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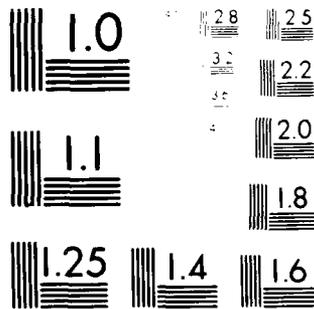
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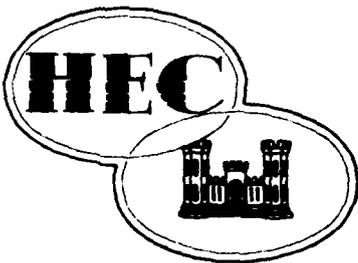# USE OF NON-SEQUENTIAL TECHNIQUES IN THE ANALYSIS OF POWER POTENTIAL AT STORAGE PROJECTS

by

GARY M. FRANC

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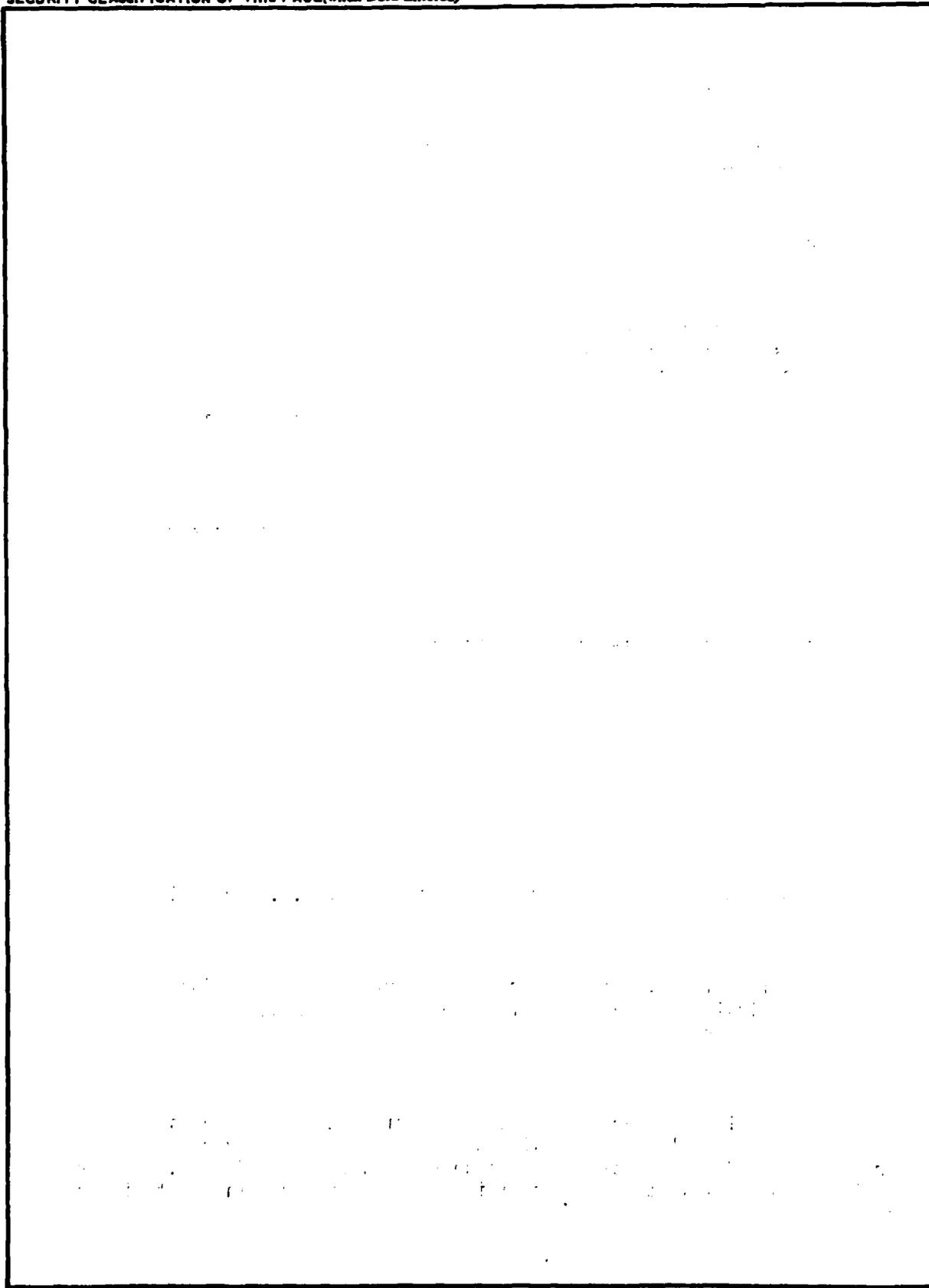
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An electronic computer procedure is described that uses an estimate of power storage available at a dam site to make estimates of average annual energy and dependable capacity using a non-sequential methodology. Comparisons of this method against the more traditional sequential routing analysis are performed.

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# USE OF NON-SEQUENTIAL TECHNIQUES
# IN THE ANALYSIS OF POWER POTENTIAL
# AT STORAGE PROJECTS

Gary M. Franc[1]

## INTRODUCTION

The analysis of hydropower storage projects has traditionally been performed by use of sequential reservoir routing techniques, whereas the use of non-sequential techniques has been traditionally limited to the study of run-of-river type projects.

While individual power storage projects should be analyzed by detailed sequential routings when sufficient funds and detail are available, the non-sequential or flow-duration technique (as modified herein) can be made to somewhat approximate the results of a sequential routing by modifying the flow duration curve to represent outflow conditions.

The intent of this paper is to briefly outline the technique developed to enable the analysis of power storage projects using a non-sequential approach and, more importantly, to illustrate the improvement in estimates of energy and capacity from employing the technique.

## FLOW-DURATION CURVE ADJUSTMENT

A storage project, in general, accumulates excessive inflows for future use during low flow periods, thereby transforming the inflow-duration curve, based on inflows into the project, into a flatter outflow-duration curve, reflecting the operation and effect of the project's storage as depicted below:

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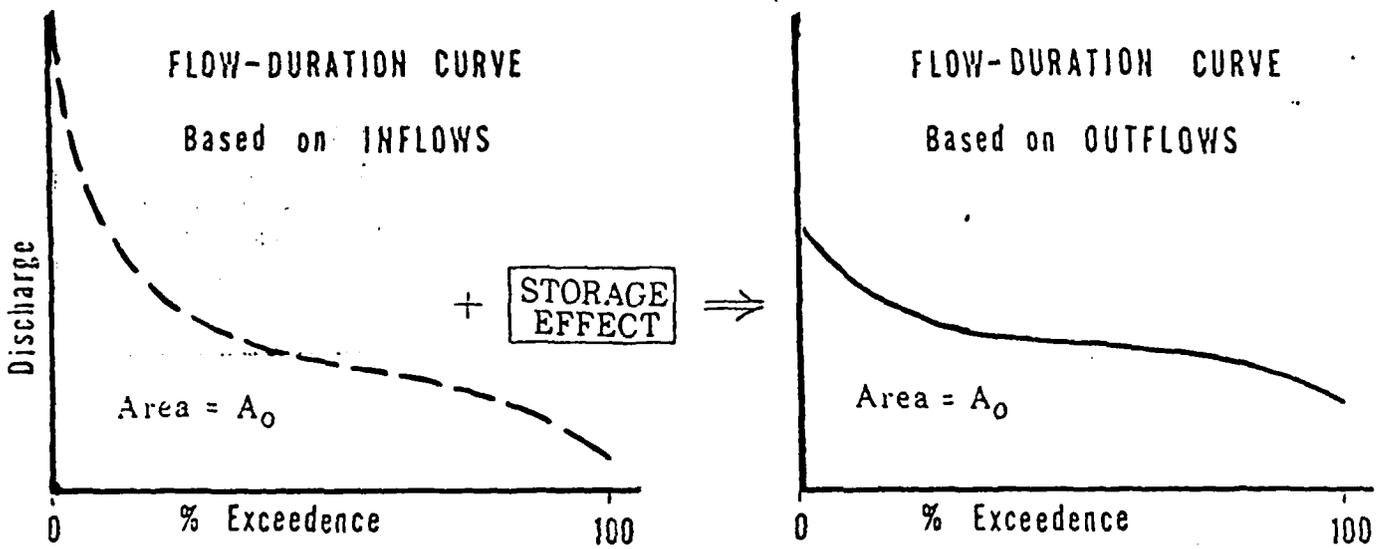[1] Hydraulic Engineer, Hydrologic Engineering Center, U. S. Army Corps of Engineers, Davis, CA  95616

Figure 1

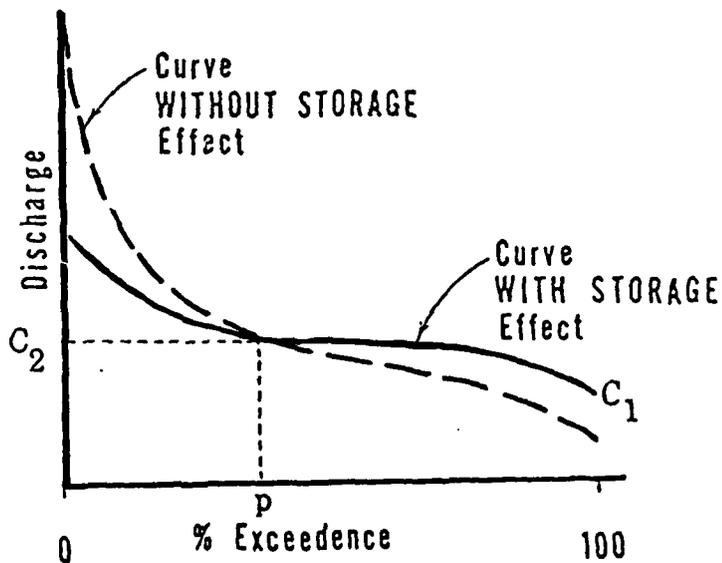Superimposing the curves in Figure 1 results in the combined curve in Figure 2.



Figure 2

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The area ($A_o$) under the original flow-duration curve is preserved and the modified flow-duration curve passes through points $C_1$ and $C_2$.

Where:

$C_1$ represents a discharge corresponding to 100% exceedence;

$C_2$ represents a point of intersection between the two curves.

An analytical technique was developed to transform the shape of the inflow-duration curve to the form of the outflow-duration curve. This mathematical algorithm will generate an outflow-duration curve and meet the following conditions:

1) the value of the function (flow-duration ordinate) at 100 percent exceedence must be $C_1$;

2) the value of the function (flow-duration ordinate) at some percent exceedence p must be $C_2$, where $0<p<1.0$;

3) the area under the modified outflow-duration curve must equal the area under the original inflow-duration curve ($A_o$).

PARAMETER DETERMINATION

Attention is now focused on making estimates for parameters $C_1$, $C_2$ and p.

The selected discharge value of $C_2$, corresponding to the percent exceedence point of intersection between the two duration curves, is critical in the mathematical algorithm for allowing feasible development of the outflow-duration curve. Comparison of inflow and outflow-duration curves for various storage projects tested revealed that the point of intersection between the two duration curves deviated unappreciably from the percent exceedence value corresponding to the average annual inflow $A_o$. Therefore, $C_2$ is assumed to be equal to $A_o$, which generally corresponds to percent exceedences ranging in value from 15 to 35 percent. The value of $A_o$ is a constant and represents the area underneath the original inflow-duration curve, which is easily determined by integration. The selection for $C_2$ will automatically determine the value of p because $C_2$ and p are functionally related through use of the flow-duration relationship.

The value of $C_1$ is dependent on the storage capability of the site being analyzed. Accordingly, it seems reasonable to assume that $C_1$ can be estimated by considering the base flow component

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of the flow regime and the minimum flow contribution due to reservoir
regulation during adverse flow conditions as follows:

$$C_1 = QMC + QMSC.................................Eq. 1$$

where:

$C_1$ = the minimum flow value on the outflow-duration curve
corresponding to 100 percent exceedence;

QMC = the minimum flow value on the original inflow-duration
curve without regard to storage effects (100% exceedence
value);

QMSC = the minimum flow contribution attributed to reservoir
operation under critical low inflow conditions.

Critical low flow conditions occur whenever, over a sustained
period of time, a reservoir is regulated to release additional
flow in excess of upstream inflows as a means of satisfying designed
project purposes. With regard to hydropower, this operational policy,
if continued, can actually exaggerate the situation since depletion
of power storage reduces the effective headwater and correspondingly
the operating power head; requiring a continually increasing amount
of flow to sustain energy requirements. The period of maximum draw-
down can be defined as the period of time which begins with full
power storage and ends when the power storage remaining is at a
minimum. By definition, the period of maximum drawdown will then
contain the most adverse streamflow conditions and will require
the maximum withdrawal of water from the power storage. An estimate
of QMSC can now be approximated by determining the depletion rate
occurring throughout this period.

As an initial step, the power storage can be converted from units
of volume, typically in acre-feet, to units of flow rate (cfs). To
perform this conversion, a time period, say one year, must be selected.
The resulting value expresses the power storage potential as the
average amount of flow that can be extracted from an initially full
power pool throughout a period of one year.

However, as defined above, the period of maximum drawdown is
unconstrained with regard to the length of time required to
complete the process, and actual reservoir operations have demonstrated
this period of time varies from a few weeks to several years in length.
Accordingly, the initial depletion rate (assuming a one-year length
in the period of maximum drawdown) must be adjusted by a factor to

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reflect the project's actual length in time to minimum pool level as shown below:

$$QMSC = PS * ACF * ADJF............................Eq. 2$$

where

  PS = power storage expressed as a volume (acre-feet);

  ACF = a conversion factor (0.00138) which when multiplied by (PS) expresses the amount of power storages in terms of an average annual flow rate (cfs-yr);

  ADJF = adjustment factor applied to the power storage to correct for variation in the length of the period of maximum drawdown.

From Equation 2, one can conclude that a length of the period of maximum drawdown exceeding one year requires the adjustment factor (ADJF) to be less than one. Conversely, a length in the period of maximum drawdown less than one year requires ADJF to exceed unity. In effect, ADJF can be alternatively defined as the reciprocal of the length in the period of maximum drawdown, when time is measured in years.

Several attempts at establishing a relationship to determine a value for ADJF were performed. The regression equation finally selected is based upon 113 existing and proposed hydro sites throughout the United States and is shown below:

$$ADJF = 0.65 + 1.113 * LOG(1/PSR)......................Eq. 3$$

where PSR represents a project's power storage to mean annual flow ratio.

Statistically, the above equation resulted in a R-squared value of 0.49 and a standard error of 0.45. A plot of this relationship can be seen in Figure 3.

The PSR is a dimensionless parameter which expresses the relative size of power storage to average annual inflow and is determined by converting power storage to an average one year flow rate, as previously suggested, and then dividing the result by the project's expected average annual inflow. In addition, this parameter is a relative measure of the ability to control the length of the period of maximum drawdown through regulation of project storage.
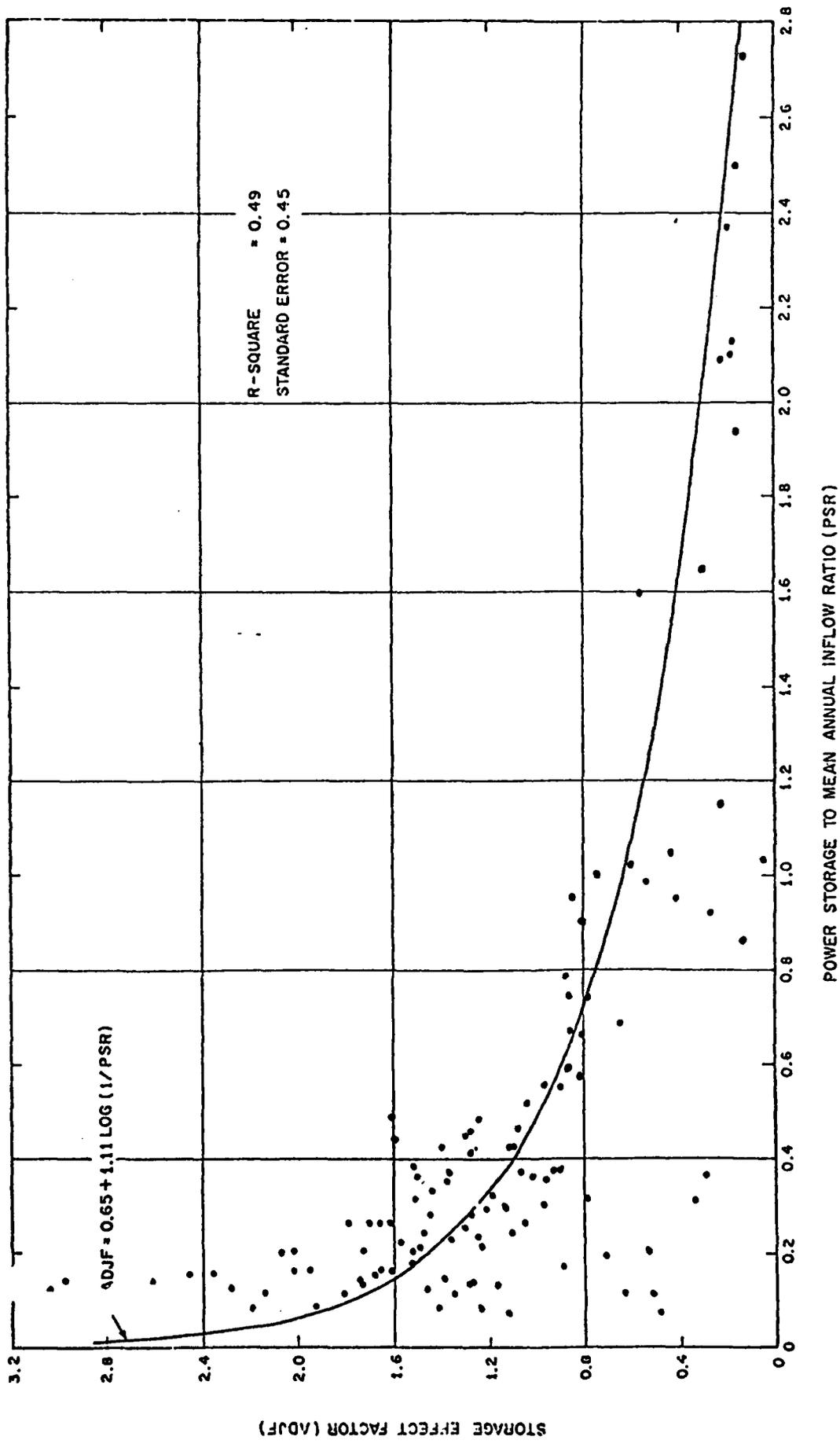
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Figure 3   PLOT OF REGRESSION ANALYSIS RESULT

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A relatively large PSR, say greater than 1.0, indicates sufficient storage capacity so that, on the average, there exists the capability of extending the period of maximum drawdown during sustained periods of low inflow. As the PSR falls below 1.0, this capability to attenuate diversity between inflow availability and project demands decreases, causing the average length of the period of maximum drawdown to decrease, accordingly. Another observation from Figure 3, substantiating this conclusion, is that as the PSR falls below 1.0, considerable increase in scatter of the data occurs. This implies that the storage effect is becoming relatively less important than the effect of diversity between inflow supply and energy demand. A direct determination of parameter $C_1$ is now possible by successive use of Equations 3, 2, and 1; allowing for a plausible solution to systematically produce a synthetic outflow-duration relationship for projects exhibiting power storage.

The substitution of the synthetic outflow-duration relationship for the original inflow-duration curve should substantially improve any estimate of average annual energy and should additionally enable an approximation of dependable capacity to be performed when used in a non-sequential power potential analysis.

AVERAGE ANNUAL ENERGY COMPARISON

Tables 1 and 2 illustrate the effect of using the flow-duration adjustment technique in the estimate of average annual energy.

Table 1 is comprised of twenty-six existing storage projects, each of which is currently installed and operating for energy production. Each project, defined by a site identification number and a project name, has been simulated on computer by using a computer program called HYDUR[1]. This program is design to perform power potential analyses using a non-sequential methodology. HYDUR can be operated in the traditional fashion or can be operated using the flow-duration adjustment option based on user input. Column 1 displays average annual energy estimates based on using standard non-sequential techniques. Column 2 contains energy estimates based on using the adjustment option. Column 3 represents the percent increase resulting from estimating average annual energy using the adjustment option as compared to standard non-sequential methods. In two cases where a decrease in the estimate of average annual energy occurred, the corresponding PSR's were 0.021 and 0.009; both relatively insignificant amounts of power storage. In general however, the use of the adjustment option resulted in an appreciable increase in the estimate of average annual energy. On the average, the increase was 13 percent. This trend is expected because the effect of the flow-duration adjustment is to produce a flatter and less "peaky" outflow-duration curve, thereby reducing the amount of average spill and increasing the amount of average annual energy.

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TABLE 1 AVERAGE ANNUAL ENERGY ESTIMATE (GWH)

| Site | Name of Project | PSR | Column 1 No Storage effect | Column 2 Storage effect | Column 3 % Increase |
|------|-----------------|-----|-----------------------------|--------------------------|----------------------|
| SWT0418 | Broken Bow | 0.539 | 114.63 | 132.86 | 16 |
| SWT0419 | Eufaula | 0.388 | 200.51 | 261.56 | 30 |
| SWT0457 | Keystone | 0.069 | 203.66 | 232.55 | 14 |
| SWF0015 | Whitney | 0.251 | 61.99 | 88.68 | 43 |
| SWF0092 | Sam Rayburn | 0.817 | 99.09 | 106.09 | 7 |
| SWL0005 | Bull Shoals | 0.482 | 633.14 | 636.77 | 1 |
| SWL0013 | Greers Ferry | 0.445 | 198.76 | 249.91 | 26 |
| SWL0010 | Beaver | 0.863 | 151.55 | 179.84 | 19 |
| SWL0126 | Table Rock | 0.667 | 454.84 | 502.48 | 10 |
| SWT0513 | Fort Gibson | *0.009 | 190.40 | 178.46 | -6 |
| LMK0003 | DeGrey Lake | 0.740 | 83.20 | 89.56 | 8 |
| LMK0008 | Quachita Lake | 1.075 | 147.57 | 169.73 | 15 |
| LMK0026 | Greeson | 0.642 | 32.66 | 36.24 | 11 |
| MRK0060 | Harry S. Truman | *0.021 | 184.25 | 181.51 | -1 |
| MRK0067 | Stockton Lake | 0.714 | 47.58 | 50.61 | 6 |
| MR00123 | Big Horn Lake | 0.140 | 922.45 | 1000.64 | 8 |
| MR00158 | Canyon Ferry | 0.171 | 352.93 | 375.64 | 6 |
| MR00215 | Lake McConaughy | 0.838 | 114.79 | 115.53 | 1 |
| MR00274 | Lake Francis Case | 0.093 | 1976.93 | 2081.48 | 5 |
| MR00326 | Boysen Reservoir | 0.406 | 80.03 | 86.16 | 8 |
| MR00366 | Glendo Reservoir | 0.344 | 95.15 | 122.03 | 28 |
| SAW0100 | John H. Kerr | 0.190 | 428.36 | 442.88 | 3 |
| SAW0101 | Philpott | 0.557 | 29.81 | 30.37 | 2 |
| SWL0004 | Norfork | 0.270 | 157.08 | 222.42 | 42 |
| SWF0001 | Toledo Bend | 0.376 | 242.68 | 256.11 | 6 |
| SWT0302 | TanKiller | 0.343 | 103.59 | 132.01 | 27 |
| | | | | Average | 13 |

Tables 2A and 2B compare average annual energy estimates derived by sequential routing methods using computer program HEC-5[2], the non-sequential adjustment technique, and traditional non-sequential techniques; both latter estimates using computer program HYDUR. For each of the twenty-six existing power projects, three separate simulations were performed to evaluate the effect of reallocating additional storage volume to the production of energy. The first simulation estimates the average annual energy potential of the existing power project. Simulations two and three estimate the average annual energy potential after reallocating ten and twenty percent of the existing flood control storage to power, respectively.

The results indicate that the non-sequential flow-duration adjustment estimates of average annual energy were generally larger than the energy estimates resulting from sequential routing efforts. Conversely, the standard non-sequential estimates were generally smaller than the energy estimates resulting from sequential routings. On the average the fractional differences were 1.046 and 0.960 for the existing project comparison; 1.054 and 0.956 for the 10 percent reallocation comparison, and 1.059 and 0.952 for the 20 percent reallocation comparison, respectively.

TABLE 2A   COMPARISON OF AVERAGE ANNUAL ENERGY
USING SEQUENTIAL AND STANDARD NON-SEQUENTIAL TECHNIQUES

| | | AVERAGE ANNUAL ENERGY (GWH) | | | | | | | | |
| | | EXISTING | | | 10 PERCENT | | | 20 PERCENT | | |
| SITE | NAME OF PROJECT | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE |
|---|---|---|---|---|---|---|---|---|---|---|
| LMK0003 | DeGrey Lake | 87.63 | 83.20 | 0.949 | 88.37 | 83.86 | 0.949 | 89.08 | 84.51 | 0.949 |
| LMK0008 | Quachita Lake | 167.99 | 147.56 | 0.878 | 168.95 | 148.52 | 0.879 | 170.22 | 149.56 | 0.879 |
| LMK0026 | Greeson | 37.13 | 32.66 | 0.880 | 37.53 | 32.97 | 0.878 | 37.94 | 33.30 | 0.878 |
| MRK0060 | Harry S. Truman | 178.20 | 184.25 | 1.034 | 203.30 | 205.53 | 1.011 | 220.90 | 221.69 | 1.004 |
| MRK0067 | Stockton Lake | 47.96 | 47.58 | 0.992 | 49.39 | 48.51 | 0.982 | 50.66 | 49.49 | 0.977 |
| MR00123 | Big Horn Lake | 933.40 | 922.46 | 0.988 | 942.60 | 931.36 | 0.988 | 951.61 | 940.06 | 0.988 |
| MR00158 | Canyon Ferry | 359.40 | 352.93 | 0.982 | 367.50 | 359.83 | 0.979 | 374.80 | 365.82 | 0.976 |
| MR00215 | Lake McConaughy | 109.20 | 114.79 | 1.051 | 109.10 | 116.12 | 1.064 | 113.60 | 117.54 | 1.035 |
| MR00274 | Lake Francis Case | 2033.80 | 1976.93 | 0.972 | 2064.20 | 1995.46 | 0.967 | 2093.80 | 2008.26 | 0.959 |
| MR00326 | Boysen Reserv. | 78.80 | 80.03 | 1.016 | 81.50 | 82.85 | 1.017 | 84.30 | 85.96 | 1.020 |
| MR00366 | Glendo Reserv. | 100.37 | 95.15 | 0.948 | 102.98 | 96.81 | 0.940 | 105.47 | 98.68 | 0.936 |
| SAW0100 | John H. Kerr | 435.96 | 428.36 | 0.983 | 448.11 | 442.71 | 0.988 | 459.44 | 451.31 | 0.982 |
| SAW0101 | Philpott | 27.84 | 29.81 | 1.071 | 28.10 | 29.98 | 1.067 | 28.25 | 30.18 | 1.068 |
| SWL0004 | Norfork | 201.70 | 157.08 | 0.779 | 204.80 | 159.00 | 0.776 | 208.10 | 160.80 | 0.773 |
| SWF0001 | Toledo Bend | 255.80 | 242.68 | 0.949 | 256.10 | 243.62 | 0.951 | 256.20 | 244.20 | 0.953 |
| SWT0302 | TanKiller | 116.80 | 103.59 | 0.887 | 119.30 | 105.66 | 0.886 | 121.40 | 107.57 | 0.886 |
| SWT0418 | Broken Bow | 129.20 | 114.63 | 0.887 | 131.20 | 116.62 | 0.889 | 132.70 | 118.49 | 0.893 |
| SWT0419 | Eufaula | 226.70 | 200.50 | 0.884 | 229.30 | 202.31 | 0.882 | 231.80 | 203.89 | 0.880 |
| SWT0457 | Keystone | 234.40 | 203.65 | 0.869 | 244.70 | 211.60 | 0.865 | 252.80 | 218.20 | 0.863 |
| SWF0015 | Whitney | 73.30 | 61.99 | 0.846 | 75.60 | 63.39 | 0.838 | 77.20 | 64.76 | 0.839 |
| SWF0092 | Sam Rayburn | 100.50 | 99.09 | 0.986 | 101.90 | 100.92 | 0.990 | 103.10 | 101.86 | 0.988 |
| SWL0005 | Bull Shoals | 598.78 | 633.14 | 1.057 | 616.92 | 646.48 | 1.048 | 637.41 | 662.39 | 1.039 |
| SWL0013 | Greers Ferry | 236.29 | 198.76 | 0.841 | 239.72 | 200.86 | 0.838 | 242.98 | 203.05 | 0.836 |
| SWL0010 | Beaver | 171.63 | 151.56 | 0.883 | 172.76 | 152.16 | 0.881 | 173.73 | 152.83 | 0.880 |
| SWL0126 | Table Rock | 456.30 | 454.84 | 0.997 | 472.33 | 457.63 | 0.969 | 473.82 | 460.41 | 0.972 |
| SWT0513 | Fort Gibson | 212.76 | 190.40 | 0.895 | 222.66 | 198.84 | 0.893 | 230.16 | 206.20 | 0.896 |
| Total | | 7611.84 | 7307.62 | 0.960 | 7778.94 | 7433.60 | 0.956 | 7921.47 | 7541.11 | 0.952 |

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TABLE 2B COMPARISON OF AVERAGE ANNUAL ENERGY
USING SEQUENTIAL AND NON-SEQUENTIAL ADJUSTMENT TECHNIQUES

| SITE | NAME OF PROJECT | AVERAGE ANNUAL ENERGY (GWH) | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | EXISTING | | | 10 PERCENT | | | 20 PERCENT | | |
| | | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE | HEC-5 | HYDUR | FRACTIONAL DIFFERENCE |
| LMK0003 | DeGrey Lake | 87.63 | 89.56 | 1.022 | 88.37 | 90.38 | 1.023 | 89.08 | 91.15 | 1.023 |
| LMK0008 | Quachita Lake | 167.99 | 169.73 | 1.010 | 168.95 | 170.99 | 1.012 | 170.22 | 172.36 | 1.013 |
| LMK0026 | Greeson | 37.13 | 36.24 | 0.976 | 37.53 | 36.62 | 0.976 | 37.94 | 37.04 | 0.976 |
| NRK0060 | Harry S. Truman | 178.20 | 181.51 | 1.019 | 203.30 | 211.27 | 1.039 | 220.90 | 233.29 | 1.056 |
| MRK0067 | Stockton Lake | 47.96 | 50.61 | 1.055 | 49.39 | 51.92 | 1.051 | 50.66 | 53.38 | 1.054 |
| MR00123 | Big Horn Lake | 933.40 | 1000.64 | 1.072 | 942.60 | 1013.27 | 1.075 | 951.61 | 1025.54 | 1.078 |
| MR00158 | Canyon Ferry | 359.40 | 375.64 | 1.045 | 367.50 | 387.87 | 1.055 | 374.80 | 399.02 | 1.065 |
| MR00215 | Lake McConaughy | 109.20 | 115.53 | 1.058 | 109.10 | 116.97 | 1.072 | 113.60 | 118.51 | 1.043 |
| MR00274 | Lake Francis Case | 2033.80 | 2081.48 | 1.023 | 2064.20 | 2124.57 | 1.029 | 2093.80 | 2159.83 | 1.032 |
| MR00326 | Boysen Reserv. | 78.80 | 86.16 | 1.093 | 81.50 | 90.23 | 1.107 | 84.30 | 94.56 | 1.122 |
| MR00366 | Glendo Reserv. | 100.37 | 122.03 | 1.216 | 102.98 | 127.09 | 1.234 | 105.47 | 131.96 | 1.251 |
| SAW0100 | John H. Kerr | 435.96 | 442.88 | 1.016 | 448.11 | 455.31 | 1.016 | 459.44 | 466.59 | 1.016 |
| SAW0101 | Philpott | 27.84 | 30.37 | 1.091 | 28.10 | 30.56 | 1.088 | 28.25 | 30.77 | 1.089 |
| SWL0004 | Norfork | 201.70 | 222.42 | 1.103 | 204.80 | 228.41 | 1.115 | 208.10 | 233.93 | 1.124 |
| SWF0001 | Toledo Bend | 255.80 | 256.11 | 1.001 | 256.10 | 258.38 | 1.009 | 256.20 | 259.75 | 1.014 |
| SWT0302 | TanKiller | 116.80 | 132.01 | 1.130 | 119.30 | 136.60 | 1.145 | 121.40 | 140.94 | 1.161 |
| SWT0418 | Broken Bow | 129.20 | 132.86 | 1.028 | 131.20 | 135.23 | 1.031 | 132.70 | 137.56 | 1.037 |
| SWT0419 | Eufaula | 226.70 | 261.56 | 1.154 | 229.30 | 266.00 | 1.160 | 231.80 | 270.20 | 1.166 |
| SWT0457 | Keystone | 234.40 | 232.55 | 0.992 | 244.70 | 249.65 | 1.020 | 252.80 | 264.80 | 1.047 |
| SWF0015 | Whitney | 73.30 | 88.68 | 1.210 | 75.60 | 95.95 | 1.269 | 77.20 | 101.17 | 1.310 |
| SWF0092 | Sam Rayburn | 100.50 | 106.09 | 1.056 | 101.90 | 107.54 | 1.055 | 103.10 | 109.16 | 1.059 |
| SWL0005 | Bull Shoals | 598.78 | 636.77 | 1.063 | 616.92 | 656.22 | 1.064 | 637.41 | 675.67 | 1.060 |
| SWL0013 | Greers Ferry | 236.29 | 249.91 | 1.058 | 239.72 | 254.12 | 1.060 | 242.98 | 258.36 | 1.063 |
| SWL0010 | Beaver | 171.63 | 179.84 | 1.048 | 172.76 | 180.81 | 1.047 | 173.73 | 181.87 | 1.047 |
| SWL0126 | Table Rock | 456.30 | 502.48 | 1.101 | 472.33 | 506.97 | 1.073 | 473.82 | 511.46 | 1.079 |
| SWT0513 | Fort Gibson | 212.76 | 178.46 | 0.839 | 222.66 | 217.76 | 0.978 | 230.16 | 231.05 | 1.004 |
| Total | | 7611.84 | 7962.12 | 1.046 | 7778.94 | 8200.69 | 1.054 | 7921.47 | 8389.92 | 1.059 |

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Additionally, comparison of average annual energy estimates calculated by both the sequential and non-sequential methods resulted in fairly constant deviations in the energy estimates for all three cases tested for each of the twenty-six projects. Although the absolute energy estimates differ on the average by five percent, the estimates of incremental energy gained from reallocating additional storage to power are averaging within about one percent.

These observations suggest that the flow-duration adjustment option is adequately redistributing the available streamflow for power potential analysis and therefore indicates that the primary cause of the difference in energy estimates is due to a difference in power head between the two techniques. This was expected because the average headwater elevation in all the non-sequential simulations was assumed to be at the top of power pool. A more practical selection would be to choose the normal pool headwater level as a fractional percent of the total power pool available. If the project is existing, past operation of the project may give a clue in establishing this fractional percent value. For proposed projects, results from Table 2B indicate that a fractional percent ranging between 0.85 to 0.95 is appropriate for projects exhibiting sufficient power storage (power storage to mean annual flow ratio greater than 0.10).

DEPENDABLE CAPACITY COMPARISON

Dependable capacity can be defined as the capacity which under the most adverse flow conditions on record, can be relied upon to carry system load, provide dependable reserve capacity, and meet firm power obligations, taking into account seasonal variations and other characteristics of the load to be supplied[3]. The association to the "most adverse flow conditions on record," in the definition of dependable capacity strongly supports the notion that parameter $C_1$ might be valuable as an indicator in approximating this capacity value. This assumption was tested and it was found that dependable capacity could be estimated by using the power equation as follows:

$$DCAP = C(C_1/PF) \text{ He} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Eq.4$$

Where:

DCAP = dependable capacity in kilowatts:

$\quad$ C = .084603 conversion factor which expresses power in kilowatts;

$\quad C_1$ = the minimum flow parameter as previously defined;

PF = the average annual plant factor relating dependable
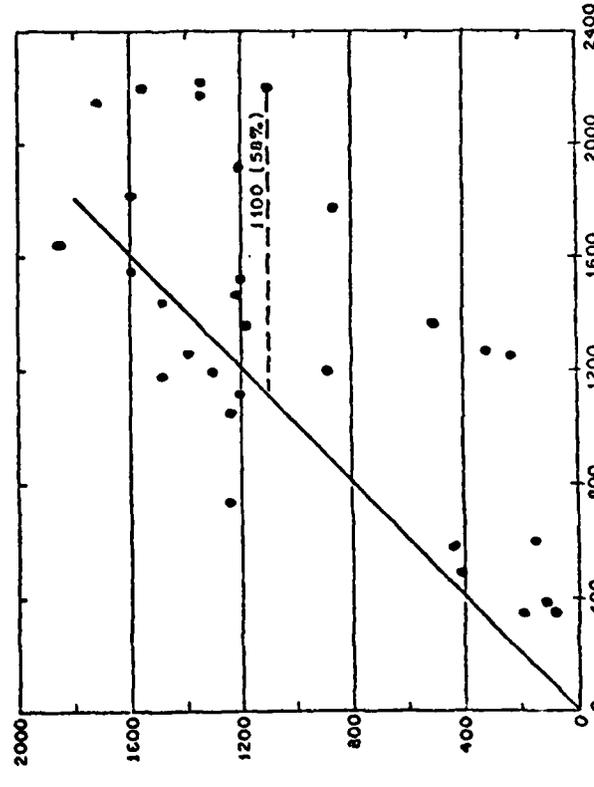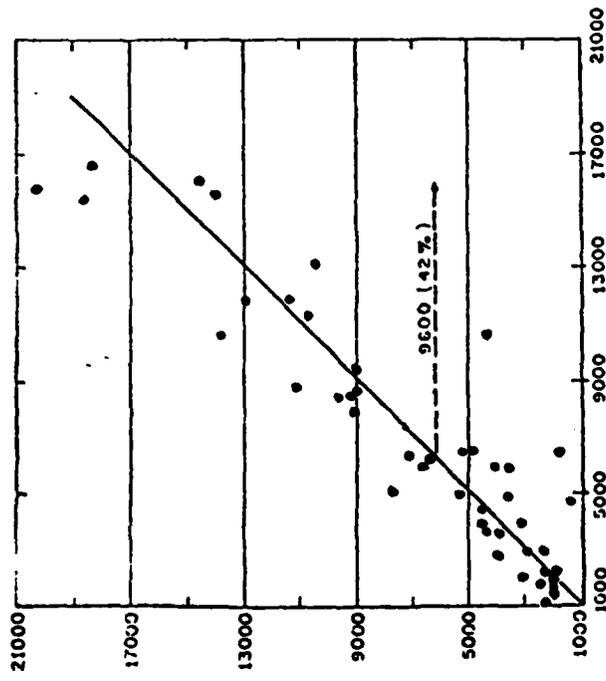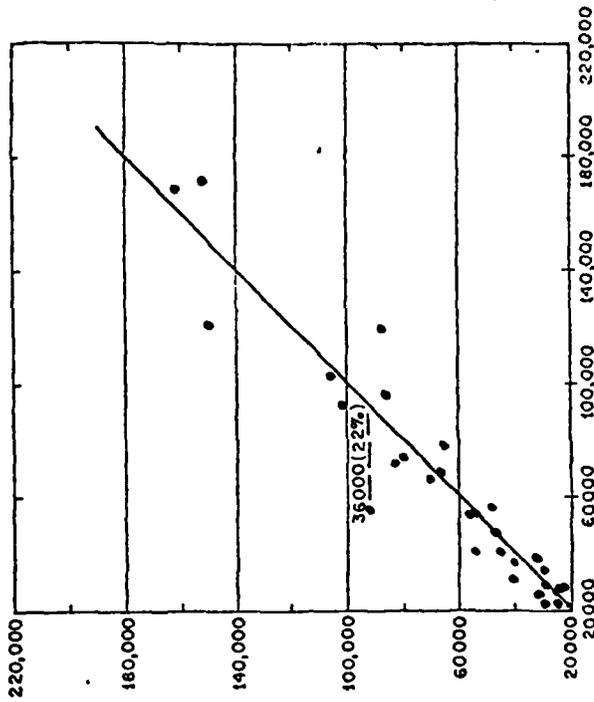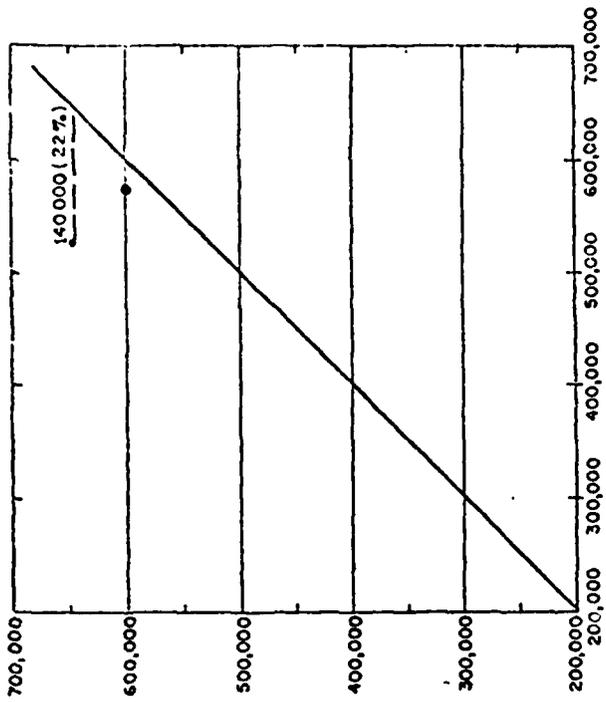        capacity to its firm energy requirement;

$H$ = net power head in feet;

e = overall efficiency (assumed equal to a constant 0.86)

The quantity ($C_1$/PF) represents the expected minimum flow adjusted
for average time of hydropower plant operation.

Equation 4 was employed with data from all 113 projects used
to develop the parameter ADJF and the resulting estimates of
dependable capacity were compared to corresponding dependable
capacity values estimated from sequential routing techniques (HEC-5).
This comparison, depicted in Figure 4, resulted in an R-squared
value of 0.985 and a standard error of 10,700 kilowatts. Comparison
of empirical (non-sequential) to sequentially determined capacities
varied over a range of 100 kilowatts to 650 megawatts. A departure
in plotting position above an imaginary 45° line represents an
underestimate of dependable capacity determined empirical as compared
to dependable capacity estimated using sequential routing techniques.
Conversely, a departure below this line represents an exaggeration
of dependable capacity. Maximum departure about this line, in terms
of percent difference, occurs for small installations (i.e., projects
having installed capacities less than 2 megawatts). Small install-
ations are generally associated with projects possessing limited
storage capacity and correspondingly small power storage to mean
annual flow ratios (PSR). Since the regression equation used to
estimate ADJF (Equation 3) was incorporated in the empirical determi-
nation of dependable capacity, the problem of increased scatter
associated with small PSR's is most probably the underlying
influence causing these maximum departures to occur in this capacity
range.

An approach to alleviate this problem of increased scatter
is to introduce a parameter into the regression analysis for
determining ADJF which represents a measure of the diversity
associated between energy demand requirements and inflow avail-
ability at a project. Although this approach was not performed
for this paper, an initial attempt at defining this parameter can
be suggested by plotting the firm energy demand requirements of a
project against project inflow in the form of normalized distributions.
As an illustration, assume the monthly distributions of inflow and
firm energy demand can be determined from available data and are
as follows:

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Figure 4  COMPARISON OF EMPIRICAL TO SEQUENTIALLY DETERMINED DEPENDABLE CAPACITIES

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Monthly

| Inflow | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| (cfsm) | 175 | 150 | 75 | 175 | 250 | 375 | 325 | 300 | 250 | 175 | 125 | 125 |

Monthly

Firm Energy Required

| (MWH) | 80 | 75 | 60 | 60 | 70 | 80 | 90 | 110 | 110 | 100 | 80 | 85 |
|-------|----|----|----|----|----|----|----|-----|-----|-----|----|----|

The distributions can be normalized by dividing the monthly values by annual inflow (2,500 cfsm) and annual firm energy (1,000MWH), respectively. Figure 5 is a superimposed plot of these normalized distributions, where the area under each distribution is unity. The plot graphically displays the diversity between energy demand and flow availability. In general, from April through August, this project will have sufficient storage available to meet all energy demands and might actually be accumulating storage and experiencing spill. From September to March, inflow recedes and storage depletion occurs to supplement flow needed for power generation. Therefore, an initial definition of the diversity parameter might be to accumulate the percent differences between the distributions throughout the year whenever percent of energy demand exceeds percent of annual inflow. This suggestion is only one of several alternatives which can be conceived to measure diversity. Future funding may allow for further investigation in this area.

In conclusion, the non-sequential adjustment technique has been shown to be a viable alternative to use in estimating energy and capacity values associated with power storage projects. It is recommended that this option be employed (through the use of computer program HYDUR) throughout the screening process of any basin wide power potential study. Once project alternatives become manageable, a more detailed sequential routing effort should be undertaken.
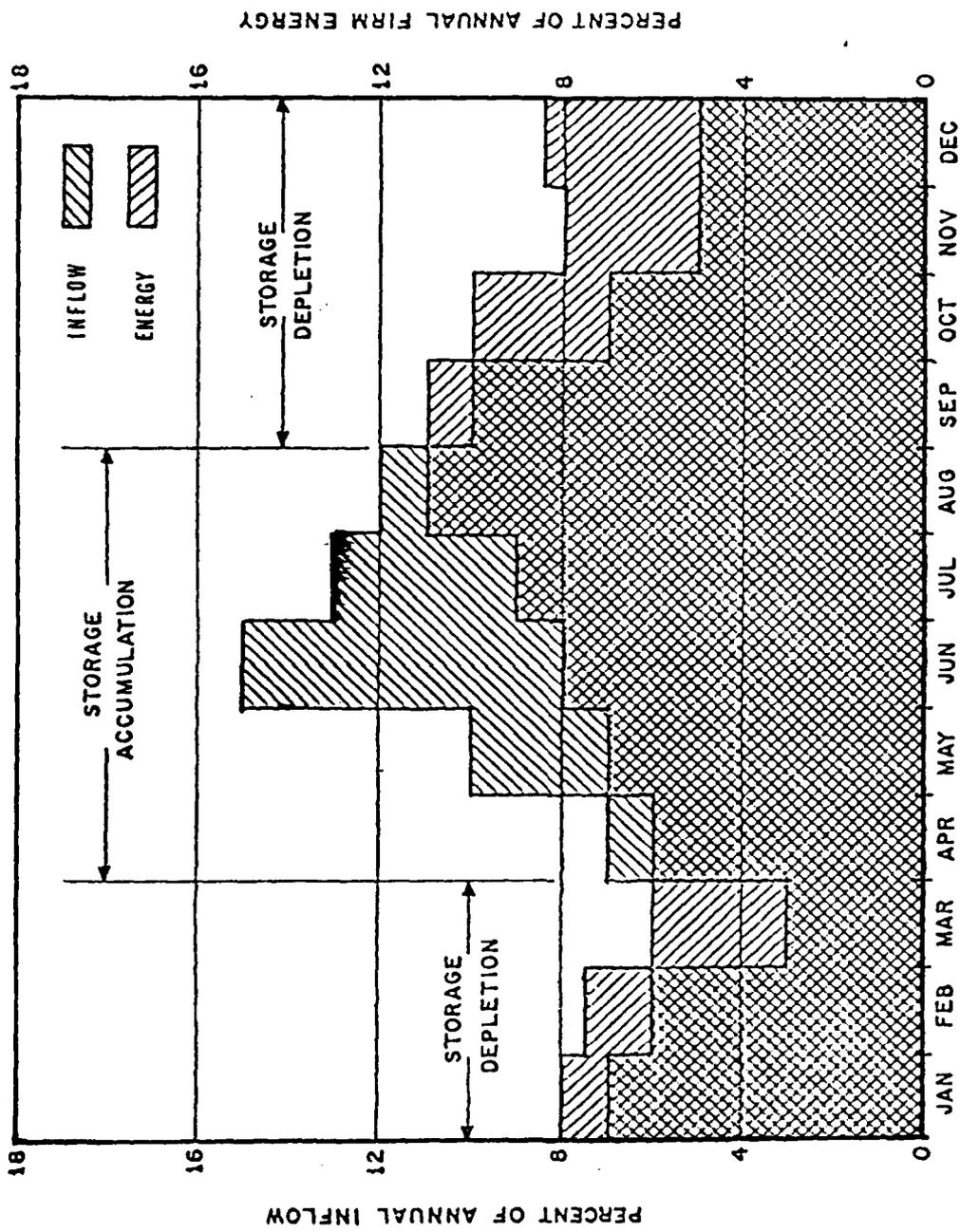
Figure 5   COMPARISON OF ANNUAL FLOW AND ANNUAL FIRM ENERGY DISTRIBUTIONS

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