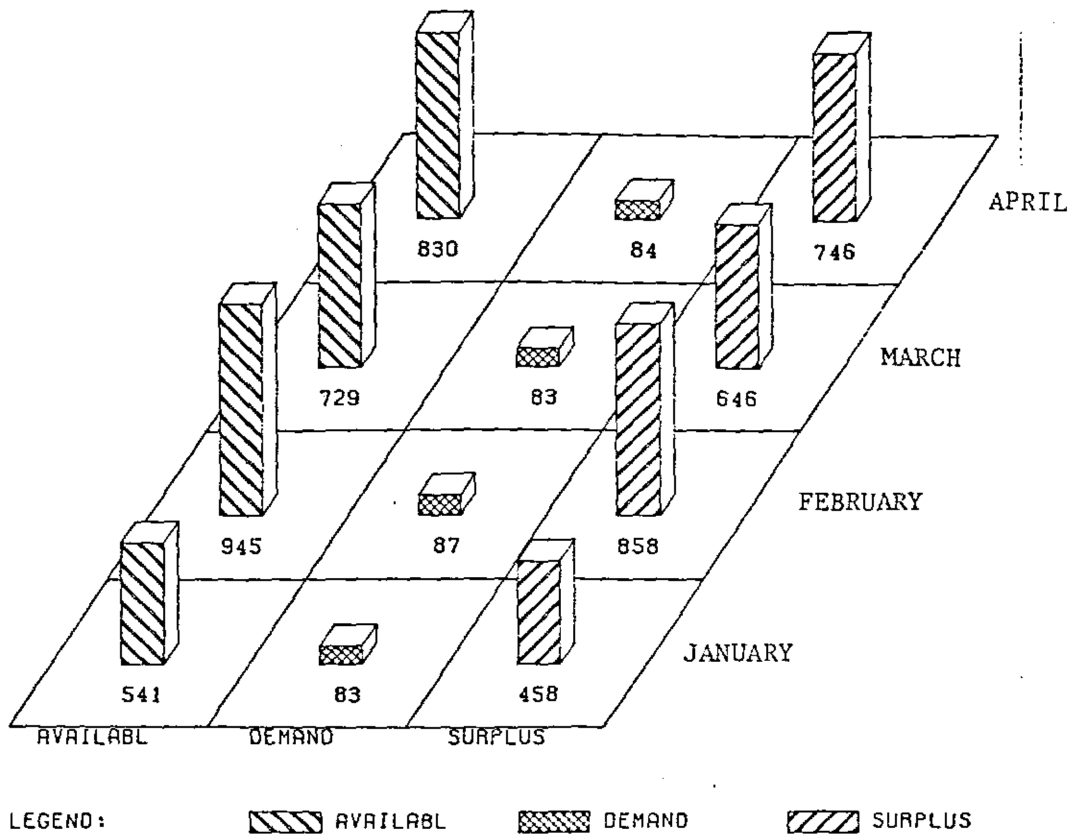


Fig. 3.15 A COMPARATIVE CHART OF MONTHLY WATER AVAILABILITY AT 5 PERCENT RISK, TOTAL WATER DEMAND AND DEFICIT OR SURPLUS.

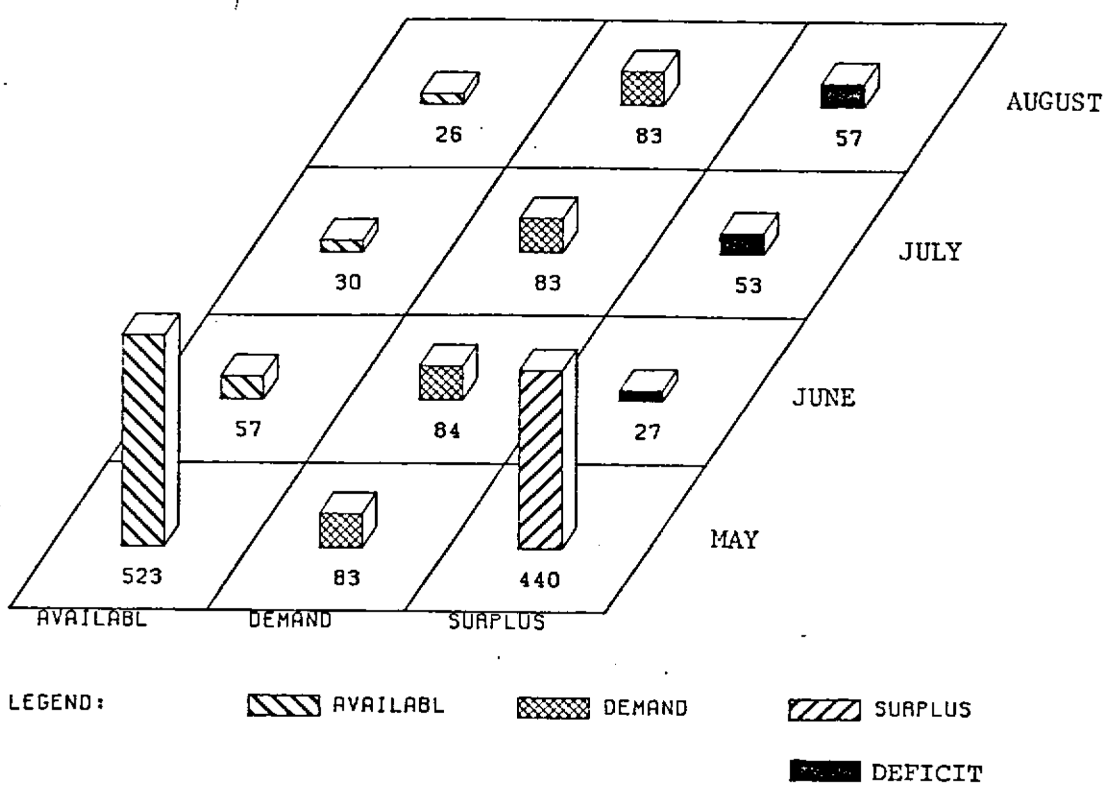


Fig. 3.15 A COMPARATIVE CHART OF MONTHLY WATER (Contd.) AVAILABILITY AT 5 PERCENT RISK, TOTAL WATER DEMAND AND DEFICIT OR SURPLUS.

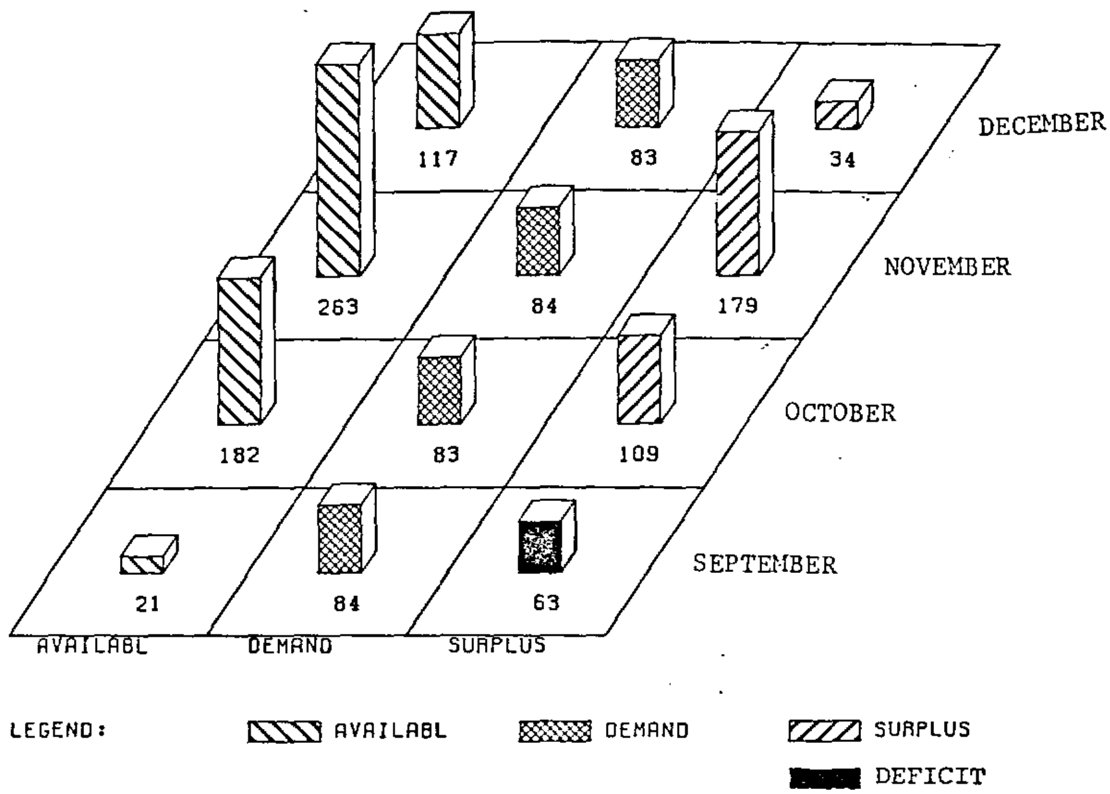


Fig. 3.15 (Contd.) A COMPARATIVE CHART OF MONTHLY WATER AVAILABILITY AT 5 PERCENT RISK, TOTAL WATER DEMAND AND DEFICIT OR SURPLUS.

CHAPTER 4

DISCUSSION AND CONCLUSION

4.1 Discussion:

Agriculture in the selected pilot study area is on a subsistence basis and less than 4 percent of the land are farm land. In this context, net consumptive use of water or the crop water requirement is irrelevant as irrigation is almost nonexistent in the largely forested county. Groundwater data was found inadequate to evaluate the groundwater situation in detail. The piezometric map of the county developed from the available data only gives an approximate picture of the groundwater situation in the study area. More detailed investiagtions of the availability of ground water in this region should be carried out as demands for water are expected to increase substantially, if coal slurry pipelines were implemented. The preliminary assessment of the groundwater situation supports the view that the conjunctive use of surface and groundwater resources may contribute significantly to meeting the seasonal deficits which extend only over four months of the year, from June to September. During the last few years coal production and marketing have seen a big boost and under this changed situation prospects for coal slurry pipeline applications in the Eastern Kentucky should be reevaluated. One of the biggest impediments to an extensive water resources planning for this region is the lack of data. Efforts should be taken immediately to improve the data collection network for precipitation, groundwater and surface water as well.

4.2 Conclusion:

The results of risk analysis showed that the total demands for all eight slurry pipelines under consideration together with urban and minimum baseflow requirement could not be met throughout the year. The risks in meeting the demand in the months of June through September was found to be too high. At 5 percent risk, month of September shows the least amount of water availability -- only 21 cfs, which is not even sufficient to meet the the minimum baseflow requirement for the stream. Two other months, July and August also contain such risks of falling short of minimum baseflow requirement. Availability of water in the month of June is sufficient to meet the minimum baseflow requirement and urban demand, though not enough to meet the slurry pipeline water demand for all eight hypothetical routes. However, in that month, the surplus water beyond the urban and baseflow demands can be utilized in meeting one or more selected coal slurry pipeline demands. Excluding these four critical months of the year, the total water demand of eight coal slurry pipelines, urban demand and minimum baseflow requirement could be met in any month of the year. From October through December there remains a surplus of water even after meeting the total demand. The highest amount of excess water in any month is 858 cfs which is almost about 10 times the total demand for that month(February). These excesses occurring for eight months of the year could be stored in a reservoir to meet the deficits extending from June through September. From the previous analyses it is evident that the reservoir only needs to carry over water volumes seasonally within a year and hence the storage volume of the proposed reservoir would be quite small. Storage regulation of Fishtrap Lake and/or Flannagan reservoir offers another possible way of meeting the seasonal low-volume deficits. Further studies should be conducted to optimize the water resources utilization and allocation in the face of highly probable application of coal slurry pipelines in this area.

APPENDIX - A

Climatological Data

Pike County, Kentucky

Monthly Mean Precipitation in Inches

1981

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	1.10	5.01	3.84	5.06	5.82	4.62	6.81	1.63	3.41	3.82	1.70	2.32
Elkhorn City	1.12	4.79	2.95	4.77	5.66	4.75	3.14	1.65	2.47	2.67	1.02	2.87
Fedscreek	0.73	4.09	3.49	4.40	3.56	3.65	3.14	2.26	2.83	2.55	1.25	2.81
Fishtrap Lake	0.83	4.19	2.86	4.31	4.41	5.77	4.69	1.43	2.36	2.67	0.87	2.98
Freeburn 2 SW	0.66	3.79	3.56	4.05	5.36	5.57	2.82	1.62	2.46	3.17	1.37	2.83
Meta 4 SE	0.77	4.03	2.98	3.95	4.87	4.57	5.36	1.42	2.12	3.84	1.16	3.03
Pikeville 2	0.95	4.95	2.75	4.70	5.55	6.36	2.50	3.38	2.64	4.29	0.95	2.89
Virgie	0.60	4.82	3.41	3.57	4.83	3.94	3.08	1.53	2.15	3.10	0.81	3.05

1980

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	4.17	1.71	5.00	4.05	2.65	1.54	5.04	4.57	4.59	1.51	2.02	1.75
Elkhorn City	3.54	1.45	5.37	4.08	1.97	1.35	5.88	6.06	3.14	1.73	3.06	1.42
Fedscreek 1SE	3.49	1.17	4.63	4.42	1.96	1.24	5.66	1.77	3.64	1.86	3.19	1.92
Fishtrap Lake	3.17	2.16	4.72	4.12	1.90	1.37	5.18	6.09	4.47	1.64	3.15	1.59
Freeburn 2SW	3.74	2.93	4.70	4.57	1.85	1.13	10.02	4.21	3.41	1.69	3.04	1.95
Meta 4 SE	3.58	1.70	4.18	3.37	2.18	0.74	7.91	4.38	3.08	1.61	2.82	1.68
Pikeville 2	-	-	-	3.85	1.96	-	-	4.46	2.41	1.57	3.26	1.68
Virgie	3.62	1.89	4.65	3.22	1.92	1.51	6.45	5.11	3.85	1.52	4.44	1.47

1979

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	7.49	5.58	3.03	4.85	4.40	8.95	3.85	2.97	4.18	2.39	4.85	2.20
Elkhorn City	5.89	3.86	2.93	3.96	4.99	5.92	5.61	6.17	4.60	2.39	4.55	1.65
Fedscreek 1SE	-	-	2.75	-	6.63	9.57	5.98	4.67	3.61	2.49	4.59	1.71
Fishtrap Lake	5.93	2.83	2.60	4.58	3.97	6.97	6.68	5.59	4.40	2.63	4.04	1.92
Freeburn 2SW	6.46	4.13	2.81	4.50	4.06	10.94	6.79	5.04	4.55	1.86	5.23	1.94
Meta 4 SE	5.53	2.34	2.22	4.35	4.24	8.98	5.23	5.41	3.85	2.77	3.30	1.84
Pikeville 2	-	3.70	2.50	4.08	-	3.95	-	5.14	3.82	-	-	2.02
Virgie	-	-	-	2.89	3.43	4.30	4.68	-	3.64	1.95	-	-

1978

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	5.09	1.32	3.32	4.50	6.05	2.55	5.35	5.95	1.80	1.85	3.08	7.04
Elkhorn City	5.03	1.58	3.32	3.84	4.47	2.79	5.19	6.35	1.08	1.98	2.29	6.45
Fedscreek 1SE	-	-	-	-	5.12	4.13	5.96	5.62	1.27	2.28	-	6.93
Fishtrap Lake	6.22	1.34	3.28	5.34	4.86	2.19	5.13	7.81	1.69	1.65	2.80	7.47
Freeburn 2 SW	5.24	1.37	3.13	4.23	4.78	2.47	6.42	9.15	1.82	2.42	3.50	8.57
Meta 4 SE	3.87	1.28	2.85	4.01	4.62	3.16	5.45	6.63	0.48	1.28	2.72	8.07
Pikeville	5.01	1.47	3.07	4.34	4.66	1.88	3.97	6.38	2.03	-	-	-
Virgie	-	-	-	-	-	-	-	5.32	0.71	-	-	6.79

1977

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	2.87	1.68	3.30	7.22	1.01	5.75	3.36	5.94	1.80	6.90	5.05	2.19
Elkhorn City	1.98	1.01	3.04	6.38	1.17	5.88	4.44	7.30	3.95	4.81	5.45	2.28
Fishtrap Lake	1.89	1.88	2.48	9.24	2.40	5.16	3.04	5.82	2.85	4.94	5.69	2.74
Freeburn 2 SW	2.17	1.30	2.54	7.32	1.79	5.94	4.13	7.31	4.80	6.69	6.03	3.47
Meta 4 SE	1.95	0.76	2.17	5.85	2.60	5.75	5.00	5.33	2.75	4.73	4.50	3.05
Pikeville	1.88	1.13	2.77	6.39	2.44	3.69	4.28	7.04	1.87	5.36	4.81	3.15

1976

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	4.28	2.80	4.60	0.56	2.86	5.33	5.05	3.00	4.82	5.40	1.15	2.48
Elkhorn City	3.14	2.61	3.49	0.41	2.85	5.66	5.37	2.31	4.84	5.27	0.52	2.55
Fishtrap Lake	4.87	3.50	5.15	0.63	3.26	5.81	5.89	4.75	6.32	4.94	0.87	2.73
Freeburn 2 SW	3.68	3.74	3.85	0.83	3.54	3.34	5.66	3.23	4.65	5.35	0.94	2.45
Meta 4 SE	3.76	3.18	4.05	0.64	2.46	3.45	3.79	2.85	4.46	4.85	0.30	3.30
Pikeville	3.97	2.99	4.81	0.93	2.99	4.08	6.19	2.61	5.69	4.48	0.91	2.42

1975

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	5.80	3.62	11.72	4.43	10.98	3.55	3.73	3.50	4.40	3.75	2.62	2.60
Elkhorn City	2.72	3.56	8.81	4.26	7.64	2.28	6.56	2.13	4.05	2.86	2.11	2.20
Fishtrap Lake	4.52	4.56	10.02	5.13	6.47	2.65	5.94	4.37	5.35	5.07	2.85	2.42
Freeburn 2 SW	4.36	4.59	10.04	3.87	5.83	3.57	4.07	2.39	4.73	4.39	3.11	3.02
Meta 4 SE	3.95	4.66	9.26	3.45	5.74	3.38	5.15	2.84	5.25	3.82	2.90	2.95
Pikeville	4.36	3.65	9.37	3.63	5.67	3.62	4.70	2.84	5.68	2.75	2.69	2.69

1974

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	6.70	2.37	5.64	3.60	5.58	10.72	2.55	6.30	3.30	2.25	3.50	4.70
Elkhorn City	7.04	1.75	5.44	4.02	5.65	8.76	2.16	4.82	1.79	2.23	3.42	2.95
Fishtrap Lake	7.23	2.22	6.91	4.28	8.62	6.95	1.51	5.84	3.07	2.27	3.24	4.07
Freeburn 2 SW	8.18	1.97	8.70	3.68	8.05	5.35	3.23	6.16	2.97	2.22	3.25	3.64
Meta 4 SE	7.74	1.91	6.47	2.92	5.47	6.28	3.65	5.66	4.94	1.90	2.29	4.06
Pikeville	7.47	2.53	7.38	3.46	6.11	7.32	3.90	5.76	2.97	2.06	2.94	4.54

1973

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	1.25	1.75	6.53	3.65	4.46	4.87	5.23	3.55	3.15	3.22	6.60	3.87
Elkhorn City	1.27	1.40	5.60	4.57	5.38	2.44	4.85	3.60	3.97	2.89	6.14	4.00
Fishtrap Lake	1.51	1.82	5.66	4.39	6.12	4.96	4.55	3.18	3.68	3.25	7.51	3.29
Freeburn 2 SW	1.55	2.23	5.45	4.35	7.03	3.98	8.47	1.12	2.72	3.25	7.51	3.82
Meta 2 SE	1.26	2.50	5.07	3.27	4.76	7.42	4.64	1.73	2.66	3.60	7.05	3.64
Pikeville	1.27	2.83	6.61	3.94	6.73	4.51	4.20	2.11	3.75	3.83	6.52	3.91

1972

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	7.32	6.52	2.39	5.92	3.10	4.62	4.43	0.98	5.16	2.52	3.52	7.16
Elkhorn City	6.37	6.30	2.25	6.11	3.19	5.26	4.82	3.93	8.44	2.68	3.18	6.23
Fishtrap Lake	6.62	6.37	2.63	6.54	2.84	4.22	6.95	2.98	5.88	2.56	3.89	5.98
Freeburn 2 SW	5.86	7.19	2.72	5.74	3.82	5.38	5.52	3.43	6.03	2.84	4.60	6.72
Meta 2 SE	6.54	-	-	-	-	-	4.77	-	6.10	2.12	-	5.91
Pikeville	5.53	4.23	2.99	6.09	3.18	4.20	3.66	2.20	4.63	1.56	4.10	6.13

1971

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	4.30	2.17	3.46	3.93	6.89	4.39	5.26	2.24	6.02	3.90	1.77	1.73
Elkhorn City	3.84	2.65	2.99	4.45	7.12	6.86	3.62	5.48	3.40	3.65	2.09	1.99
Fishtrap Lake	3.46	2.87	2.60	3.34	6.77	6.79	2.64	3.41	6.47	3.67	1.75	2.13
Freeburn 2 SW	4.51	2.95	3.28	3.06	7.19	6.59	5.40	3.04	4.89	3.63	1.97	2.49
Meta	-	-	-	-	-	6.33	-	-	6.53	-	-	-
Pikeville	3.01	2.52	2.60	2.98	7.42	6.98	3.44	2.64	6.45	2.65	1.74	2.16

1967

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	2.22	2.41	5.51	4.85	5.05	4.36	3.66	3.27	1.80	2.23	4.00	4.23
Elkhorn City	-	-	4.86	4.32	4.26	4.26	-	-	-	-	-	-
Freeburn 2 SW	1.91	2.88	6.70	2.90	4.17	3.67	5.62	3.30	1.70	2.42	4.60	6.02
Pikeville	1.55	2.50	6.50	3.64	3.79	3.22	4.10	2.73	2.03	1.77	4.80	5.03

1966

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	3.02	3.65	2.55	4.48	5.03	2.72	5.65	6.18	5.56	3.87	4.10	3.96
Elkhorn City	2.23	3.79	2.74	5.14	1.55	2.70	9.48	6.38	6.20	3.30	3.80	4.00
Freeburn 2 SW	3.08	2.85	2.76	4.33	2.02	1.93	7.90	3.64	8.03	3.01	3.38	4.01
Pikeville	2.61	3.62	0.95	3.62	1.17	1.02	6.56	7.35	6.68	2.25	3.55	3.40

1965

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	3.95	1.73	6.48	3.42	2.92	2.93	4.74	3.19	1.33	2.66	1.69	0.15
Elkhorn City	3.85	1.99	6.59	4.92	4.35	3.30	4.15	5.34	1.89	2.36	2.35	0.27
Freeburn 2 SW	5.04	2.20	5.95	4.60	1.59	3.62	6.60	2.65	1.32	2.40	1.60	0.40
Pikeville	3.87	1.87	5.53	4.79	3.00	3.23	5.04	2.19	1.44	2.17	1.38	0.28

1964

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	4.07	3.91	5.02	4.48	1.72	3.84	4.64	3.16	5.62	3.38	2.75	3.02
Elkhorn City	5.86	3.86	5.20	5.30	1.95	4.40	5.57	3.17	6.08	4.00	3.15	2.54
Freeburn 2 SW	3.56	4.49	4.51	3.93	2.44	4.39	4.34	3.02	6.51	3.72	2.28	3.77
Pikeville	3.71	3.63	4.64	3.36	2.26	3.76	6.81	3.04	5.55	3.39	2.38	3.15

1963

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	3.14	3.08	10.55	1.29	2.78	2.08	2.97	2.87	3.76	0.10	4.76	1.65
Elkhorn City	2.51	2.75	11.73	1.97	3.20	2.79	5.16	3.17	3.11	0.00	5.24	2.41
Freeburn 2 SW	2.61	4.71	9.78	1.02	4.11	5.08	3.86	2.14	2.83	0.10	5.15	1.61
Pikeville	2.00	3.02	9.02	1.42	3.44	3.52	3.87	2.83	3.62	0.09	4.71	1.24

1962

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	5.30	5.07	3.24	3.33	4.72	5.80	3.27	2.52	4.07	1.93	4.85	2.84
Elkhorn City	4.26	5.77	3.65	3.36	4.57	6.50	6.28	1.99	3.23	1.59	6.27	4.49
Freeburn 2 SW	4.68	6.26	3.32	3.73	4.70	5.22	4.43	2.67	3.10	1.89	6.40	3.94
Pikeville	4.47	6.78	3.36	3.23	6.44	6.14	3.64	1.01	2.70	2.11	5.15	3.45

1961

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	3.42	5.22	3.80	5.05	2.83	5.13	8.00	3.77	1.73	3.14	2.73	5.10
Elkhorn City	2.75	3.80	4.26	5.11	3.82	5.80	10.02	3.31	2.63	3.60	2.89	4.77
Freeburn 2 SW	3.29	4.75	3.88	5.23	3.76	6.19	9.03	2.22	1.17	3.36	2.66	5.31
Pikeville	4.29	5.11	4.12	5.46	3.33	6.43	10.12	5.23	1.80	1.40	3.67	2.51

1960

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	2.65	4.65	3.20	1.67	2.78	2.66	5.17	2.22	3.70	2.83	1.95	2.85
Elkhorn City	3.87	4.00	3.95	2.56	3.29	4.62	6.80	2.80	3.48	4.88	2.08	3.01
Freeburn 2 SW	2.90	4.14	3.23	1.90	2.31	3.28	7.07	4.87	2.99	4.88	2.42	2.48
Pikeville	3.05	4.85	2.66	1.69	2.40	4.22	4.86	4.88	4.06	3.00	2.00	2.56

1959

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	3.13	2.62	2.84	4.62	3.95	2.60	3.60	2.61	4.33	3.83	6.14	2.33
Elkhorn City	3.44	2.14	3.61	4.95	3.51	3.67	4.94	5.67	3.14	5.17	5.90	4.48
Freeburn 2 SW	2.60	2.31	3.25	5.41	3.63	4.53	3.90	3.37	2.37	5.26	5.81	3.53
Pikeville	2.94	1.84	2.76	4.76	4.49	3.44	4.48	4.84	1.89	4.47	5.26	2.42

1958

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	1.73	3.52	2.38	5.94	7.21	3.18	4.70	4.18	1.14	2.37	1.42	1.70
Elkhorn City	3.02	3.47	4.89	7.49	9.16	4.82	8.33	5.62	1.32	2.12	2.91	2.57
Freeburn 2 SW	3.23	4.41	4.50	6.09	8.99	4.20	8.41	3.22	1.88	2.14	2.56	2.03
Pikeville	3.17	3.44	3.77	5.84	6.33	3.43	12.53	8.05	1.96	1.63	2.43	1.61

1957

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	7.22	4.81	4.00	3.90	3.15	8.55	2.26	0.61	5.54	1.05	3.20	3.94
Elkhorn City	8.71	5.26	4.03	4.47	2.49	5.16	3.32	2.17	5.06	2.13	3.86	4.02
Freeburn 2 SW	5.63	5.75	3.22	5.41	1.11	5.18	5.42	2.22	6.62	1.63	3.37	4.13
Pikeville	7.89	5.60	2.26	5.62	1.46	4.29	3.01	0.99	6.90	1.12	2.62	4.28

1956

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	2.40	8.61	6.24	5.07	4.47	4.02	9.64	5.50	3.23	1.35	2.64	4.31
Elkhorn City	2.02	7.56	6.30	5.32	3.30	3.77	7.15	4.97	3.06	1.13	2.31	3.54
Pikeville	2.25	8.96	7.53	7.17	3.43	4.84	8.49	2.49	5.26	1.52	2.14	4.29

1955

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	2.67	7.05	10.12	2.35	1.26	3.82	5.68	2.39	1.45	1.23	1.15	1.70
Elkhorn City	2.68	6.22	6.29	3.41	1.57	2.11	4.29	2.33	1.37	1.87	1.47	1.23
Pikeville	2.29	7.74	9.71	3.09	3.28	3.62	2.44	0.99	1.84	1.80	1.78	1.77

1954

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	6.42	1.12	3.20	2.00	3.09	2.25	6.64	2.62	1.90	1.74	2.35	4.56
Elkhorn City	5.16	0.91	3.29	2.28	3.83	2.47	4.32	3.75	2.00	2.21	1.95	4.48
Freeburn	2.44	-	-	-	1.12	0.42	-	-	-	-	-	-
Pikeville	4.74	1.33	3.98	2.75	5.47	2.45	3.68	3.83	3.11	1.09	2.21	3.71

1953

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine 2 NE	4.35	3.03	3.68	3.85	7.24	5.49	-	2.45	2.11	0.70	1.40	2.69
Elkhorn City	3.66	3.62	3.85	2.86	5.61	4.33	2.01	2.18	2.22	0.47	1.02	2.25
Freeburn	3.08	-	2.26	1.97	4.54	2.38	2.00	0.94	0.82	0.32	0.47	-
Pikeville	3.46	2.55	3.68	2.41	3.89	4.61	5.09	2.42	2.75	0.29	0.99	2.27

1952

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Burdine	-	1.78	5.41	-	-	-	-	-	-	-	-	-
Elkhorn City	5.73	1.81	5.23	4.10	4.53	3.83	3.54	3.02	0.98	1.24	3.81	2.66
Freeburn	-	1.95	5.36	-	-	4.80	4.26	5.57	1.50	1.56	2.88	2.93
Pikeville	5.78	2.50	4.82	3.91	6.21	4.50	3.65	4.82	2.09	0.74	4.07	2.99

1951

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Elkhorn City	-	-	-	-	-	-	-	-	-	2.32	5.76	5.40
Freeburn	-	-	-	-	-	-	-	-	-	0.72	4.76	5.47
Pikeville	3.80	4.00	3.86	2.69	6.39	4.48	2.46	2.64	7.09	1.67	3.18	5.43

1950

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Pikeville	5.98	3.99	2.98	1.73	6.40	5.25	6.01	4.43	4.87	1.90	3.90	2.96

Monthly Mean Temperature at Pikeville 2, Pike county, Kentucky.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	31.1	37.0	41.1		60.3	74.1	76.3	71.4	66.0		45.0	33.7
1980	34.0				64.3	71.9	77.5	77.1	71.4	52.9	43.0	
1979	29.2	31.4		56.6	64.2	67.8	75.1	74.0	67.7	54.4		37.8
1978	27.5	28.8	46.4	59.6	64.9	73.8	77.5	77.6	75.0			
1977	24.2	37.9		63.9	69.2	71.4	79.1	77.4	72.4	55.6	51.5	38.7
1976	34.2	47.6	52.5	56.8		72.8	75.7	73.8	67.3	53.1	42.5	35.7
1975	42.3	44.6	46.7	55.9	70.4	74.3	77.0	79.5	68.5	62.1	52.5	41.5
1974	46.6	41.8	53.7	60.1	66.7	69.6	77.0	75.6	66.9	56.0	49.1	40.9
1973	38.5	39.9	57.2	55.9	63.0	75.8	78.1	77.1	73.6	63.4	52.0	42.5
1972	41.2	39.7	47.8	57.7	65.3	69.5	76.1	76.3	72.0	56.5	48.1	44.8
1971	36.5	40.4	44.5	56.8	62.4	76.4	75.7	75.4	73.0	65.8	48.0	49.9
1967	41.6	36.1	53.1	61.7	62.5	73.3	73.2	72.5	65.3	59.1	45.2	44.1
1966	31.5	39.2	50.0	55.9	65.0	73.4	77.7	75.5	67.7	56.0	49.3	38.9
1965	39.0	40.2	44.4	60.8	71.1	72.5	76.4	75.8	72.7	57.7	50.5	41.7
1964	37.0	35.5	48.4	61.1	68.2	74.8	77.1	75.4	69.5	55.9	52.2	43.3
1963	31.8	33.4	53.2	60.2	65.5	73.1	74.7	75.0	68.5	61.9	48.7	29.9
1962	36.6	46.1	45.9	54.5	72.5	73.5	75.8	75.8	67.7	60.5	46.3	33.7
1961	33.2	45.0	53.3	52.9	62.0	71.2	75.4	76.4	73.5	59.0	50.0	40.7
1960	40.8	37.9	36.3	61.9	64.3	72.9	76.4	77.9	72.2	61.3	48.5	33.4
1959	36.5	44.1	46.6	59.2	71.3	73.2	77.8	79.5	72.6	61.8	46.3	42.3
1958	35.0	31.4	43.5	58.6	66.9	72.8	79.3	77.0	70.1	58.8	50.2	34.1
1957	36.7	46.5	48.6	62.2	68.5	76.3	77.4	75.7	72.1	55.7	49.5	44.1
1956	34.5	46.2	48.9	55.6	69.6	74.5	77.2		67.8	62.9	47.1	47.9
1955	37.1	40.8	51.5	62.3	69.6	69.1	80.1	80.0	73.6	60.4	46.5	36.6
1954	39.5	46.8	46.6	64.5	62.9	75.9	79.8	78.0	74.4	61.0	46.2	38.0
1953	44.0	44.1	52.0	57.1	71.6	76.8	78.2	77.1	70.5	61.8	45.7	40.1
1952	45.1	43.3	47.6	58.1	68.3	80.2	80.4	77.0	71.1	54.1	47.5	41.9
1951	41.4	41.4	48.9	56.7	66.5	74.7	78.4	76.0	70.3	61.5	43.1	42.8
1950	49.8	43.3	44.0	53.7	68.4	73.7	75.0	74.5	68.9	64.4	42.5	35.5

APPENDIX - B

Streamflow Records

Levisa Fork at Pikeville, Kentucky.

USGS Gaging Station No. 03209500

Location: Latitude 37° -27'-51", Longitude 82° -31'-35", Pike County, on right bank 20 ft downstream from bridge on State Highway 1426, 1.0 mile south of Pikeville, 1.5 mile upstream from Harolds Branch, 0.75 mile downstream from Lanks Branch, and at mile 90.5.

Drainage Area: 1232 sq miles

DISCHARGE IN CUBIC FEET PER SECOND

MONTHLY MEAN VALUES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	278	1921	1581	1919	1160	1895	362	263	378			
1980	2586	2527	3188	2013	1239	326	534	452	524	384	640	300
1979	6116	3617	4311	2111	1779	3492	1855	759	869	900	2655	1254
1978	3680	2096	3829	1824	2914	684	659	887	390	735	686	3204
1977	1021	1198	1663	7646	675	528	384	768	377	1568	3991	2530
1976	2293	2291	2223	903	349	491	339	288	386	2054	737	1379
1975	3409	3939	8081	3897	3894	583	385	353	475	659	1163	743
1974	6861	2538	5153	2137	1975	2583	445	445	449	619	1287	1974
1973	991	1830	4978	2797	2881	716	756	378	445	638	2351	2928
1972	6693	5533	2253	5221	1478	680	746	937	635	1451	1612	5385
1971	1974	3226	1719	1547	5166	2121	766	1022	802	1916	1216	1478
1970	2010	3719	869	2550	2118	214	208	212	444	534	807	798
1969	1365	2216	1380	1276	586	258	360	203	168	158	353	1379
1968	2654	630	2893	2140	2535	977	300	506	166	207	371	616
1967	1853	2330	6060	2080	2213	1960	652	428	121	235	587	2228
1966	132	1227	1127	1532	2025	109	581	1505	1596	1529	1777	3386
1965	3293	1805	5506	3470	836	227	339	190	98	163	83	71
1964										962	1055	2038

Russell Fork at Bartlick, Virginia.

USGS Gaging Station No. 03209200

Location: Latitude 37°-14'-45", Longitude 82°-19'-25", Dickenson County, Virginia, on left bank at Bartlick, just upstream from bridge on State Highway 611, 0.2 mile downstream from Pound River, and 1.1 mile upstream from Fall Branch.

Drainage Area: 526 sq miles

DISCHARGE IN CUBIC FEET PER SECOND

MONTHLY MEAN VALUES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1977	389	597	702	3099	278	203	115	194	157	812	1835	967
1976	1024	1022	964	479	139	170	114	122	139	833	315	637
1975	1497	1573	3494	1439	1980	231	158	152	196	323	489	339
1974	2821	1193	2158	849	860	993	175	178	204	290	694	731
1973	406	729	2090	1272	969	268	281	162	123	236	985	1459
1972	2847	2088	732	2056	662	287	257	266	193	426	520	2072
1971	788	1318	742	687	1910	946	461	486	244	957	613	647
1970	937	1468	510	1140	767	96	108	120	106	150	393	389
1969	588	1158	645	340	183	136	217	115	95	110	199	567
1968	1160	285	1323	818	947	357	89	287	94	140	318	283
1967	835	1007	2330	835	1114	1042	403	247	55	159	362	1063
1966	54	620	562	550	800	40	266	651	557	669	940	1425
1965	1322	833	2029	1312	518	94	93	41	54	125	41	29
1964	946	971	1787	1251	198	399	100	67	129	433	562	992
1963	730	1005	4016	209	266	136	90	108	76	110	116	150

Levisa Fork at Bigrock, Virginia.

USGS Gaging Station No. 03207800

Location: Latitude 37°-21'-13", Longitude 82°-11'-45", Buchanan County, Virginia, on left bank at Big Rock, 2,000 feet downstream from Rocklick Creek, and 2,500 feet downstream from bridge on State Highway 645.

Drainage Area: 297 sq miles

DISCHARGE IN CUBIC FEET PER SECOND

MONTHLY MEAN VALUES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1978	945	330	972	567	631	111	175	214	63			
1977	257	380	444	1908	215	233	102	253	68	308	911	448
1976	498	544	572	303	113	108	69	51	80	535	126	391
1975	802	924	2107	794	655	132	63	50	95	75	159	128
1974	1596	658	1240	673	471	466	103	49	66	67	156	445
1973	231	379	1107	777	545	147	110	66	31	110	585	638
1972	1567	1264	346	1311	451	135	186	296	236	299	350	1201
1971	440	722	362	624	1086	560	184	325	148	448	242	346
1970	263	910	281	846	272	40	29	56	85	65	229	223
1969	273	515	289	376	157	56	117	33	13	7	19	308
1968	570	168	631	550	719	208	51	79	44	29	101	130
1967										38	104	456

Levisa fork at Prestonburg, Kentucky.

USGS Gaging Station No. 03209800

Location: Latitude 37°-40'-15", Longitude 82°-46'-38", on right bank 50 feet downstream from concrete highway bridge on State highway 114 at Prestonburg, 150 feet downstream from the mouth of Trimble Branch, 450 feet upstream from Middle Creek and at mile 81.4.

Drainage Area: 1,701 sq miles

DISCHARGE IN CUBIC FEET PER SECOND

MONTHLY MEAN VALUES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	3568	2255	4687	2951	1562	362	734	579	644			
1979	8107	4966	5025	3323	2164	4314	2188	980	1051	1034	2998	1868
1978	4455	2803	5175	2575	3905	895	775	1079	531	788	746	5106
1977	1317	1530	2318	7236	832	592	601	1392	409	1843	4129	3057
1976	3409	3301	3170	1466	441	577	413	368	431	2483	941	1885
1975	4704	5398	10330	5137	5502	880	458	390	619	893	1653	1086
1974	9397	3098	7040	3309	2372	3614	635	508	607	724	1638	2700
1973	1312	2396	6017	3543	3424	921	836	383	448	665	3129	3924
1972	7868	7246	3465	7277	1886	739	774	1013	585	1490	1901	6996
1971	2576	4328	2332	2065	6497	2467	933	1197	1197	2046	1339	1815
1970	2839	4992	1700	3951	2584	249	217	260	485	656	1186	1221
1969	1947	2802	1849	1990	834	298	415	224	189	159	359	1286
1968	2997	840	4205	3142	3196	1418	383	945	209	255	525	917
1967	1360	1460	1690	894	944	300	303	140	76	255	846	3266
1966	211	2129	1657	2320	2617	140	572	1832	1993	517	660	945
1965	4276	2188	6610	5097	1193	286	445	214	129	214	102	91.5
1964	2562	2748	5592	3292	608	705	264	254	175	1449	1281	2984
1963										32.9	184	373

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