APPENDIX G

KW/CFS CURVE COMPUTATION

G-1. Introduction.

a. Curves (or tables) specifying the amount of power that can be obtained per cfs of powerplant discharge versus head or reservoir elevation were originally developed to simplify hand SSR power routings. This data is also required by some SSR models and can be provided as an option in others. The simple kW/cfs vs. head curve reflects efficiency and the necessary conversion factors to yield power in kilowatts, given the discharge and the operating head, while the kW/cfs vs. reservoir elevation curve accounts for tailwater elevation and head losses as well.

b. The kW/cfs curve reflects only the effects of head on plant performance, but not the effects of discharge. Therefore, certain assumptions must be made with respect to plant loading in order to select proper efficiency values and tailwater elevations. The example shown in this appendix is based on a "block loaded" operation, where the plant is assumed to operate at full output when it is running and to be shut down the remainder of the time. The number of hours that the plant operates per day would be a function of the available water. With this type of operation, the efficiency values would be based on operation at full gate discharge for heads below rated head, and at rated capacity for heads above rated head. The tailwater elevation would be based on corresponding discharge values. Alternative plant loadings may be assumed, and methods for treating several of the more common loadings are discussed in Section G-3.

G-2. Example.

a. Assumptions. Assume a power installation at a storage project that will be block loaded. Preliminary studies indicate that the average flow available for power generation is 628 cfs, so the hydraulic capacity, based on an assumed average annual plant factor of 20 percent, would be 3,140 cfs. The estimated average pool elevation, based on 25 percent storage drawdown, would be El. 592.3. It is assumed that the rated head will be 95 percent of the average or design head (see Section 5-5b(8)). The head range suggests the use of Francis units, and for the initial kW/cfs curve, the generalized turbine performance curve for Francis units (Figure 2-39) will be used. Eighty-eight percent is a typical value for overall efficiency at rated head, and that value is assumed for this case. Friction head losses are assumed to total 1.0 feet.

b. Procedure for Developing kW/cfs vs. Head Curve.

(1) The kW/cfs versus head curve will be examined first. The first step is to determine the rated head. From the tailwater rating curve, it is found that the tailwater elevation at the desired hydraulic capacity of 3140 cfs is El. 404.3. The design head (head at average reservoir elevation) would be (El. 592.3 - El. 404.3 - 1.0 feet head loss) = 187.0 feet. The rated head is assumed to be 95 percent of design head, or (187.0 x 0.95) = 177.6 feet.

(2) The rated discharge of the plant would be equal to the desired hydraulic capacity. and the efficiency at rated output was assumed to be 88 percent. Based on this data, the rated capacity is computed as follows:

$$kW = \frac{QHe}{11.81} = \frac{(3140 \text{ cfs})(177.6 \text{ ft})(0.88)}{11.81} = 41{,}600 \text{ kW}$$

The kW/cfs for that head would be (41,600 kW/3140 cfs) = 13.2.

(3) Referring to Figure 2-39, values would be computed for additional heads, following the 100 percent rated capacity line above rated head and the full gate discharge line below rated head. For example, at a head of 130 percent of rated head, the discharge would be 76 percent of rated discharge (hydraulic capacity).

$$\text{Head} = (1.30)(177.6 \text{ ft}) = 230.9 \text{ ft.}$$

$$kW/cfs = \frac{41{,}600 \text{ kW}}{(0.76)(3140 \text{ cfs})} = 17.4$$

At a head of 85 percent of rated head, Figure 2-39 shows the maximum output to be 83 percent of rated output and the full gate discharge to be 95 percent of rated discharge.

$$\text{Head} = (0.85)(177.6 \text{ ft.}) = 151.0 \text{ ft.}$$

$$kW/cfs = \frac{(0.83)(41{,}600 \text{ kW})}{(0.95)(3140 \text{ cfs})} = 11.6$$

(4) Similar computations would be made for different heads until sufficient points are developed to describe the expected range of heads. Figure G-1 shows the resulting kW/cfs curve.

c. <u>Procedure for Developing kW/cfs vs. Reservoir Elev. Curve.</u>

(1) In some cases it is more convenient to use a kW/cfs versus reservoir elevation curve. Values of kW/cfs would be computed for various heads, as described above, and the head values would be converted to reservoir elevations by adding tailwater elevations and head losses.

(2) For a head equal to 130 percent of rated head (230.9 ft), the kW/cfs value was computed to be 17.4. The discharge at that head would be 76 percent of rated discharge, or (0.76 x 3140 cfs) = 2390 cfs. The tailwater elevation for that discharge (obtained from a tailwater rating curve) is found to be El. 403.5. The reservoir elevation corresponding to 130 percent of rated head is therefore equal to El. 403.5 + 230.9 ft. + 1.0 ft. = El. 635.4.

(3) Similar computations would be made for different heads and a kW/cfs versus reservoir elevation curve would be plotted. Figure G-1

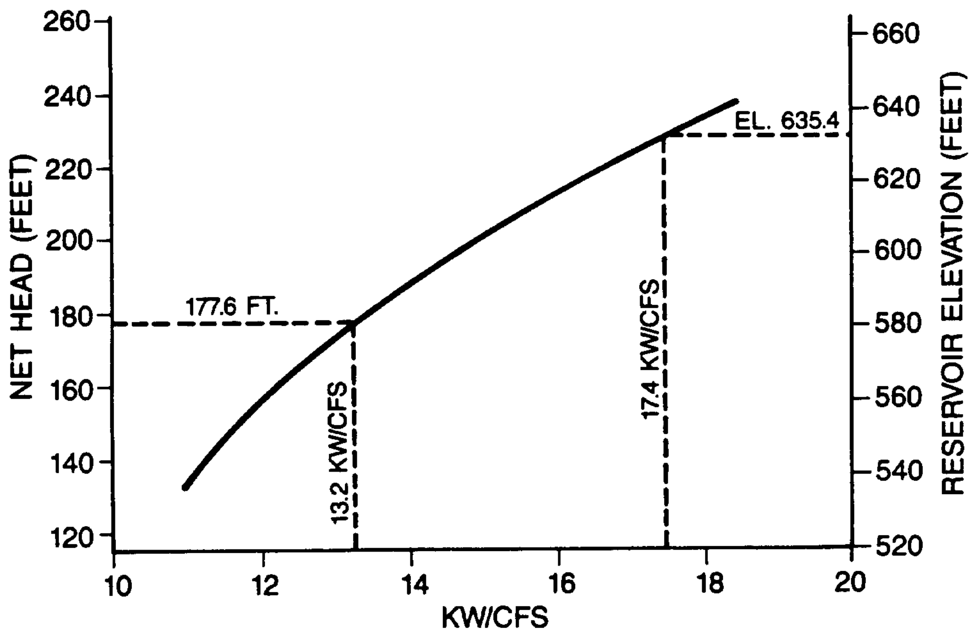

Figure G-1. KW/cfs curve

also includes a scale for determining kW/cfs versus reservoir elevation for the example project.

(4) Figure G-2 shows the KW/cfs versus reservoir elevation curve that was used in the example routings in Appendices H and I.

G-3. Treatment of Alternative Plant Loadings.

a. Assuming that a plant will be operated at full output (block-loaded) may be appropriate for projects that are operated in systems where on-peak energy has a very high value. However, this is not always the case, and alternative approaches may be required. Following are suggested approaches for deriving kW/cfs curves for several different situations.

b. For preliminary studies, a fixed efficiency value of 80 to 85 percent can be assumed (Section 5-5e(2)), and a kW/cfs versus head curve can be constructed based on that value. For higher head projects where variations in tailwater elevation have very little effect on net head, a fixed tailwater elevation can be derived based on a typical plant loading. A kW/cfs versus reservoir elevation curve could then be constructed using the fixed tailwater elevation, a fixed efficiency value, and an estimated head loss value.

c. For more detailed studies, where it is desired to reflect variation of efficiency with head but the project is not block-loaded, an alternative approach must be used. For a project with multiple units, it can often be assumed that sufficient units will be placed on line that the plant will operate at or near best efficiency most of the time. To reflect this operation, it will be necessary to obtain a more detailed turbine performance curve, such as Figure 5-8. The generalized performance curves (Figures 2-39 through 2-45) would not be suitable. Using Figure 5-8 as an example, the unit would operate at best efficiency at about 65 percent gate. Efficiency values can be estimated from the figure for various heads, and a kW/cfs versus head curve can be constructed. Care should be taken to be sure that a generator efficiency loss of about two percent is included in the analysis (turbine performance curves frequently do not reflect generator efficiency losses).

d. During high flow periods, a plant must often be loaded at full output, and thus the "best efficiency" assumption would not be valid. This could be handled by using a curve based on full output during the high runoff season and a curve based on best efficiency operation during the remainder of the year. Or, a single composite curve can be constructed that is intermediate between a block-loading curve and a best-efficiency curve. The latter approach might be particularly useful where plant operation varies widely from period to period or where it is not possible to precisely identify a high-runoff season. A composite curve could also be used for plants with a small number of units, where the "best efficiency" assumptions would not be appropriate.

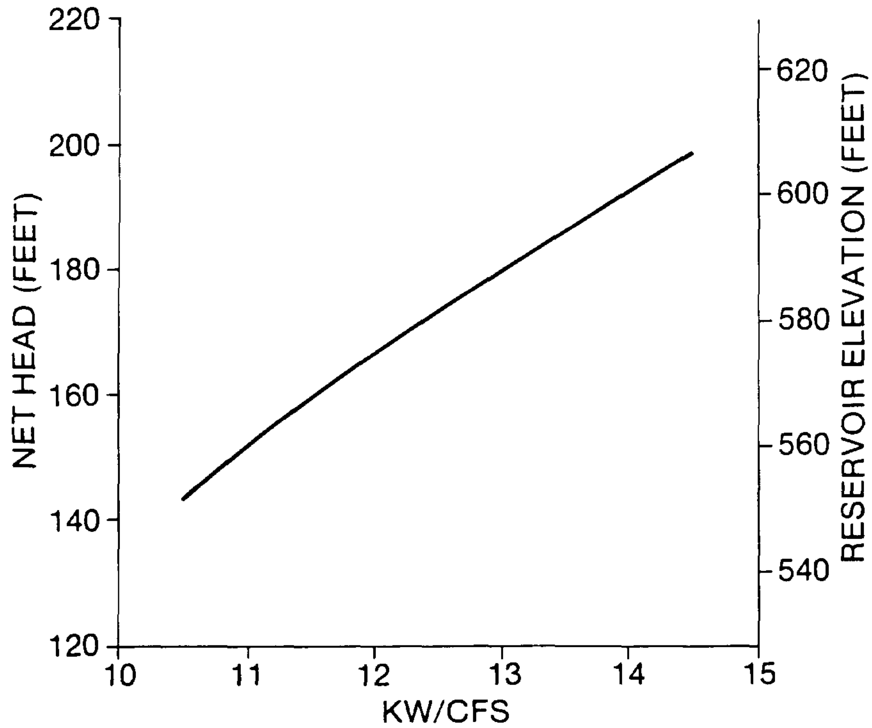

Figure G-2. KW/cfs versus reservoir elevation curve for Broken Bow Reservoir, Oklahoma.