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APPLICATION OF THEORETICAL EQUATIONS TO ESTIMATE THE DISCHARGE NEEDED TO MAINTAIN CHANNEL WIDTH IN A REACH OF THE PLATTE RIVER NEAR LEXINGTON, NEBRASKA

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METRIC CONVERSIONS

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
acre-foot	0.001233	cubic hectometer

LIST OF SYMBOLS AND DEFINITIONS

a	Aspect ratio
B	Width of channel
Critical reach	Reach of the Platte River between Lexington, Nebraska, and Grand Island, Nebraska, with habitat conditions designated as crucial to the roosting, feeding, and courting of the sandhill and whooping cranes
d	Depth of channel
d_c	Center depth of channel
D_s	Bed material particle size for which s percent of the sample is finer
Effective discharge	Discharge necessary to maintain a required width of channel
g	Acceleration of gravity
G	Channel slope obtained from topographic maps
Q	Water discharge
Q_s	Bed-material load
$\tilde{Q}$	Dimensionless water discharge
$\tilde{Q}_s$	Dimensionless bed-material load
R	Density difference between sediment and water
R_c	Relative roughness of channel
V_s	Particle fall velocity

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ABSTRACT

Theoretically developed regime equations (Parker, 1978) for estimating river channel cross-sectional characteristics are calibrated using onsite data obtained from the Platte River, Nebraska. These equations are proposed as a means for estimating the discharge necessary to maintain a required channel width in a critical waterfowl-habitat reach of the Platte River. Channel slope and a bed-material size are required input to the equations. A bed-material design curve is developed for channel widths ranging from 100 feet to 800 feet. The problem of specifying minimum duration of the design discharge also is discussed.

INTRODUCTION

Prediction of channel-geometry response to changes in water discharge is necessary for effective management of waterfowl habitats. Many types of roosting waterfowl require wide and shallow river channels as a buffer against predators; therefore, wildlife managers would like to predict channel characteristics resulting from anticipated hydrologic factors, or to determine discharges required to maintain a channel of prespecified or existing cross-sectional properties.

The discharge responsible for the cross-sectional characteristics of an alluvial channel at a given location is called the effective discharge. This discharge generally is defined as the discharge that formed the contemporary channel; but, in this report, the term effective discharge will be used to describe the discharge that at least maintains, if not forms, the channel.

Various empirical regime relations have been developed that estimate changes in channel width as a function of channel depth (Lane, 1937), or changes in channel depth and width as power functions of discharge (Leopold and Maddock, 1953). Parker (1978) has developed a set of theoretical regime equations for straight reaches of rivers with bank and bed materials consisting of non-cohesive sands; this set of equations goes beyond similar studies by theoretically examining the multivariate structure of the empirical relations. These equations comprise an algorithm that is unique in that channel cross-sectional characteristics (top width and center or average depth) are mathematically integrated with bed material size, sediment load, channel slope, and an effective discharge. Applicability of any particular method to determine channel geometry is somewhat dependent on the river; however, Parker's procedure seems to be a general treatment of the problem that explicitly considers more relevant parameters, and, therefore, offers more checks on the solution.

The purpose of this report is to compare theoretically determined channel characteristics using Parker's method to onsite data obtained from the Platte River in south-central Nebraska, and to analyze and develop a use for the algorithm in management of the waterfowl habitat along the Platte River. This analysis was made for five sites in or near the critical reach from Lexington to Grand Island, Nebraska (fig. 1).

REGIME EQUATIONS

Parker (1978) developed three equations that relate channel slope, G; center depth of channel, d_c; width of channel, B; effective discharge, Q; total bed-material load, Q_s; and the particle size at which s percent of the bed material is finer, D_s. For purposes of this report, center depth will be synonymous with average depth (although center depth has a more specific use in Parker's development). These relationships form a set of regime equations that can be solved simultaneously to determine any three of the above variables, if the remaining three are known.

The first regime equation relates slope, depth, and particle size independent of the remaining variables:

$$R_c = d_c/D_s = 46.5\ R_f^{\ 0.4}\ G^{\ -0.6} \tag{1}$$

where

R_c = relative roughness of channel

dc = center depth of channel (ft)

D_s = bed material particle size for which S percent of the sample is finer

R_f = $V_s/\sqrt{RD_s g}$;

V_s = particle fall velocity (feet per second);

R = difference in density between sediment and water (1.65);

g = acceleration of gravity (feet per second); and

G = channel slope.

The remaining regime equations establish dimensionless water discharge, $\tilde{Q}$, and dimensionless sediment discharge, $\tilde{Q}_s$, as functions of particle size and hydraulic parameters:

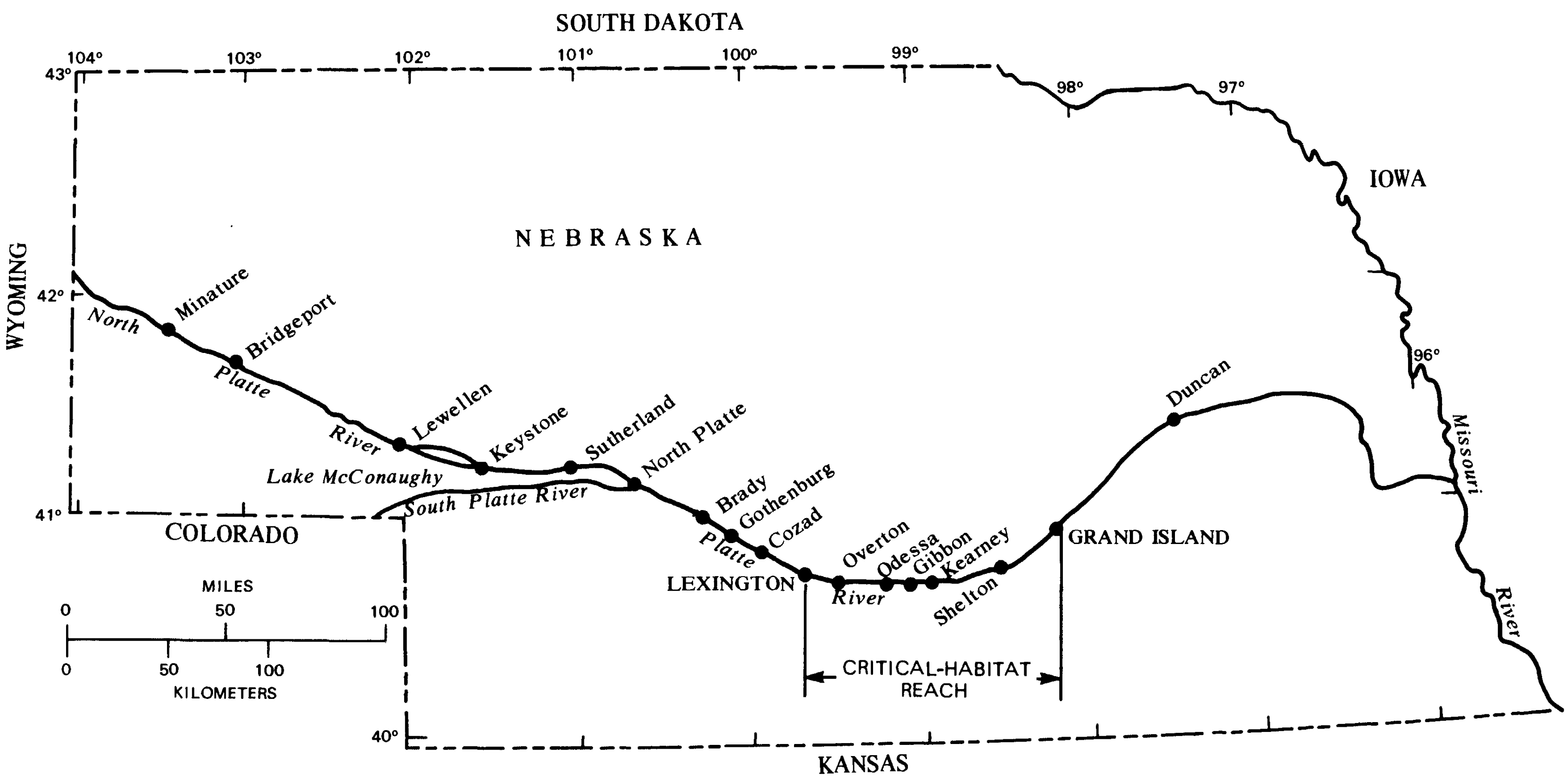

Figure 1.--Critical-habitat reach along the Platte River.

$$\tilde{Q} = 0.958\, R_c^3\, G \ln(1.06\, R_c^2\, G) \left[a - 0.921\, R_c^{1/2}\, G^{1/2}\, R_f^{-1} \right] \quad (2a)$$

$$\tilde{Q}_s = 0.601\, R_c^{11/2}\, G^{9/2} \left[a - 1.41\, R_c^{1/2}\, G^{1/2}\, R_f^{-1} \right] + 2.97*10^{-4}$$

$$* R_c^{13/2}\, G^{9/2}\, R_f^{-1} \ln(1.06\, R_c^3\, G) \left[a - 1.33\, R^{1/2}\, G^{1/2}\, R_f^{-1} \right] \quad (3a)$$

In equations (2a) and (3a), a is the aspect ratio defined as B/d_c, where B is the channel top width. $\tilde{Q}$ and $\tilde{Q}_s$ are defined as:

$$\tilde{Q} = Q/(\sqrt{RgD_s} * D_s^2) \quad (2b)$$

$$\tilde{Q}_s = Q_s/(\sqrt{RgD_s} * D_s^2) \quad (3b)$$

Given R_f, and values for any pair of parameters from the set R_c, $\tilde{Q}$, $\tilde{Q}_s$, and a, the remaining variables can be calculated, using equations (1), (2), and (3). Because the choice of which variables will be input and which will be determined for particular predictive purposes, the solution to the equations can be used to address a variety of interrelationships between hydraulic properties of the flow and channel geometry.

A graph of a family of curves characterizing the solutions to equations (1) and (2) for various parameter combinations is shown in figure 2. Because prediction of the river flow necessary to maintain a given width of channel for the waterfowl habitat is one of the primary interests for applying this method to the Platte River, discharge and width were chosen as the cartesian variables and channel slope and sediment size were chosen as parameters. Depth is not a parameter, but it is shown because it is specified by equation (1) through a choice of sediment size and channel slope. The following section offers procedures for obtaining values of sediment size and channel slope to accompany desired channel width as input for determining an effective discharge using the Parker methodology.

DEVELOPMENT OF CALIBRATION CURVE

Data were collected at five sites in or near the critical habitat reach of the Platte River. Measurements were made along the reach near Cozad, Lexington, Overton, and Odessa (fig. 3). Measurements were taken at two sites near Lexington: One upstream from the Johnson-2 powerplant return canal (Lexington-1 site) and one downstream from the return (Lexington-2 site). At each site, measurements were made of channel cross-sectional characteristics for several values of water discharge. Examples of five channel cross sections at the sites are illustrated in figure 4. Width measurements and their respective discharges were plotted for each site (fig. 5). Points then were selected from these graphs that reflected channel conditions, as indicated by the cross sections, conducive to waterfowl habitat, especially by sandhill and whooping cranes. These conditions

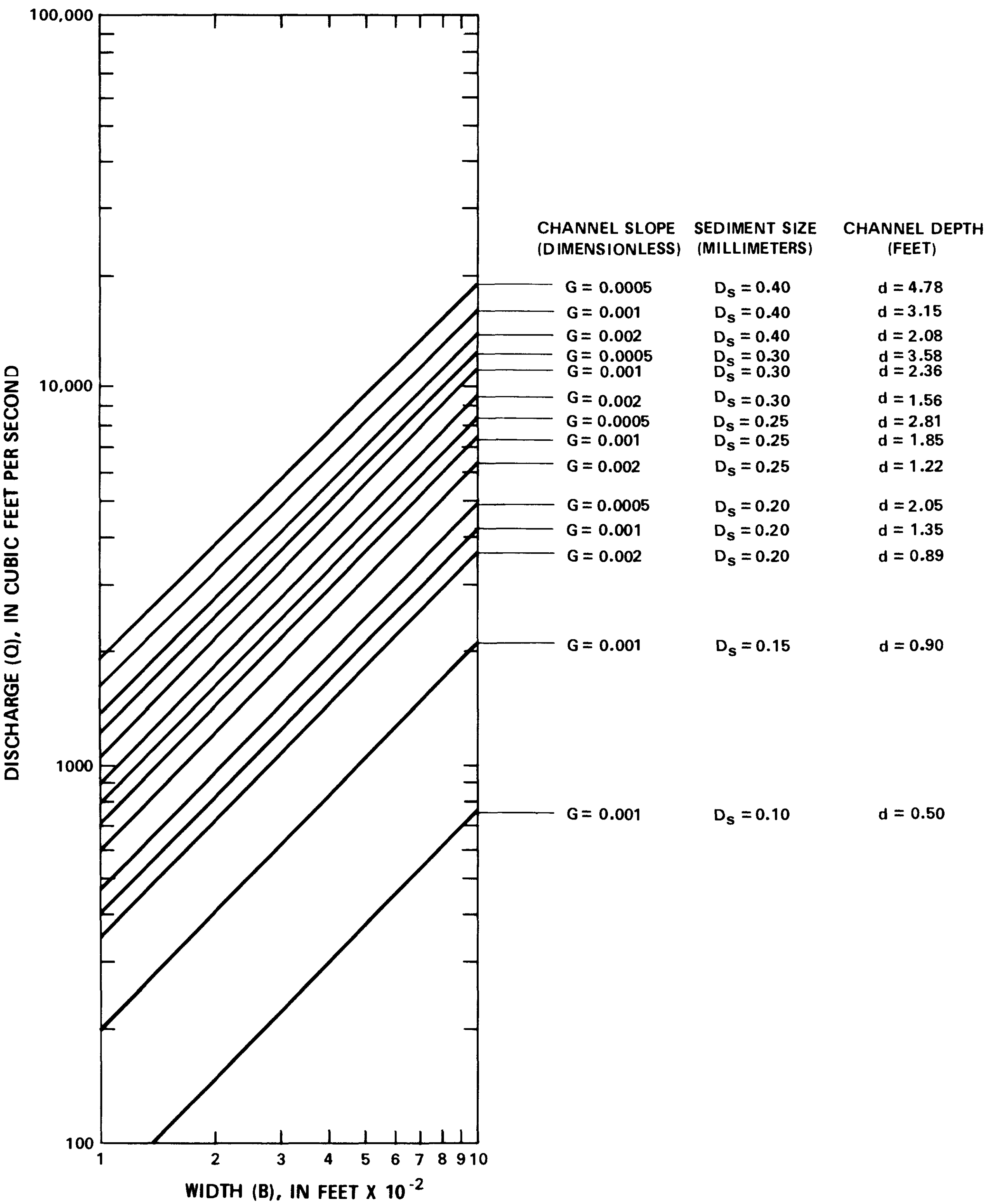

Figure 2.--Solution of Parker's regime equations (1) and (2).

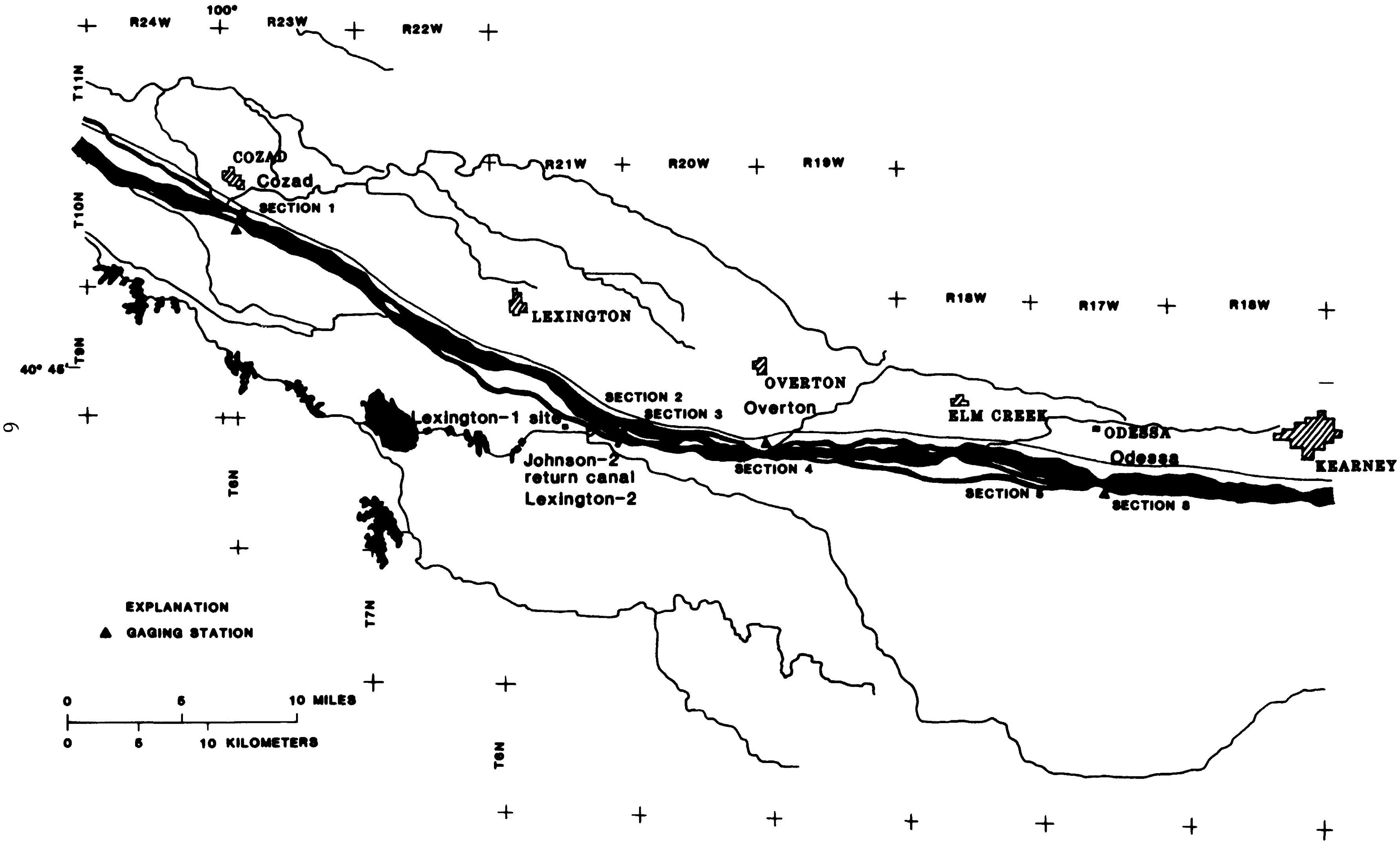

Figure 3.--Location of measurement sites along the Platte River.

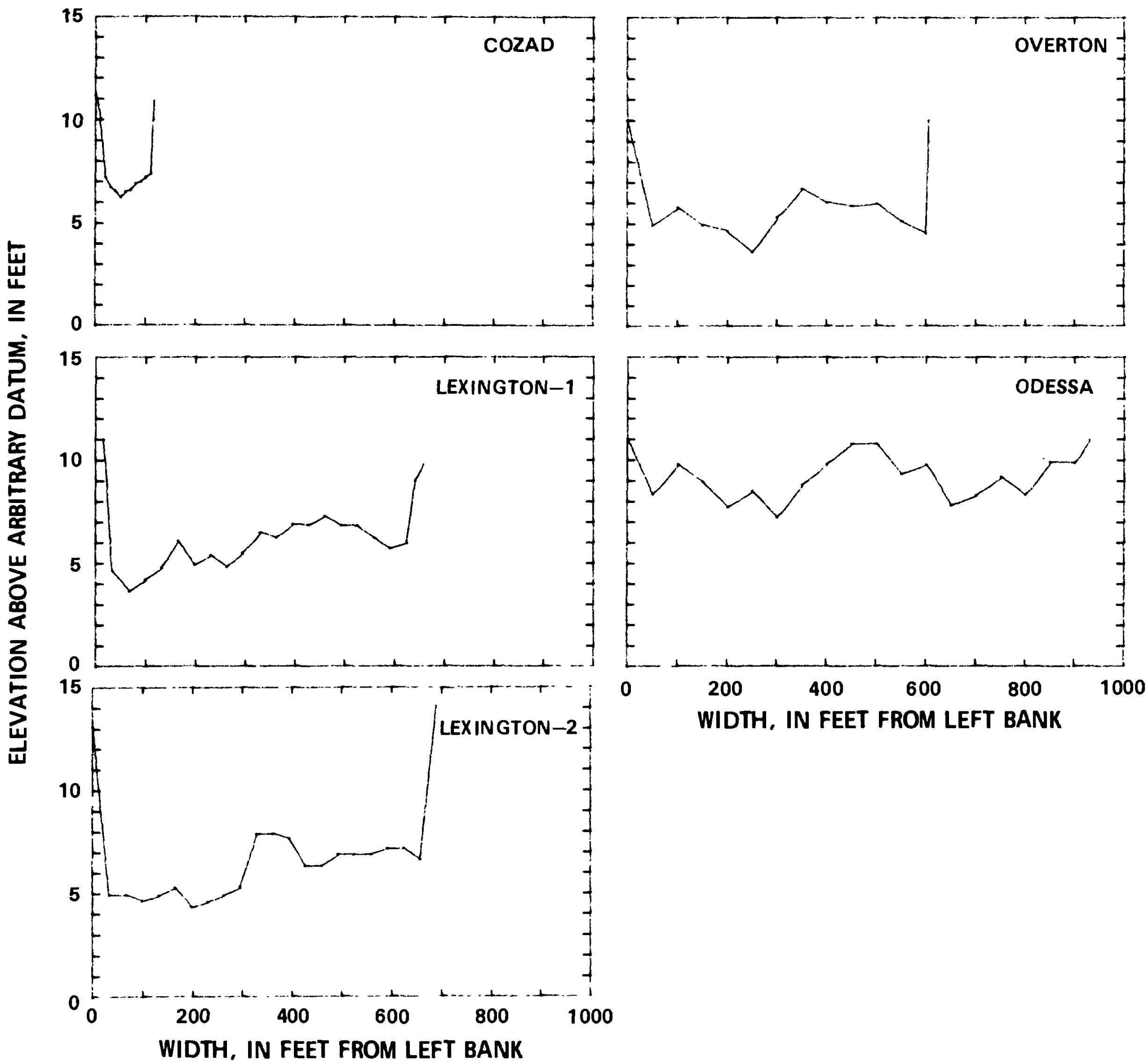

Figure 4.--Channel cross sections for Cozad, Overton, Lexington 1 and 2, and Odessa sites.

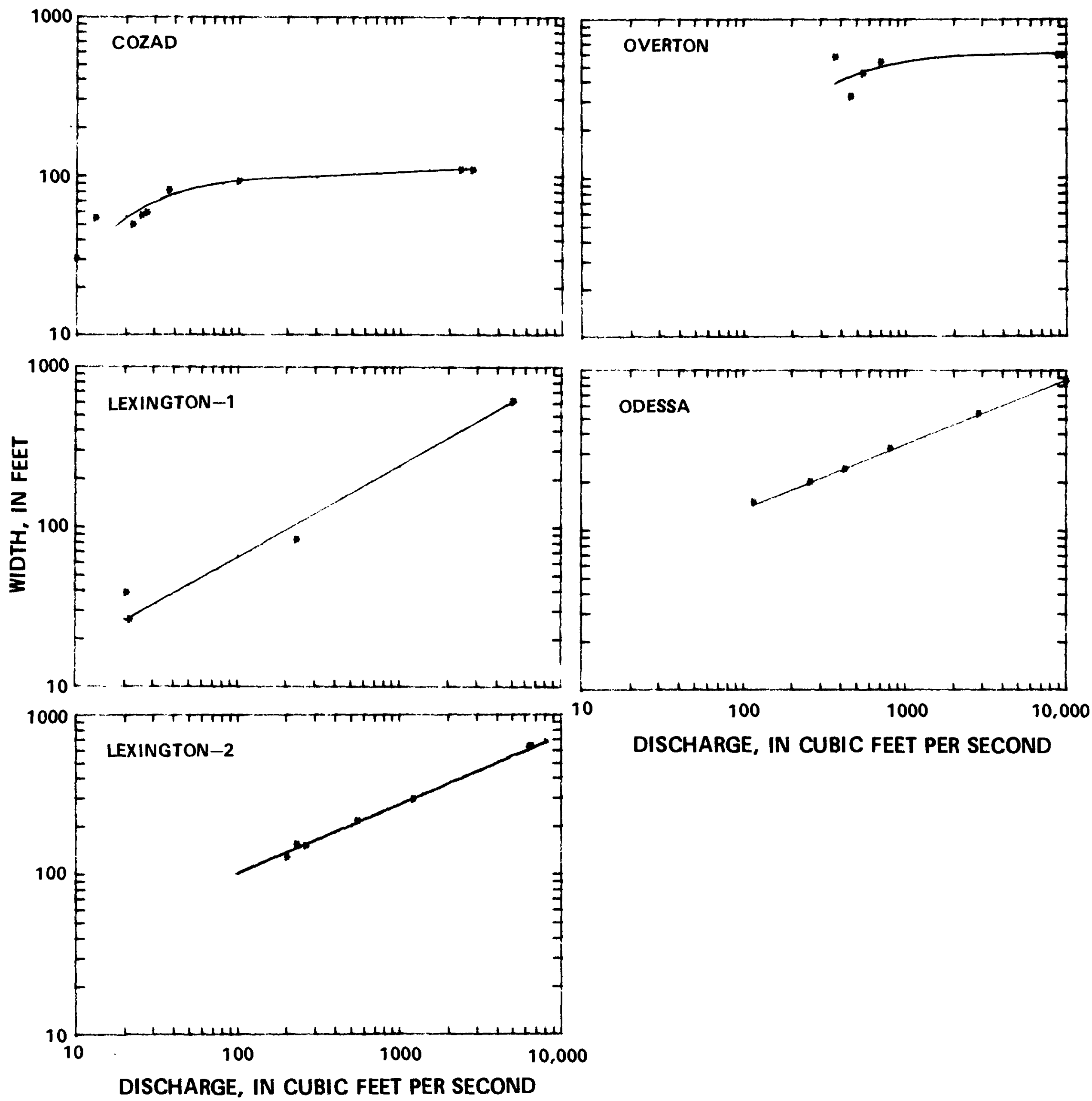

Figure 5.--Width-discharge curves for Cozad, Overton, Lexington 1 and 2, and Odessa sites.

are widths ranging from 400 to 1200 ft and depths less than 2 ft (G. Krapu, U.S. Fish and Wildlife Service, oral communication, 1981). Because according to the cross sections both of these conditions could not be met simultaneously for most of the sites and because the width factor is the more important of the two, (G. Krapu, U.S. Fish and Wildlife Service, oral communication, 1981) it was given primary consideration in selecting the points from figure 5. Therefore, for all sites except Cozad, the points chosen from figure 5 are characterized by unobstructed channel widths satisfying the 400 to 1200 ft constraint, while at the same time rendering an average channel depth in the neighborhood of 2 ft. The constraint on channel width for Cozad was a maximum of 102 ft.

The width-discharge points selected from figure 5 and a channel slope for each site then were used as input variables in equations (1) and (2) to calibrate a sediment size, D_s, necessary for calculated width to equal measured width for the given discharge. These sediment sizes were plotted against width to establish a design curve (fig. 6) to determine appropriate sediment sizes used in applying the curves in figure 2 to any site within the actual reach. This established an effective discharge. The data used to develop figure 6 are summarized in table 1.

The particle-size distribution curves shown in figure 7 support the proposed use of figure 6 as a design tool for the following reasons: (1) The overlap of the five distribution curves characterizes a homogeneity in sediment size distribution for the entire reach; and (2) the percent finer values of the sediment sizes used in figure 6 are in the smaller fractions of the distribution curves as proposed by Parker (1978).

Channel slopes used in the regime equations were obtained from topographic maps containing the five sites. Channel bed elevations were plotted as a function of distance, beginning about 5 mi upstream from Cozad and ending near Kearney. Slopes for the five sites were computed as tangents to this river profile at the respective sites. Although water-surface slopes need to be used, they would not be available in practice because they are a result of the model computations.

RESULTS

The regime equations resulting from Parker's work are valid only for material of uniform particle size. Because the assumption of uniform particle size around the channel perimeter is unrealistic for onsite applications, there is some question as to the best value to use for s in D_s. Parker (1978) states that the results using the regime equations were most accurate in canal comparisons, when the value for D_s used was an average of D_{50} of bank material and D_{15} of bed material. In a study of the Niobrara River near Cody, Nebraska, an estimate of D_{15} for the bed material gave the best results (Parker, 1978). An analysis similar to the one in figure 6 may be more efficient in synthesizing information from collected bed-material samples and more exacting for a

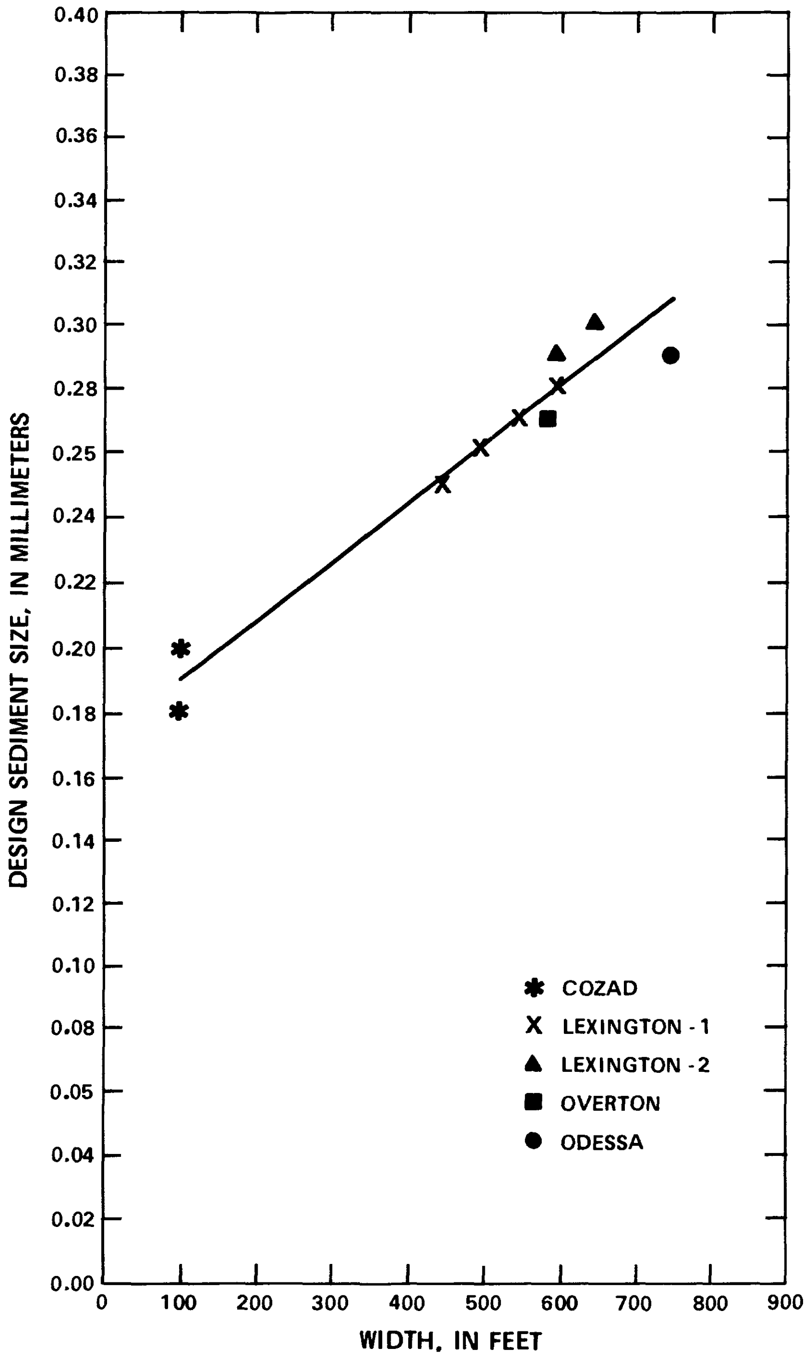

Figure 6.--Width-sediment-size design curve for Cozad, Overton, Lexington 1 and 2, and Odessa sites.

Table 1.--*Cross-sectional characteristics and sediment sizes for given discharges*

[B = maximum width, in feet; Q = water discharge, in cubic feet per second; d = depth, in feet; D = sediment size, in millimeters; s = design size of sediment]

Site	Obtained from onsite measurements						Calculated from regime equations		
	$B_{maximum}$ (ft)	Q (ft^3/s)	B (ft)	d (ft)	D_{50} (bank) (mm)	D_{15} (bed) (mm)	D_s (mm)	B (ft)	d (ft)
Cozad	102	400	102	2.05	0.15	0.36	0.20	99	1.20
		300	100	1.75	---	---	.18	93	1.06
Lexington 1	660	3,000	450	2.00	.68	.37	.25	436	1.71
		3,600	500	2.15	---	---	.26	474	1.81
		4,300	550	2.30	---	---	.27	532	1.88
		5,000	600	2.50	---	---	.28	565	1.98
Lexington 2	660	5,600	600	2.60	.33	.31	.29	584	2.08
		6,500	650	3.00	---	---	.30	625	2.18
Overton	585	4,500	585	2.30	.44	.37	.27	562	1.84
Odessa	750	7,000	750	2.10	.71	.38	.29	727	2.10

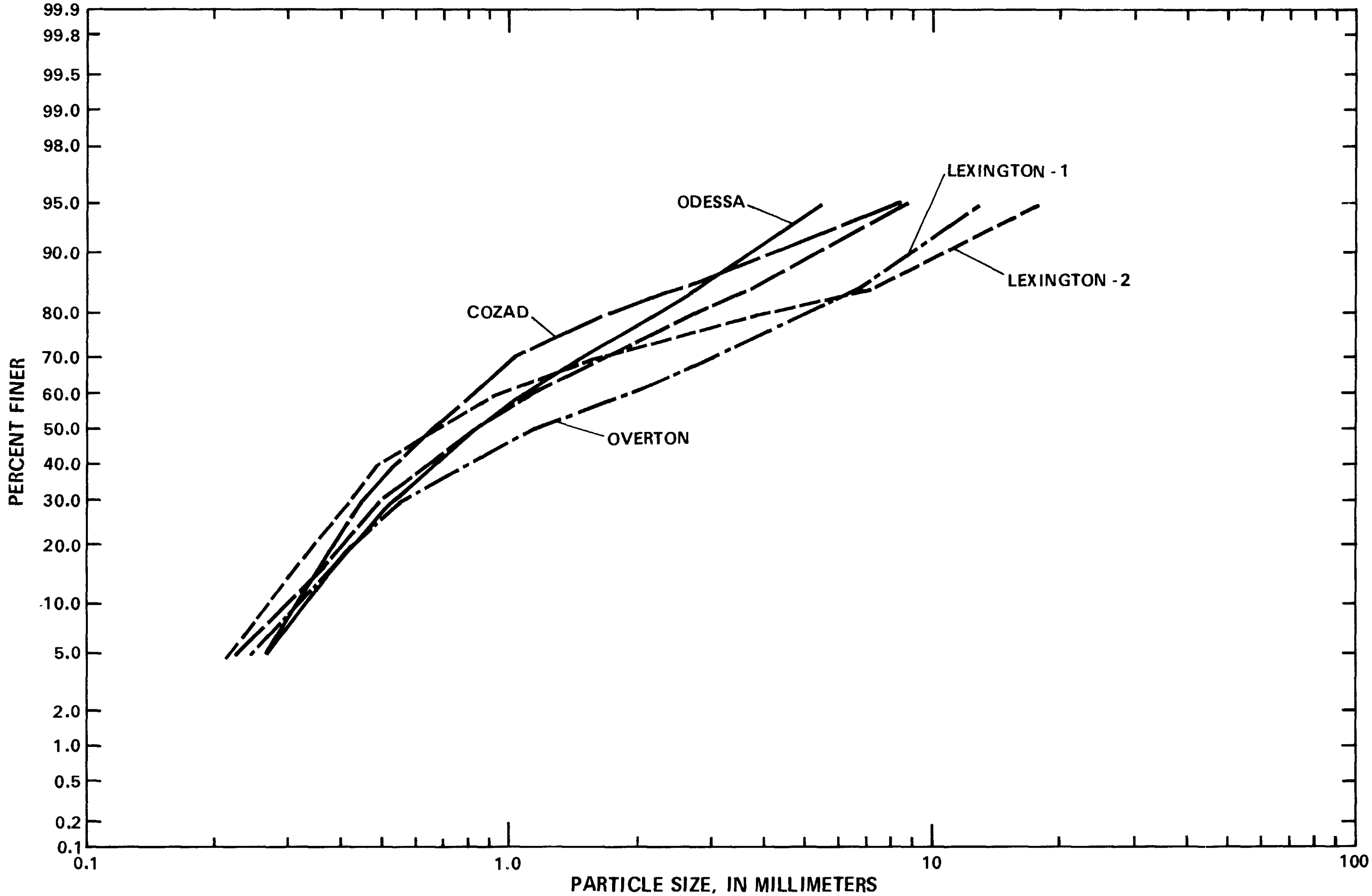

Figure 7.--Particle-size distribution curves for bed material at Cozad, Overton, Lexington 1 and 2, and Odessa sites.

choice of sediment size as an input parameter. A new curve would need to be calibrated for different rivers or different reaches. For comparison purposes, D_{15} of the bed material and D_{50} of the bank material for the five sites discussed in the report are listed in table 1.

The points in figure 5 for determining the design curve in figure 6 were chosen because of the habitat requirements and the nature of the channel banks. For all sites, especially Cozad and Overton, stabilizing vegetation on the banks prevents immediate widening of the channel in response to increasing discharge; any increase in conveyance is reflected in an increase in depth. Maximum values of width listed in table 1 reflect these constraints; if larger values were used the assumptions in Parker's regime equations would not be met. To apply this proposed design procedure to any intermediate site, a reasonable maximum width needs to be defined; larger values would result in the method being inappropriate for determining a maintenance discharge.

EXAMPLE APPLICATION

When the Parker method is used as a design tool to determine the necessary discharge for maintaining a desired channel width, the magnitude of flow is specified but the necessary frequency or duration of this flow is not determined. All regime-type relationships have this problem.

Vegetation of the banks and channel bars is the major cause of channel narrowing on the Platte River. If an existing channel is stable, the effective flow is recurring at a frequency that maintains the channel geometry. From a management point of view, a flow-duration curve can be used to estimate the minimum amount of water needed to maintain that channel geometry. An analysis of historic-flow data also can determine the number of times the effective flow has been equaled or exceeded for any number of consecutive days in any year. Without specific information on the timing of seedling germination, the distribution of consecutive days the flow has been equaled or exceeded could give some idea how one would establish operating rules of a reservoir with contents needed for the channel maintenance.

For a hypothetical example, a minimum channel width of 500 ft for a reach of the Platte River near Overton, Nebraska, is required for roosting of sandhill cranes. Wildlife managers would like to know the discharge necessary to maintain this width of channel for the given reach, and if possible, what duration and frequency of this discharge will give optimal results.

From figure 6, a width of 500 ft specifies a design sediment size of approximately 0.26 mm (millimeter) (to be used in fig. 2). From topographic maps, the channel slope for this reach is approximately 0.00100 (G in fig. 2). Therefore, from the graphs of Parker's regime equations, these input parameter values indicate a minimum effective discharge of about 3,800 ft^3/s; corresponding depth is estimated to be 2.0 ft.

Because encroachment of vegetation contributes to channel narrowing, an optimal time for effective discharge would be during germination of seeds. If flow during the germination period of past years has maintained the channel, an analysis of the flow duration during past germination periods would indicate flow management during this critical time.

A study by P. J. Currier and A. G. Van Der Valk (U.S. Fish and Wildlife Service, written communication, 1981) indicates that the germination period begins in early May and can last through August. A flow-duration curve based on these months was developed for Overton (fig. 8). The data in figure 8 indicates that the minimum effective discharge (3,800 ft^3/s) has been equaled or exceeded approximately 6 percent of the time, or an average of 8 days from May through August for the past 28 years. Flows exceeded less than 6 percent of the time also have been instrumental in maintaining the channel. If the future discharges are limited to the magnitude of the effective discharge, perhaps a more appropriate duration would be that having a streampower equivalent to the streampower of the upper part of the flow-duration curve (fig. 8). This duration would be determined by first integrating the flow-duration curve between 0 and 6 percent probability of being equaled or exceeded and then dividing the solution by 3,800 ft^3/s. This results in a new duration of approximately 13 percent or 16 days. The constant flow duration of 16 days is equivalent to 120, 600 acre-feet.

To be most effective in preventing rooting of seedlings, operating rules of water release would need to be coordinated with a germination monitoring system. In the absence of a monitoring system, natural flow at the specified location could be augmented to achieve the equivalent of 16 days discharge of 3,800 ft^3/s; the 16 days could be equally spaced to inhibit germination of both early and late falling seeds. The amount and duration of each release would be determined by the viability of the seeds and the amount of natural flow.

SUMMARY AND CONCLUSIONS

The set of regime equations proposed by Parker (1978) was calibrated using data from five sites along the Platte River to demonstrate use of the equations as a management tool for preservation of migratory bird habitat. The five sites are near Cozad, Lexington (two sites), Overton, and Odessa. An algorithm was developed for determining the minimum discharge necessary to maintain a given channel width; sediment material size (obtained from fig. 6) and channel slope are required input. The channel-maintaining process involves both bed and bank sediments, and the sediment size obtained from the design curve in figure 6 indicates the appropriate fraction from both bed and bank to approximate agreement between theoretical and actual width. Any hydrologically maintained channel probably would be no wider than the existing channel without using mechanical methods to first establish a wider channel.

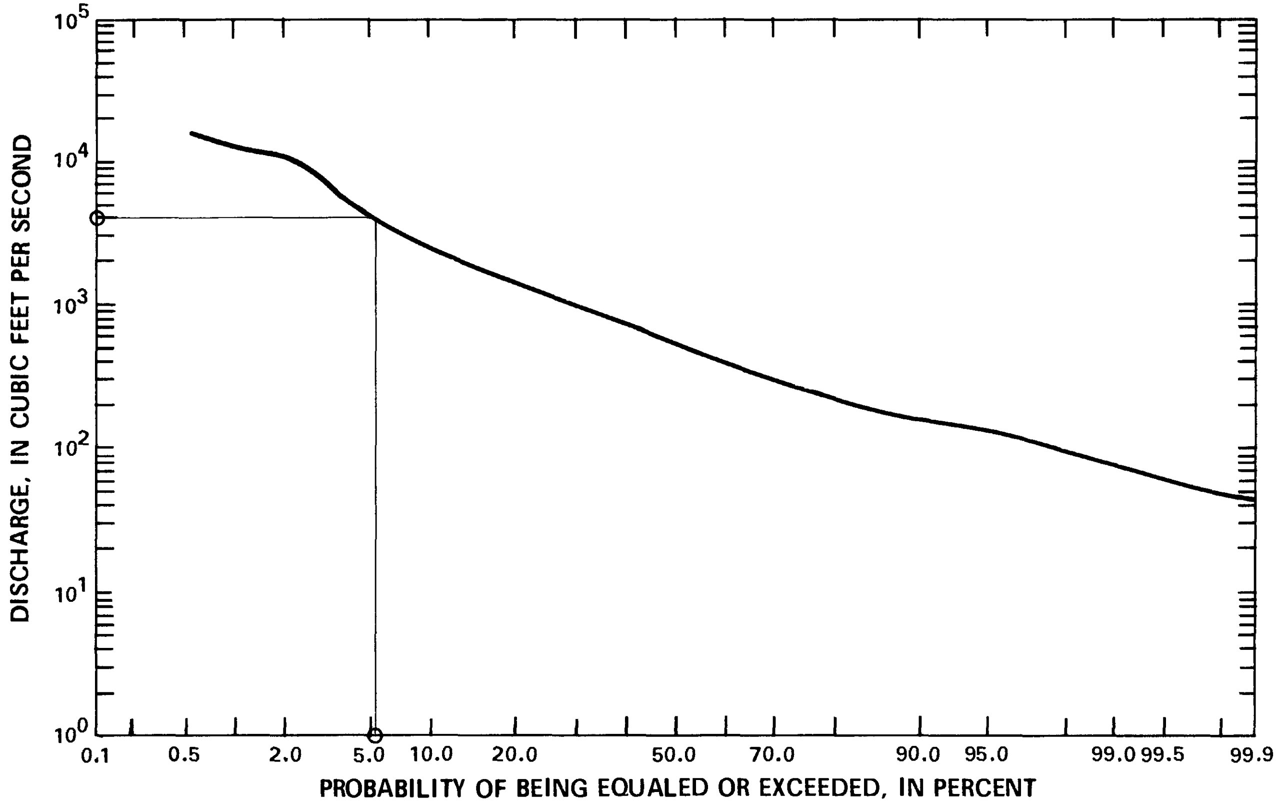

Figure 8.--Critical period (May through August) flow-duration curve for Overton site.

An example problem is presented to illustrate steps of the procedure to determine an effective discharge for a reach near Overton. A flow-duration analysis is included to specify frequency and magnitude for the discharge.

Certain points need to be emphasized in the use of figure 2. A given point in figure 2 does not represent a unique solution for slope and grain size. The effects of slope and grain size counterbalance each other; a given point in figure 2 could be maintained by simultaneously increasing or decreasing both slope and grain size. The slope and grain-size combinations presented in figure 2 were chosen because they encompass the range determined at the sites, and because they are clearly discernible in the figure.

The purpose of the procedure presented in this paper is to estimate the minimum discharge necessary to maintain a given channel width; however, there also is a maximum allowable discharge for channel maintenance. If a flow exceeds this maximum, new bedforms could be created, and large vegetated islands might form; the original design discharge might then be ineffective for maintaining a new channel. Determination of this maximum discharge is beyond the scope of this paper; however, it is a consideration in channel maintenance.

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