WATER RESOURCES ANALYSIS
AND INFORMATION SECTION

Office Report No. 37

A RECONNAISSANCE STUDY OF CERTAIN WATER RESOURCES MANAGEMENT PROBLEMS OF THE CEDAR RIVER BASIN

by

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(For Use by the Water Resources Management Division)

June 1976
Department of Ecology
Olympia, Washington

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INTRODUCTION

The purpose of this report is to present the information developed on the water resources of the Cedar River above Lake Washington. Much work remains to be done before a logical water management policy can be developed for the Cedar River. How much work is actually done will depend on the requirements of the policy development section.

BASIN DESCRIPTION

The Cedar River is located in the eastern Puget Sound region (see Figures 1 and 2). It has a drainage area of 188 square miles and flows northwesterly from its source in the Cascade foothills into Lake Washington at Renton.

The Cedar River has two primary tributaries; Rex River and Taylor Creek. Approximate average annual flows for these tributaries are 120 cfs for Rex River and 103 cfs for Taylor Creek.

Average annual runoff in the Cedar River Basin is approximately 900 cfs. This includes an average annual flow of 695 cfs at Renton and an average annual diversion rate of 210 cfs at Landsburg. Seattle diverts this water for municipal and industrial water supply use. The monthly diversion rate varies with a maximum monthly rate over 300 cfs during the critical summer months.

Land use for the Basin was described by the Soil Conservation Service in an addendum to the Columbia-North Pacific Region Comprehensive Framework Study, published in 1970. The following table shows the SCS land use designations. In this description the land use classified as "other" includes urban, suburban, roads, water surfaces, and other miscellaneous uses.

Land Use	Acres	Percent of Total Acres
Forest Land	113,187	90
Cropland	2,672	2
Other	9,431	8
Totals	125,290	100

This table shows that the majority of the Basin's land (approximately 90 percent) is undeveloped. The major portion of it is owned by the City of Seattle. Seattle's land occupies the area of the Basin above their water supply diversion site at Landsburg. The purpose of this ownership is to protect the Cedar River from contamination through development, sabotage, and/or other potential harm.

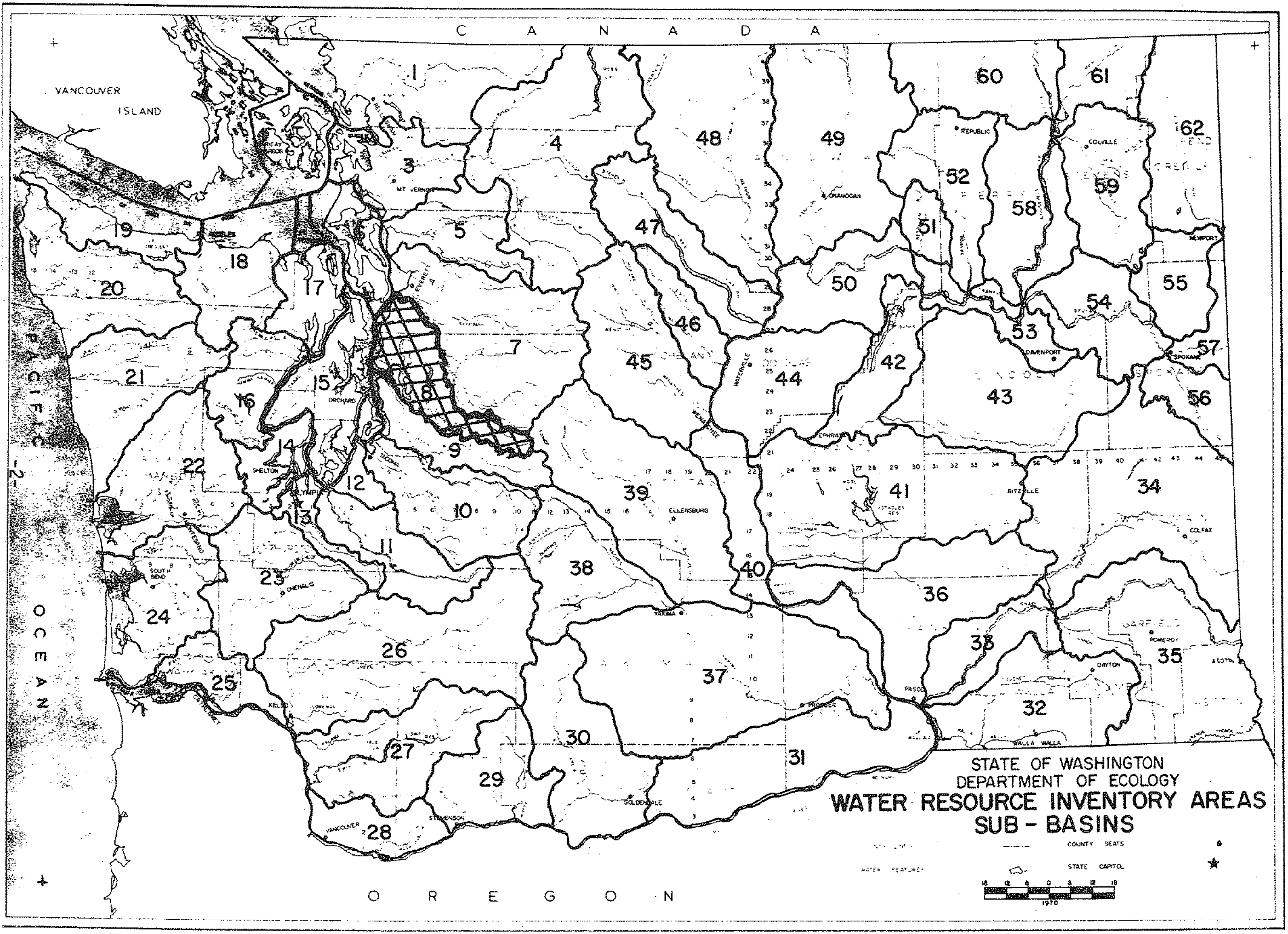

FIGURE 1: Location of Cedar Basin.

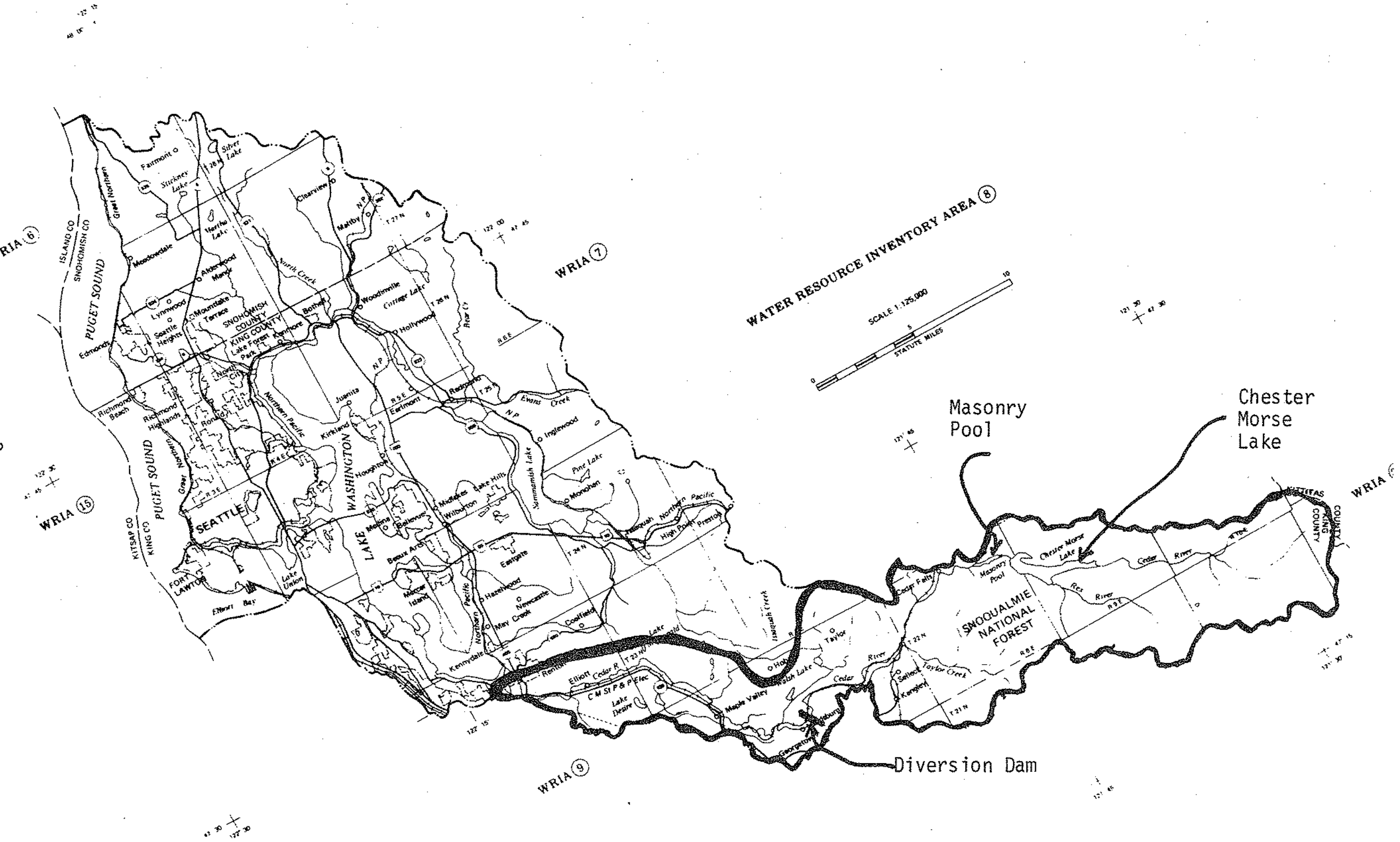

FIGURE 2: Cedar River above Lake Washington.

The federal government also owns undeveloped lands within this Basin. Their ownership consists of those Basin lands located in the Snoqualmie National Forest.

The developed lands occur in the downstream area of the Basin near Renton and Lake Washington.

With the amount of government ownership, both local and federal, within this Basin, no major land use changes or developments are likely to occur. 1/ An exception could be the conversion of existing cropland to urban usage.

There are three dams, two reservoirs, and a hydroelectric power plant located on the Cedar River system. The following paragraphs briefly describe these structures:

1. Crib Dam - Chester Morse Lake

   The present dam is of a rock filled timber-crib design constructed in 1903. The damming occurred below the natural outlet for what was then Cedar Lake. Its construction created Chester Morse Lake. This dam raised the lake level 18 feet and allowed for a maximum storage capacity of approximately 55,500 acre-feet and a normal storage capacity of 49,568 acre-feet.

2. Masonry Dam - Masonry Pool

   The present structure was built in 1914, 1.5 miles downstream from the timber-crib dam. The purpose of its construction was to inundate the old dam and enlarge the lake to a capacity of 160,000 acre-feet. A problem immediately arose in that extensive seepage was discovered through the north bank of the reservoir. This precluded operation of the reservoir at full capacity and at present the pool is held 20 feet below the spillway crest. Because of this problem, there are still two reservoirs present; one behind the masonry dam and a second behind the timber-crib dam. This has limited storage to a maximum level of 105,440 acre-feet and a normal storage of 66,525 acre-feet.

3. Landsburg Dam - Diversion Site Seattle M & I Supply

   A small concrete intake dam was constructed between 1930-1935 at Landsburg to provide for the City of Seattle's M & I requirements. Present diversionary capacity is approximately 340 cfs.

1/ CH_2M/Hill, Environmental Management for the Metropolitan Area, Part I Water Resources, December 1974, p. 21.

4. Hydroelectric Plant - City of Seattle

This plant was constructed in conjunction with the masonry dam in 1914. Several additional power units have since been added. It is located slightly downstream from the masonry dam and just north of the Cedar River. Water is diverted from the Cedar River at the masonry dam, run through the power plant, and then returned to the river 1.5 miles downstream. The water right associated with operation of this plant is classified as partially consumptive because it bypasses a section of the stream. Maximum capacity for the system is 700 cfs, while Seattle's water right is for 200 cfs.

THE SEEPAGE PROBLEM

As noted previously, a major problem with the Cedar River's storage system is seepage which occurs because of the glacial outwash composition of the area.

The U.S. Geological Survey made a study of the problem in 1967 and published their results in a report titled, "Evaluation of Seepage from Chester Morse Lake and Masonry Pool, King County, Washington." The results of this study are summarized below (for the period of 1957-1964):

1. Average seepage losses from Masonry Pool were 220 cfs.
2. Average gain to Cedar River was 180 cfs ± 20 cfs.
3. Average gain to South Fork Snoqualmie was 50-60 cfs.

The measurement of seepage losses and gains was not exact due to the potential error in estimates. Therefore, the varying levels of gains and losses are stated within their relevant range of occurrence.

Due to the seepage losses from the reservoir, the flow of the Cedar River doubles between Cedar Falls (gage 12-1165) and Landsburg (gage 12-1175), while the drainage area increases by 45 percent.

WATER BALANCE

The USGS operates a number of streamflow gaging stations on the Cedar River system; the location of the station is shown on Figure 3 and information on the stations given Table 1. This study will be primarily interested in the data from two of them. These are the Cedar River at Renton (12-1190) and the, Cedar River near Landsburg (12-1175).

Table 1: Location of Stream Gaging Stations in the Cedar Basin.

Number	Name	Location T R Sec	Cedar River Mile	Drainage Area Sq. Mi.	Period of Record
12-1135	N. F. Cedar River nr. Lester	21N 10E 11	-	8.8	10/44 - 12/63
12-1140	S. F. Cedar River nr. Lester	21N 10E 15	-	6.0	10/44 - 1974
12-1145	Cedar River below Bear Creek nr. Cedar Falls	22N 10E 32	-	25.4	10/45 - 12/63
12-1150	Cedar River nr. Cedar Falls	22N 9E 23	43.5	40.7	10/45 - 1974
12-1155	Rex River nr. Cedar Falls	22N 9E 33	-	13.4	10/45 - 1974
12-1161	Canyon Creek nr. Cedar Falls	22N 8E 3	-	0.2	5/45 - 1974
12-1165	Cedar River at Cedar Falls	22N 8E 4	33.2	84.2	4/14 - 1974
12-1167	M. F. Taylor Creek nr. Selleck	22N 8E 33	-	5.2	8/56 - 12/63
12-1168	N. F. Taylor Creek nr. Selleck	22N 8E 29	-	3.8	6/56 - 12/63
12-1170	Taylor Creek nr. Selleck	22N 8E 19	-	17.2	8/56 - 1974
12-1175	Cedar River nr. Landsburg	22N 7E 17	23.4	122	7/95 - 1974
12-1183	Rock Creek nr. Ravensdale	22N 6E 26	-		8/56 - 10/58
12-1184	Rock Creek at State Highway 5A nr. Ravensdale	22N 6E 26	-	11.2	6/56 - 9/62
12-1185	Rock Creek nr. Maple Valley	22N 6E 22	-	12.6	6/45 - 9/73
	Rock Creek diversion nr. Landsburg	22N 6E 13	-	11	10/32 - 10/48
12-1190	Cedar River at Renton	23N 5E 17	1.6	186	8/45 - 1974

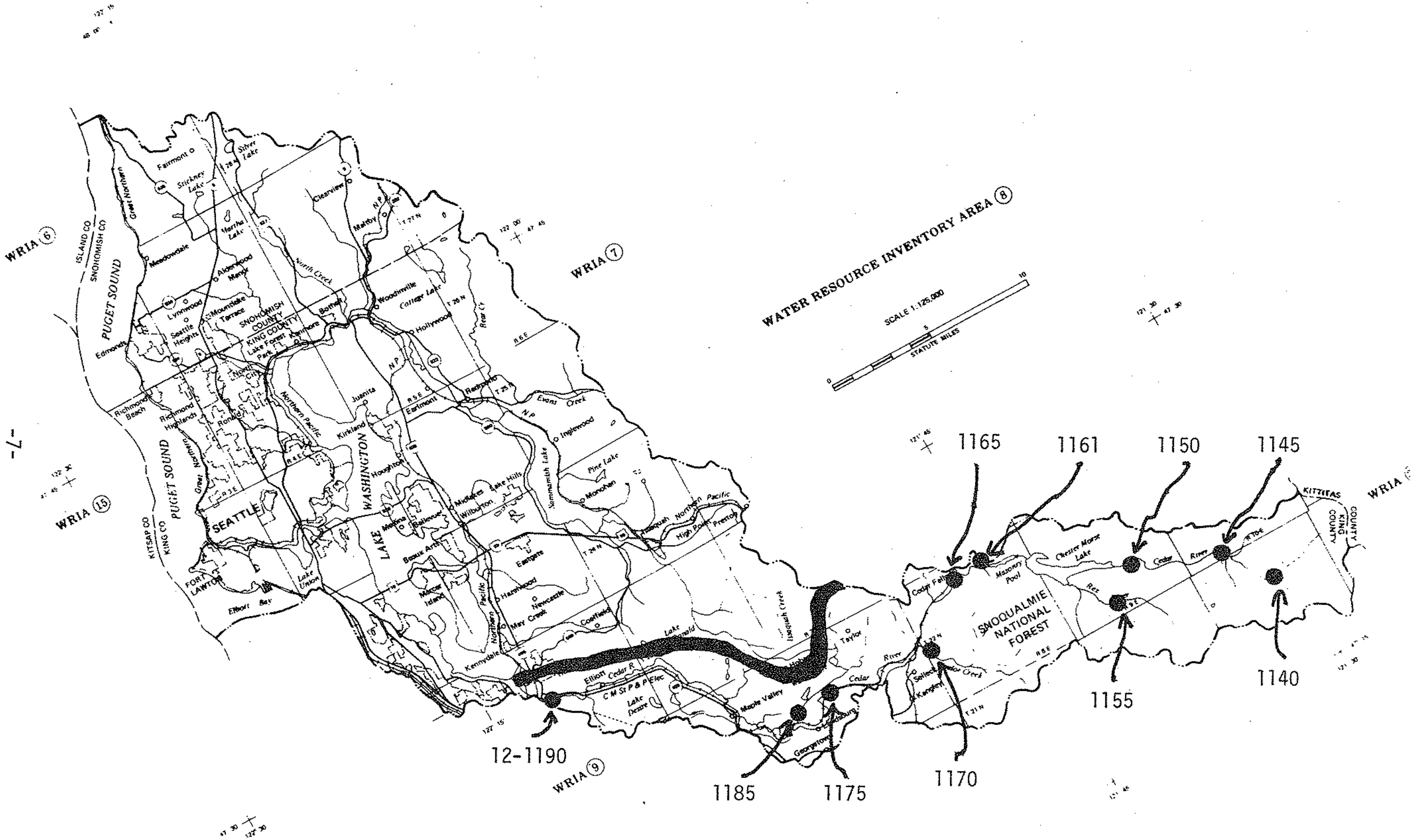

FIGURE 3: Location of Gaging Stations in Cedar Basin.

The gage on the Cedar River near Landsburg (12-1175), has been operating continuously (neglecting several months of no record) since 1895. Because it is approximately 1 mile above the Landsburg diversion, an estimate can be made of the annual natural flow of the Cedar River at Landsburg.

The gage on the Cedar River at Renton (12-1190), has been operating since 1945. This gage is important since it is the point around which Cedar River flows are regulated by the Department of Ecology's minimum flow regulation.

An approximate annual water balance for the Cedar River below the dams is shown in Figure 4. The information in the diagram is based on published information. The water balance will be discussed in greater detail in a following section.

WATER USE

The consumptive water right requirements for the Cedar River Basin are shown in Table 2 (current through July 1975).

The irrigation requirements used in this table were developed from information presented in the Puget Sound and Adjacent Water Study, Appendix VII/Irrigation, pp. 8-4. Table 3 was prepared to determine irrigation depletion requirements for the Cedar Basin from diversion requirements per acre. A 63 percent efficiency rate and a 50 percent per month return flow of the 37 percent lost were used. There are 176.25 acres of irrigated land in this basin.

The City of Seattle municipal and industrial water use was determined from data (compiled by the City) for water years 1964-1969. The average monthly diversion rate for these years is shown below (in cfs).

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
168	162	175	185	195	191	209	200	228	254	246	185

The maximum individual monthly diversion rate for Seattle's municipal and industrial supply is as follows for water years 1964-1969 (in cfs).

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
204	189	202	256	226	234	228	212	262	287	301	242

To develop the trends in consumptive water right use, the information in Table 4 and Figure 5 was developed. These trends were developed from information on consumptive water rights for WRIA 8, which includes the whole of the Lake Washington drainage basin and Urban drainage from Seattle which directly enters Puget Sound.

TABLE 1 - Simulation 1973 Spawning Run:
Four day Release Interval

```
ALPHA   .008384 (1/(CFS))              M   3045600 (SQ.FT.)

S     8.100 (SQ.FT./FISH)            1973 SPAWNING RUN

DATE   DISCHARGE    INCREASE    VOLUME      VOLUME     FISH      FISH TO
         (CFS)        (CFS)                TO DATE    COUNT       DATE
                                   (ACRE-FEET)        X1000       X1000

SEPT  4    80.0          .0       635        635         0           0
      8    80.0          .0       635       1269         0           0
     12    80.0          .0       635       1904         1           1
     16    80.0          .0       635       2539         1           2
     20    80.0          .0       635       3174        15          16
     24    80.0          .0       635       3808        25          42
     28    80.0          .0       635       4443        41          83
OCT   2    80.0          .0       635       5078        22         105
      6    80.0          .0       635       5712        13         118
     10    80.0          .0       635       6347        13         131
     14    93.3        13.3       741       7088        21         153
     18   112.8        19.4       895       7982        28         181
     22   138.9        26.1      1102       9084        32         213
     26   155.7        16.8      1235      10319        16         229
     30   172.0        16.4      1365      11684        14         243
NOV   3   187.5        15.4      1487      13172        11         255
      7   202.0        14.5      1603      14774        10         264
     11   226.1        24.2      1794      16568        14         278
     15   261.0        34.9      2071      18639        16         295
     19   289.3        28.3      2295      20934        10         305
     23   305.4        16.1      2423      23357         5         309
     27   319.8        14.4      2537      25894         4         313
DEC   1   319.8          .0      2537      28432         0         313
      5   319.8          .0      2537      30969         0         313
      9   319.8          .0      2537      33506         0         313
     13   319.8          .0      2537      36043         0         313
     17   319.8          .0      2537      38580         0         313
     21   319.8          .0      2537      41118         0         313
     25   319.8          .0      2537      43655         0         313
     29   319.8          .0      2537      46192         0         313
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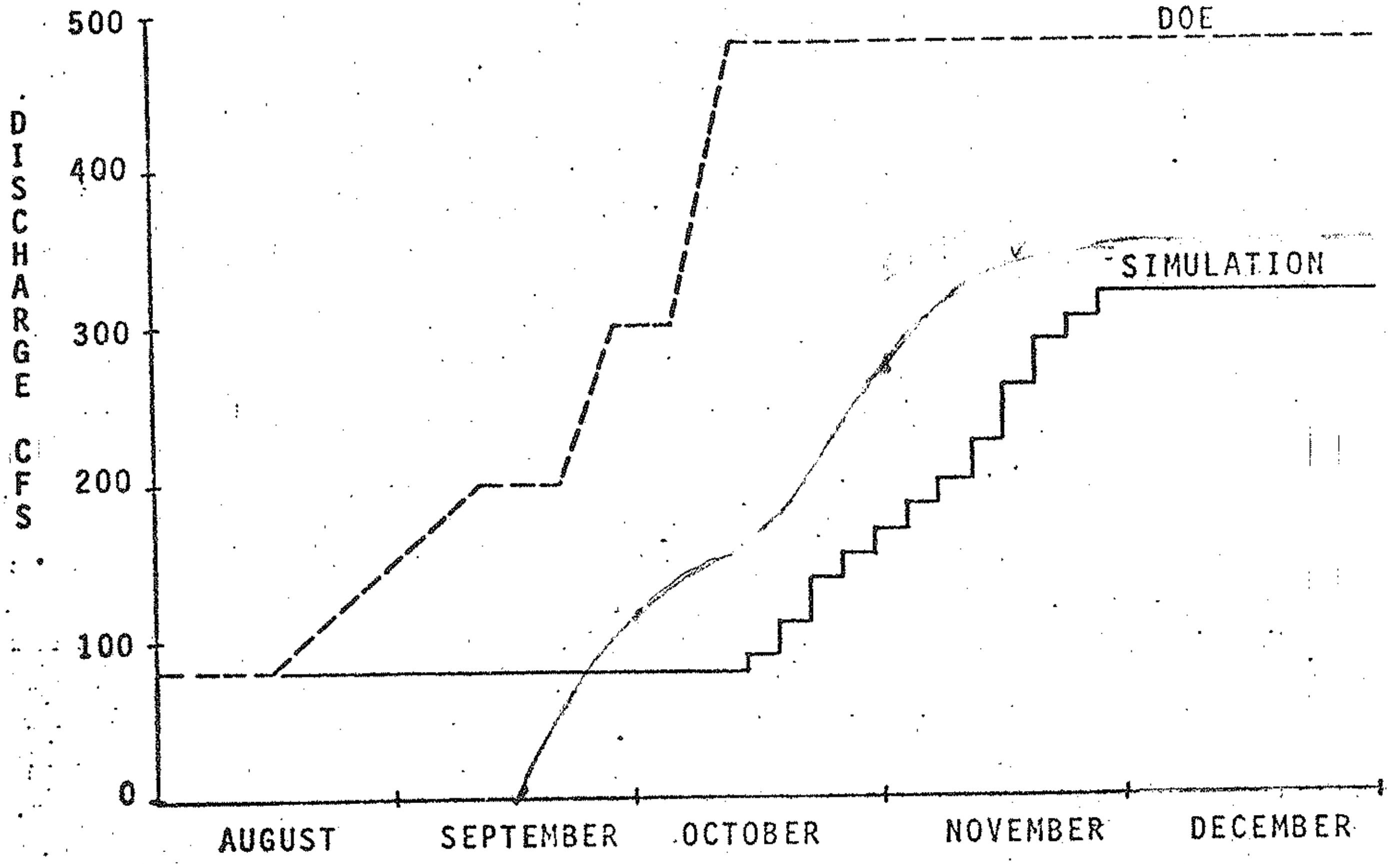


FIGURE 1: FISH FLOW MANAGEMENT SIMULATION FOR 1973

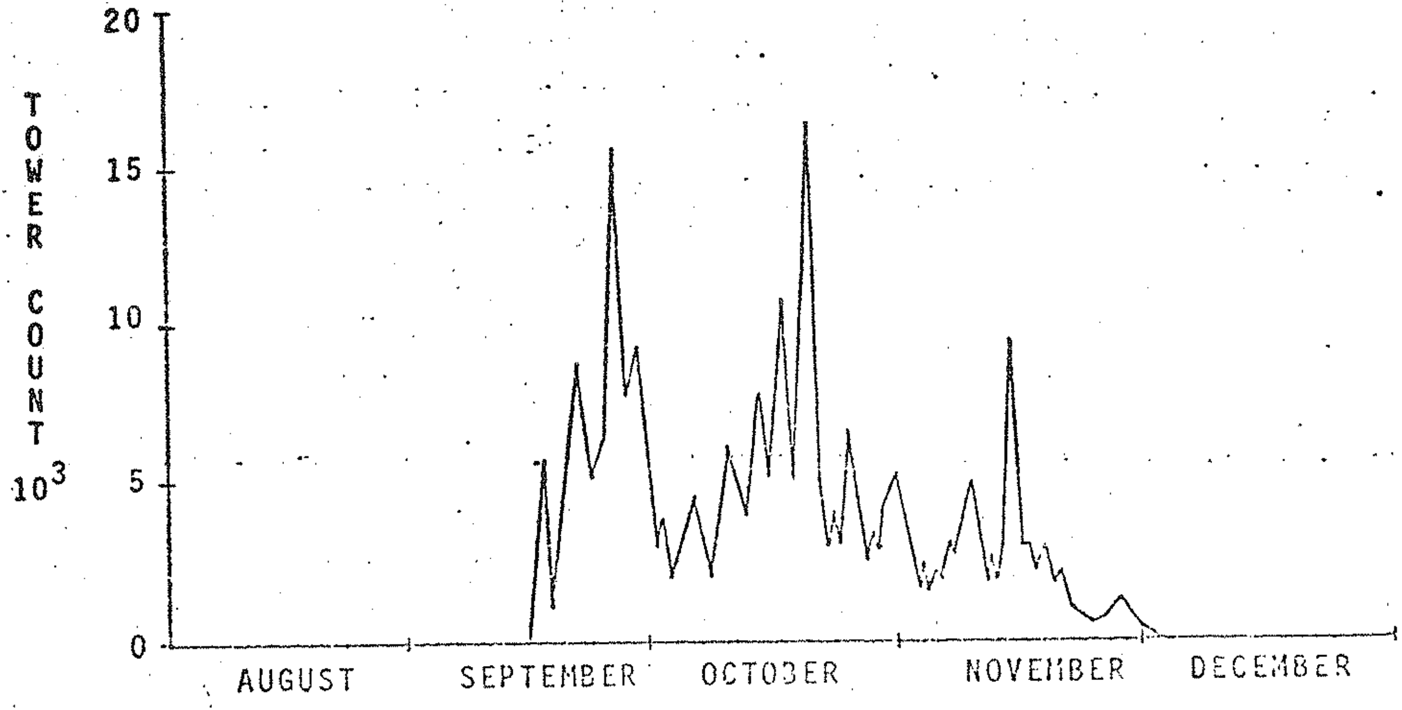


FIGURE 2: TOWER COUNTS FOR 1973 SPAWNING SEASON

of 376,000 spawners which when combined with s yields a maximum accumulative area, m, of 3,045,600 (ft^2). The exponential coefficient, α was obtained from Figure 17, of "Effects of Discharge in the Cedar River on Sockeye Salmon Spawning Area", Stober and Graybill, June 1974, assuming that the 11 reaches represented in the figure are characteristic of the whole river.

The area available for spawing at the initial flow rate should be utilized before any increase of the flow rate begins. The area available for the first spawners was computed using a polynomial relating spawnable area to flow rate. This polynomial is a sum of the polynomials contained in Table 1 of the report referred to above and extrapolated to the whole river based on the magnitude of ~~N~~m. The initial available area for a discharge of 80 cfs is sufficient to accommodate 130,000 fish. This may seem unrealistic (high) but the polynomials developed by Stober indicate that at 80 cfs, 4,000 fish can be accommodated on the 11 reaches. These reaches represent approximately 1,400 feet or 1/65th of the river's total length. Prorating for the full length of the river would indicate a capacity for about 260,000 fish. Such an estimate would be overly optimistic since the 11 reaches studied by Stober were chosen on the basis of observed spawning activity. For the purpose of this example, the initial area available at 80 cfs was assumed to be adequate for 130,000 fish.

The results of the simulation are represented in Table 1. The simulation was done for a four day release interval. This interval between releases could be any convenient interval but should not exceed redd duration L. The volume of flow from August 15th to year-end under DOE recommendation is about 10^5 (acre-ft.) whereas the volume using the fish flow management model amounts to slightly less than 48,000 (acre-ft.) or less than half. It should be noted that a significant portion of the total spawners are accommodated by the initial flow rate as discussed above.

This simulation represents minimum flow pattern since, the value of parameters "m" and "s", are considered maximum values for utilization of the river. By experimentation, the analysis was found to be least sensitive to variation in the exponential coefficient α. Estimates of the values of the parameters involved could probably improve with further study; the values used here were intended to illustrate a potential use of this fish flow management model.

The wetted perimeter was found by Stober to vary in a manner which is similar to the variation of cumulative spawnable area. The wetted perimeter therefore follows a function similar to (2),

$$P(Q) = p(1 - e^{-\beta Q}) \quad , \quad (10)$$

in which P is the wetted perimter and p and β are representative coefficients for the spawnable sections of the river. The plotted data show that, for practical purposes, the wetted perimeter reaches a "maximum" at a discharge which is considerably lower than the discharge required for the later stages of the spawning period. Designating this discharge Q(p), the volume of water required for incubation , is given by,

$$V_I' = \int_{T}^{I} Q(p)\,dt \quad , \quad (11)$$

By comparing (11) and (9) the difference in total water volume is indicated.

Example of Idealized Operation During 1973 Spawning Season

To illustrate the use of the method, the actual (recorded) counts of fish entering the Cedar River have been used to calculate the discharge which would have been ideal for spawning and incubation. In this analysis the parameters were assigned the following values:

$s = 8.1\ (ft^2/fish)$

$m = 3{,}045{,}600\ (ft^2)$

$\alpha = 0.008384\ (cfs^{-1})$

The parameter s, area necessary per fish, was based on a maximum density of 13.5 (ft^2/female) and a female: male ratio of 60:40. Stober estimates the Cedar River has a maximum capacity as indicated by (7) but can only be changed in steps. This is because actual counts of spawners entering the river must be made over some finite time interval and the fish themselves require some time interval during which they can construct a redd and deposit eggs. Let this time interval be L.

The total volume of water required during the spawning period can be determined from (4) by integrating the right hand side over the appropriate time interval. Letting this volume be V_s,

$$V_s = -\frac{L}{\alpha}\int_0^T \ln\left\{1 - \frac{A(t)}{m}\right\} dt \quad , \quad (8)$$

in which the integral has been multiplied by the redd duration L and spawning has been assumed to begin at time 0 and end at time T.

If A(t) is a suitable mathematical function (8) could be integrated in closed form. In applications, during the spawning period as counts of spawners entering the river mouth become available, it will be desireable to carry out the integration numerically. In this way the forecasted total water requirement can be updated frequently.

Water Required for Incubation

Following spawning it is necessary to maintain sufficient streamflow to permit successful incubation of the deposited eggs. Up until now the biologists, both those acting for the State and our own consultant Stober, have suggested maintaining the final spawning discharge throughout the incubation period. If this procedure is followed, the total water volume required for incubation would be given by,

$$V_I = -\frac{1}{\alpha}\int_T^I \ln\left\{1 - \frac{A(T)}{m}\right\} dt \quad , \quad (9)$$

An alternative would be to decrease the discharge immediately after spawning has been completed to a value sufficient to cover the eggs and provide adequate oxygen temperature control and flushing of waste products generated during incubation.

$$m(1 - e^{-\alpha Q}) = A(t) \quad , (3)$$

$$Q(t) = -\frac{1}{\alpha} \ln\left\{1 - \frac{A(t)}{m}\right\} \quad , (4)$$

So, if the accumulated spawnable area required by time t is A(t), the discharge should be gradually raised to Q(t) to allow utilization of the spawnable areas at all lower discharges.

The rate at which the discharge should be changed should consider the rate at which new spawners arrive in the river.

Hence, the rate of change of discharge is given by,

$$\frac{dQ}{dt} = \frac{\partial A}{\partial t} \cdot \frac{\partial Q}{\partial A} \quad , (5)$$

Now $\frac{\partial A}{\partial t}$ is just $s \cdot h(t)$ and $\frac{\partial Q}{\partial A}$ is determined by differentiating (2). Therefore,

$$\frac{dQ}{dt} = \frac{s \cdot h(t)\, e^{\alpha Q}}{\alpha m} \quad , (6)$$

or,

$$dQ = \frac{s .\, h(t)\, e^{\alpha Q}\, dt}{\alpha m} \quad , (7)$$

in which $h(t) \cdot dt$ is the number of spawners which have arrived during the time interval dt. The rate at which the discharge should change is seen to be a variable, depending on the current discharge and the arrival of spawners. This is contrary to the Sate's ruling which shows the discharge to vary according to a fixed pattern.

Now in practice the discharge cannot be varied continuously discharge was determined by Stober by experiments at eleven stations on the Cedar River. It should be possible to estimate this relationship for the spawnable sections of the entire river and the resulting relationship for the river as a whole will resemble Figure 1.

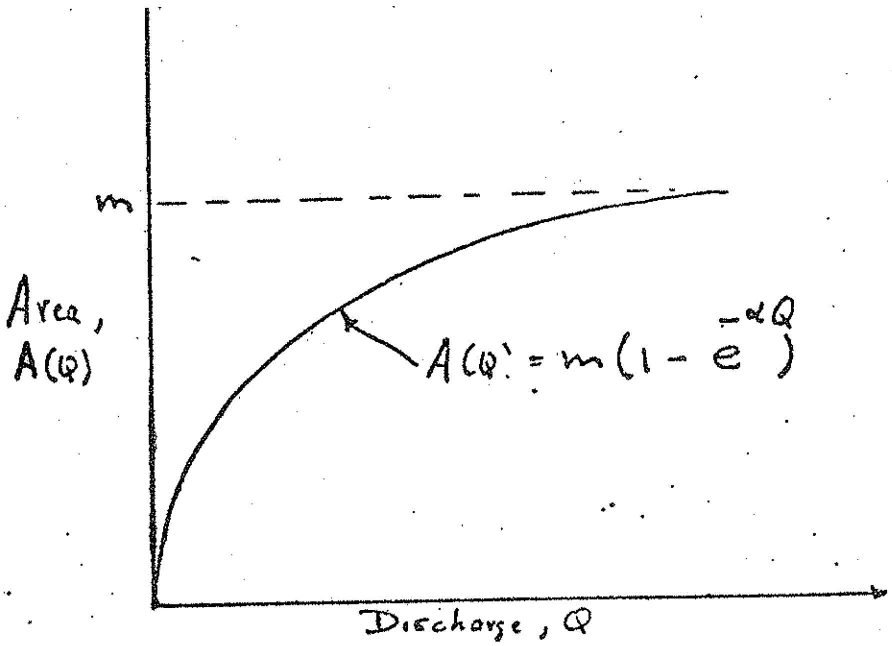


Figure 1. Cedar River, Cumulative Spawnable Area

The Cumulative spawnable area is given by,

$$A(Q) = m\left(1 - e^{-\alpha Q}\right) \qquad , (2)$$

Equation (2) was found to fit Stober's data quite closely, with the coefficients m and α determined to be different for each of the eleven reaches which he studied.

Equating (1) and (2) provides the means for determining the required discharge at time t.

JH
AC

Water Resources
Analysis and Information
Section

RECEIVED
MAR 31 '75
SEATTLE
WATER DEPT

MEMORANDUM

TO: Harry Pratt

DATE: March 27, 1975

FROM: Charles D. D. Howard and
Doug Smith (UNIES Ltd.)

FILE: 026-401

RE: Fish Flow Management
Cedar River, Washington

Introduction:

The State has presented a pattern of releases with specified minimum discharges throughout the year. Stober has provided data which can be used to both evaluate and improve on the pattern presented by the State. The purpose of this memorandum is to outline the techniques for using tower counts of fish entering the river and Stober's data, to optimize the use of available water.

Water Required for Spawning

Consider first the problem of calculating the minimum volume of water required to meet the needs of a projected spawning run or of a run whose numbers are known by a count at the mouth of the stream. Suppose the fish arrive according to some distribution h(t). That is, the number of spawners arriving between time $t - \frac{dt}{2}$ and $t + \frac{dt}{2}$ is $h(t)$.

The cumulative area required at time t is

$$A(t) = s\int_0^t h(t)\,dt \qquad , \qquad (1)$$

in which s is the area required by each spawner.

The relationship between cumulative spawnable area and

APPENDIX A

FIGURE 13: Frequency Curve for the Cedar River at Renton.

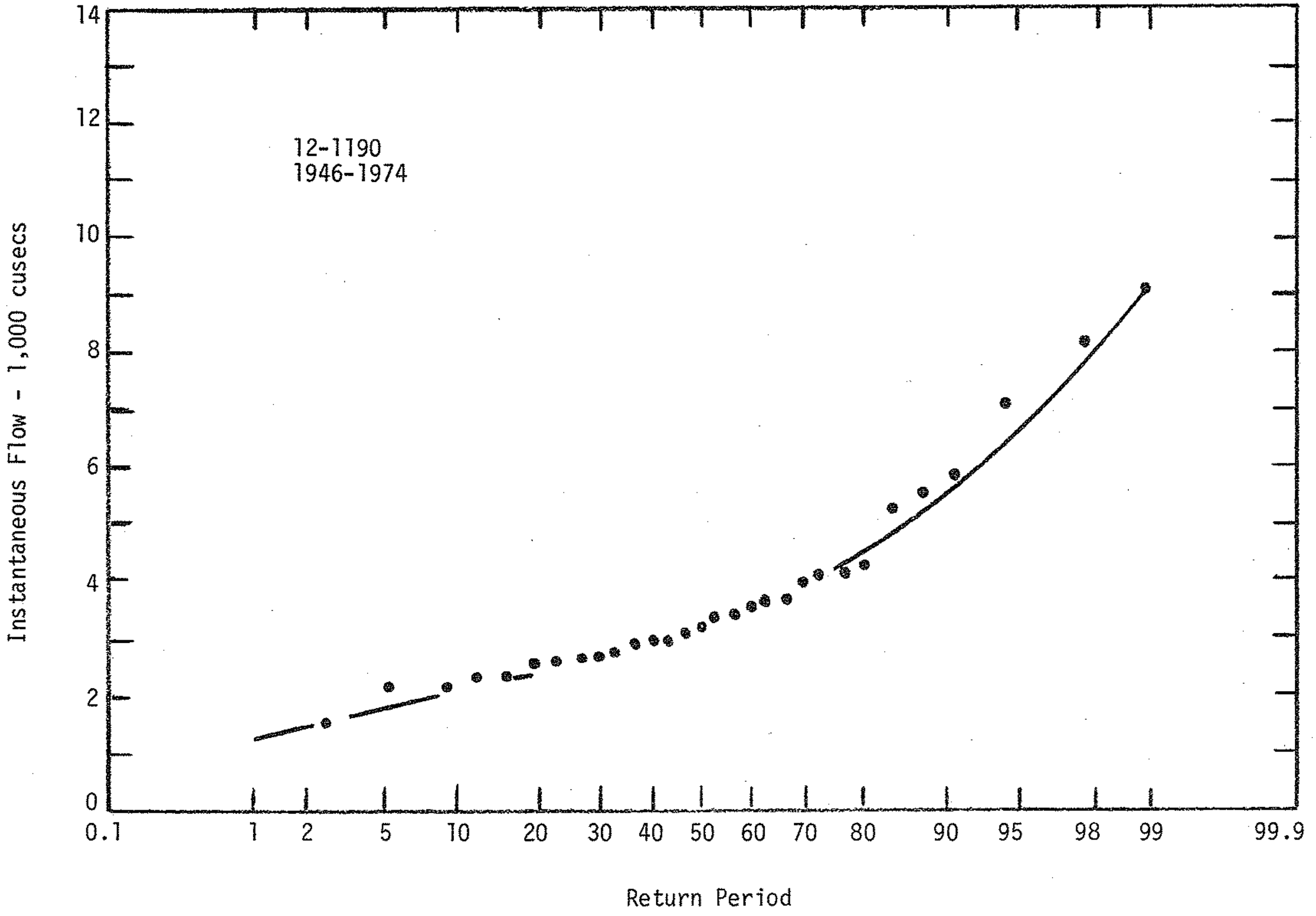


TABLE 18 FREQUENCY OF PEAK

Flows of Cedar River at Renton.
(USGS Gage Number 12-1190)
Period of Record 1946-1974.

Return Period (Years)	Log Normal	Extreme Value	Method and Source of Analysis Pearson Type III Data Skew (g = 0.50)	Corps of Engineers
2	3400	3390	3290	3350
5	4640	4720	4580	4800
10	5450	5600	5540	5900
20	6040	6450	6600	6900
25	6490	6710	6880	7300
50	7260	7530	7980	8400
100	8020	8340	9170	9700

All flows in cfs. Comments:

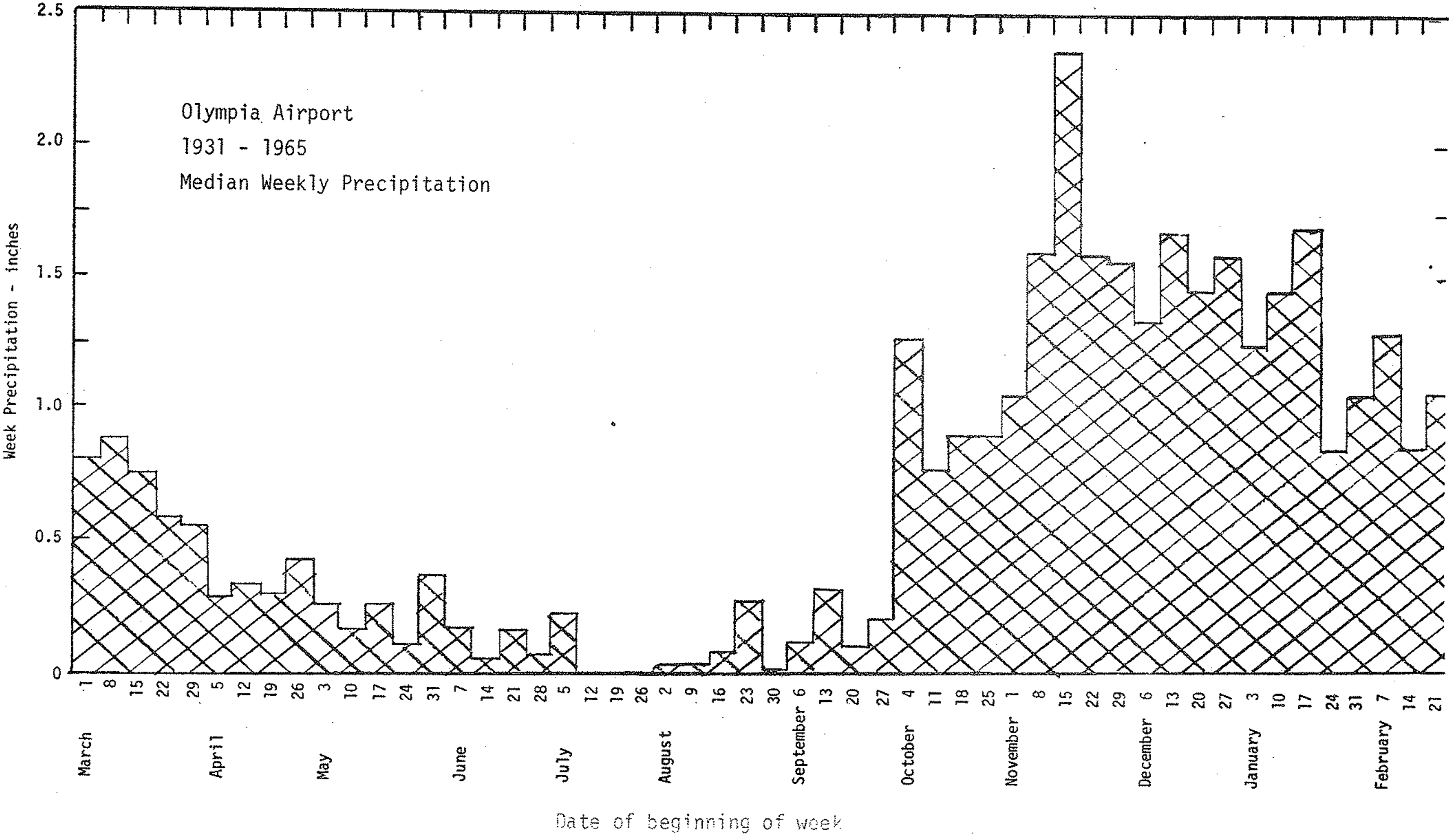
TABLE 17 FREQUENCY OF PEAK

Flows of Cedar River near Landsburg.
(USGS Gage Number 12-1175)
Period of Record 1916-1974

Return Period (Years)	Log Normal	Extreme Value	Method and Source of Analysis Pearson Type III Data Skew ($g = 0.50$)
2	2520	2570	2420
5	3720	3890	3670
10	4570	4750	4660
20	5200	5600	5900
25	5680	5850	6110
50	6540	6660	7360
100	7420	7470	8760

All flows in cfs. Comments:

FIGURE 12: Median Weekly Precipitation for Olympia Airport - 1931 through 1965.



Under natural conditions severe availability problems would arise during the months of July, August, and September.

Another factor is that it takes an initial runoff event in a year to start the in-migration of fish. The runoff event is typically the first week of October and results from the increase in precipitation typical for October. The median weekly precipitation at Olympia Airport is given in Figure 12. It is not uncommon for the initial runoff event to occur late in October or in November with the result that releases for fish are either very costly to other uses or wasted because the fish are not in the river. In many ways the month of October is the most difficult for which to develop operation criteria.

FLOOD FLOWS

Information on the maximum annual peak discharge for the Cedar River near Landsburg and for the Cedar River at Renton was analyzed. The results are given in Tables 17 and 18. The data and frequency curve for the Cedar River at Renton are given in Figure 13.

FIGURE 11: Frequency Curve for Spawnable Area (Reach B) - October

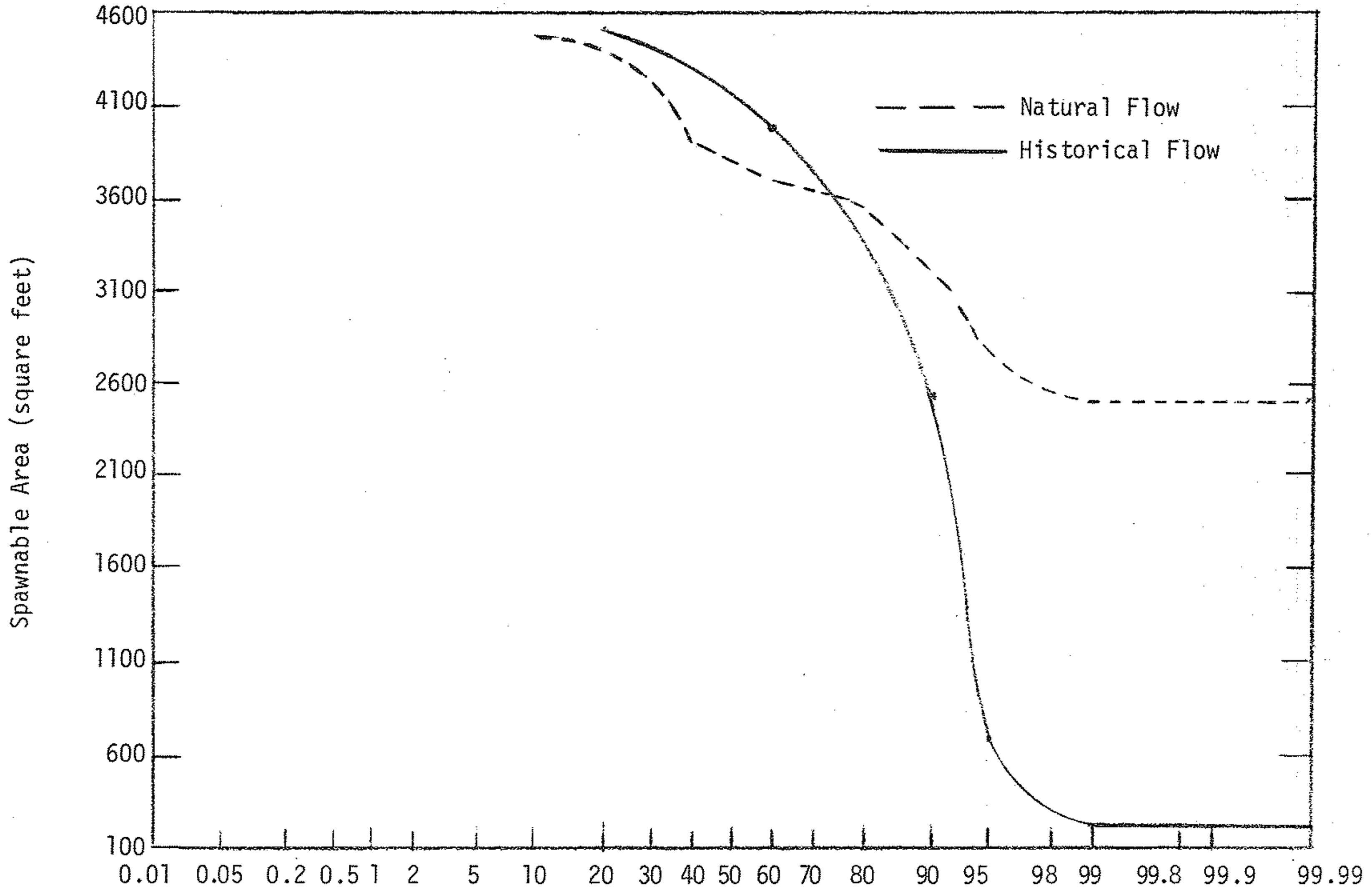


FIGURE 10: Frequency Curve for Wetted Perimeter (Reach B) - August

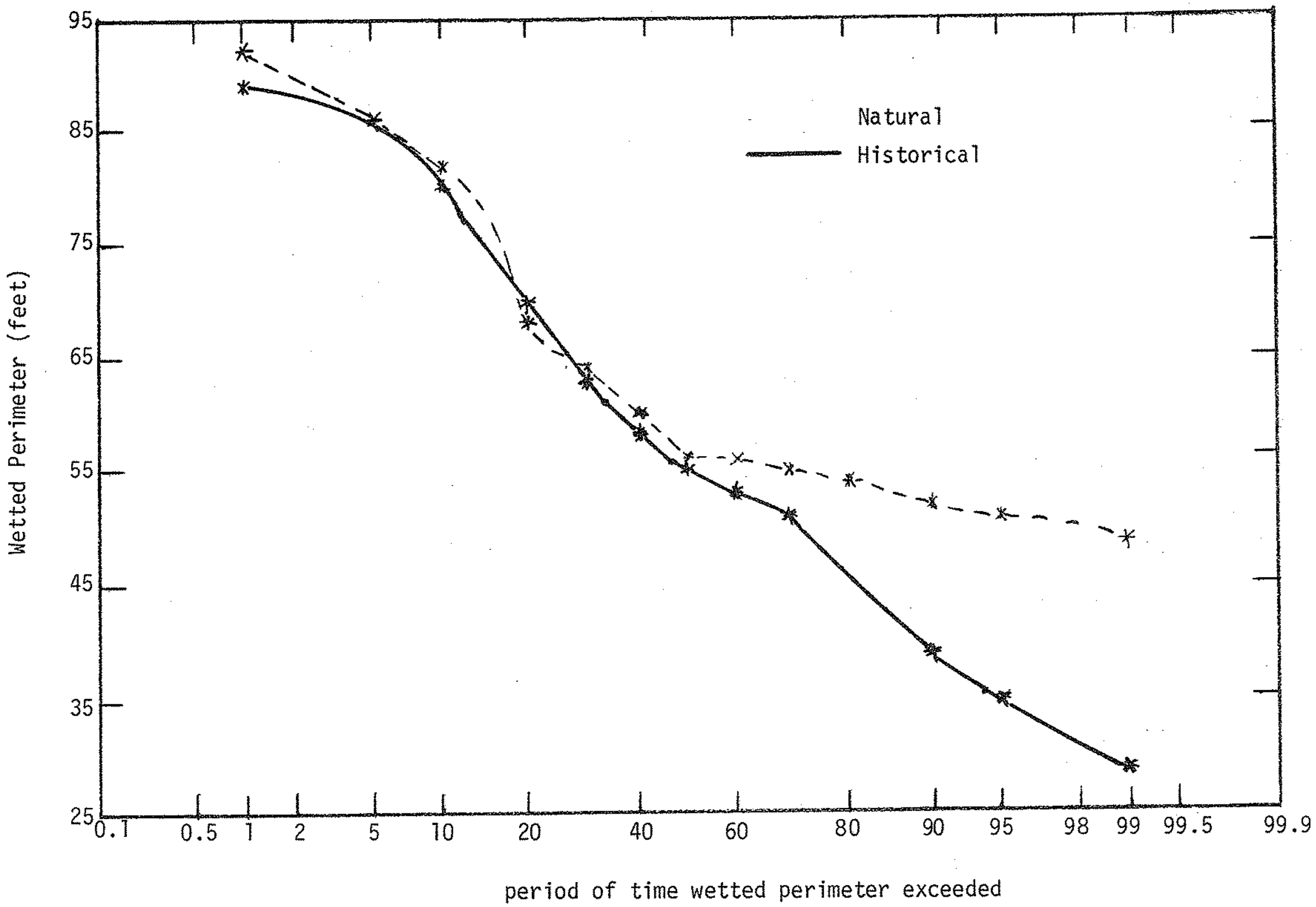


Table 16: Summary of Exceedence Information for Cedar River.

	Number of years in 10 exceeded			
	9	5	1	0.1
Wetted Perimeter (feet)				
August				
Measured	89	55	39	29
Natural	92	56	52	49
Ratio	0.97	0.98	0.75	0.59
September				
Measured	91	81	43	30
Natural	92	87	52	44
Ratio	0.99	0.93	0.83	0.68
October				
Measured	94	67	52	35
Natural	96	86	56	52
Ratio	0.98	0.78	0.93	0.67
Spawnable Area (square feet)				
August				
Measured	4500	3300	350	150
Natural	4500	3570	2500	2200
Ratio	1.00	0.92	0.14	0.07
September				
Measured	4500	3750	600	150
Natural	4500	4000	2450	2030
Ratio	1.00	0.94	0.24	0.07
October				
Measured	4500	3950	250	200
Natural	4450	3700	3200	2500
Ratio	1.01	1.07	0.08	0.08
November				
Measured	4500	3750	3550	200
Natural	4400	3600	3570	3450
Ratio	1.02	1.04	0.99	0.06
December				
Measured	4500	3630	3600	3250
Natural	3700	3600	3550	3000
Ratio	1.22	1.01	1.01	1.08

TABLE 15: Expected Wetted Perimeters and Spawnable Area: Cedar River at Renton

Month	Wetted Perimeter (feet)			Spawnable Area* (square feet)		
	Historic	Natural	Ratio	Historic	Natural	Ratio
Oct.	66	78	0.85	3596	3790	0.95
Nov.	80	89	0.90	3734	3685	1.01
Dec.	88	94	0.94	3610	3646	0.99
Jan.	91	94	0.97			
Feb.	90	96	0.94			
Mar.	90	93	0.97			
Apr.	89	94	0.95			
May	88	94	0.94			
June	80	90	0.89			
July	64	72	0.89			
Aug.	55	60	0.92	2728	3483	0.78
Sept.	57	64	0.89	3048	3685	0.83

Source: WRA & IS Office Report 47.

*Sockeye Salmon

(e.g., water temperature, water quality, commercial fish harvesting, etc.). However, a direct relationship can be established between changes in flow and "potential" fish production levels. This relationship assumes that those variables, other than streamflow which affect fish production, are held constant. The results of the analysis for the Cedar Basin are presented in Office Report 47 and summarized here.

The river is a fish habitat all year. Fisheries' biologists consider the wetted parameter to be an index of the suitability of the fish habitat for rearing. A review of the various arguments suggests wetted parameters may be a good index for the overall fish habitat except for spawning. Methods for calculating the spawnable area have been developed by the Washington Department of Fisheries and the U.S. Geological Survey. The index of the suitability of the habitat for spawning is the spawnable area.

The most important fish species in the Cedar River Basin above Lake Washington is the Sockeye Salmon. The Sockeye Salmon spawns between August and December with most of the spawning in late September and October.

The expected wetted parameter and spawnable areas for the Cedar River at Renton are given in Table 15. The measured flows and estimates of "natural" flows have been used to develop the data in Table 15. A possible approach for the future would be to develop flows for alternative operating criteria for the Cedar River System and to compare the expected wetted parameters resulting from the alternative operating criteria.

A problem with the use of expected wetted parameter and spawnable area is that the use of the water has the largest impact on flows less than average. The wetted parameter and spawnable area at various frequencies is given in Table 16. The frequency of wetted parameter during August and spawnable area in October is given in Figures 10 and 11.

FACTORS IMPORTANT IN WATER MANAGEMENT

There are several key factors which limit the operation of the Cedar River System to supply water for all uses. These are:

1. A combination of a light winter snowpack and a light spring rain. This gives low spring runoff to the storage reservoir.

2. A warm, dry, late spring and early summer giving an early spring runoff which overflows the reservoir and reduces late spring flow into storage.

3. A dry fall limits the capabilities of remaining water to meet expected demand.

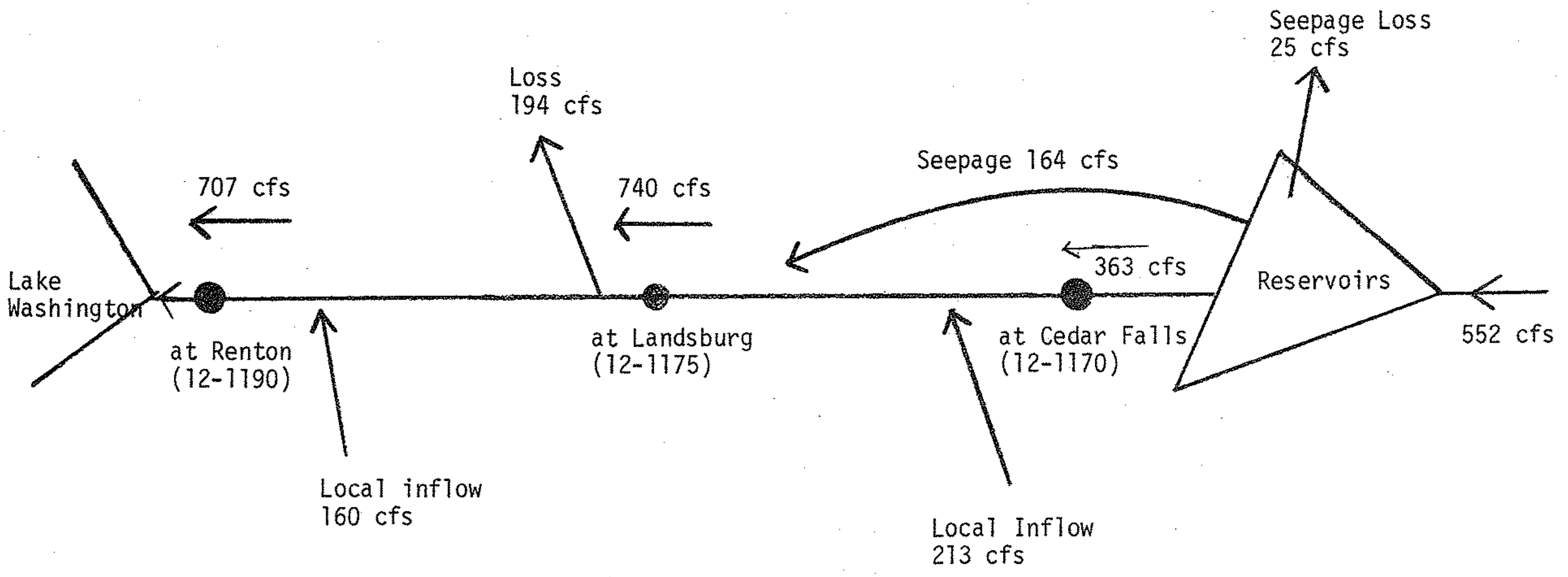


FIGURE 9: Annual Water Balance for Cedar Basin based on RIBCO Natural Flows (1947-1972).

TABLE 14: Measured Flows in the Lower Cedar River Basin: 1947 - 1972 Water Years

Month	Cedar River at Cedar Falls (cfs)	Inflow-Cedar Falls to Landsburg		Cedar River at Landsburg (cfs)	Inflow-Landsburg to Renton		Cedar River at Renton (cfs)
		Natural (cfs)	Seepage (cfs)		Natural (cfs)	Loss (cfs)	
Oct.	167	136	117	420	74	152	342
Nov.	371	233	111	715	167	174	708
Dec.	526	310	139	975	287	210	1052
Jan.	483	326	188	997	330	227	1100
Feb.	514	371	160	1045	334	235	1144
Mar.	432	311	157	900	260	193	967
Apr.	442	293	145	880	187	188	879
May	501	188	196	885	103	172	816
June	474	161	184	819	75	186	708
July	220	93	207	520	44	219	345
Aug.	127	65	199	391	32	216	207
Sept.	117	81	163	361	40	157	244
Annual	363	213	164	740	160	194	707
Drainage Area (sq. mi.)	84.2	33	-	117	69	-	186

TABLE 13: Natural Flows in the Lower Cedar River Basin: 1947 - 1972 Water Years

Month	Cedar River at Cedar Falls (cfs)	Inflow-Cedar Falls to Landsburg (cfs)	Cedar River at Landsburg (cfs)	Inflow-Landsburg to Renton (cfs)	Cedar River at Renton (cfs)
Oct.	397	136	534	74	607
Nov.	657	233	890	167	1057
Dec.	746	310	1056	287	1343
Jan.	632	326	958	330	1288
Feb.	685	371	1056	334	1389
Mar.	505	311	816	260	1075
Apr.	731	293	1024	187	1211
May	882	188	1071	103	1173
June	705	161	866	75	941
July	351	93	444	44	489
Aug.	158	65	223	32	255
Sept.	191	81	272	40	313
Annual	552	213	765	160	925
Drainge Area (sq. mi.)	84.2	33	117	69	186

Data Sources = CH2m - Hill RIBCO Report

TABLE 12: Depletions from the Cedar River above Renton - 1947 to 1972.

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1947	366	437	461	564	452	66	299	85	339	-33	-15	201
1948	909	393	358	324	536	-61	319	788	140	-150	-87	45
1949	-100	142	482	36	164	141	78	350	-246	-218	-147	-57
1950	301	233	442	-275	218	103	663	773	-125	599	232	23
1951	574	423	338	132	190	-262	623	703	509	218	117	225
1952	772	830	544	155	430	471	234	339	58	51	28	16
1953	21	90	271	1122	125	169	403	537	247	63	23	12
1954	-181	520	639	69	511	185	472	234	247	-22	-261	26
1955	54	690	476	348	218	-103	614	275	114	151	96	34
1956	571	342	306	110	83	309	655	391	-76	154	42	-201
1957	214	122	191	-220	127	505	-57	129	396	83	57	58
1958	118	398	166	393	383	86	588	158	126	134	76	114
1959	335	-169	329	239	63	356	348	305	187	120	31	333
1960	-112	-54	273	-82	535	130	-48	606	134	-82	89	-7
1961	102	233	81	457	687	-193	78	555	245	101	54	133
1962	242	-139	206	406	100	210	468	428	695	258	122	107
1963	223	888	222	-60	339	-63	248	653	339	190	103	63
1964	289	757	210	323	154	-60	601	678	-173	304	198	97
1965	127	392	-14	43	265	-29	424	173	437	226	93	-42
1966	327	315	295	279	421	511	315	151	-22	55	55	-64
1967	420	544	620	207	69	326	465	401	270	120	43	5
1968	621	513	133	73	241	301	344	-376	643	-41	281	209
1969	286	509	114	-92	407	584	391	430	839	82	-63	182
1970	150	262	465	284	65	387	105	268	157	17	44	160
1971	81	249	107	464	10	148	370	327	181	358	8	17
1972	194	137	-149	-143	-401	-1410	-375	-85	396	997	33	92
Average	266	348	291	188	246	108	332	357	233	144	48	69

Source: Natual flows from CH2M/Hill RIBCO Report, Measured flows from U.S.G.S.

TABLE 11

FREQUENCY AND WATER USE DATA

FOR Cedar River at Renton. U.S.G.S. GAGE 12-1190

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	607	1057	1343	1288	1389	1075	1211	1197	941	489	255	313
Discharge not exceeded two in three years	678	1195	1488	1421	1511	1167	1286	1286	1039	524	278	341
Discharge not exceeded one in two years (Q_2)	521	960	1263	1213	1333	1039	1193	1168	883	408	229	269
Discharge not exceeded one in ten years (Q_{10})	237	499	776	758	919	735	955	876	544	194	129	133
$Q_2 - Q_{10}$	284	461	488	455	415	304	239	292	339	215	100	136
Water Use (Depletions)	266	348	291	188	246	108	332	357	233	144	48	69

Period of Record 1947-1972. Remarks: Natural Flows from RIBCO Study, log-normal distribution.

TABLE 10

FREQUENCY AND WATER USE DATA

FOR Cedar River at Landsburg . U.S.G.S. GAGE 12-1175

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	534	890	1056	958	1056	816	1024	1071	866	444	223	272
Discharge not exceeded two in three years	599	1005	1166	1060	1152	891	1098	1194	958	473	242	296
Discharge not exceeded one in two years (Q_2)	457	813	993	883	1005	785	1004	1015	812	362	197	232
Discharge not exceeded one in ten years (Q_{10})	204	432	616	511	669	540	769	625	496	163	106	112
$Q_2 - Q_{10}$	253	381	377	372	336	246	235	389	316	199	91	120
Water Use (Depletions)	113	175	81	-39	11	-84	143	185	47	-76	-168	-89

Period of Record 1947-1972 Remarks: Natural Flows from RIBCO Study, log-normal distribution.

TABLE 9

FREQUENCY AND WATER USE DATA

FOR Cedar River at Cedar Falls. U.S.G.S. GAGE 12-1170

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	397	657	746	632	685	505	731	882	705	351	158	191
Discharge not exceeded two in three years	448	742	823	702	758	560	787	1025	784	360	170	206
Discharge not exceeded one in two years (Q_2)	336	597	698	559	628	473	715	809	651	262	133	157
Discharge not exceeded one in ten years (Q_{10})	141	311	426	284	358	285	537	400	374	101	64	70
$Q_2 - Q_{10}$	194	286	271	275	270	187	178	409	277	161	69	87
Water Use (Depletions)	230	285	220	149	171	73	289	382	231	132	31	74

Period of Record 1947 - 1972. Remarks: Natural flows from RIBCO Study, log - normal distribution.

Table 8

FREQUENCY AND WATER USE DATA

FOR CEDAR RIVER AT RENTON. U.S.G.S. GAGE 12-1190

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Discharge	1115	1138	975	880	813	720	356	214	242	344	697	1056
One in Three Year Discharge (Q_3)	1224	1246	1060	940	871	799	394	234	266	381	779	1213
One in Two Year Discharge (Q_2)	1065	1080	907	864	797	625	293	180	205	302	583	944
One in Ten Year Discharge (Q_{10})	702	704	569	671	611	300	121	82	94	150	246	446
$Q_2 - Q_{10}$	363	375	338	193	186	325	172	98	111	152	337	497
Water Use	-	-	-	-	-	-	-	-	-	-	-	-

Period of Record: 1946-1972. Remarks: Measured data, log-normal distribution.

Table 7

FREQUENCY AND WATER USE DATA

FOR CEDAR RIVER AT LANDSBURG. U.S.G.S. GAGE 12-1175

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Discharge	1004	1034	902	878	880	829	527	396	359	420	704	974
One in Three Year Discharge (Q_3)	1095	1131	979	928	932	913	576	426	390	459	778	1094
One in Two Year Discharge (Q_2)	967	979	860	868	869	771	501	384	343	393	628	902
One in Ten Year Discharge (Q_{10})	669	637	584	711	706	466	331	280	233	246	331	508
$Q_2 - Q_{10}$	299	343	276	157	163	305	170	104	110	146	297	394
Water Use	-	-	-	-	-	-	-	-	-	-	-	-

Period of Record: 1946 - 1972. Remarks: Measured Data, log-normal distribution.

Table 6

FREQUENCY AND WATER USE DATA

FOR CEDAR RIVER AT CEDAR FALLS. U.S.G.S. GAGE 12-1170

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean Discharge	484	504	433	440	497	481	224	131	115	168	365	527
One in Three Year Discharge (Q_3)	539	557	477	479	540	535	244	142	123	183	404	604
One in Two Year Discharge (Q_2)	446	449	390	424	480	385	174	110	94	138	293	467
One in Ten Year Discharge (Q_{10})	254	236	215	293	338	144	63	51	41	60	112	218
$Q_2 - Q_{10}$	192	213	175	130	142	241	110	59	53	78	181	250
Water Use	-	-	-	-	-	-	-	-	-	-	-	-

Period of Record: 1946 - 1972. Remarks: Measured Data, log-normal distribution.

FIGURE 8: Annual Discharge of the Cedar River at Landsburg - 1897 through 1974.

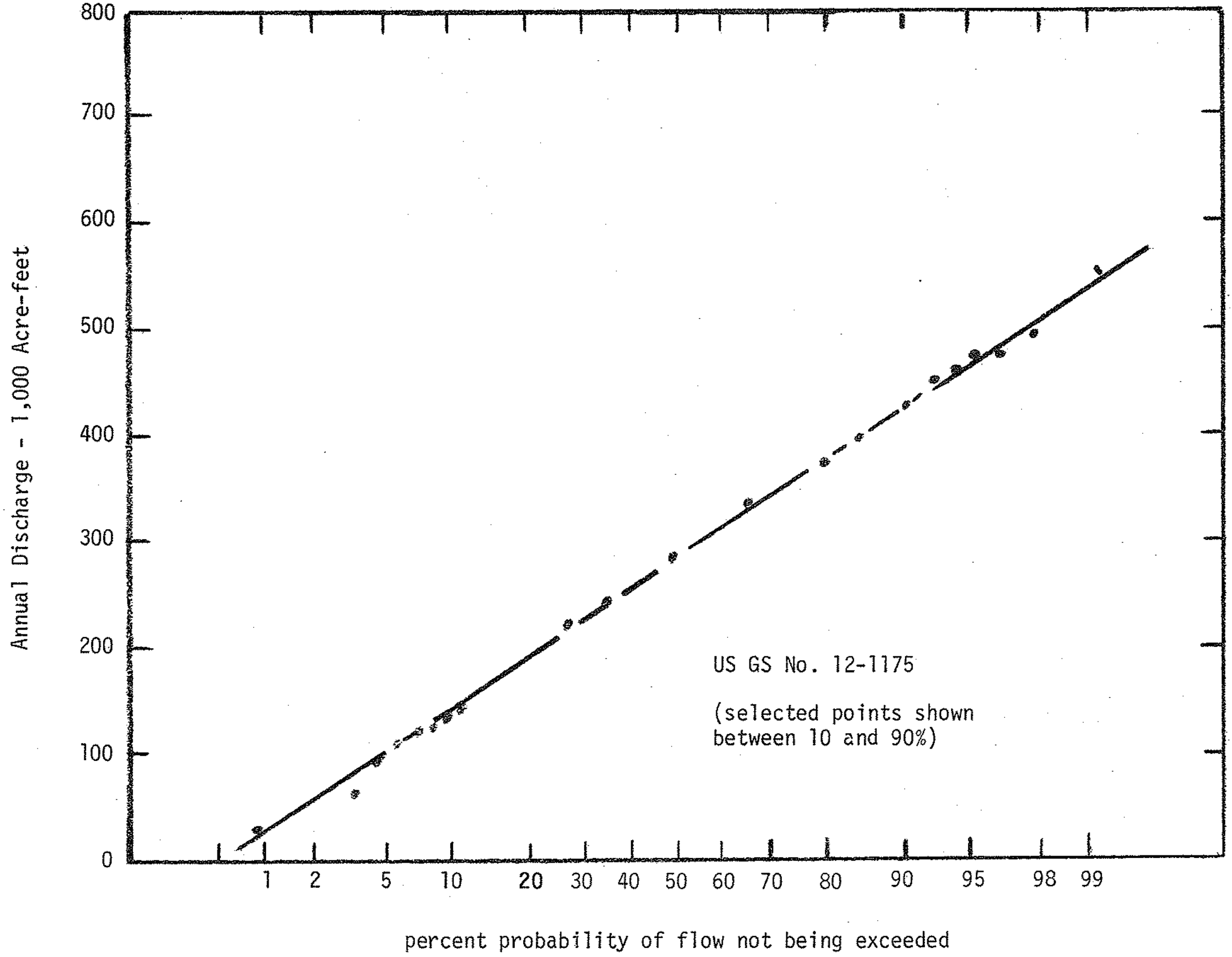


FIGURE 7: Comparison of the Department of Ecology Minimum Flow Regulation to natural and measure flows not exceeded one in ten years.

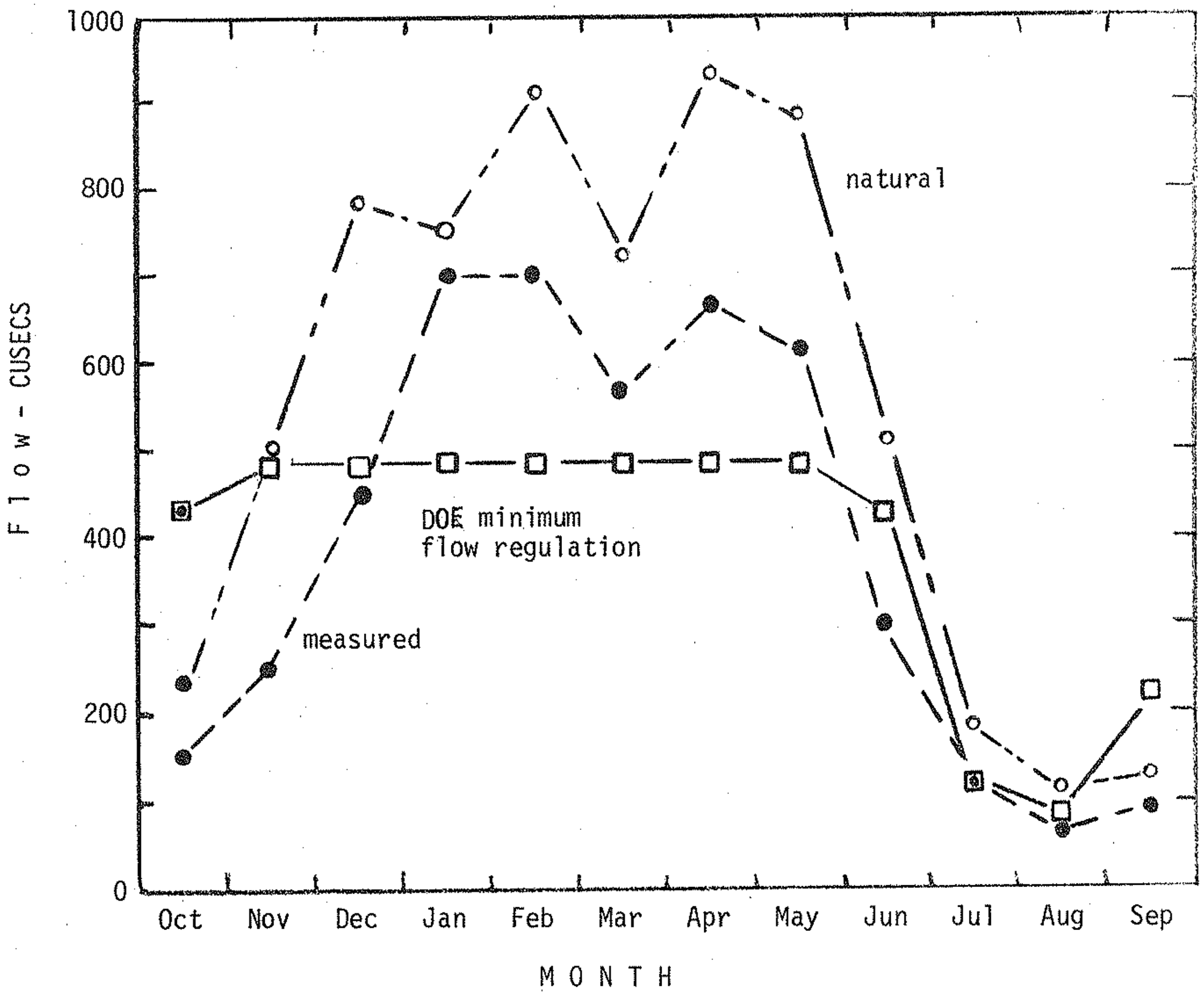
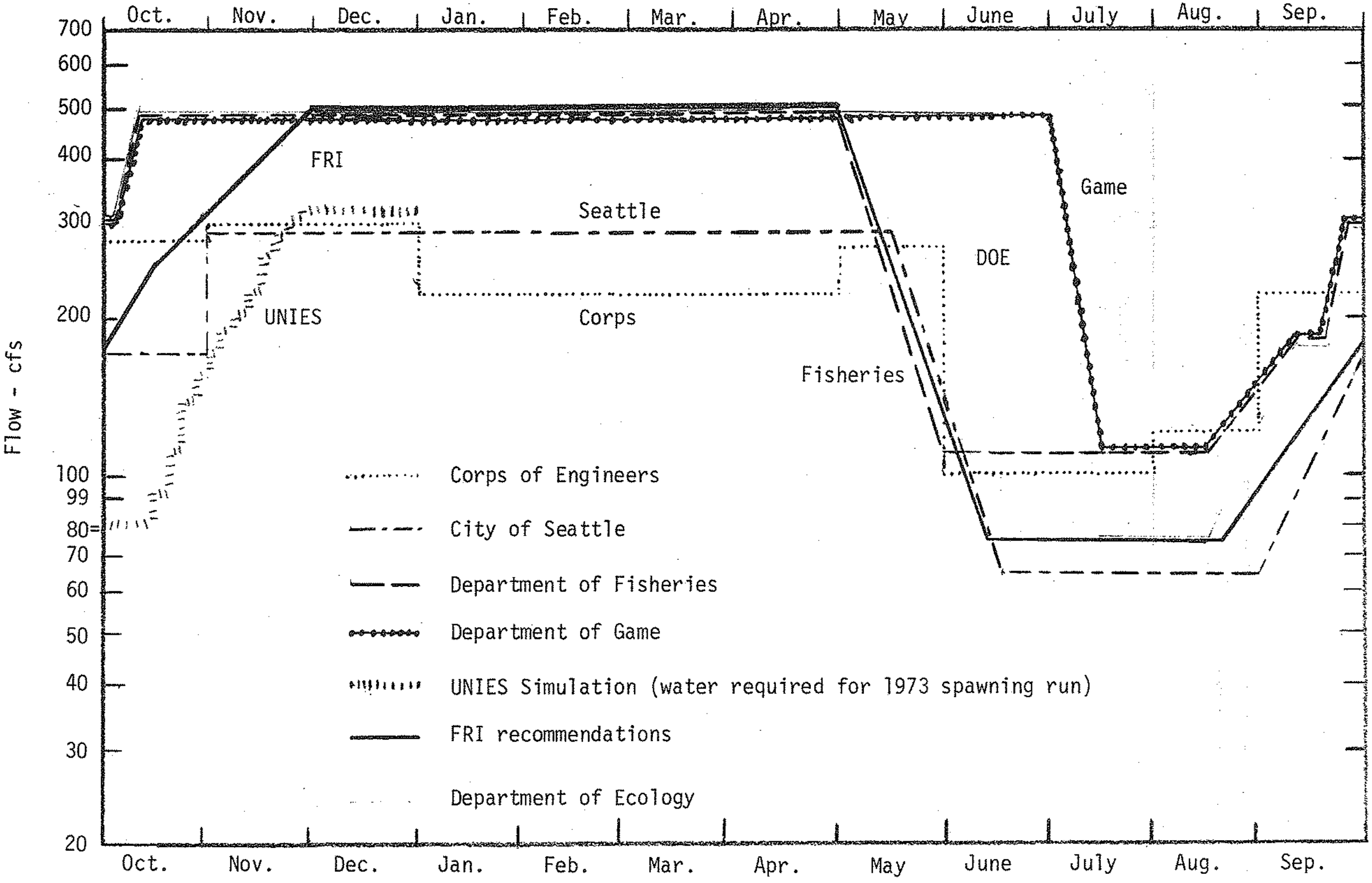


TABLE 5: Comparison of the Department of Ecology Minimum Flow Regulation to the Water Supply.

Month	Minimum Flow Regulations (cfs)	Average Monthly Flows Not Exceeded One in Ten Years	
		Natural (cfs)	Measured (cfs)
Oct.	436	220	150
Nov.	480	500	250
Dec.	480	780	450
Jan.	480	750	700
Feb.	480	910	700
Mar.	480	720	570
Apr.	480	930	670
May	480	880	610
June	427	520	300
July	120	180	120
Aug.	84	120	80
Sept.	216	130	90

Natural for 1943 - 1972 water years.
Measured for 1946 - 1972 calendar years.

FIGURE 6: Comparison of Suggested Minimum Flows.



A summary of all the above flow requests is shown in Figure 6.

Comparison of Fisheries Flows to Flow Available

A comparison of the fisheries flows as given in the DOE minimum flow regulation is given in Table 5 and Figure 7. These data clearly indicate the nature of the conflict between competing uses. The major conflict is in the months of September, October, and November. The water supply of the Cedar Basin is discussed in the following section.

WATER SUPPLY

The average annual water supply of the Cedar River at Landsburg was 512,000 acre-feet over the 77 years between 1898 and 1974. Losses from the basin due to seepage into the Snohomish Basin is most likely 20,000 acre-feet, on an average, and began in 1914. The net seepage loss is about 4 percent of the average annual supply. The period 1947 through 1972 was used for most of the analysis that is present in this section; the average annual discharge during the shorter period was 537,000 acre-feet. A frequency curve for the Cedar at Landsburg is given in Figure 8.

Information on the frequency of monthly flows of the Cedar Basin is given in Tables 6 and 8 for the measured flows of the Cedar at Cedar Falls, Cedar at Landsburg, and Cedar at Renton. As described in previous sections, the measured flows are modified significantly from natural flows by the water management activities of the City of Seattle.

Information on the "natural" flows in the Cedar Basin was developed as part of the RIBCO study. This information has been analyzed and the results presented in Tables 9 through 11. The average water use was obtained by subtracting the measured flows from the "natural" flows and averaging over the period. The results for the Cedar River at Renton are given in Table 12.

A water balance under "natural" conditions for the Cedar River Basin is given in Table 13 and for the conditions with development in Table 14. The annual water balance based on Table 14 is given in Figure 9. The results are similar to the information from published sources given in Figure 4.

IMPACT OF WATER USE ON FISHERIES POTENTIAL

The development of a direct relationship between incremental changes in streamflow and fish production levels would be extremely useful in the establishment of a comprehensive multipurpose water management program for the Cedar Basin. Unfortunately, this direct relationship cannot be developed because of the numerous variables which affect fish production

The following data outlines the actual and planned diversionary history for the City of Seattle.

A. Initial diversion from the Cedar River was in 1905.

B. The actual diversionary capacity in 1917 was approximately 108 cfs. This figure was approximated from delivery capacity (mgd). 1/

C. The planned diversionary capacity in 1917 was approximately 232 cfs (150 mgd). 2/

D. The present diversionary capacity is 340 cfs.)
) Seattle
) Testimony
) 1969 at

E. The projected diversionary need is 570 cfs.) DOE Hearings

F. The projected diversionary needs for Seattle have been revised to 465 cfs. This number was shown by the water right claim filed by Seattle in 1974.

<u>Minimum Flow Regulation</u> - State (Department of Ecology)

The Department of Ecology after reviewing all of the above information (excepting the FRI & UNIES studies) adopted the following regime:

Oct. 1 - Oct. 5	300 cfs
Oct. 5 - Oct. 11	Linear increase 300 to 480 cfs
Oct. 11 - June 15	480 cfs
June 15 - July 15	Linear decrease 480 cfs to 75 cfs
Jul. 15 - Aug. 15	75 cfs
Aug. 15 - Sep. 11	Linear increase 75 cfs to 180 cfs
Sep. 11 - Sep. 20	180 cfs
Sep. 20 - Sep. 26	Linear increase 180 cfs to 300 cfs
Sep. 26 - Oct. 1	300 cfs

"These flows were authorized in accordance with the provisions of Chapter 90.22 RCW to establish minimum flows pursuant to the requests of the Washington State Departments of Fisheries and Game after evaluation of views presented at a public hearing held upon due notice."

Management on the basis of either upper or lower flow extremes may result in adverse impacts on those reaches near the opposite extreme and may preclude other beneficial uses.

1/ McWilliams, M; Seattle Water Department History 1854-1954, Seattle 1955, p. 70.

2/ Ibid.

They decided that if the level of the lake could be maintained between 20 and 22 feet then lock operation could be maintained and saltwater intrusion prevented.

If these lake levels were not maintained then great expense could be generated by modification requirements to existing docks, bulkheads, lockage system, etc. At a 19-foot lake level, cost of modification would be approximately $1.5 million, while at an 18-foot lake level it would be approximately $2.5 million. At a level below 18 feet, changes would be required to the approaches to the floating bridges.

The following flows were recommended by the Corps (to maintain the lake level between 20 and 22 feet):

Jan-Apr	220 cfs
May	270 cfs
Jun-Jul	100 cfs
Aug	120 cfs
Sep	220 cfs
Oct	280 cfs
Nov-Dec	300 cfs

These operating criteria assume that under natural conditions the lake level would fall below 20 feet once every 10 years and below 19 feet once every 100 years. Monthly variations in river flow would be tolerable so long as seasonal volume remains constant. It is assumed that a lake level of 21.9 feet will be reached by May 1.

Provision of M & I Supply - City of Seattle

The City of Seattle, after projecting their future water needs, suggested the following flow regime in 1969.

Oct. 1 - Oct. 30	170 cfs
Oct. 30 - May 15	290 cfs
May 15 - June. 15	Linear decrease from 290 to 65 cfs
June. 15 - Aug. 31	65 cfs
Aug. 31 - Oct. 1	Linear increase from 65 to 170 cfs

This flow regime would have allowed for Seattle's planned diversionary expansion from present capacity of just over 300 cfs to just under 600 cfs.

Since the time of this proposal, the City of Seattle has reduced their planned maximum diversionary capacity from 570 cfs to 465 cfs. The new figure was obtained from the vested water right claim Seattle filed with the Department of Ecology in 1974.

Apr. 30 - May 31	Linear decrease from above level to 75 cfs
May 31 - Sept. 1*	75 cfs

The mean peak spawning discharge for the 11 stations determined by polynomial analysis was 240 cfs.

The "peak" spawning discharge for the 11 stations ranged from 165 cfs to 338 cfs.

Management on the basis of either upper or lower flow extremes may result in adverse impacts on those reaches near the opposite extreme and may preclude other beneficial uses.

UNIES Ltd. Study

The consulting firm of UNIES Ltd. is conducting a study, by request of the Seattle Water Department, to optimize the use of streamflow for multipurpose use.

The methodology is mathematical in nature and uses actual tower counts of fish entering the stream and data developed by Q. J. Stober in the FRI study.

A copy of the methodology developed by UNIES is attached as Appendix A to this report.

Maintenance of Water for Lake Washington

A sufficient amount of water is required from the Cedar River to maintain a number of water related activities associated with Lake Washington. These activities include:

1. Maintenance of Lake levels.
2. Maintenance of lock operation.
3. Prevention of saltwater intrusion.
4. Flushing of the lake to maintain or enhance water quality.

Corps of Engineers

The Corps of Engineers suggested a flow regime to cope with the first three of the above activities.

4. Assessment of the timing of the run, population dynamics, and effects of predicted discharge levels during times of low water supply on future salmon runs.

The study concluded that two flow regimes should be used; one for high runoff or wet years and the other for low runoff or dry years. The study did not quantitatively define wet or dry years.

Wet Year

Aug. 20 - Oct. 15	Linear increase 75 cfs to 250 cfs
Oct. 15 - Nov. 30	Linear increase 250 cfs to 500 cfs
Nov. 30 - Apr. 30	500 cfs
Apr. 30 - May 31	Linear decrease 500 cfs to 75 cfs
May 31 - Aug. 20	75 cfs

(Report states that there is little incremental increase in spawning after 450 cfs)

Dry Year

Sept. 1 - Oct. 15	Linear increase 75 cfs to 250 cfs
Oct. 15 - Nov. 30	Linear increase 250 cfs to 500 cfs - if water is available - no increase or only incremental increase - dependent upon the amount of water available
Nov. 30 - Apr. 30	250-500 dependent upon availability of water and spawning capacity (if spawning has occurred at a low level then high flows are not required)

May 30-Aug. 15 = 110 cfs
Aug. 15-Sept. 10 = Linear increase from 110 to 180 cfs
Sept. 10-Sept. 20 = 180 cfs
Sept. 20-Sept. 25 = Linear increase from 180 to 300 cfs
Sept. 25-Sept. 30 = 300 cfs

B. Department of Game (DOG)

The Department of Games minimum flow request was nearly the same as that by Fisheries except the high flow level (480 cfs) was extended from April 30 to June 30 followed by a linear decrease to 110 cfs on July 15.

This extension was to assure an adequate intragravel flow of water to provide satisfactory temperature and oxygen supply to incubating eggs and pre-emergent fry. This is primarily associated with steelhead.

C. Fisheries Research Institute (FRI), University of Washington

In June 1974, Q. J. Stober and J. P. Graybill of the Fisheries Research Institute released the results of a study done in conjunction with RIBCO. This study was entitled, "Effects of Discharge In the Cedar River on Sockeye Salmon Spawning Area." It discussed the effects of streamflow in the sockeye salmon resource of the Cedar. The FRI study assumed that satisfying the sockeye salmon water requirements would adequately satisfy the requirements of other fish species.

This study tried to maximize spawning area per increment of discharge. Mean peak spawning discharge levels were developed and utilized.

Several study objectives were stated:

1. Determination of the depths and velocities "preferred" by spawning sockeye salmon in the Cedar River.
2. Development of the relationships between spawnable area and discharge.
3. Formulation of the relationship between actual spawner use and empirical calculations of spawnable area within river reaches.

Several parameters are important in sustaining the fisheries resource:

1. Sufficient flow to offer accessibility to adult salmon moving into the river.

2. Sufficient flow to provide adequate spawning depth and velocity conditions so adults can carry out spawning activities.

3. Relatively stable and adequate flow level for proper egg incubation.

4. Relatively stable and adequate flow level for rearing juveniles.

Following are the flow regimes suggested by DOF, DOG, FRI, and UNIES Ltd. for the preservation of the Cedar River fisheries resource:

A. Department of Fisheries (DOF)

The Department of Fisheries suggested flow regime was their determination of those flow levels required to provide necessary spawning conditions for sockeye during the spawning season throughout the Cedar.

They also suggested that the availability of spawning gravel area was the limiting factor for chinook and sockeye production, while amount and quality of rearing habitat was the limiting factor for coho production.

The river below Landsburg is used as the primary spawning tributary for Lake Washington sockeye as well as chinook, coho, steelhead, and cutthroat.

Upstream migration is heaviest from mid-summer to early winter while downstream migration is heaviest in March through June.

Sockeye were introduced into the Lake Washington Drainage System in 1930.

The Department of Fisheries requested that the following flows be adopted to support the present fisheries resource:

Oct. 1-Oct. 5 = 300 cfs
Oct. 5-Oct. 11 = Linear increase from 300 to 480 cfs
Oct. 11-Apr. 30 = 480 cfs
Apr. 30-May 30 = Linear decrease from 480 to 110 cfs

MINIMUM FLOW CONSIDERATIONS

Many factors must be considered when discussing minimum flow considerations for a river system such as the Cedar.

The Cedar River has many potential water uses in addition to the three listed above due to its location (close to Seattle), its abundant supply of clean water, and its contribution to the Lake Washington drainage system. These potential uses include:

1. Municipal and industrial water supply for Seattle.
2. Maintenance of Lake Washington water level.
3. Maintenance of adequate flow to enable operation of Chittenden locks.
4. Maintenance of adequate flow to enable operation of the power generation facilities on the Cedar.
5. Protection of fish and wildlife resources.
6. Maintenance of sufficient flow to aid in the flushing of Lake Washington.
7. Waste assimilation.
8. Recreation.

The prioritization of these potential water uses is essential for the development of a comprehensive water management program for the Cedar River system. Within this system, conflicts have arisen due to numerous competing demands upon the system. The nature of these competing demands is discussed in the following paragraphs.

Fisheries Resource

The Cedar River supports a significant fisheries resource. Those species of anadromous fish present include chinook, coho, sockeye, steelhead, and cutthroat while the resident species include rainbow, brook, and cutthroat trout.

There are several factors which limit fish production in this system:

1. Low river flows accompanied by an increase in water temperature and a decrease in dissolved oxygen.
2. Contamination from water runoff.
3. Physical obstacles such as diversion dams.

Regulation of the river flows has a direct effect on the fisheries resource; beneficially if the flow is enhanced or detrimentally if the flow is reduced as compared to natural flows.

PRESENT SITUATION

At the present time water from the Cedar River is principally used for municipal and industrial water supply, fisheries production, and navigation. The navigation use is as a water supply for operation Ballard Locks downstream of Lake Union.

The Department of Ecology, under authority given it by Chapter 90.22 RCW, has the responsibility to establish minimum water levels for streams, lakes, and other public waters when requested to do so by the Department of Fisheries or Game to "protect" 1/ resources under jurisdiction of the requesting agency.

In August 1969, the Department of Ecology received a letter from the Department of Fisheries requesting that minimum flows be established for the Cedar River. The purpose of this request was to protect the fish resources of the Cedar.

The Fisheries' letter presented the minimum flow regime which they wished to have adopted for the Cedar system. Initially the flow levels were to be regulated at Cedar Grove, but since a flow measurement station was not present at this location, the flows were modified 2/ and moved downstream to the USGS gaging station at Renton (#1190).

The Department of Game at first concurred with the Fisheries' requested flows, but then in a letter dated August 20, 1969 it amended its concurrence and requested its own flow regime.

After due consideration a minimum flow regulation was adopted by the Department of Ecology on August 17, 1971.

The results of the RIBCO Study and other work show that the water supply is not adequate to supply both existing municipal and industrial water supply demand and the water required to meet the fisheries demand as given in the Department of Ecology regulation. Consequently, a major conflict exists between competing water uses.

The conflict is particularly interesting in the Cedar Basin because many of the uses did not exist in 1905 when the city of Seattle began using the river as a public water supply. Sockeye Salmon could not reach the river (or Lake Washington) until the Mountlake cut was constructed in 1917 and navigation use was of a different character.

1/ It has not been defined whether protection means to sustain or to enhance.

2/ $Q_cG = 0.59 (Q_r)^{1.07}$

Where: Q_cG = discharge in cfs at Cedar Grove
Q_r = discharge in cfs at Renton

FIGURE 5: Trends in Consumptive Water Rights in WRIA 8 (Lake Washington Basin) 1930 through 1975.

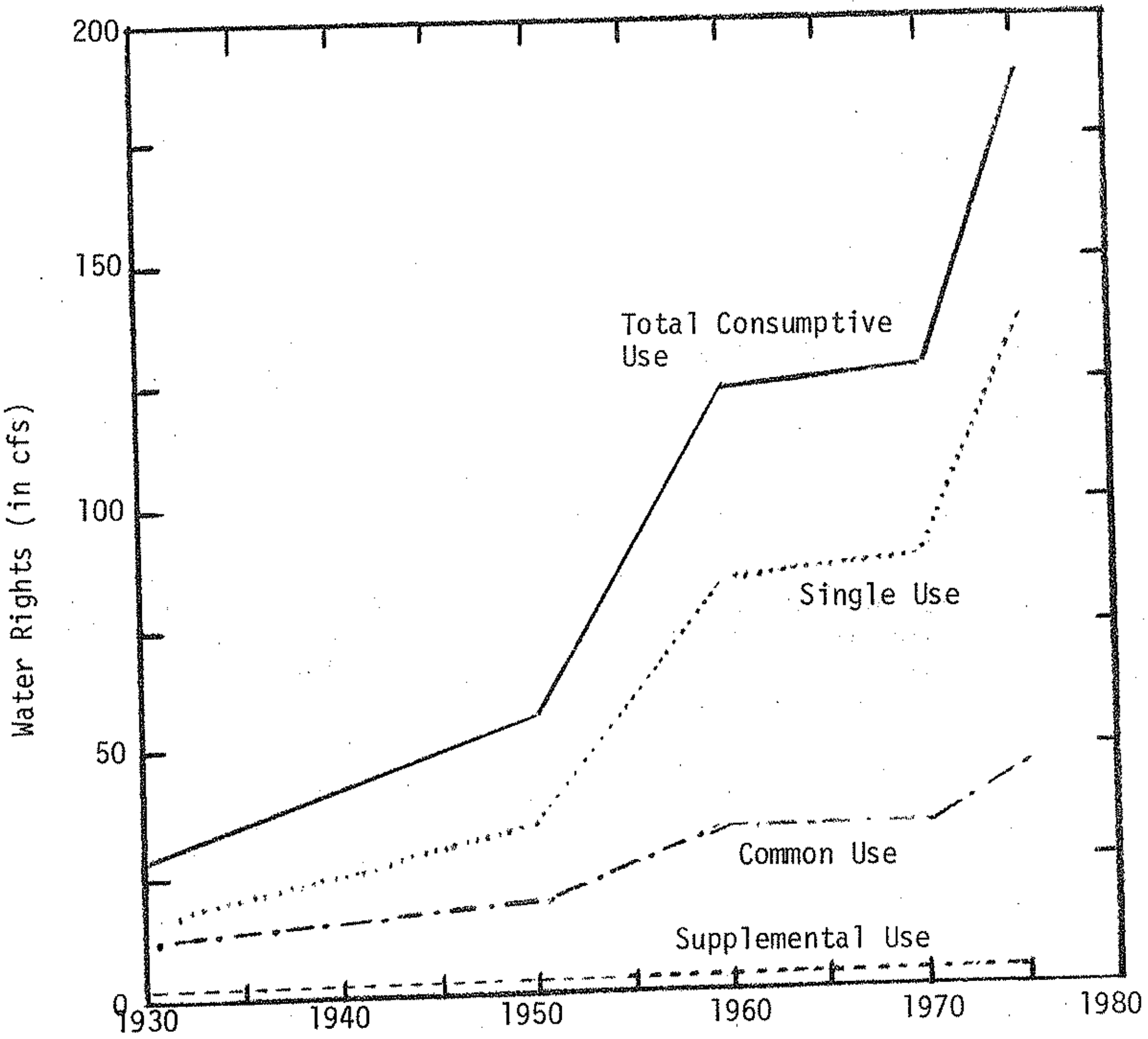


TABLE 4: Trends in Consumptive Water Rights in WRIA 8 (Lake Washington Basin) - 1930 through 1975.

Period	Type of Use			Total Use
	Single Use	Common Use	Supplemental	
Through 1930	16.07 cfs	11.54 cfs	1.50 cfs	29.11 cfs
Through 1940	24.24 cfs	15.72 cfs	1.50 cfs	41.46 cfs
Through 1950	35.23 cfs	18.20 cfs	3.08 cfs	56.51 cfs
Through 1960	85.91 cfs	34.09 cfs	3.93 cfs	123.93 cfs
Through 1967	89.65 cfs	34.26 cfs	4.08 cfs	127.99 cfs
Through 1975	132.33 cfs	46.31 cfs	4.16 cfs	187.8 cfs

TABLE 3: Irrigation Requirements (Cedar River Basin).

DIVERSIONS acre-ft / acre		RETURN FLOW (acre-ft/acre)						DEPLETIONS		Total DEPLETIONS (in cfs) (176.25 Acres)
		MAY	JUN	JUL	AUG	SEP	TOTAL	Acre-ft / Acre	cfs / acre	
May	0.09	0.02	–	–	–	–	0.020	0.070	0.001	0.18
Jun	0.43	0.01	0.085	–	–	–	0.095	0.335	0.006	1.06
Jul	0.71	0.005	0.042	0.145	–	–	0.192	0.518	0.008	1.41
Aug	0.62	–	0.021	0.072	0.125	–	0.218	0.402	0.007	1.23
Sep	0.30	–	0.01	0.036	0.062	0.060	0.168	0.132	0.002	0.35
Oct	–	–	0.005	0.018	0.031	0.030	0.084	–0.084	-0.001	-0.24
Nov	–	–	–	0.009	0.016	0.015	0.040	–0.040	-0.001	-0.12
Dec	–	–	–	0.004	0.008	0.008	0.021	–0.021	0	-0.06
Jan	–	–	–	–	0.004	0.004	0.008	–0.008	0	-0.02

TABLE 2: Total Monthly Depletions, Cedar River at Renton (#12-1190) (in cfs).

USE	MONTH											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Domestic Single**	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Domestic Multiple**	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Domestic Non-Municipal**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Stock**	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Irrigation**	-	-	-	-	-	-	-	0.18	1.06	1.41	1.23	0.35
Seattle M & I*	167.65	162.41	174.69	184.79	194.96	191.36	208.96	200.15	228.23	254.45	245.64	184.67
TOTAL	169.97	164.73	177.01	187.11	197.28	193.68	211.28	202.65	231.61	258.18	249.19	187.34

** Water rights

* Actual water use

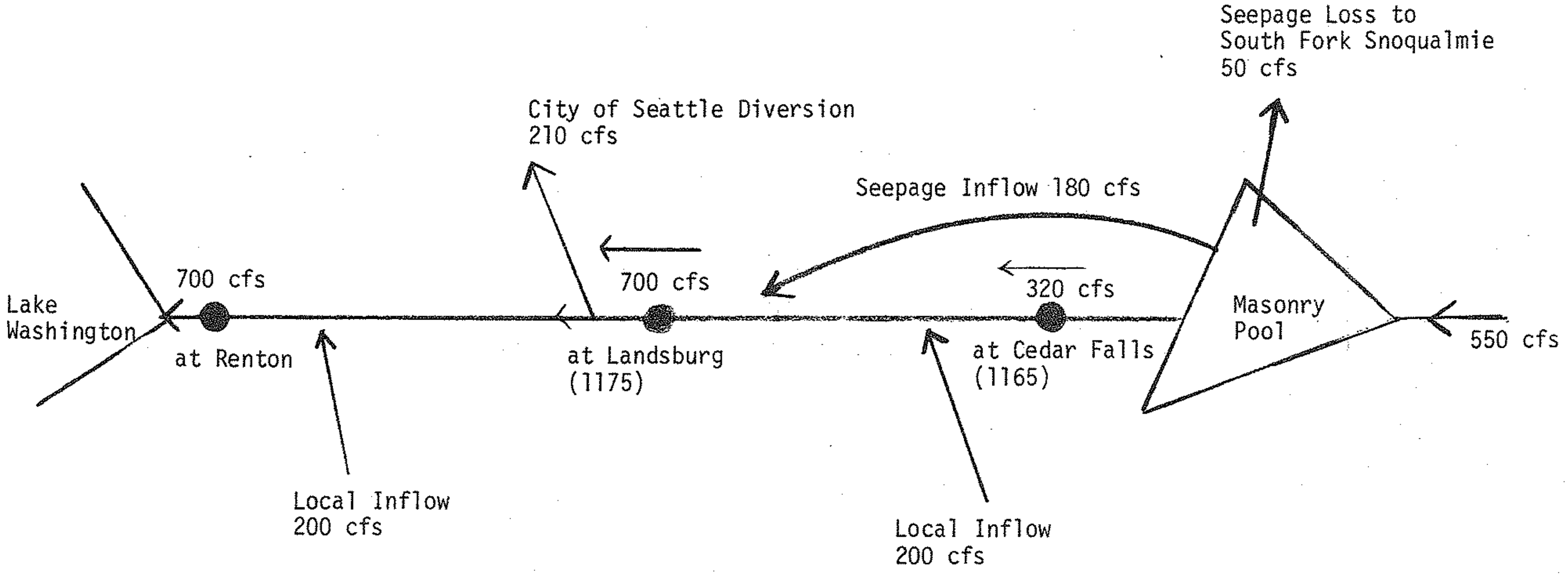


FIGURE 4: Approximate Annual Water Balance for the Cedar River above Lake Washington.