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# PRELIMINARY ASSESSMENT OF CHANNEL CHANGE, ELK RIVER, KANSAS

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## INTRODUCTION

This paper considers the geomorphic response of the Longton reach of the Elk River to anticipated modifications in stream flow and sediment load as a result of construction of a number of small flood retention reservoirs in the upstream watershed. Within the constraints of data and time for problem analysis, only a preliminary qualitative assessment of response is attempted, but a methodology is outlined that will provide both quantitative results and a reasonable prediction of anticipated response. The approach has been applied to river systems as large as the Upper and Lower Mississippi River and as small as ephemeral arroyos in New Mexico, with excellent results. The methodology is currently being applied to an analysis of the response of the Cochiti to Isleta reach of the Rio Grande in New Mexico to the construction of the main-stem dam at Cochiti in 1973. As results of this latter study are pertinent to the Workshop theme of downstream river channel changes from diversions and reservoir construction, they will be available during the general discussion session of the Workshop to illustrate the methodology outlined in this paper.

## METHODOLOGY

The approach recommended for analysis of Elk River response has been described in detail and applied to the Upper Mississippi River in a reference document, "The River Environment," prepared for the Fish and Wildlife Service, Twin Cities, Minnesota by Simons, Lagasse, Chen, and Schumm in 1975. It was refined further relative to an "Assessment of Geomorphic Response of River Systems to Hydraulic Structures" in a paper I prepared for an International Symposium on "Environmental Effects of Hydraulic Engineering Works," held at Knoxville, Tennessee, 12-14 September 1978. The brief outline of the methodology which follows is extracted from these references.

Depending on the data and resources available for analysis the problem of response of the Elk River to the construction of a number of small hydraulic structures should be approached in three phases.

1. A qualitative analysis based on general geomorphic parameters.
2. A quantitative analysis based on specific geomorphic and hydraulic data.

3. A mathematical model of watershed and channel processes in the reach or system of concern.

As listed, each phase requires an increasing commitment of resources, but individully each phase yields meaningful results. These range from a purely qualitative assessment of trends to the numerical results and predictive capability of physical process computer modeling. When applied sequentially this multi-phase approach constitutes a powerful methodology for the evaluation of short and long range response of river systems to development.

To the extent that data permits it is desirable to establish, first, the morphologic and hydraulic conditions of the river or reach under consideration before man's intervention. Conditions on the "natural" river form a baseline against which the impacts of man's activity can be assessed. Unfortunately, the historic record and data are usually not sufficient to establish a complete picture of the natural river, except on major systems such as the Mississippi or Rio Grande. As a minimum, it is usually possible to reconstruct the history of engineering activity on a river or reach of concern. Although data on the Elk River provided for the Workshop do not provide a complete picture of engineering activity in the watershed, indications are that such information could be developed with a minimal investment of research effort.

A qualitative analysis of geomorphic response should include an examination of the river in planform, longitudinal profile, and cross section. Where data are available for different time periods (for example, before and after construction of a dam), this analysis produces a time-sequenced picture of morphologic change in three dimensions which can be correlated with the history of engineering activity in the study reach. This correlation provides a qualitative assessment, in terms of trends, of the impacts of man's activity in the reach. In systems that have experienced multiple development techniques (dredging, dikes, navigation dams, levees) an attempt can then be made to isolate the system response to a particular activity of concern, or to predict response to hydraulic structures and development measures being considered.

Township plats normally provide the earliest accurate planform data on a river system. Comparison of these with later topographic surveys, aerial photographs, or the current USGS quadrangle sheets establishes the degree of bankline stability in a system. Even within relatively stable banklines most alluvial rivers exhibit changes in bankline and the number, location and configuration of bars and islands. As these features influence resistance to flow and act as controls in a river reach, an understanding of their evolution is imperative.

Time-sequenced comparison of selected reaches and measuring and comparison of river widths, island area, and river bed area, all provide useful data for establishing and evaluating morphologic characteristics of an alluvial river. Graphical, tabular, and plan view representation of this data provide insight into the evolution of alluvial processes of a particular region and their relation to man's development in the region. The impact of such development techniques as bankline stabilization, contraction dikes, and jetty fields is usually quite apparent in the planform comparisons.

While longitudinal profiles are normally not directly available, they can be constructed from cross section data derived from hydrographic surveys. Comparisons of profiles can be made using either the average depth of the cross section or the thalweg depth, that is, the deepest point in the cross section. Evidence from analysis of the Upper Mississippi indictes that thalweg bed elevations, in general, vary in the same manner as average river bed elevations, and so provide a good, readily obtainable indicator of trends in bed elevation. Both tabular compilations and time-sequenced longitudinal profiles are useful in establishing trends in aggradation or degradation.

The tabulation and plotting of cross section data reveal changes in such morphologic parameters as surface width, bed elevation, average depth, and thalweg position. Cross sections can be established at equal intervals throughout a reach or can be concentrated in those portions of the reach that planform analysis has shown to be morphologically active. Comparison of cross sections adds a third dimension to the qualitative analysis and normally provides the clearest indicator of the impact of such stabilization measures as revetment, contraction dikes, and jetty fields.

In correlating the planform, longitudinal, and cross-sectional data accumulated by these and other techniques, it is not uncommon to encounter apparently conflicting indicators. Here, an understanding of the natural morphologic conditions of the system provides an essential baseline for interpreting apparently anomolous behavior. Efforts directed at synthesizing the geologic history of the region and identifying existing geologic controls, as well as the historical research required to provide clues as to the natural conditions of the river system, often pay unexpected dividends in this regard.

While a qualitative analysis, alone, will yield meaningful results, refinement of conclusions resulting from such an analysis and a more precise assessment of trends as well as a predictive capability can be derived from both quantitative analysis and mathematical modeling. It should be noted, that calibration of a mathematical model involves evaluation and modification of supplementary relations to the basic process equations using field data or theory so that the model will reproduce the historical response of the modeled river system. Establishing the trends in geomorphic components which constitute this historical response by a qualitative analysis, then, provides an essential base for model calibration.

The conventional or traditional quantitative techniques of river engineering are well known and do not require discussion here, however, a few general comments on these techniques in relation to geomorphic analysis and mathematical modeling may be appropriate. Quantitative techniques include using unit hydrographs for water routing and yield from watersheds, the Universal Soil Loss Equation for estimating erosion from watersheds, time-lag methods for flood routing in the channel, sediment rating curve techniques for estimating deposition in reservoirs, and developing relationships for hydraulic geometry of the reach under study. These techniques can be applied to only a relatively small number of conditions and alternatives because of cost limitations for most studies. It is often difficult to predict the response of a system to development alternatives using these methods as they are based on the assumption of homogeneity in time and space. While this approach may be feasible for selected reaches, application on a system-wide basis quickly leads to unmanageable computational requirements. Such dynamic features as degradation and aggradation are difficult to account for, and integrating the subsets of a traditional quantitative analysis into a basin-wide system analysis presents complex problems. The traditional quantitative techniques are, however, extremely valuable in either refining or substantiating the conclusions of a qualitative analysis, or in providing a basis for mathematical model calibration.

To conduct an analysis with a physical process computer model, several major tasks must be accomplished. The first is to develop a mathematical model for routing water and sediment from the watershed and through the existing and modified channel and reservoir systems. This model could be used to determine flow lines and identify areas where excessive sediment aggradation and degradation may occur, as well as to indicate major sources of sediments that flow from tributary systems to the main channel. With such a comprehensive model developed and verified, the second task is to evaluate various operational alternatives or development scenarios. The final task involves selecting an optimum plan for the development or operation of the river basin considering flood control, sediment control, minimizing environmental impact, maximizing water salvage, and other factors of concern for a particular region.

The detailed development of such a mathematical model involves the following steps: data assembly and inventory; data evaluation; development of a data storage and retrieval system; collection of required data that cannot be synthesized; identification of data gaps and synthesis of additional data required for analysis; overall system design including spatial and temporal design, subsystem model development such as the main-stem model, tributary models and watershed models; validation and linking of the subsystem models; development of applicaton data files; model calibration and validation; application of the models to evaluate system response for different design alternatives; and finally, conducting a detailed analysis of selected alternatives.

## ANALYSIS

If the analysis of the Elk River were to concentrate on only the Longton reach, that is the 8 river miles between Sections 11-15 and 3-3, it is doubtful that much more than a qualitative geomorphic assessment of response to the proposed flood retention reservoirs could be justified. Selected aspects of the trends revealed by this geomorphic analysis could be verified by quantitative calculations. However, if a complete analysis of the response of the Elk River system to the construction of the 48 floodwater retarding structures is desired, the application of physical process computer modeling would be required.

With the data and time presently available, and considering just the eight miles of the Longton reach, only a preliminary qualitative assessment of geomorphic response will be attempted here. This should provide a basis for more detailed analysis and discussion during the Workshop.

Control of floodwater run off from 59% of the Elk River drainage area and retention of the expected 100 year accumulation of sediment from this area will induce geomorphic change along the Elk River, including the Longton reach. On each of the many tributaries with retention dams one would expect some tendency toward the classic response of a river to dam construction. As a result of clear water release local effects below each dam could include local scour at the dam, channel degradation below the dam, and possible bank instability if significant degradation takes place. The downstream effects could include degradation and bank instabilities along the entire reach between the retention structure and the junction of the tributary with the Elk River. Over the short term this could produce an increase in sediment supply from these tributaries to the main-stem, even though the dam might trap virtually all the sediment produced from the upstream watershed. The magnitude of any short term increase in sediment load depends on resistance of each tributary reach to degradation. This resistance would come from bed and banks of cohesive material, bed rock or geologic control, or armoring of alluvial reaches of the tributary.

As each tributary adjusts to regulated flows of water and sediment over the long-term, and cohesive materials, or bed rock, or a well developed armor layer become sufficient to resist scour by regulated flows, a net reduction in sediment supply to the Elk River should be anticipated. (Note pre- and post-project estimates of Elk River sediment yield in the data package.) The magnitude and duration of any short term increase in sediment supply from the tributaries following construction of a retention dam and the development of a stable channel in the reach below the structure will depend on individual channel and watershed characteristics. Based on the characteristics of bed, bed material, and armor layer of the Elk River cross-sections described in detail in the data package, and information in the soil survey of Chautauqua County, any initial increase in sediment load from the tributaries should be of short duration, and degradation in tributary reaches below retention structures should be limited.

For the Elk River main-stem, the cumulative effect of this sequence of geomorphic change on multiple tributaries could be significant. There is potential for both short- and long-term change in meander pattern and planform configuration, composition of the bed, and the riffle/pool sequence along the Elk River. With specific reference to the Longton reach the magnitude of this change will depend, to some extent, on the ability of the channel to absorb and redistribute any short term increase in tributary sediment load, but primarily on the resistance of the reach to a long term tendency toward degradation because of reduced sediment inflow from the tributaries.

The characteristics of the bed, bed load, armor layer and banks described for Sections 11-15 to 3-3 of the Longton reach indicate that this reach should be quite resistant to both degradation and planform change through bank erosion. Of the sections described in detail most show a geologic control (limestone, rock, shale) either exposed in the section or a few feet below an armored alluvial bed. For sections such as 3-1, 3-3, and 11-9, where the bed material is apparently alluvium, the resistance to degradation will depend on development and stability of an armor layer. With indications of an armor layer at 7 of the 13 sections described in the data package, there is sufficient evidence to assume that the channel bed contains the necessary gradation and quantity of coarse material to produce armoring as degradation progresses. However, the response of the Elk River to changes in discharge of sediment and water on multiple tributaries will be so complex that a quantitative determination of the actual amount of degradation to be anticipated in alluvial reaches would require physical process computer modeling of the watershed, tributary, main-stem system. A quantitative approach, short of modeling, would probably not produce an estimate any more reliable than that derived from a purely qualitative assessment. From the morphologic characteristics of the Longton reach one would expect no more than 2 or 3 feet of degradation before either bed rock control or armoring produces stability against the reduced flood peaks of controlled flows.

There are several techniques in the literature for computation of river bed degradation as a result of altered sediment regime, but the assumptions required in their application to a field situation are quite limiting. For example, Komura and Simons developed a technique for calculating "River-Bed Degradation Below Dams" in 1967 but the assumptions required in the numerical example include (with an indication of applicability to the Elk River problem):

1. Sediment transport is completely arrested by the dam (OK),

2. River banks are not erodible (No),

3. Seasonal variations in discharge and temperature of water do not occur (No),

4. Sediment injections by tributaries do not occur (No), and

5. Meandering and growth of vegetation do not occur (No).

Similarly, the USBR "Design of Small Dams" contains an approach for estimating degradation and armoring which places heavy reliance on "engineering judgement" and limiting assumptions.

In the case of the Longton reach of the Elk River the key factor in the analysis must be the influence on the main-stem of altered tributary flow conditions. As with the Komura and Simons approach, most quantitative techniques for estimating degradation and stability through armoring cannot handle this complexity. Important tributaries to the Longton reach include: Wildcat Creek - 2 miles above Section 11-15, Clear Creek - .5 miles above Section 11-15, Hitchen Creek at Section 11-1, Painterhood Creek below Section 3-1; and several smaller unnamed tributaries in the vicinity of Sections 11-11 and 11-15. Under "natural" flow conditions (prior to the construction of flood dentention dams) one would expect that slope and sediment inflow of these tributaries would be adjusted to the existing base level of the main-stem. While delta deposits from flood flows on the tributaries might temporarily divert or control the base level of the main-stem, these deposits would normally be redistributed during flood flows on the Elk River proper.

Under post-project conditions on the Elk River (as illustrated by the unit discharge hydrograph in the data package) the tributaries could assume a dominant role in controlling base level. This would be particularly true during any initial period of degradation below structures on the tributaries, when regulated flows on the main-stem may be incapable of moving either the size or volume of material deposited in tributary deltas.

As a case in point, on-going analysis of the response of the Rio Grande to the construction of the main-stem dam at Cochiti reveals that degradational processes have been far more complex than would be predicted by available quantitative techniques. The "classic" degradational wedge, deepest at the dam and tailing out at some downstream geologic control, has not developed. Instead, the initial 8 miles below the dam have shown remarkable stability, apparently because of the inability of regulated flows to move the size or volume of material in numerous arroyo deltas in the reach. The availability of significant quantities of gravel in these deltas has resulted in development of a stable armor layer in the reach. Downstream, beyond the influence of these arroyos, 6 to 8 feet of degradation has occured.

Over the short-term, then, planform change could be expected as a result of diversion or blocking of the Elk River at tributary junctions. With time, redistribution of this material could alter the existing riffle and pool sequence as "slugs" or waves of deltaic sedimentary material are moved through the system. High flows will be comparatively rare, and extended periods of low flow will scour the crossings and fill the pools of the existing meander sequence. As tributaries adjust over the long term to altered flow conditions a period of degradation can be expected in reaches such as the Longton reach. A fairly recent (natural?) cut off of a meander bend is evident below section 11-11. Degradation could induce bank instability with a potential for additional meander loop cut offs at several locations in the reach. This would produce a radical change in slope, velocity, and transport capacity and, again, alter the riffle/pool sequence. However, degradation should be limited in most sections of the Longton reach to no more than 2 to 3 feet by either geologic controls such as the limestone ledge at Section 13-2 (photo 25-2) or development of an armor layer. Once developed, an armor layer should be sufficient to provide stability under conditions of reduced main stem flows. There are several locations in the Longton reach (Sections 11-15, 2180, 11-1, 3-5, 3-4) where degradation could expose rock, shale, or limestone, thus altering the existing substrate material as well as modifying the riffle and pool sequence.

## SUMMARY

In summary, there is potential for geomorphic change in the Longton reach of the Elk River as a result of construction of flood retention structures on tributaries. While a qualitative assessment can indicate possible trends (aggradation/degradation, stability/instability) with reasonable assurance, a complete quantitative assessment of response would require application of the multiphase approach outlined at the outset of this paper. Response to altered conditions of water and sediment flow on 48 tributary reaches and 59% of the drainage area will be complex, and will require computer modeling to refine initial conclusions derived from qualitative analysis.

Although the data package provided for this analysis was reasonably complete, additional information concerning bank material and bankline stability would have been useful. With the Elk River system "fixed" in the vertical dimension by numerous geologic controls, bankline stability becomes the crucial indicator of geomorphic stability in terms of the meander pattern and the riffle and pool sequence. Along these lines, a site visit must be considered an absolutely essential element of analysis for any river related problem. Results of any analysis, even at the qualitative level, must be considered tentative until the analysis is supported by at least one day in the field on-site. For example, the preceding qualitative assessment assumed that bed rock control was dominant in the Longton reach, that the tributaries were similar to the main-stem Elk River in terms of geologic controls, alluvium, and bankline vegetation, and that active measures to insure the integrity of bankline vegetation were in effect or planned. If a site visit demonstrated that any of these assumptions was in error, the conclusions of this preliminary qualitative assessment would require revision.

An additional technique that I consider essential for analysis of response in any river system is a literature search for well-documented case studies of river response to similar engineering activity in related physiographic settings. This is particularly important where conclusions or projections of response are required using only a limited data base, as was the case with the Elk River. For example, Haung (1977) analyzed the response to large impoundment structures of seven major streams in Kansas. Qualitative methods of fluvial geomorphology as outlined in this paper and hydraulic engineering techniques (quantitative methods) were applied to the problem of river response, to include analysis of the Fall River just to the north of the Elk River watershed. While response to a single large impoundment structure on each river sysem was analyzed, several conclusions derived from Haung's study are of interest in anticipating response of the Elk River system to multiple small impoundment structures. Degradation below the impoundment structure was experienced on all streams considered by Huang, and in all cases the stream below the structure tended to form a relatively narrower and deeper channel, that is, width to depth ratio decreased.

## CONCLUSIONS

The following specific conclusions on the Elk River problem are listed by categories for comparison with conclusions from other Elk River papers.

### Aggradation/Degradation

Over the short-term some aggradation, particularly in the vicinity of tributary junctions, should be anticipated as tributaries respond to the construction of detention dams. After tributaries have adjusted to altered flow and sediment regimes, degradation along the main-stem Elk River including the Longton reach can be anticipated. Because of geologic controls and the probability of armoring in alluvial reaches, this degradation should not exceed 2 to 3 feet. In fact, geologic controls will limit degradation to alluvial reaches where lowering of bed elevations might be more accurately characterized as "local scour."

### Bed Material Size

Over the long-term bed material size will increase along the Elk River and in the Longton reach as fines are removed and armoring develops through hydraulic sorting. In terms of altered substrate conditions reaches where a geologic control is covered by a thin veneer of alluvium could be swept clean.

### Bank Stability and Width

Two fundamental assumptions of this analysis have been that the banks are composed of predominately cohesive materials and are (and will remain) stabilized by vegetation. Unless a site visit were to contradict these assumptions, channel banks, and width can be considered stable in most reaches. Degradation in alluvial reaches might undercut bankline vegetation and produce local instances of channel widening.

### Width to Depth Ratio

With stable banklines and limited degradation, width to depth ratios should change only slightly. With reference to Huang's case studies of response of Kansas streams to impoundment a slight increase in width to depth ratio should be anticipated in some alluvial reaches.

### Pool and Riffle Spacing

Redistribution of material produced by short-term tributary adjustment to detention structures could alter the composition of bed materials in the riffle and pool sequence as "slugs" of deltaic sediments move along the main-stem. Over the long-term under regulated conditions, high flows will be comparatively rare and extended periods of low flow will tend to scour the crossings and fill the pools of the existing meander sequence; however the spacing of the riffle and pool sequence would not be altered by this process.

## Sinuosity Change

There is evidence of at least one recent (?) natural (?) cut off in the Longton reach. A site visit would be required to determine age and origin, but cut off of a meander loop could produce a radical change in slope, velocity, and transport capacity of the reach. Cut off a meander loop is one geomorphic event that could alter the riffle and pool spacing in the reaches above and below the cut off. Documentation by Stevens (1980) of a flood of record of 200,000 cfs on the Elk River in July 1976 (six times larger than the mean annual flood of 32,800 cfs) indicates a potential mechanism for developing cut offs of the existing meander pattern.

As a result of the analysis of the Elk River problem and discussion during the Workshop several general conclusions are offered.

## Site Visit

A site visit is an absolutely essential element of analysis for any river related problem. Results of any analysis, even at the qualitative level, must be considered tentative until supported by reconnaissance in the field. The time required for a site visit depends on the areal extent and complexity of the watershed. For the Elk River, one day on-site to include examination of the main-stem and several representative tributaries might suffice. Aerial reconnaissance is, in most cases, an essential adjunct to a site visit.

## Case Studies

Well documented case studies of river response to similar engineering activity in related physiographic settings constitute an important supplement to analysis of river response. This is particularly true where conclusions or projections of response are required using only a limited data base, as was the case with the Elk River. Hydraulic engineering projects can induce major changes in the hydrologic, hydraulic, and sediment regimes of river systems, and at present, theory alone is not capable of predicting this complex response. Research effort committed to producing documented case studies can provide a valuable resource for evaluating river response.

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# PREDICTED RESPONSE OF THE ELK RIVER AT LONGTON, KANSAS

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## GENERAL INFORMATION

The Elk River is a tributary of the Verdigris River in the Arkansas River basin in southeastern Kansas. The Elk River reach selected to evaluate is near Longton, Kansas and has a drainage area ranging from 285.7 square miles at the upper end (Section 11-15) to 390.5 square miles at the lower end (Section 3-3). This discussion is an analysis and evaluation of the expected response of this reach of river to the installation of 45 floodater retarding dams in the upstream reaches of the watershed under the USDA Soil Conservation Service small watershed program authorized under P.L. 83-566.

The watershed consists of gently sloping flood plains and steep bluffs of the Flint Hills escarpment in the upper reaches. In the channel study reach, the area consists of thick beds of sandy shale with interbedded limestone ranging from thin beds to thick ledges. Soils of the watershed are thin over the thick limestone ledges. Floodplain soils are deep and friable and are mainly silty clay loams. Land use over the watershed is about 13% cropland, 82% grassland, 3% woodland, and 2% a mixture of other uses. Of the approximately 7,320 acres of woodlands, about 5,350 acres are on the flood plain, primarily in narrow belts adjacent to the Elk River and its tributaries.

The average annual precipitation for Howard, Kansas, located about 12 miles northwest of Longton near the middle of the watershed, is 35.07 inches. The largest total annual precipitation recorded at Howard is 56.07 inches and the smallest is 18.47 inches. Normally, about 75 percent of the precipitation falls during the growing season, April to October. The Elk River floodplain is flooded frequently--two to three flows a year exceed bank-full capacity. Flooding duration in the study reach is usually 24 to 36 hours. Sediment deposition on the flood plain during flooding causes problems in localized areas.

The average growing season is 185 days. An average year would be frost free from 15 April to 17 October. Daily temperatures average 35°F during January and 80°F during July. Extreme temperatures have been above 115°F and below -20°F.

The proposed project is a system of 45 floodwater retarding dams above the study reach to be installed on the major tributary drainages to the Elk River. The dams are to be earthen with vegetated or rock emergency spillways to provide safe passage of the runoff that exceeds the reservoir detention storage capacity. These spillways are planned so that their chance of operation in any 1 year ranges from 4 to < 1 percent. The principal spillways for the dams are of reinforced concrete with a crest at the elevation of the 100-year accumulation of sediment and have an uncontrolled release rate of 20 cubic feet per second per square mile of contributing drainage area (CSM).

Reservoir detention storage capacity is planned to handle from 3.0 to 5.25 inches of runoff from the contributing drainage area. The storage allocated for sediment accumulation ranges from 0.51 to 1.79 inches from the contributing drainage area. An ungated orifice through the principal spillway is to be provided at the elevation of the 50-year accumulation of sediment. After depletion of this storage, the orifice can be plugged and submerged storage is then available below the principal spillway crest elevation.

The State Geological Survey of Kansas issued a report in July 1958 on the rock formations and mineral and ground-water resources for Elk County where the study reach is located. The report states that the flood plain alluvium consists of two strata. The lower stratum is coarse material, predominately chert, limestone, and sandstone gravel and ranges from a fraction of an inch to 10 feet in thickness but generally is about 5 feet thick. Sand is intermingled with the pebbles, some of which are 2 to 3 inches in diameter. These deposits are the better aquifers in the area, even though their yield is not large. Household wells in the area usually yield less than 50 gallons per minute. The lower stratum yields water freely but is not continuous over the entire valley. The upper stratum of alluvium is a deposit of mostly clay and silt which grades downward to more sandy materials.

## ANALYSIS

This section describes the concepts and methods used to estimate the future form and substrate of the selected reach (between Sections 3-3 and 11-15). The floodplain along the reach is 6.8 miles long and the stream channel length is 10.2 miles long.

### General Geomorphology

To make a prediction of performance, it first is necessary to establish the general state of equilibrium of the stream. This is best done by evaluation of the geomorphic setting and as many quantitative factors as possible that are useful in supporting the identified state of equilibrium.

The general trend is erosional; the channel is gradually cutting into the underlying bedrock. The local irregularities of rock elevation in the bed and of depth of alluvium are due to different degrees of erosion resistance and bedding thickness. Within this reach, the stream flows across the Lawrence Shale Formation, which has a thick limestone stratum and a sandstone member of variable thickness. The sandstone member (Ireland) is a significant aquifer for domestic water wells, even though its yield is relatively low (1 to 10 gpm).

Field inspection, probing, and sampling of the channel bed indicate that, with a few exceptions, bedrock is within 48 inches below the stream bed. This indicates, without doubt, that the stream is in a very active state of degradation, but degradation is restricted by the resistant bed material. With the exception of limestone encountered at the upper end of the reach and sandstone at the lower end, all bedrock in the bed is shale.

Field inspection indicated the streambanks are in alluvium, with two exceptions. One is where the stream encroaches on the valley flank, exposing shale bedrock in the right bank (Section 3-5). The other exception is located in Section 11-12 where the channel is not encroaching on the valley flank. The streambank is in shale that extends 12 inches above the waterline and is capped with alluvium.

The limestone at the upper end of the reach (Sections 13-2 to 11-14) has significantly restricted the valley width compared to the shale upstream and downstream from this location. This restriction is verified by the existence of a limestone ledge outcrop across the channel. Another valley restriction occurs just below Longton near Section 11-1. There is no rock ledge outcrop in this area but limestone talus is identified on the right streambank. In addition, very coarse angular limestone fragments were described in an alternate bar about 1 mile downstream near Section 3-4. The fragments range in size to 36 inches in the longest dimension with the average being 6 to 8 inches. Downstream from the study reach, about 2 miles below Section 3-3 near Oak Valley, there is a third valley restriction, probably the result of sandstone (believed to be the Ireland member). This restriction, along with a significant addition of drainage area between Sections 11-1 and 3-7, needs to be recognized in any prediction about the study reach.

The stream valley form is dominated by the resistant geologic formations and the pattern cannot be predicted in terms of a consistently recurring sinuosity. There are two major patterns of sinuosity established by the channel--one with a wave length of about 2 miles, and the other with a wave length varying from 1,000 to 3,000 feet.

## Hydraulics

The data submitted indicate that the stream transports 90 percent of the sediment as wash load. The project is expected to reduce the sediment discharge by about 60%, but the proportion of wash load to bed load is not expected to change much. The total sediment yield at the lower end of the study reach is estimated to be 31,000 tons per year before project installation and 13,000 tons per year after installation.

Storm runoff values are tabulated below for the bank-full channel condition. This is generally the maximum tractive stress condition and can indicate the time of maximum bed load movement. The existing bank-full discharge in the study reach is about 24 csm.

Table 1. Channel bankfull conditions.

| Project Status | Runoff (in.) | Frequency Return Pd. (yr.) |
|---|---|---|
| w/o project | 0.8 | 0.6 |
| w/ project | 1.6 | 1.8 |

Based upon this examination, it can be seen that the "maximum stress" on the bed will be less frequent. Instead of at least annually, it will be only about every other year.

Installation within the watershed of floodwater retarding dams with fixed releases will result in above-average flows for a prolonged period. Table 2 shows the approximate amount and duration of prolonged flow.

Table 2. Approximate amount and duration of prolonged flow.

| Section | Drainage Area Size ($mi^2$) | Drainage Area Controlled (%) | Spillway Controlled Release Outflow Rate (cfs) | Spillway Controlled Release Outflow Duration (hours) | Flow Depth (ft) | Bank Full Discharge (cfs) |
|---|---|---|---|---|---|---|
| 11-15 | 284.5 | 59 | 3,370 | 110 | 13 | 5-6,000 |
| 11-1 | 297.1 | 57 | 3,370 | 110 | 9 | 5-6,000 |
| 3-7 | 341.0 | 56 | 3,791 | 110 | 10 | 7-9,000 |
| 3-3 | 390.5 | 60 | 4,651 | 110 | 10 | 7-9,000 |

The prolonged flows will start 18 to 24 hours after the flood crest passes (based upon the synthetic 6-hour storm provided).

Twenty-three of the 45 project dams to be installed are designed to control the 25-year frequency flood event. These dams have overflow emergency spillways which will result in outflow greatly beyond the 20 csm release rate for storms with a magnitude greater than those with a 25-year return period. The runoff for a 6-hour storm of a 25-year return period is 4.5 inches. About 3.5 inches of this amount will be temporarily detained by each retarding structure. Nearly 60 percent of the drainage area above the study reach is controlled by floodwater retarding structures.

After the project is installed, out-of-bank flow will still occur as a result of the runoff from a 6-hour storm having a 25-year return period. This is based on the data supplied. The unit hydrograph discharge is 14.74 csm per inch of runoff. There is about 4.5 inches of runoff for this size storm. Therefore, the stream discharge will be 14.74 x 4.5, which is about 66 csm and exceeds the bankfull capacity of about 24 csm.

After the project is installed, the frequency of flooding due to out-of-bank flow can be determined by first dividing the 24 csm by 14.74 csm per inch to obtain a storm runoff value of 1.62. By use of the frequency-runoff curve provided, a storm of 6-hour duration and a 1.8-year return period will result in 1.6 inches of runoff.

The frequency of flooding due to out-of-bank flow will be reduced but still will be a common occurrence. However, the duration of flooding will be less. The long duration flows from the principal spillways are about one-half the channel capacity. The added flows from that portion of the watershed not controlled by dams will contribute the remainder of the runoff necessary to cause flooding. This portion of the runoff will be flashy or of short duration.

## ADDITIONAL DATA REQUIREMENTS

The review and analysis of information provided indicates that the existing physical characteristics of the channel study reach are dominated by the geologic conditions and not the hydraulic or fluvial forces. The streambed is controlled by bedrock. However, information about the streambanks is very limited and general. To fully verify the streambank stability, it is desirable to collect additional data on the streambank material. These data would allow evaluation of both the structural stability of the streambanks against slides and their resistance to erosion from flow in the channel.

A review of old aerial photos and maps to provide information on the rate of stream alignment changes is advised. Photos taken before and after major storms would be especially valuable.

Examination of other watersheds in the area which have had similar project development would be very valuable in making evaluations. A detailed profile of the channel thalweg would be of value in contrast to the low flow water surface for hydraulic purposes.

It is necessary to examine upstream channel conditions for availability of bed materials to be transported into the reach under study. The channel performs and responds as a system in conjunction with the watershed, and a single reach cannot properly be evaluated without information about the other parts. In this case, the long-term performance of the channel bed materials will be greatly influenced by the bed materials upstream as well as the runoff.

This project is located in a subhumid region and, as a result, vegetation within the channel section will seasonally affect its flow characteristics. Knowing the woody and herbaceous climax species can provide some insight into the potential for an accelerated rate of channel choking, protection of the banks against erosion due to flow impingement, and also the need for maintenance thrugh the removal of snags and windfalls. Some tree species are significantly more susceptible to damage at an early age than others. Some have deeper or more dispersed root structure than others. Each of these items is valuable in anticipating the effects of vegetation.

## EVALUATION

On the basis of available data, the channel study reach has been evaluated to anticipate the project's short- and long-term alterations to

1. Meander pattern,
2. Configuration of the channel,
3. Substrate material, and
4. Pool-riffle sequence.

The meander pattern is very stable. The streambanks are covered with mature vegetation, the channel is very narrow and uniform, and there are no extensive point bars. The hydraulic stress of bankfull flows has been very frequent. On the basis of past demonstrated stability, a reduced frequency of stress will likely result in an even more stable meander pattern in the future, or essentially no change.

The channel cross section shape or configuration also appears to be very stable. In many areas it is made up of a compound slope on each bank. There is a flattened slope in the bottom 2 to 4 feet, and above it is the steepest slope, about 1 to 1, for a height of 6 to 15 feet. Above this steep section there is usually a flattened bench-like slope, topped off with another steep section. The base of the streambank is a gravel layer resting on bedrock of shale, limestone, or sandstone. The generally benched slope and solid foundation provide a generally stable section, as demonstrated by the presence of mature vegetation on the bank.

The Elk River location in a subhumid area is adequate for bank vegetation. The average velocity of streamflow at bankfull capacity ranges from 2.5 to 4 feet per second throughout the reach. The maximum velocity at the point of extreme nonuniformity on curves is greater, but probably no more than 8 feet per second. These relatively low velocities will not inhibit vegetative growth from maturing in the future. The vegetation will provide increased bank protection against hydraulic erosion. The vegetated banks will tend to reduce the velocity at the boundary layer causing some sediment deposition. Channel cross sectional areas are not very likely to diminish as the stream normally carries little sediment and the project should reduce the sediment load in the future by one half.

The substrate material consists of either exposed bedrock or coarse gravel. The change in gradation is not anticipated to be significant.

Because the streambanks in the study reach will be more stable, the dominant source of bed materials will increasingly be the transient bed load moving out of upstream reaches. There should be no long-term change in bed material characteristics due to the existing volume of material in the "pipeline." The rate of delivery of bed material will be reduced to about one-half the present rate and, therefore, the volume of bed material should be ample for a very long time since the maximum hydraulic stress at bankfull flow still will move the bed materials but at a less frequent rate.

The bed materials are expected to become generally coarser through removal of some of the sand sizes, because the reservoir release will increase the duration of one-half bankfull flows. This should result in a veneer type of armoring on the bed after each flood event. The veneer size can be evaluated for stability using the Shields diagram. The gravelly bed material is not expected to become choked with silts and clays, since there will be a cleansing at least biannually (on the average) when bankfull flow disturbs the bed surface during its transport.

There will be no significant deepending of the channel since it rests on bedrock of moderate resistance. Bed materials form the pool riffle sequence, but the underlying bedrock restricts the pool depth. In at least one location the riffle is created by a bedrock ledge outcrop crossing the stream.

## CONCLUSIONS

The channel study reach of the Elk River demonstrates itself as being very stable, and its characteristics are controlled by geologic factors rather than hydraulic forces. The potential for degradation of the channel bed is limited because of bedrock that is exposed or at shallow depth.

The installation of floodwater retarding dams for controlling runoff from 60% of the watershed will generally result in an even more stable channel. A slight coarsening of the bed material will occur.

The potential for channel choking or obstruction of flow will increase because of increased aging of trees and other vegetation. In addition, growth will provide increased protection against erosion at locations that are lower on the banks and more vulnerable to flow impingement. Both of these effects will result in increased stability of channel alignment.

Most of the answers on anticipated changes would be provided by an examination of the study reach data along with field verification by a person knowledgeable of stream channel behavior and experience with similar streams in the humid or subhumid area. This, along with a simple analysis using the Shields diagram, should provide a good estimate of the substrate size likely to result.

# ASSESSMENT OF ANTICIPATED CHANNEL CHANGES IN THE ELK RIVER NEAR LONGTON, KANSAS DUE TO UPSTREAM DEVELOPMENTS

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## INTRODUCTION

The Elk River is a stream draining the east flank of the Flint Hills Escarpment primarily in Elk County in southeastern Kansas (Figure 1). The reach of interest here is at Longton, Kansas which is approximately 70 miles east-southeast of Wichita. At the downstream end of the reach, the drainage area is 405.3 mi$^2$.

The floodplain of the Elk River is the prime agricultural land in the area. Beef production is the main agricultural activitity. The native pasture, which covers over 76% of the watershed, is utilized as grazing land. Feed grain and alfalfa are produced on the floodplain. Almost 80% of the floodplain is in crops. The 15,375 ac of floodplain cropland represent approximately 45% of the cropland in the watershed so farmers try to keep these lands in production despite frequent damaging floods. On the average, two to three flows a year exceed bankfull capacities. Flooding usually occurs during the growing season.

The U.S. Department of Agriculture, Soil Conservation Service has designed a system of 48 floodwater retarding structures to be installed in the Elk River catchment. The function of these structures is to store floods in the headwaters so as to mitigate flood damage to the cropland on the floodplain downstream.

The system of earth dams will provide 50,253 ac ft of floodwater detention storage and 12,942 ac ft of sediment storage. The system of structures will control the runoff from 239.8 mi$^2$ which is 59% of the watershed area.

Floodwater storage will be provided for from 3.0 to 5.25 in. of runoff from the upstream drainage area. Also, storage will be provided for the 10-year accumulation of sediment, this volume being equivalent to 0.51 to 1.79 in. of sediment yield from the upstream drainage area. An ungated orifice will be placed at the elevation of the 50-year accumulation of sediment.

The principal spillway of each structure will be reinforced concrete or comparable quality material with a single stage inlet. The uncontrolled design release rate is 20 ft$^3$/s per mi$^2$ of drainage per in. of runoff.

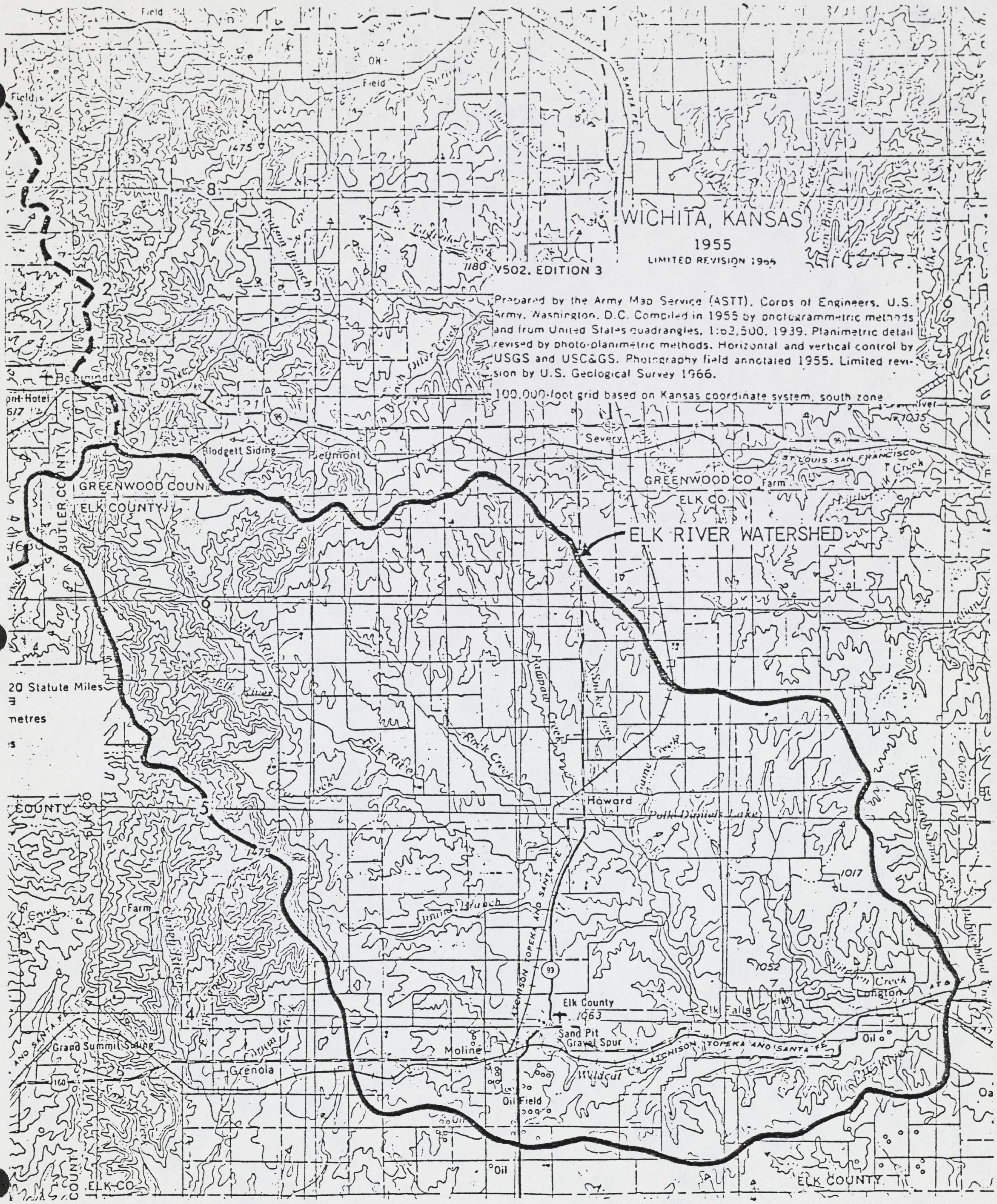

Figure 1. Elk River Watershed upstream from Longton, Kansas

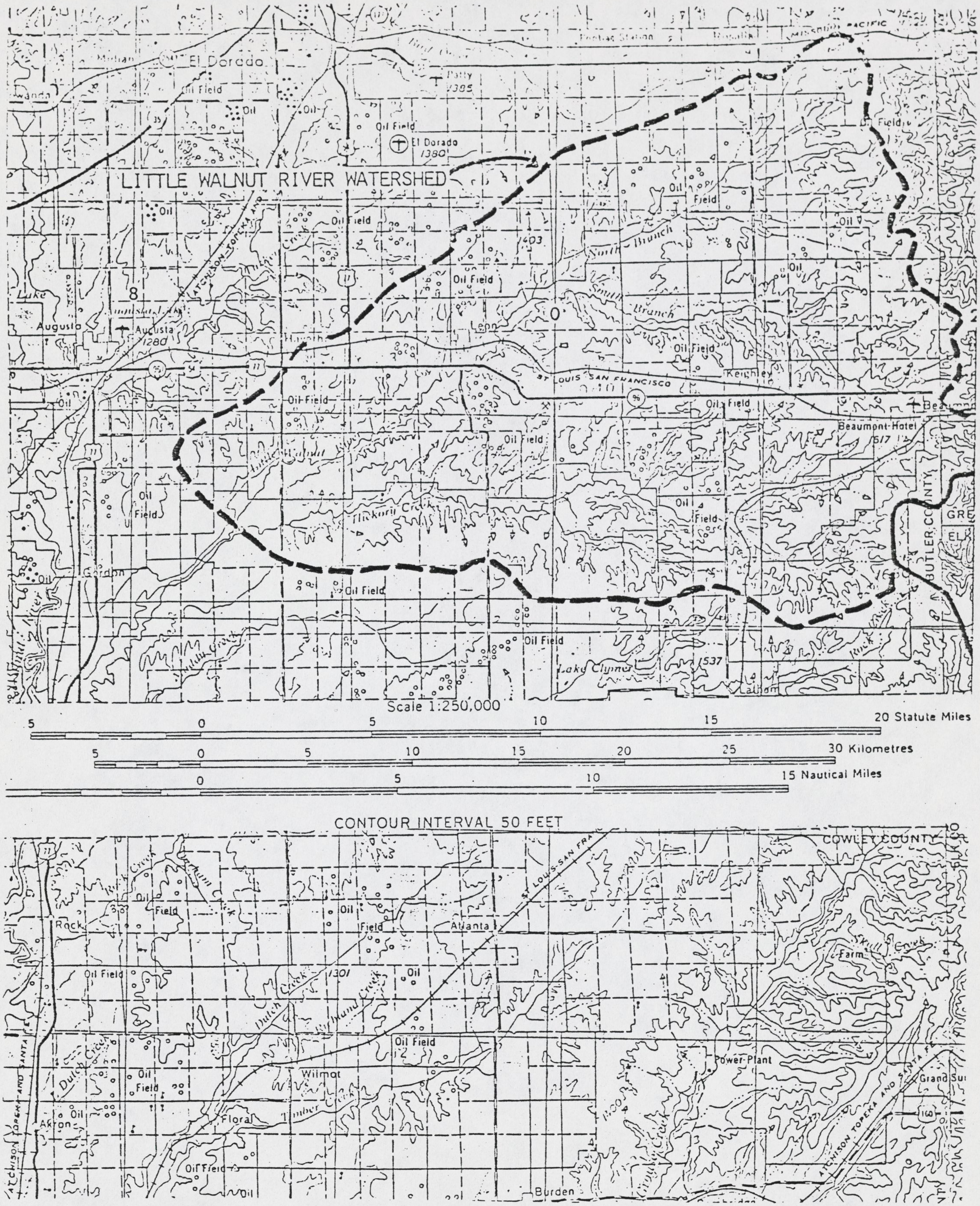

Figure 1. Elk River Watershed upstream from Longton, Kansas (Continued).

Each dam has a vegetated or rock emergency spillway to discharge runoff exceeding reservoir storage capacity. The chance of the spillway operating in any one year is 4% or less.

The question addressed herein is, "What will happen to the morphology of the Elk River as a result of changes in streamflow and sediment discharge caused by the construction of the 48 small flood retention reservoirs upstream?" Specifically, both the short and long term changes in meander pattern, channel configuration, substrate material, and pool riffle sequence are desired.

## GENERAL DESCRIPTION

### Climate

The climate of southeastern Kansas is sub-humid. The average annual participation is 35.07 in. The largest annual precipitation recorded at Howard, Kansas was 56.07 in. in 1961; the smallest was 18.47 in. in 1956. Normally, approximately 75 percent of the precipitation falls during the growing season, April to October (U.S. Department of Agriculture 1967).

The average growing season is 185 days, and in a normal year the area is frost free from 15 April to 17 October.

Temperatures generally average 35°F during January and 80┌F during July. Extreme temperatures have been above 115┌F and below -20┌F.

### Valley

The valley of the Elk River in the vicinity of Longton, Kansas lies in an east-west direction and is relatively straight (Figure 2). The valley floor is approximately 3500 ft wide on the average, and is some 100 to 150 ft below the level of the surrounding hills.

The north side of the valley floor from Longton to 3 mi west of Longton is terraces (Verville et al., 1958). The stream-laid deposits of gravel, sand, silt, and clay are as much as 40 ft thick. The course materials, predominantly chert, limestone, and sandstone gravel are commonly found in the lower zone ranging from a fraction of an inch to 8 ft in thickness. Sand is intermingled with the pebbles, some of which are 2 to 3 in. in diameter. The upper part of the deposit consists mostly of clay and silt but grades downward to more sandy material.

At Longton, the valley slope changes from 6.5 ft/mi upstream to 5.0 ft/mi downstream. The reason could be rock outcrops on the valley floor. Downstream from Longton the valley is wider and there are no terraces, at least to Elk City.

### River Morphology

Shown on Figure 2, the study reach is that 50,000 ft long section of the Elk River between River Station 96+000 and 146+000. The

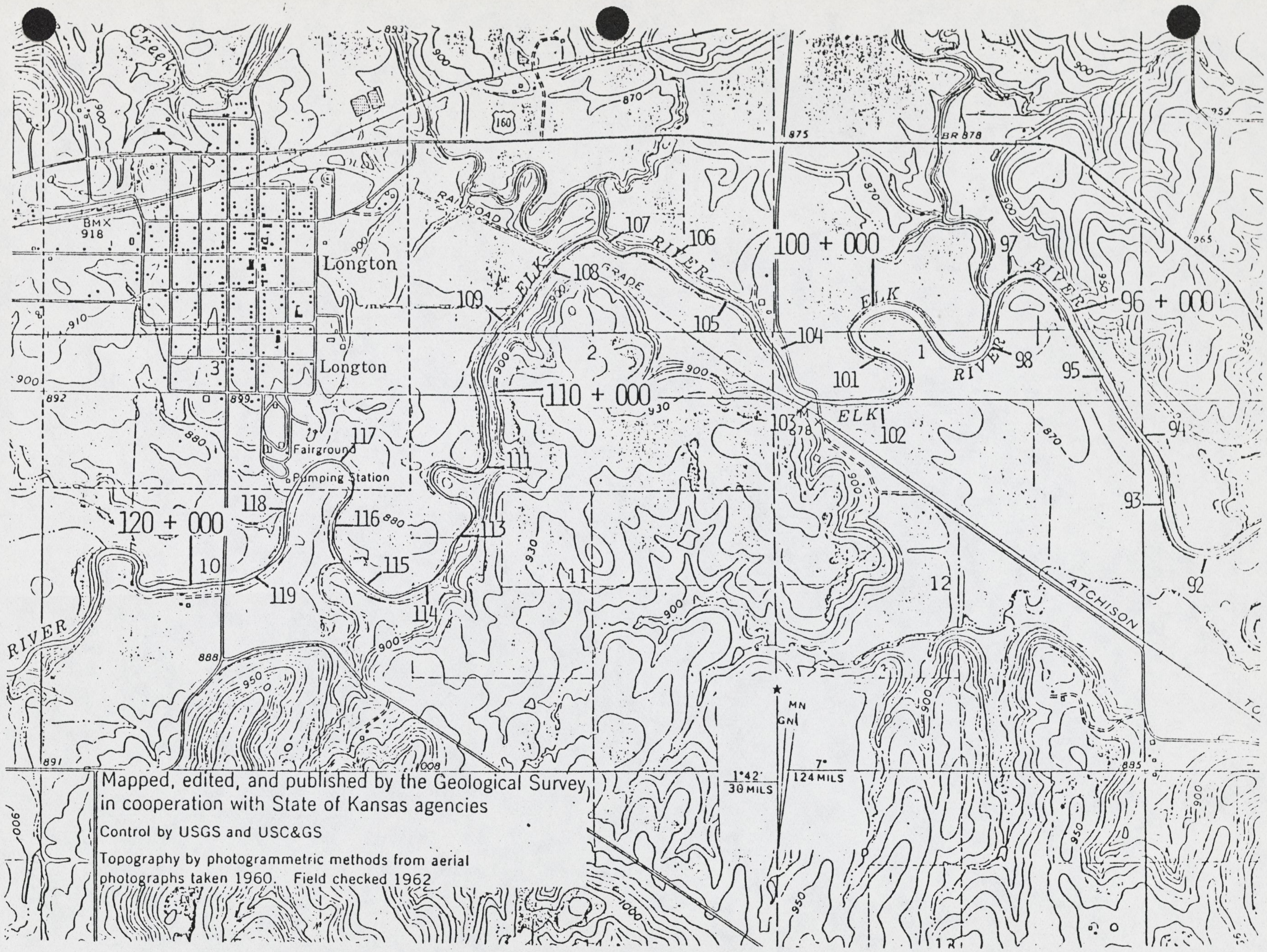

Figure 2. Elk River near Longton, Kansas

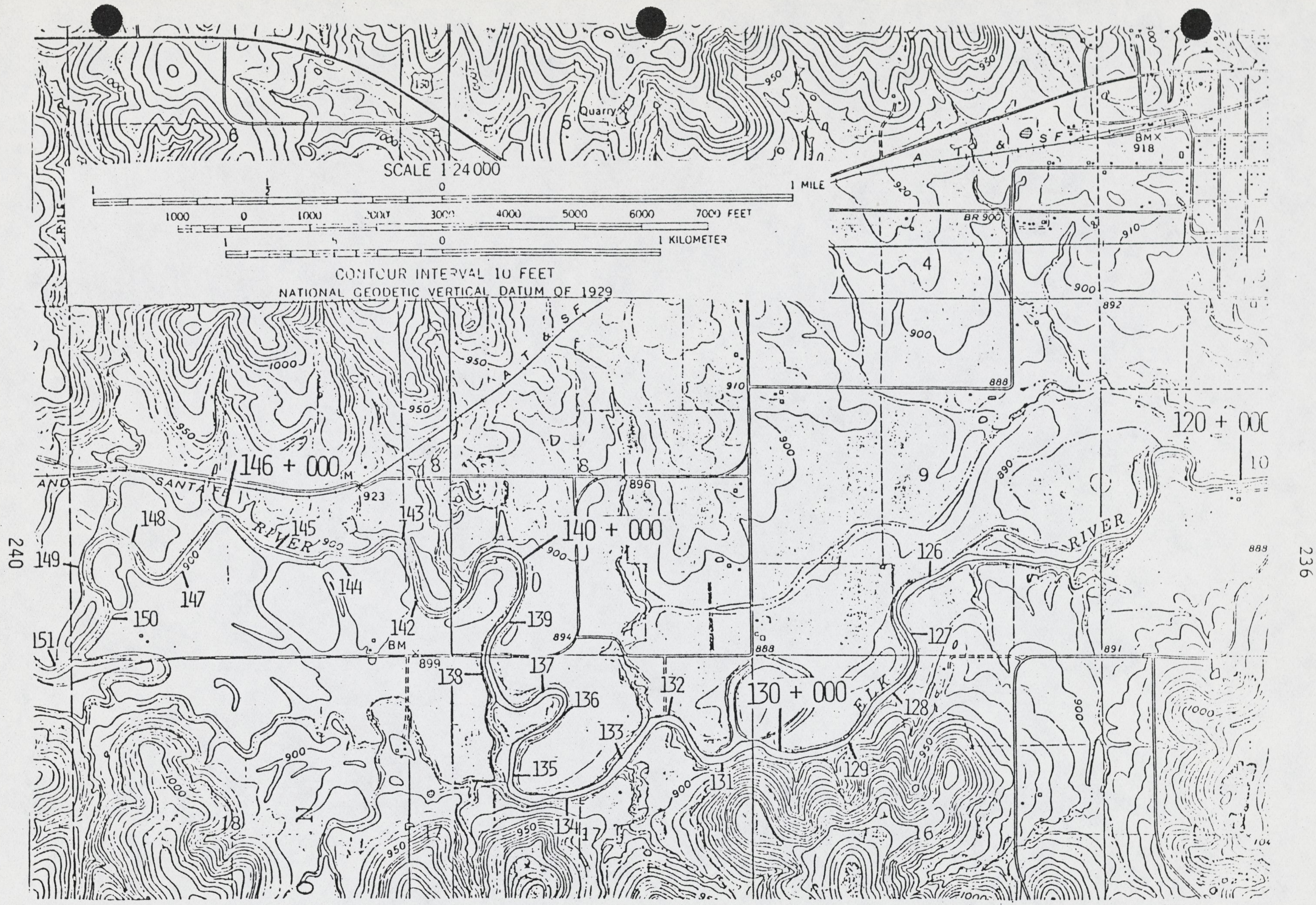

Figure 2. Elk River near Longton, Kansas (Continued).

stationing is in feet. River Station 0+000 was chosen as the U.S. gaging station downstream from Elk City. Below this gage the river cuts through the hills and enters a reservoir.

The slope of the river channel in the study reach changes from approximately 1.5 ft/mi at the downstream end and to approximately 3.5 ft/mi at the upstream end. The channel profile has a discontinuity upstream at the Elk Falls where the river drops at least 10 ft in a 1000 ft long reach.

At the upstream end of the study reach the river is against the north valley wall. Thereafter, the river crosses the valley floor to wander along the south valley wall. Downstream from Longton, the river meanders abruptly to the north side of the valley. In the 5.3 mi length of the valley, the river channel is against the valley wall for approximately 2.5 mi.

In this reach, the sinuosity of the Elk River is approximately 1.8 overall. One cutoff has occurred recently leaving a timbered loop on the floodplain at River Station 130+500.

The bankfull width of the river channel averages 200 ft with variations of 50 ft in either direction. The banks are timbered throughout the entire reach.

The bankfull depth varies from approximately 25 to 50 ft; the average is 33 ft. Thus, the width-to-depth ratio for bankfull flow in the Elk River is approximately 6.0 in the study reach.

Based on the plan, profile, and cross-sectional surveys conducted for the Elk River Watershed, the bankfull discharge for the reach is in the range from 5000 $ft^3/s$ to 10,800 $ft^3/s$; the average is 7800 $ft^3/s$.

## Streamflow

Streamflow records have been kept for the U.S. Geological Survey gaging station on the Elk River at Elk Falls from January 1967 to the current year. The drainage area for the station is 220 $mi^2$.

In the 11 years of complete annual record, the average discharge has been 181 $ft^3/s$ which corresponds to an average runoff of 11.18 in./year from the entire catchment upstream.

Monthly records of streamflow have been compiled for the 1968 to 1976 water years inclusive. These are summarized in Table 1.

Table 1. Mean Monthly Streamflow Elk River at Elk Falls (Units of $ft^3/s$ and %)

| Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 153 | 233 | 139 | 141 | 135 | 336 | 284 | 250 | 236 | 292 | 24.4 | 56.7 | 190 |
| 6.83 | 10.05 | 6.21 | 6.28 | 5.50 | 14.99 | 12.26 | 11.16 | 10.16 | 13.02 | 1.09 | 2.45 | 100 |

In a normal year, streamflow is a maximum in March when 15% of the annual runoff occurs on the average. August is the driest month with only 1% of the annual runoff.

A listing of all floods greater than 4000 $ft^3/s$ at Elk Falls is given in Table 2. Based on the 11 years of annual peaks, the mean annual flood is 32,800 $ft^3/s$; the coefficient of variation is a rather large value of 1.7.

The flood of record occurred on 3 July 1976 when the momentary discharge reached an estimated 200,000 $ft^3/s$, a value 6 times greater than the mean annual flood and 40 times greater than the minimum bankfull discharge.

In the 11-years of record, the flood peak at Elk Falls has exceeded the lowest bankfull discharge (5000 $ft^3/s$) in the study reach 40 times. Eighteen of these 40 floods occurred in the growing season.

## Sediment Yield

There has been only one suspended sediment sample taken in the Elk River in the period of record. Sediment yield has been estimated by the Soil Conservation Service in order to design the detention reservoirs. Their estimates of sediment yield range from 0.51 in. to 1.79 in. equivalent erosion in 100 years.

The development plan is to store 12,942 ac ft of sediment from a drainage area of 239.8 $mi^2$ in 100 years. If it is assumed that all sediment is stored, the equivalent sediment yield is approximately 0.01 in./year. This value corresponds to an average annual suspended sediment concentration of approximately 900 mg/l.

By way of comparison, the rate of sedimentation in Howard Lake near Howard, Kansas (Figure 1) since 1936 is equivalent to an erosion rate of 0.007 in./year.

The Soil Conservation Service (1967) reports that upland erosion is a serious problem. Floods occurring in the springtime after the thaw but before vegetative cover developes cause extreme land damage. Furthermore, the sediment deposited on the floodplain is infertile silt,

Table 2. Floods in the Elk River at Elk Falls.

| Water Year | Date | Hour | Discharge $ft^3/s$ |
|---|---|---|---|
| 1967 | 5 Jul | | 7,240 |
| 1968 | 7 Oct | 1900 | 5,850 |
| | 3 Apr | 1300 | 4,150 |
| | 25 May | 1045 | 9,610* |
| 1969 | 9 Oct | 1300 | 5,480 |
| | 2 Nov | 2400 | 7,900 |
| | 24 Mar | 0330 | 5,480 |
| | 18 Apr | 0515 | 10,100 |
| | 27 Apr | 0500 | 10,100 |
| | 8 May | 1400 | 4,720 |
| | 30 May | 1300 | 8,940 |
| | 1 Jun | 1300 | 19,100* |
| | 24 Jun | 0600 | 4,860 |
| | 16 Sep | 0800 | 5,160 |
| 1970 | 12 Oct | 2100 | 9,460 |
| | 1 Apr | 1715 | 12,400 |
| | 18 Apr | 2015 | 29,300* |
| | 12 Jun | 0600 | 6,380 |
| 1971 | 3 Jan | 1645 | 4,580* |
| 1972 | 15 Dec | 1045 | 6,220 |
| | 18 Jul | 2200 | 15,200* |
| 1973 | 13 Nov | 0915 | 7,050 |
| | 30 Dec | 0915 | 8,430 |
| | 1 Feb | 1330 | 4,460 |
| | 4 Mar | 1630 | 7,110 |
| | 6 Mar | 2000 | 6,170 |
| | 9 Mar | 0415 | 9,620 |
| | 10 Mar | 2130 | 10,700* |
| | 25 Mar | 1045 | 6,420 |
| | 31 Mar | 0700 | 5,790 |
| | 15 Apr | 2100 | 4,230 |
| 1974 | 11 Oct | 1630 | 5,100 |
| | 20 Nov | 1230 | 5,580 |
| | 4 Dec | 1115 | 8,920 |
| | 9 Mar | 0400 | 4,400 |
| | 10 Mar | 0745 | 14,500* |
| | 30 Apr | 1100 | 4,290 |
| | 22 May | 0915 | 6,460 |
| | 24 May | 0015 | 5,160 |

Table 2. (Concluded).

| Water Year | Date | Hour | Discharge $ft^3/s$ |
|---|---|---|---|
| 1975 | 31 Oct | 0400 | 12,900 |
| | 3 Nov | 1000 | 22,400* |
| | 31 Jan | 0100 | 6,830 |
| | 27 Mar | 1745 | 6,570 |
| 1976 | 28 Apr | 1500 | 8,120 |
| | 3 Jul | 0700 | 200,000* |
| 1977 | 13 Apr | 2130 | 6,420 |
| | 21 May | 1345 | 9,100 |
| | 22 Jun | 1130 | 24,100* |
| 1978 | 24 Mar | 1230 | 4,370 |
| | 19 May | 1415 | 11,700* |

[a] The symbol "*" denotes the peak discharge for the year.

sandy silts, and clays. From the information given by the Soil Conservation Service (1967), Verville et al. (1958), and Bell and Rowland (undated), it is concluded that the sediment yield of the Elk River catchment must be mostly silt and clay.

## Bed Material

The material on the bed of the Elk River in the study reach was investigated in February 1980. The data collected indicate that the riverbed level is controlled by rock outcrops and that there is but a thin vein of coarse alluvium on the bed at other locations.

Immediately above the upstream end of the reach (RS 152+000) the river is flowing on limestone. Between here and the abandoned railroad grade (RS 108+000) the riverbed consists of Lawrence Shale overlain with alluvium and an armor layer of limestone, sandstone, and shale material in the gravel, cobble, and boulder sizes. The particles are very angular indicating they have not travelled far from their parent rocks. In the areas sampled, the depth of alluvium varied from zero (RS 138+000) to 4 ft (RS 124+000).

Downstream from the abandoned railroad grade, the river flows on a relatively thin layer of alluvium on top of the Ireland Sandstone member of the Lawrence Shale formation. At River Station 103+000, sandstone was encountered 6 in. below the bottom of the channel. At other locations an armor layer of gravel and boulder sandstone particles covered the bed.

It is apparent that the bed of the Elk River is not, in general, alluvial. The bed level is controlled by outcrops of rock or gravel and boulder particles of angular rock obtained from the outcrops but not transported far from their source. It is inferred that the bedload of this river is very small.

## Bank Material

The river banks are alluvial at almost all cross sections investigated in February 1980. One exception is at River Station 103+000 where the river is against the south valley wall. Here the right bank is limestone talus of gravel and cobble sizes.

The upper (above the low-water channel) slopes of the river banks are approximately 2.5 horizontal to 1 vertical and support a growth of old timber, and grass. In locations where the upper slopes are steeper but not yet caving, only grass and willows grow. It appears that the alluvial banks are composed almost entirely of silt and clay materials.

Bank erosion was observed in February 1980 at two locations on the outside of bends. Here the caving banks were vertical and bare of vegetation.

The river banks are timbered all along the reach and, at many cross sections, there appear to be natural levees on the floodplain side, in some cases, at least 3 feet high. There are no man-made levees.

### Floodplain

The valley floor of the Elk River in the study reach is on the average 3500 ft wide. The land which is floodplain is cropped with alfalfa and feed grains. There are roads and small drainage channels on the floodplain. The cross-sectional surveys indicate the surface of the floodplain is very irregular.

## EFFECTS OF DEVELOPMENT

The 48 flood retention reservoirs in the upstream catchment will affect the amount and delivery of water and sediment to the Elk River. Estimates of these have been made by the Soil Conservation Service.

### Water Yield

The annual water yield from the Elk River catchment will be only slightly decreased because of evaporation from the water ponded in the flood retention reservoirs.

### Flood Hydrographs

Floods will be decreased greatly when the 48 flood retention reservoirs are constructed. The peak of the unit hydrograph will be reduced from 30.3 to 14.7 $ft^3/s$ per $mi^2$ per in. of runoff. That is a reduction of approximately 50 percent. Also, the volume of water in the main part of the hydrograph (first 36 hours) will be reduced approximately the same amount.

### Sediment Discharge

The sediment trapped in the flood retention reservoirs will result in an estimated 58% reduction in the annual sediment load in the Elk River at Longton. As the bed-load transport is very small now, the reduction will be primarily in the suspended load which is presumed to be mostly silt and clay.

## RESPONSE OF THE RIVER

### Methods

The response of the Elk River to the great decreases in flood peaks and sediment discharge can be predicted on the basis of general geomorphic relations developed from experiences in many rivers in many parts of the world. Normally, I would supplement the geomorphic analysis with some mathematical modeling of the water and sediment transport, and changes in bed-material size and configuration. In this case, the mathematical modeling is foregone for these reasons: 1) the river bed is not entirely alluvial which means that the bed load at a section may not be related to the local shear stress but controlled entirely by the amount coming in from above; 2) much of the material on the bed is very angular gravel, cobbles, and boulders which have not been transported far from their parent rock. Existing bed-load equations are for more rounded rock and not this talus material; 3) the river meanders appreciably, so average flow properties at any cross section may not represent values to be used in existing gravel transport equations (which were developed for more regular reaches of rivers); 4) it appears that the amount of bed load in the river is very small and of little consequence; and 5) there are no field data with which to calibrate a mathematical model of the sediment transport process.

The geomorphic relations employed in this paper are those developed by Schumm (1977) but modified slightly based on experience on tropical islands in the Orient where sediment concentrations reach values as large as 100,000 mg/l in the rivers and 20,000 mg/l in the irrigation canals.

## Geomorphic Equations

The basic premise is that the river morphology is in "regime." That is, the width, depth, and other features have adjusted over a long period of time to conform to the stresses caused by the water and sediment load. It appears that the Elk River is in regime because there are no reports of geomorphic change caused by the enormous flood of 3 July 1976. Also, if a flood with a peak 6 times the mean annual flood could not cause widespread bank caving and channel change, one must presume the banks and bed are stable and will not respond quickly to changes in water and sediment discharge.

Schumm's expression relating river channel morphology to water discharge is

$$Q \sim \frac{b, d, \lambda}{s} \qquad (1)$$

in which, $Q$ = either the mean annual discharge, or the mean annual flood
$b$ = bankfull width
$d$ = bankfull depth
$\lambda$ = meander wave length
$S$ = riverbed slope

Equation 1 is not an equality but merely a short-hand method of saying that the magnitudes of the width, depth, and wave length are directly proportional to the magnitude of the streamflow and the bed-slope is inversely proportional to the magnitude of the streamflow.

In relating channel morphology to sediment load, Schumm assumed that the percent of silt and clay in the wetted perimeter is inversely proportional to the bed load and that the total load is directly proportional to the bed load. In general, these assmptions may be valid. However, it would seem that one can expand Schumm's analysis to reflect the fact that some rivers have noncohesive beds but transport mostly silt and clay. These rivers can respond differently depending on whether it is the silt and clay load or the noncohesive load which is affected by development.

Schumm has shown that channel width and depth are related closely to the percentage of silt and clay (M) in the sediments forming the perimeter of the channel.

For the range of channels studied by Schumm

$$\frac{b}{d} = \frac{225}{M^{1.08}} \tag{2}$$

$$b = 37 \frac{Q^{0.38}}{M^{0.39}} \tag{3}$$

and

$$d = 0.6\, M^{0.34}\, Q^{0.29} \tag{4}$$

Here Q is the mean annual discharge in $ft^3/s$ and b and d have units of ft.

In general, it is expected that the values of the coefficients and exponents in the above equations vary somewhat with geological setting and size of river.

Equations 2, 3, and 4 indicate that, for these particular channels, the percent silt and clay was inversely proportional to the river size or

$$M = \frac{57}{Q^{0.26}} \tag{5}$$

One can argue that it is the amount of silt and clay in the banks only that determines the width of the alluvial channel and that the composition of the bed is less important in determining the width. That is, one can have the same channel width and shape with a sand bed or gravel bed provided the banks are clay. It is the cohesion in the clay that allows clay-bank channels to withstand higher stresses developed in narrow channels. Thus, one can use the wash load $Q_w$ (silt and clay transported in suspension) as the indicator of the effect of sediment on channel width. Furthermore, $M$ is directly proportional to $Q_w$ so Equation 3 can be expressed as

$$b \sim \frac{Q}{Q_w} \tag{6}$$

The same type of argument applies to depth. If the wash load is large (large concentration of silts and clays), the river channel is narrow, flood depths are large, a large amount of sediment can be deposited on the flood plain, thus building up high banks. Therefore Equation 4 can be expressed as

$$d \sim Q_w, Q \tag{7}$$

It follows that the bankfull width-to-depth ratio b/d is almost entirely dependent on the wash load.

Following this type of reasoning and by considering $Q$ constant, an expression relating channel morphology to wash load (silt and clay carried as suspended load) can be derived

$$Q_w \sim \frac{d,P}{b,\lambda,S} \tag{8}$$

in which $P$ = sinuosity of the channel

$\lambda$ = meander wavelength

$S$ = riverbed slope

It has been assumed that the valley slope is an independent variable, the valley having been carved by hydrologic events no longer directly influencing the river channel shape.

Equation 8 is equivalent to Schumm's if one assumes $Q_w$ is inversely proportional to the bed-material load $Q_b$. In this expression, the bed slope change is accomplished by changes in sinuosity and meander wavelength and not by aggradation and degradation.

Now, it is known that for rivers with alluvial beds and fixed cross-sectional shape,

$$Q_b \sim \frac{Q, S}{d_{50}} \tag{9}$$

This is Lanes' (1955) qualitative relation between bed-material load $Q_b$, water discharge $Q$, median bed sediment $d_{50}$, and riverbed slope $S$. The expression can also be derived mathematically by relating shear stress on the bed with the transport of non-cohesive bed particles. The change in slope in Equation 9 is accomplished by aggradation or degradation and not by a change in alignment as in Equation 8.

For a fixed discharge, then

$$Q_b \sim \frac{S}{d_{50}} \tag{10}$$

Now, Equations 1, 8, and 10 form a set of relations among water and sediment discharge and alluvial river morphology. The assumptions are that the wash load and water discharge have the major influence on the cross-sectional shape, slope, and sinuosity of the channel, and the bed-material load relates closely to only the material size $d_{50}$ and the slope $S$.

For the relatively straight forward cases of an increase or decrease in discharge, washload, or bed-material load alone, the response of a channel to change is

$$Q^+ \sim b^+, d^+, \lambda^+, S^- \tag{11}$$

$$Q^- \sim b^-, d^-, \lambda^-, S^+ \tag{12}$$

$$Q_w^+ \sim b^-, d^+, \lambda^-, S^-, P^+ \tag{13}$$

$$Q_w^- \sim b^+, d^-, \lambda^+, S^+, P^- \tag{14}$$

$$Q_b^+ \sim S^+,\ d_{50}^- \tag{15}$$

$$Q_b^- \sim S^-,\ d_{50}^+ \tag{16}$$

Here, a plus or minus exponent is used to indicate how, with an increase or decrease of water or sediment discharge, the various aspects of channel morphology change. The plus exponent indicates an increase and a negative exponent indicates a decrease. No change is denoted with a zero exponent.

One physical interpretation of the set of expressions given above is this. The water discharge represents processes which tend to erode the banks and bed and straighten the channel alignment. The wash load represents processes which tend to build and maintain banks and to contort the alignment. The bed-material load represents processes which tend to change mainly the level and configuration of the bed and the size of material on the bed. The physical interpretation is important because the expressions may not represent all possible sequences.

Immediate Response

The immediate effect of decreasing the flood discharges and sediment load in the Elk River system should be as follows.

1. The bed material will be coarser as the supply of bed-material load from upstream is decreased. There will be less fines on the river bed, however, little or no decrease in riverbed level in the study reach is anticipated as the armor coat is non-alluvial, angular, and very course in most places. Rock outcrops in the bed at other places. The riverbed slope will not decrease due to degradation. Therefore

$$Q_b \sim \frac{S^o}{d_{50}^+} \tag{17}$$

   It is assumed that the tributary channels on which the dams will be constructed have essentially coarse gravel, non-alluvial beds. If the beds of some tributaries are composed of sand, these channels could supply an excess bed load to the main stream during the first few years of operation.

2. The decrease in flood discharge will decrease the processes tending to widen the channel by erosion and undercutting the banks. As the bed level will not change appreciably and

sediment deposition on the floodplain will decrease, the bank full depth should not change immediately. The meander wave length will not change rapidly as considerable time (a century or more) is required for the river to work laterally across the floodplain destroying one pattern and building another if the existing floodplain deposits are tough cohesive materials. Then it follows that the channel should narrow if the sediment required to build banks is available. That is

$$Q^{-} \sim \frac{b^{-},\ d^{o},\ \lambda^{o}}{S^{o}} \tag{18}$$

A new and more vigorous growth of vegetation may result on the banks as plant scouring will be reduced because flow velocities will be lower.

3. There will be a considerable decrease in the amount of wash load carried by the river. The turbidity of the water will be much less. Wash load is the material from which new banks are made. New deposits on the banks could be facilitated by more luxurious vegetation on the banks. It follows then, from the geomorphic expression relating wash load and channel shape, that the channel should widen initially. That is

$$Q_{w}^{-} \sim \frac{d^{o},\ P^{o}}{b^{+},\ \lambda^{o},\ S^{o}} \tag{19}$$

This is in contradiction with the conclusion drawn from the geomorphic expression relating discharge and channel shape. However, the influence of $Q_w$ on the width-to-depth ratio is much more pronounced than the influence of the water discharge. Therefore, the channel should tend to widen.

It is concluded that the short-term response will be a channel which is deeper than required and which is slightly too narrow now. The channel will not degrade but the bed will become cleaner as the finer material is removed leaving even more armor coat than is currently on the bed. The pool and ripple sequence will remain unchanged.

## Long-term Response

If left unimpeded over a very long period of time, the Elk River would move its channel laterally across the floodplain eroding one bank and building the other. Even though the farmers would not tolerate the river destroying their cropland by moving laterally, it is useful to estimate the change in river form which would result from migration. Because of the changes in water and sediment discharges, the new river will have a different form than the current river. The differences can be estimated as follows.

1. The long-term response to the decrease in bed-material load will be the same as the short-term response. That is, the river will not be able to degrade because the bed material is very coarse and there are rock outcrops controlling the bed level. Therefore, the slope will not change due to degradation, but the bed material will become coarser. That is, the new regime will be

$$Q_b^- \sim \frac{S^o}{d_{50}^+} \qquad (20)$$

2. The long-term response to the decrease in water discharge and wash load can be determined by noting that the combined response is

$$Q^- \; Q_w^- \sim \frac{b^{\pm}, \; d^-, \; P^-, \; \lambda^{\pm}}{S^+} \qquad (21)$$

   That is, the new river will be shallower (flood discharges are not as large so the floodplain will not build up as high as before), less sinuous, and will have larger bed slope (due to less meandering, not aggradation). There should be fewer pools and ripples. There are questions concerning whether the channel will become wider ($b^+$) or narrower ($b^-$) and whether the meander wave length will be longer ($\lambda^+$) or shorter ($\lambda^-$).

First the width. It is my opinion that the vegetation on the banks will be the added stabilizing factor which will cause the new river to be narrower. Vegetation is effective in slowing down the velocity and trapping fine sediment on the bank.

The meander wave length must increase because the sinuosity will decrease and the slope will increase (due to strengthening, not aggradation).

In order to predict the magnitude of the anticipated long-term changes in river form, the geomorphoric equations developed by Schumm

(1977) are used here. These equations were developed from rivers with width-to-depth ratios from 2 to 300 so represent a wide range of river forms. The equations are

$$\frac{b_f}{b_o} = {\frac{Q_f}{Q_o}}^{0.38} {\frac{Q_{wo}}{Q_{wf}}}^{0.39} \tag{22}$$

$$\frac{d_f}{d_o} = {\frac{Q_{wf}}{Q_{wo}}}^{0.34} {\frac{Q_f}{Q_o}}^{0.29} \tag{23}$$

$$\frac{P_f}{P_o} = {\frac{Q_{wf}}{Q_{wo}}}^{0.25} \tag{24}$$

and

$$\frac{\lambda_f}{\lambda_o} = {\frac{Q_f}{Q_o}}^{0.48} {\frac{Q_{wo}}{Q_{wf}}}^{0.74} \tag{25}$$

Here the subscripts "o" and "f" refers to conditions before and after development, respectively.

Because the valley slope remains changed, it follows that

$$\frac{S_f}{S_o} = \frac{P_o}{P_f} \tag{26}$$

Using the values,

$b_o = 200$ ft

$d_o = 33$ ft

$P_o = 1.8$

$\frac{Q_f}{Q_o} = 0.50$

$\frac{Q_{wf}}{Q_{wo}} = 0.58$

the following estimates of the changed river form are obtained.

$b_f$ = 190 ft (5% smaller)

$d_o$ = 22 ft (32% smaller)

$P_f$ = 1.6 (13% smaller)

Currently, there are 17 meanders with a wide range of wave lengths in the study reach. As wave length is inversely proportional to number of meanders, one anticipates there will be one less meander after development. Similarly there should be a reduction of approximately 10 percent in the number of pools and ripples.

The rate at which the Elk River could move laterally across its valley will be much slower after development. Since there is very little evidence of bank caving now, it is anticipated that it will be decades before one will notice any response. The geological survey indicates that the alluvium on the valley floor is primarily silt and clay but if the river was to encounter non-cohesive materials in the former alluvial deposits, response would be much faster. If any local area becomes unstable, for example, if the river cuts into a sandy deposit, this area will probably be stabilized immediately at the request of the local land owners.

## Other Considerations

Changes in river form due to changes in wash load and vegetal factors are not so well documented in geomorphic literature as the response due to changes in discharge and bed-material load. Therefore, some caution is warranted. Two studies should be done to improve estimates made above. They are to

1. Develop geomorphic equations based on the data of rivers in southeastern Kansas, and

2. Study the effect 93 flood retention reservoirs in the Little Walnut River catchment have had on the Walnut River. This catchment is immediately west of the Elk River catchment (Figure 1). Also, the vegetation along the river banks must be maintained. There is a question concerning what will happen when the large trees die of old age. A study of the vegetation succession for this river is warranted.

## SUMMARY

The anticipated response of the Elk River near Longton to the construction of 48 flood retention reservoirs in the upstream catchment is as follows.

1. In the short term, the material on the riverbed will become coarser.

2. If left unimpeded in the long-term, the river would become slightly narrower, much shallower, slightly less sinuous, slightly steeper (but with no aggradation) and the number of ripples and pools would decrease slightly. However, it is anticipated that the land owners will not tolerate lateral migration of the river. Therefore, in the long term, the Elk River will become slightly narrower and will be left with its large remnant bankfull depth developed during a period before dams when water and sediment discharges were much greater.

3. Very little effort will be required to keep the Elk River in its stable regime even after development...if the vegetation on the banks can be maintained. More effort should be given to vegetation studies along this river and land owners should be informed of the importance of river bank vegetation.

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# APPENDIX A

# CHANNEL CHANGE WORKSHOP: PROBLEM NUMBER 1
## YAMPA RIVER, COLORADO

## THE QUESTION

The question relative to the Yampa River is "What will happen to the morphology of the stream channel as a result of the changes in stream flows and sediment discharge caused by the construction of a number of reservoirs upstream of a reach of stream?" Specifically, for both a short and a long time after construction of the reservoirs:

1. What will be the meander pattern?
2. What will be the configuration of the channel?
3. What will be the substrate material?
4. What will be the pool riffle sequence?

The Yampa River is located in Northwestern Colorado. All the reaches of interest are in the lower part of the river. Data are supplied for four reaches but only two are to be considered in any detail. These two are

1. The Box Elder Reach, and
2. The Lily Park Reach.

Lily Park Reach is located just above the Little Snake Rver and the Box Elder Reach is located just above the junction of the Yampa River with the Green River. Data were obtained from the U.S. Geological Survey and from the U.S. Fish and Wildlife Service. The full problem set is available from the Instream Flow Group, U.S. Fish and Wildlife Service.

## CONTENTS[1]

General location of Yampa River Basin, Colorado

Monthly Streamflow Data for Yampa River Basin, Colorado

Annual Peak Flow Frequency Analysis

Average Monthly Discharge for Yampa River Basin, Colorado

Average Daily Discharge for Yampa River Basin, Colorado

Yampa River Cross Section

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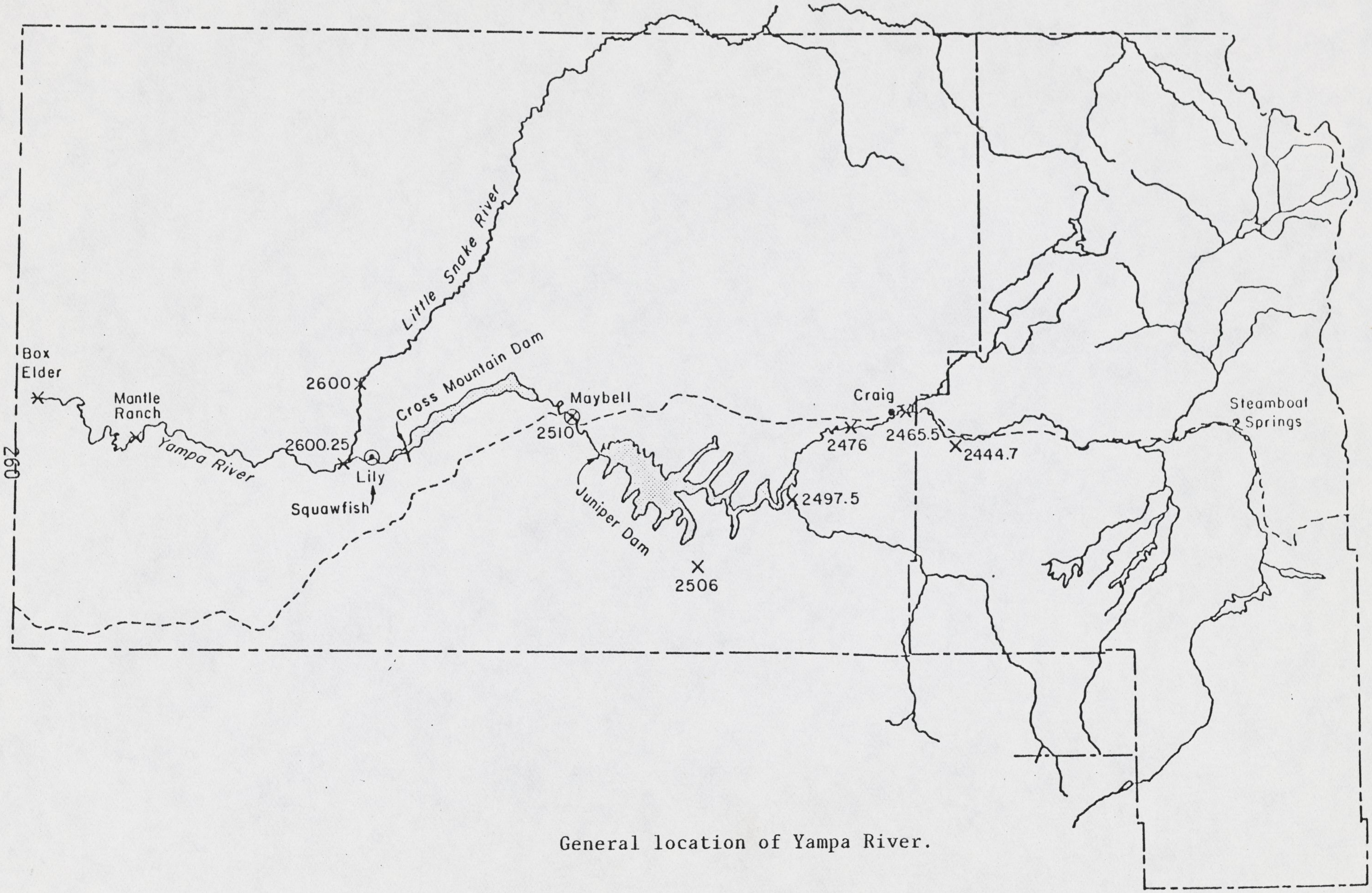
[1] Only selected data are provided in this appendix. Contact the Instream Flow Group of the Fish and Wildlife Service for the complete data set.



General location of Yampa River.

YAMPA RIVER BELOW PROPOSED JUNIPER RESERVOIR
SIMULATION OF MONTHLY FLOWS
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 0. | 0. | 0. | 0. | 0. | 628. | 200. | 200. | 200. | 200. | 200. | 0. | 137. |
| 1928 | 0. | 0. | 0. | 272. | 401. | 200. | 200. | 200. | 200. | 200. | 200. | 200. | 171. |
| 1929 | 0. | 0. | 0. | 465. | 486. | 0. | 200. | 200. | 200. | 200. | 200. | 200. | 177. |
| 1930 | 200. | 200. | 218. | 499. | 532. | 399. | 200. | 200. | 200. | 200. | 200. | 0. | 253. |
| 1931 | 0. | 0. | 353. | 511. | 496. | 0. | 200. | 200. | 200. | 0. | 0. | 0. | 162. |
| 1932 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 200. | 200. | 0. | 84. |
| 1933 | 0. | 0. | 0. | 0. | 0. | 485. | 200. | 200. | 200. | 200. | 0. | 0. | 108. |
| 1934 | 0. | 0. | 0. | 0. | 0. | 0. | 411. | 200. | 0. | 0. | 0. | 0. | 51. |
| 1935 | 0. | 0. | 0. | 0. | 0. | 0. | 508. | 200. | 200. | 0. | 0. | 0. | 75. |
| 1936 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 200. | 0. | 0. | 67. |
| 1937 | 0. | 0. | 0. | 0. | 0. | 0. | 386. | 200. | 200. | 0. | 0. | 0. | 65. |
| 1938 | 0. | 0. | 0. | 0. | 0. | 551. | 200. | 200. | 200. | 200. | 0. | 0. | 114. |
| 1939 | 0. | 0. | 0. | 0. | 0. | 482. | 200. | 200. | 200. | 0. | 0. | 0. | 91. |
| 1940 | 0. | 0. | 0. | 0. | 0. | 0. | 292. | 200. | 200. | 0. | 0. | 0. | 57. |
| 1941 | 0. | 0. | 0. | 0. | 0. | 0. | 404. | 200. | 200. | 0. | 0. | 0. | 67. |
| 1942 | 0. | 0. | 647. | 0. | 0. | 477. | 200. | 200. | 200. | 200. | 0. | 0. | 162. |
| 1943 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 0. | 0. | 0. | 50. |
| 1944 | 0. | 0. | 0. | 0. | 0. | 0. | 489. | 200. | 200. | 0. | 0. | 0. | 74. |
| 1945 | 0. | 0. | 0. | 0. | 0. | 0. | 383. | 200. | 200. | 200. | 0. | 0. | 82. |
| 1946 | 0. | 0. | 0. | 0. | 0. | 541. | 200. | 200. | 200. | 0. | 0. | 0. | 95. |
| 1947 | 0. | 0. | 0. | 0. | 0. | 481. | 200. | 200. | 200. | 200. | 0. | 0. | 108. |
| 1948 | 0. | 0. | 0. | 774. | 698. | 646. | 200. | 200. | 200. | 200. | 0. | 0. | 241. |
| 1949 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 200. | 200. | 0. | 84. |
| 1950 | 0. | 0. | 0. | 728. | 0. | 0. | 310. | 200. | 200. | 0. | 0. | 0. | 121. |
| 1951 | 0. | 0. | 0. | 0. | 0. | 609. | 206. | 200. | 200. | 200. | 0. | 0. | 119. |
| 1952 | 0. | 0. | 0. | 0. | 750. | 0. | 200. | 200. | 200. | 200. | 200. | 200. | 158. |
| 1953 | 0. | 0. | 0. | 0. | 0. | 0. | 480. | 200. | 200. | 0. | 0. | 0. | 73. |
| 1954 | 0. | 0. | 0. | 0. | 0. | 0. | 390. | 200. | 0. | 0. | 0. | 0. | 49. |
| 1955 | 0. | 0. | 0. | 748. | 0. | 0. | 344. | 200. | 200. | 0. | 0. | 0. | 125. |
| 1956 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 200. | 0. | 0. | 67. |
| 1957 | 247. | 0. | 0. | 0. | 0. | 0. | 324. | 200. | 200. | 200. | 200. | 200. | 131. |
| 1958 | 200. | 200. | 200. | 200. | 229. | 301. | 234. | 200. | 200. | 200. | 200. | 200. | 214. |
| 1959 | 0. | 200. | 0. | 659. | 0. | 0. | 424. | 200. | 200. | 0. | 0. | 0. | 141. |
| 1960 | 0. | 672. | 0. | 762. | 0. | 0. | 200. | 200. | 200. | 0. | 0. | 0. | 170. |
| 1961 | 0. | 0. | 0. | 0. | 0. | 0. | 571. | 200. | 200. | 0. | 0. | 0. | 80. |
| 1962 | 502. | 0. | 679. | 0. | 475. | 440. | 200. | 200. | 200. | 200. | 200. | 0. | 258. |
| 1963 | 0. | 0. | 0. | 0. | 0. | 621. | 277. | 200. | 200. | 0. | 0. | 0. | 109. |
| 1964 | 0. | 0. | 0. | 0. | 0. | 0. | 470. | 200. | 200. | 0. | 0. | 0. | 72. |
| 1965 | 0. | 0. | 0. | 0. | 0. | 656. | 0. | 200. | 200. | 200. | 200. | 0. | 123. |
| 1966 | 200. | 0. | 200. | 351. | 0. | 474. | 200. | 200. | 200. | 0. | 0. | 0. | 154. |
| 1967 | 0. | 0. | 0. | 0. | 0. | 0. | 413. | 200. | 200. | 0. | 0. | 0. | 67. |
| 1968 | 0. | 0. | 0. | 0. | 703. | 0. | 377. | 200. | 200. | 200. | 0. | 0. | 136. |
| 1969 | 0. | 0. | 0. | 0. | 0. | 0. | 200. | 200. | 200. | 200. | 0. | 0. | 67. |

```
      YAMPA RIVER BELOW PROPOSED JUNIPER RESERVOIR                                                    (CONTINUED)

   1970           0.         0.       640.         0.         0.       609.       263.       200.       200.       200.       200.       200.              211.
   1971           0.       200.       200.       295.       426.       247.       200.       200.       200.       200.       200.       200.              213.
   1972         200.       198.         0.       200.       200.       200.       200.       200.       200.         0.         0.         0.              132.
   1973           0.         0.         0.         0.       730.         0.       368.       200.       200.       200.       200.         0.              154.
   1974           0.         0.         0.       710.         0.         0.       200.       200.       200.       200.       200.         0.              144.
   1975           0.         0.         0.         0.         0.         0.       410.       200.       200.       200.         0.         0.               84.
   1976           0.         0.         0.         0.         0.         0.       422.       200.       200.         0.         0.         0.               68.

  AVERAGE        31.        33.        63.       143.       123.       181.       283.       200.       192.       108.        60.        28.       120.

   Q/QANN     2.186      2.281      4.428     10.126      7.880     12.769     19.336     14.114     13.113      7.622      4.234      1.912    100.000

  COV VAR     3.006      3.299      2.679      1.800      1.934      1.382       .413      0.000       .206       .932      1.543      2.504       .461

   SKEW       3.489      4.476      2.916      1.558      1.679       .838       .522          I     -4.841      -.166       .900      2.140       .840

  MAXIMUM      502.       672.       679.       774.       750.       656.       571.       200.       200.       200.       200.       200.       258.

  MINIMUM        0.         0.         0.         0.         0.         0.         0.       200.         0.         0.         0.         0.        49.
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```
STATISTICAL PARAMETERS FOR STATION   CP18          YAMPA RIVER BELOW PROPOSED JUNIPER RESERVOIR
  SIMULATION OF MONTHLY FLOWS


                              ARTH.                  LOG PARAMETERS
                 MONTH       AVERAGE      MEAN    VARIANCE  STD. DEV.    SKEW


          1       OCT          30.98    -2.3540    3.1249    1.7677     2.4158
          2       NOV          33.40    -2.3534    3.1329    1.7700     2.4192
          3       DEC          62.74    -2.1152    4.2026    2.0500     1.9218
          4       JAN         143.48    -1.4139    6.6131    2.5716     1.0169
          5       FEB         122.52    -1.6379    6.0033    2.4502     1.2602
          6       MAR         180.94     -.8523    7.6895    2.7730      .5140
          7       APR         283.12     2.3237     .6137     .7834    -6.6479
          8       MAY         200.00     2.3010     .0000     .0000     1.0312
          9       JUNE        192.00     2.0890    1.1011    1.0493    -4.8413
         10       JULY        108.00     -.1374    7.1227    2.6688     -.1655
         11       AUG          60.00    -1.4097    6.0216    2.4539      .9001
         12       SEPT         28.00    -2.2579    3.4524    1.8581     2.1397
         13       ANNUAL      120.27     2.0363     .0389     .1972      .1026


          SAMPLE SIZE   50 YEARS
```

```
LOG NORMAL DISTRIBUTION STATION   CP18          YAMPA RIVER BELOW PROPOSED JUNIPER RESERVOIR
  SIMULATION OF MONTHLY FLOWS


                             YEARS FLOW IS NOT EXCEEDED

     MONTH   9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20              Q2 - Q10

    OCT           1.        0.        0.        0.        0.        0.                    0.
    NOV           1.        0.        0.        0.        0.        0.                    0.
    DEC           3.        0.        0.        0.        0.        0.                    0.
    JAN          76.        0.        0.        0.        0.        0.                    0.
    FEB          32.        0.        0.        0.        0.        0.                    0.
    MAR         504.        2.        0.        0.        0.        0.                    0.
    APR        2128.      457.      211.       46.       21.       11.                  190.
    MAY         200.      200.      200.      200.      200.      200.                    0.
    JUNE       2718.      346.      123.       16.        6.        2.                  117.
    JULY       1923.       10.        1.        0.        0.        0.                    1.
    AUG          54.        0.        0.        0.        0.        0.                    0.
    SEPT          1.        0.        0.        0.        0.        0.                    0.
    ANNUAL      195.      132.      109.       74.       61.       52.                   48.


              Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
```

```
LOG-PEARSON TYPE III DISTRIBUTION FOR STATION  CP18
                    YAMPA RIVER BELOW PROPOSED JUNIPER RESERVOIR
                         SIMULATION OF MONTHLY FLOWS

         DATA SKEW K FACTORS

 MONTH      SKEW                                                 RETURN PERIOD

                          10 YRS          6.67 YRS              2 YRS          1.25 YRS          1.11 YRS          1.05 YRS

OCT         2.42          1.2639             .1041             -.3494            -.7272            -.7988            -.8239
NOV         2.42          1.2643             .1046             -.3491            -.7277            -.7996            -.8249
DEC         1.92          1.3117             .1788             -.2914            -.7904            -.9255            -.9918
JAN         1.02          1.3398             .3085             -.1613            -.8523           -1.1312           -1.3231
FEB         1.26          1.3406             .2862             -.1860            -.8464           -1.0986           -1.2653
MAR          .51          1.3222             .3731             -.0806            -.8559           -1.2181           -1.4956
APR        -6.65           .6600             .5184              .3960            -.4200           -1.1800           -2.0030
MAY         1.03          1.3397             .3104             -.1590            -.8526           -1.1339           -1.3282
JUNE       -4.84           .6600             .5184              .3960            -.4200           -1.1800           -2.0030
JULY        -.17          1.2535             .4531              .0389            -.8279           -1.3038           -1.7090
AUG          .90          1.3390             .3197             -.1480            -.8540           -1.1470           -1.3530
SEPT        2.14          1.2972             .1514             -.3142            -.7698            -.8793            -.9279
ANNUAL       .10          1.2917             .4183             -.0166            -.8459           -1.2703           -1.6168

FREQUENCY OF FLOWS

                              YEARS FLOW IS NOT EXCEEDED

         MONTH    9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20             Q2 - Q10

         OCT           1.        0.        0.        0.        0.        0.                   0.
         NOV           1.        0.        0.        0.        0.        0.                   0.
         DEC           4.        0.        0.        0.        0.        0.                   0.
         JAN         108.        0.        0.        0.        0.        0.                   0.
         FEB          44.        0.        0.        0.        0.        0.                   0.
         MAR         652.        2.        0.        0.        0.        0.                   0.
         APR         693.      537.      430.       99.       25.        6.                 405.
         MAY         200.      200.      200.      200.      200.      200.                   0.
         JUNE        605.      429.      320.       44.        7.        1.                 312.
         JULY       1614.       12.        1.        0.        0.        0.                   1.
         AUG          75.        0.        0.        0.        0.        0.                   0.
         SEPT          1.        0.        0.        0.        0.        0.                   0.
         ANNUAL      195.      131.      108.       74.       61.       52.                  47.

                  Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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LITTLE SNAKE RIVER NEAR LILY, COLORADO
MEASURED FLOWS IN CUBIC FEET PER SECOND
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 142. | 84. | 81. | 81. | 72. | 228. | 1835. | 3899. | 1875. | 597. | 53. | 77. | 755. |
| 1928 | 189. | 363. | 244. | 179. | 191. | 785. | 1468. | 4230. | 2067. | 115. | 13. | 16. | 825. |
| 1929 | 303. | 166. | 120. | 150. | 150. | 950. | 2000. | 5539. | 4116. | 581. | 167. | 260. | 1212. |
| 1930 | 255. | 147. | 85. | 70. | 120. | 255. | 1283. | 1471. | 973. | 54. | 94. | 83. | 407. |
| 1931 | 101. | 25. | 25. | 67. | 145. | 620. | 2074. | 2268. | 1367. | 455. | 85. | 15. | 604. |
| 1932 | 176. | 260. | 140. | 205. | 210. | 1135. | 2344. | 4505. | 2919. | 529. | 56. | 43. | 1046. |
| 1933 | 136. | 182. | 90. | 16. | 18. | 390. | 1116. | 3056. | 3642. | 254. | 10. | 3. | 743. |
| 1934 | 1. | 34. | 65. | 16. | 18. | 200. | 465. | 477. | 37. | 0. | 0. | 0. | 110. |
| 1935 | 0. | 0. | 33. | 65. | 36. | 179. | 397. | 1431. | 1666. | 114. | 28. | 55. | 334. |
| 1936 | 2. | 59. | 130. | 98. | 108. | 311. | 1233. | 2824. | 958. | 65. | 237. | 3. | 505. |
| 1937 | 59. | 105. | 49. | 49. | 18. | 211. | 1175. | 3394. | 2052. | 732. | 82. | 103. | 672. |
| 1938 | 71. | 114. | 111. | 128. | 155. | 320. | 1197. | 3391. | 2059. | 184. | 42. | 171. | 663. |
| 1939 | 93. | 183. | 175. | 109. | 137. | 544. | 902. | 2196. | 646. | 6. | 0. | 6. | 418. |
| 1940 | 43. | 47. | 36. | 22. | 46. | 225. | 841. | 2222. | 767. | 8. | 4. | 29. | 359. |
| 1941 | 202. | 70. | 35. | 40. | 56. | 338. | 779. | 2947. | 1265. | 87. | 534. | 145. | 545. |
| 1942 | 323. | 242. | 178. | 118. | 112. | 447. | 1801. | 2247. | 1986. | 176. | 4. | 0. | 636. |
| 1943 | 48. | 70. | 47. | 66. | 93. | 230. | 1237. | 1399. | 2274. | 144. | 43. | 7. | 470. |
| 1944 | 17. | 66. | 73. | 65. | 72. | 127. | 622. | 2446. | 2737. | 242. | 7. | 0. | 540. |
| 1945 | 80. | 59. | 78. | 66. | 90. | 160. | 640. | 2689. | 2957. | 823. | 213. | 73. | 662. |
| 1946 | 102. | 136. | 86. | 69. | 139. | 325. | 1504. | 1826. | 1058. | 68. | 50. | 4. | 447. |
| 1947 | 154. | 179. | 91. | 67. | 95. | 534. | 966. | 3150. | 1919. | 348. | 84. | 120. | 645. |
| 1948 | 177. | 141. | 72. | 60. | 60. | 85. | 640. | 2304. | 1052. | 100. | 2. | 0. | 393. |
| 1949 | 22. | 101. | 115. | 114. | 118. | 248. | 1335. | 3597. | 2797. | 396. | 20. | 9. | 741. |
| 1950 | 193. | 126. | 101. | 78. | 80. | 285. | 1172. | 2588. | 2374. | 290. | 11. | 16. | 610. |
| 1951 | 53. | 102. | 73. | 61. | 145. | 239. | 597. | 1970. | 1452. | 164. | 15. | 4. | 407. |
| 1952 | 243. | 92. | 81. | 71. | 83. | 89. | 3259. | 4817. | 2927. | 241. | 123. | 31. | 1005. |
| 1953 | 31. | 51. | 65. | 75. | 75. | 308. | 431. | 1441. | 1828. | 84. | 60. | 2. | 371. |
| 1954 | 9. | 94. | 72. | 75. | 118. | 216. | 885. | 1112. | 305. | 25. | 0. | 41. | 246. |
| 1955 | 45. | 63. | 68. | 57. | 59. | 272. | 587. | 1600. | 961. | 77. | 58. | 2. | 322. |
| 1956 | 3. | 69. | 146. | 115. | 89. | 1240. | 1172. | 2611. | 1200. | 38. | 82. | 1. | 567. |
| 1957 | 7. | 63. | 54. | 59. | 80. | 210. | 591. | 2438. | 3632. | 1100. | 129. | 45. | 701. |
| 1958 | 103. | 150. | 109. | 94. | 165. | 309. | 777. | 3548. | 1666. | 69. | 6. | 17. | 587. |
| 1959 | 29. | 62. | 61. | 58. | 83. | 253. | 421. | 1128. | 1002. | 146. | 64. | 270. | 298. |
| 1960 | 174. | 162. | 85. | 51. | 68. | 151. | 1474. | 1534. | 1222. | 53. | 3. | 4. | 414. |
| 1961 | 34. | 44. | 44. | 36. | 54. | 279. | 320. | 1016. | 795. | 5. | 10. | 57. | 225. |
| 1962 | 213. | 159. | 155. | 139. | 452. | 1260. | 2663. | 2727. | 1412. | 249. | 6. | 0. | 786. |
| 1963 | 14. | 53. | 59. | 46. | 124. | 232. | 483. | 1460. | 747. | 18. | 76. | 57. | 281. |
| 1964 | 7. | 51. | 40. | 51. | 57. | 81. | 390. | 2338. | 1918. | 294. | 21. | 4. | 439. |
| 1965 | 6. | 75. | 102. | 92. | 95. | 191. | 957. | 2591. | 2728. | 612. | 178. | 314. | 652. |
| 1966 | 224. | 146. | 130. | 135. | 96. | 1119. | 1006. | 1542. | 616. | 28. | 4. | 0. | 423. |
| 1967 | 54. | 67. | 89. | 63. | 80. | 341. | 524. | 1691. | 2298. | 448. | 31. | 59. | 479. |
| 1968 | 75. | 65. | 104. | 101. | 128. | 262. | 591. | 2882. | 3243. | 367. | 94. | 29. | 662. |
| 1969 | 91. | 105. | 92. | 91. | 87. | 429. | 1482. | 2664. | 1271. | 296. | 30. | 43. | 558. |

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LOG-PEARSON TYPE III DISTRIBUTION FOR STATION  09260000
                 LITTLE SNAKE RIVER NEAR LILY, COLORADO
                      MEASURED  FLOWS IN CUBIC FEET PER SECOND


          DATA SKEW K FACTORS

 MONTH      SKEW                                              RETURN PERIOD

                            10 YRS          6.67 YRS            2 YRS        1.25 YRS        1.11 YRS        1.05 YRS

OCT       -3.26              .6600             .5184            .3960         -.4200         -1.1800         -2.0030
NOV       -5.97              .6600             .5184            .3960         -.4200         -1.1800         -2.0030
DEC        -.40             1.2307             .4686            .0664         -.8158         -1.3171         -1.7506
JAN        -.94             1.1154             .5184            .1736         -.7502         -1.3406         -1.8872
FEB        -.39             1.2298             .4691            .0673         -.8154         -1.3175         -1.7519
MAR         .39             1.3016             .4063           -.0342         -.8502         -1.2571         -1.5839
APR         .11             1.2907             .4195           -.0148         -.8455         -1.2716         -1.6199
MAY        -.85             1.1372             .5116            .1563         -.7633         -1.3395         -1.8678
JUNE      -2.55              .7345             .5333            .3723         -.4881         -1.2304         -2.0125
JULY      -1.66              .9602             .5443            .2735         -.6534         -1.3217         -1.9755
AUG       -2.36              .7863             .5407            .3543         -.5301         -1.2576         -2.0114
SEPT      -1.77              .9377             .5457            .2855         -.6383         -1.3157         -1.9833
ANNUAL    -1.04             1.0945             .5238            .1889         -.7373         -1.3404         -1.9035


FREQUENCY OF FLOWS


                              YEARS FLOW IS NOT EXCEEDED

          MONTH   9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20            Q2 - Q10

          OCT        184.      138.      107.       20.        4.        1.                103.
          NOV        245.      192.      156.       38.       10.        3.                145.
          DEC        153.      106.       88.       57.       45.       37.                 43.
          JAN        136.       99.       83.       50.       37.       28.                 46.
          FEB        216.      131.      100.       56.       40.       30.                 60.
          MAR        725.      399.      297.      172.      131.      106.                166.
          APR       1891.     1170.      921.      582.      461.      380.                460.
          MAY       3955.     2964.     2515.     1646.     1261.      988.               1254.
          JUNE      2747.     2353.     2078.     1070.      604.      331.               1474.
          JULY       629.      327.      214.       50.       17.        6.                196.
          AUG        132.       75.       49.        6.        1.        0.                 48.
          SEPT       159.       49.       22.        1.        0.        0.                 22.
          ANNUAL     841.      658.      570.      383.      295.      232.                275.


                    Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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STATISTICAL PARAMETERS FOR STATION   09260000     LITTLE SNAKE RIVER NEAR LILY, COLORADO
  MEASURED  FLOWS IN CUBIC FEET PER SECOND

                                  ARTH.               LOG PARAMETERS
                        MONTH    AVERAGE       MEAN   VARIANCE  STD. DEV.    SKEW

               1         OCT        101.46     1.6760      .7961      .8923   -3.2628
               2         NOV        112.75     1.8974      .5565      .7460   -5.9743
               3         DEC         94.32     1.9284      .0436      .2088    -.3977
               4         JAN         84.88     1.8763      .0535      .2313    -.9400
               5         FEB        117.64     1.9814      .0822      .2868    -.3922
               6         MAR        383.96     2.4829      .0840      .2898     .3931
               7         APR       1077.96     2.9677      .0573      .2394     .1131
               8         MAY       2569.34     3.3693      .0402      .2004    -.8482
               9         JUNE      1885.27     3.1930      .1121      .3348   -2.5457
              10         JULY       275.04     2.1431      .4656      .6823   -1.6609
              11         AUG         64.90     1.3364      .9985      .9992   -2.3635
              12         SEPT        50.24      .9710     1.7200     1.3115   -1.7708
              13         ANNUAL     569.20     2.7205      .0349      .1867   -1.0405

              SAMPLE SIZE    50 YEARS
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LOG NORMAL DISTRIBUTION STATION   09260000     LITTLE SNAKE RIVER NEAR LILY, COLORADO
  MEASURED  FLOWS IN CUBIC FEET PER SECOND

                          YEARS FLOW IS NOT EXCEEDED

        MONTH   9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20          Q2 - Q10

       OCT          660.      114.       47.        8.        3.        2.               44.
       NOV          714.      165.       79.       19.        9.        5.               70.
       DEC          157.      104.       85.       57.       46.       38.               39.
       JAN          149.       95.       75.       48.       38.       31.               37.
       FEB          223.      127.       96.       55.       41.       32.               55.
       MAR          715.      405.      304.      173.      129.      101.              175.
       APR         1882.     1176.      928.      584.      458.      375.              470.
       MAY         4229.     2853.     2340.     1587.     1295.     1096.             1045.
       JUNE        4190.     2171.     1560.      815.      580.      439.              979.
       JULY        1042.      273.      139.       37.       19.       10.              120.
       AUG          414.       58.       22.        3.        1.        0.               21.
       SEPT         449.       34.        9.        1.        0.        0.                9.
       ANNUAL       912.      632.      525.      366.      303.      259.              223.

                  Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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LITTLE SNAKE RIVER NEAR LILY, COLORADO (CONTINUED)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 148. | 135. | 86. | 94. | 190. | 241. | 651. | 3503. | 2979. | 464. | 43. | 63. | 718. |
| 1971 | 183. | 167. | 133. | 141. | 159. | 612. | 1607. | 3370. | 3606. | 584. | 25. | 55. | 887. |
| 1972 | 123. | 147. | 154. | 140. | 424. | 752. | 808. | 1697. | 1625. | 102. | 7. | 3. | 497. |
| 1973 | 73. | 153. | 106. | 100. | 91. | 127. | 1061. | 3572. | 2517. | 586. | 109. | 84. | 717. |
| 1974 | 98. | 166. | 132. | 106. | 113. | 189. | 1073. | 4140. | 2540. | 281. | 48. | 7. | 743. |
| 1975 | 57. | 104. | 78. | 71. | 96. | 246. | 409. | 2605. | 2526. | 758. | 119. | 76. | 597. |
| 1976 | 88. | 134. | 139. | 124. | 330. | 419. | 653. | 2374. | 1685. | 296. | 68. | 9. | 527. |
| AVERAGE | 101. | 113. | 94. | 85. | 118. | 384. | 1078. | 2569. | 1885. | 275. | 65. | 50. | 569. |
| Q/QANN | 1.513 | 1.627 | 1.406 | 1.266 | 1.599 | 5.725 | 15.555 | 38.311 | 27.204 | 4.101 | .968 | .725 | 100.000 |
| COV VAR | .834 | .585 | .460 | .468 | .728 | .782 | .579 | .412 | .506 | .926 | 1.359 | 1.422 | .380 |
| SKEW | .777 | 1.314 | .970 | .777 | 2.430 | 1.752 | 1.389 | .537 | .324 | 1.152 | 3.433 | 2.273 | .546 |
| MAXIMUM | 323. | 363. | 244. | 205. | 452. | 1260. | 3259. | 5539. | 4116. | 1100. | 534. | 314. | 1212. |
| MINIMUM | 0. | 0. | 25. | 16. | 18. | 81. | 320. | 477. | 37. | 0. | 0. | 0. | 110. |

YAMPA RIVER AT MAYHELL, COLORADO
MEASURED FLOWS IN CUBIC FEET PER SECOND
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 306. | 305. | 330. | 320. | 310. | 590. | 3189. | 8261. | 6118. | 1564. | 508. | 356. | 1851. |
| 1928 | 499. | 673. | 540. | 420. | 520. | 1445. | 2879. | 9963. | 5733. | 1401. | 470. | 362. | 2083. |
| 1929 | 409. | 476. | 380. | 400. | 400. | 1900. | 4941. | 11270. | 8953. | 2566. | 792. | 972. | 2795. |
| 1930 | 697. | 570. | 480. | 340. | 380. | 785. | 4349. | 4396. | 4022. | 569. | 623. | 437. | 1469. |
| 1931 | 682. | 691. | 505. | 325. | 360. | 740. | 2750. | 3864. | 2974. | 468. | 193. | 152. | 1142. |
| 1932 | 300. | 300. | 247. | 177. | 195. | 915. | 3361. | 8282. | 6167. | 2073. | 631. | 259. | 1915. |
| 1933 | 341. | 392. | 245. | 170. | 300. | 470. | 1890. | 4975. | 7573. | 822. | 269. | 163. | 1465. |
| 1934 | 183. | 191. | 195. | 115. | 340. | 535. | 1567. | 2450. | 548. | 20. | 27. | 28. | 517. |
| 1935 | 121. | 195. | 180. | 262. | 368. | 455. | 1173. | 3886. | 6336. | 1174. | 283. | 139. | 1213. |
| 1936 | 169. | 234. | 215. | 240. | 270. | 440. | 4285. | 7634. | 4204. | 730. | 352. | 136. | 1579. |
| 1937 | 210. | 201. | 180. | 175. | 260. | 600. | 1673. | 6436. | 4098. | 1208. | 288. | 177. | 1297. |
| 1938 | 315. | 353. | 376. | 357. | 434. | 818. | 2854. | 6889. | 6100. | 1121. | 311. | 401. | 1696. |
| 1939 | 247. | 314. | 355. | 252. | 254. | 1216. | 2964. | 6136. | 2926. | 338. | 144. | 217. | 1284. |
| 1940 | 304. | 250. | 162. | 154. | 249. | 563. | 2412. | 6076. | 3264. | 391. | 74. | 91. | 1169. |
| 1941 | 345. | 312. | 248. | 221. | 296. | 639. | 1546. | 7338. | 4036. | 811. | 339. | 191. | 1356. |
| 1942 | 654. | 474. | 391. | 343. | 345. | 815. | 4009. | 5874. | 5524. | 952. | 226. | 84. | 1641. |
| 1943 | 171. | 247. | 208. | 188. | 244. | 753. | 3190. | 3850. | 4539. | 1143. | 323. | 144. | 1249. |
| 1944 | 166. | 239. | 199. | 168. | 179. | 292. | 735. | 5064. | 5827. | 1039. | 131. | 33. | 1174. |
| 1945 | 142. | 268. | 208. | 197. | 177. | 381. | 1497. | 7143. | 6611. | 2648. | 915. | 333. | 1716. |
| 1946 | 274. | 319. | 263. | 227. | 330. | 645. | 3614. | 3584. | 3831. | 704. | 261. | 149. | 1181. |
| 1947 | 333. | 413. | 319. | 225. | 269. | 1233. | 2760. | 8007. | 5327. | 1929. | 527. | 278. | 1809. |
| 1948 | 352. | 445. | 624. | 610. | 644. | 924. | 3277. | 7368. | 4035. | 837. | 319. | 97. | 1631. |
| 1949 | 263. | 278. | 258. | 250. | 288. | 711. | 3223. | 6868. | 7270. | 1953. | 334. | 178. | 1824. |
| 1950 | 391. | 335. | 252. | 245. | 277. | 448. | 2239. | 4410. | 5497. | 1273. | 218. | 191. | 1314. |
| 1951 | 250. | 287. | 268. | 235. | 268. | 533. | 1852. | 5356. | 5299. | 1761. | 475. | 214. | 1403. |
| 1952 | 334. | 265. | 202. | 228. | 252. | 306. | 4033. | 8394. | 7971. | 1186. | 542. | 243. | 1997. |
| 1953 | 190. | 208. | 222. | 237. | 220. | 401. | 1218. | 3602. | 6116. | 842. | 396. | 102. | 1145. |
| 1954 | 151. | 264. | 189. | 237. | 272. | 382. | 1728. | 3398. | 1436. | 273. | 122. | 183. | 721. |
| 1955 | 378. | 273. | 204. | 202. | 191. | 456. | 2009. | 4881. | 3355. | 503. | 248. | 67. | 1067. |
| 1956 | 133. | 263. | 322. | 277. | 246. | 489. | 3598. | 6518. | 4358. | 539. | 280. | 64. | 1426. |
| 1957 | 126. | 213. | 187. | 206. | 234. | 467. | 2108. | 7156. | 11430. | 5819. | 1052. | 450. | 2459. |
| 1958 | 469. | 483. | 405. | 328. | 504. | 675. | 2716. | 8931. | 5539. | 573. | 178. | 165. | 1751. |
| 1959 | 216. | 246. | 215. | 220. | 262. | 350. | 1501. | 4306. | 4827. | 783. | 351. | 205. | 1124. |
| 1960 | 665. | 532. | 377. | 235. | 221. | 663. | 4035. | 4675. | 4496. | 592. | 155. | 97. | 1394. |
| 1961 | 197. | 254. | 211. | 199. | 215. | 309. | 948. | 3790. | 3272. | 356. | 131. | 534. | 869. |
| 1962 | 1001. | 566. | 353. | 322. | 743. | 733. | 6496. | 7145. | 5119. | 1841. | 295. | 113. | 2059. |
| 1963 | 288. | 288. | 217. | 213. | 391. | 466. | 1324. | 4081. | 2475. | 270. | 215. | 199. | 870. |
| 1964 | 117. | 201. | 137. | 137. | 160. | 221. | 1128. | 5428. | 4916. | 1348. | 317. | 177. | 1194. |
| 1965 | 172. | 231. | 273. | 270. | 266. | 285. | 2626. | 6280. | 7648. | 2439. | 753. | 501. | 1813. |
| 1966 | 604. | 421. | 326. | 335. | 280. | 1427. | 2044. | 3858. | 1848. | 285. | 123. | 48. | 970. |
| 1967 | 268. | 218. | 206. | 192. | 228. | 691. | 1486. | 4063. | 5305. | 1766. | 347. | 237. | 1252. |
| 1968 | 273. | 246. | 195. | 222. | 244. | 454. | 1494. | 5584. | 7832. | 1532. | 598. | 256. | 1578. |
| 1969 | 354. | 325. | 278. | 283. | 284. | 419. | 4173. | 6510. | 3732. | 1216. | 340. | 337. | 1523. |

YAMPA RIVER AT MAYBELL, COLORADO (CONTINUED)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 450. | 412. | 360. | 350. | 394. | 489. | 1374. | 8302. | 7449. | 1992. | 442. | 287. | 1864. |
| 1971 | 470. | 437. | 345. | 374. | 384. | 1081. | 4649. | 6401. | 7756. | 1901. | 320. | 254. | 2030. |
| 1972 | 306. | 355. | 310. | 347. | 436. | 1175. | 2116. | 4248. | 4872. | 538. | 151. | 197. | 1253. |
| 1973 | 400. | 382. | 351. | 305. | 284. | 428. | 1626. | 7689. | 6022. | 2128. | 517. | 205. | 1701. |
| 1974 | 250. | 338. | 357. | 308. | 271. | 577. | 3775. | 9695. | 6208. | 1236. | 314. | 89. | 1957. |
| 1975 | 207. | 280. | 138. | 220. | 298. | 458. | 1566. | 5439. | 7270. | 3388. | 509. | 180. | 1666. |
| 1976 | 247. | 298. | 272. | 246. | 343. | 531. | 1463. | 5011. | 3712. | 997. | 357. | 165. | 1140. |
| AVERAGE | 328. | 335. | 286. | 262. | 312. | 656. | 2589. | 6015. | 5236. | 1277. | 362. | 223. | 1492. |
| Q/QANN | 1.864 | 1.845 | 1.624 | 1.491 | 1.615 | 3.729 | 14.252 | 34.214 | 28.818 | 7.262 | 2.057 | 1.226 | 100.000 |
| COV VAR | .549 | .363 | .367 | .328 | .360 | .520 | .478 | .324 | .385 | .767 | .588 | .720 | .290 |
| SKEW | 1.568 | 1.235 | 1.129 | 1.436 | 1.837 | 1.636 | .821 | .497 | .322 | 2.291 | 1.203 | 2.384 | .456 |
| MAXIMUM | 1001. | 691. | 624. | 610. | 743. | 1900. | 6496. | 11270. | 11430. | 5819. | 1052. | 972. | 2795. |
| MINIMUM | 117. | 191. | 137. | 115. | 160. | 221. | 735. | 2450. | 548. | 20. | 27. | 28. | 517. |

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STATISTICAL PARAMETERS FOR STATION   09251000     YAMPA RIVER AT MAYBELL, COLORADO
  MEASURED FLOWS IN CUBIC FEET PER SECOND


                          ARTH.                    LOG PARAMETERS
              MONTH      AVERAGE       MEAN   VARIANCE  STD. DEV.    SKEW


      1       OCT          327.80     2.4602      .0477      .2184      .2398
      2       NOV          335.22     2.5008      .0206      .1434      .5849
      3       DEC          285.60     2.4296      .0225      .1502      .2929
      4       JAN          262.18     2.3979      .0180      .1343      .1505
      5       FEB          311.60     2.4710      .0186      .1365      .7031
      6       MAR          655.58     2.7690      .0399      .1997      .4250
      7       APR         2589.26     3.3642      .0447      .2115     -.1107
      8       MAY         6015.30     3.7565      .0207      .1439     -.1812
      9       JUNE        5235.52     3.6774      .0472      .2173    -1.9386
     10       JULY        1276.77     2.9807      .1472      .3837    -1.6247
     11       AUG          361.72     2.4789      .0831      .2883    -1.0081
     12       SEPT         222.73     2.2530      .0903      .3004     -.4325
     13       ANNUAL      1492.17     3.1548      .0180      .1340     -.6993


SAMPLE SIZE   50 YEARS



LOG NORMAL DISTRIBUTION STATION   09251000     YAMPA RIVER AT MAYBELL, COLORADO
  MEASURED FLOWS IN CUBIC FEET PER SECOND


                          YEARS FLOW IS NOT EXCEEDED

  MONTH   9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20             Q2 - Q10

  OCT        550.      358.      289.      189.      151.      126.                 137.
  NOV        484.      365.      317.      240.      208.      184.                 109.
  DEC        419.      312.      269.      201.      173.      152.                  96.
  JAN        372.      285.      250.      193.      168.      150.                  82.
  FEB        443.      338.      296.      227.      198.      176.                  98.
  MAR       1059.      716.      587.      399.      326.      276.                 262.
  APR       4319.     2851.     2313.     1535.     1239.     1038.                1074.
  MAY       8729.     6579.     5708.     4318.     3732.     3309.                1975.
  JUNE      9037.     5897.     4758.     3122.     2505.     2089.                2253.
  JULY      2969.     1397.      957.      455.      308.      224.                 648.
  AUG        705.      400.      301.      172.      129.      101.                 173.
  SEPT       435.      241.      179.      100.       74.       57.                 105.
  ANNUAL    2121.     1630.     1428.     1101.      962.      860.                 467.


              Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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LOG-PEARSON TYPE III DISTRIBUTION FOR STATION  09251000
               YAMPA RIVER AT MAYBELL, COLORADO
                     MEASURED FLOWS IN CUBIC FEET PER SECOND

          DATA SKEW K FACTORS

 MONTH      SKEW                                                    RETURN PERIOD

                             10 YRS          6.67 YRS              2 YRS          1.25 YRS          1.11 YRS          1.05 YRS

OCT           .24            1.2974            .4115              -.0266            -.8484           -1.2628           -1.5979
NOV           .58            1.3179            .3820              -.0686            -.8552           -1.2287           -1.5190
DEC           .29            1.2926            .4173              -.0181            -.8463           -1.2692           -1.6139
JAN           .15            1.2869            .4238              -.0084            -.8440           -1.2761           -1.6306
FEB           .70            1.3328            .3465              -.1155            -.8570           -1.1835           -1.4241
MAR           .43            1.3150            .3868              -.0620            -.8545           -1.2345           -1.5318
APR          -.11            1.2464            .4585               .0482            -.8246           -1.3081           -1.7232
MAY          -.18            1.2556            .4515               .0362            -.8289           -1.3025           -1.7049
JUNE        -1.94             .8790            .5466               .3144            -.5986           -1.2971           -1.9991
JULY        -1.62             .9512            .5451               .2785            -.6472           -1.3195           -1.9788
AUG         -1.01            1.0877            .5256               .1938            -.7331           -1.3401           -1.9087
SEPT         -.43            1.2052            .4829               .0938            -.8026           -1.3264           -1.7895
ANNUAL       -.70            1.1829            .4940               .1161            -.7899           -1.3330           -1.8191

FREQUENCY OF FLOWS

                         YEARS FLOW IS NOT EXCEEDED

          MONTH   9 IN 10    2 IN 3   1 IN 2    1 IN 5   1 IN 10   1 IN 20            Q2 - Q10

         OCT        554.      355.     285.      188.      153.      129.                132.
         NOV        490.      359.     310.      239.      211.      192.                 99.
         DEC        420.      311.     267.      201.      173.      154.                 94.
         JAN        372.      285.     249.      193.      168.      151.                 81.
         FEB        450.      330.     285.      226.      204.      189.                 81.
         MAR       1076.      702.     571.      397.      333.      290.                238.
         APR       4245.     2892.    2368.     1548.     1223.      999.               1145.
         MAY       8652.     6629.    5776.     4337.     3707.     3244.               2070.
         JUNE      7386.     6254.    5568.     3526.     2486.     1750.               3082.
         JULY      2217.     1548.    1224.      540.      298.      167.                925.
         AUG        620.      427.     343.      185.      124.       85.                219.
         SEPT       412.      250.     191.      103.       72.       52.                120.
         ANNUAL    2057.     1663.    1480.     1119.      947.      815.                534.

                  Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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YAMPA RIVER PELOW PROPOSED CROSS MOUNTAIN DAM
SIMULATED MONTHLY FLOWS
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 57. | 52. | 57. | 59. | 57. | 517. | 344. | 1731. | 3421. | 3226. | 2342. | 507. | 1038. |
| 1928 | 517. | 380. | 501. | 568. | 556. | 344. | 344. | 2479. | 3357. | 3191. | 2336. | 1464. | 1342. |
| 1929 | 401. | 581. | 627. | 597. | 597. | 344. | 344. | 2859. | 3923. | 3408. | 2394. | 1587. | 1477. |
| 1930 | 600. | 600. | 663. | 678. | 627. | 490. | 494. | 2158. | 3043. | 3054. | 2369. | 1022. | 1322. |
| 1931 | 607. | 724. | 725. | 681. | 602. | 344. | 344. | 1720. | 2005. | 1720. | 382. | 246. | 844. |
| 1932 | 0. | 52. | 42. | 33. | 36. | 166. | 344. | 1720. | 3256. | 3318. | 2365. | 960. | 1030. |
| 1933 | 571. | 565. | 658. | 375. | 55. | 353. | 344. | 1720. | 2855. | 3087. | 457. | 577. | 974. |
| 1934 | 698. | 550. | 34. | 22. | 62. | 97. | 362. | 1720. | 1393. | 0. | 0. | 0. | 412. |
| 1935 | 0. | 32. | 30. | 48. | 67. | 83. | 431. | 1720. | 2305. | 2427. | 440. | 528. | 679. |
| 1936 | 442. | 39. | 37. | 44. | 51. | 80. | 344. | 1720. | 2941. | 3083. | 1205. | 574. | 885. |
| 1937 | 650. | 605. | 31. | 32. | 48. | 109. | 344. | 1720. | 2424. | 2552. | 385. | 479. | 745. |
| 1938 | 577. | 62. | 67. | 64. | 79. | 423. | 344. | 1720. | 3186. | 3134. | 1069. | 409. | 933. |
| 1939 | 615. | 564. | 373. | 46. | 47. | 344. | 344. | 1720. | 2570. | 2097. | 462. | 565. | 816. |
| 1940 | 394. | 42. | 27. | 29. | 46. | 102. | 344. | 1720. | 2240. | 1885. | 464. | 554. | 657. |
| 1941 | 377. | 54. | 43. | 41. | 54. | 116. | 344. | 1720. | 2577. | 2776. | 344. | 436. | 744. |
| 1942 | 381. | 448. | 568. | 211. | 63. | 344. | 344. | 1720. | 3097. | 3110. | 592. | 566. | 959. |
| 1943 | 661. | 598. | 35. | 34. | 45. | 137. | 344. | 1720. | 2119. | 2293. | 424. | 574. | 752. |
| 1944 | 414. | 40. | 34. | 31. | 33. | 54. | 344. | 1720. | 2426. | 2493. | 458. | 569. | 722. |
| 1945 | 323. | 46. | 35. | 36. | 34. | 71. | 344. | 1720. | 3000. | 3422. | 1766. | 510. | 949. |
| 1946 | 606. | 611. | 209. | 41. | 59. | 418. | 344. | 1720. | 2256. | 1720. | 417. | 569. | 751. |
| 1947 | 453. | 72. | 55. | 41. | 49. | 344. | 344. | 1759. | 3292. | 3292. | 2051. | 462. | 1025. |
| 1948 | 529. | 606. | 439. | 689. | 689. | 663. | 344. | 1828. | 3044. | 3090. | 456. | 576. | 1082. |
| 1949 | 675. | 284. | 45. | 46. | 53. | 129. | 344. | 1720. | 3177. | 3290. | 2304. | 564. | 1060. |
| 1950 | 513. | 621. | 243. | 670. | 165. | 82. | 344. | 1720. | 2323. | 2480. | 448. | 551. | 851. |
| 1951 | 419. | 50. | 47. | 43. | 49. | 506. | 344. | 1720. | 2504. | 3256. | 447. | 571. | 835. |
| 1952 | 462. | 58. | 36. | 42. | 665. | 176. | 344. | 1720. | 3729. | 3153. | 2349. | 1443. | 1183. |
| 1953 | 673. | 698. | 684. | 47. | 40. | 73. | 393. | 1720. | 2231. | 2180. | 407. | 575. | 814. |
| 1954 | 447. | 46. | 32. | 44. | 49. | 70. | 344. | 1720. | 1720. | 812. | 0. | 0. | 442. |
| 1955 | 5. | 47. | 35. | 692. | 138. | 82. | 344. | 1720. | 2021. | 1720. | 409. | 147. | 617. |
| 1956 | 0. | 45. | 57. | 51. | 45. | 88. | 344. | 1720. | 2641. | 3036. | 384. | 578. | 753. |
| 1957 | 687. | 377. | 33. | 38. | 43. | 85. | 344. | 1720. | 3912. | 4027. | 2440. | 1480. | 1272. |
| 1958 | 605. | 597. | 639. | 654. | 582. | 434. | 344. | 2254. | 3309. | 3035. | 2276. | 1435. | 1352. |
| 1959 | 681. | 686. | 688. | 691. | 293. | 64. | 397. | 1720. | 2120. | 1720. | 403. | 344. | 820. |
| 1960 | 57. | 585. | 238. | 698. | 160. | 120. | 344. | 1720. | 2407. | 2585. | 465. | 579. | 833. |
| 1961 | 330. | 44. | 36. | 36. | 40. | 57. | 492. | 1720. | 1720. | 1505. | 0. | 0. | 501. |
| 1962 | 493. | 588. | 592. | 209. | 344. | 344. | 344. | 2362. | 3234. | 3263. | 2297. | 1191. | 1276. |
| 1963 | 688. | 696. | 690. | 60. | 70. | 513. | 344. | 1720. | 1721. | 1517. | 0. | 0. | 673. |
| 1964 | 0. | 34. | 23. | 26. | 29. | 41. | 393. | 1720. | 2328. | 2179. | 447. | 572. | 652. |
| 1965 | 412. | 40. | 48. | 50. | 49. | 555. | 344. | 1720. | 2624. | 3384. | 2393. | 344. | 1006. |
| 1966 | 482. | 601. | 618. | 612. | 652. | 344. | 344. | 1720. | 1834. | 1720. | 213. | 0. | 763. |
| 1967 | 0. | 36. | 36. | 36. | 42. | 125. | 344. | 1720. | 2206. | 2644. | 436. | 524. | 683. |
| 1968 | 500. | 42. | 34. | 41. | 620. | 200. | 344. | 1720. | 2890. | 3214. | 625. | 553. | 900. |
| 1969 | 617. | 642. | 135. | 52. | 52. | 75. | 344. | 1720. | 2641. | 3165. | 488. | 540. | 877. |

YAMPA RIVER BELOW PROPOSED CROSS MOUNTAIN DAM (CONTINUED)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 559. | 612. | 662. | 350. | 72. | 504. | 344. | 1720. | 3405. | 3297. | 2337. | 1457. | 1284. |
| 1971 | 524. | 580. | 614. | 606. | 588. | 344. | 344. | 2078. | 3709. | 3274. | 2302. | 1451. | 1372. |
| 1972 | 432. | 66. | 62. | 55. | 657. | 190. | 344. | 1720. | 2982. | 3328. | 2344. | 498. | 1060. |
| 1973 | 611. | 581. | 254. | 641. | 190. | 105. | 344. | 1872. | 3444. | 3162. | 2301. | 876. | 1205. |
| 1974 | 652. | 644. | 671. | 147. | 55. | 83. | 377. | 1720. | 2784. | 3549. | 1991. | 506. | 1106. |
| 1975 | 620. | 614. | 164. | 45. | 63. | 97. | 344. | 1720. | 2092. | 2345. | 398. | 572. | 760. |
| AVERAGE | 449. | 352. | 259. | 226. | 199. | 233. | 356. | 1805. | 2703. | 2678. | 1104. | 634. | 921. |
| Q/QANN | 4.141 | 3.137 | 2.390 | 2.084 | 1.673 | 2.150 | 3.175 | 16.637 | 24.105 | 24.679 | 10.172 | 5.658 | 100.000 |
| COV VAR | .487 | .786 | 1.047 | 1.190 | 1.195 | .743 | .094 | .128 | .229 | .295 | .842 | .662 | .275 |
| SKEW | -1.086 | -.121 | .657 | .940 | 1.202 | .701 | 3.271 | 3.117 | .052 | -1.191 | .470 | .856 | .284 |
| MAXIMUM | 698. | 724. | 725. | 698. | 689. | 663. | 494. | 2859. | 3923. | 4027. | 2440. | 1587. | 1477. |
| MINIMUM | 0. | 32. | 23. | 22. | 29. | 41. | 344. | 1720. | 1393. | 0. | 0. | 0. | 412. |

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STATISTICAL PARAMETERS FOR STATION   CP19        YAMPA RIVER BELOW PROPOSED CROSS MOUNTAIN DAM
  SIMULATED MONTHLY FLOWS


                          ARTH.                  LOG PARAMETERS
            MONTH        AVERAGE       MEAN   VARIANCE  STD. DEV.    SKEW


    1       OCT          449.33       2.0540    3.0867     1.7569   -2.5446
    2       NOV          351.78       2.2895     .3038      .5512    -.2931
    3       DEC          259.33       2.0920     .3194      .5651     .2546
    4       JAN          226.16       2.0115     .3000      .5478     .6300
    5       FEB          199.20       2.0179     .2258      .4752     .8152
    6       MAR          233.24       2.2389     .1200      .3464     .0940
    7       APR          355.98       2.5498     .0013      .0361    3.0898
    8       MAY         1805.31       3.2537     .0023      .0477    2.8707
    9       JUNE        2702.82       3.4200     .0109      .1042    -.4342
   10       JULY        2677.92       3.2883     .8585      .9266   -6.7818
   11       AUG         1103.71       2.4546    2.8190     1.6790   -2.9153
   12       SEPT         634.39       2.2039    3.1835     1.7842   -2.6458
   13       ANNUAL       920.96       2.9473     .0156      .1249    -.4480


   SAMPLE SIZE   49 YEARS
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LOG NORMAL DISTRIBUTION STATION   CP19        YAMPA RIVER BELOW PROPOSED CROSS MOUNTAIN DAM
  SIMULATED MONTHLY FLOWS


                        YEARS FLOW IS NOT EXCEEDED

   MONTH    9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20              Q2 - Q10

  OCT        20246.      642.      113.       4.        1.        0.                   113.
  NOV          991.      336.      195.      67.       38.       24.                   156.
  DEC          655.      216.      124.      41.       23.       15.                   100.
  JAN          517.      176.      103.      36.       20.       13.                    82.
  FEB          424.      167.      104.      41.       26.       17.                    79.
  MAR          482.      244.      173.      89.       62.       47.                   111.
  APR          395.      368.      355.     331.      319.      309.                    36.
  MAY         2065.     1880.     1794.    1635.     1558.     1497.                   235.
  JUNE        3578.     2915.     2630.    2149.     1933.     1772.                   697.
  JULY       29931.     4850.     1942.     322.      126.       58.                  1816.
  AUG        40463.     1496.      285.      11.        2.        0.                   283.
  SEPT       30996.      932.      160.       5.        1.        0.                   159.
  ANNUAL      1281.     1002.      886.     695.      613.      552.                   273.

          Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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LOG-PEARSON TYPE III DISTRIBUTION FOR STATION  CP19
YAMPA RIVER BELOW PROPOSED CROSS MOUNTAIN DAM
SIMULATED MONTHLY FLOWS

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         DATA SKEW K FACTORS

 MONTH      SKEW                                                       RETURN PERIOD

                             10 YRS           6.67 YRS             2 YRS          1.25 YRS           1.11 YRS            1.05 YRS

 OCT       -2.54              .7343              .5332             .3724            -.4879            -1.2302             -2.0124
 NOV        -.29             1.2440              .4601             .0511            -.8235            -1.3095             -1.7276
 DEC         .25             1.2961              .4131            -.0243            -.8478            -1.2646             -1.6024
 JAN         .63             1.3265              .3631            -.0942            -.8567            -1.2048             -1.4679
 FEB         .82             1.3355              .3351            -.1296            -.8562            -1.1686             -1.3933
 MAR         .09             1.2707              .4392             .0160            -.8364            -1.2914             -1.6713
 APR        3.09             1.1800              .0202            -.3960            -.6360             -.6600              -.6650
 MAY        2.87             1.2199              .0561            -.3783            -.6766             -.7176              -.7287
 JUNE       -.43             1.2055              .4827             .0935            -.8027            -1.3263             -1.7891
 JULY      -6.78              .6600              .5184             .3960            -.4200            -1.1800             -2.0030
 AUG       -2.92             2.0312              .7635             .4163            -.3997             -.7190              -.8649
 SEPT      -2.65              .7121              .5295             .3803            -.4687            -1.2164             -2.0109
 ANNUAL     -.45             1.2077              .4816             .0913            -.8038            -1.3256             -1.7860
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 FREQUENCY OF FLOWS

                         YEARS FLOW IS NOT EXCEEDED

         MONTH    9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20            Q2 - Q10

         OCT        2208.      979.      511.       16.        1.        0.                510.
         NOV         944.      349.      208.       68.       37.       22.                171.
         DEC         668.      212.      120.       41.       24.       15.                 96.
         JAN         547.      162.       91.       35.       22.       16.                 69.
         FEB         449.      150.       90.       41.       29.       23.                 61.
         MAR         478.      246.      176.       89.       62.       46.                114.
         APR         391.      355.      343.      336.      336.      336.                  7.
         MAY        2051.     1805.     1721.     1665.     1658.     1656.                 63.
         JUNE       3513.     2953.     2690.     2169.     1913.     1712.                777.
         JULY       7940.     5869.     4521.      793.      157.       27.               4364.
         AUG      732713.     5451.     1424.       61.       18.       10.               1407.
         SEPT       2992.     1408.      763.       23.        1.        0.                762.
         ANNUAL     1254.     1017.      909.      703.      605.      530.                304.

                    Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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PGM J407 VER 3.4                                 U. S. GEOLOGICAL SURVEY
(REV 10/22/79)                          ANNUAL  PEAK  FLOW  FREQUENCY  ANALYSIS
                                         FOLLOWING WRC GUIDELINES BULL. 17-A.


EXECUTION BEGINNING AT DATE, TIME =    5/13/80    134

INPUT FORMAT =   1  WATSTORE PEAK FILE RETRIEVAL


 EXPLANATION OF PEAK DISCHARGE QUALIFICATION CODES

 J407   FILE   MEANING

   D       3    DAM FAILURE, NON-RECURRENT FLOW ANOMALY
   G       8    DISCHARGE GREATER THAN STATED VALUE
   X     3+8    BOTH OF THE ABOVE
   L       4    DISCHARGE LESS THAN STATED VALUE
   K  6 OR C    KNOWN EFFECT OF REGULATION OR URBANIZATION
   H       7    HISTORIC PEAK


REPORT TROUBLE TO WATSTORE USER ASSISTANCE.
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PGM J407 VER 3.4                              U. S. GEOLOGICAL SURVEY
(REV 10/22/79)                        ANNUAL  PEAK  FLOW  FREQUENCY  ANALYSIS
                                      FOLLOWING WRC GUIDELINES BULL. 17-A.          RUN-DATE  5/13/80 AT  134   SEQ  1.0001

OPTIONS IN EFFECT --   PLOT  NOBC  LGPT  NODB  PPOS  NORS  EXPR  CLIM

 STATION -       09251000/USGS    YAMPA RIVER NEAR MAYBELL, CO.                      1904-1978                      09251000/USGS

                                          I N P U T   D A T A   S U M M A R Y

   -- YEARS OF RECORD --     HISTORIC   GENERALIZED    SKEW      GAGE BASE     USER-SET OUTLIER CRITERIA
   SYSTEMATIC   HISTORIC      PEAKS        SKEW       OPTION     DISCHARGE     HIGH OUTLIER   LOW OUTLIER

       65          0            0         -0.300    WRC WEIGHTED     0.0            --             --

                             *********     NOTICE  --  PRELIMINARY MACHINE COMPUTATIONS.          *********
                             *********   USER RESPONSIBLE FOR ASSESSMENT AND INTERPRETATION.     *********

   WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                       0.0
   WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.               2895.6
   WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS WERE NOTED.

                          ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

                                             FLOOD BASE                         LOGARITHMIC
                            FLOOD BASE       EXCEEDANCE     LOGARITHMIC          STANDARD       LOGARITHMIC
                            DISCHARGE        PROBABILITY       MEAN              DEVIATION          SKEW

       SYSTEMATIC RECORD       0.0             1.0000          3.9871             0.1350           -0.676
       W R C  ESTIMATE         0.0             1.0000          3.9871             0.1350           -0.501

                 ANNUAL FREQUENCY CURVE ORDINATES -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

                   ANNUAL                                          'EXPECTED-          95-PCT CONFIDENCE LIMITS
                 EXCEEDANCE          W R C         SYSTEMATIC     PROBABILITY'          FOR  W R C  ESTIMATES
                 PROBABILITY        ESTIMATE         RECORD         ESTIMATE            LOWER           UPPER

                   0.9950            3772.2          3589.6          3556.9             3167.3          4312.9
                   0.9900            4212.8          4057.1          4038.8             3598.4          4757.3
                   0.9500            5592.6          5524.9          5505.0             4980.4          6132.1
                   0.9000            6434.5          6416.9          6361.7             5837.2          6968.1
                   0.8000            7551.0          7588.4          7510.8             6973.3          8088.3
                   0.5000            9961.1         10050.5          9961.1             9346.7         10627.6
                   0.2000           12667.4         12669.8         12714.7            11816.2         13737.1
                   0.1000           14165.0         14040.0         14263.5            13114.6         15551.3
                   0.0400           15797.9         15462.5         15966.8            14494.1         17585.2
                   0.0200           16861.6         16346.1         17114.4            15376.8         18936.0
                   0.0100           17817.6         17110.1         18144.9            16161.5         20165.6
                   0.0050           18687.7         17779.4         19122.5            16869.3         21296.4
                   0.0020           19730.6         18547.9         20226.0            17710.5         22665.2
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PGM J407 VER 3.4                           U. S. GEOLOGICAL SURVEY
(REV 10/22/79)                        ANNUAL  PEAK  FLOW  FREQUENCY  ANALYSIS
                                     FOLLOWING WRC GUIDELINES BULL. 17-A.               RUN-DATE  5/13/80 AT  134   SEQ  1.0001


 STATION -        09251000/USGS    YAMPA RIVER NEAR MAYBELL, CO.                        1904-1978                          09251000/USGS


                              *********     NOTICE  --  PRELIMINARY MACHINE COMPUTATIONS.          *********
                              *********   USER RESPONSIBLE FOR ASSESSMENT AND INTERPRETATION.      *********


                INPUT DATA LISTING                      EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

          WATER                                          WATER           RANKED          SYSTEMATIC        W R C
           YEAR          DISCHARGE    CODES               YEAR          DISCHARGE          RECORD        ESTIMATE

           1904            8050.0                         1917           17900.0          0.0152          0.0152
           1905           11400.0                         1921           17700.0          0.0303          0.0303
           1916           11700.0                         1920           16000.0          0.0455          0.0455
           1917           17900.0                         1957           15700.0          0.0606          0.0606
           1918           10500.0                         1974           15400.0          0.0758          0.0758
           1919            7670.0                         1929           14400.0          0.0909          0.0909
           1920           16000.0                         1952           13800.0          0.1061          0.1061
           1921           17700.0                         1928           13700.0          0.1212          0.1212
           1922           10800.0                         1970           12700.0          0.1364          0.1364
           1923           10900.0                         1947           12400.0          0.1515          0.1515
           1924            7810.0                         1958           12200.0          0.1667          0.1667
           1925            6640.0                         1932           12100.0          0.1818          0.1818
           1926            9090.0                         1938           12100.0          0.1970          0.1970
           1927           11800.0                         1973           12100.0          0.2121          0.2121
           1928           13700.0                         1927           11800.0          0.2273          0.2273
           1929           14400.0                         1965           11800.0          0.2424          0.2424
           1930            7980.0                         1916           11700.0          0.2576          0.2576
           1931            6500.0                         1941           11700.0          0.2727          0.2727
           1932           12100.0                         1975           11700.0          0.2879          0.2879
           1933           11200.0                         1978           11600.0          0.3030          0.3030
           1934            4080.0                         1962           11500.0          0.3182          0.3182
           1935            9870.0                         1905           11400.0          0.3333          0.3333
           1936           10600.0                         1968           11400.0          0.3485          0.3485
           1937           10000.0                         1948           11300.0          0.3636          0.3636
           1938           12100.0                         1933           11200.0          0.3788          0.3788
           1939            7860.0                         1923           10900.0          0.3939          0.3939
           1940            9170.0                         1945           10900.0          0.4091          0.4091
           1941           11700.0                         1922           10800.0          0.4242          0.4242
           1942            9930.0                         1936           10600.0          0.4394          0.4394
           1943            9280.0                         1918           10500.0          0.4545          0.4545
           1944            9080.0                         1971           10300.0          0.4697          0.4697
           1945           10900.0                         1953           10100.0          0.4848          0.4848
           1946            6850.0                         1937           10000.0          0.5000          0.5000
           1947           12400.0                         1964            9990.0          0.5152          0.5152
           1948           11300.0                         1942            9930.0          0.5303          0.5303
           1949            9730.0                         1935            9870.0          0.5455          0.5455
           1950            8210.0                         1956            9870.0          0.5606          0.5606
           1951            8870.0                         1949            9730.0          0.5758          0.5758
           1952           13800.0                         1943            9280.0          0.5909          0.5909
           1953           10100.0                         1940            9170.0          0.6061          0.6061

                                     -- CONTINUED --
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PSM J407 VER 3.4                          U. S. GEOLOGICAL SURVEY
(REV 10/22/79)                    ANNUAL  PEAK  FLOW  FREQUENCY  ANALYSIS
                                  FOLLOWING WRC GUIDELINES BULL. 17-A.          RUN-DATE  5/13/80 AT  134   SEQ  1.0001

 STATION -        09251000/USGS    YAMPA RIVER NEAR MAYBELL, CO.                    1904-1978                  09251000/USGS

                        *********     NOTICE  --  PRELIMINARY MACHINE COMPUTATIONS.          *********
                        *********   USER RESPONSIBLE FOR ASSESSMENT AND INTERPRETATION.      *********

             INPUT DATA LISTING                   EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

         WATER                                        WATER         RANKED        SYSTEMATIC        W R C
          YEAR        DISCHARGE   CODES                YEAR        DISCHARGE        RECORD         ESTIMATE

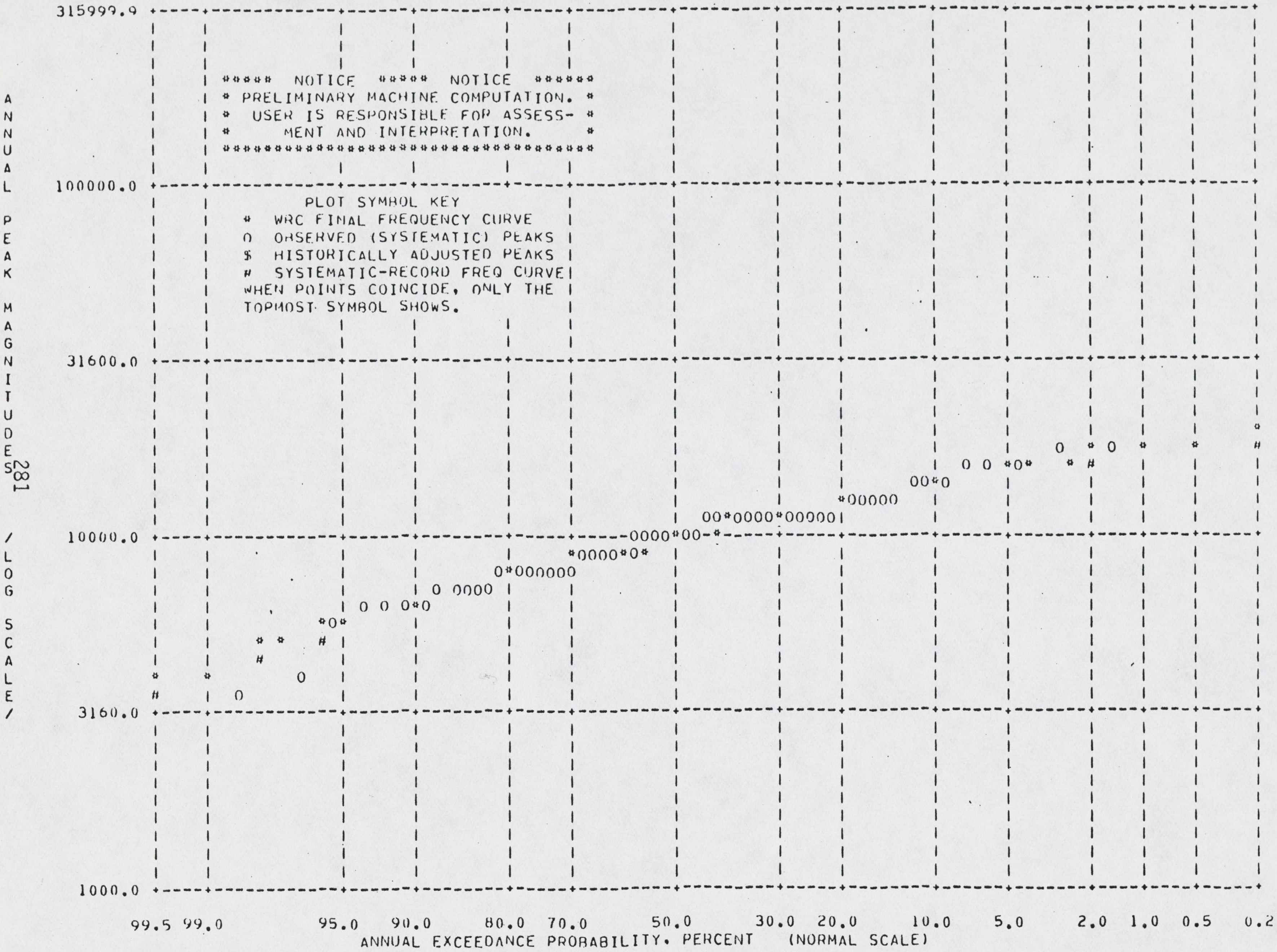
                                    -- CONTINUED --
          1954          5480.0                         1926          9090.0         0.6212          0.6212
          1955          7000.0                         1944          9080.0         0.6364          0.6364
          1956          9870.0                         1967          8890.0         0.6515          0.6515
          1957         15700.0                         1972          8890.0         0.6667          0.6667
          1958         12200.0                         1951          8870.0         0.6818          0.6818
          1959          6690.0                         1969          8290.0         0.6970          0.6970
          1960          8000.0                         1950          8210.0         0.7121          0.7121
          1961          6350.0                         1904          8050.0         0.7273          0.7273
          1962         11500.0                         1960          8000.0         0.7424          0.7424
          1963          6290.0                         1930          7980.0         0.7576          0.7576
          1964          9990.0                         1939          7860.0         0.7727          0.7727
          1965         11800.0                         1924          7810.0         0.7879          0.7879
          1966          6900.0                         1919          7670.0         0.8030          0.8030
          1967          8890.0                         1976          7450.0         0.8182          0.8182
          1968         11400.0                         1955          7000.0         0.8333          0.8333
          1969          8290.0                         1966          6900.0         0.8485          0.8485
          1970         12700.0                         1946          6850.0         0.8636          0.8636
          1971         10300.0                         1959          6690.0         0.8788          0.8788
          1972          8890.0                         1925          6640.0         0.8939          0.8939
          1973         12100.0                         1931          6500.0         0.9091          0.9091
          1974         15400.0                         1961          6350.0         0.9242          0.9242
          1975         11700.0                         1963          6290.0         0.9394          0.9394
          1976          7450.0                         1954          5480.0         0.9545          0.9545
          1977          3620.0                         1934          4080.0         0.9697          0.9697
          1978         11600.0                         1977          3620.0         0.9848          0.9848
```

PGM J407 3.4
(REV 10/22/79)

U. S. GEOLOGICAL SURVEY
ANNUAL PEAK FLOW FREQUENCY ANALYSIS
FOLLOWING WRC GUIDELINES BULL. 17-A.

RUN-DATE 5/13/80 AT 134 SEQ 1.0001

STATION - 09251000/USGS YAMPA RIVER NEAR MAYBELL, CO. 1904-1978 09251000/USGS



***** NOTICE ***** NOTICE ******
* PRELIMINARY MACHINE COMPUTATION. *
* USER IS RESPONSIBLE FOR ASSESSMENT AND INTERPRETATION. *

PLOT SYMBOL KEY
* WRC FINAL FREQUENCY CURVE
O OBSERVED (SYSTEMATIC) PEAKS
$ HISTORICALLY ADJUSTED PEAKS
# SYSTEMATIC-RECORD FREQ CURVE
WHEN POINTS COINCIDE, ONLY THE TOPMOST SYMBOL SHOWS.

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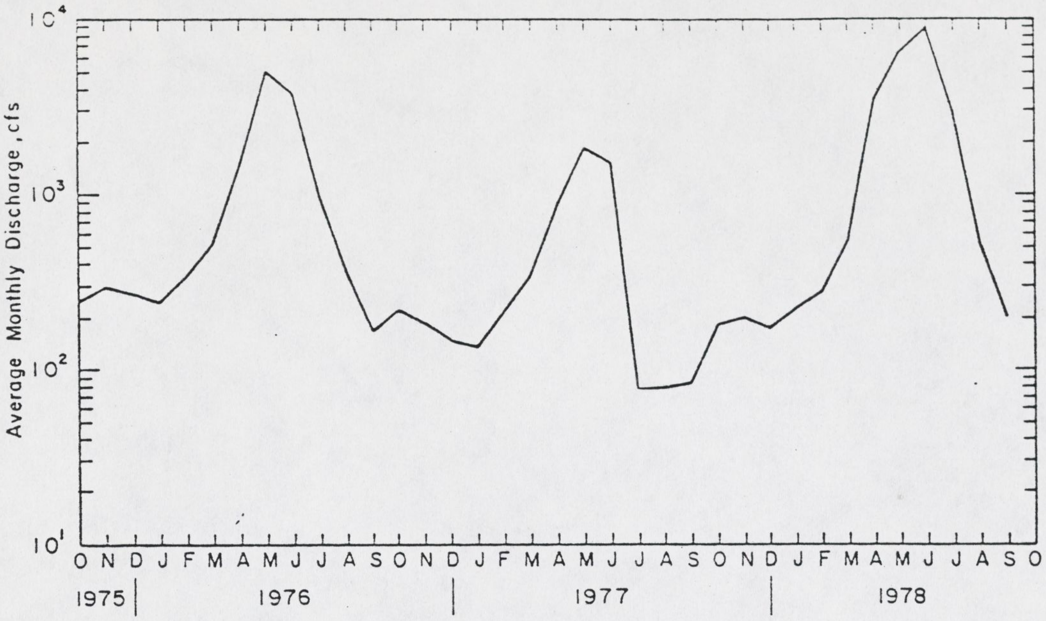
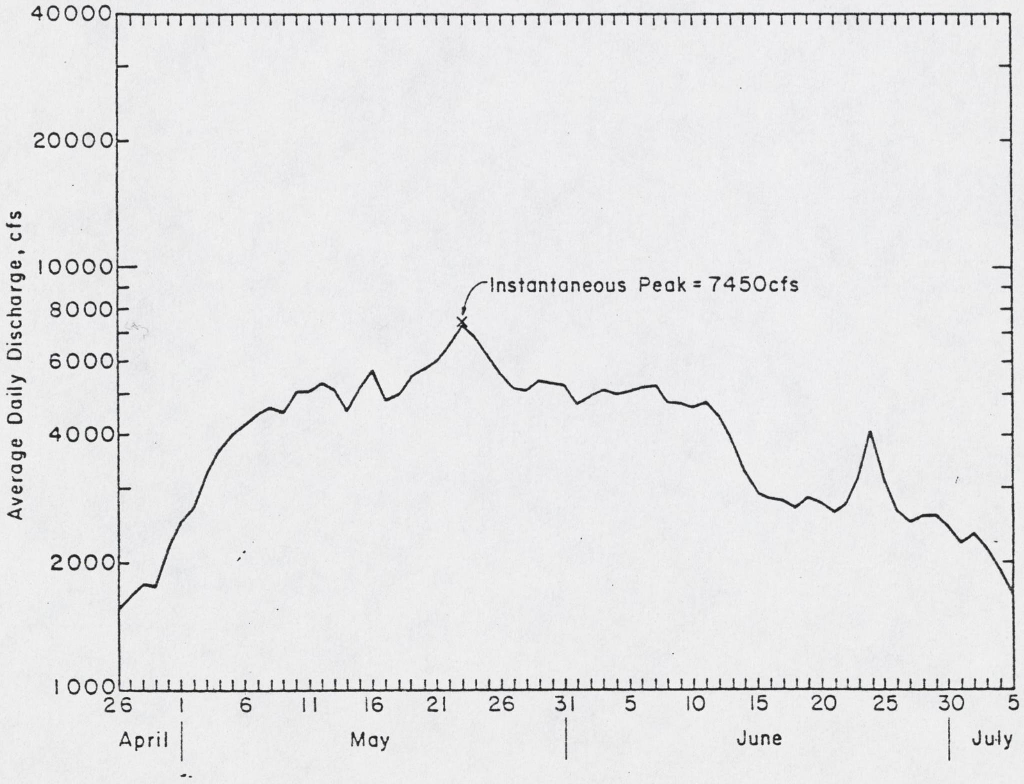
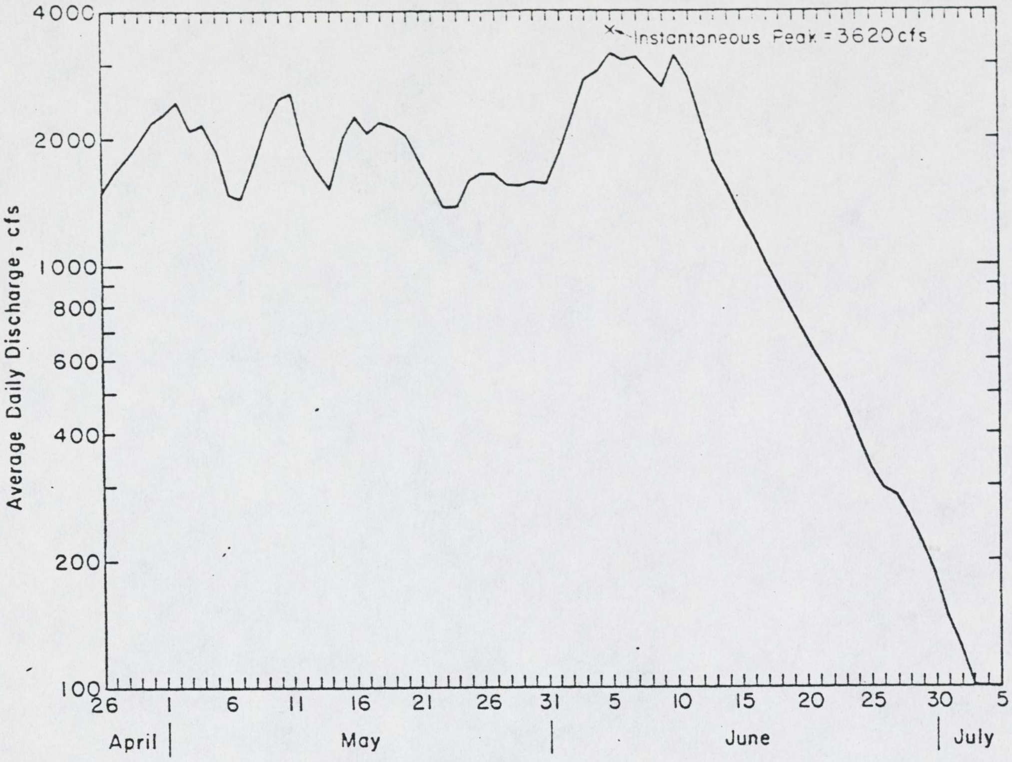


Average monthly discharge for Yampa River near Maybell, Colorado (October 1975-September 1978).

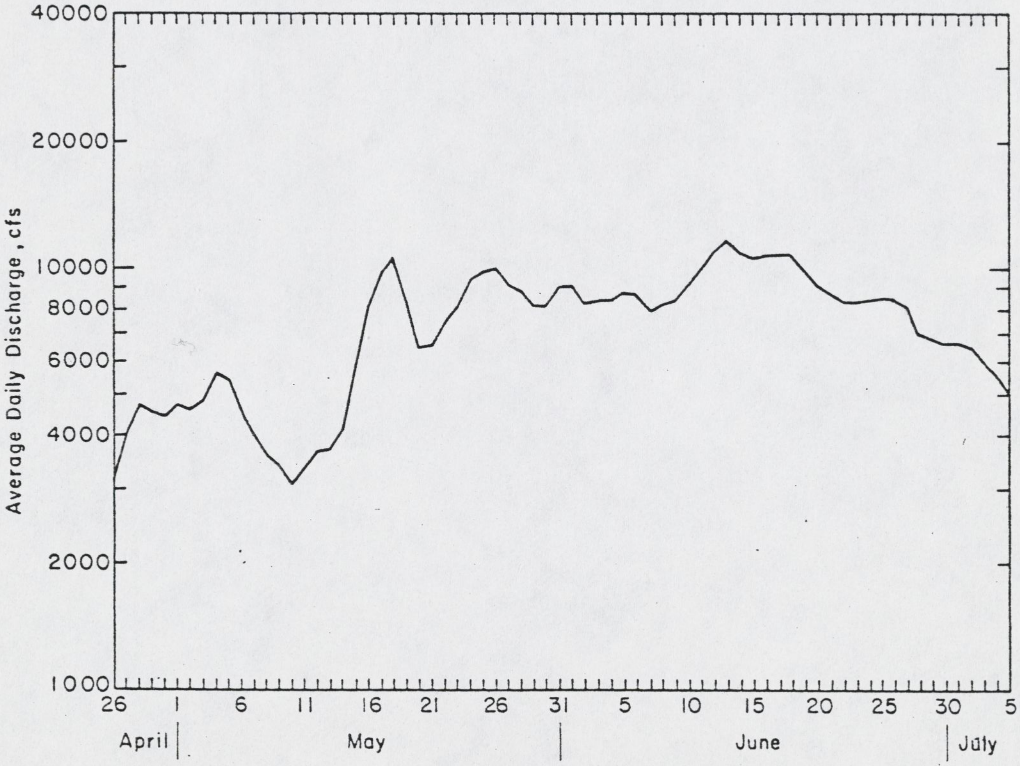
ANNUAL PEAK FLOW FREQUENCY ANALYSIS



Average daily discharges for Yampa River near Maybell, Colorado (April 26-July 5, 1976).



Average daily discharges for Yampa River near Maybell, Colorado
(April 26-July 5, 1977).



Average daily discharges for Yampa River near Maybell, Colorado
(April 26-July 5, 1978).

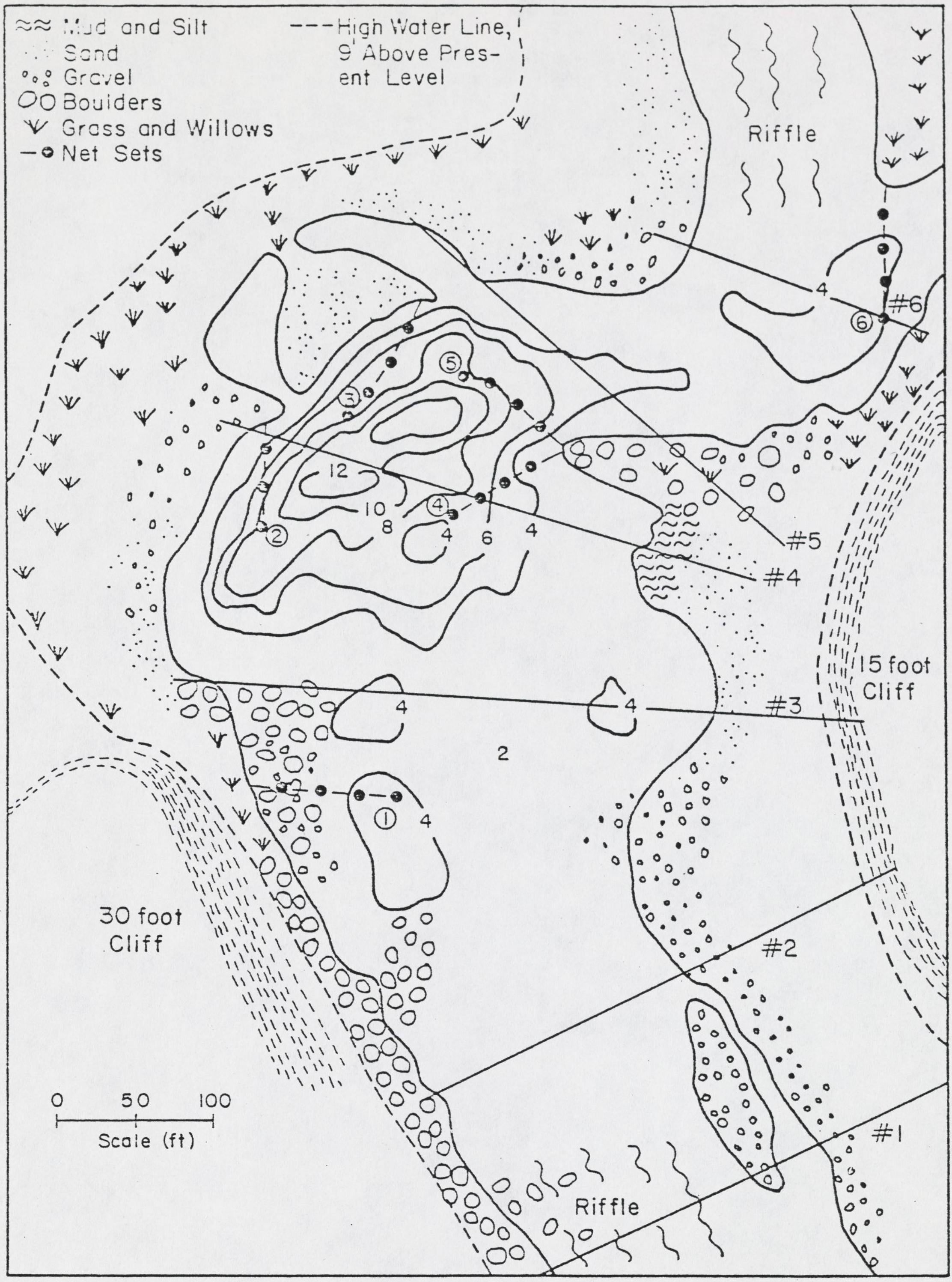
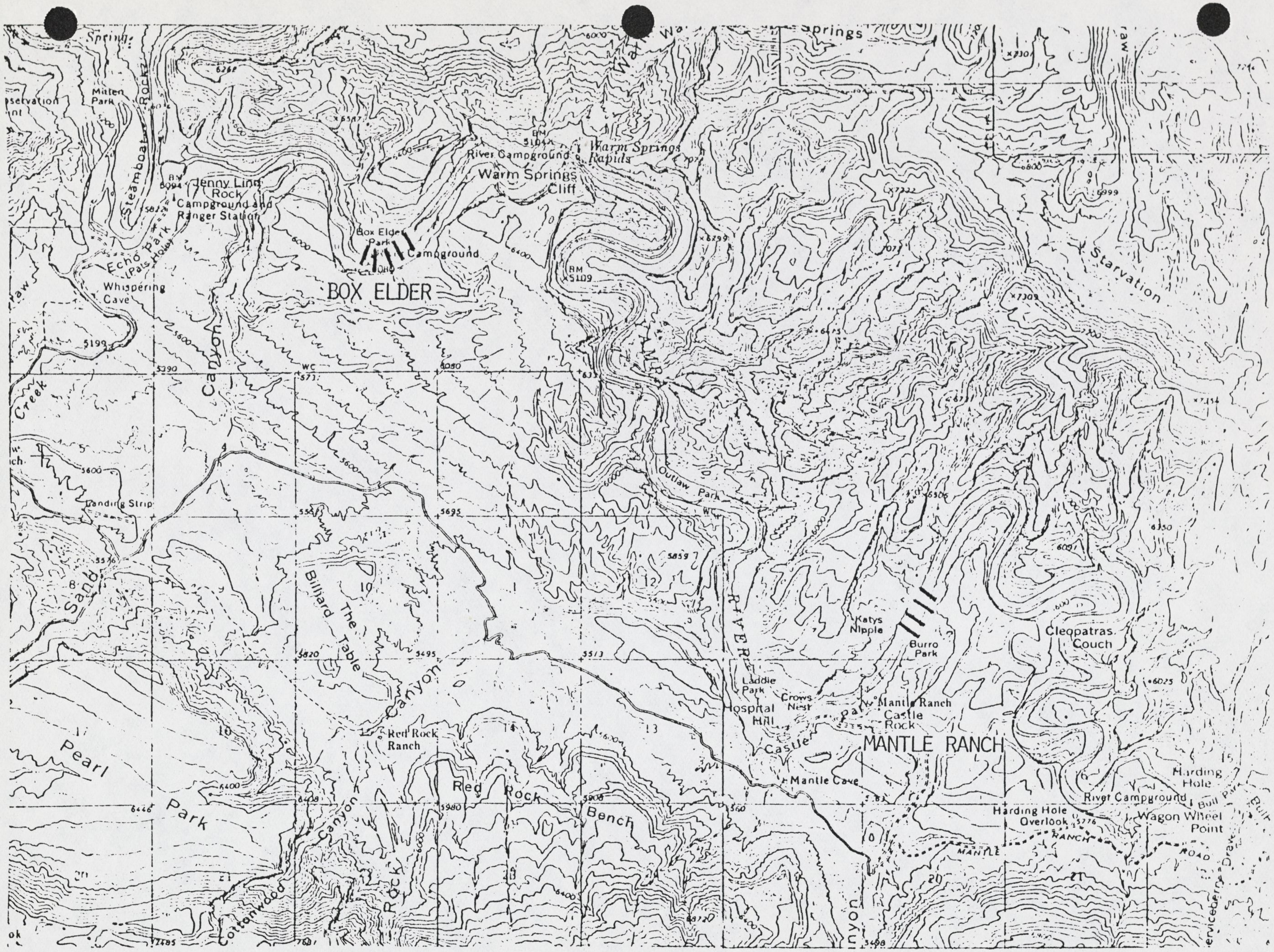
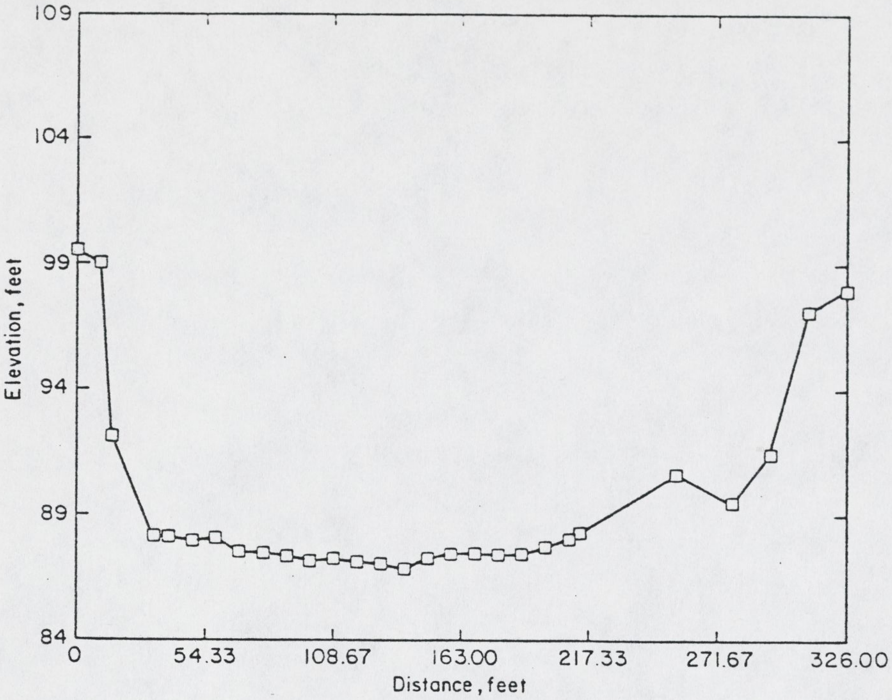


Diagram of a pool riffle habitat used by Colorado squawfish on the Yampa River in Lily Park. (Contours indicate depth in feet, 30 August 1976).

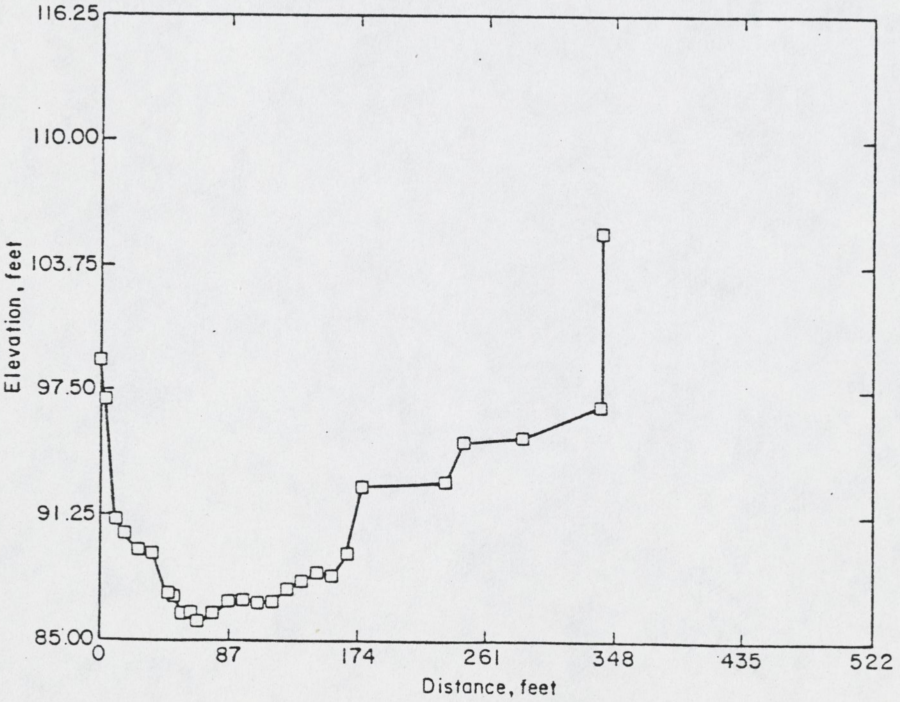


Location of Box Elder and Mantle Ranch reaches.

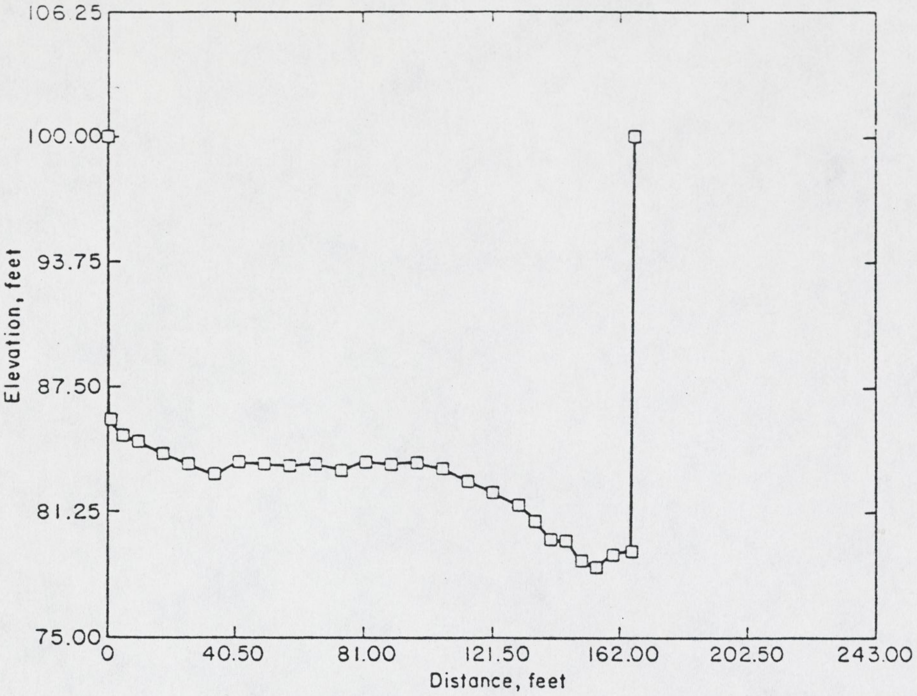
YAMPA RIVER CROSS SECTIONS



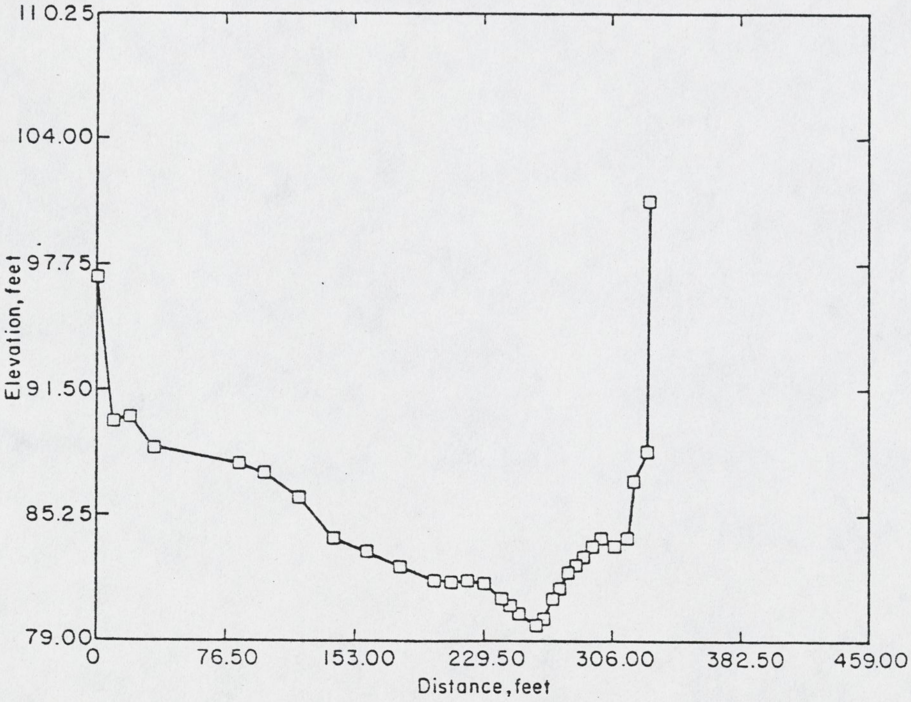
Cross section of Yampa River at Maybell Reach.



Cross section of Yampa River at Lily Park.



Cross section of Yampa River at Dinosaur National Monument near Mantle Ranch.



Cross section of Yampa River at Dinosaur National Monument at Box Elder Reach.

# APPENDIX B

# CHANNEL CHANGE WORKSHOP: PROBLEM NUMBER 2
# POPLAR CREEK, CALIFORNIA

## THE QUESTION

The question relative to the Poplar Creek is "What will happen to the morphology of the stream channel as a result of the changes in streamflows and sediment discharge caused by the construction of a reservoir upstream of a reach of stream?" Specifically, for both a short and a long time after construction of the reservoir:

1. What will be the meander pattern?
2. What will be the configuration of the channel?
3. What will be the substrate material?
4. What will be the pool riffle sequence?

Poplar Creek is located in a semi-arid region of northern California. Poplar is not the actual name of the stream. The problem as presented here has been abstracted from the data for the actual project to the extent it no longer is representative of the concern about the actual project. In order to make it clear the comments on the workshop problem are not necessarily applicable to the actual project, the name of the stream has been changed.

The reach of interest is the reach of the stream from just below Dutch Gulch dam site to the junction with the south fork. Special attention should be given to the reach just downstream of Dry Creek.

## CONTENTS[1]

Location of Reach of Interest

Monthly Flows

Cross Sections of Reach of Interest

Peak Flows and Flow Duration Curves

Bed Material

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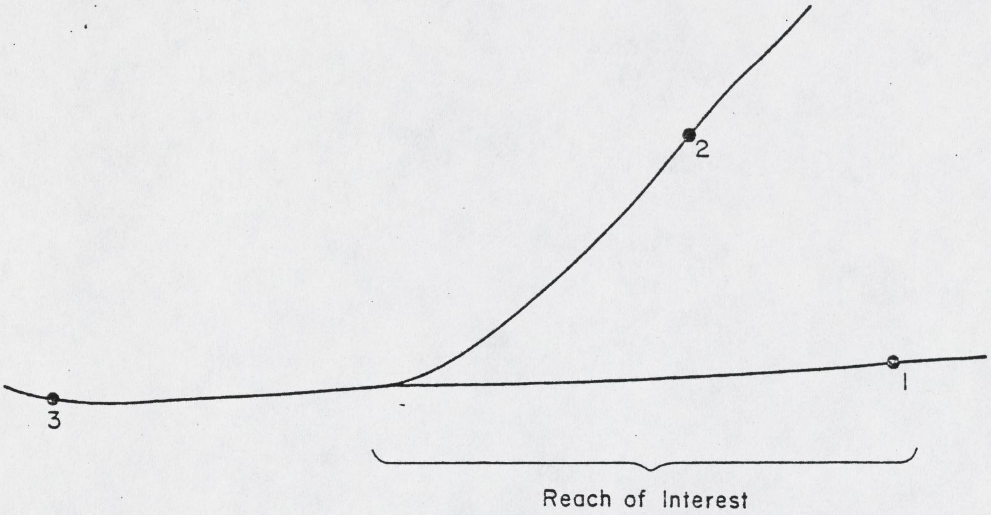
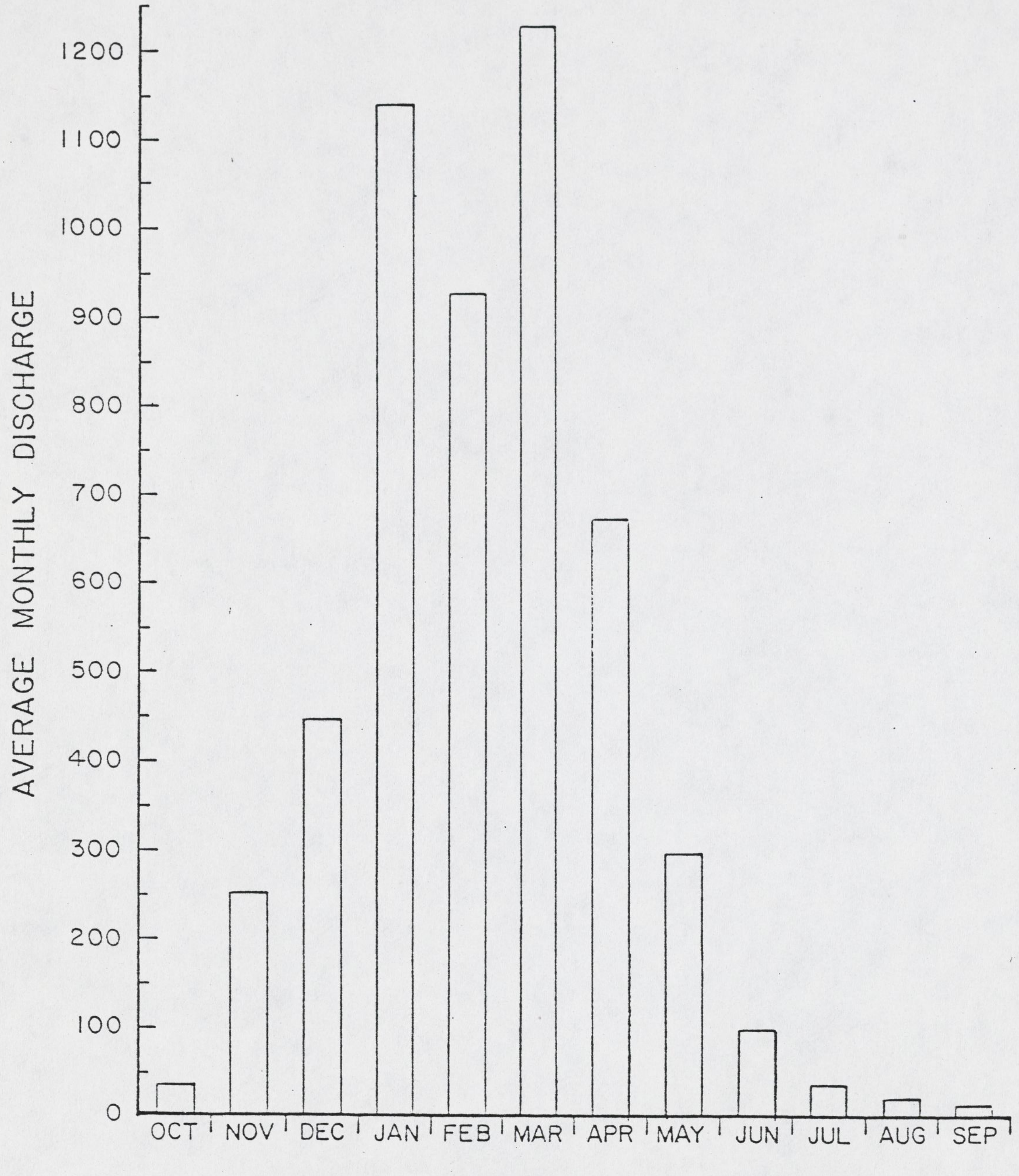
[1] Only selected data are provided in this appendix. Contact the Instream Flow Group of the Fish and Wildlife Service for the complete data set.

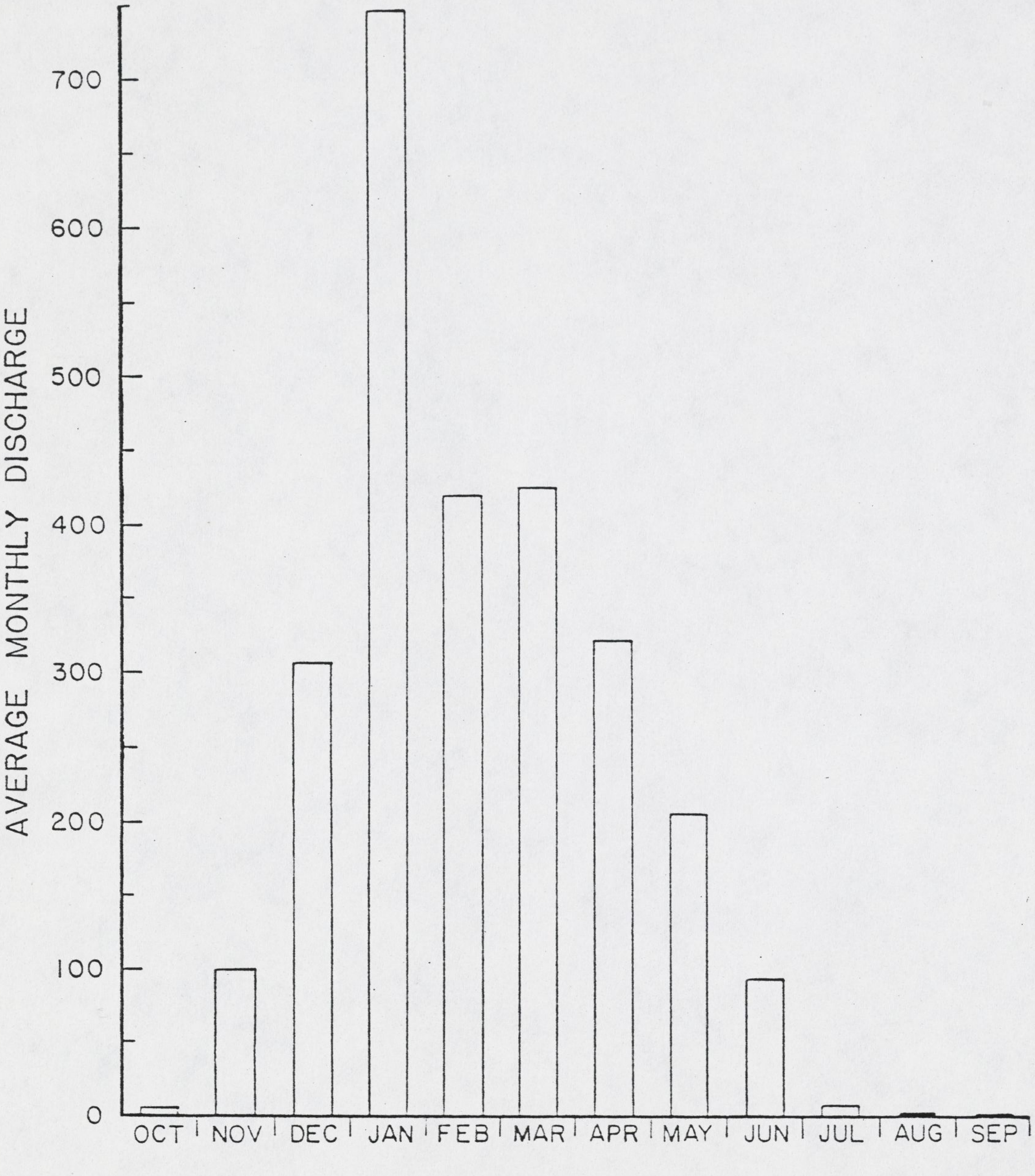


Skematic diagram showing relative location of gaging stations.

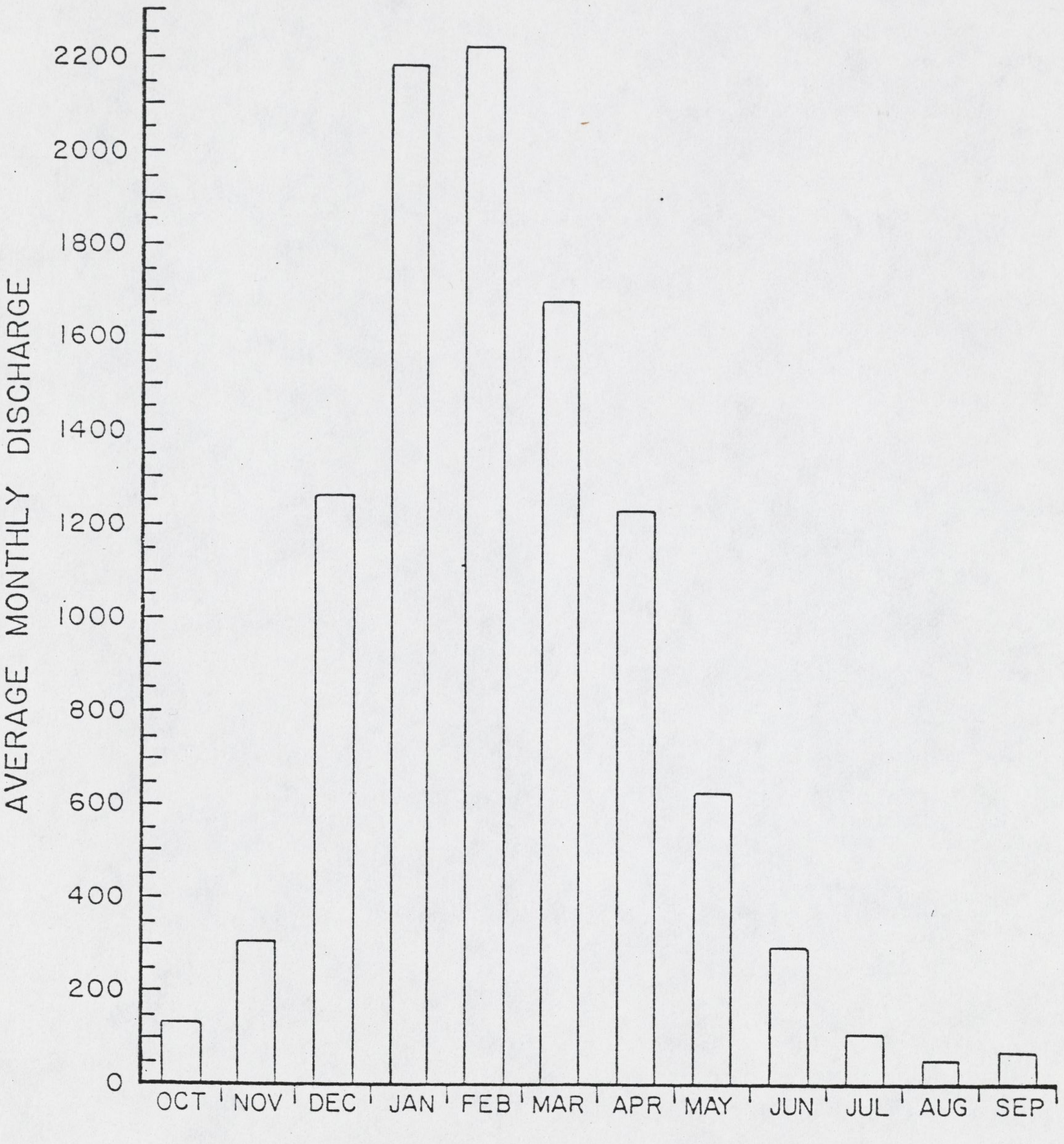
MONTHLY FLOW



Poplar Creek at Station 1 (1972-1978)



Poplar Creek at Station 2 (1963-1978)



Poplar Creek at Station 3 (1941-1979)

POPLAR CREEK AT STATION 1
CHANNEL CHANGE WORKSHOP PROBLEM
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1972 | 26. | 89. | 201. | 362. | 370. | 618. | 248. | 126. | 51. | 10. | 4. | 5. | 175. |
| 1973 | 63. | 462. | 668. | 1871. | 1855. | 1466. | 646. | 298. | 95. | 33. | 20. | 15. | 619. |
| 1974 | 65. | 1102. | 1604. | 3155. | 795. | 1883. | 1620. | 419. | 153. | 96. | 49. | 21. | 916. |
| 1975 | 32. | 61. | 158. | 215. | 1547. | 2853. | 1000. | 590. | 197. | 73. | 28. | 21. | 560. |
| 1976 | 70. | 114. | 146. | 84. | 305. | 298. | 240. | 95. | 19. | 7. | 28. | 21. | 118. |
| 1977 | 17. | 35. | 28. | 52. | 45. | 78. | 43. | 63. | 17. | 1. | 0. | 10. | 32. |
| 1978 | 17. | 99. | 699. | 2925. | 1722. | 1811. | 1027. | 412. | 138. | 63. | 17. | 23. | 743. |
| 1979 | 24. | 45. | 53. | 289. | 764. | 813. | 453. | 347. | 93. | 26. | 13. | 14. | 242. |
| AVERAGE | 39. | 251. | 445. | 1119. | 925. | 1227. | 660. | 294. | 95. | 38. | 20. | 16. | 426. |
| Q/QANN | .780 | 4.842 | 8.866 | 22.317 | 16.819 | 24.477 | 12.729 | 5.857 | 1.841 | .767 | .393 | .311 | 100.000 |
| COV VAR | .580 | 1.477 | 1.207 | 1.183 | .753 | .767 | .798 | .632 | .681 | .908 | .780 | .404 | .766 |
| SKEW | .506 | 2.206 | 1.711 | .878 | .254 | .496 | .766 | .146 | .205 | .590 | .704 | -.804 | .264 |
| MAXIMUM | 70. | 1102. | 1604. | 3155. | 1855. | 2853. | 1620. | 590. | 197. | 96. | 49. | 23. | 916. |
| MINIMUM | 17. | 35. | 28. | 52. | 45. | 78. | 43. | 63. | 17. | 1. | 0. | 5. | 32. |

```
STATISTICAL PARAMETERS FOR STATION   11375810     POPLAR CREEK AT STATION 1
  CHANNEL CHANGE WORKSHOP PROBLEM

                             ARTH.                  LOG PARAMETERS
                    MONTH    AVERAGE      MEAN   VARIANCE  STD. DEV.    SKEW

          1         OCT        39.14     1.5261      .0667      .2583      .2088
          2         NOV       250.93     2.0870      .2633      .5131     1.1211
          3         DEC       444.59     2.3382      .3541      .5950     -.0609
          4         JAN      1119.11     2.6535      .4743      .6887      .0705
          5         FEB       925.43     2.7734      .2903      .5388    -1.3737
          6         MAR      1227.45     2.9024      .2659      .5157    -1.1586
          7         APR       659.61     2.6368      .2520      .5020    -1.1302
          8         MAY       293.71     2.3622      .1255      .3542     -.6264
          9         JUNE       95.38     1.8464      .1671      .4088     -.7648
         10         JULY       38.45     1.2634      .5628      .7502    -1.4250
         11         AUG        19.70      .7246     2.3693     1.5392    -2.5942
         12         SEPT       16.13     1.1612      .0575      .2397    -1.5946
         13         ANNUAL    425.61     2.4472      .2463      .4963     -.9517

          SAMPLE SIZE    8 YEARS


LOG NORMAL DISTRIBUTION STATION   11375810     POPLAR CREEK AT STATION 1
  CHANNEL CHANGE WORKSHOP PROBLEM

                            YEARS FLOW IS NOT EXCEEDED

       MONTH   9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20            Q2 - Q10

      OCT          72.       43.       34.       20.       16.       13.                 18.
      NOV         556.      203.      122.       45.       27.       17.                 95.
      DEC        1262.      392.      218.       69.       38.       23.                180.
      JAN        3439.      889.      450.      118.       59.       33.                391.
      FEB        2911.     1010.      593.      209.      121.       77.                472.
      MAR        3660.     1329.      799.      294.      174.      113.                624.
      APR        1907.      712.      433.      164.       98.       65.                335.
      MAY         655.      327.      230.      116.       81.       60.                149.
      JUNE        235.      105.       70.       32.       21.       15.                 49.
      JULY        168.       38.       18.        4.        2.        1.                 16.
      AUG         499.       24.        5.        0.        0.        0.                  5.
      SEPT         29.       18.       14.        9.        7.        6.                  7.
      ANNUAL     1212.      457.      280.      107.       65.       43.                215.

            Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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LOG-PEARSON TYPE III DISTRIBUTION FOR STATION  11375810
                  POPLAR CREEK AT STATION 1
                        CHANNEL CHANGE WORKSHOP PROBLEM

          DATA SKEW K FACTORS

 MONTH      SKEW                                              RETURN PERIOD

                          10 YRS          6.67 YRS           2 YRS          1.25 YRS          1.11 YRS          1.05 YRS

OCT           1.21        1.3002           .4081            -.0316          -.8496           -1.2591           -1.5886
NOV           1.12        1.3408           .2948            -.1766          -.8488           -1.1114           -1.2878
DEC           -.06        1.2653           .4436             .0232          -.8337           -1.2955           -1.6835
JAN            .07        1.2735           .4367             .0120          -.8378           -1.2890           -1.6647
FEB          -1.37        1.0350           .5356             .2289          -.7011           -1.3359           -1.9414
MAR          -1.16        1.0769           .5278             .2012          -.7266           -1.3396           -1.9162
APR          -1.13        1.0706           .5290             .2055          -.7229           -1.3393           -1.9205
MAY           -.63        1.1705           .4993             .1278          -.7826           -1.3352           -1.8337
JUNE          -.76        1.1593           .5036             .1376          -.7761           -1.3371           -1.8457
JULY         -1.43        1.0000           .5404             .2505          -.6788           -1.3300           -1.9592
AUG          -2.59         .7457           .5351             .3685          -.4978           -1.2372           -2.0129
SEPT         -1.59         .9927           .5413             .2548          -.6742           -1.3287           -1.9625
ANNUAL        -.95        1.1179           .5177             .1717          -.7517           -1.3405           -1.8852

FREQUENCY OF FLOWS

                          YEARS FLOW IS NOT EXCEEDED

      MONTH    9 IN 10    2 IN 3    1 IN 2    1 IN 5   1 IN 10   1 IN 20          Q2 - Q10

      OCT          73.       43.       33.       20.       16.       13.               17.
      NOV         596.      173.       99.       45.       33.       27.               66.
      DEC        1234.      400.      225.       70.       37.       22.              188.
      JAN        3393.      900.      459.      119.       58.       32.              401.
      FEB        2143.     1153.      788.      249.      113.       53.              675.
      MAR        2869.     1495.     1014.      337.      163.       82.              852.
      APR        1494.      799.      549.      188.       92.       47.              457.
      MAY         598.      346.      256.      122.       77.       52.              178.
      JUNE        209.      113.       80.       34.       20.       12.               60.
      JULY        103.       47.       28.        6.        2.        1.               26.
      AUG          75.       35.       20.        1.        0.        0.               20.
      SEPT         25.       20.       17.       10.        7.        5.               10.
      ANNUAL     1005.      506.      341.      119.       61.       32.              280.

              Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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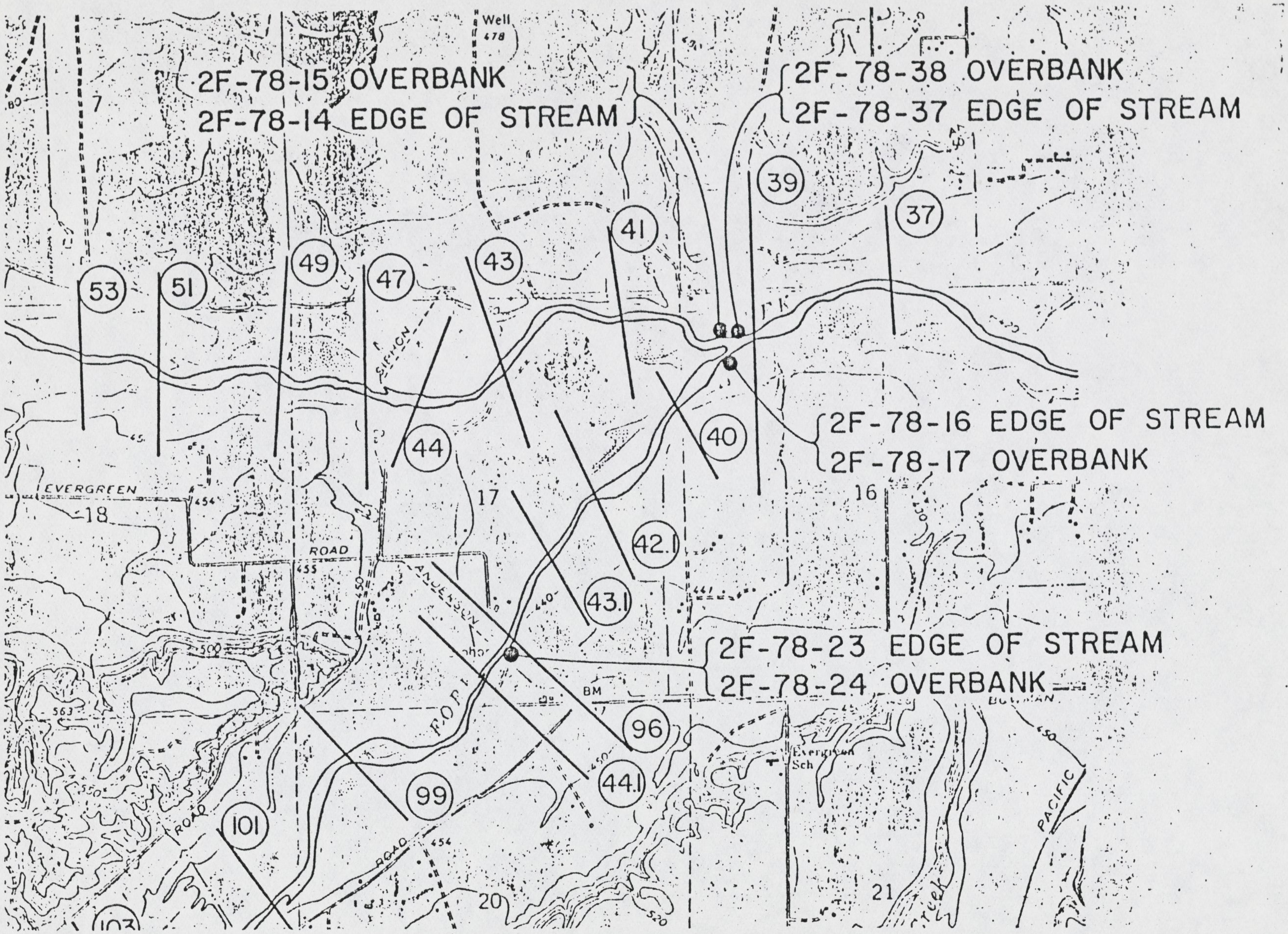
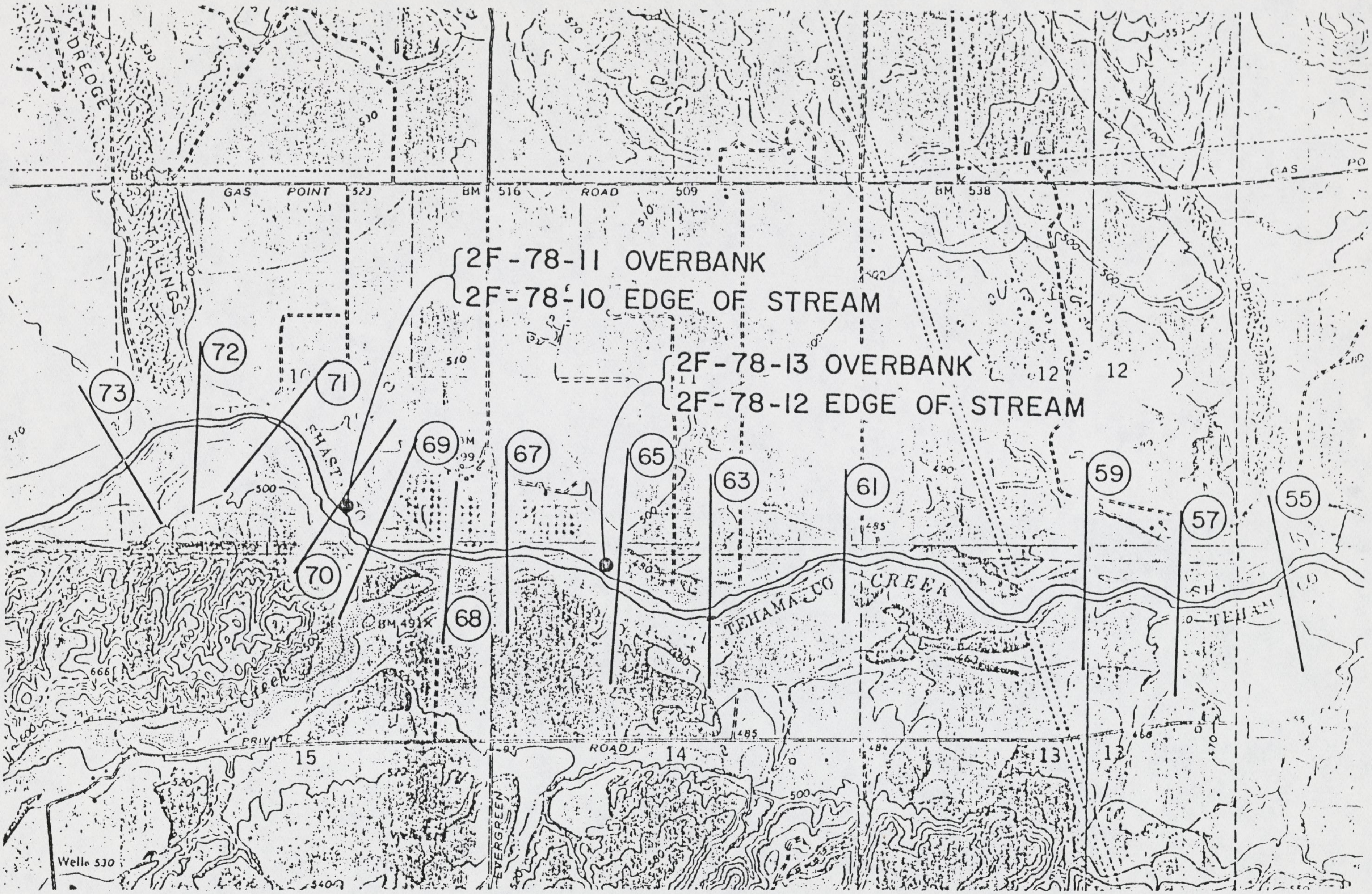
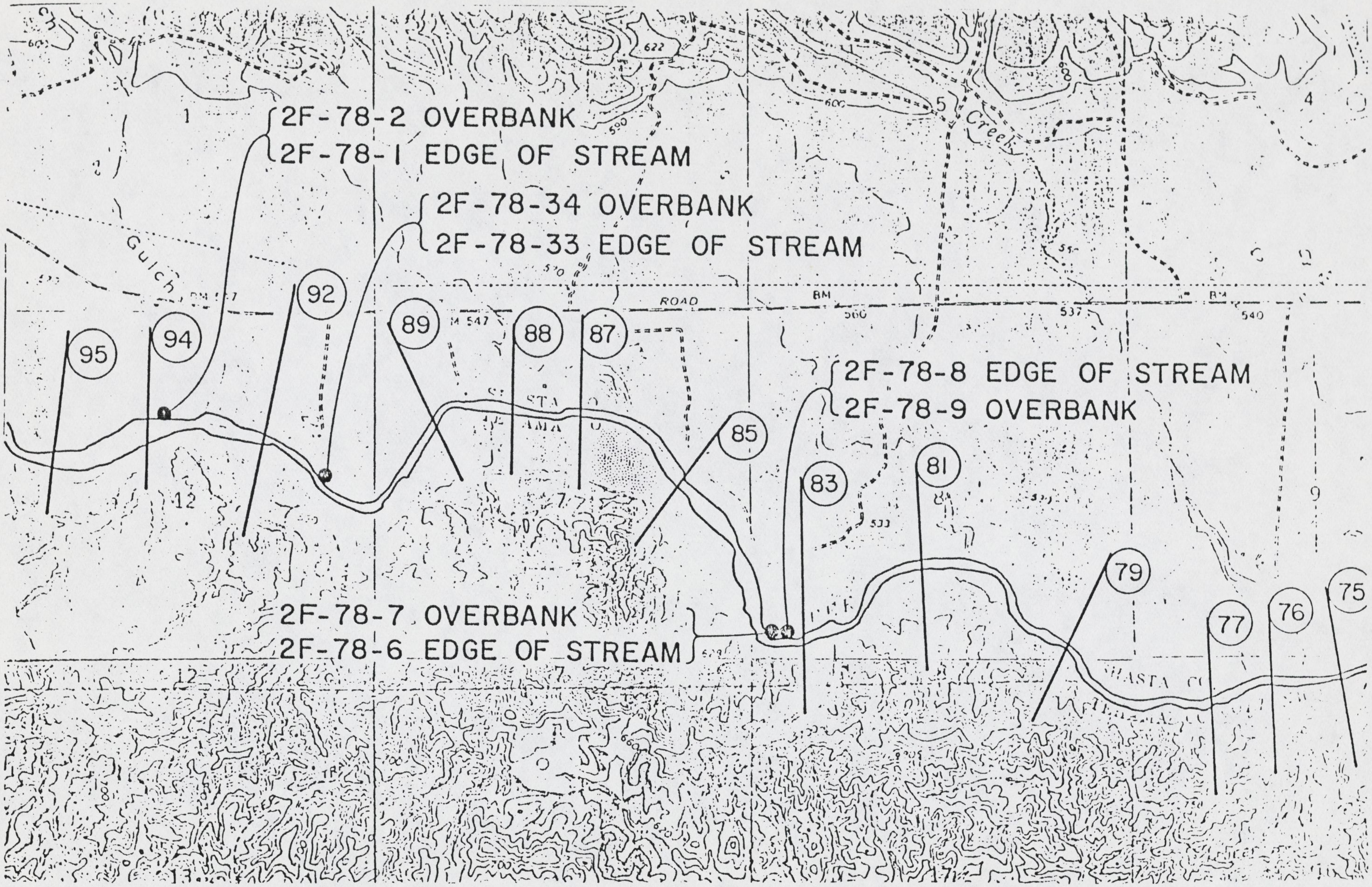
CROSS SECTIONS OF REACH OF INTEREST



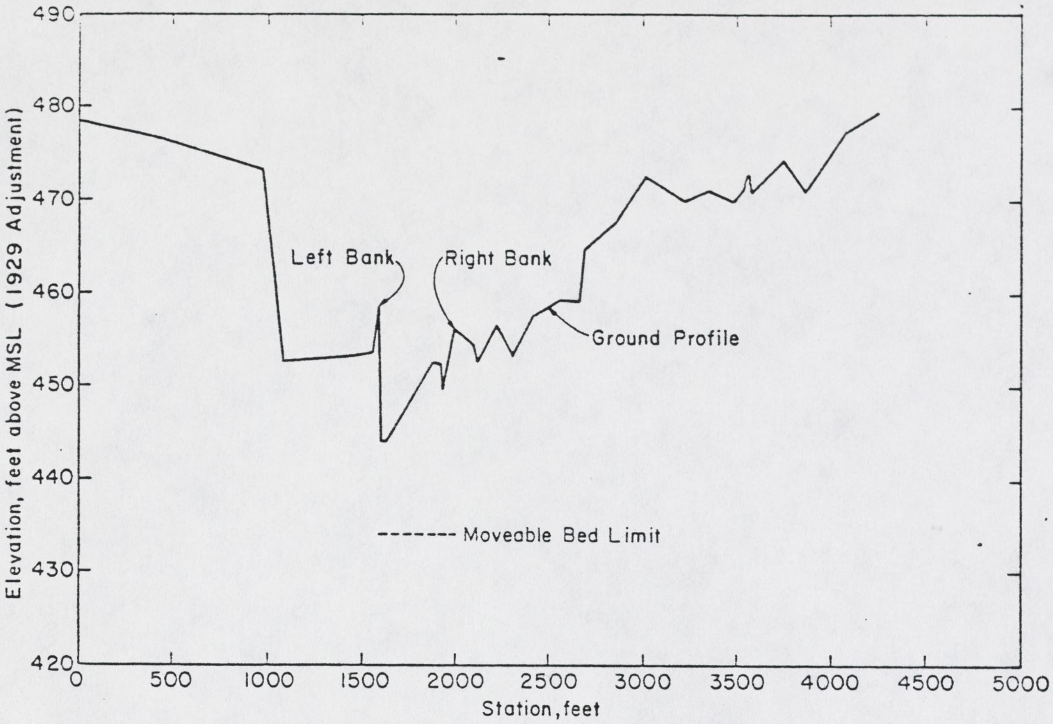
Approximate location of cross sections and soil samples (scale 1:24,000 approx., April 1980).



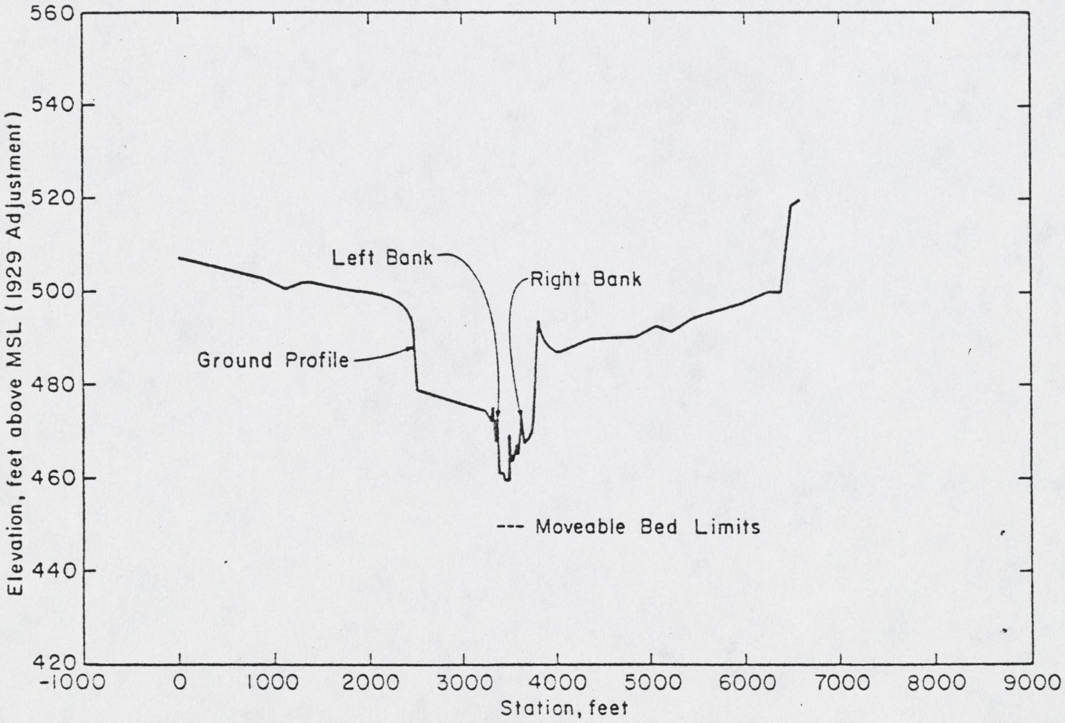
Approximate location of cross sections and soil samples (scale 1:24,000 approx., April 1980, continued).



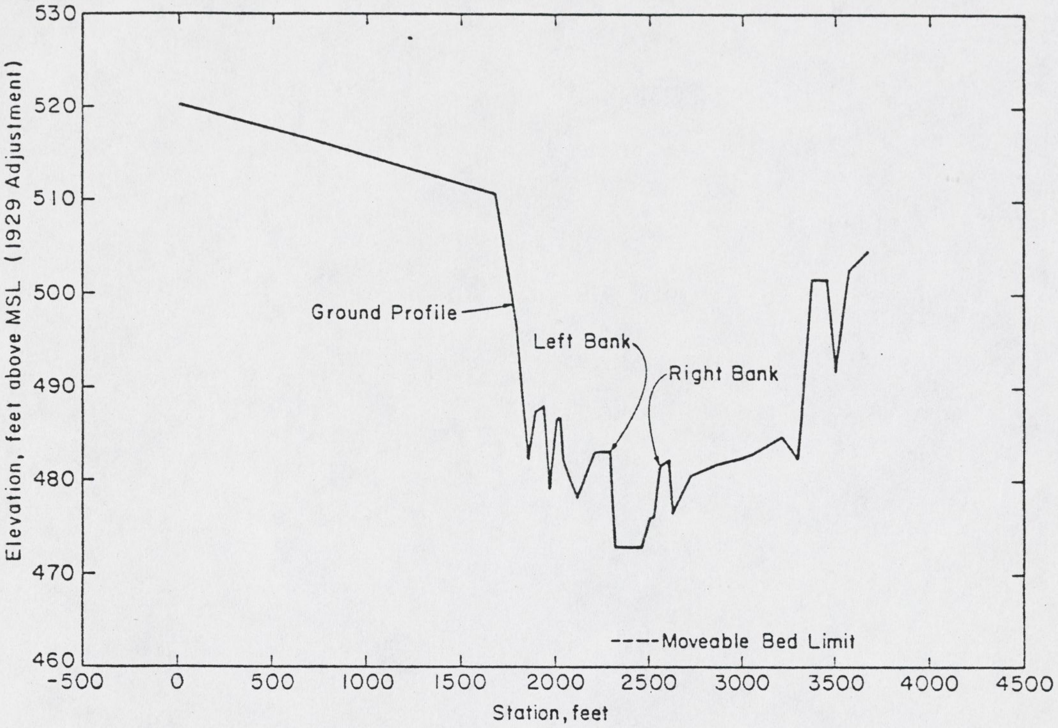
Approximate location of cross sections and soil samples (scale 1:24,000 approx., April 1980, continued).



Station compared to elevation for Section 57.



Station compared to elevation for Section 67.



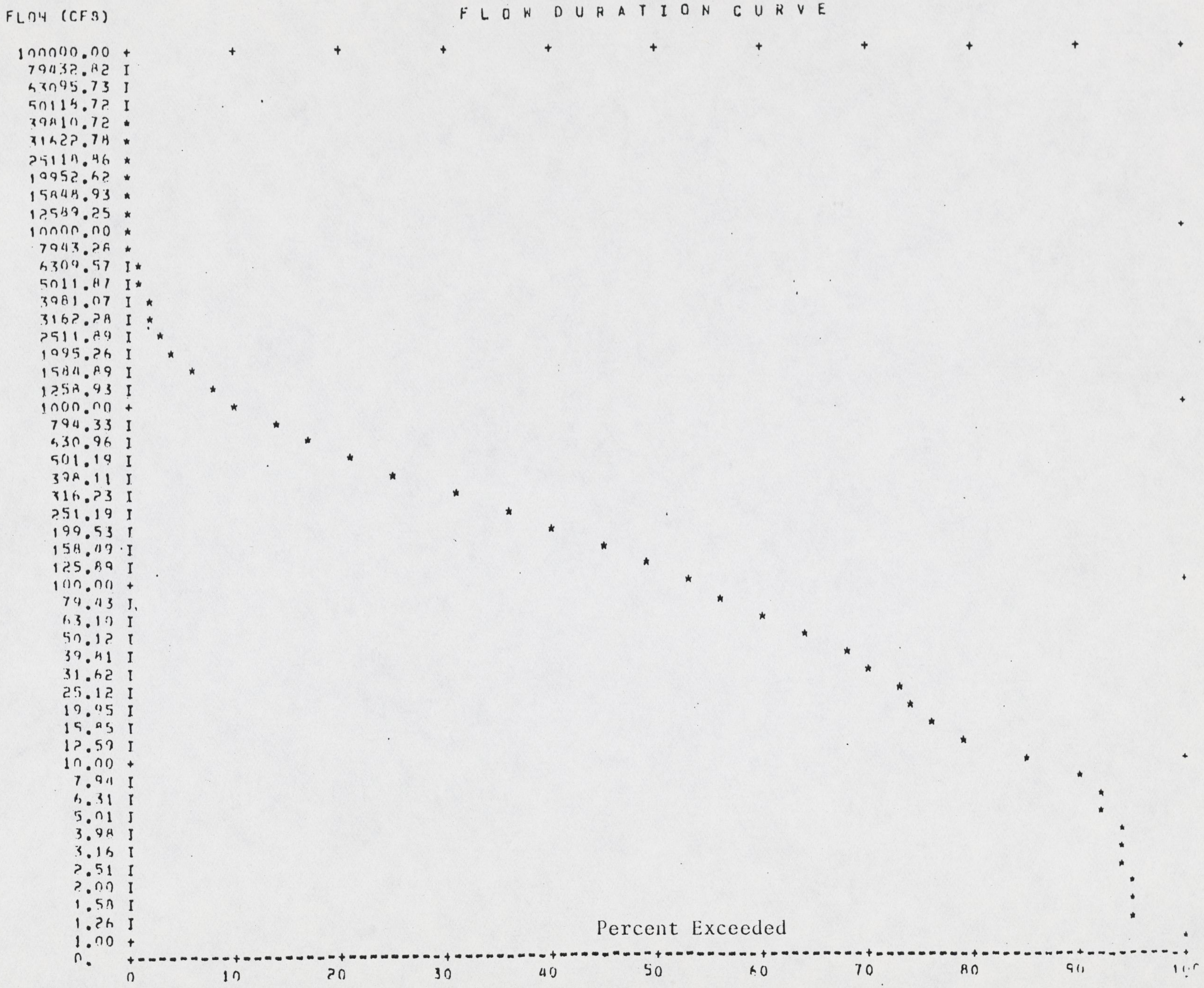
Station compared to elevation for Section 72.

# PEAK FLOWS AND FLOW DURATION CURVES

JUST ABOVE REACH OF INTEREST

NATURAL CONDITIONS

JOB NUMBER 1

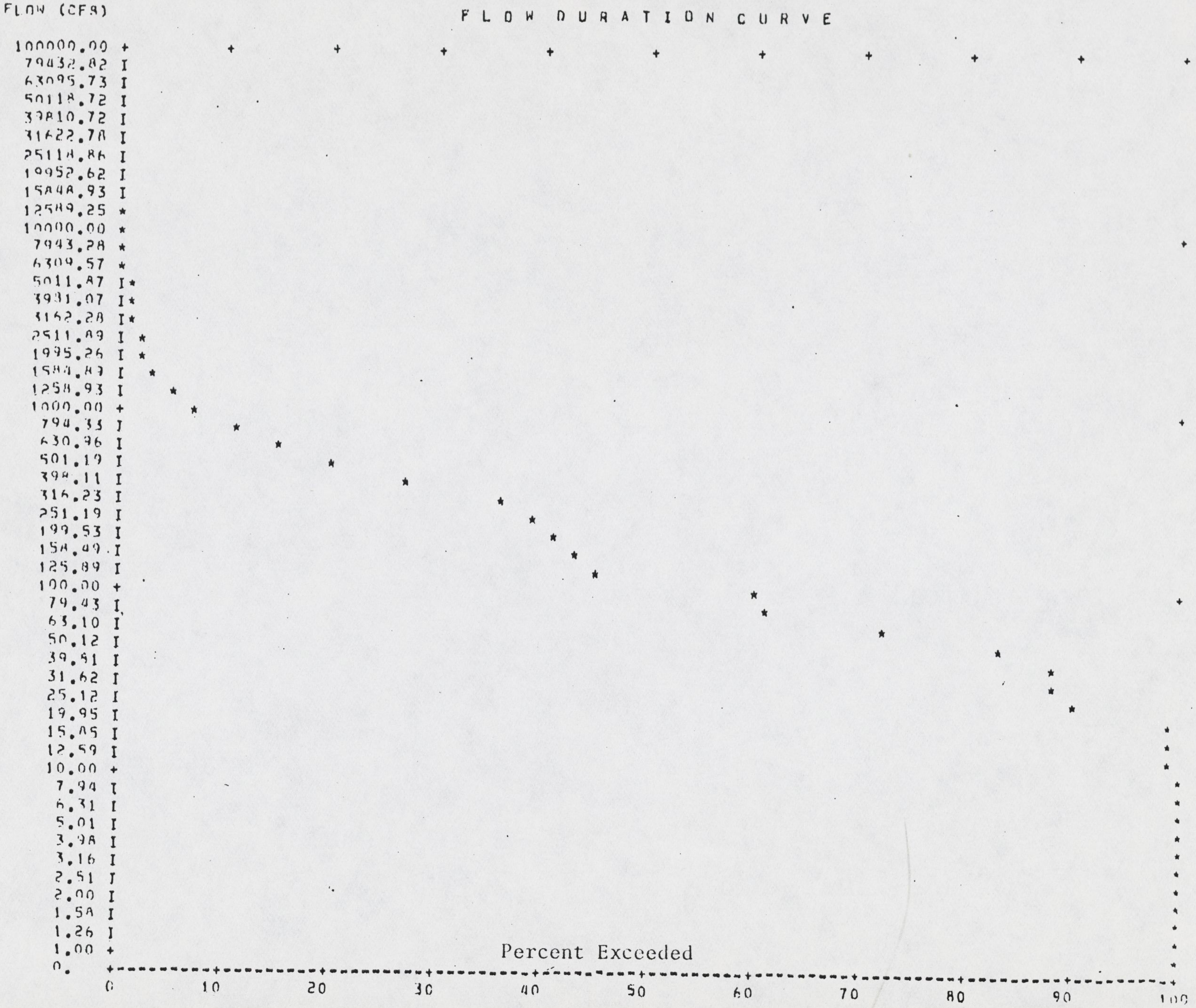


```
*****************************************************************************************

                                              NATURAL CONDITIONS
JOB NUMBER     1
*****************************************************************************************

STREAM FLOW DATA INPUT

FL CARD          FTYPE        FMTYPE        PUNCH
                  FILE           STD           NO

FM CARD           TERM        ITVALS        NVALS
               -999.00       1000000            0

 UNADJUSTED FLOW DURATION CURVE -- FLOWS IN CFS AND EXCEEDENCE PROBABILITIES AS DECIMAL FRACTIONS

PE              1.0000       .9467       .9467       .9467       .9416       .9365       .9365       .9238       .9162       .9035
QQ                1.00        1.26        1.58        2.00        2.51        3.16        3.98        5.01        6.31        7.94

PE               .8451       .7918       .7639       .7436       .7257       .6979       .6777       .6408       .6033       .5602
QQ               10.00       12.59       15.85       19.95       25.12       31.62       39.81       50.12       63.10       79.43

PE               .5271       .4931       .4472       .3975       .3553       .3110       .2504       .2098       .1750       .1362
QQ              100.00      125.89      158.49      199.53      251.19      316.23      398.11      501.19      630.96      794.33

PE               .1004       .0754       .0561       .0418       .0306       .0216       .0150       .0097       .0059       .0031
QQ             1000.00     1258.93     1584.89     1995.26     2511.89     3162.28     3981.07     5011.87     6309.57     7943.28

PE               .0015       .0006       .0003       .0002       .0001       .0000       0.
QQ            10000.00    12589.25    15848.93    19952.62    25118.86    31622.78    39810.72
```

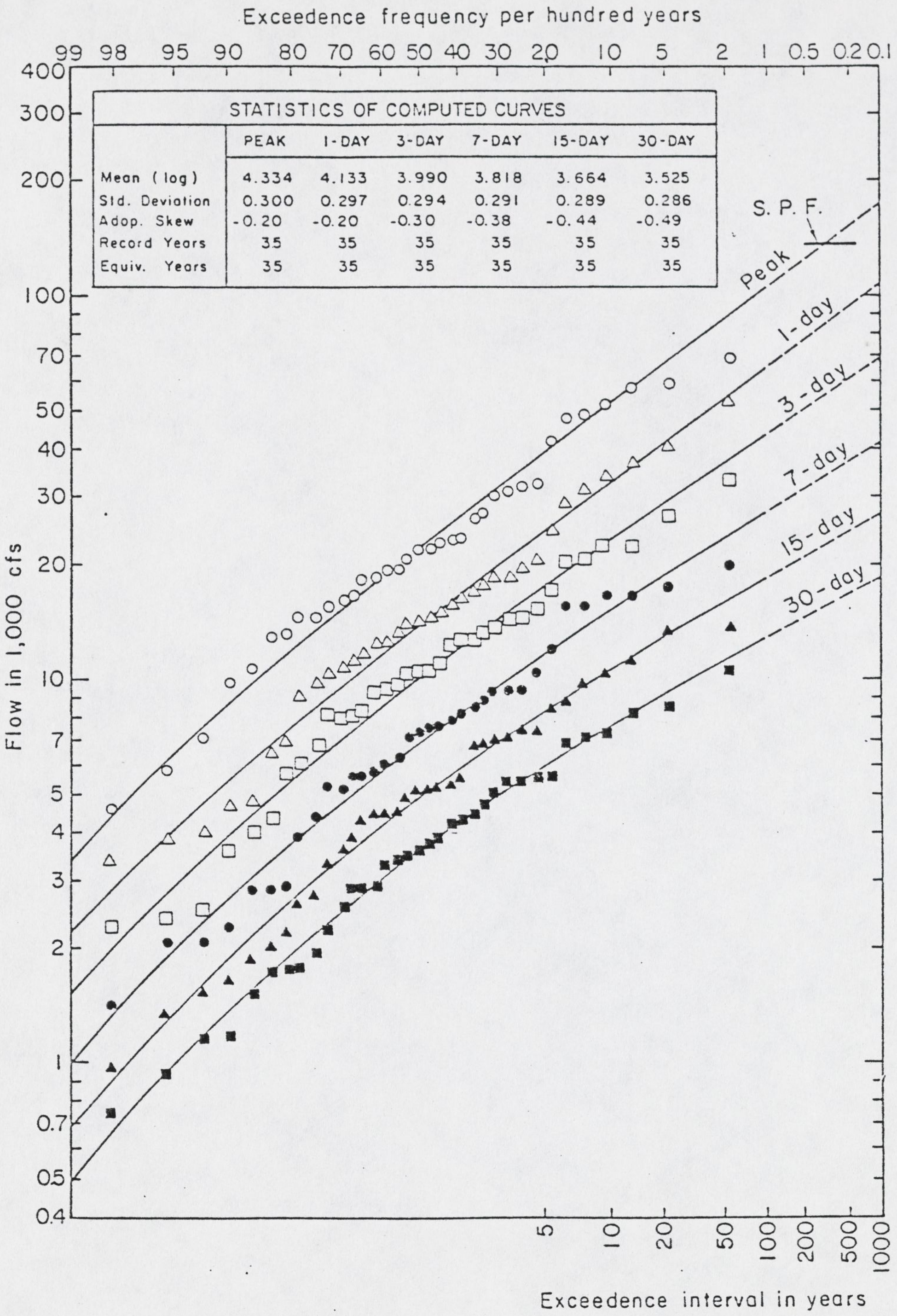
JUST ABOVE REACH OF INTEREST

PROJECT CONDITIONS

```
JOB NUMBER      1
```



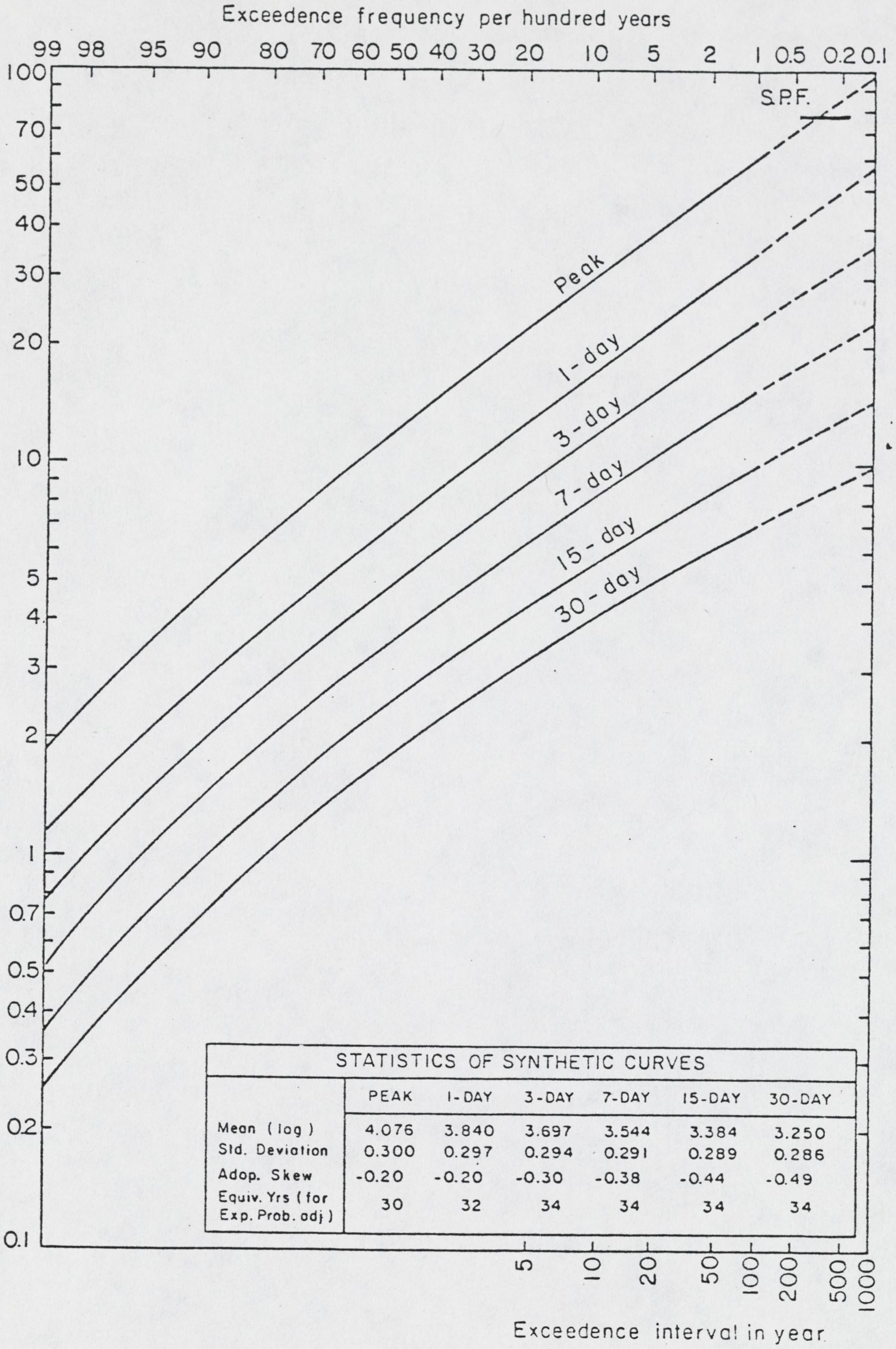
```
*******************************************************************************

JOB NUMBER     1                         PROJECT CONDITIONS
*******************************************************************************

STREAM FLOW DATA INPUT

FL CARD          FTYPE        FMTYPE        PUNCH
                  FILE           STD           NO

FM CARD           TERM        ITVALS        NVALS
               -999.00       1000000            0

 UNADJUSTED FLOW DURATION CURVE -- FLOWS IN CFS AND EXCEEDENCE PROBABILITIES AS DECIMAL FRACTIONS

PE              1.0000        1.0000        1.0000        1.0000         .9975         .9975         .9975         .9975         .9975         .9975
QQ                1.00          1.26          1.58          2.00          2.51          3.16          3.98          5.01          6.31          7.94

PE               .9975         .9902         .9902         .9902         .8970         .8847         .8823         .8295         .7233         .6114
QQ               10.00         12.59         15.85         19.95         25.12         31.62         39.81         50.12         63.10         79.43

PE               .6032         .4534         .4349         .4123         .3941         .3567         .2672         .1994         .1538         .1055
QQ              100.00        125.89        158.49        199.53        251.19        316.23        398.11        501.19        630.96        794.33

PE               .0654         .0457         .0350         .0248         .0190         .0145         .0108         .0075         .0049         .0032
QQ             1000.00       1258.93       1584.89       1995.26       2511.89       3162.28       3981.07       5011.67       6309.57       7943.28

PE               .0007         0.
QQ            10000.00      12589.25
```



STATISTICS OF COMPUTED CURVES

| | PEAK | 1-DAY | 3-DAY | 7-DAY | 15-DAY | 30-DAY |
|---|---|---|---|---|---|---|
| Mean (log) | 4.334 | 4.133 | 3.990 | 3.818 | 3.664 | 3.525 |
| Std. Deviation | 0.300 | 0.297 | 0.294 | 0.291 | 0.289 | 0.286 |
| Adop. Skew | -0.20 | -0.20 | -0.30 | -0.38 | -0.44 | -0.49 |
| Record Years | 35 | 35 | 35 | 35 | 35 | 35 |
| Equiv. Years | 35 | 35 | 35 | 35 | 35 | 35 |

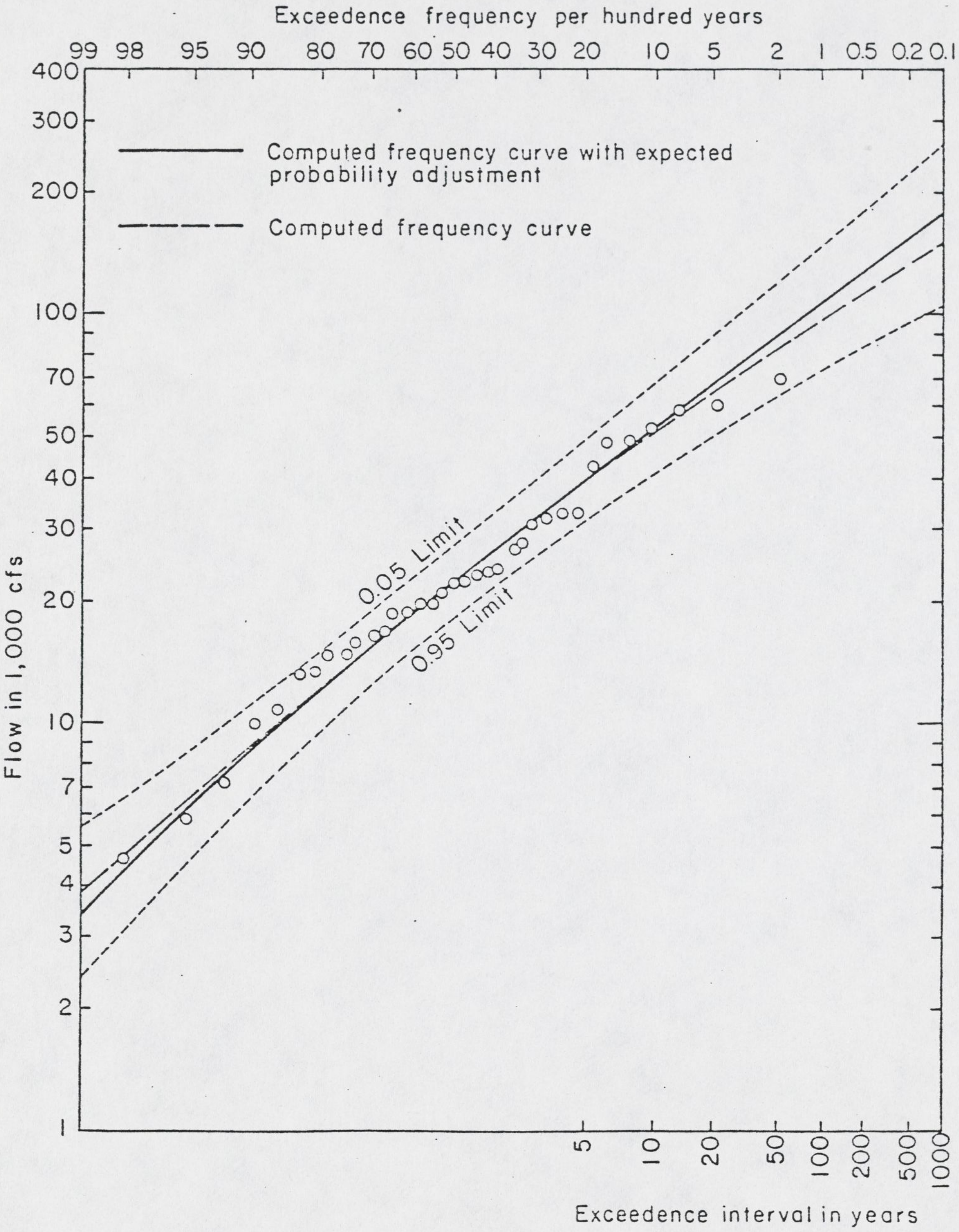
Flow frequency Poplar Creek near Site 1 (Corps of Engineers, April 1977).
Drainage area: 927 sq. mi. Period of record: 1941-1975.



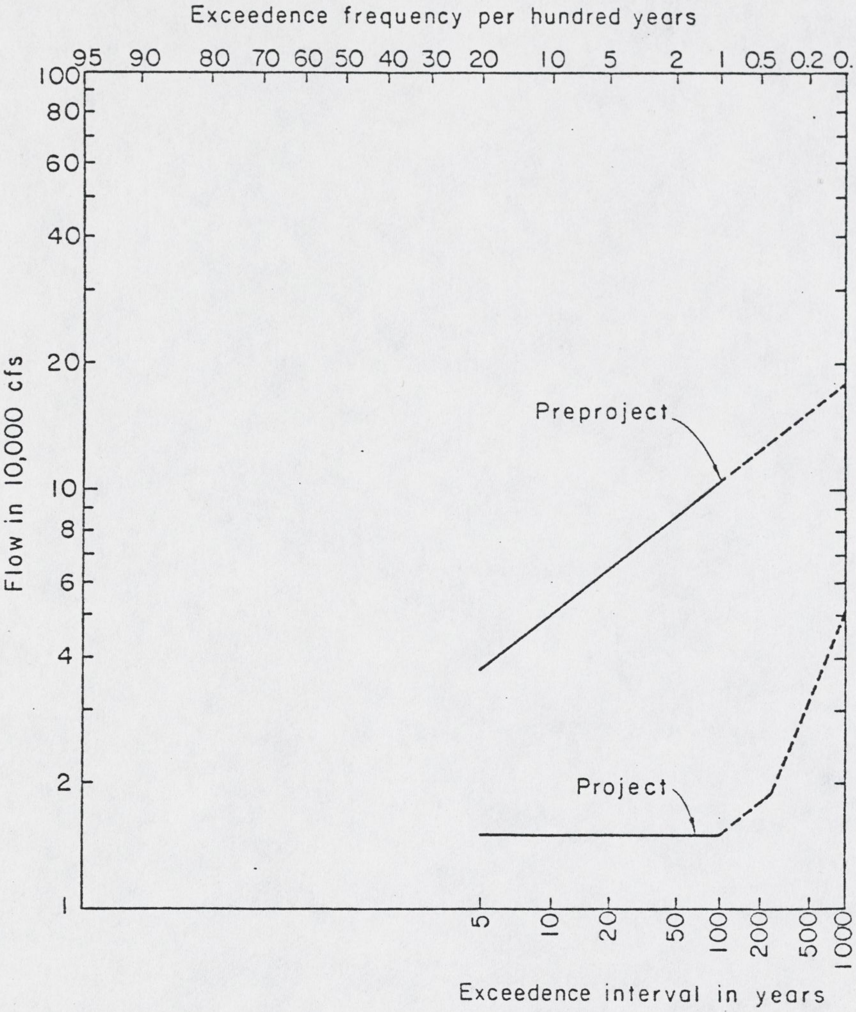
STATISTICS OF SYNTHETIC CURVES

| | PEAK | 1-DAY | 3-DAY | 7-DAY | 15-DAY | 30-DAY |
|---|---|---|---|---|---|---|
| Mean (log) | 4.076 | 3.840 | 3.697 | 3.544 | 3.384 | 3.250 |
| Std. Deviation | 0.300 | 0.297 | 0.294 | 0.291 | 0.289 | 0.286 |
| Adop. Skew | -0.20 | -0.20 | -0.30 | -0.38 | -0.44 | -0.49 |
| Equiv. Yrs (for Exp. Prob. adj) | 30 | 32 | 34 | 34 | 34 | 34 |

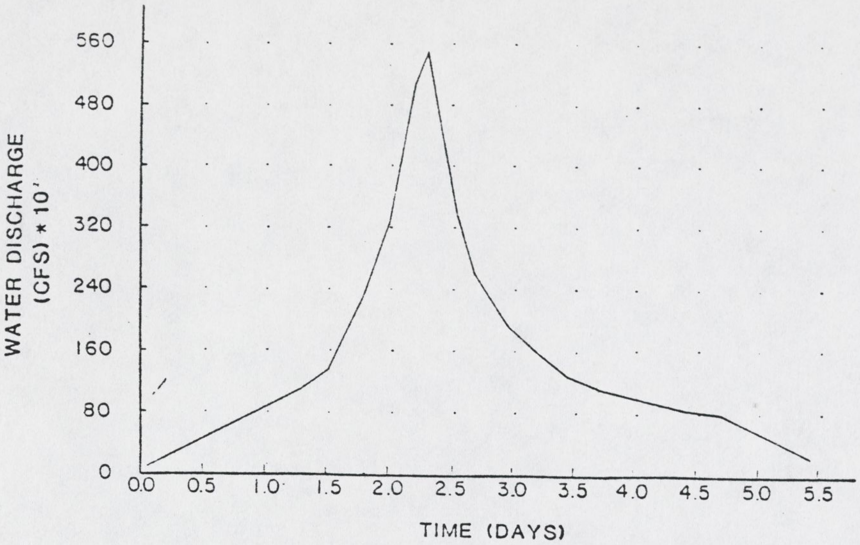
Flow frequency Poplar Creek at dam site above Site 1 (Corps of Engineers, April 1977).
Drainage area: 394.2 sq. mi.



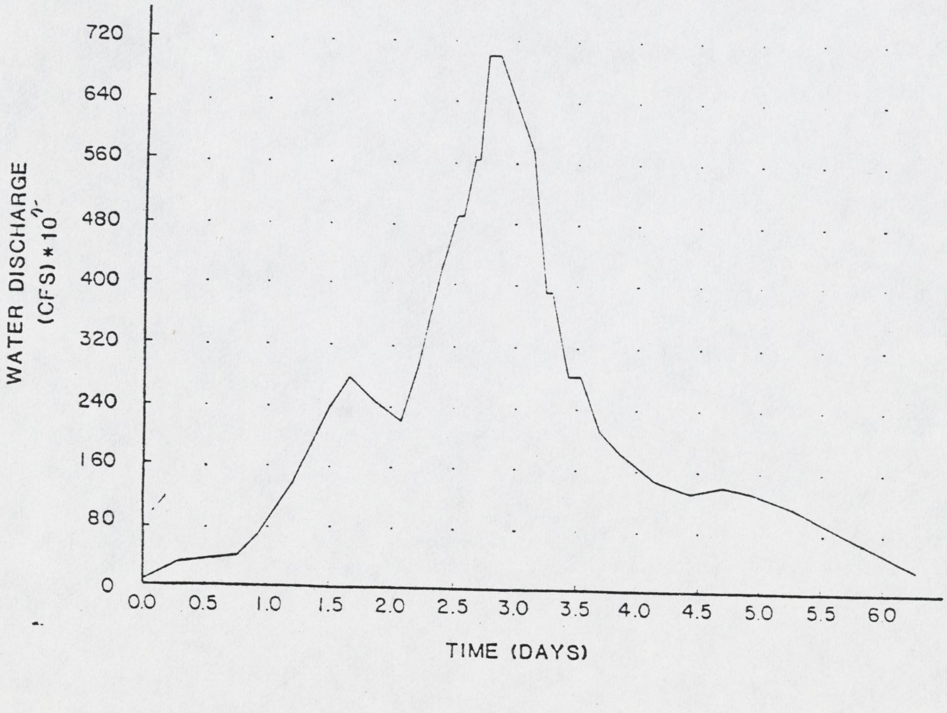
Peak flow frequency Poplar Creek at Site 3 (Corps of Engineers, April 1977).
Drainage area: 927.0 sq. mi. Period of record: 1941-1975.



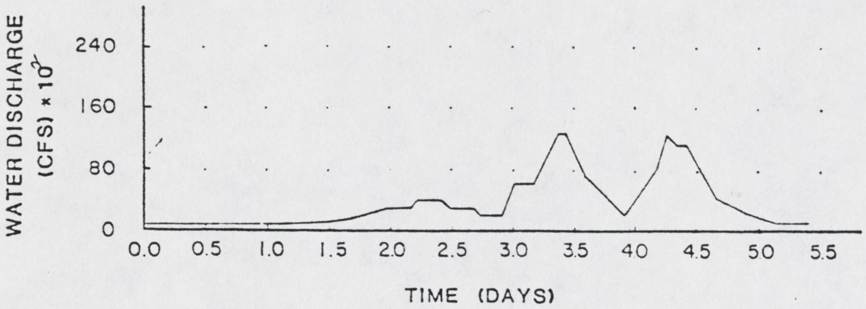
Peak flow frequency Poplar Creek near Site 1 for preproject and postproject conditions (Corps of Engineers, July 1969).



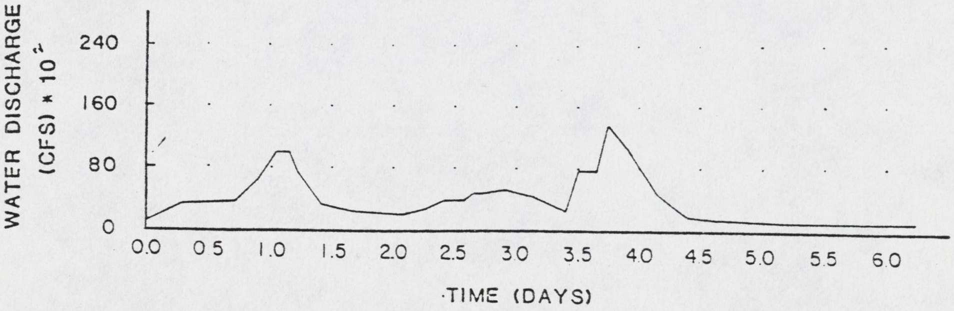
Poplar Creek preproject flood (1970).



Poplar Creek preproject flood (1974).



Poplar Creek project flood (1970).



Poplar Creek project flood (1974).

# BED MATERIAL

## BED MATERIAL

Total Depth of Hole: 1.0 ft each
Date Started: 18 July 78
Date Completed: 19 July 78

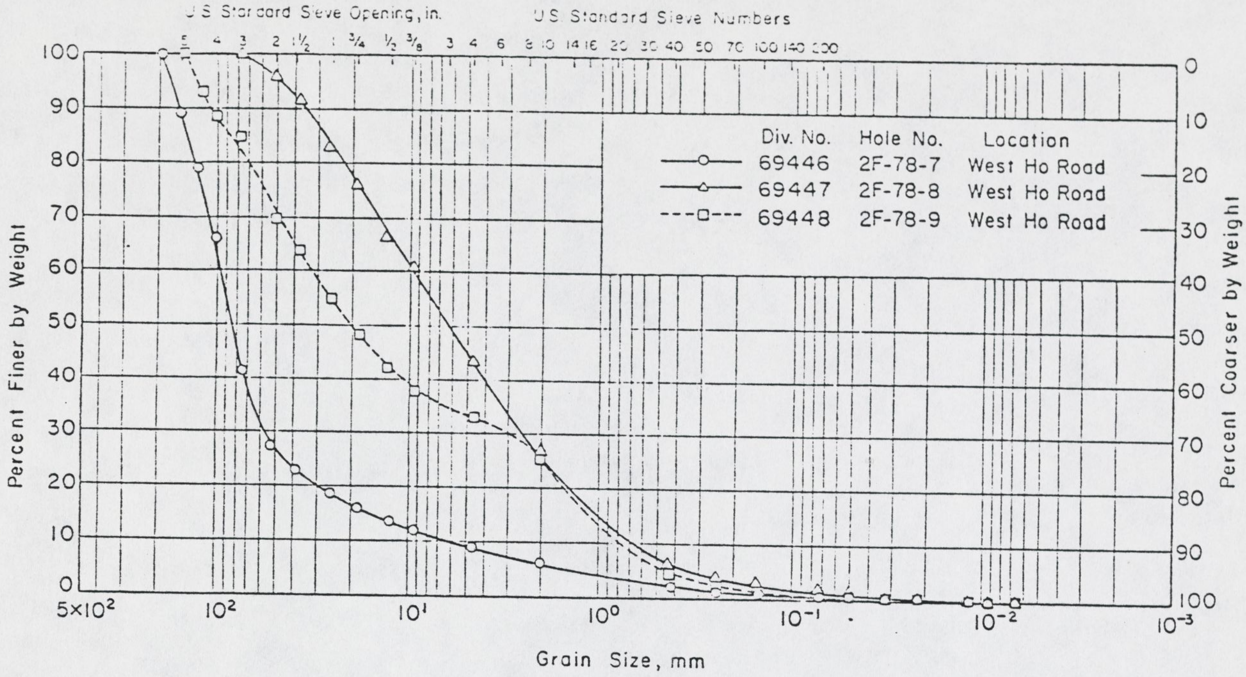
Size and Type of Bit: Shovel
Manufacturer's Designation of Drill:
Ames Middleweight #2

| DEPTH | CLASSIFICATION OF MATERIALS | TEST HOLE NUMBERS |
|---|---|---|
| 0.0<br>0.5<br>1.0 | sandy gravel, 75% rounded gravel, 25% fine to coarse subangular sand, to 4" maximum. | 2F-78-8 |
| 0.0<br>0.5<br>1.0 | sandy gravel with scattered cobbles. 75% rounded gravel, 25% fine to coarse subangular sand, to 5" maximum. | 2F-78-9 |
| 0.0<br>0.5<br>1.0 | cobbly sandy gravel, 60% rounded gravel, 30% fine to coarse angular sand, 10% rounded cobbles. | 2F-78-10 |
| 0.0<br>0.5<br>1.0 | sandy gravel with cobbles, 90% rounded cobbles 10% fine-coarse, angular sand, cobbles to 6" maximum. | 2F-78-11 |
| 0.0<br>0.5<br>1.0 | sandy, gravelly cobbles, 40% rounded cobbles, 30% rounded gravels, 30% fine to coarse angular sand. | 2F-78-12 |
| 0.0<br>0.5<br>1.0 | sandy gravel with scattered cobbles, 90% rounded gravels, 10% fine-coarse angular sand, Cobbles to maximum 6". | 2F-78-13 |
|  | 19 July 78 |  |
| 0.0<br>0.5<br>1.0 | Sandy gravel, 65% gravel, 35% sand, Gravel maximum dimension 5" but would go through 3" square. | 2F-78-14 |

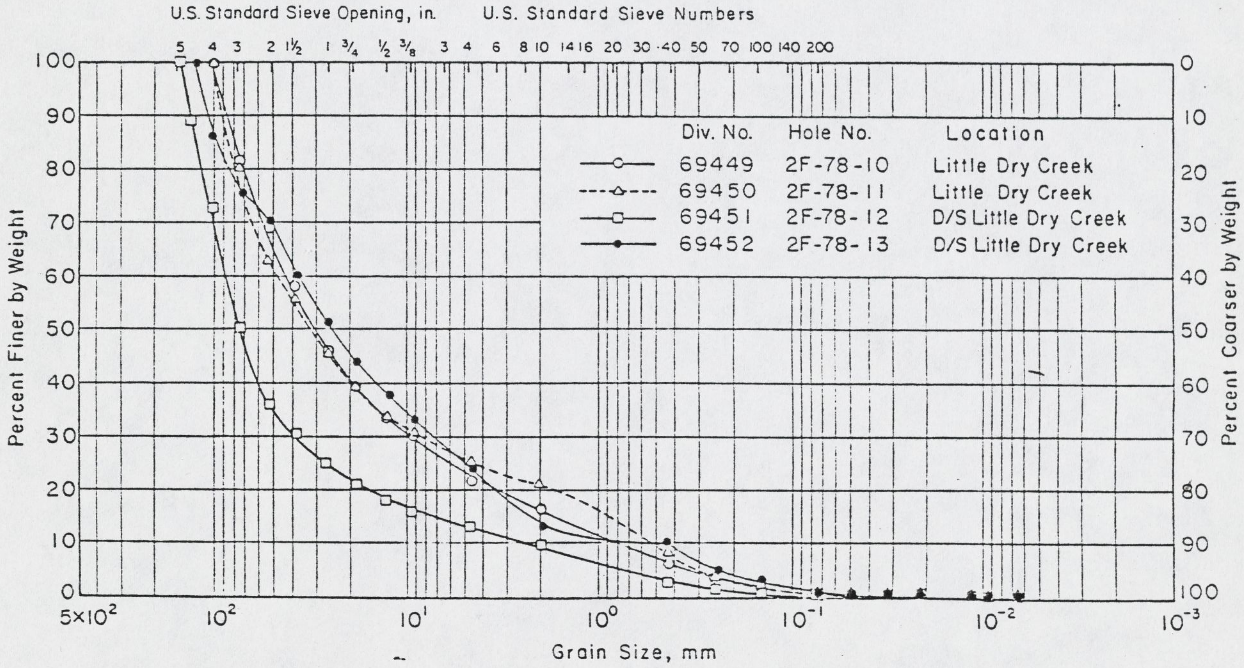
Drilling log for Poplar Creek sedimentation study

| DIVISION SERIAL NO. | HOLE NO. | CO-ORD OR STA. | MECHANICAL ANALYSIS--% FINER | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Gravel | | | | Sand | | | | Fines | | |
| | | | $^{6}/_{3}$ | $^{2}/_{1}{}^{1}/_{2}$ | $^{1}/{}^{3}/_{4}$ | $^{1}/_{2}{}^{3}/_{8}$ | No. 4 | No. 10 | No. 40 | No. 80 | No. 200 | | |
| 69440 | 2F-78-1 | Dutch Gulch | 100 | 98/97 | 94/91 | 88/84 | 74 | 57 | 19 | 9 | 1 | | 2 Sacks |
| 69441 | 2F-78-2 | Dutch Gulch | | 100/96 | 94/86 | 76/67 | 52 | 37 | 8 | 3 | 0.5 | | 2 Sacks |
| 69442 | 2F-78-3 | Dutch Gulch Bridge | 82/58 | 45/40 | 32/27 | 22/20 | 16 | 9 | 3 | 2 | 1 | 42% Cobbles | 4 Sacks |
| 69443 | 2F-78-4 | Dutch Gulch Bridge | 94/80 | 74/72 | 68/66 | 64/63 | 62 | 50 | 8 | 5 | 4 | 20% Cobbles | 3 Sacks |
| 69444 | 2F-78-5 | Dutch Gulch Bridge | 100 | 97/91 | 79/73 | 65/61 | 52 | 35 | 3 | 2 | 1 | | 2 Sacks |
| 69445 | 2F-78-6 | West Ho Road | 91/64 | 55/49 | 41/35 | 30/27 | 21 | 16 | 5 | 4 | 2 | 36% Cobbles | 4 Sacks |
| 69446 | 2F-78-7 | West Ho Road | 89/41 | 27/23 | 18/15 | 13/12 | 9 | 6 | 2 | 2 | 1 | 59% Cobbles | 4 Sacks |
| 69447 | 2F-78-8 | West Ho Road | 100 | 97/93 | 83/76 | 68/61 | 43 | 27 | 8 | 5 | 1 | | 2 Sacks |
| 69448 | 2F-78-9 | West Ho Road | 100/85 | 71/65 | 56/48 | 42/39 | 33 | 26 | 5 | 3 | 1 | 15% Cobbles | 2 Sacks |
| 69449 | 2F-78-10 | Little Dry Cr. | 100/82 | 69/58 | 46/40 | 34/30 | 22 | 17 | 6 | 4 | 1 | 18% Cobbles | 3 Sacks |
| 69450 | 2F-78-11 | Little Dry Cr. | 100/80 | 63/56 | 46/40 | 35/31 | 26 | 22 | 9 | 4 | 1 | 20% Cobbles | 4 Sacks |
| 69451 | 2F-78-12 | D/S Little Dry Cr. | 100/50 | 36/31 | 25/21 | 18/16 | 13 | 10 | 3 | 2 | 1 | 50% Cobbles | 4 Sacks |
| 69452 | 2F-78-13 | D/S Little Dry Cr. | 100/75 | 70/60 | 51/45 | 38/33 | 23 | 13 | 10 | 5 | 1 | 25% Cobbles | 2 Sacks |
| 69453 | 2F-78-14 | Confluence of N&S Forks | 100/98 | 90/79 | 64/52 | 43/37 | 29 | 21 | 7 | 3 | 0.5 | 2% Cobbles | 2 Sacks |
| 69454 | 2F-78-15 | Confluence of N&S Forks | 80/41 | 31/28 | 23/19 | 16/14 | 10 | 7 | 3 | 1 | 0 | 59% Cobbles | 4 Sacks |
| 69455 | 2F-78-16 | Confluence of N&S Forks | | 100/93 | 82/72 | 62/54 | 39 | 29 | 9 | 6 | 2 | | 2 Sacks |
| 69456 | 2F-78-17 | Confluence of N&S Forks | 100/78 | 73/70 | 62/56 | 48/42 | 27 | 14 | 6 | 3 | 2 | 22% Cobbles | 2 Sacks |

Soil test result summary for Poplar Creek, August 1978.



Sedimentation study (Poplar Creek, 2F-78-7 to 2f-78-9).



Sedimentation study (Poplar Creek, 2f-78-10 to 2F-78-13).

# APPENDIX C

# CHANNEL CHANGE WORKSHOP: PROBLEM NUMBER 3
## ELK RIVER, KANSAS

## THE QUESTION

The question relative to the Elk River is "What will happen to the morphology of the stream channel as a result of the changes in streamflows and sediment discharge caused by the construction of a number of small flood retaining reservoirs upstream of a reach of stream?" Specifically, for both a short and long time after construction of the reservoirs:

1. What will be the meander pattern?,
2. What will be the configuration of the channel?,
3. What will be the substrate material?, and
4. What will be the pool riffle sequence?

Elk River is located in southeastern Kansas in an area with subhumid climate. The materials in this appendix describe the basin and present the data on both pre and post project conditions. The soils data is for Chautauqua County, the county immediately below Elk County. The Elk River is located in the southern part of Elk County.

The reach of interest is the reach of the river near Longton, Kansas; specifically between Cross Sections 11-15 and 3-3 as shown on the enclosed plan.

Most of the data enclosed were obtained from the Kansas State Office of the Soil Conservation Service. Other data were obtained from U.S. Geological Survey reports. The geology data is from a Kansas Geological Survey report.

## CONTENTS

General Location of Elk River, Kansas

General Plan - Elk River Watershed Joint District No. 47 (Partial)[1]

Soil Survey of Chautauqua County, Kansas (Partial)[1]

Geology, Mineral Resources and Groundwater Resources of Elk County, Kansas (Partial)[1]

Plan, Profile, and Cross Section Diagrams for the Longton Reach of the Elk River, Kansas[2]

Monthly Streamflow Data for the Elk River Basin, Kansas

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[1] These items are not included in the information supplied in this appendix. The following bibliography lists the sources of these data.

[2] Only part of the diagrams included in the original data set are supplied and included in this appendix. The others may be reviewed at the office of the Instream Flow Group in Fort Collins, Colorado.

Elk River Bed Material

Elk River Sediment Yield

Frequency - Runoff Curve

Elk River Hydrographs and Elevation vs. Discharge Data

- Unit Discharge Hydrograph
- Unit Discharge Hydrograph Table
- Elevation - Discharge Plots
- Elevation - Discharge Table

## USGS MAPS SHOWING THE ELK RIVER AREA INCLUDED IN THE ORIGINAL DATA SETS

1:250,000
Joplin, Missouri; Kansas
Wichita, Kansas

1:24,000
Longton NW, Kansas
Elk Falls, Kansas
Longton, Kansas
Oak Valley, Kansas

## BIBLIOGRAPHY OF REPORTS USED IN DATA SET

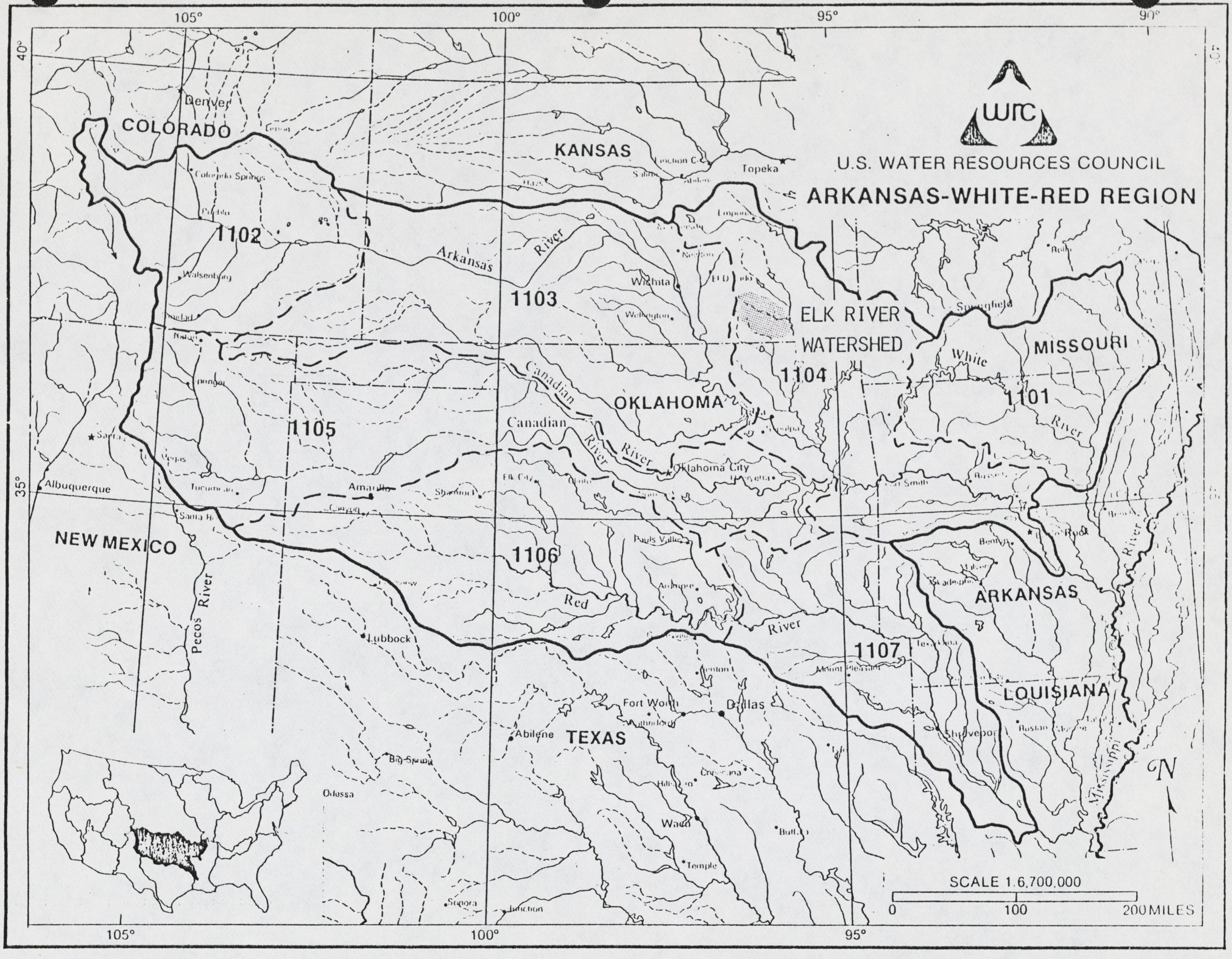
General Plan - Elk River Watershed Joint District No. 47, Kansas State Office, Soil Conservation Service, USDA, Salina, Kansas, January 1967.

Bell, E. L., and H. T. Rowland. Soil Survey of Chautauqua County, Kansas, Soil Conservation Service, USDA, Washington, D.C., October 1976.

Verville, G. J. R., Kulstad, N. Plummer, W. H. Schoewa, E. D. Goebel, and C. K. Bayhe. Geology, Mineral Resources, and Ground-Water Resources of Elk County, Kansas, State Geological Survey of Kansas (Volume 14), Lawrence, Kansas, July 1958.

## PLAN, PROFILE, AND CROSS SECTION DIAGRAMS FOR THE LONGTON REACH OF THE ELK RIVER, KANSAS

The following figures illustrate the reach of the Elk River for which an estimate of the future form of the channel and substrate is needed. The reach is between Sections 3-3 and 11-15. Only a few of the diagrams are included in this appendix.



General location of Elk River, Kansas.

## DIAGRAMS INCLUDED IN ORIGINAL DATA SETS

Plan-Profile Reach Numbers 3 and 11

Plan-Profile Reach Numbers 11 and 13

Cross Section 3-3
3-4
3-5
11-1 and 11-2
11-3 and 11-4
11-5 and 11-7
11-8 and 11-9
11-14 and 11-15

## MONTHLY STREAMFLOW DATA FOR THE ELK RIVER BASIN, KANSAS

### Drainage Areas

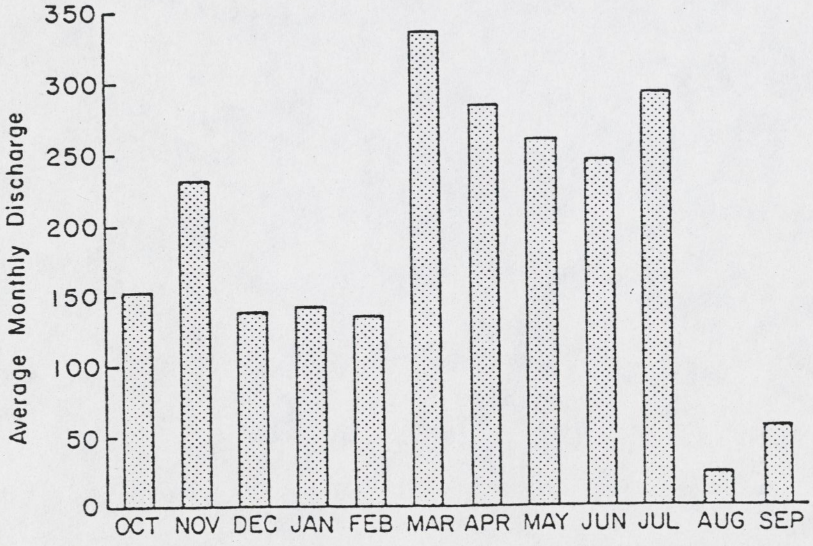
Study Reach:

Head of Reach: 285.7 square miles
Bottom of Reach: 405.3 square miles

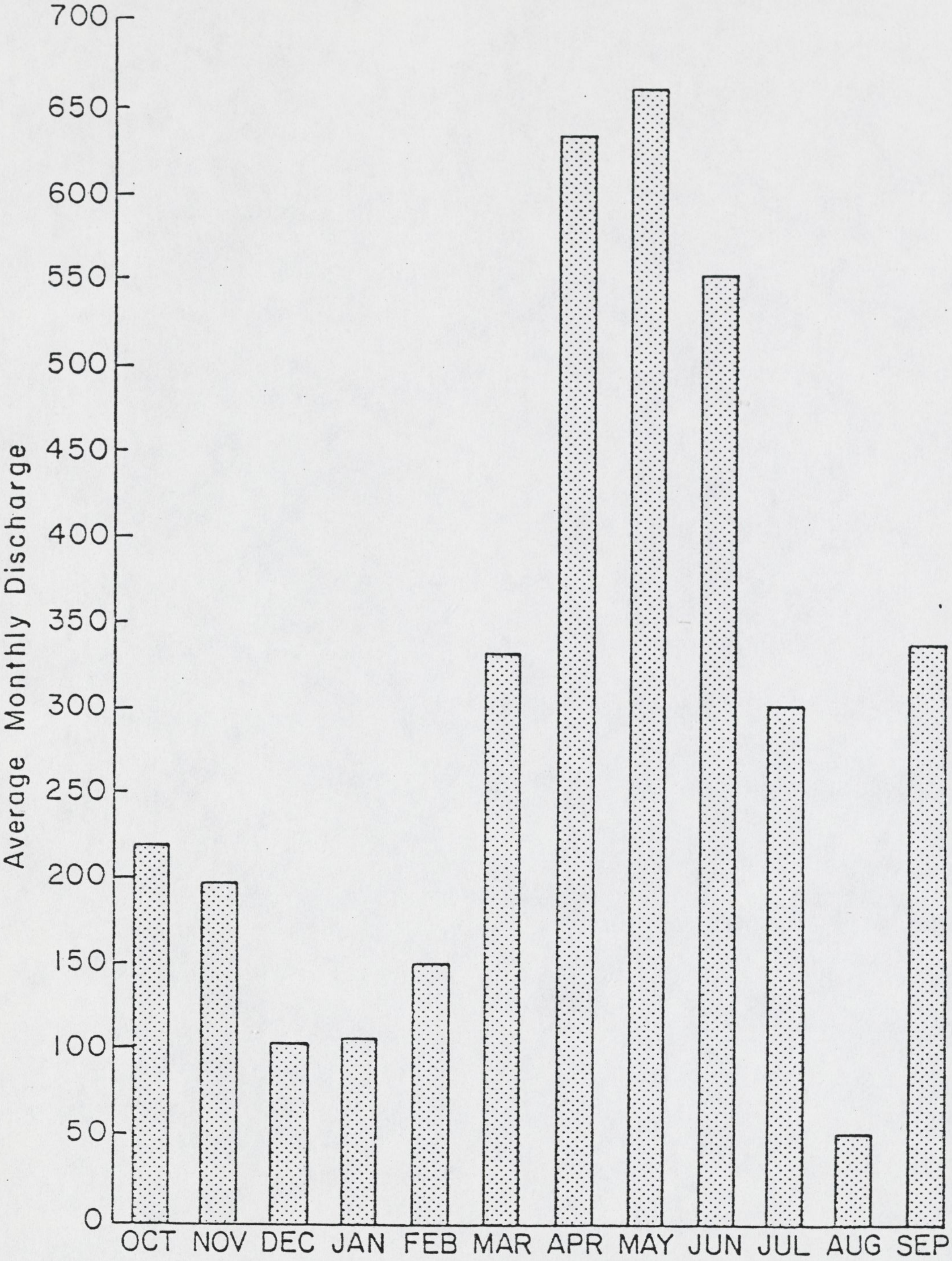
Gaging Station:

07-1698 Elk River at Elk Falls: 220 square miles
07-1700 Elk River near Elk City: 575 square miles

Included in the original data set were data from the U.S. Geological Survey report "Water Resources Data for Kansas." The data included were from water year 1978 and were on pages 15 and 297. Most of the data are from records of the U.S. Geological Survey.



Elk River at Elk Falls, Kansas (1968-1976)



Elk River near Elk City, Kansas (1939-1969)

ELK RIVER AT ELK FALLS, KANSAS
ARKANSAS RIVER BASIN
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1968 | 234.00 | 104.00 | 45.40 | 31.50 | 29.20 | 22.80 | 131.00 | 311.00 | 75.90 | 25.60 | 32.60 | 14.20 | 88.62 |
| 1969 | 197.00 | 390.00 | 143.00 | 84.00 | 158.00 | 332.00 | 444.00 | 614.00 | 758.00 | 34.20 | 2.29 | 169.00 | 276.23 |
| 1970 | 288.00 | 62.30 | 74.90 | 30.40 | 19.30 | 58.00 | 992.00 | 62.80 | 201.00 | 5.59 | .25 | 13.90 | 149.87 |
| 1971 | 31.10 | 6.52 | 4.35 | 117.00 | 126.00 | 67.10 | 23.90 | 60.80 | 74.30 | 65.80 | 1.24 | .33 | 47.86 |
| 1972 | 12.70 | 5.32 | 173.00 | 39.30 | 22.60 | 14.20 | 24.50 | 52.50 | 2.65 | 389.00 | 10.90 | 27.60 | 65.38 |
| 1973 | 19.40 | 398.00 | 229.00 | 394.00 | 265.00 | 1247.00 | 436.00 | 108.00 | 16.00 | 3.70 | .77 | 128.00 | 270.73 |
| 1974 | 207.00 | 199.00 | 364.00 | 261.00 | 171.00 | 802.00 | 154.00 | 543.00 | 464.00 | 6.35 | 153.00 | 143.00 | 290.37 |
| 1975 | 389.00 | 930.00 | 215.00 | 309.00 | 426.00 | 477.00 | 140.00 | 354.00 | 508.00 | 20.00 | 12.70 | 11.70 | 314.31 |
| 1976 | 1.26 | 2.32 | 5.30 | 2.54 | 1.80 | 7.18 | 212.00 | 147.00 | 19.90 | 2080.00 | 5.73 | 2.76 | 210.48 |
| AVERAGE | 153.27 | 233.05 | 139.33 | 140.97 | 135.43 | 336.36 | 284.16 | 250.34 | 235.53 | 292.25 | 24.39 | 56.72 | 190.43 |
| Q/QANN | 6.831 | 10.052 | 6.210 | 6.283 | 5.501 | 14.992 | 12.256 | 11.158 | 10.159 | 13.025 | 1.087 | 2.446 | 100.000 |
| COV VAR | .925 | 1.306 | .859 | 1.016 | 1.039 | 1.299 | 1.078 | .863 | 1.164 | 2.332 | 2.021 | 1.211 | .549 |
| SKEW | .327 | 1.733 | .616 | .880 | 1.163 | 1.384 | 1.776 | .786 | 1.040 | 2.831 | 2.773 | .899 | -.269 |
| MAXIMUM | 389.00 | 930.00 | 364.00 | 394.00 | 426.00 | 1247.00 | 992.00 | 614.00 | 758.00 | 2080.00 | 153.00 | 169.00 | 314.31 |
| MINIMUM | 1.26 | 2.32 | 4.35 | 2.54 | 1.80 | 7.18 | 23.90 | 52.50 | 2.65 | 3.70 | .25 | .33 | 47.86 |

Monthly streamflow data.

## STATISTICAL PARAMETERS FOR STATION 07169800 ELK RIVER AT ELK FALLS, KANSAS
## ARKANSAS RIVER BASIN

| | MONTH | ARTH. AVERAGE | LOG PARAMETERS MEAN | VARIANCE | STD. DEV. | SKEW |
|---|---|---|---|---|---|---|
| 1 | OCT | 153.27 | 1.7793 | .7025 | .8331 | -1.0480 |
| 2 | NOV | 233.05 | 1.7973 | .8888 | .9427 | -.4516 |
| 3 | DEC | 139.33 | 1.8379 | .5017 | .7083 | -1.0740 |
| 4 | JAN | 140.97 | 1.8306 | .4686 | .6845 | -1.0222 |
| 5 | FEB | 135.43 | 1.7717 | .5584 | .7473 | -.9952 |
| 6 | MAR | 336.36 | 2.0174 | .6591 | .8119 | -.0464 |
| 7 | APR | 284.16 | 2.2031 | .2982 | .5461 | -.4234 |
| 8 | MAY | 250.34 | 2.2297 | .1782 | .4221 | .0952 |
| 9 | JUNE | 235.53 | 1.9147 | .6731 | .8204 | -.5918 |
| 10 | JULY | 292.25 | 1.5653 | .8158 | .9032 | .9755 |
| 11 | AUG | 24.39 | .7039 | .7483 | .8651 | .2077 |
| 12 | SEPT | 56.72 | 1.2505 | .7817 | .8842 | -.7961 |
| 13 | ANNUAL | 190.43 | 2.1973 | .0960 | .3098 | -.7273 |

SAMPLE SIZE 9 YEARS

## LOG NORMAL DISTRIBUTION STATION 07169800 ELK RIVER AT ELK FALLS, KANSAS
## ARKANSAS RIVER BASIN

YEARS FLOW IS NOT EXCEEDED

| MONTH | 9 IN 10 | 2 IN 3 | 1 IN 2 | 1 IN 5 | 1 IN 10 | 1 IN 20 | Q2 - Q10 |
|---|---|---|---|---|---|---|---|
| OCT | 714.17 | 137.68 | 60.16 | 11.85 | 5.07 | 2.52 | 55.09 |
| NOV | 1013.60 | 159.11 | 62.70 | 10.08 | 3.88 | 1.76 | 58.82 |
| DEC | 557.13 | 138.60 | 68.85 | 17.44 | 8.51 | 4.71 | 60.34 |
| JAN | 510.61 | 133.11 | 67.69 | 17.96 | 8.97 | 5.06 | 58.72 |
| FEB | 536.63 | 123.67 | 59.11 | 13.88 | 6.51 | 3.49 | 52.60 |
| MAR | 1143.32 | 232.08 | 104.08 | 21.57 | 9.47 | 4.81 | 94.60 |
| APR | 800.31 | 273.79 | 159.64 | 55.37 | 31.84 | 20.17 | 127.79 |
| MAY | 590.00 | 257.52 | 169.72 | 74.87 | 48.82 | 34.31 | 120.90 |
| JUNE | 925.87 | 184.80 | 82.18 | 16.75 | 7.29 | 3.67 | 74.88 |
| JULY | 528.72 | 89.70 | 36.76 | 6.38 | 2.56 | 1.20 | 34.20 |
| AUG | 65.00 | 11.88 | 5.06 | .95 | .39 | .19 | 4.66 |
| SEPT | 242.08 | 42.64 | 17.80 | 3.21 | 1.31 | .63 | 16.49 |
| ANNUAL | 393.05 | 213.90 | 157.52 | 86.40 | 63.13 | 48.73 | 94.39 |

Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW

## LOG-PEARSON TYPE III DISTRIBUTION FOR STATION 07169800
ELK RIVER AT ELK FALLS, KANSAS
ARKANSAS RIVER BASIN

### DATA SKEW K FACTORS

| MONTH | SKEW | RETURN PERIOD<br>10 YRS | 6.67 YRS | 2 YRS | 1.25 YRS | 1.11 YRS | 1.05 YRS |
|---|---|---|---|---|---|---|---|
| OCT | -1.05 | 1.0961 | .5234 | .1878 | -.7382 | -1.3405 | -1.9023 |
| NOV | -.45 | 1.2083 | .4813 | .0907 | -.8041 | -1.3254 | -1.7851 |
| DEC | -1.07 | 1.1015 | .5221 | .1839 | -.7416 | -1.3407 | -1.8982 |
| JAN | -1.02 | 1.0907 | .5248 | .1917 | -.7349 | -1.3402 | -1.9064 |
| FEB | -1.00 | 1.1270 | .5152 | .1648 | -.7574 | -1.3400 | -1.8776 |
| MAR | -.05 | 1.2636 | .4451 | .0256 | -.8328 | -1.2968 | -1.6875 |
| APR | -.42 | 1.2037 | .4836 | .0953 | -.8019 | -1.3268 | -1.7916 |
| MAY | .10 | 1.2706 | .4393 | .0162 | -.8363 | -1.2915 | -1.6717 |
| JUNE | -.59 | 1.1986 | .4863 | .1004 | -.7992 | -1.3284 | -1.7988 |
| JULY | .98 | 1.3367 | .3298 | -.1359 | -.8555 | -1.1613 | -1.3744 |
| AUG | .21 | 1.3003 | .4080 | -.0318 | -.8497 | -1.2589 | -1.5883 |
| SEPT | -.80 | 1.1653 | .5015 | .1326 | -.7796 | -1.3361 | -1.8397 |
| ANNUAL | -.73 | 1.1522 | .5062 | .1436 | -.7720 | -1.3382 | -1.8528 |

### FREQUENCY OF FLOWS

YEARS FLOW IS NOT EXCEEDED

| MONTH | 9 IN 10 | 2 IN 3 | 1 IN 2 | 1 IN 5 | 1 IN 10 | 1 IN 20 | Q2 - Q10 |
|---|---|---|---|---|---|---|---|
| OCT | 498.85 | 165.21 | 86.44 | 14.47 | 4.53 | 1.53 | 81.91 |
| NOV | 863.65 | 178.23 | 76.35 | 10.94 | 3.53 | 1.30 | 72.82 |
| DEC | 415.09 | 161.32 | 92.93 | 20.54 | 7.73 | 3.11 | 85.20 |
| JAN | 377.68 | 154.81 | 91.57 | 21.26 | 8.19 | 3.35 | 83.38 |
| FEB | 411.00 | 143.43 | 78.49 | 16.06 | 5.89 | 2.34 | 72.59 |
| MAR | 1104.59 | 239.17 | 109.17 | 21.94 | 9.22 | 4.44 | 99.96 |
| APR | 725.30 | 293.26 | 179.95 | 58.24 | 30.10 | 16.78 | 149.86 |
| MAY | 583.49 | 260.10 | 172.41 | 75.29 | 48.37 | 33.43 | 124.04 |
| JUNE | 790.91 | 205.92 | 99.34 | 18.16 | 6.68 | 2.75 | 92.66 |
| JULY | 592.46 | 72.98 | 27.71 | 6.20 | 3.28 | 2.09 | 24.42 |
| AUG | 67.41 | 11.40 | 4.75 | .93 | .41 | .21 | 4.33 |
| SEPT | 190.87 | 49.42 | 23.32 | 3.64 | 1.17 | .42 | 22.15 |
| ANNUAL | 358.29 | 226.01 | 174.51 | 90.82 | 60.65 | 42.01 | 113.86 |

Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW

ELK RIVER NEAR ELK CITY, KANSAS
ARKANSAS RIVER BASIN
UNITS OF DISCHARGE ARE CUSECS

| YEAR | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1939 | 2.00 | 9.40 | 5.70 | 8.10 | 9.80 | 35.50 | 260.00 | 350.00 | 195.00 | 6.00 | 1.80 | .10 | 73.63 |
| 1940 | 0.00 | 0.00 | 0.00 | 0.00 | .40 | .70 | 55.30 | 101.00 | 74.30 | 1.30 | 28.70 | 27.80 | 24.14 |
| 1941 | .90 | 118.00 | 55.00 | 296.00 | 253.00 | 69.20 | 1181.00 | 158.00 | 892.00 | 10.10 | 7.10 | 584.00 | 298.10 |
| 1942 | 1424.00 | 645.00 | 208.00 | 83.70 | 380.00 | 181.00 | 1293.00 | 268.00 | 1284.00 | 48.10 | 154.00 | 1564.00 | 623.37 |
| 1943 | 408.00 | 106.00 | 496.00 | 206.00 | 212.00 | 181.00 | 85.40 | 3692.00 | 1373.00 | 68.30 | 12.00 | 3.90 | 574.95 |
| 1944 | 14.10 | 2.70 | 13.10 | 11.40 | 43.40 | 1008.00 | 3400.00 | 785.00 | 186.00 | 23.50 | 45.90 | 226.00 | 478.02 |
| 1945 | 538.00 | 20.10 | 778.00 | 74.70 | 73.10 | 1368.00 | 2556.00 | 220.00 | 501.00 | 564.00 | 11.00 | 2740.00 | 785.05 |
| 1946 | 802.00 | 40.30 | 29.70 | 516.00 | 340.00 | 498.00 | 248.00 | 58.70 | 23.10 | 6.41 | 27.60 | 27.50 | 218.65 |
| 1947 | 1.67 | 150.00 | 46.90 | 24.60 | 11.90 | 403.00 | 3370.00 | 1374.00 | 275.00 | 54.10 | 7.89 | 6.19 | 475.42 |
| 1948 | .74 | .53 | 1.94 | 2.19 | 2.74 | 156.00 | 216.00 | 112.00 | 1330.00 | 3096.00 | 105.00 | 9.38 | 422.84 |
| 1949 | 2.91 | 102.00 | 10.80 | 770.00 | 1629.00 | 493.00 | 673.00 | 918.00 | 1575.00 | 417.00 | 51.40 | 182.00 | 560.00 |
| 1950 | 30.30 | 20.00 | 22.00 | 55.60 | 29.50 | 39.60 | 19.60 | 74.80 | 682.00 | 644.00 | 495.00 | 110.00 | 186.12 |
| 1951 | 11.80 | 7.14 | 8.87 | 9.30 | 70.60 | 62.90 | 220.00 | 1237.00 | 2721.00 | 2461.00 | 51.80 | 415.00 | 607.83 |
| 1952 | 68.30 | 603.00 | 164.00 | 210.00 | 164.00 | 850.00 | 585.00 | 95.50 | 49.30 | 6.57 | 3.17 | .05 | 232.93 |
| 1953 | 0.00 | 0.00 | 1.14 | 1.04 | 76.00 | 18.90 | 4.20 | 96.40 | 2.14 | 3.24 | 0.00 | 0.00 | 16.65 |
| 1954 | .60 | 13.40 | 6.16 | .27 | 4.76 | 2.69 | 264.00 | 608.00 | 21.20 | .62 | 9.73 | 1.35 | 78.31 |
| 1955 | 72.20 | .62 | .07 | 2.80 | 13.90 | 3.45 | 4.50 | 625.00 | 149.00 | 8.39 | .80 | 0.00 | 74.22 |
| 1956 | 91.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.36 | 25.60 | 35.90 | .05 | 0.00 | 13.32 |
| 1957 | 0.00 | 0.00 | 0.00 | 0.00 | .83 | 1.83 | 156.00 | 1562.00 | 2322.00 | 68.80 | 34.00 | 40.20 | 343.45 |
| 1958 | 16.20 | 88.60 | 20.00 | 49.00 | 88.90 | 1885.00 | 756.00 | 514.00 | 75.50 | 440.00 | 19.70 | 259.00 | 353.58 |
| 1959 | 13.90 | 26.50 | 12.90 | 20.40 | 30.20 | 62.70 | 292.00 | 452.00 | 40.30 | 767.00 | 79.40 | 25.30 | 153.41 |
| 1960 | 1754.00 | 78.40 | 52.30 | 172.00 | 393.00 | 774.00 | 437.00 | 405.00 | 107.00 | 53.40 | 67.90 | 7.85 | 360.43 |
| 1961 | 29.50 | 13.80 | 79.10 | 10.10 | 59.70 | 312.00 | 721.00 | 4773.00 | 193.00 | 322.00 | 21.60 | 2874.00 | 787.69 |
| 1962 | 737.00 | 2085.00 | 462.00 | 481.00 | 202.00 | 286.00 | 85.80 | 26.30 | 86.20 | 84.30 | 3.49 | 497.00 | 418.37 |
| 1963 | 155.00 | 52.80 | 56.20 | 296.00 | 48.70 | 291.00 | 43.30 | 82.30 | 58.30 | 2.65 | 4.24 | .19 | 91.78 |
| 1964 | 0.00 | 0.00 | 0.00 | 0.00 | .38 | .46 | 11.10 | 54.30 | 133.00 | 1.55 | 43.40 | 25.50 | 22.42 |
| 1965 | .22 | 922.00 | 189.00 | 95.60 | 72.70 | 192.00 | 1603.00 | 130.00 | 550.00 | 31.60 | 9.48 | 189.00 | 328.70 |
| 1966 | 6.29 | 1.81 | 26.40 | 16.00 | 78.60 | 99.90 | 72.10 | 75.90 | 16.10 | 13.90 | 27.90 | .02 | 36.08 |
| 1967 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | .01 | 18.60 | 19.60 | 518.00 | 372.00 | 23.10 | 469.00 | 117.79 |
| 1968 | 383.00 | 281.00 | 120.00 | 82.60 | 68.30 | 146.00 | 361.00 | 646.00 | 177.00 | 109.00 | 334.00 | 36.10 | 230.04 |
| 1969 | 292.00 | 802.00 | 402.00 | 209.00 | 358.00 | 813.00 | 737.00 | 1055.00 | 1628.00 | 60.90 | 7.13 | 248.00 | 549.14 |
| AVERAGE | 221.18 | 199.68 | 105.40 | 119.46 | 152.11 | 330.16 | 636.42 | 663.65 | 556.87 | 315.54 | 54.46 | 340.92 | 307.78 |
| Q/QANN | 6.099 | 5.329 | 2.906 | 3.294 | 3.823 | 9.104 | 16.983 | 18.300 | 14.861 | 8.701 | 1.502 | 9.098 | 100.000 |
| COV VAR | 1.937 | 2.152 | 1.752 | 1.543 | 1.974 | 1.370 | 1.455 | 1.589 | 1.311 | 2.206 | 1.912 | 2.133 | .760 |
| SKEW | 2.501 | 3.283 | 2.377 | 2.130 | 4.238 | 1.972 | 2.114 | 2.902 | 1.591 | 3.277 | 3.367 | 2.897 | .450 |
| MAXIMUM | 1754.00 | 2085.00 | 778.00 | 770.00 | 1629.00 | 1885.00 | 3400.00 | 4773.00 | 2721.00 | 3096.00 | 495.00 | 2874.00 | 787.69 |
| MINIMUM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.36 | 2.14 | .62 | 0.00 | 0.00 | 13.32 |

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STATISTICAL PARAMETERS FOR STATION   07170000     ELK RIVER NEAR ELK CITY, KANSAS
  ARKANSAS RIVER BASIN


                              ARTH.                  LOG PARAMETERS
                   MONTH     AVERAGE        MEAN   VARIANCE  STD. DEV.    SKEW


         1         OCT         221.18      .7633     3.9216     1.9803     -.8753
         2         NOV         199.68      .7421     4.2304     2.0568     -.9864
         3         DEC         105.40      .7743     3.5297     1.8787    -1.2300
         4         JAN         119.46      .8588     3.6232     1.9035    -1.2581
         5         FEB         152.11     1.3333     2.1019     1.4498    -1.8474
         6         MAR         330.16     1.6873     2.1792     1.4762    -1.7081
         7         APR         636.42     2.1550     1.5293     1.2367    -2.5448
         8         MAY         663.65     2.3898      .4654      .6822     -.3205
         9         JUNE        556.87     2.2826      .5596      .7481     -.4246
        10         JULY        315.54     1.6504      .9519      .9757      .0208
        11         AUG          54.46     1.0957     1.1884     1.0901    -2.0410
        12         SEPT        340.92     1.0676     3.6020     1.8979     -.9720
        13         ANNUAL      307.78     2.2802      .2703      .5199     -.8993


        SAMPLE SIZE   31 YEARS



LOG NORMAL DISTRIBUTION STATION   07170000     ELK RIVER NEAR ELK CITY, KANSAS
  ARKANSAS RIVER BASIN

                           YEARS FLOW IS NOT EXCEEDED

      MONTH   9 IN 10     2 IN 3     1 IN 2     1 IN 5   1 IN 10   1 IN 20          Q2 - Q10

     OCT      2004.55      41.00       5.80        .12       .02       .00              5.78
     NOV      2392.80      42.12       5.52        .10       .01       .00              5.51
     DEC      1523.61      38.05       5.95        .16       .02       .00              5.92
     JAN      1990.93      47.36       7.22        .18       .03       .01              7.20
     FEB      1555.64      90.21      21.54       1.30       .30       .09             21.24
     MAR      3800.41     209.23      48.68       2.78       .62       .18             48.05
     APR      5500.27     484.75     142.89      12.99      3.71      1.32            139.17
     MAY      1838.20     481.37     245.36      65.37     32.75     18.52            212.61
     JUNE     1744.31     401.35     191.69      44.95     21.07     11.27            170.63
     JULY      796.51     117.20      44.71       6.74      2.51      1.11             42.20
     AUG       311.38      36.59      12.47       1.51       .50       .20             11.97
     SEPT     3167.47      76.17      11.68        .29       .04       .01             11.64
     ANNUAL    884.43     318.58     190.63      69.58     41.09     26.61            149.54

              Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW
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## LOG-PEARSON TYPE III DISTRIBUTION FOR STATION 07170000
## ELK RIVER NEAR ELK CITY, KANSAS
## ARKANSAS RIVER BASIN

### DATA SKEW K FACTORS

| MONTH | SKEW | RETURN PERIOD<br>10 YRS | 6.67 YRS | 2 YRS | 1.25 YRS | 1.11 YRS | 1.05 YRS |
|---|---|---|---|---|---|---|---|
| OCT | -.88 | 1.1423 | .5097 | .1520 | -.7663 | -1.3392 | -1.8627 |
| NOV | -.99 | 1.1252 | .5157 | .1662 | -.7562 | -1.3401 | -1.8793 |
| DEC | -1.23 | 1.0479 | .5333 | .2205 | -.7092 | -1.3376 | -1.9341 |
| JAN | -1.26 | 1.0544 | .5321 | .2163 | -.7131 | -1.3382 | -1.9304 |
| FEB | -1.85 | .9068 | .5463 | .3008 | -.6175 | -1.3058 | -1.9927 |
| MAR | -1.71 | .9220 | .5459 | .2930 | -.6283 | -1.3106 | -1.9884 |
| APR | -2.54 | .7343 | .5332 | .3724 | -.4880 | -1.2303 | -2.0124 |
| MAY | -.32 | 1.2191 | .4754 | .0795 | -.8096 | -1.3218 | -1.7591 |
| JUNE | -.42 | 1.2039 | .4835 | .0951 | -.8020 | -1.3268 | -1.7914 |
| JULY | .02 | 1.2795 | .4316 | .0035 | -.8408 | -1.2841 | -1.6508 |
| AUG | -2.04 | .8542 | .5457 | .3255 | -.5814 | -1.2881 | -2.0640 |
| SEPT | -.97 | 1.1221 | .5165 | .1685 | -.7544 | -1.3403 | -1.8618 |
| ANNUAL | -.90 | 1.1469 | .5081 | .1481 | -.7689 | -1.3390 | -1.8581 |

### FREQUENCY OF FLOWS

YEARS FLOW IS NOT EXCEEDED

| MONTH | 9 IN 10 | 2 IN 3 | 1 IN 2 | 1 IN 5 | 1 IN 10 | 1 IN 20 | Q2 - Q10 |
|---|---|---|---|---|---|---|---|
| OCT | 1060.16 | 59.25 | 11.59 | .18 | .01 | .00 | 11.58 |
| NOV | 1138.42 | 63.49 | 12.13 | .15 | .01 | .00 | 12.12 |
| DEC | 553.43 | 59.73 | 15.44 | .28 | .02 | .00 | 15.42 |
| JAN | 734.09 | 74.41 | 18.64 | .32 | .02 | .00 | 18.62 |
| FEB | 444.65 | 133.46 | 58.81 | 2.74 | .28 | .03 | 58.53 |
| MAR | 1117.96 | 311.32 | 131.79 | 5.75 | .57 | .06 | 131.23 |
| APR | 1156.30 | 652.23 | 412.61 | 35.61 | 4.30 | .46 | 408.31 |
| MAY | 1665.20 | 517.78 | 278.01 | 68.78 | 30.77 | 15.24 | 247.24 |
| JUNE | 1524.83 | 440.88 | 225.80 | 48.16 | 19.50 | 8.76 | 206.30 |
| JULY | 792.06 | 117.88 | 45.06 | 6.76 | 2.50 | 1.10 | 42.57 |
| AUG | 106.41 | 49.05 | 28.22 | 2.90 | .49 | .08 | 27.73 |
| SEPT | 1574.91 | 111.66 | 24.40 | .43 | .03 | .00 | 24.37 |
| ANNUAL | 752.34 | 350.22 | 227.61 | 75.94 | 38.38 | 20.62 | 189.23 |

Q2 - Q10 IS THE 1 IN 2 YEAR FLOW MINUS THE 1 IN 10 YEAR FLOW

## ELK RIVER BED MATERIAL

The following information on the bed material was prepared by the staff of the Kansas Office of the Soil Conservation Service. (Additional ·diagrams on sphericity and shape factor were included in the original data set. Also, the plotted size distribution curves were included.)

Cross Section 3-1: Inspected 4/2/80

The section was investigated with an 8 feet probe to determine the thickness of the material in the bottom. Five feet of water with 2-3 inches of ice was penetrated before the probe encountered the bottom. The probe was pushed another 3 feet without encountering any resistance. It is assumed the bottom consisted of alluvium because both banks consist of alluvium.

Cross Section 3-3: Inspected 5/2/80

This section had 6.5 feet of water overlying the bottom. The probe was pushed another 12 inches before it become too hard to push. The material was not rock (Ls, SS, or Sh). It is assumed the bottom consists of alluvium, because both banks consisted of alluvium.

Cross Section 3-4: Inspected 5/2/80

Rock was encountered 2.5 feet below the channel bottom. The rock is assumed to be sandstone since the Ireland Sandstone member of the Lawrence Shale formation is exposed in the bluff north of the channel. Rock is exposed not in either bank of the channel. The material is CL, ML type alluvium.

The armor layer is estimated at 6 inches except for those areas where the 28 inches x 15 inches x 6 inches boulders are stacked one on another. The armor layer consists of sandstone fragments with the following gradation.

| % Retained By Size | Particle Dimensions | |
|---|---|---|
| 10 | 28 x 15 x 6 | Sandstone |
| 25 | 6 x 6 x 2 | Sandstone |
| 35 | 8 x 3 x 2 | Sandstone |
| 30 | 2 x 2.5 x 0.75 | Sandstone |

An alternate bar is located on the left (north) side of the channel. This bar contained 3 feet boulders along with materials found in the armor layer.

A sample of the bedload was not taken because of the depth of water (3 feet).

Cross Section 3-5: Inspected 5/2/80

Rock was encountered 6 feet below the bottom of the channel. The rock is assumed to be sandstones. The depth of water made it impossible to see the rock.

The Amazonia limestone member of the Lawrence Shale formation was exposed in the right bank. Alluvium was observed in the left bank.

The armor layer is estimated to range from 4-6 inches across the channel bottom. The armor layer consists of sandstone and limestone fragments with the following gradation:

| % Retained By Size | Particle Dimensions (inches | |
|---|---|---|
| 1 | 28 x 17 x 14 | Located by right bank limestone |
| 2 | 24 x 15 x 2.5 | Located by right bank limestone |
| 10 | 16 x 10.5 x 2 | Sandstone |

Cross Section 3-5: Inspected 2/5/80

| % Retained By Size | Particle Dimensions (inches | |
|---|---|---|
| 2 | 13 x 7 x 2 | Sandstone |
| 15 | 8.5 x 4 x 2 | Limestone |
| 30 | 5.5 x 3.5 x 2 | Limestone |
| 40 | 3.5 x 3.5 x 1 | Limestone |

A sample of the underlying material was taken and will be sent to the SML at Lincoln, Nebraska, for sieve analysis.

Cross Section 11-1: Inspected 5/2/80

The probe was pushed 18 inches below the bottom of the channel. The material pushed like shale. It is assumed to be shale of the Lawrence Shale formation. Alluvium was observed in both banks.

The armor layer is estimated at 4-6 inches. This layer consists of sandstone, limestone, and shale fragments with the following gradation:

| % Retained By Size | Particle Dimensions (inches) | |
|---|---|---|
| 15 | 43 x 38 x 1.75 | Gray silty clay shale |
| 5 | 40 x 26 x 11 | Sandstone |
| 10 | 28 x 20 x 4 | Limestone |
| 10 | 23 x 14 x 2 | Limestone |
| 5 | 13 x 11 x 1.5 | Gray silty clay shale |

| % Retained By Size | Particle Dimensions (inches) | |
|---|---|---|
| 20 | 9.5 x 6.5 x 1.5 | Sandstone |
| 20 | 6 x 4.5 x 1.5 | Sandstone |
| 10 | 4.5 x 2.5 x 3 | Sandstone |
| 5 | 4 x 3 x 1 | Limestone |

A sample of the underlying material was taken and will be sent to the SML at Lincoln, Nebraska, for sieve analysis.

Cross Section 11-7: Inspected 5/2/80

It was not possible to determine what is in the bottom at this section because the water depth is too deep (6-8 feet). Probing was done near the shore with the probe penetrating to 8 feet without encountering resistance. Alluvium was observed in both abutments. No rock was observed 1000' upstream or downstream from the bridge. Shale is assumed to underlie the bottom.

Cross Section 11-8: Inspected 6/2/80

Shale was encountered 4 feet below the bottom of the channel. The shale is the Lawrence Shale. The shale is a gray silty clay shale. Alluvium is in both banks of the channel.

The armor layer is estimated to range from 4-8 inches. This layer consists of limestone and standstones fragments with the following gradation:

| % Retained By Size | Particle Dimensions | |
|---|---|---|
| 1 | 24 x 14 x 4 | Sandstone |
| 5 | 13 x 13 x 2 | Sandstone |
| 35 | 9 x 6 x 1 | Limestone |
| 5 | 7 1/2 x 12 x 4 | Sandstone |
| 40 | 7 x 5 x 1.75 | Sandstone |
| 14 | 4 x 3 x 2.5 | Sandstone |

A sample of the underlying material was taken and will be sent to the SML at Lincoln, Nebraska for sieve analysis.

Cross Section 11-9: Inspected 6/2/80

Under 6 inches of ice was 3.5 feet of water at this section. Probing indicates 6 to 8 feet of gravelly material on the bottom with softer material underneath to the depth probed (12-16 inches). Because of the water depth, samples were not taken. Alluvium was observed in both banks.

Between Cross Sections 11-11 and 11-12 at Station 2180:
Inspected 6/2/80

Shale was encountered 12 inches below the bottom of the channel. The shale is the Lawrence Shale formation. The shale is fairly soft for 6 inches and then a very hard layer is encountered. This layer is assumed to be sandstone. The shale is a gray silty clay shale and is exposed 2 feet above the channel bottom in the right bank. Alluvium is observed in both banks. The right bank is vertical and eroding.

The armor layer is 4 inches thick and consists of limestone and sandstone fragments with the following gradation:

| % Retained By Size | Particle Dimensions (inches) | |
|---|---|---|
| 2 | 8 x 5.5 x 3 | Sandstone |
| 3 | 7 x 5 x 1 | Sandstone |
| 40 | 5 x 3 x .5 | Shaley Limestone |
| 4 | 4.5 x 3 x 2.5 | Limestone |
| 25 | 3.5 x 2.5 x .5 | Sandstone |
| 26 | 3 x 2 x .25 | Sandstone |

A sample of the underlying material was taken and will be sent to the SML of Lincoln, Nebraska for sieve analysis. A soil sample was taken from the right bank.

Cross Section 11-12: Inspected 6/2/80

Shale is exposed in the bottom of the channel. A few 2 feet sandstone fragments are scattered over the bottom. No armor or bedload exists at this location. Depth of weathering in the shale is 8". The shale is the Lawrence Shale formation. Alluvium is exposed in both banks. The shale is exposed 12 inches above the waterline in the left abutment. The shale is a gray silty clay shale. The left bank is vertical and eroding.

Between Cross Sections 11-14 and 11-15 at Station 2080: Inspected 6/2/80

Shale was encountered 3.5 feet below the bottom of the channel. This shale is the Lawrence Shale formation. It is a gray silty clay shale.

The armor layer is 4-6 inches. The layer consists of limestone and sandstone fragments with the following gradation:

| % Retained By Size | Particle Dimensions (inches) | |
|---|---|---|
| 1 | 11.5 x 6 x 3 | Limestone |
| 5 | 8 x 6 x 1 | Limestone |
| 25 | 5 x 3 x 2 | Limestone |

| % Retained By Size | Particle Dimesnions (inches) | |
|---|---|---|
| 30 | 4 x 3 x .75 | Limestone |
| 19 | 2.5 x 2.25 x .25 | Limestone |
| 20 | 2.5 x 2 x .75 | Limestone |

Alluvium is exposed in both abutments. A sample of the underlying was taken and will be sent to the SML in Lincoln, Nebraska for sieve analysis.

Cross Section 11-15: Inspected 6/2/80

Rock was encountered 12 inches below the bottom of the channel. This rock is interpreted to be limestone.

The armor thickness is 6 inches with 6 inches of bedload underlying the armor. The armor layer consists of limestone and sandstone fragments with the following gradation:

| % Retained By Size | Particle Dimensions (inches) | |
|---|---|---|
| 5 | 22 x 17 x 4 | Limestone |
| 5 | 16 x 11 x 3 | Shaley Sandstone |
| 15 | 11.5 x 7 x 4 | Limestone |
| 15 | 9 x 7 x 3 | Limestone |
| 10 | 8 x 5 x 1.5 | Limestone |
| 10 | 3.5 x 2.5 x 2 | Sandstone |
| 5 | 3 x 2.5 x 1 | Sandstone |
| 25 | 3 x 2.25 x .25 | Limestone |
| 10 | 1.5 x 1.75 x .5 | Limestone |

Alluvium exposed in both banks of the channel.

Cross Section 13-2: Inspected 2/6/80

Limestone is exposed in the bottom of the channel. The limestone is clear of any armor or bedload. This limestone is the Amazonia limestone member of the Lawrence Shale formation.

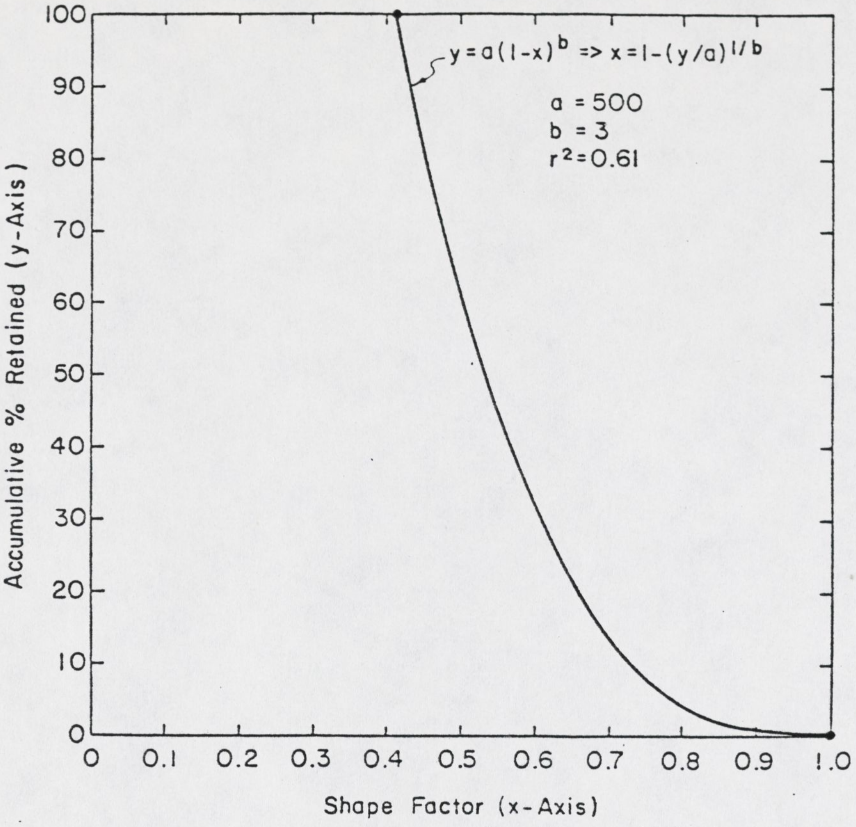
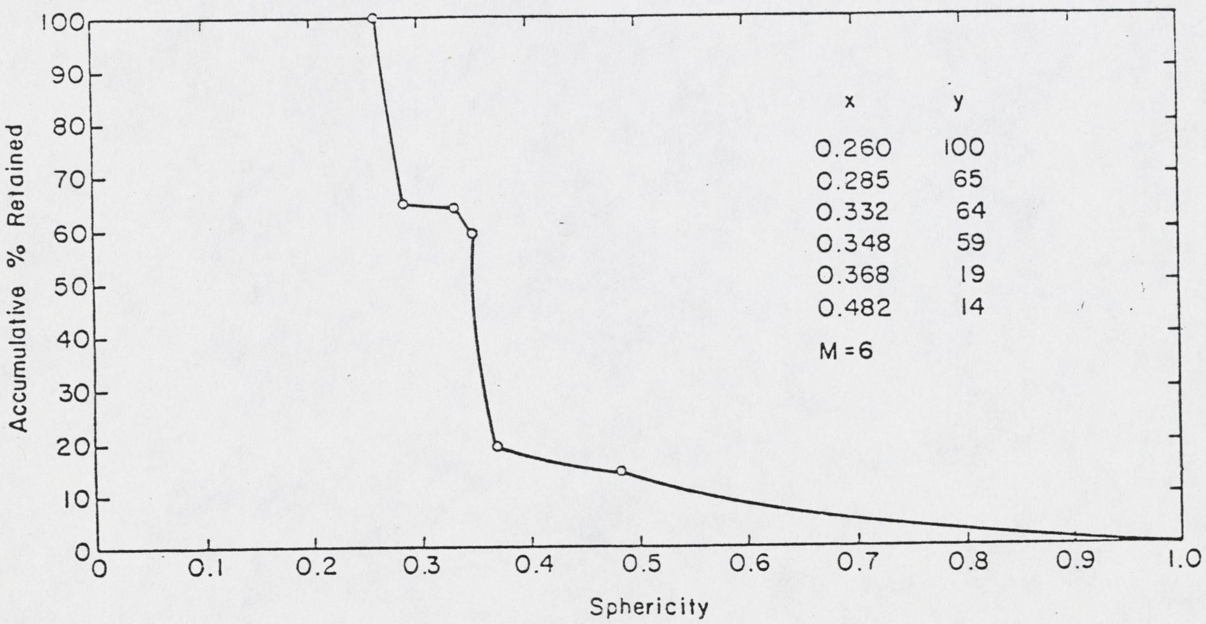


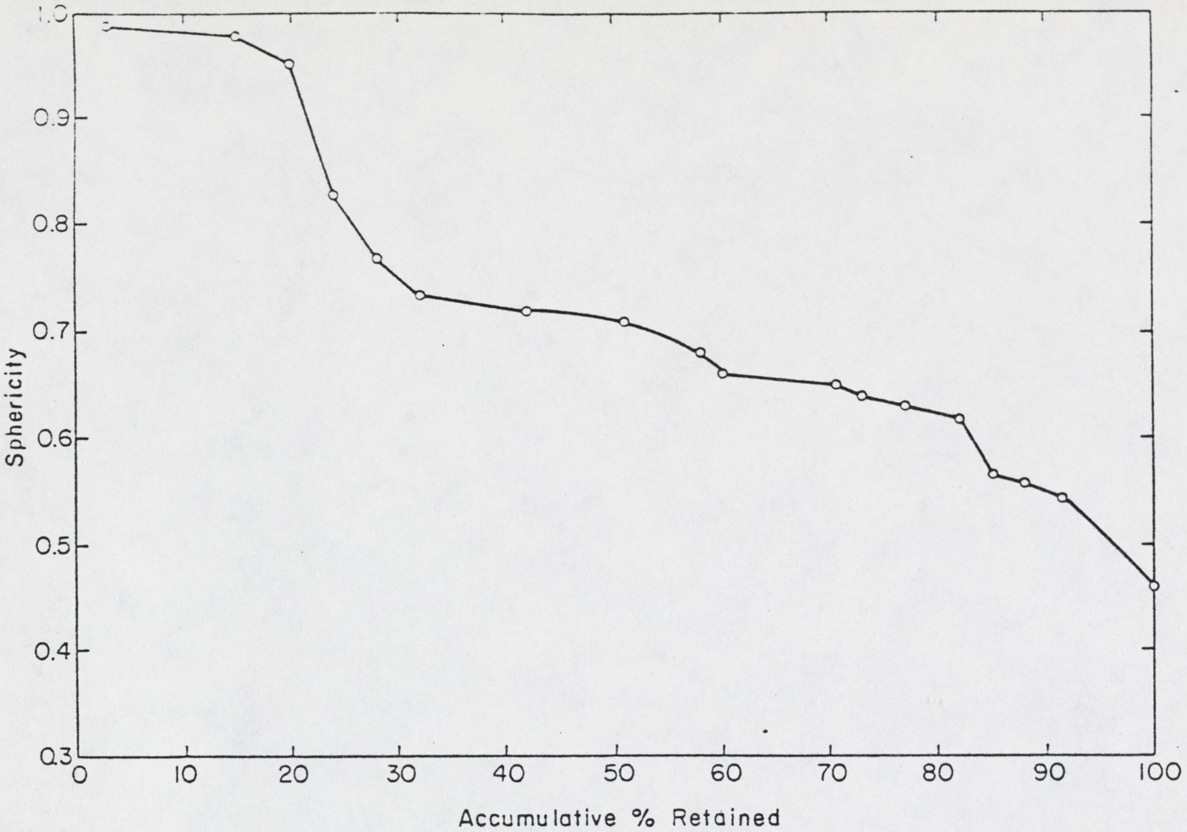
Figure C- . Channel bed material armor, shape factor-composite curve fit. $S_f = [(a\cdot b\cdot c)^{13}]/a$ where a is the longest axis of rock particle and b and c are the remaining axis of rock particle (Elk River, Kansas).



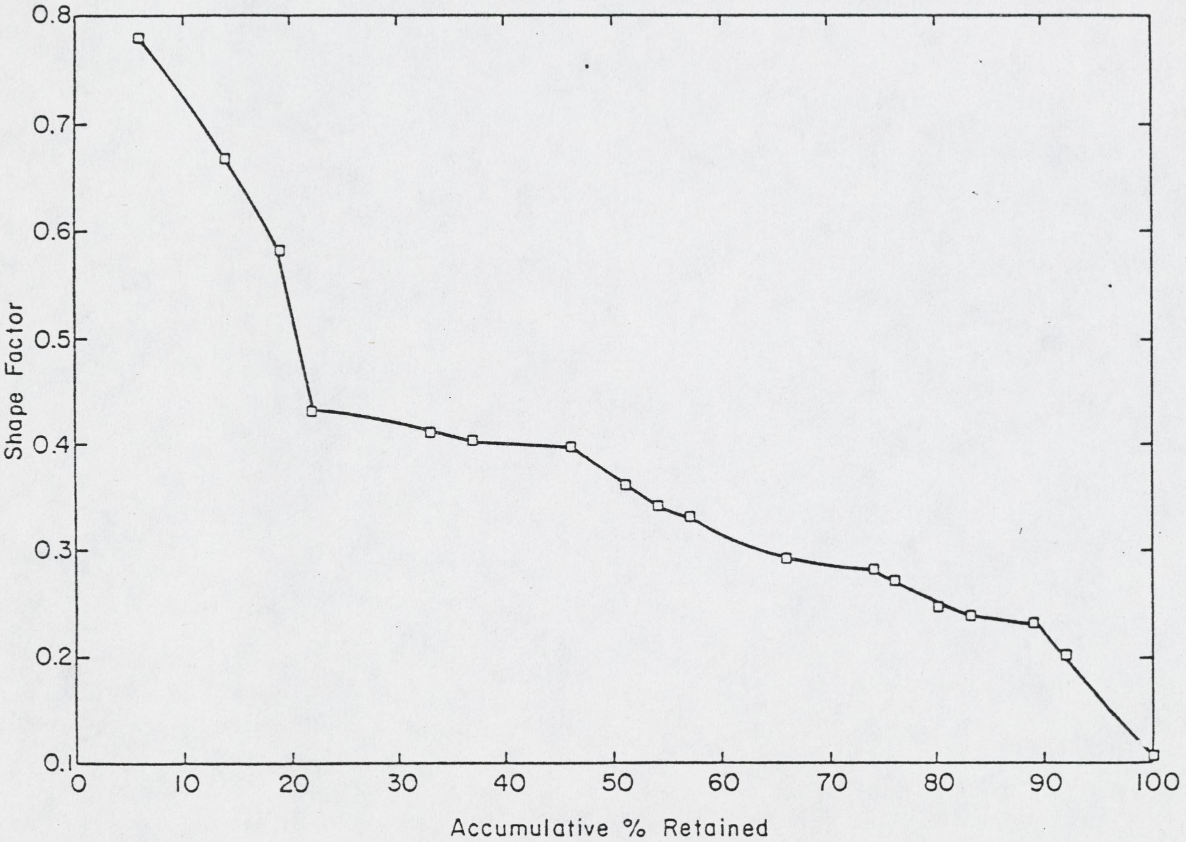
MECHANICAL ANALYSIS - PERCENT FINER

| LOCATION | 6" | 3" | 2" | 1 1/2" | 1" | 3/4" | 1/2" | 3/8" | No. 4 | No. 10 | No. 40 | No. 60 | No. 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream, x-sect 3-5, Bedload | 8 | 9 | 13 | 14 | 17 | 24 | 34 | 45 | 53 | 64 | 71 | 81 | 100 |
| Stream, x-sect 11-1 Bedload | 7 | 7 | 8 | 9 | 11 | 19 | 32 | 48 | 57 | 70 | 78 | 87 | 100 |
| Stream, x-sect 11-8, Bedload | 4 | 5 | 6 | 7 | 9 | 17 | 28 | 39 | 45 | 56 | 65 | 84 | 100 |
| Stream, x-sect 11-11, Bedload | 8 | 9 | 12 | 13 | 17 | 28 | 43 | 59 | 68 | 80 | 89 | 98 | 100 |
| Stream, x-sect 11-15, Bedload | 7 | 8 | 10 | 12 | 16 | 24 | 36 | 53 | 64 | 82 | 90 | 98 | 100 |

Soil mechanics laboratory data (lower Elk River stream channel).



Sphericity compared with percent retained (Elk River Watershed, Kansas; cross section 11-8, 3/31/80 C.T.)



Shape factor compared with percent retained (Elk River Watershed, Kansas; cross section 11-8, 3/31/80 C.T.)

## ELK RIVER SEDIMENT YIELD

The following information on sediment yield was developed by the staff of the Kansas Office of the Soil Conservation Service. Only one suspended sediment measurement has been made and is included.

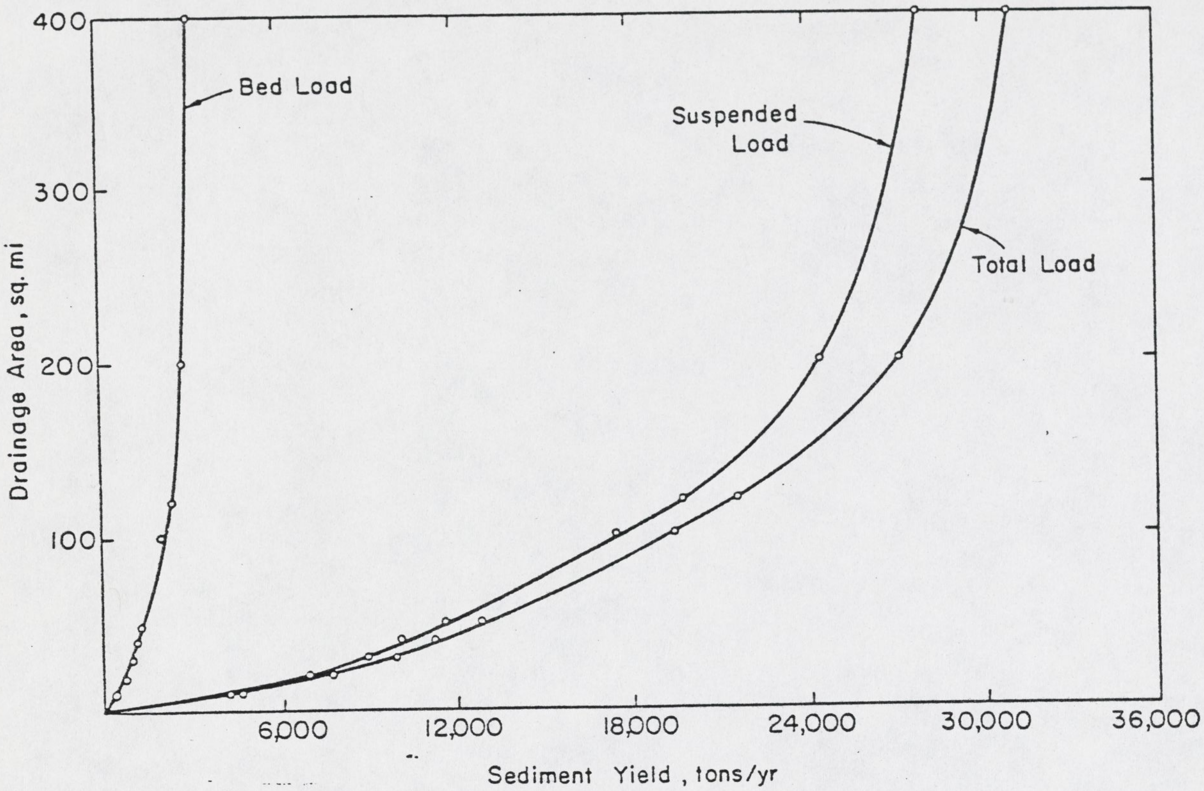


Figure C- . Drainage area compared with sediment yield without project (Elk River, Kansas 1980).

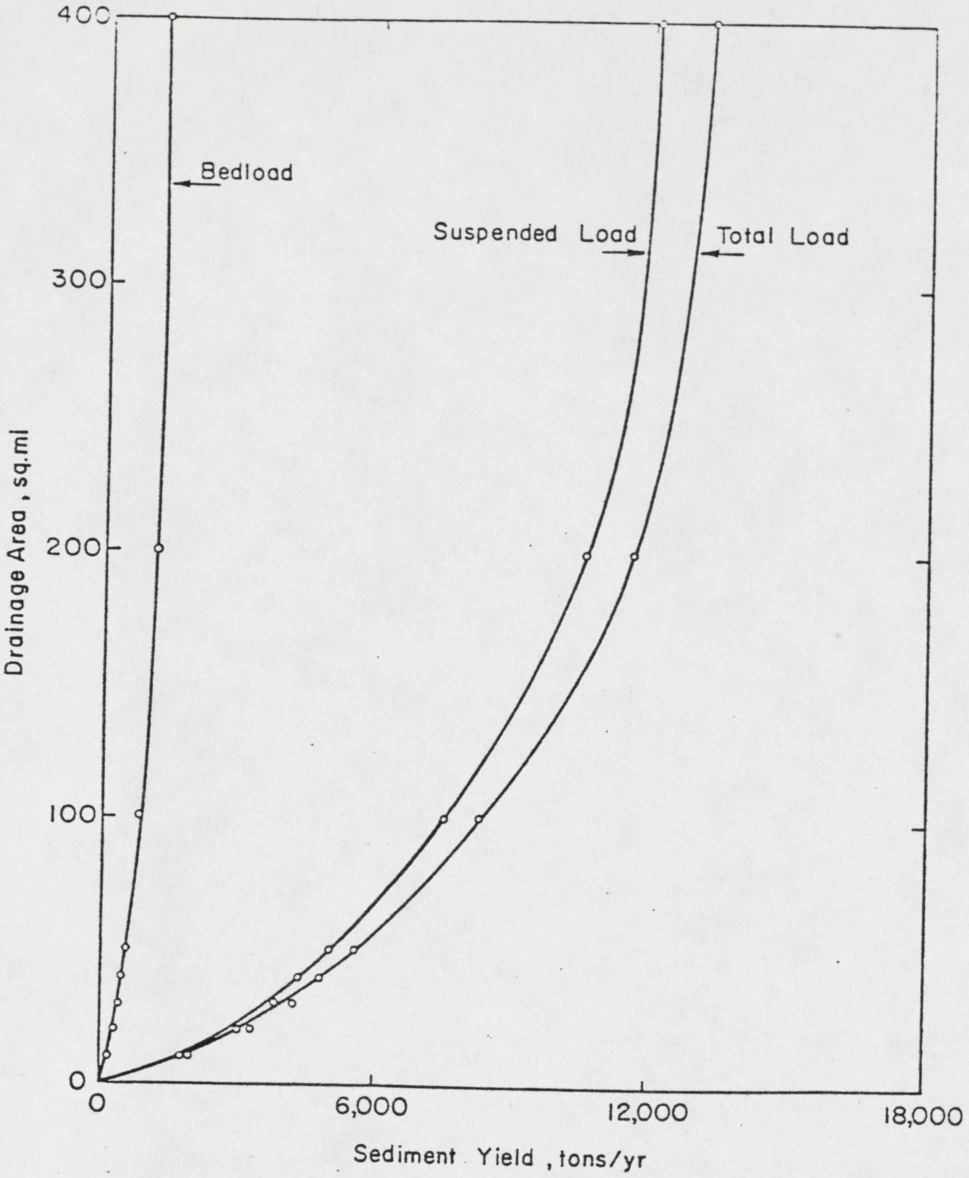


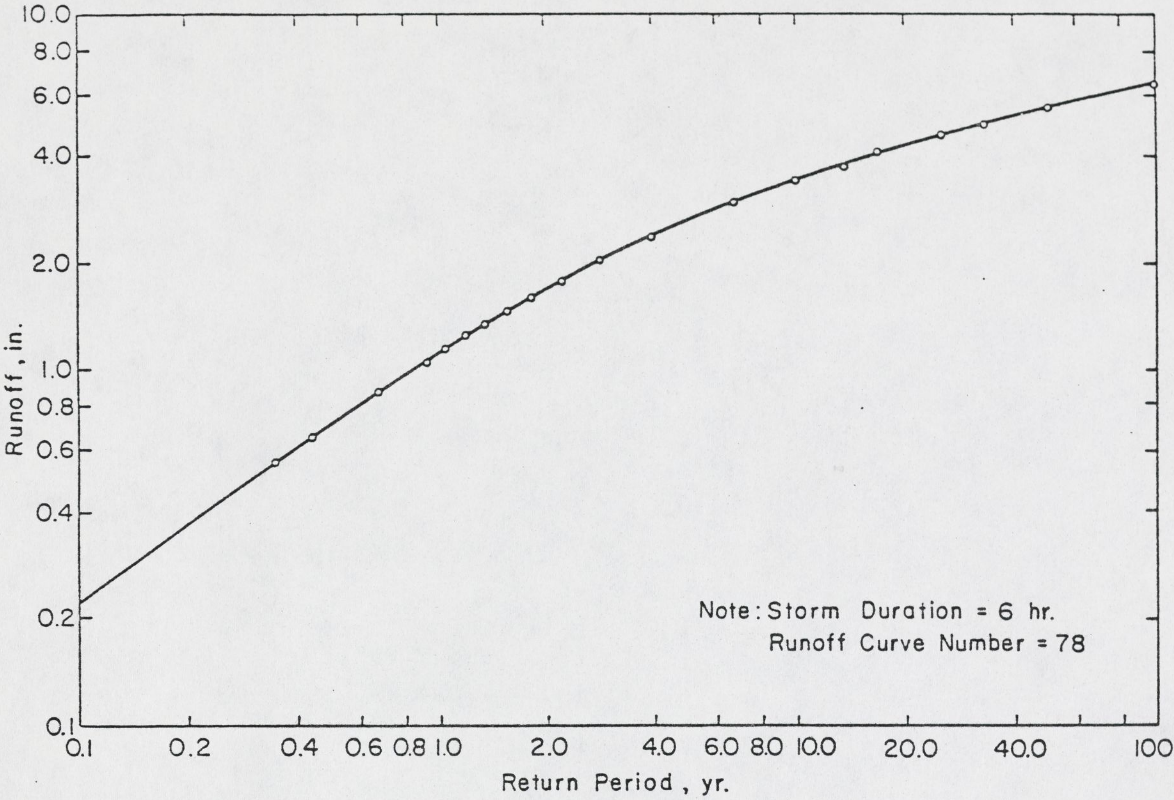
Figure C- . Draiange area compared with sediment yield with project (Elk River, Kansas 1980).

Suspended Sediment Measurement

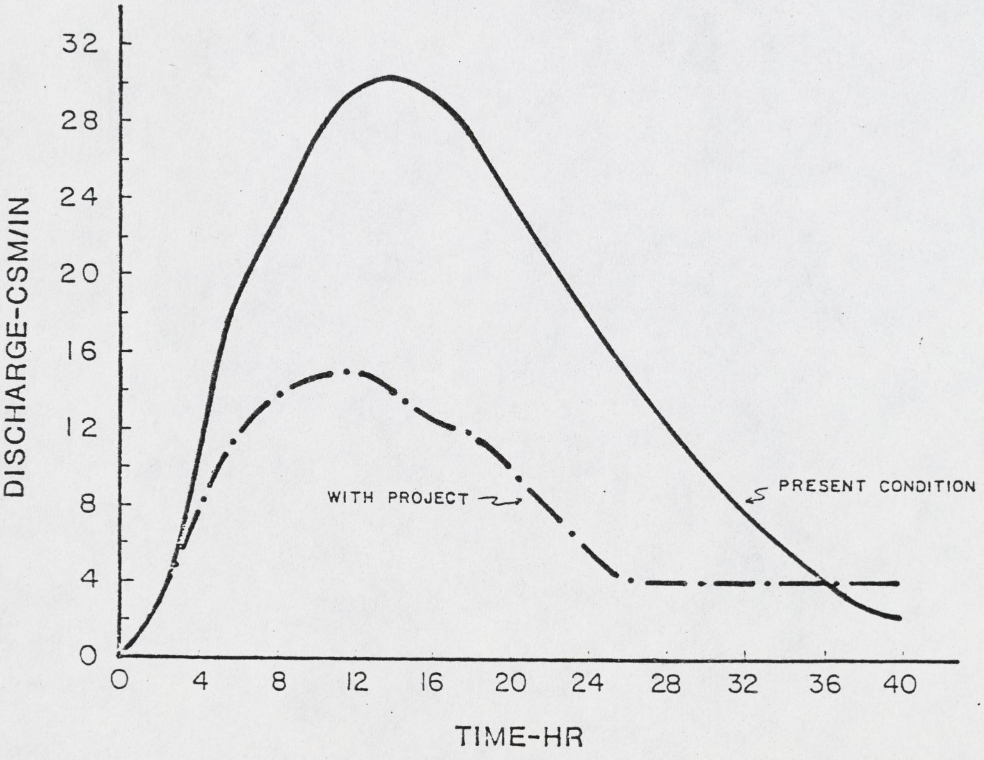
07169800-Elk River at Elk Falls, Kansas

| Date | Time | Discharge (cfs) | Specific conductance (micromhas) | Sediment suspended (MG/L) | Sediment discharge (T/Day) |
|---|---|---|---|---|---|
| 11-15-77 (1978 water year) | 1430 | 154 | 460 | 61 | 25 |

ELK RIVER HYDROGRAPHS AND ELEVATION VS. DISCHARGE DATA



Frequency-runoff curve (annual series) (Elk River, Kansas).



Unit discharge hydrograph (Elk River, Kansas).

Table C. Unit Discharge Hydrograph (Elk River, Kansas)

[See proceeding page]

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[a] discharge in cfs per sq. mi. per inch of runoff applicable for reaches 3 and 11.

[b] drainage area controlled equal 239.83 sq. mi. with average uncontrolled release rate from structures equal to 20 csm.

Elevation-discharge plots (Elk River, Kansas).

Unit Discharge Hydrograph Table (Elk River, Kansas)

| hr. Time | Discharge-csm/in.* condition Present | with Project** |
|---|---|---|
| 0 | 0 | 0 |
| 2 | 3.69 | 2.69 |
| 4 | 11.32 | 8.21 |
| 6 | 18.51 | 11.92 |
| 8 | 23.02 | 13.93 |
| 10 | 26.66 | 14.61 |
| 12 | 29.55 | 14.74 |
| 14 | 30.29 | 13.93 |
| 16 | 29.41 | 12.22 |
| 18 | 27.21 | 10.91 |
| 20 | 24.23 | 9.36 |
| 22 | 21.01 | 7.88 |
| 24 | 17.85 | 5.45 |
| 26 | 14.87 | 4.00 |
| 28 | 12.12 | |
| 30 | 9.72 | |
| 32 | 7.55 | |
| 34 | 5.56 | |
| 36 | 3.86 | |
| 38 | 2.70 | |
| 40 | 2.00 | |

| Reach | Drainage Area Sq. Mi. |
|---|---|
| 11 U.S. | 284.5 |
| 11 D.S. | 297.1 |
| 3 U.S. | 341.0 |
| 3 D.S. | 405.3 |

U.S. - Upstream

D.S. - Downstream

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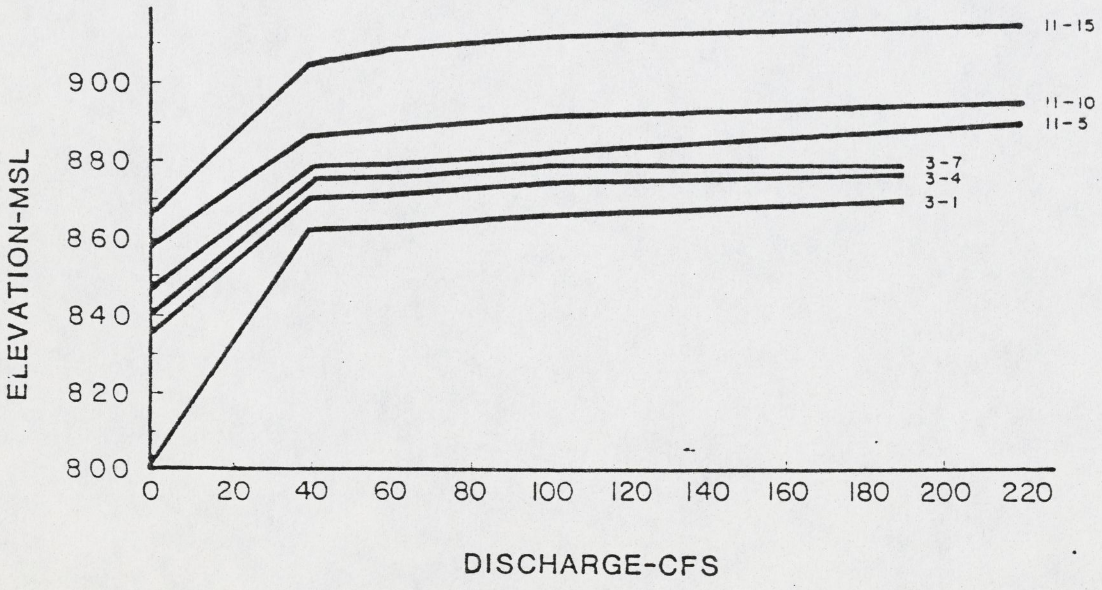
*discharge in cfs per sq. mi. per inch of runoff applicable for reaches 3 and 11.

**drainage area controlled equal 239.83 sq. mi. with average uncontrolled release rate from structures equal to 20 csm.



Elevation-discharge plots (Elk River, Kansas).

Table C-. Elevation-discharge table (Elk River, Kansas)[a]

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[a] Spatially-varied steady flow assumption was used.

[b] Contributing drainage area changes at low flows due to confluence.

# Elevation-Discharge Table (Elk River, Kansas)[a]

| | | | | Bankfull | | | | Out-of-Bank Flow | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Q=0 | | Q | | ft.$^2$ | fps | 40 csm | | 60 csm | | 100 csm | | 190 csm | | 220 csm | |
| x-sec | DA | Elev-msl | E-msl | cfs | csm | A | $\bar{v}$ | Q-cfs | E-msl | Q-cfs | E-msl | Q-cfs | E-msl | Q-cfs | E-msl | Q-cfs | E-msl |
| Reach 3 | | | | | | | | | | | | | | | | | |
| 3-1 | 405.3 | 832.2 | 855.5 | 6500 | 16 | 1862 | 3.49 | 15,708 | 863.6 | 23,562 | 865.8 | 40,530 | 865.6 | 77,007 | 870.5 | — | |
| 3-2 | 392.2 | 832.2 | 855.0 | 3750 | 10 | 2086 | 1.80 | 15,688 | 866.5 | 23,532 | 867.4 | 39,220 | 868.9 | 74,518 | 871.8 | — | |
| 3-3 | 390.5 | 833.2 | 864.5 | 9200 | 24 | 3586 | 2.57 | 15,620 | 867.9 | 23,430 | 869.0 | 39,050 | 870.9 | 74,195 | 873.6 | — | |
| 3-4 | 388.0 | 835.9 | 866.0 | 9700 | 25 | 3123 | 3.11 | 15,520 | 869.5 | 23,280 | 871.1 | 38,800 | 873.1 | 73,720 | 875.9 | — | |
| 3-5[b] | 387.6/341.3 | 837.2 | 867.5 | 7250 | 21 | 2180 | 3.33 | 13,652 | 871.9 | 20,478 | 873.4 | 38,760 | 875.5 | 73,644 | 878.1 | — | |
| 3-7 | 341.0 | 840.0 | 869.5 | 7250 | 21 | 3232 | 2.24 | 13,640 | 874.0 | 20,460 | 875.3 | 34,100 | 877.3 | 64,790 | 879.9 | — | |
| Reach 11 | | | | | | | | | | | | | | | | | |
| 11-1 | 297.1 | 842.5 | 873.0 | 8750 | 29 | 4630 | 1.89 | 11,884 | 874.9 | 17,826 | 876.5 | 29,710 | 879.6 | — | | 65,362 | 882.4 |
| 11-3 | 297.1 | 842.5 | 871.0 | 6300 | 21 | 3078 | 2.05 | 11,884 | 875.1 | 17,826 | 876.8 | 29,710 | 880.6 | — | | 65,362 | 887.9 |
| 11-4 | 296.6 | 844.8 | 871.0 | 5500 | 19 | 2261 | 2.43 | 11,864 | 876.6 | 17,796 | 878.7 | 29,667 | 881.7 | — | | 65,252 | 888.6 |
| 11-5 | 296.3 | 845.5 | 872.5 | 6500 | 22 | 1802 | 3.61 | 11,852 | 877.7 | 17,778 | 879.8 | 29,630 | 882.4 | — | | 65,186 | 888.9 |
| 11-7 | 295.2 | 849.2 | 877.5 | 8300 | 28 | 2667 | 3.11 | 11,808 | 880.0 | 17,712 | 881.9 | 29,520 | 884.3 | — | | 64,944 | 889.8 |
| 11-8 | 294.0 | 856.0 | 881.5 | 9600 | 33 | 3924 | 2.45 | 11,760 | 883.3 | 17,640 | 885.5 | 29,400 | 887.5 | — | | 64,680 | 891.5 |
| 11-9 | 291.8 | 857.2 | 881.0 | 6750 | 23 | 2091 | 3.23 | 11,672 | 885.8 | 17,508 | 888.1 | 29,180 | 890.5 | — | | 64,196 | 893.8 |
| 11-10 | 291.2 | 858.5 | 880.0 | 5000 | 17 | 1999 | 2.50 | 11,648 | 887.2 | 17,472 | 889.6 | 29,120 | 892.4 | — | | 64,064 | 895.9 |
| 11-11 | 290.8 | 860.6 | 886.0 | 7000 | 24 | 2730 | 2.56 | 11,632 | 889.3 | 17,448 | 890.8 | 29,080 | 893.6 | — | | 63,976 | 897.2 |
| 11-12 | 288.4 | 861.0 | 869.0 | 8500 | 29 | 2074 | 4.10 | 11,536 | 891.2 | 17,304 | 893.1 | 28,840 | 895.5 | — | | 63,448 | 899.0 |
| 11-14 | 286.3 | 863.2 | 891.0 | 8500 | 30 | 3546 | 2.40 | 11,452 | 893.2 | 17,178 | 895.6 | 28,630 | 897.8 | — | | 62,986 | 901.2 |
| 11-15 | 285.7 | 865.6 | 895.0 | 10,750 | 38 | 3030 | 3.88 | 11,428 | 895.5 | 17,142 | 898.2 | 28,570 | 901.0 | — | | 62,854 | 904.7 |

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[a] Spatially-varied steady flow assumption was used.

[b] Contributing drainage area changes at low flows due to confluence.