US Army Corps of Engineers
Hydrologic Engineering Center

Pilot Study for Storage Requirements for Low Flow Augmentation

April 1968

TP-7

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 1968

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Pilot Study for Storage Requirements for Low Flow Augmentation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
A.J. Fredrich

5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at 49th Annual Meeting of the American Geophysical Union in Washington, D.C., 8 April 1968

14. ABSTRACT
By supplementing traditional sequential routing techniques with a relatively simple optimization process and with appropriate generalized physical data it is possible to develop a screening procedure which provides simple application and rapid evaluation of flow augmentation needs and which utilizes most of the available physical data in order to minimize the possibility of an erroneous ranking of alternatives. A pilot stud consisted of an analysis of storage requirements for low-flow augmentation to meet pre-established quality demands at forty-six locations in the Grand River Basin, Missouri and Iowa. The studies required approximately eight minutes of computer time on the Control Data Corporation (CDC) 6600 computer. Data preparation for the computer required less than ten man-hours for the ninety-two studies. The procedure is flexible enough to consider all available physical and hydrologic data relative to the design and operation of a reservoir project. However, use of the procedure is not limited to areas where a large amount of data is available because analyses may be performed utilizing generated or generalized streamflow data and the simplest reservoir operating rules.

15. SUBJECT TERMS
systems analysis, computer programs, low-flow augmentation, reservoir design, optimization, synthetic hydrology, reservoir operations, flow control, regulation, waste dilution

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER
U	U	U	UU	34	

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

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A PILOT STUDY OF STORAGE REQUIREMENTS FOR LOW FLOW AUGMENTATION(1)

by Augustine J. Fredrich(2)

INTRODUCTION

The contrivance of a good screening procedure for use in the initial planning studies has been one of the most perplexing problems encountered in the planning and design of water resources development for large basins. Ordinarily the problems associated with devising a screening procedure are related to the magnitude of the screening task rather than to a lack of knowledge of what should be done. In the typical initial planning study the alternatives are abundant, the data are sparse, and the time and funds available are insufficient. Due to this situation, the screening procedure is often concocted in a manner which produces only a simple ranking function which is based upon many simplifying assumptions.

The use of simplifying assumptions is one of the most important factors in the creation of a good screening procedure. Each assumption should be evaluated with respect to its effect on the screening objective. Assumptions which obliterate important differences among alternatives should not be used because a procedure based upon such assumptions could produce results which would be questioned at a later stage in the planning process. When this occurs, the screening procedure that should be the foundation for the

(1) For presentation at 49th Annual Meeting of the American Geophysical Union in Washington, D.C., 8 April 1968.

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planning studies becomes the fault which may undermine the entire planning effort.

In order for the screening procedure to be of maximum benefit it should: (1) be relatively easy to apply, requiring only a limited amount of physical data; (2) be capable of producing evaluations for many alternative developments without exceeding either schedule or funds limitations of the overall study; and (3) produce results which are valid not only in the screening analysis but also as a useful starting point in the more detailed design studies.

If a screening procedure is to satisfy the third condition it must produce results which satisfy two criteria. First, the results for all alternative developments should be consistent with respect to the screening objective, that is, no assumption, either explicit or implicit, which would alter the ranking of alternatives can be tolerated. And second, the magnitude of the screening objective, in this case the storage requirement, should be sufficiently accurate to permit its use in more detailed analyses of the surviving alternatives.

The purpose of the pilot study described herein is to demonstrate that by supplementing traditional sequential routing techniques with a relatively simple optimization process and with appropriate generalized physical data it is possible to develop a screening procedure which provides simply application and rapid evaluation, and which utilizes most of the available physical data in order to minimize the possibility of an erroneous ranking of alternatives.

Furthermore, the procedure is economical with respect to both time and funds when applied via a high-speed, large-memory computer.

DESCRIPTION OF THE PILOT STUDY

The pilot study consists of an analysis of storage requirements for low-flow augmentation to meet pre-established quality demands at 46 locations in the Grand River Basin, Missouri and Iowa. The study was requested by members of the Work Group on Hydrologic Analyses and Projections - Missouri Basin Inter-Agency Committee because of a need to establish a screening procedure for use in the Comprehensive Framework Study of the Missouri River Basin. The framework study will require analyses at more than 2500 locations throughout the basin.

As a prelude to this study, various task forces were organized to assemble basic data, make economic, population, and demand projections, and to establish demand criteria for planning purposes. From the reports of these task forces quality demands and generalized seasonal variations in demands were established. The quality demands for use in the pilot study were supplied as an annual target demand in cfs with an associated seasonal distribution which expressed the monthly demands as a percentage of the annual target.

The Missouri River Basin was then divided into sub-areas of similar climatological and physiographic characteristics. Generalized reservoir area-capacity relationships were developed for each sub-area. Analyses of climatologic and hydrologic data for each sub-area provided seasonal patterns and annual indices of runoff and evaporation for computation of net evaporation. Existing sediment data for each sub-area were related to soil types and runoff to develop generalized sediment deposition quantities for use in estimating sediment reserve storage requirements.

The objective of the initial screening studies is to obtain an estimate of storage required to meet the water quality demands on an individual site basis under specified shortage criteria. A screening procedure which would satisfy this objective using technical procedures consistent with those which will be utilized in advanced planning and design studies would be superior to a procedure which simply ranked alternatives because of the time savings which will result from the future use of data derived from the screening analyses.

ACQUISITION OF BASIC DATA

Streamflow data. Ten U. S. Geological Survey stream gaging stations in the Grand River Basin with lengths of record ranging from 6 to 43 years were initially selected for study. Two of the stations have record lengths greater than 40 years and only one station has less than 20 years of record. The station with six years of record was eliminated from the study because of its short length and because of the proximity of stations with longer records.

From inspection of the records of the nine remaining stations a 40-year base period (1924-1963) was adopted for use in the pilot study. The Hydrologic Engineering Center (HEC) computer program 23-67, "Monthly Streamflow Simulation"[1], was utilized to estimate the missing monthly flows at the seven stations which did not have recorded data for the entire 40-year study period.

This program performs a multiple correlation analysis of the concurrent records at each station and computes the mean, standard deviation, skew coefficient, and lag-one serial correlation coefficients of the streamflows for each month at each station. Using these statistical parameters and the results of the correlation analysis, the missing flow events are estimated by the computer from concurrent recorded data. A random component is then added to the estimated flows to preserve the variance exhibited by the historical flows. After this analysis streamflow data for the 1924-1963 study period were available for each of the nine base stations.

The flow data for the nine base stations were then used to estimate monthly streamflow data for each of the 46 study locations. The estimated streamflows were developed by use of drainage areas ratios and ratios of geometric mean annual runoff for each study location and the pertinent base station.

Area-capacity data. A generalized area-capacity curve was developed for the Grand River Basin by examination of the area-capacity curves for existing and planned reservoirs in the region. Despite the fact that this generalized relationship is probably not strictly representative of any particular reservoir, it appears that the use of the generalized data will provide reasonable estimates of water surface area for subsequent use in determining the effect of evaporation upon the storage requirements.

Evaporation data. Generalized net evaporation data for the Grand River Basin were developed from the pan evaporation data at Norwich, Iowa, and from precipitation stations throughout the basin. From analysis of these data a schedule was developed for monthly net evaporation expressed as a percentage of annual net evaporation. A similar schedule for monthly runoff was developed from analysis of the streamflow data. Examination of the historical records of streamflow and evaporation produced annual indices of runoff and evaporation. The net evaporation for each month is computed from the equation

$$NE_{j,k} = (EL-P)_j \times PE_k + RO_j \times PR_k$$

where $NE_{j,k}$ is the net evaporation in the kth month of the jth year

$(EL-P)$ is the lake evaporation minus precipitation index for the jth year

PE_k is the percent of the annual evaporation that occurs in the kth month

RO_j is the runoff index for the jth year

and PR_k is the percent of the annial runoff that occurs in the kth month

Demand data. The demand data for this study were based upon consideration of quality parameters such as total dissolved solids, chlorides, sulfates, coliform organisms, temperature, BOD, and dissolved oxygen. It was found that in most cases the requirement of 5 mg/l of dissolved oxygen was the controlling quality demand.

Maximum annual demands in cubic feet per second were estimated for each of the 46 study locations. Seasonal variations in the water quality demands are expected and these variations are accounted for by a schedule which expresses each monthly demand as a percentage of the annual maximum demand.

The consideration of seasonal variations in streamflow and demand is an important aspect of this study. One of the basic assumptions common to virtually all simplified methods used in screening studies is that the demand is uniform. It can be shown, however, that this assumption, if untrue, can cause large errors in both the estimates of storage requirements and the ranking of alternatives.

Sediment reserve storage. Sediment storage requirements were based upon an assumed 100-year project life. From an analysis of the sediment producing characteristics of the basin it was estimated that sediment deposition would occur at the rate of 200 acre-feet per year per square mile of drainage area. Inactive storage was provided at each location for the 100-year sediment volume.

STUDY ASSUMPTIONS

Shortage criteria. One of the most important aspects of this study was the necessity for establishment of a shortage indicator that would give an accurate representation of the comparative shortages at various locations and yet be amenable to some type of mathematical evaluation. It was believed that shortage frequency which is often employed as an indicator would not be suitable for this study because of the basic incompatibility of the frequency concept and the reservoir routing techniques that were to be employed in the study.

It appeared that some indicator which would account for both frequency and magnitude would be more desirable than one which accounted for frequency alone. An indicator of this type, if properly computed, could embody all of the pertinent information relative to shortages except for information concerning their time distribution. Another important property of this type of indicator is the likelihood that there would be a recognizable relationship between the indicator and storage requirements. The indicator adopted was the shortage index originally proposed by Leo R. Beard[2]. This index possessed all of the necessary properties and there were indications that a definite relationship existed between shortage index and storage requirements.

Beard's shortage index is defined as the sum of the squares of the annual shortages (expressed as a ratio of the annual demand) converted to a 100-year base. This implies that the economic consequences of shortages vary as the square of the shortage, i.e., a 20 percent annual shortage is four times as severe as a 10 percent annual shortage in terms of the economic consequences.

If the demand is not uniform, the shortage index is calculated by computing for each year the average shortage and the average demand. The ratio of the average shortage to the average demand is computed and squared. Finally the squares are summed for all years and the total is converted to a 100-year base by multiplying by 100 and dividing by the number of years actually involved. A sample computation of the shortage index is shown on Page 3 of Exhibit 6.

Reservoir location. Since one of the objectives of the screening procedure is to determine the relative need for storage to meet quality demands at the various locations it was decided that the pilot study should be based upon the assumption that each location would be analyzed as if it were the only demand location in the basin. It was recognized that this would give an inaccurate representation of the storage requirements for the basin as a whole because in reality there would be improvements at some demand locations due to upstream storage. These improvements, however, could be calculated and accounted for in a system operation study for the entire basin but such a study is beyond the scope of normal screening studies.

In the pilot studies a reservoir site was assumed to exist immediately upstream of the demand location so that the demand would be supplied solely from reservoir releases. However, the screening procedure developed is not dependent upon this assumption. Provisions were made for assuming that the reservoir site would be located some distance upstream from the demand location.

Reservoir operation. For purposes of the pilot study it was assumed that there would be no flood control storage in any reservoir. Furthermore, it was assumed that there would be no competing conservation demands in the pilot study. The effects of flood control storage and operation and the effects of other conservation purposes would be considered in future planning studies. Again, however, the adapted procedure does not preclude the consideration of these aspects in the screening stage.

It was assumed that each project would be operated to supply the full water demand at the demand point as long as there is water available in the active storage. When the active storage is depleted, no water is supplied to the demand point although evaporation continues from the sediment reserve storage. Supply to the demand point is not resumed until the inflow is sufficient to offset the evaporation demand and the storage is returned to the minimum active storage level. All inflows in excess of the demands are spilled if the reservoir capacity is equal to the sum of the active storage and the sediment reserve storage, i.e., there is no provision for storage above the top of the active storage.

Consideration was given to the possibility that the reservoir might be operated in a manner which would allow small shortages at the beginning of a drought in hopes of averting large shortage later in the drought. However, it was believed that this too could be better accounted for in the future studies although the capabilities for operating in this manner are included in the adopted procedure.

PROSECUTION OF THE PILOT STUDY

Target shortage index. A target shortage index of 0.25 was selected for use in the pilot study. This would be approximately the index which would result from one 15 percent annual shortage every ten years. However, it should be recognized that more frequent shortages of lesser magnitude or less frequent shortages of greater magnitude would also produce a shortage index of 0.25.

Technical methods. The pilot study consisted of performing monthly sequential reservoir routing studies for each location to determine the storage required to supply the given demands with a shortage index of 0.25. The HEC computer program 23-45, "Reservoir Yield"[3], was available for performing the routing studies for a given storage capacity. However, when the storage requirement is unknown a great deal of time is consumed in analysis of the results of a trial run and in making estimates for subsequent runs. This becomes impractical when large numbers of projects are to be studied. To circumvent this time-consuming phase of the study an optimization routine was developed to enable the computer to analyze results, make new estimates, and make new routings until the target is achieved.

Optimization routine. The major problem associated with the development of the optimization routine for this study is that the relationship between storage and shortage index is very irregular in most cases. One would expect this to be true because the relationship is dependent upon seasonal variations in streamflow, evaporation, and demand. As shown on Exhibits 1 thru 3, the relationships between storage and shortage index are not smooth curves and are not amenable to simple mathematical analysis.

The optimization routine for this study would have to be relatively efficient because a complete month-by-month routing of the 40-year study period is necessary for each trial. The final construction of the optimization routine required that a routing be made under natural conditions to determine whether or not storage was required to meet the target shortage index. If the shortage index under natural conditions exceeded the target shortage index, a routing was made with no active storage in order to obtain the shortage index at the top of the sediment reserve storage.

This shortage index and the corresponding storage as well as those resulting from all subsequent trials are stored in memory. New estimates of storage required to achieve the target are made by straight line interpolation if points have been obtained on both sides of the target. If points are only available on one side of the target or if the two closest points are both on the same side of the target, straight line extrapolation is used to obtain a new storage estimate. The stored shortage indices and the corresponding shortages are scanned by the computer after each estimate to insure that the estimate is reasonable before the trial routing is made.

Exhibit 5 shows the progress of the optimization routine in determining the required storage at Galt, Missouri for a target demand of 15.5 cfs. The estimated storage requirement and the resulting shortage index are underlined for each trial and the trials are separated by dashed lines. The curve showing storage vs. shortage index for this location is included as Exhibit 3. On this exhibit the small numbers near the circled points denote the optimization trial number and thus one can readily trace the progress of the optimization routine. The unnumbered points were computed after the study was completed in order to better define the curve for illustrative purposes.

Tolerance limits smaller than those justifiable by the data were used in order to demonstrate the feasibility of the procedure. Optimization was not declared until the computed shortage index was within $\pm$ 1% of the target value of 0.25.

Upon determination of the storage requirement the program prints out a detailed monthly routing for the 40-year study period. This routing shows, for each month of each year, the inflow, end-of-month storage, evaporation, demand, release, and shortage. A sample of this printout for Galt, Missouri, is shown as Exhibit 6 (3 pages). This can be used to determine when the shortages occurred and the magnitude of each shortage. It can also be used as a guide in estimating changes in operating criteria to minimize shortages in future analyses.

Exhibit 4 is a tabulation which shows the storage required for a shortage index of 0.25 at each of the 46 locations studied. This exhibit also shows storage requirements for a shortage index of 0.25 with a demand ten times the actual demand. These data were computed in order to thoroughly test the optimization routine and in order to demonstrate the capabilities of the procedure.

SUMMARY

The studies described herein required approximately eight minutes of computer time on the Control Data Corporation (CDC) 6600 computer. The optimization routine required, on the average, about seven trials to obtain the required storage. The number of trials required appeared to be almost independent of the initial estimate of storage furnished to the computer. However, the irregularity of the storage vs. shortage index curve was very influential upon the number of trials required - the most irregular curves requiring the greatest number of trials.

The estimation of missing flow events required 29 seconds of computer time on the CDC 6600 and the flow data were punched out from this program in a form which was usable for the monthly routing analyses.

Data preparation for the computer required less than ten man-hours for the 92 studies. This time does not include the time required for development of demand data, seasonal variations in runoff and evaporation, and generalized area vs. capacity relationship.

The pilot study demonstrates the feasibility of a screening analysis conducted almost wholly by computer. The procedure is flexible enough to consider all available physical and hydrologic data relative to the design and operation of a reservoir project. However, use of the procedure is not limited to areas where a large amount of data is available because analyses may be performed utilizing generated or generalized streamflow data and the simplest reservoir operating rules.

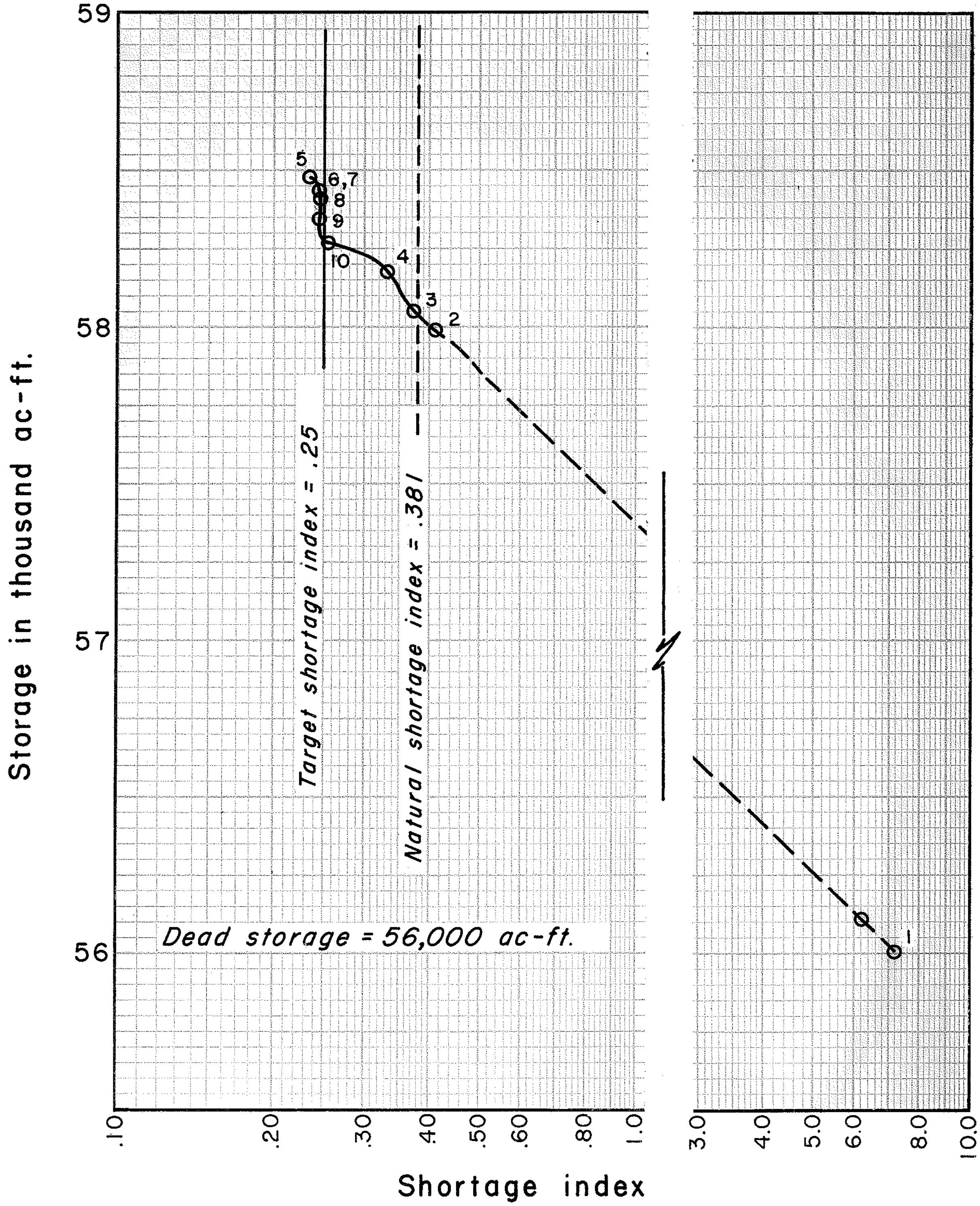
Since the procedure is capable of utilizing all available data it can be expected to produce results which are considerably better than those obtained by most other simplified techniques. The results should be improved with respect to the magnitude of the storage requirement for any location and with respect to the relative ranking among locations. The availability of the detailed routing for the target shortage index is a bonus which should be invaluable in formulating criteria for more detailed analyses.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance of Mr. Harold Kubik of the HEC staff and the assistance and advice of Mr. Leo R. Beard, Chief of The Hydrologic Engineering Center. Mr. Elmo McClendon of the Corps of Engineers Missouri River Division was instrumental in effecting the necessary liaison between the Missouri Basin Inter-Agency Committee and The Hydrologic Engineering Center. Furthermore, his assistance in the acquisition of the basic physical and hydrologic data and in the formulation of the problem contributed significantly to the timely completion of the study.

REFERENCES

1. Beard, Leo R., "Monthly Streamflow Simulation", Computer Program Description, HEC Program No. 23-67, 1967.
2. Beard, Leo R., "Estimating Long-Term Storage Requirements and Firm Yield of Rivers", General Assembly of Berkeley of International Union on Geodesy and Geophysics, 1964, Surface Waters, pp. 151-166.
3. Beard, Leo R., "Reservoir Yield", Computer Program Description, HEC Program No. 23-45, 1965.

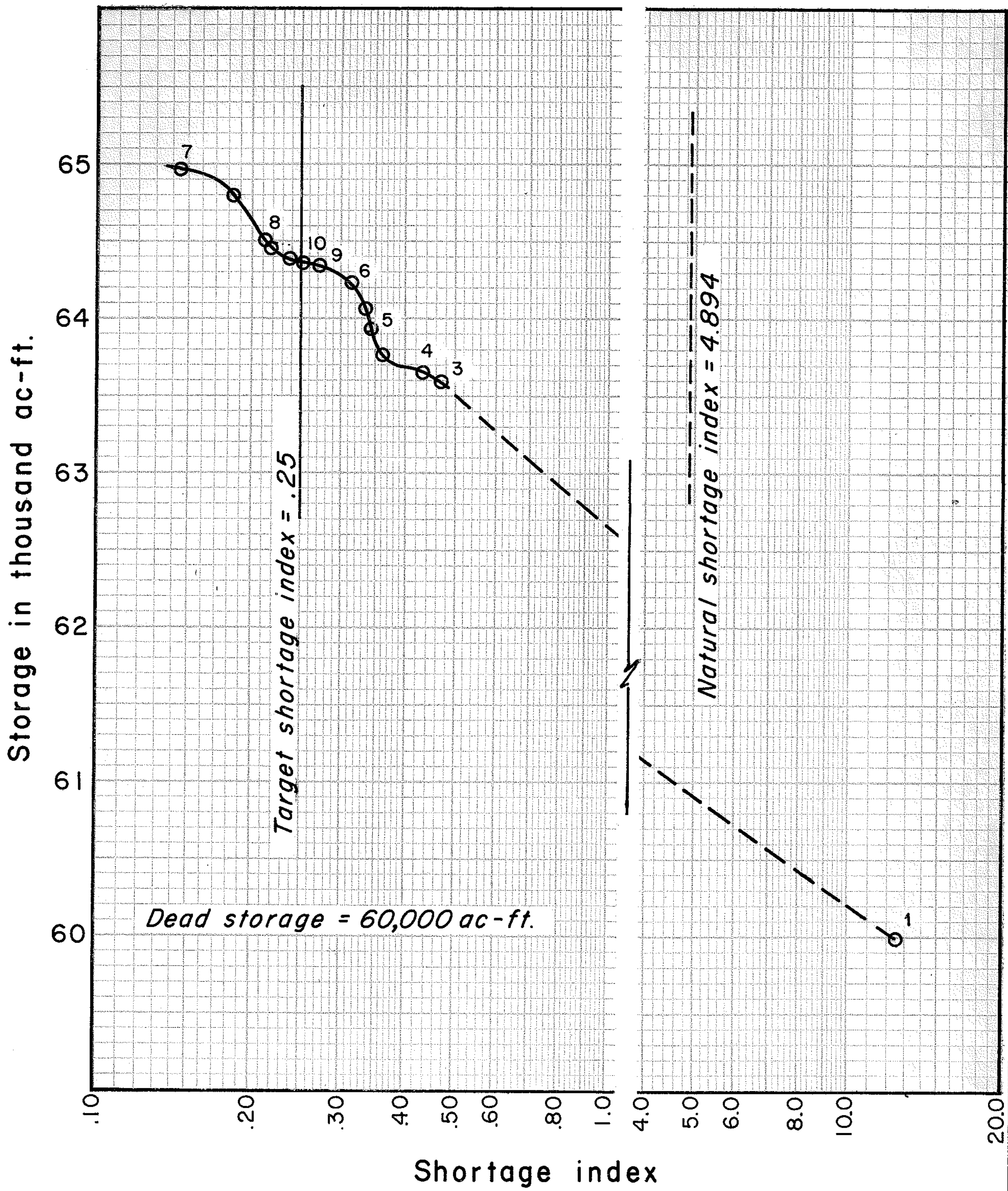


CHULA-STA. NO. 33

STORAGE VS SHORTAGE INDEX

TARGET Q = 3.40 c.f.s.

EXHIBIT 1

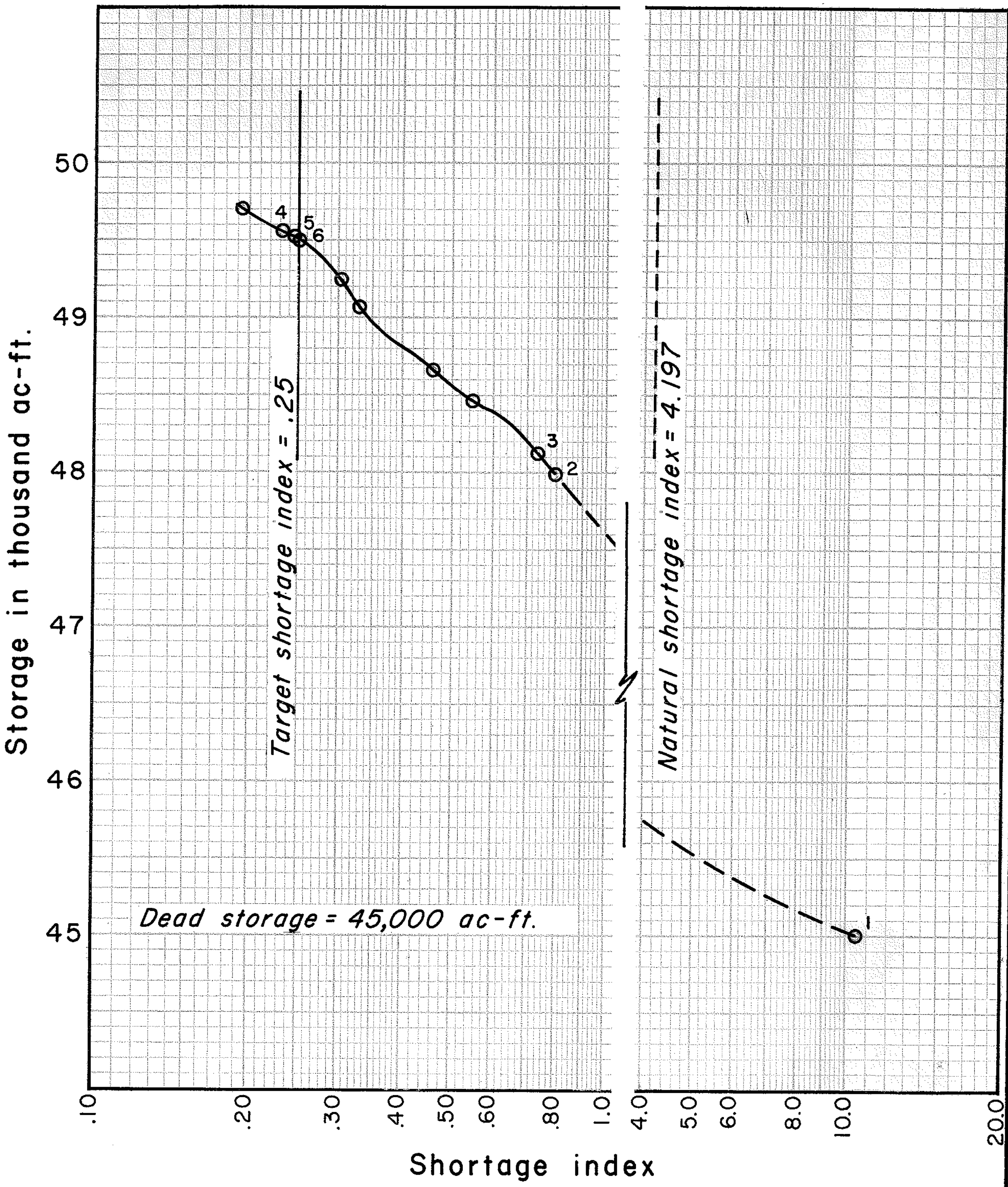


BETHANY - STA. NO. 10

STORAGE VS SHORTAGE INDEX

TARGET Q = 4.99 c.f.s.

EXHIBIT 2



GALT - STA. NO. 31

STORAGE VS SHORTAGE INDEX

TARGET Q = 15.50 c.f.s.

SUMMARY OF STORAGE REQUIREMENTS FOR WATER QUALITY CONTROL
GRAND RIVER BASIN, MISSOURI

							WITH ACTUAL WATER QUALITY REQUIREMENTS				WITH 10X ACTUAL WQ REQUIREMENTS			
Location (1)	Station No. (2)	Source Stream for Dilution Water (3)	Estimated Drainage Area at Point of Dilution in Sq. Mi. (4)	GMR in CFS/Sq. Mi. (5)	GMR in CFS (6)	Dead Storage (Sediment) AF (7)	Target Flow CFS (8)	Active Storage AF (9)	Shortage Index (11)	No. Computer Cycles (12)	Target Flow CFS (13)	Active Storage AF (14)	Shortage Index (15)	No. Computer Cycles (16)
Mt. Ayr	1	E. Fork, Grand	50	.36	18.0	10,000	2.63	1730	.254	15	26.3	21,960	.249	9
Grant City	2	M. Fork, Grand	75	.35	26.2	15,000	1.23	1390	.259	6	12.3	5,660	.251	7
Diagonal	3	W. Fork, Grand	80	.39	31.2	16,000	0.69	1260	.226	12	6.9	3,430	.251	9
Stanberry	4	Br. W. Fork, Grand	50	.35	17.5	10,000	2.14	1560	.251	13	21.4	12,900	.249	10
Kellerton	5	Lotts Creek	30	.37	11.1	6,000	0.53	710	.252	9	5.3	2,560	.251	7
Albany	6	E. Fork, Grand	380	.37	141.0	76,000	2.52	4580	.246	14	25.2	11,670	.245	13
Maysville	7	W. Fork, Locust Cr.	30	.45	13.5	6,000	1.14	390	.254	9	11.4	3,850	.252	8
Lamoni	8	Thompson	690	.35	252.0	138,000	3.29	0	.007	1	32.9	10,700	.251	6
Ridgeway	9	E. Fork, Big Creek	60	.39	23.4	12,000	0.57	1010	.224	4	5.7	2,820	.252	10
Bethany	10	Big Creek	300	.38	114.0	60,000	4.99	4380	.251	12	49.9	20,650	.250	8
Gallatin	11	Grand River	2250	.37	833.0	450,000	2.51	0	0	1	25.1	0	.147	1
Jamesport	12	Grand River					0.75	-	-	-	-	-	-	-
Hamilton	13		-	-	-	-	0.86	-	-	-	-	-	-	-
Breckenridge	14	Grand River	2500	.37	925.0	500,000	0.74	0	0	1	7.4	0	0	1
Greenfield	15	Thompson	12	.38	4.6	4,800	3.39	3630	.246	8	33.9*	515,430	.251	10
Afton	16	Twelve Mile Creek	40	.39	15.6	8,000	0.93	840	.240	11	9.3	5,510	.252	8
Davis City	17	Thompson	701	.35	247.0	140,200	0.42	0	0	0	4.2	0	.026	1
Garden Grove	18	Branch, Weldon	30	.41	12.3	6,000	0.41	720	.277	13	4.1	1,670	.255	12
Leon	19	Little River	35	.41	14.4	7,000	3.04	1480	.255	11	30.4*	51,180	.250	7
Princeton	20	Weldon	440	.41	180.0	88,000	2.19	3720	.250	9	21.9	8,110	.250	11
Spickardsville	21	Weldon	510	.41	209.0	102,000	0.54	0	.095	1	5.4	4,700	.252	6
Lineville	22	Weldon	220	.41	90.2	44,000	0.71	3210	.241	4	7.1	4,810	.268	9
Trenton	23	Thompson	1670	.41	685.0	334,000	4.59	0	0	0	45.9	11,240	.250	7
Chillicothe	24	Grand	4900	.39	1920.0	980,000	20.10	0	0	1	200.1	20,830	.251	6
Lathrop	25	Little Platte	-	-	-	-	-	-	-	-	-	-	-	-
Cameron	26	Shoal Creek	80	.45	36.0	16,000	5.39	1500	.249	5	53.9*	67,120	.251	8
Hamilton	27	Shoal Creek	200	.45	90.0	40,000	0.86	0	0	1	8.6	1,930	.252	6
Braymer	28	Shoal Creek	80	.50	40.0	16,000	1.06	0	.095	1	10.6	2,360	.248	6
Allerton	29	Chariton	-	-	-	-	-	-	-	-	-	-	-	-
Newtown	30	E. Fork, Medicine Cr.	160	.42	67.1	32,000	0.32	0	.020	1	3.2	1,820	.247	7
Galt	31	Medicine Creek	225	.44	99.0	45,000	1.55	0	.235	1	15.5	4,510	.250	7
Laredo	32	Medicine Creek	260	.44	114.0	52,000	0.45	0	.013	1	4.5	2,450	.248	11
Chula	33	Medicine Creek	280	.44	123.0	56,000	0.34	0	.003	1	3.4	2,350	.247	11
Meadville	34	Parsons Creek	90	.51	45.9	18,000	0.54	750	.220	12	5.4	1,510	.251	11
Milan	35	E. Fork, Locust Cr.	65	.48	31.2	13,000	2.53	930	.250	13	25.3	17,630	.250	6
Browning	36	Locust Creek	380	.47	179.0	76,000	0.50	0	.015	1	5.0	2,840	.248	8
Linneus	37	Locust Creek	550	.47	258.0	110,000	0.57	0	.007	1	5.7	3,590	.248	8
Green City	38	Yellow Creek	20	.48	9.6	4,000	0.76	350	.248	9	7.6	4,950	.251	11
Brookfield	39	Yellow Creek	200	.51	102.0	40,000	8.43	2470	.249	11	84.3	54,810	.250	8
Marcelina	40	E. Yellow Creek	150	.53	79.5	30,000	3.79	1540	.255	10	37.9	16,830	.250	10
Mendon	41	Yellow Creek	400	.52	208.0	80,000	1.13	0	.084	1	11.3	3,680	.252	7
Laclede	42	Turkey Creek	25	.52	13.0	5,000	0.97	420	.238	11	9.7	6,380	.250	11
Hale	43	Grand River	6880	.40	2750.0	1,376,000	1.15	0	0	0	11.5	0	0	1
Bogard	44	Big Creek	15	.54	8.1	3,000	0.33	190	.243	13	3.3	950	.258	8
Bosworth	45	Grand River	7680	.40	3070.0	1,536,000	0.56	0	0	1	5.6	0	0	1
Brunswick	46	Grand River	7900	.40	3160.0	1,580,000	4.25	0	0	1	42.5	0	0	1

Col (3) - Effluent from town assumed to be piped up to 10 miles distance to reach stream with greater runoff potential.
Col (5) - Geometric Mean Annual Runoff (GMR) based on selected regression equations in Generalized Streamflow Probability working papers.
Col (7) - Dead storage assumed to be equivalent to 100-year sediment allocation, which was based on 200 acre-feet per square mile per 100 years.
Col (8) - Target flow shown is mean cfs required in month of maximum demand. Average annual requirements are 50% of these values.
Col (9) - Based on Hydrologic Engineering Center computer study of monthly inflows during period 1924 - 1963, to achieve shortage index of 0.25.
Col (10) - Shortage index is accumulated sum of squares of annual shortages, in per cent, during a 100-year period.
Col (11) & Col (15) - The number of times the computer conducted a 40-year, monthly reservoir regulation study to determine the optimum storage required.
*Runoff capabilities of the stream are less than the flow requirements and cannot support the reservoir storages indicated.

EXHIBIT 4

PILOT STUDY FOR MRD LOW FLOW ANALYSIS
GRAND RIVER BASIN - NOVEMBER, 1967

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 1 TOTAL STORAGE = 48000 DEAD STORAGE = 45000 TARGET FLOW = 15.50

SHORTAGE INDEX IS 4.197 UNDER NATURAL CONDITIONS

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	43220			45000	1399	0	0	0	7.78	136.15	1.79	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET 10.636 DOWNSTREAM 0. POWER 0.

SHORTAGE INDEX IS 10.636 WITH NO ACTIVE STORAGE

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 2 TOTAL STORAGE = 48000 DEAD STORAGE = 45000 TARGET FLOW = 15.50

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	44135			48000	1459	0	0	0	7.78	136.01	.27	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .794 DOWNSTREAM 0. POWER 0.

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 3 TOTAL STORAGE = 48170 DEAD STORAGE = 45000 TARGET FLOW = 15.50

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	44135			48170	1463	0	0	0	7.78	136.00	.23	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .735 DOWNSTREAM 0. POWER 0.

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 4 TOTAL STORAGE = 49570 DEAD STORAGE = 45000 TARGET FLOW = 15.50

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	44540			49570	1497	0	0	0	7.78	135.95	.09	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .231 DOWNSTREAM 0. POWER 0.

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 5 TOTAL STORAGE = 49520 DEAD STORAGE = 45000 TARGET FLOW = 15.50

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	44540			49520	1496	0	0	0	7.78	135.96	.09	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .246 DOWNSTREAM 0. POWER 0.

GALT STA NO 31

NO. OF YRS = 40 OPT RUN NO 6 TOTAL STORAGE = 49510 DEAD STORAGE = 45000 TARGET FLOW = 15.50

GRAND AVERAGE

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
YR	138	44540			49510	1496	0	0	0	7.78	135.96	.10	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .250 DOWNSTREAM 0. POWER 0.

EXHIBIT 5

GALT - STA NO 31

NO. OF YRS = 40 OPT RUN NO 7 TOTAL STORAGE = 49510 DEAD STORAGE = 45000 TARGET FLOW = 15.50

YEAR 1924

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	36.23	45000	45000	49510	49510	15	0	0	0	3.10	35.99	0.	999999	11	0
2	155.46	45000	45000	49510	49510	29	0	0	0	3.10	154.94	0.	999999	11	0
3	373.42	45000	45000	49510	49510	87	0	0	0	6.20	372.00	0.	999999	11	0
4	80.60	45000	45000	49510	49510	131	0	0	0	6.20	78.40	0.	999999	11	0
5	11.55	45000	45000	49510	49510	189	0	0	0	6.20	8.47	0.	999999	11	0
6	604.37	45000	45000	49510	49510	44	0	0	0	15.50	603.63	0.	999999	11	0
7	50.68	45000	45000	49510	49510	408	0	0	0	15.50	44.04	0.	999999	11	0
8	119.90	45000	45000	49510	49510	160	0	0	0	15.50	117.30	0.	999999	11	0
9	11.47	45000	45000	49510	49510	146	0	0	0	6.20	9.02	0.	999999	11	0
10	1.81	45000	45000	49066	49510	174	0	0	0	6.20	6.20	0.	999999	5	0
11	3.70	45000	45000	48874	49510	43	0	0	0	6.20	5.20	0.	999999	5	0
12	10.32	45000	45000	49289	49510	29	0	0	0	3.10	3.10	0.	999999	5	0
YR	121			49289		1456	0	0	0	7.78	119.06	0.	999999		

YEAR 1925

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	5.23	45000	45000	49405	49510	15	0	0	0	3.10	3.10	0.	999999	5	0
2	196.71	45000	45000	49510	49510	29	0	0	0	3.10	194.30	0.	999999	11	0
3	44.52	45000	45000	49510	49510	87	0	0	0	6.20	43.09	0.	999999	11	0
4	344.03	45000	45000	49510	49510	131	0	0	0	6.20	341.83	0.	999999	11	0
5	32.52	45000	45000	49510	49510	189	0	0	0	6.20	29.44	0.	999999	11	0
6	418.43	45000	45000	49510	49510	44	0	0	0	15.50	417.70	0.	999999	11	0
7	17.74	45000	45000	49241	49510	407	0	0	0	15.50	15.50	0.	999999	5	0
8	9.32	45000	45000	48702	49510	159	0	0	0	15.50	15.50	0.	999999	5	0
9	74.20	45000	45000	49510	49510	145	0	0	0	6.20	58.19	0.	999999	11	0
10	341.61	45000	45000	49510	49510	175	0	0	0	6.20	338.77	0.	999999	11	0
11	140.40	45000	45000	49510	49510	44	0	0	0	6.20	139.67	0.	999999	11	0
12	145.45	45000	45000	49510	49510	29	0	0	0	3.10	144.98	0.	999999	11	0
YR	146			49510		1453	0	0	0	7.78	143.74	0.	999999		

YEAR 1926

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	217.84	45000	45000	49510	49510	-14	0	0	0	3.10	218.06	0.	999999	11	0
2	142.36	45000	45000	49510	49510	-28	0	0	0	3.10	142.85	0.	999999	11	0
3	74.00	45000	45000	49510	49510	-83	0	0	0	6.20	75.35	0.	999999	11	0
4	136.57	45000	45000	49510	49510	-124	0	0	0	6.20	138.65	0.	999999	11	0
5	15.13	45000	45000	49510	49510	-179	0	0	0	6.20	18.05	0.	999999	11	0
6	294.67	45000	45000	49510	49510	-41	0	0	0	15.50	295.36	0.	999999	11	0
7	22.23	45000	45000	49510	49510	-385	0	0	0	15.50	29.51	0.	999999	11	0
8	13.39	45000	45000	49510	49510	-152	0	0	0	15.50	15.86	0.	999999	11	0
9	1067.27	45000	45000	49510	49510	-138	0	0	0	6.20	1069.59	0.	999999	11	0
10	423.61	45000	45000	49510	49510	-166	0	0	0	6.20	426.31	0.	999999	11	0
11	86.77	45000	45000	49510	49510	-41	0	0	0	6.20	87.46	0.	999999	11	0
12	75.45	45000	45000	49510	49510	-29	0	0	0	3.10	75.90	0.	999999	11	0
YR	213			49510		-1380	0	0	0	7.78	214.69	0.	999999		

YEAR 1927

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	16.81	45000	45000	49510	49510	35	0	0	0	3.10	16.24	0.	999999	11	0
2	107.21	45000	45000	49510	49510	70	0	0	0	3.10	105.96	0.	999999	11	0
3	136.16	45000	45000	49510	49510	209	0	0	0	6.20	132.76	0.	999999	11	0
4	671.37	45000	45000	49510	49510	314	0	0	0	6.20	666.09	0.	999999	11	0
5	55.52	45000	45000	49510	49510	454	0	0	0	6.20	48.14	0.	999999	11	0
6	325.17	45000	45000	49510	49510	105	0	0	0	15.50	323.41	0.	999999	11	0
7	15.55	45000	45000	48544	49510	969	0	0	0	15.50	15.50	0.	999999	5	0
8	10.29	45000	45000	47849	49510	375	0	0	0	15.50	15.50	0.	999999	5	0
9	3.57	45000	45000	47355	49510	337	0	0	0	6.20	6.20	0.	999999	5	0
10	132.58	45000	45000	49510	49510	411	0	0	0	6.20	90.85	0.	999999	11	0
11	13.80	45000	45000	49510	49510	105	0	0	0	6.20	12.04	0.	999999	11	0
12	10.97	45000	45000	49510	49510	70	0	0	0	3.10	9.83	0.	999999	11	0
YR	124			49510		3453	0	0	0	7.78	118.88	0.	999999		

YEAR 1928

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	9.00	45000	45000	49510	49510	-10	0	0	0	3.10	9.17	0.	999999	11	0
2	166.61	45000	45000	49510	49510	-20	0	0	0	3.10	166.97	0.	999999	11	0
3	76.10	45000	45000	49510	49510	-61	0	0	0	6.20	77.09	0.	999999	11	0
4	60.57	45000	45000	49510	49510	-91	0	0	0	6.20	62.10	0.	999999	11	0
5	14.94	45000	45000	49510	49510	-132	0	0	0	6.20	17.08	0.	999999	11	0
6	458.90	45000	45000	49510	49510	-30	0	0	0	15.50	459.41	0.	999999	11	0
7	93.26	45000	45000	49510	49510	-284	0	0	0	15.50	97.88	0.	999999	11	0
8	147.00	45000	45000	49510	49510	-112	0	0	0	15.50	148.82	0.	999999	11	0
9	459.87	45000	45000	49510	49510	-102	0	0	0	6.20	461.57	0.	999999	11	0
10	150.65	45000	45000	49510	49510	-122	0	0	0	6.20	152.63	0.	999999	11	0
11	33.90	45000	45000	49510	49510	-30	0	0	0	6.20	34.41	0.	999999	11	0
12	103.81	45000	45000	49510	49510	-20	0	0	0	3.10	104.14	0.	999999	11	0
YR	147			49510		-1016	0	0	0	7.78	147.98	0.	999999		

YEAR 1929

	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
PER	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	47.48	45000	45000	49510	49510	-13	0	0	0	3.10	47.69	0.	999999	11	0
2	291.11	45000	45000	49510	49510	-26	0	0	0	3.10	291.57	0.	999999	11	0
3	291.68	45000	45000	49510	49510	-77	0	0	0	6.20	292.93	0.	999999	11	0
4	807.00	45000	45000	49510	49510	-116	0	0	0	6.20	808.94	0.	999999	11	0
5	77.94	45000	45000	49510	49510	-167	0	0	0	6.20	80.65	0.	999999	11	0
6	477.27	45000	45000	49510	49510	-39	0	0	0	15.50	477.91	0.	999999	11	0
7	212.39	45000	45000	49510	49510	-360	0	0	0	15.50	218.24	0.	999999	11	0
8	17.10	45000	45000	49510	49510	-141	0	0	0	15.50	19.39	0.	999999	11	0
9	42.43	45000	45000	49510	49510	-128	0	0	0	6.20	44.59	0.	999999	11	0
10	244.48	45000	45000	49510	49510	-154	0	0	0	6.20	246.99	0.	999999	11	0
11	207.07	45000	45000	49510	49510	-39	0	0	0	6.20	207.71	0.	999999	11	0
12	35.23	45000	45000	49510	49510	-26	0	0	0	3.10	35.64	0.	999999	11	0
YR	227			49510		-1284	0	0	0	7.78	228.84	0.	999999		

YEAR 1954

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	1.03	45000	45000	45000	49510	25	0	0	0	3.10	.62	2.48	999999	10	0
2	2.14	45000	45000	45000	49510	50	0	0	0	3.10	1.24	1.86	999999	10	0
3	2.68	45000	45000	45000	49510	151	0	0	0	6.20	.23	5.97	999999	10	0
4	18.17	45000	45000	45485	49510	227	0	0	0	6.20	6.20	0.	999999	5	0
5	59.94	45000	45000	48451	49510	338	0	0	0	6.20	6.20	0.	999999	5	0
6	273.07	45000	45000	49510	49510	81	0	0	0	15.50	253.91	0.	999999	11	0
7	1.32	45000	45000	47887	49510	751	0	0	0	15.50	15.50	0.	999999	5	0
8	15.32	45000	45000	47586	49510	290	0	0	0	15.50	15.50	0.	999999	5	0
9	1.00	45000	45000	47015	49510	262	0	0	0	6.20	6.20	0.	999999	5	0
10	77.52	45000	45000	49510	49510	320	0	0	0	6.20	31.73	0.	999999	11	0
11	2.60	45000	45000	49214	49510	81	0	0	0	6.20	6.20	0.	999999	5	0
12	1.39	45000	45000	49055	49510	54	0	0	0	3.10	3.10	0.	999999	5	0
YR	38			49055		2630	0	0	0	7.78	28.68	.86	999999		

YEAR 1955

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	27.94	45000	45000	49510	49510	49	0	0	0	3.10	19.74	0.	999999	11	0
2	142.29	45000	45000	49510	49510	98	0	0	0	3.10	140.52	0.	999999	11	0
3	45.77	45000	45000	49510	49510	294	0	0	0	6.20	40.99	0.	999999	11	0
4	77.33	45000	45000	49510	49510	442	0	0	0	6.20	69.91	0.	999999	11	0
5	144.32	45000	45000	49510	49510	638	0	0	0	6.20	133.95	0.	999999	11	0
6	21.03	45000	45000	49510	49510	147	0	0	0	15.50	18.56	0.	999999	11	0
7	96.71	45000	45000	49510	49510	1374	0	0	0	15.50	74.36	0.	999999	11	0
8	3.13	45000	45000	48216	49510	534	0	0	0	15.50	15.50	0.	999999	5	0
9	1.47	45000	45000	47457	49510	476	0	0	0	6.20	6.20	0.	999999	5	0
10	5.32	45000	45000	46839	49510	565	0	0	0	6.20	6.20	0.	999999	5	0
11	1.43	45000	45000	46415	49510	140	0	0	0	6.20	6.20	0.	999999	5	0
12	1.58	45000	45000	46229	49510	93	0	0	0	3.10	3.10	0.	999999	5	0
YR	47			46229		4850	0	0	0	7.78	44.03	0.	999999		

YEAR 1956

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	1.00	45000	45000	46052	49510	48	0	0	0	3.10	3.10	0.	999999	5	0
2	2.29	45000	45000	45911	49510	96	0	0	0	3.10	3.10	0.	999999	5	0
3	2.90	45000	45000	45421	49510	287	0	0	0	6.20	6.20	0.	999999	5	0
4	1.97	45000	45000	45000	49510	426	0	0	0	6.20	1.88	4.32	999999	10	0
5	2.45	45000	45000	44540	49510	611	0	0	0	6.20	0.	6.20	999999	10	0
6	3.20	45000	45000	44590	49510	140	0	0	0	15.50	0.	15.50	999999	10	0
7	127.58	45000	45000	49510	49510	1372	0	0	0	15.50	25.26	0.	999999	11	0
8	60.52	45000	45000	49510	49510	563	0	0	0	15.50	51.36	0.	999999	11	0
9	1.77	45000	45000	48738	49510	508	0	0	0	6.20	6.20	0.	999999	5	0
10	1.10	45000	45000	47823	49510	601	0	0	0	6.20	6.20	0.	999999	5	0
11	1.80	45000	45000	47413	49510	148	0	0	0	6.20	6.20	0.	999999	5	0
12	2.74	45000	45000	47292	49510	99	0	0	0	3.10	3.10	0.	999999	5	0
YR	18			47292		4899	0	0	0	7.78	9.50	2.16	999999		

YEAR 1957

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	2.00	45000	45000	47212	49510	12	0	0	0	3.10	3.10	0.	999999	5	0
2	2.86	45000	45000	47175	49510	24	0	0	0	3.10	3.10	0.	999999	5	0
3	2.68	45000	45000	46887	49510	72	0	0	0	6.20	6.20	0.	999999	5	0
4	92.53	45000	45000	49510	49510	110	0	0	0	6.20	46.61	0.	999999	11	0
5	111.06	45000	45000	49510	49510	162	0	0	0	6.20	108.43	0.	999999	11	0
6	7.43	45000	45000	48993	49510	37	0	0	0	15.50	15.50	0.	999999	5	0
7	5.23	45000	45000	48018	49510	343	0	0	0	15.50	15.50	0.	999999	5	0
8	2.23	45000	45000	47070	49510	132	0	0	0	15.50	15.50	0.	999999	5	0
9	1.67	45000	45000	46681	49510	119	0	0	0	6.20	6.20	0.	999999	5	0
10	5.71	45000	45000	46509	49510	142	0	0	0	6.20	6.20	0.	999999	5	0
11	4.23	45000	45000	46356	49510	35	0	0	0	6.20	6.20	0.	999999	5	0
12	10.32	45000	45000	46777	49510	24	0	0	0	3.10	3.10	0.	999999	5	0
YR	21			46777		1211	0	0	0	7.78	19.78	0.	999999		

YEAR 1958

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	5.13	45000	45000	47151	49510	-3	0	0	0	3.10	3.10	0.	999999	5	0
2	90.64	45000	45000	49510	49510	-7	0	0	0	3.10	48.29	0.	999999	11	0
3	53.97	45000	45000	49510	49510	-21	0	0	0	6.20	54.30	0.	999999	11	0
4	25.37	45000	45000	49510	49510	-31	0	0	0	6.20	25.89	0.	999999	11	0
5	125.74	45000	45000	49510	49510	-45	0	0	0	6.20	126.47	0.	999999	11	0
6	57.97	45000	45000	49510	49510	-10	0	0	0	15.50	58.14	0.	999999	11	0
7	596.74	45000	45000	49510	49510	-97	0	0	0	15.50	598.31	0.	999999	11	0
8	118.13	45000	45000	49510	49510	-38	0	0	0	15.50	118.75	0.	999999	11	0
9	66.60	45000	45000	49510	49510	-35	0	0	0	6.20	67.18	0.	999999	11	0
10	112.68	45000	45000	49510	49510	-41	0	0	0	6.20	113.35	0.	999999	11	0
11	181.57	45000	45000	49510	49510	-10	0	0	0	6.20	181.74	0.	999999	11	0
12	20.81	45000	45000	49510	49510	-7	0	0	0	3.10	20.92	0.	999999	11	0
YR	122			49510		-345	0	0	0	7.78	118.99	0.	999999		

YEAR 1959

PER	CFS INFLOW	END OF MONTH STORAGE IN AC-FT MIN	BUFFER	ACTUAL	MAX	AC-FT EVAP	CFS TO PIPELINE REQ	ACTUAL	SHRTG	RELEASE TO RIVER IN CFS REQ	ACTUAL	SHRTG	MAX	CASE	RES QUAL
1	21.00	45000	45000	49510	49510	-6	0	0	0	3.10	21.10	0.	999999	11	0
2	358.54	45000	45000	49510	49510	-12	0	0	0	3.10	358.75	0.	999999	11	0
3	474.52	45000	45000	49510	49510	-36	0	0	0	6.20	475.10	0.	999999	11	0
4	422.27	45000	45000	49510	49510	-53	0	0	0	6.20	423.17	0.	999999	11	0
5	218.29	45000	45000	49510	49510	-77	0	0	0	6.20	219.55	0.	999999	11	0
6	84.90	45000	45000	49510	49510	-18	0	0	0	15.50	85.20	0.	999999	11	0
7	54.58	45000	45000	49510	49510	-166	0	0	0	15.50	57.29	0.	999999	11	0
8	661.35	45000	45000	49510	49510	-65	0	0	0	15.50	662.42	0.	999999	11	0
9	179.67	45000	45000	49510	49510	-59	0	0	0	6.20	180.67	0.	999999	11	0
10	398.00	45000	45000	49510	49510	-71	0	0	0	6.20	399.16	0.	999999	11	0
11	27.87	45000	45000	49510	49510	-18	0	0	0	6.20	28.17	0.	999999	11	0
12	149.35	45000	45000	49510	49510	-12	0	0	0	3.10	149.55	0.	999999	11	0
YR	254			49510		-594	0	0	0	7.78	254.99	0.	999999		

YEAR 1960

PER	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	371.97	45000	45000	49510	49510	4	0	0	0	3.10	371.90	0.	999999	11	0
2	120.04	45000	45000	49510	49510	8	0	0	0	3.10	119.89	0.	999999	11	0
3	679.06	45000	45000	49510	49510	24	0	0	0	6.20	678.67	0.	999999	11	0
4	444.03	45000	45000	49510	49510	36	0	0	0	6.20	443.42	0.	999999	11	0
5	569.71	45000	45000	49510	49510	52	0	0	0	6.20	568.86	0.	999999	11	0
6	175.73	45000	45000	49510	49510	12	0	0	0	15.50	175.53	0.	999999	11	0
7	338.06	45000	45000	49510	49510	113	0	0	0	15.50	336.23	0.	999999	11	0
8	12.90	45000	45000	49306	49510	44	0	0	0	15.50	15.50	0.	999999	5	0
9	5.63	45000	45000	49232	49510	40	0	0	0	6.20	6.20	0.	999999	5	0
10	15.32	45000	45000	49510	49510	48	0	0	0	6.20	10.02	0.	999999	11	0
11	48.43	45000	45000	49510	49510	12	0	0	0	6.20	48.23	0.	999999	11	0
12	9.26	45000	45000	49510	49510	8	0	0	0	3.10	9.13	0.	999999	11	0
YR	234			49510		402	0	0	0	7.78	233.58	0.	999999		

YEAR 1961

PER	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	6.74	45000	45000	49510	49510	-16	0	0	0	3.10	7.00	0.	999999	11	0
2	112.21	45000	45000	49510	49510	-31	0	0	0	3.10	112.78	0.	999999	11	0
3	781.71	45000	45000	49510	49510	-94	0	0	0	6.20	783.24	0.	999999	11	0
4	257.00	45000	45000	49510	49510	-141	0	0	0	6.20	259.38	0.	999999	11	0
5	137.84	45000	45000	49510	49510	-204	0	0	0	6.20	141.16	0.	999999	11	0
6	40.93	45000	45000	49510	49510	-47	0	0	0	15.50	41.73	0.	999999	11	0
7	132.06	45000	45000	49510	49510	-440	0	0	0	15.50	139.22	0.	999999	11	0
8	39.94	45000	45000	49510	49510	-173	0	0	0	15.50	42.75	0.	999999	11	0
9	555.23	45000	45000	49510	49510	-157	0	0	0	6.20	557.88	0.	999999	11	0
10	300.29	45000	45000	49510	49510	-189	0	0	0	6.20	303.36	0.	999999	11	0
11	1132.60	45000	45000	49510	49510	-47	0	0	0	6.20	1133.39	0.	999999	11	0
12	80.32	45000	45000	49510	49510	-31	0	0	0	3.10	80.83	0.	999999	11	0
YR	297			49510		-1572	0	0	0	7.78	299.60	0.	999999		

YEAR 1962

PER	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	252.58	45000	45000	49510	49510	19	0	0	0	3.10	252.27	0.	999999	11	0
2	597.54	45000	45000	49510	49510	38	0	0	0	3.10	596.85	0.	999999	11	0
3	683.90	45000	45000	49510	49510	114	0	0	0	6.20	682.05	0.	999999	11	0
4	51.90	45000	45000	49510	49510	171	0	0	0	6.20	49.03	0.	999999	11	0
5	394.52	45000	45000	49510	49510	247	0	0	0	6.20	390.50	0.	999999	11	0
6	170.97	45000	45000	49510	49510	57	0	0	0	15.50	170.01	0.	999999	11	0
7	40.90	45000	45000	49510	49510	531	0	0	0	15.50	32.26	0.	999999	11	0
8	10.61	45000	45000	49002	49510	208	0	0	0	15.50	15.50	0.	999999	5	0
9	18.43	45000	45000	49510	49510	189	0	0	0	6.20	6.72	0.	999999	11	0
10	183.00	45000	45000	49510	49510	228	0	0	0	6.20	179.30	0.	999999	11	0
11	76.83	45000	45000	49510	49510	57	0	0	0	6.20	75.88	0.	999999	11	0
12	28.77	45000	45000	49510	49510	38	0	0	0	3.10	28.16	0.	999999	11	0
YR	207			49510		1895	0	0	0	7.78	204.77	0.	999999		

YEAR 1963

PER	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
1	12.74	45000	45000	49510	49510	26	0	0	0	3.10	12.32	0.	999999	11	0
2	95.32	45000	45000	49510	49510	52	0	0	0	3.10	94.39	0.	999999	11	0
3	582.77	45000	45000	49510	49510	155	0	0	0	6.20	580.25	0.	999999	11	0
4	156.43	45000	45000	49510	49510	233	0	0	0	6.20	152.52	0.	999999	11	0
5	113.32	45000	45000	49510	49510	336	0	0	0	6.20	107.85	0.	999999	11	0
6	13.80	45000	45000	49331	49510	78	0	0	0	15.50	15.50	0.	999999	5	0
7	44.13	45000	45000	49510	49510	723	0	0	0	15.50	29.46	0.	999999	11	0
8	8.19	45000	45000	48778	49510	283	0	0	0	15.50	15.50	0.	999999	5	0
9	6.93	45000	45000	48566	49510	255	0	0	0	6.20	6.20	0.	999999	5	0
10	4.48	45000	45000	48157	49510	304	0	0	0	6.20	6.20	0.	999999	5	0
11	8.67	45000	45000	48228	49510	76	0	0	0	6.20	6.20	0.	999999	5	0
12	7.58	45000	45000	48145	49510	51	0	0	0	3.10	3.10	0.	999999	5	0
YR	88			48145		2572	0	0	0	7.78	86.17	0.	999999		

GRAND AVERAGE

PER	CFS	END OF MONTH STORAGE IN AC-FT				AC-FT	CFS TO PIPELINE			RELEASE TO RIVER IN CFS					RES
	INFLOW	MIN	BUFFER	ACTUAL	MAX	EVAP	REQ	ACTUAL	SHRTG	REQ	ACTUAL	SHRTG	MAX	CASE	QUAL
YR	138	44540			49510	1496	0	0	0	7.78	135.96	.10	999999		

SHORTAGE INDEX, PIPELINE 0. OUTLET .250 DOWNSTREAM 0. POWER 0.

SAMPLE COMPUTATION OF SHORTAGE INDEX

AVG. ANNUAL SHORTAGES:

1953 = 0.81 cfs
1954 = 0.86 cfs
1956 = 2.16 cfs

ALL OTHER YEARS = 0.00 cfs

AVG. ANNUAL DEMAND = 7.78 cfs

ANNUAL SHORTAGES/ANNUAL DEMAND:

$$1953 = \frac{0.81}{7.78} = .104$$

$$1954 = \frac{0.86}{7.78} = .110$$

$$1956 = \frac{2.16}{7.78} = .277$$

SUM OF SQUARES OF ANNUAL SHORTAGES:

$= (.104)^2 + (.110)^2 + (.277)^2$
$= .0108 + .0121 + .0767$
$= .0996$

STUDY LENGTH = 40 YEARS

CONVERT TO 100-YR. BASE:

$$\text{SHORTAGE INDEX} = .0996 \left(\frac{100}{40}\right)$$

$$= .250$$

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