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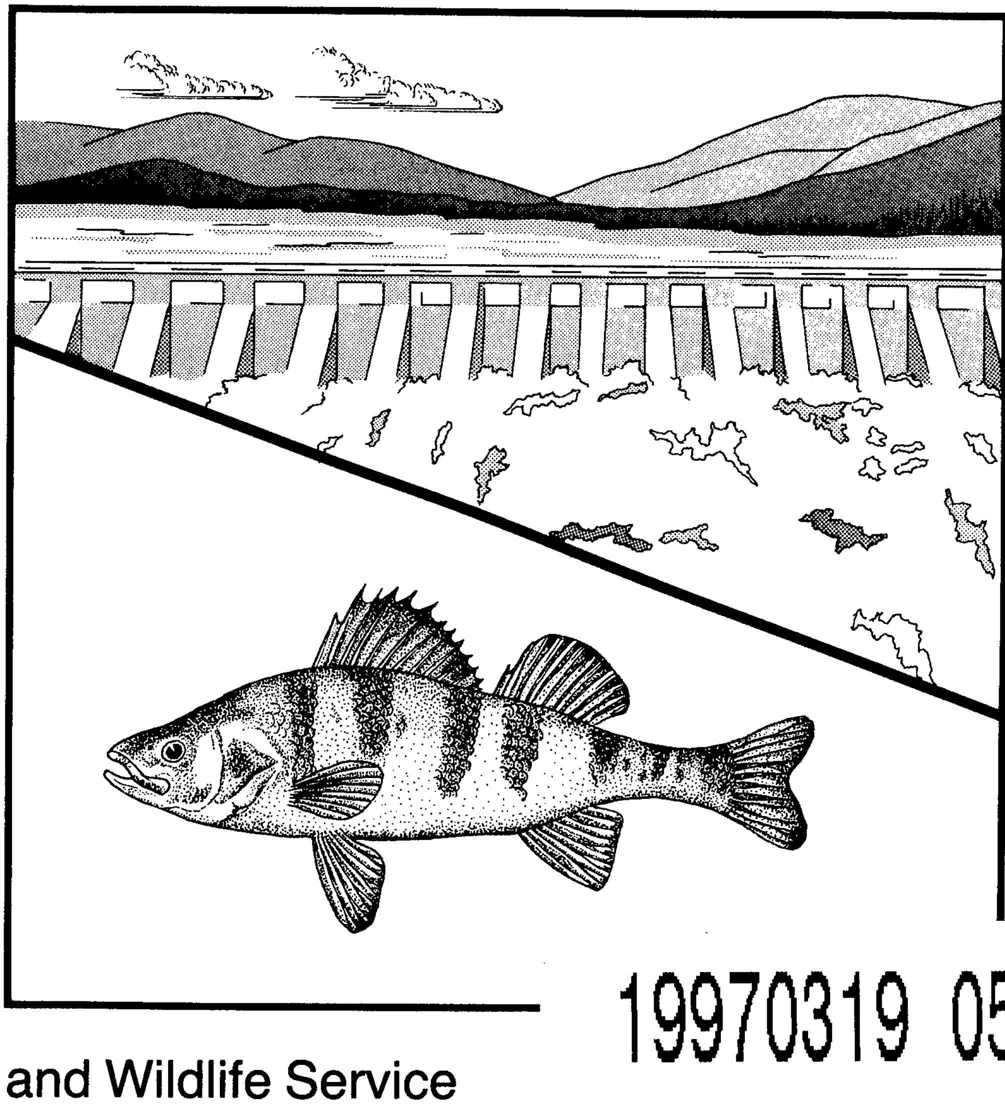
NOVEMBER 1984

HABITAT SUITABILITY INDEX MODELS: A LOW EFFORT SYSTEM FOR PLANNED COOLWATER AND COLDWATER RESERVOIRS (Revised)



Fish and Wildlife Service

U.S. Department of the Interior

MODEL EVALUATION FORM

Habitat models are designed for a wide variety of planning applications where habitat information is an important consideration in the decision process. However, it is impossible to develop a model that performs equally well in all situations. Assistance from users and researchers is an important part of the model improvement process. Each model is published individually to facilitate updating and reprinting as new information becomes available. User feedback on model performance will assist in improving habitat models for future applications. Please complete this form following application or review of the model. Feel free to include additional information that may be of use to either a model developer or model user. We also would appreciate information on model testing, modification, and application, as well as copies of modified models or test results. Please return this form to:

Habitat Evaluation Procedures Group
or
Instream Flow Group
U.S. Fish and Wildlife Service
2627 Redwing Road, Creekside One
Fort Collins, CO 80526-2899

Thank you for your assistance.

Species ______________ Geographic Location ________________________________

Habitat or Cover Type(s) ____

Type of Application: Impact Analysis ____ Management Action Analysis _____
Baseline _____ Other ____

Variables Measured or Evaluated ____
____
____
____

Was the species information useful and accurate? Yes ____ No ____

If not, what corrections or improvements are needed? ____________________
____
____
____

Were the variables and curves clearly defined and useful? Yes ____ No ____

If not, how were or could they be improved? ______________________________

____

____

____

Were the techniques suggested for collection of field data:

Appropriate? Yes ____ No ____

Clearly defined? Yes ____ No ____

Easily applied? Yes ____ No ____

If not, what other data collection techniques are needed? ______________

____

____

____

Were the model equations logical? Yes ____ No ____

Appropriate? Yes ____ No ____

How were or could they be improved? ____________________________________

____

____

____

Other suggestions for modification or improvement (attach curves, equations, graphs, or other appropriate information) ________________

____

____

____

Additional references or information that should be included in the model:

____

____

____

____

____

Model Evaluater or Reviewer ___________________________ Date ______________

Agency ____

Address ____

____

____

Telephone Number Comm: _________________________ FTS ______________________

FWS/OBS-82/10.3A
November 1984

HABITAT SUITABILITY INDEX MODELS: A LOW EFFORT SYSTEM FOR PLANNED COOLWATER AND COLDWATER RESERVOIRS (Revised)

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DISCLAIMER

This report should be cited as:

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PREFACE

The system presented in this publication is designed to classify proposed coolwater and coldwater reservoirs into four categories of fish habitat suitability based on the physical configuration of the reservoir basin, site climate, operational regime, and inflow characteristics. Instructions for deriving the reservoir classifications and sources of input data for the system are provided. Instructions are also provided for converting the system output into Habitat Suitability Indices (HSI's) for use with the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980).[1] Data requirements for the system are low. The intended use of the system is for early planning stages of reservoir construction projects, when several alternatives must be evaluated.

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[1]U.S. Fish and Wildlife Service. 1980. Habitat Evaluation Procedures (HEP) U.S.D.I., Fish and Wildlife Service, Division of Ecological Services, Washington, D.C. 102ESM. n.p.

SUMMARY

A novel approach to reservoir habitat evaluation is described and habitat ratings are proposed for five fish species in coolwater and coldwater reservoirs. This approach has the advantages of procedural simplicity and ready availability of input data; consequently, it has potential utility as a screening tool in the early stages of the reservoir planning process.

Habitat suitability is determined on the basis of a composite score for five "primary" reservoir attributes (temperature, turbidity, nonliving cover, drawdown, and shallow cove frequency). The value of each primary reservoir attribute is determined from one or more "secondary" attributes, which are easily measured variables. Secondary attributes (for example, length of growing season or mean July air temperature) can be directly obtained, prior to construction, from published documents, maps, reservoir plans, and on-site inspections of the proposed reservoir basin.

Evaluation criteria and ratings are presented for rainbow trout (Salmo gairdneri), white sucker (Catostomus commersonii), yellow perch (Perca flavescens), common carp (Cyprinus carpio), and black crappie (Pomoxis nigromaculatus). These ratings were derived from literature reviews and from personal experience and knowledge of the authors; however, the system is easily adaptable to change upon further review, differences of opinion by experts, or evaluation of test results under diverse conditions.

This technique can be used to evaluate the suitability of a proposed reservoir for different species and to compare the outcomes of alternative construction plans. It could also be expanded to include additional species, which will improve its utility. The system should be useful in determining losses relative to benefits, trade-offs, and potential mitigation measures in reservoir projects.

CONTENTS

TABLES

ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

a	acres
A	surface area
D_L	shoreline development factor (or SDF)
ha	hectares
km	kilometers
L	shoreline length
m	meters
mg/l	milligrams per liter
TDS	total dissolved solids

SYMBOLS

K^+	potassium
Na^+	sodium
Ca^{++}	calcium
Mg^{++}	magnesium
HCO_3^-	bicarbonate
CO_3^{--}	carbonate
Cl^-	chloride
SO_4^{--}	sulfate

INTRODUCTION

PURPOSE AND USE LIMITS

The purpose of the system is to rate the suitability of planned coolwater and coldwater reservoirs for selected fish species. It may be applied to reservoirs that meet the following conditions:

(1) The reservoir is north of latitude 37° N.

(2) The volume weighted mean total dissolved solids (TDS) of inflow is less than 3,000 mg/l.

(3) The preponderant ions of inflow are some mixture of K^+, Na^+, Ca^{++}, Mg^{++}, HCO_3^-, CO_3^{--}, Cl^-, and SO_4^{--}, in which HCO_3^- plus CO_3^{--} is no more than 300 mg/l and pH is less than 8.5.

(4) The surface area is greater than 3 km^2 (867 acres).

(5) The river to be impounded is not grossly polluted. This may be indicated by a diverse fish population and absence of conspicuous fish kills. Quality or use classification by the State in which the river is located may also be a reasonable guide.

(6) The proposed reservoir is seldom to be drawn down to a volume less than 1/4 of maximum capacity.

(7) The water body should be an impounded river and not merely a natural lake with a raised level.

The number of species for which a proposed reservoir might be moderately suitable will probably be considerably greater than the number of species actually present in the completed reservoir at any given time. Factors important in determining which fish become important as time passes include species present in the drainage and those introduced as a result of stocking by the responsible conservation agency, surreptitious introductions, and temporal population changes due to species interactions and differential harvest.

DATA CHARACTERISTICS

In this section, we present criteria used to select attributes of proposed reservoirs which are most consistent with the purpose and limits of the system. Specific data required and their sources and integration are explained later.

The most restrictive criterion is that attribute values be easily acquired some time before reservoir construction begins. In broad terms, this limits attributes to those of the proposed reservoir basin, its operation, characteristics of the inflow, and site climate.

Attributes are limited to those which are readily available in publications, public records, construction agency plans, or are observable during a site visit. Aerial observations may be necessary in some instances, although technical measurements are not required.

SYSTEM LOGIC

Habitat suitability for a reservoir is obtained from a five-digit number (reservoir description) in which the letters A, B, C, D, and E are used to designate each of the five sequential positions of primary attributes. Each primary attribute is derived from one or more "simple" secondary attributes, which are usually single "raw" facts, and each primary attribute has an individual rating of 1, 2, or 3. The composite pattern of these individual primary attribute ratings can be interpreted as having a single expression (rating) of overall habitat suitability (i.e., low, low medium, high medium, or high[2]). System logic is diagrammed in Figure 1.

The primary attributes referred to in positions A-E are:

A - Temperature;

B - Mineral turbidity;

C - Nonliving cover (structure);

D - Maximum drawdown and timing of drawdown;

E - Frequency of shallow coves.

Secondary attributes are listed, beginning on page 21. Each of the 243 possible reservoir descriptions for a species (permutations of three levels of suitability for each of five attributes) is listed in Tables 1-5 in an orderly progression, 11111 to 33333, with corresponding suitability ratings of L (low), LM (low medium), HM (high medium), or H (high).

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[2]Four levels of habitat suitability are described: low, low medium, high medium, and high. Habitat Evaluation Procedures (HEP) require that habitat suitability be described in terms of a Habitat Suitability Index (HSI) with values ranging from 0.0 to 1.0. Corresponding numerical values of 0.2, 0.4, 0.7, and 1.0 may be substituted for low, low medium, high medium, and high, in that order.

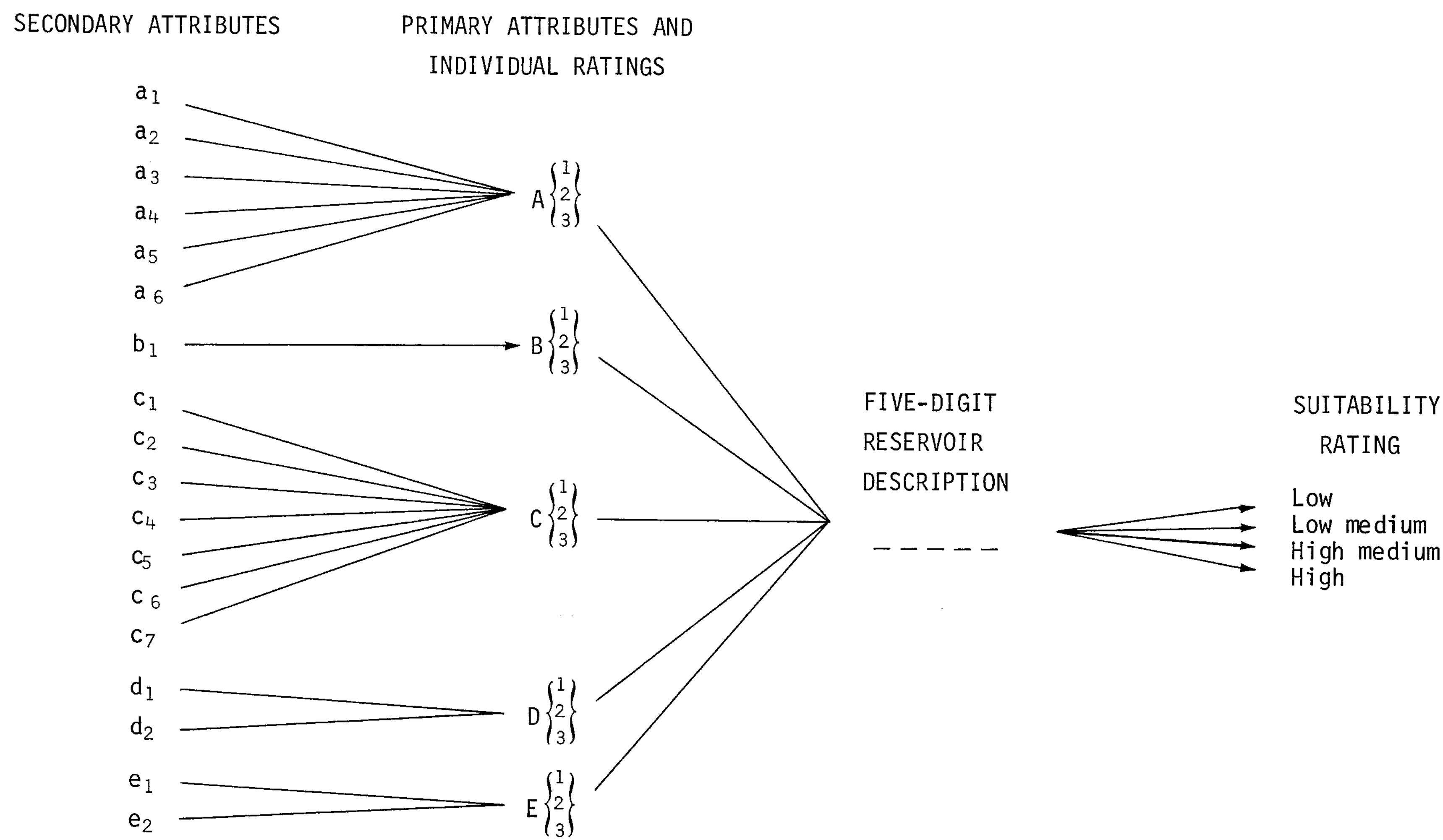

Figure 1. System logic for deriving reservoir habitat suitability ratings from primary and secondary attributes.

Table 1. Reservoir descriptions and suitability ratings for black crappie.

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
11111	L	12111	L	13111	L
11112	L	12112	L	13112	L
11113	L	12113	L	13113	L
11121	L	12121	L	13121	L
11122	L	12122	L	13122	L
11123	L	12123	L	13123	L
11131	L	12131	L	13131	L
11132	L	12132	L	13132	L
11133	L	12133	LM	13133	LM
11211	L	12211	L	13211	L
11212	L	12212	L	13212	L
11213	L	12213	L	13213	L
11221	L	12221	L	13221	L
11222	L	12222	L	13222	L
11223	L	12223	L	13223	L
11231	L	12231	L	13231	L
11232	L	12232	L	13232	L
11233	L	12233	LM	13233	LM
11311	L	12311	L	13311	L
11312	L	12312	L	13312	L
11313	L	12313	L	13313	L
11321	L	12321	L	13321	L
11322	L	12322	L	13322	L
11323	L	12323	L	13323	L
11331	L	12331	L	13331	L
11332	L	12332	L	13332	L
11333	L	12333	LM	13333	LM

Table 1. (continued)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
21111	L	22111	LM	23111	LM
21112	L	22112	LM	23112	LM
21113	L	22113	LM	23113	LM
21121	L	22121	LM	23121	LM
21122	L	22122	HM	23122	HM
21123	L	22123	HM	23123	HM
21131	L	22131	LM	23131	LM
21132	L	22132	HM	23132	HM
21133	L	22133	HM	23133	HM
21211	L	22211	LM	23211	LM
21212	L	22212	LM	23212	LM
21213	L	22213	LM	23213	LM
21221	L	22221	HM	23221	HM
21222	L	22222	HM	23222	HM
21223	L	22223	HM	23223	HM
21231	L	22231	HM	23231	HM
21232	L	22232	HM	23232	HM
21233	L	22233	HM	23233	HM
21311	L	22311	LM	23311	LM
21312	L	22312	LM	23312	LM
21313	L	22313	LM	23313	LM
21321	L	22321	HM	23321	HM
21322	L	22322	HM	23322	HM
21323	L	22323	HM	23323	HM
21331	L	22331	HM	23331	HM
21332	L	22332	HM	23332	HM
21333	L	22333	HM	23333	HM

Table 1. (concluded)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
31111	L	32111	LM	33111	LM
31112	L	32112	LM	33112	LM
31113	L	32113	LM	33113	LM
31121	L	32121	LM	33121	LM
31122	L	32122	HM	33122	HM
31123	L	32123	HM	33123	HM
31131	L	32131	LM	33131	LM
31132	L	32132	HM	33132	HM
31133	L	32133	HM	33133	HM
31211	L	32211	LM	33211	LM
31212	L	32212	LM	33212	LM
31213	L	32213	LM	33213	LM
31221	L	32221	HM	33221	HM
31222	L	32222	HM	33222	HM
31223	L	32223	HM	33223	HM
31231	L	32231	HM	33231	HM
31232	L	32232	H	33232	H
31233	L	32233	H	33233	H
31311	L	32311	LM	33311	LM
31312	L	32312	LM	33312	LM
31313	L	32313	LM	33313	LM
31321	L	32321	HM	33321	HM
31322	L	32322	HM	33322	HM
31323	L	32323	HM	33323	HM
31331	L	32331	HM	33331	HM
31332	L	32332	H	33332	H
31333	L	32333	H	33333	H

Table 2. Reservoir descriptions and suitability ratings for white sucker.

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
11111	L	12111	LM	13111	LM
11112	L	12112	LM	13112	LM
11113	L	12113	LM	13113	LM
11121	L	12121	LM	13121	LM
11122	L	12122	LM	13122	LM
11123	L	12123	LM	13123	LM
11131	L	12131	LM	13131	LM
11132	L	12132	LM	13132	LM
11133	L	12133	LM	13133	LM
11211	L	12211	LM	13211	LM
11212	L	12212	LM	13212	LM
11213	L	12213	LM	13213	LM
11221	L	12221	LM	13221	LM
11222	L	12222	LM	13222	LM
11223	L	12223	LM	13223	LM
11231	L	12231	LM	13231	LM
11232	L	12232	LM	13232	LM
11233	L	12233	LM	13233	LM
11311	L	12311	LM	13311	LM
11312	L	12312	LM	13312	LM
11313	L	12313	LM	13313	LM
11321	L	12321	LM	13321	LM
11322	L	12322	LM	13322	LM
11323	L	12323	LM	13323	LM
11331	L	12331	LM	13331	LM
11332	L	12332	LM	13332	LM
11333	L	12333	LM	13333	LM

Table 2. (continued)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
21111	LM	22111	LM	23111	LM
21112	LM	22112	LM	23112	LM
21113	LM	22113	LM	23113	LM
21121	LM	22121	HM	23121	HM
21122	LM	22122	HM	23122	HM
21123	LM	22123	HM	23123	HM
21131	LM	22131	HM	23131	HM
21132	LM	22132	HM	23132	HM
21133	LM	22133	HM	23133	HM
21211	LM	22211	LM	23211	LM
21212	LM	22212	LM	23212	LM
21213	LM	22213	LM	23213	LM
21221	LM	22221	HM	23221	HM
21222	LM	22222	HM	23222	HM
21223	LM	22223	HM	23223	HM
21231	LM	22231	HM	23231	HM
21232	LM	22232	HM	23232	HM
21233	LM	22233	HM	23233	HM
21311	LM	22311	LM	23311	LM
21312	LM	22312	LM	23312	LM
21313	LM	22313	LM	23313	LM
21321	LM	22321	HM	23321	HM
21322	LM	22322	HM	23322	HM
21323	LM	22323	HM	23323	HM
21331	LM	22331	HM	23331	H
21332	LM	22332	HM	23332	H
21333	LM	22333	HM	23333	H

Table 2. (concluded)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
31111	LM	32111	LM	33111	LM
31112	LM	32112	LM	33112	LM
31113	LM	32113	LM	33113	LM
31121	LM	32121	HM	33121	H
31122	LM	32122	HM	33122	H
31123	LM	32123	HM	33123	H
31131	LM	32131	HM	33131	H
31132	LM	32132	HM	33132	H
31133	LM	32133	HM	33133	H
31211	LM	32211	LM	33211	LM
31212	LM	32212	LM	33212	LM
31213	LM	32213	LM	33213	LM
31221	LM	32221	HM	33221	HM
31222	LM	32222	HM	33222	HM
31223	LM	32223	HM	33223	HM
31231	LM	32231	H	33231	HM
31232	LM	32232	H	33232	HM
31233	LM	32233	H	33233	HM
31311	LM	32311	LM	33311	LM
31312	LM	32312	LM	33312	LM
31313	LM	32313	LM	33313	LM
31321	LM	32321	HM	33321	HM
31322	LM	32322	HM	33322	HM
31323	LM	32323	HM	33323	HM
31331	LM	32331	H	33331	H
31332	LM	32332	H	33332	H
31333	LM	32333	H	33333	H

Table 3. Reservoir descriptions and suitability ratings for put-and-grow rainbow trout.

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
11111	L	12111	L	13111	L
11112	L	12112	L	13112	L
11113	L	12113	L	13113	L
11121	L	12121	L	13121	L
11122	L	12122	L	13122	L
11123	L	12123	L	13123	L
11131	L	12131	L	13131	L
11132	L	12132	L	13132	L
11133	L	12133	L	13133	L
11211	L	12211	L	13211	L
11212	L	12212	L	13212	L
11213	L	12213	L	13213	L
11221	L	12221	L	13221	L
11222	L	12222	L	13222	L
11223	L	12223	L	13223	L
11231	L	12231	L	13231	L
11232	L	12232	L	13232	L
11233	L	12233	L	13233	L
11311	L	12311	L	13311	L
11312	L	12312	L	13312	L
11313	L	12313	L	13313	L
11321	L	12321	L	13321	L
11322	L	12322	L	13322	L
11323	L	12323	L	13323	L
11331	L	12331	L	13331	L
11332	L	12332	L	13332	L
11333	L	12333	L	13333	L

Table 3. (continued)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
21111	L	22111	LM	23111	LM
21112	L	22112	LM	23112	LM
21113	L	22113	LM	23113	LM
21121	L	22121	LM	23121	LM
21122	L	22122	LM	23122	HM
21123	L	22123	LM	23123	HM
21131	L	22131	LM	23131	LM
21132	L	22132	LM	23132	HM
21133	L	22133	LM	23133	HM
21211	L	22211	LM	23211	LM
21212	L	22212	LM	23212	LM
21213	L	22213	LM	23213	LM
21221	L	22221	LM	23221	LM
21222	L	22222	LM	23222	HM
21223	L	22223	LM	23223	HM
21231	L	22231	LM	23231	LM
21232	L	22232	LM	23232	HM
21233	L	22233	LM	23233	HM
21311	L	22311	LM	23311	LM
21312	L	22312	LM	23312	LM
21313	L	22313	LM	23313	LM
21321	L	22321	LM	23321	LM
21322	L	22322	LM	23322	HM
21323	L	22323	LM	23323	HM
21331	L	22331	LM	23331	LM
21332	L	22332	LM	23332	HM
21333	L	22333	LM	23333	HM

Table 3. (concluded)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
31111	L	32111	LM	33111	LM
31112	L	32112	LM	33112	LM
31113	L	32113	LM	33113	LM
31121	L	32121	LM	33121	HM
31122	L	32122	HM	33122	H
31123	L	32123	HM	33123	H
31131	L	32131	LM	33131	HM
31132	L	32132	HM	33132	H
31133	L	32133	HM	33133	H
31211	L	32211	LM	33211	LM
31212	L	32212	LM	33212	LM
31213	L	32213	LM	33213	LM
31221	L	32221	LM	33221	HM
31222	L	32222	HM	33222	H
31223	L	32223	HM	33223	H
31231	L	32231	LM	33231	HM
31232	L	32232	HM	33232	H
31233	L	32233	HM	33233	H
31311	L	32311	LM	33311	LM
31312	L	32312	LM	33312	LM
31313	L	32313	LM	33313	LM
31321	L	32321	LM	33321	HM
31322	L	32322	HM	33322	H
31323	L	32323	HM	33323	H
31331	L	32331	LM	33331	HM
31332	L	32332	HM	33332	H
31333	L	32333	HM	33333	H

Table 4. Reservoir descriptions and suitability ratings for yellow perch.

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
11111	L	12111	LM	13111	LM
11112	L	12112	LM	13112	LM
11113	L	12113	LM	13113	LM
11121	L	12121	LM	13121	LM
11122	L	12122	LM	13122	LM
11123	L	12123	LM	13123	LM
11131	L	12131	LM	13131	LM
11132	L	12132	LM	13132	LM
11133	L	12133	LM	13133	LM
11211	L	12211	LM	13211	LM
11212	L	12212	LM	13212	LM
11213	L	12213	LM	13213	LM
11221	L	12221	LM	13221	LM
11222	L	12222	LM	13222	LM
11223	L	12223	LM	13223	LM
11231	L	12231	LM	13231	LM
11232	L	12232	LM	13232	LM
11233	L	12233	LM	13233	LM
11311	L	12311	LM	13311	LM
11312	L	12312	LM	13312	LM
11313	L	12313	LM	13313	LM
11321	L	12321	LM	13321	LM
11322	L	12322	LM	13322	LM
11323	L	12323	LM	13323	LM
11331	L	12331	LM	13331	LM
11332	L	12332	LM	13332	LM
11333	L	12333	LM	13333	LM

Table 4. (continued)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
21111	L	22111	LM	23111	LM
21112	L	22112	LM	23112	LM
21113	L	22113	LM	23113	LM
21121	L	22121	LM	23121	HM
21122	L	22122	LM	23122	HM
21123	L	22123	LM	23123	HM
21131	L	22131	LM	23131	HM
21132	L	22132	LM	23132	HM
21133	L	22133	LM	23133	HM
21211	L	22211	LM	23211	LM
21212	L	22212	LM	23212	LM
21213	L	22213	LM	23213	LM
21221	L	22221	LM	23221	HM
21222	L	22222	LM	23222	HM
21223	L	22223	LM	23223	HM
21231	L	22231	LM	23231	HM
21232	L	22232	LM	23232	H
21233	L	22233	LM	23233	H
21311	L	22311	LM	23311	LM
21312	L	22312	LM	23312	LM
21313	L	22313	LM	23313	LM
21321	L	22321	LM	23321	HM
21322	L	22322	LM	23322	HM
21323	L	22323	LM	23323	HM
21331	L	22331	LM	23331	HM
21332	L	22332	LM	23332	H
21333	L	22333	LM	23333	H

Table 4. (concluded)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
31111	L	32111	LM	33111	LM
31112	L	32112	LM	33112	LM
31113	L	32113	LM	33113	LM
31121	L	32121	LM	33121	HM
31122	L	32122	LM	33122	HM
31123	L	32123	LM	33123	HM
31131	L	32131	LM	33131	HM
31132	L	32132	LM	33132	HM
31133	L	32133	LM	33133	HM
31211	L	32211	LM	33211	LM
31212	L	32212	LM	33212	LM
31213	L	32213	LM	33213	LM
31221	L	32221	LM	33221	HM
31222	L	32222	LM	33222	H
31223	L	32223	LM	33223	H
31231	L	32231	LM	33231	HM
31232	L	32232	LM	33232	H
31233	L	32233	LM	33233	H
31311	L	32311	LM	33311	LM
31312	L	32312	LM	33312	LM
31313	L	32313	LM	33313	LM
31321	L	32321	LM	33321	HM
31322	L	32322	LM	33322	H
31323	L	32323	LM	33323	H
31331	L	32331	LM	33331	HM
31332	L	32332	LM	33332	H
31333	L	32333	LM	33333	H

Table 5. Reservoir descriptions and suitability ratings for carp.

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
11111	L	12111	L	13111	L
11112	L	12112	L	13112	L
11113	L	12113	L	13113	L
11121	L	12121	L	13121	L
11122	L	12122	L	13122	L
11123	L	12123	L	13123	L
11131	L	12131	L	13131	L
11132	L	12132	L	13132	L
11133	LM	12133	LM	13133	LM
11211	L	12211	L	13211	L
11212	L	12212	L	13212	L
11213	L	12213	L	13213	L
11221	L	12221	L	13221	L
11222	L	12222	L	13222	L
11223	L	12223	L	13223	L
11231	L	12231	L	13231	L
11232	L	12232	L	13232	L
11233	LM	12233	LM	13233	LM
11311	L	12311	L	13311	L
11312	L	12312	L	13312	L
11313	L	12313	L	13313	L
11321	L	12321	L	13321	L
11322	L	12322	L	13322	L
11323	L	12323	L	13323	L
11331	L	12331	L	13331	L
11332	L	12332	L	13332	L
11333	LM	12333	LM	13333	LM

Table 5. (continued)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
21111	L	22111	LM	23111	LM
21112	L	22112	LM	23112	LM
21113	L	22113	LM	23113	LM
21121	LM	22121	HM	23121	HM
21122	LM	22122	HM	23122	H
21123	LM	22123	HM	23123	H
21131	LM	22131	HM	23131	HM
21132	LM	22132	H	23132	H
21133	LM	22133	H	23133	H
21211	L	22211	LM	23211	LM
21212	L	22212	LM	23212	LM
21213	L	22213	LM	23213	LM
21221	LM	22221	HM	23221	HM
21222	LM	22222	HM	23222	H
21223	LM	22223	HM	23223	H
21231	LM	22231	HM	23231	HM
21232	LM	22232	H	23232	H
21233	LM	22233	H	23233	H
21311	L	22311	LM	23311	LM
21312	L	22312	LM	23312	LM
21313	L	22313	LM	23313	LM
21321	LM	22321	HM	23321	HM
21322	LM	22322	HM	23322	H
21323	LM	22323	HM	23323	H
21331	LM	22331	HM	23331	HM
21332	LM	22332	H	23332	H
21333	LM	22333	H	23333	H

Table 5. (concluded)

Reservoir description	Suitability	Reservoir description	Suitability	Reservoir description	Suitability
31111	L	32111	LM	33111	LM
31112	L	32112	LM	33112	LM
31113	L	32113	LM	33113	LM
31121	LM	32121	HM	33121	HM
31122	LM	32122	HM	33122	H
31123	LM	32123	HM	33123	H
31131	LM	32131	HM	33131	HM
31132	LM	32132	H	33132	H
31133	LM	32133	H	33133	H
31211	L	32211	LM	33211	LM
31212	L	32212	LM	33212	LM
31213	L	32213	LM	33213	LM
31221	LM	32221	HM	33221	HM
31222	LM	32222	HM	33222	H
31223	LM	32223	HM	33223	H
31231	LM	32231	HM	33231	HM
31232	LM	32232	H	33232	H
31233	LM	32233	H	33233	H
31311	L	32311	LM	33311	LM
31312	L	32312	LM	33312	LM
31313	L	32313	LM	33313	LM
31321	LM	32321	HM	33321	HM
31322	LM	32322	HM	33322	H
31323	LM	32323	HM	33323	H
31331	LM	32331	HM	33331	HM
31332	LM	32332	H	33332	H
31333	LM	32333	H	33333	H

Rules that were used in deciding the meanings of the five-digit reservoir descriptions, in terms of habitat suitability ratings, are listed in Appendix A for black crappie (Pomoxis nigromaculatus), white sucker (Catostomus commersoni), put-and-grow rainbow trout (Salmo gairdneri), yellow perch (Perca flavescens), and common carp (Cyprinus carpio).

As an example, a reservoir description of 31322 would have the following characteristics:

A. Temperature (3) (Option I: warmwater species). More than 170 days in the growing season; mean July air temperature greater than 70° F.

B. Mineral turbidity (1). Predicted Secchi disk depth less than 0.5 m.

C. Nonliving cover (3). Boulders, standing timber, and talus cover 30-70% of deepest half of lake bottom; over 30% of bottom is covered by structure units over 7 cm in diameter and 0.5 m high; mean height of these units is greater than 20% of greatest mean depth and density exceeds 100 units/ha.

D. Drawdown (2). Extent of maximum drawdown over 5 years is 2 to 5 m, and it occurs during August through October.

E. Shallow cove frequency (2). Mean depth is 10 to 20 m and shoreline development factor is between 5 and 10.

The meaning of 31322 as an expression of habitat suitability is based on the composite pattern of attribute ratings rather than a score derived from mathematical manipulation of the numbers.

The importance of an attribute in assigning an overall suitability varies with the fish species being considered. Importance is based on statements in the literature validated, when possible, by the status of populations of the species in existing reservoirs which exhibit an extreme of the attribute. For example, high turbidity might exclude one species but not another depending on the sensitivity of the species being considered. If a species were excluded by turbidity, the status of the other attributes would have no weight in assigning overall suitability. In contrast, a species tolerant of high turbidity might not become as numerous or grow as rapidly if turbidity were extremely high but it would not be excluded; therefore, one or more of the other attributes would have weight in judging overall suitability.

To give another example, a warmwater species might be excluded by a description of 13322 but 13333 would indicate the presence of stable, shallow coves in the spring and could possibly mitigate the low surface temperature sufficiently to allow the species to survive and reproduce to a limited extent.

The foregoing irregular attribute relations and others can be expressed more easily with pattern systems than with scoring systems. If experience or further review indicates that ratings assigned to a species are inappropriate, two approaches can be used to change the rating system. The simplest approach is to change the suitability rating. However, the rationale leading to a change of one rating will probably require changes in other ratings. For complete consistency, the rules for deriving the ratings from primary attribute scores (Appendix A) should be changed so that the new rating may be derived from the rules. An alternative to changing the rules is to change the method of deriving primary attribute scores from secondary attributes. However, in some cases this alternative may also require changes in the rules.

INSTRUCTION OVERVIEW

1. Read all instructions first.
2. Examine attribute matrices to determine which secondary attributes need to be estimated for the species under consideration.
3. Check suggested sources or other material to obtain values for secondary attributes.
4. Determine primary attribute scores using appropriate attribute matrices.
5. Compile five-digit reservoir description from the five primary attribute scores.
6. From Tables 1-5, find the appropriate five-digit reservoir description and read corresponding habitat suitability.

SECONDARY ATTRIBUTE LISTING WITH SOURCES

Levels of all or most of the secondary attributes listed below will need to be determined to use this model. In some situations, fewer measurements may be made. This can be determined as you progress through the work sheet and will depend on the species used and individual reservoir descriptions. See attribute matrices beginning on page 27 for units in which attributes are measured.

GROWING SEASON

Growing season is the mean number of days between the last spring and the first fall frost at the reservoir site. This information is recorded at weather stations which may not be at the reservoir site; however, an estimate of the growing season can usually be made by using data from the nearest weather station if care is taken to obtain data from stations at similar altitudes, latitudes, and aspects.

Sources: National Oceanic and Atmospheric Administration. 1974. Climates of the States. Vol. I, Eastern States plus Puerto Rico and U.S. Virgin Islands; Vol. II, Western States including Alaska and Hawaii. Water Information Center, Inc., Port Washington, NY. 975 pp.

National Oceanic and Atmospheric Administration. 1978. Climates of the States, with current tables of normals 1941-1970 and means and extremes to 1975. James A. Ruffner, compiler. Vol. I, Alabama-Montana; Vol. II, Nebraska-Wyoming, Puerto Rico, and U.S. Virgin Islands. Gale Research Company, Detroit, MI.

U.S. Department of Commerce, Environmental Services Administration, Environmental Data Service. Climatography of the United States. No. 60-5.

U.S. Weather Bureau. 1959-1960. Climates of the States, 1951-1960. Climatography of the United States, Series 86. U.S. Dept. Commerce, Washington, DC.

MEAN JULY AIR TEMPERATURE

If mean July air temperatures at the reservoir site are not available, follow the same procedures for growing season determination.

Sources: The four sources listed under Growing Season and the following:

U.S. Weather Bureau. Climatic summary of the United States, Bulletin W supplement, 1931-1952. Climatography of the United States, Series 11. U.S. Dept. Commerce, Washington, DC.

STORAGE RATIO

Storage ratio is the ratio of reservoir volume (at the listed elevation) to the average annual discharge.

Sources: Construction agency records.

Operations schedule.

USGS flow records plus reservoir volume.

DEPTH OF OUTLET IN RELATION TO MEAN DEPTH

The outlet depth is the midline depth of the principal outlet at the listed surface area. The position of the outlet in relation to mean depth is above, below, or within the middle one-third of the mean depth (± 0.33 mean depth).

Sources: Construction agency records.

Mean depth = volume/surface area (at full basin).

MAXIMUM FETCH

The maximum uninterrupted distance across the lake or reservoir's surface is the maximum fetch. This attribute can be obtained from a map of the reservoir site. The direction of the fetch measured should parallel the direction of predominant winds at the reservoir site.

Sources: Contour map.

MEAN DEPTH

Mean depth is the lake volume divided by its surface area.

Sources: Reservoir specifications from construction agency.

MINERAL TURBIDITY

Turbidity of inflow streams is not a reliable indicator of turbidity levels to be expected in the impounded reservoir; therefore, an approximation of expected turbidity can be obtained from direct or estimated Secchi disk readings at nearby reservoirs with similar morphometry, inflow streams, altitude, operational regime, and other associated factors.

AREAL EXTENT OF BOTTOM COVERED BY STRUCTURAL UNITS

Designated structural units are rubble, boulders, tree stumps, or similar structures which are over 7 cm in diameter and 50 cm high.

Sources: Site visit and visual estimation of the percent of bottom that will be covered with structural units.

PERCENT STRUCTURAL UNITS ON DEEPEST HALF OF BOTTOM

The deepest half of bottom is that portion of lake or reservoir lying below the mid-depth contour. Locate and mark this contour on a topographic map; then, in conjunction with a site visit, determine where this contour is and visually estimate what percent of all structural units are below it. At large reservoir sites, estimate percentage in smaller areas and calculate a mean for the entire site.

Sources: Contour map.

Site visit.

MEAN HEIGHT OF STRUCTURAL UNITS AS A PERCENT OF MEAN DEPTH

Designated mean depth is at full basin; structural units are boulders, standing timber, talus fields, or any combination of these or similar structures. It may be necessary to measure the structures directly, because height can be deceiving when viewed from a distance. Divide mean height by mean depth and multiply by 100 to obtain a percent value.

Sources: Contour map.

Site visit.

Environmental impact statement.

MEAN DENSITY OF STRUCTURAL UNITS

Density is expressed here as the number of structural units per hectare, obtained by visual estimation during a site visit.

Sources: Site visit.

LINEAR EXTENT OF STRUCTURE IN DEEPEST HALF OF RESERVOIR

Structures here refer to cliffs or shoals >45°. A topographic map with frequent contour intervals (≤ 20 ft) should be used to estimate this attribute, particularly for shallow reservoirs. To determine:

(1) Divide reservoir maximum depth by two and subtract that number from surface elevation to obtain mid-depth elevation. Total length of the mid-depth contour is determined by running a wheeled map measuring device along that contour.

(2) Locate and mark on the contour map all areas at or below the mid-depth contour which have slopes > 45°.[3] Measure the length of each contour line within the marked slope areas.

(3) Sum the lengths of sections obtained in (2) and divide by the mid-depth contour length obtained in (1). Multiply by 100 for a percent value.

In the final analysis, the question is, "Is there a lot of structure or not very much?" The calculated value for this attribute can be compared with a visual estimation during a site visit and modified according to one's best judgment.

Sources: Site visit.

Contour map.

LINEAR EXTENT OF STRUCTURE AT FULL BASIN

Structures are cliffs or shoals >45° and determination is similar to that of the preceding attribute, except that full basin contour (greatest shoreline length) replaces the mid-depth contour.

Sources: Site visit.

Contour map.

MEAN HEIGHT OF CLIFFS OR SHOALS AS A PERCENT OF MEAN DEPTH

Cliffs or shoals are designated below high water line and mean depth is at full basin. Mark the maximum and minimum elevations of each cliff or shoal

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[3]A helpful tool for this step is the USGS Topo Map - Land Area and Slope Indicator for use on 7.5 and 15 minute series maps available from Reproduction Specialites, Inc., 4990 East Asbury Avenue, Denver, CO 80222.

on a detailed contour map. Determine the height of each area and calculate the mean height for all areas. Divide this value by mean depth.

Sources: Contour map.

Site visit.

EXTENT OF MAXIMUM DRAWDOWN

Extent of drawdown is expressed as percent of maximum area at full pool, and the period of consideration is 5 years.

Sources: Construction agency operating plans.

TIME OF MAXIMUM DRAWDOWN

Time is month(s) of the year; it is assumed the reservoir is static or filling in other months.

Sources: Construction agency operating plans.

Environmental impact statement.

SHORELINE DEVELOPMENT FACTOR (D_L)

The shoreline development factor is an index of shoreline complexity and is calculated from the equation

$$D_L = \frac{L}{2\sqrt{\pi A}}$$

where L = shoreline length in m and A = surface area (m^2). If an exact area estimate is not available, a rough estimate of D_L can be obtained by comparing the shape of the proposed reservoir to the reservoirs with known shoreline development factors given in Appendix B.

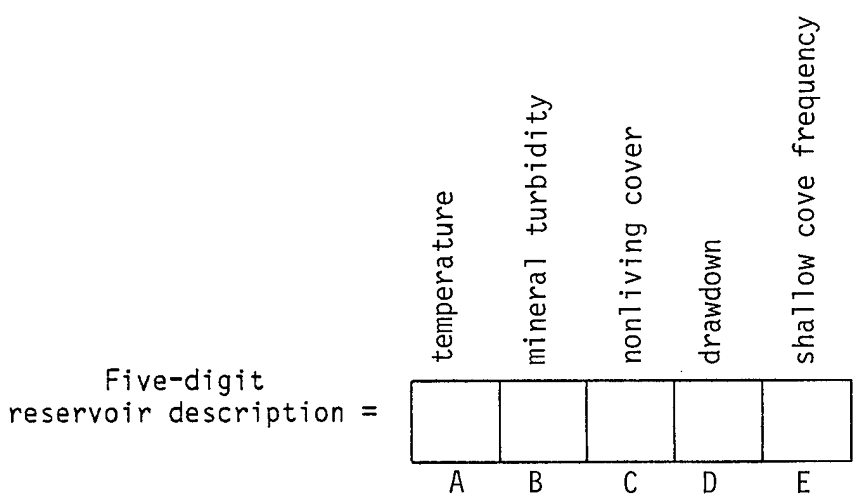
Sources: Contour map.

Appendix B.

THE USE OF PRIMARY ATTRIBUTE SCORES TO DETERMINE RESERVOIR DESCRIPTIONS AND SPECIES SUITABILITY

Water temperature, mineral turbidity, nonliving cover, extent and timing of drawdown, and frequency of shallow coves constitute the five primary attributes. These attributes are composites of two or more secondary attributes with the exception of mineral turbidity, which is based on levels of a single attribute. Primary attribute scores are derived by examining the relationship between selected secondary attribute scores in a two-dimensional matrix. To determine a primary attribute score, locate the number (usually 1, 2, or 3) in the matrix that corresponds to the levels of the secondary attributes being considered on the matrix axes. In calculating the primary attribute score for nonliving cover, two or more matrices may need to be examined sequentially before deriving the score. Numerical values entered in the octagons become the primary attribute scores if all appropriate conditions have been met.

The five-digit number resulting from scoring each of the five primary attributes becomes the reservoir description.



To determine the suitability of the reservoir for the species of concern, find the reservoir description and its corresponding suitability in Tables 1 through 5.

MATRICES FOR DERIVING PRIMARY ATTRIBUTE SCORES

TEMPERATURE

A separate temperature score option is required for each species-temperature group; i.e., warmwater, coolwater and coldwater species. Examples of species in each of these groups are given below.

Warmwater	Coolwater	Coldwater
Black crappie	White sucker	Rainbow trout
Smallmouth bass	Walleye	
Common carp	Yellow perch	

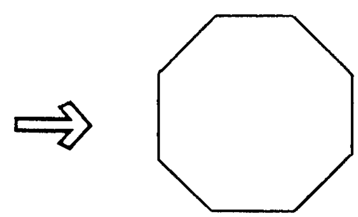
The species-temperature group of concern must be identified before proceeding with development of the numerical reservoir description.

Option I: Warmwater Species

a. Climate score

Growing season (days)	<60° F / <15° C	60-70° F / 15-21° C	>70° F / >21° C
>170	2	3	3
120-170	1	2	2
<120	1	1	2

Mean July air temp.



Option I
Primary temperature score [4]

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[4]When you encounter an octagon, ENTER A NUMBER. The number you enter is the primary attribute score for the selected attribute. Only one score will be calculated for each of the five primary attributes. When one is completed, go on to next primary attribute.

Option II: Coolwater Species

To obtain a temperature score for coolwater fishes, three secondary attributes need to be determined: 1) climate score; 2) operations score; and 3) stratification score. After they are determined, scores for these secondary attributes are combined to arrive at the primary temperature score.

a. Climate score

Growing season (days)	>70° F / >21° C	60-70° F / 15-21° C	<60° F / <15° C
<120	2	3	3
120-170	1	2	2
>170	1	1	2

Mean July air temp.

⇨ ________

b. Operations score

Storage ratio (5 yr mean)	Below	Within Middle 1/3	Above
<1	2	3	3
1-3	1	2	3
>3	1	1	2

Depth of outlet in relation to mean depth

⇨ ________

c. Stratification score

Mean depth (m) \ Maximum fetch (km)	<2	2-6	>6
<10	2	1	1
10-20	3	2	1
>20	3	3	2

The climate score (a) above is used to determine which of the following three matrices will be used to derive the Option II coolwater species temperature score.

If climate score = 1

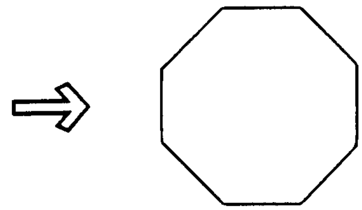
Operation score \ Stratification score	1	2	3
3	1	2	2
2	1	1	2
1	1	1	1

Option II

Primary temperature score

If climate score = 2

Operation score			
3	2	3	3
2	2	3	3
1	2	2	2
	1	2	3
	Stratification score		

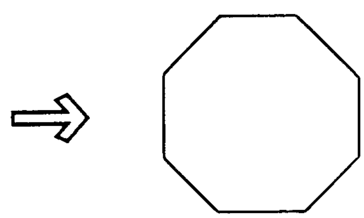


Option II

Primary temperature score

If climate score = 3

Operation score			
3	2	2	2
2	2	2	2
1	2	2	2
	1	2	3
	Stratification score		



Option II

Primary temperature score

Option III: Coldwater Species [5]

Growing season (days)	>70° F / >21° C	60-70° F / 15-21° C	<60° F / <15° C
<120	2	3	3
120-170	1	2	2
>170	1	1	2

Mean July air temp.

Option III
Primary temperature
score

MINERAL TURBIDITY

The degree of muddiness of the water, caused by mineral turbidity, is estimated from either direct or approximate Secchi disk readings at nearby similar reservoirs. Approximate Secchi disk depths can be based on user judgement if direct measurements are not possible.

Three levels of mineral turbidity are considered:

Secchi disk depth more than one-half time due to mineral turbidity

< 0.5 m = 1
0.5-1 m = 2
> 1 m = 3

Primary water
quality score

[5] This matrix differs from that used for warmwater species in that July air temperatures and growing season are reversed on their axes. The scoring procedure remains the same.

NONLIVING COVER

Rating of nonliving cover or structure is based on the types of cover that are likely to be inundated by the new reservoir. Three cover options are described:

I. Boulders, standing timber, talus fields - individually or in any combination.

II. Steep (> 45°) shoals or cliffs.

III. Combination of options I and II.

Nonliving Cover Matrix 1

Option I. Boulder, standing timber, and talus

1A

%structural units on deepest half of bottom	<10%	10-30%	>30%
30-70%	1	3	3
10-30% or 70-90%	1	2	2
<10% or >90%	1	1	2

Areal extent of bottom covered by structural units (%)

1B

Mean height of structural units as a % of mean depth	<50	50-100	>100
>20%	1	2	3
5-20%	1	2	2
<5%	1	1	2

Mean density of structural units (units/ha)

Cover rating for Option I is derived from a combination of scores from Matrix 1A and 1B.

Score 1B \ Score 1A	1	2	3
3	2	2	3
2	1	2	2
1	1	1	2

Option I
Primary nonliving
cover score

Nonliving Cover Matrix 2

Option II. Cliffs and shoals

2A

Linear extent of structure in deepest half of reservoir \ Linear extent of structure at full basin	20%	20-50%	50%
30-70%	1	2	3
10-30 or 70-90%	1	2	2
<10 or >90%	1	1	2

2B

Mean height of cliffs or shoals as % mean depth (below high water)	1	2	3
>20%	1	2	3
5-20%	1	2	3
<5%	1	1	2

Score from Option 2A

Option II

Primary nonliving cover score

Nonliving Cover Matrix 3

Option III. If talus fields are present in association with cliffs or shoals, the scores from Options I and II are combined to derive the final structure score:

Score Option 1	1	2	3
3	3	3	3
2	2	3	3
1	1	2	3

Score Option 2

Option III

Primary nonliving cover score

DRAWDOWN EXTENT AND TIMING

Fluctuation score

Extent of maximum drawdown over 5 years	Mar-Jul	Aug-Oct	Nov-Feb
<2m	2	3	3
2-5m	1	2	3
>5m or 50% max depth	1	1	2

Primary drawdown extent and timing score

SHALLOW COVE FREQUENCY

Mean depth	<5	5-10	>10
<10m	2	3	3
10-20m	1	2	2
>20m	1	1	2

Shoreline development factor

Primary shallow cove frequency score

BIBLIOGRAPHY

The following information sources are provided to aid the user in calculating secondary attribute scores. These only represent a partial list of available sources, and the user may wish to consult other documents. Annotated entries represent suggested sources for the user to examine. The remaining sources plus annotated entries were used by the authors to determine species-habitat interactions and reservoir habitat suitability ratings.

Benci, J. F., and T. B. McKee. 1977. Colorado monthly temperature and precipitation summary for period 1951-1970. Colorado Climatology Office, Dept. Atmospheric Science, Colorado State Univ., Ft. Collins.

A monthly climatological summary for 162 National Weather Service reporting stations in Colorado. Only stations with 20 years of data (temperature, precipitation, or both) from 1951-1970 were selected. A State map showing station locations is presented with a table of stations, county, latitude, longitude, elevation, and observation time. This is followed by detailed monthly summaries (including maximum, minimum, and mean temperatures) for each alphabetically listed station. This is an excellent example of a statewide, long-term weather summary, and similar types of publications may be put out by other States.

Cross, F. B. 1967. Handbook of fishes of Kansas. Museum of Natural History Miscellaneous Publication No. 45. Univ. of Kansas, Lawrence. 357 pp.

Duerre, D. C. 1973. Ecological investigations of lakes, streams and impoundments in North Dakota (surveys). Dingell-Johnson Division, Project F-2-R-20, Study II, Jobs IIa and IIB, Report A-1028, North Dakota State Game and Fish Department.

Hall, G. E. (Ed.). 1971. Reservoir fisheries and limnology. American Fisheries Society, Special Publication No. 8, Washington, D.C. 511 pp.

Hokanson, K. E. F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. J. Fish. Res. Board Can. 34:1524-1550.

Jenkins, R. M., and D. I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. Pages 371-384 in G. E. Hall (Ed.), Reservoir fisheries and limnology. American Fisheries Society Special Publication No. 8, Washington, D.C. 511 pp.

The influence of selected environmental variables (area, mean depth, outlet depth, thermocline depth, water level fluctuation, storage ratio, shore development, total dissolved solids, growing season, and age of impoundment) on sport fishing effort and harvest were analyzed for 103 U.S. reservoirs (> 200 ha). Data for these reservoirs are presented in a table insert along with data on harvest of rainbow trout, catfishes, sunfishes, and black basses.

Koster, W. J. 1957. Guide to the fishes of New Mexico. University of New Mexico Press in cooperation with New Mexico Department of Game and Fish. Albuquerque, N. Mex. 116 pp.

LaRivers, I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Commission. Carson City, Nevada. 782 pp.

Leidy, G. R., and R. M. Jenkins. 1977. The development of fishery compartments and population rate coefficients for use in reservoir ecosystem modeling. USDI Fish and Wildlife Service, National Reservoir Research Program. Fayetteville, Arkansas. Final Contract Report 4-77-1. Prepared for Office, Chief of Engineers, U.S. Army, Washington, D.C. (Vicksburg, U.S. Army Engineer Waterways Experiment Station.)

Appendixes contain physical and chemical descriptions of 187 Corps of Engineers reservoirs > 500 acres in surface area, sport and commercial fish harvests, estimated standing crops of fish species groups from summer cove rotenone sampling, and temperature tolerance and preference data for various reservoir fish species. Not much data on western reservoirs.

National Oceanic and Atmospheric Administration. 1974. Climates of the States. Vol. I, Eastern States; Vol. II, Western States including Alaska and Hawaii. Water Information Center, Inc., Port Washington, N.Y. 975 pp.

National Oceanic and Atmospheric Administration. 1978. Climates of the States, with current tables of normals 1941-1970 and means and extremes to 1975. James A. Ruffner, compiler. Vol. 1, Alabama-Montana; Vol. 2, Nebraska-Wyoming, Puerto Rico, and U.S. Virgin Islands. Gale Research Company, Detroit, Mich.

Based on Climatography of the United States, No. 60, issued serially 1959-1960 by U.S. Weather Bureau, and data from NOAA. For each alphabetically listed State, there is a narrative with references and bibliography; tables of freeze data for numerous stations (from which growing season is obtained); and tables of normals (temperature and precipitation) by climatological division or drainage area, for the period 1931-1960.

Nelson, W. R., and C. H. Walburg. 1977. Population dynamics of yellow perch (*Perca flavescens*), sauger (*Stizostedion canadense*), and walleye (*S. vitreum vitreum*) in four main stem Missouri River reservoirs. J. Fish. Res. Board Can. 34:1748-1763.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.

Puttmann, S., and L. Finnell. 1979. Warmwater fisheries investigations. Federal Aid Project F-34-R-11, Job Progress Report. Colorado Division of Wildlife. 47 pp.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184. Ottawa. 966 pp.

Smith-Vaniz, W. F. 1968. Freshwater fishes of Alabama. Auburn Univ. Agricultural Experiment Station. Auburn, AL. 211 pp.

Trautman, M. B. 1981. The fishes of Ohio. Ohio State Univ. Press, Columbus. 782 pp.

U.S. Department of Commerce, Environmental Services Administration, Environmental Data Service. Climatography of the United States. No. 60-5.

U.S. Environmental Protection Agency. 1975. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the Northeast and North-central U.S. Working paper number 474. National Eutroph. Surv. Environmental Monitoring Support Lab. Las Vegas, NV. Contains mainly water quality data, including mean Secchi disk extinction depths. (not seen)

U.S. Geological Survey. Water resources data. Part 2, Water Quality Records. (Annual reports for various States.) U.S. Dept. Interior.

From the 1964 water year (Oct 1-Sep 30) to the present, these reports are issued on a State-by-State basis. From 1941-1963, water quality records were compiled from 14 major drainage basins within the United States and were called "Quality of Surface Waters of the United States." Data are listed in a downstream sequence beginning at the headwaters, and each natural drainage is called a Part and is numbered 1-14. Records range from "spot" observations to tables of continuous daily records.

U.S. Weather Bureau. Climatic summary of the United States, Bulletin W (1930 edition). Climatography of the United States. Series 10. U.S. Dept. Commerce, Washington, D.C.

U.S. Weather Bureau. Climatic summary of the United States; Supplement for 1931-1952 (Bulletin W supplement). Climatography of the United States. Series 11. U.S. Dept. of Commerce, Washington, D.C. First supplement to 1930 edition. (not seen)

U.S. Weather Bureau. Climatic summary of the United States, Bulletin W, Second supplement, 1951-1960. Climatography of the United States. Series 86. U.S. Dept. of Commerce, Washington, D.C.

A five-volume State-by-State compilation of temperature and precipitation data for each weather station in the State. Monthly mean temperatures are listed by year for the period (1951-1960) and are compared with the normals for that station. Especially useful is the section on station history, which includes the county where the station is located, latitude, longitude, elevation, distance and direction to nearest post office, and the month and year records began (and ended) within the time period.

APPENDIX A

RULES FOR ASSIGNING RESERVOIR HABITAT SUITABILITY RATINGS

The following sets of rules form the bases for determining the level of habitat suitability for all 243 five-digit reservoir descriptions for each species under consideration. To use the rules, proceed sequentially only; all low, all low medium, all high medium, and all high. When one or more conditions for a rule are met, use the corresponding suitability rating. Experience or further review may dictate changes in one or more rating assignments. In each description, A = temperature; B = mineral turbidity; C = nonliving cover; D = maximum drawdown; and E = frequency of shallow, protected coves.

BLACK CRAPPIE[6]

If A = 1 (unless D = E = 3) or B = 1	Low
If not as above, and C = E = 1 or D = 1	Low Medium
If not as above, and A = 2 or D = 2 or C = 1 or E = 1	High Medium
If not as above	High

[6]A = Temperature Option I, warmwater species.

WHITE SUCKER[7,8]

If A = B = 1	Low
If not as above, and A = 1 or B = 1 or D = 1	Low Medium
If not as above, and A = B = 2 or A = D = 2 or B = D = 2	High Medium
If not as above	High

PUT-AND-GROW RAINBOW TROUT[9,10]

If A = 1 or B = 1	Low
If not as above, and A = B = 2 or D = 1 or E = 1 and A = 2 or E = 1 and B = 2	Low Medium
If not as above, and A = 2 or B = 2 or E = 1	High Medium
If not as above	High

YELLOW PERCH[8]

If B = 1	Low
If not as above, and A = 1 or D = 1 or B = 2	Low Medium
If not as above, and C = 1 or E = 1 or A = D = 2	High Medium
If not as above	High

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[7]C and E were irrelevant for white sucker and were not used.
[8]A = Temperature Option II, coolwater species.
[9]C is irrelevant for rainbow trout and was not used.
[10]A = Temperature Option III, coldwater species.

CARP[11,12]

If A = 1 and D = 1 or A = 1 and E = 1 or A = 1 and E = 2 or B = D = 1	Low
If not as above, and A = 1 or B = 1 or D = 1	Low Medium
If not as above, and E = 1 or B = D = 2 or	High Medium
If not as above	High

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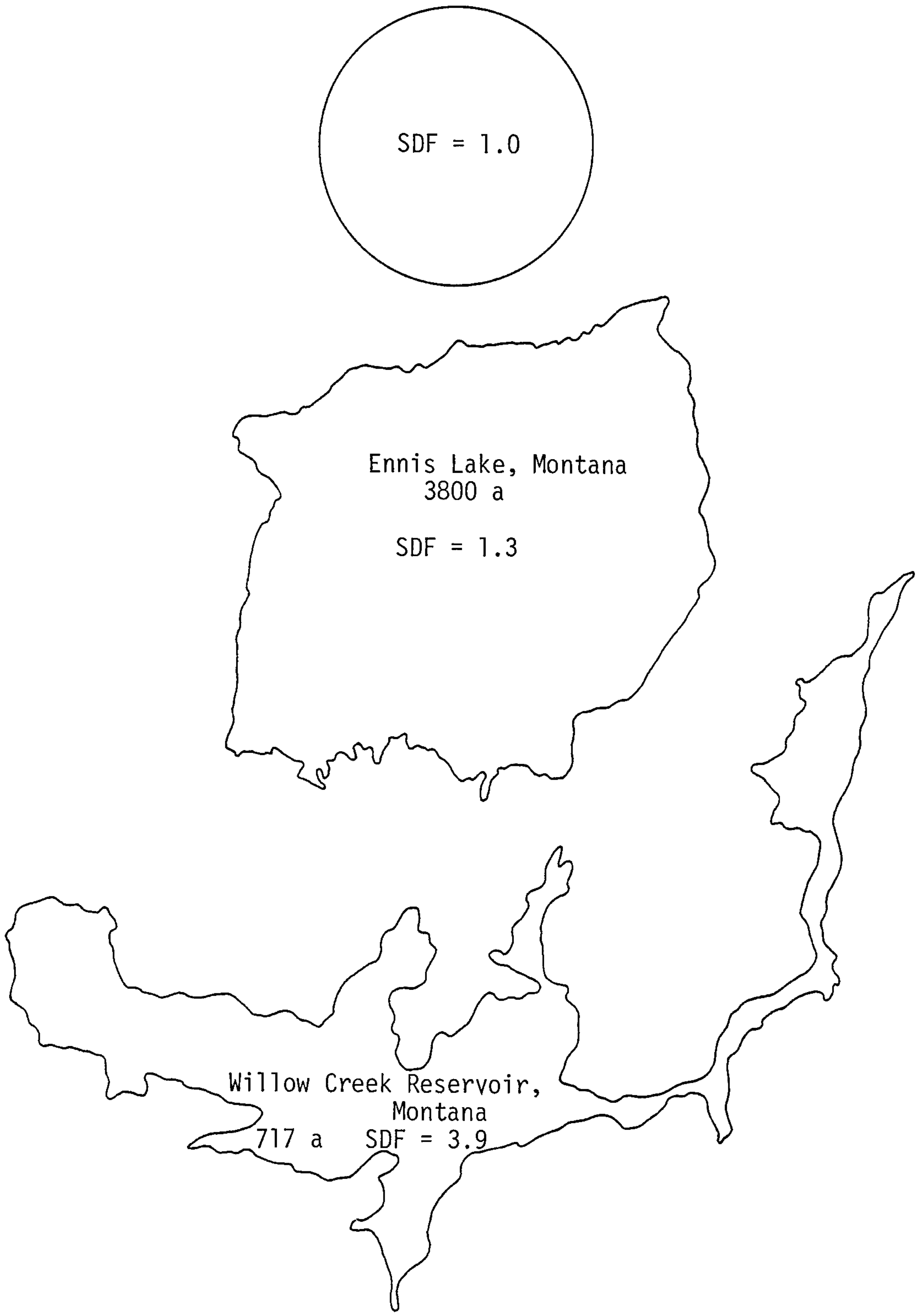
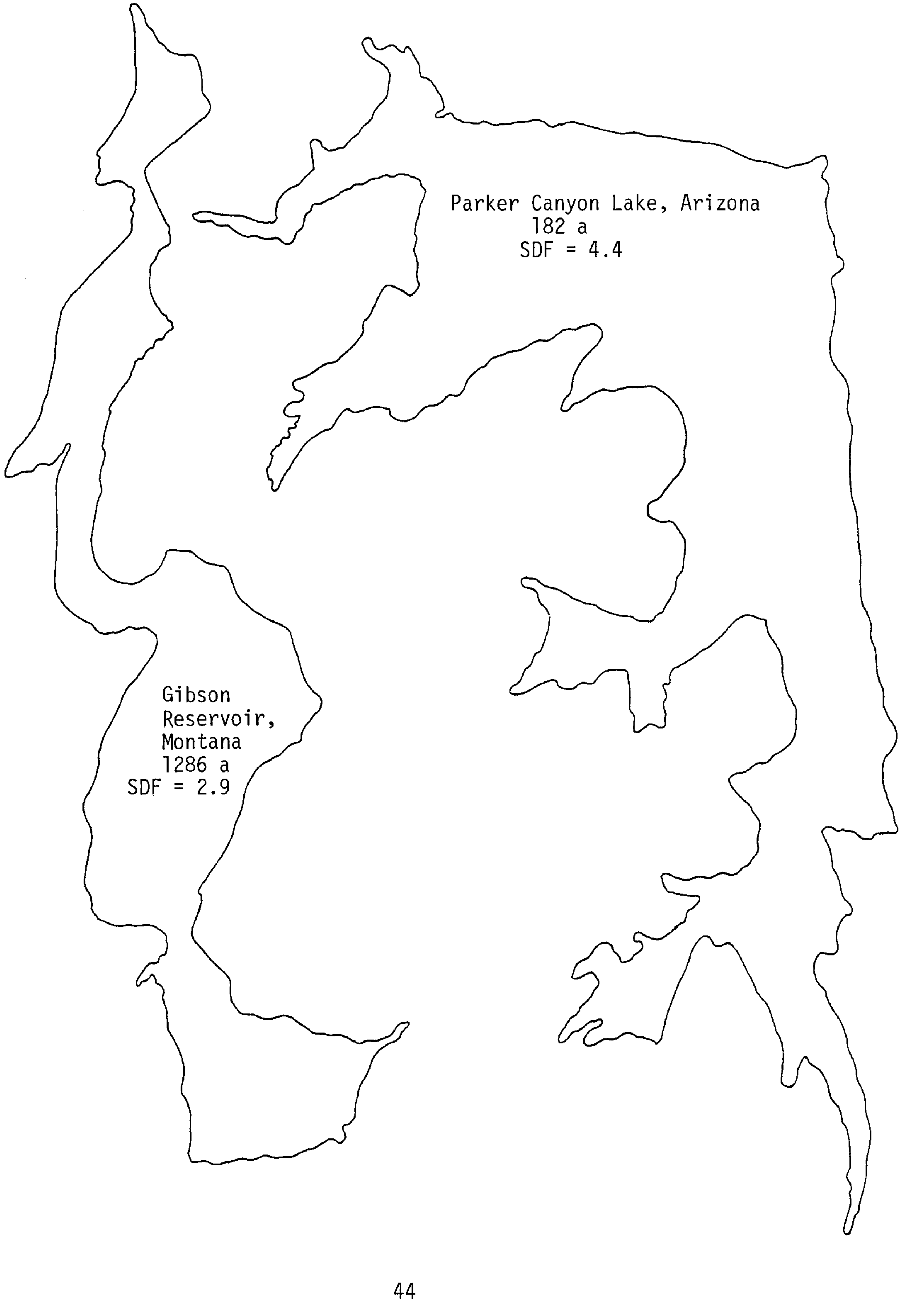
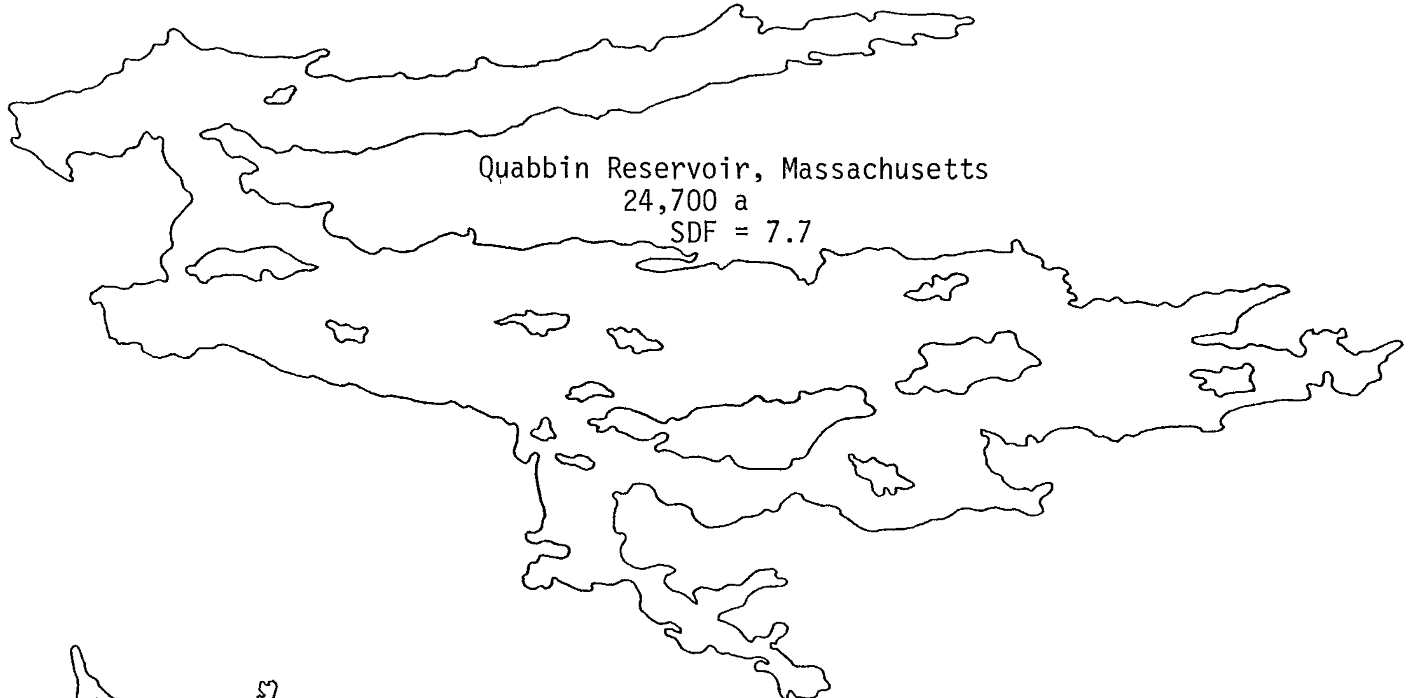
[11]C is irrelevant for carp and was not used.
[12]A = Temperature Option I, warmwater species.

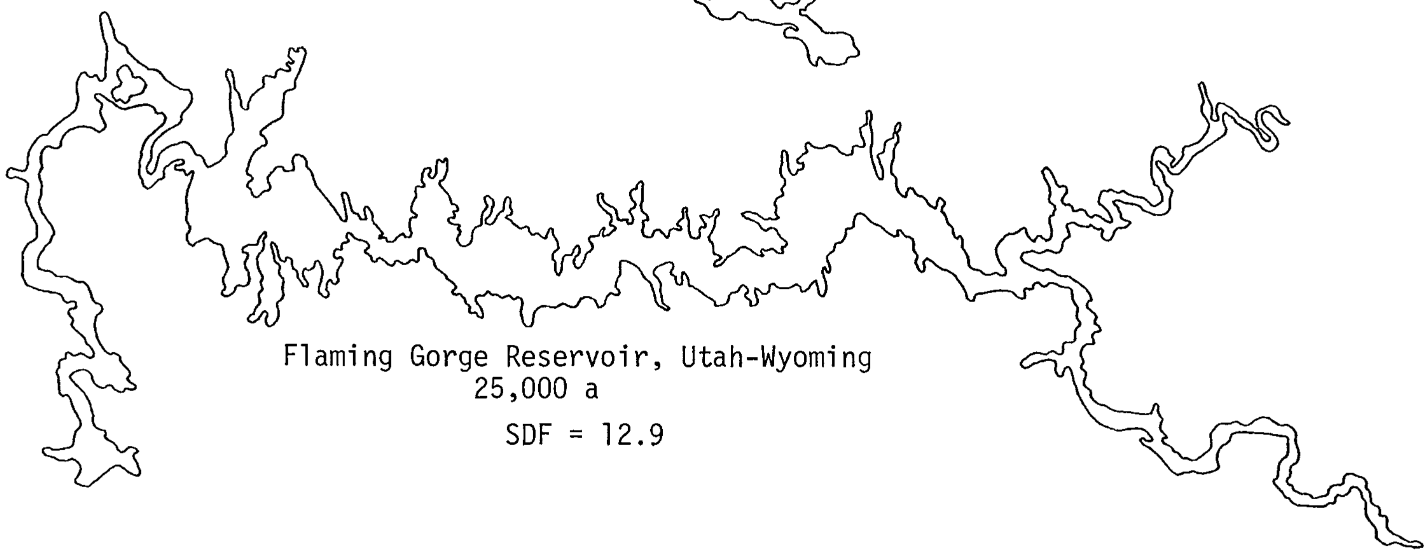
APPENDIX B

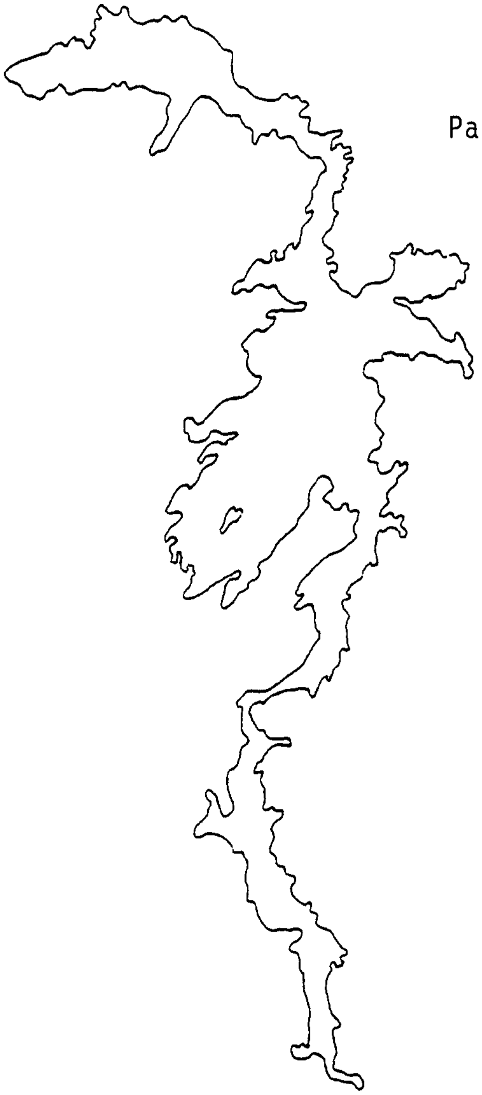
LAKESHORES AND KNOWN SHORELINE DEVELOPMENT FACTORS




Parker Canyon Lake, Arizona
182 a
SDF = 4.4
Gibson
Reservoir,
Montana
1286 a
SDF = 2.9

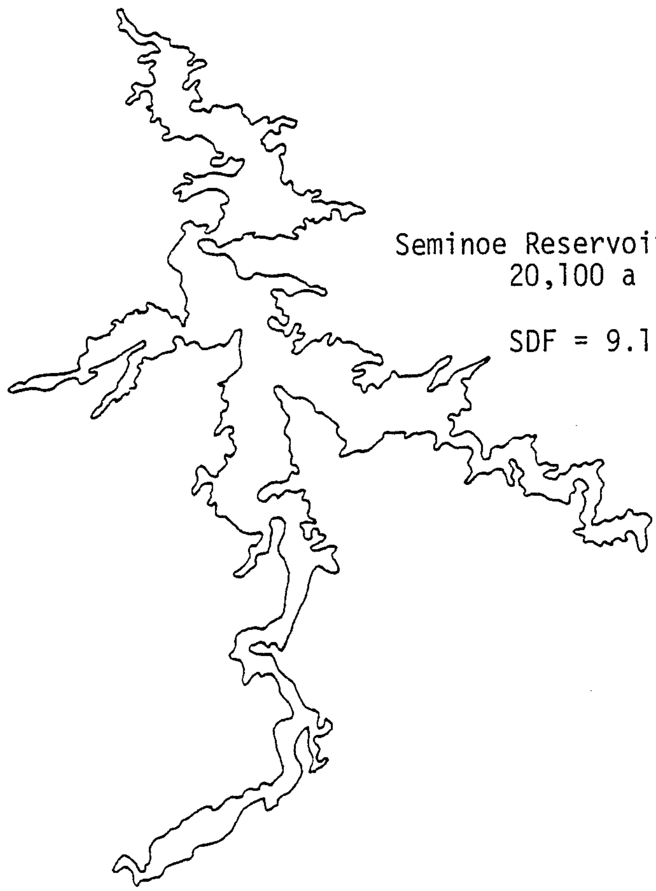

Quabbin Reservoir, Massachusetts
24,700 a
SDF = 7.7


Flaming Gorge Reservoir, Utah-Wyoming
25,000 a
SDF = 12.9



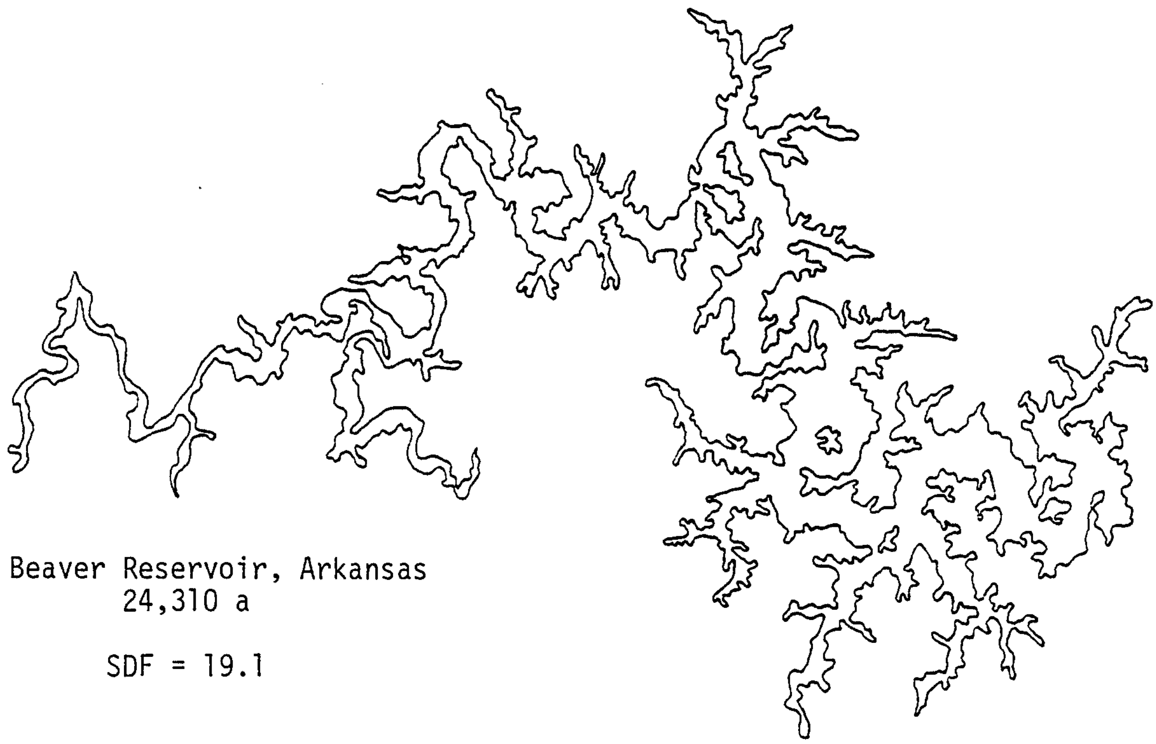
Pathfinder Reservoir, Wyoming
22,000 a

SDF = 10.6



Seminoe Reservoir, Wyoming
20,100 a

SDF = 9.1



Beaver Reservoir, Arkansas
24,310 a

SDF = 19.1

APPENDIX C. JUSTIFICATION OF PATTERN JUDGEMENTS IN HABITAT EVALUATION

This account of the procedure used by the authors in assigning suitability ratings to each reservoir description should help readers understand the discussions that follow and in turn enable them to modify the reservoir evaluation system or create new systems for other species of fish or types of habitat. Initially, we used published literature, informal records, and our expertise to select reservoirs which we judged to have high suitability or low suitability for a given species. Descriptions of these reservoirs were constructed and examined for conjunctions. We also considered reservoirs of medium habitat suitability for the species being considered that had an extreme quality level (1 or 3) for one attribute only.

Generalities regarding the relative importance of each of the five primary attributes were developed and then criticized. Exceptions to generalities were noted as possible evidence for interactions between pairs of attributes. At this point, we were able to agree on a tentative set of rules for assigning habitat suitabilities. In the process of applying these rules to each reservoir description, inconsistencies and counter-intuitive ratings were noted and the tentative rules were modified accordingly. The final rules are described in Appendix A.

The relative simplicity of pattern judgement systems derives from the fact that each reservoir description must be examined and judged by one or more fishery biologists. It would only be necessary to raise the number of attribute quality levels to 4 to bring the number of reservoir descriptions to 1024 (4^5). Each description is a separate permutation (not a combination) because the order of the three attribute quality levels has significance. Five quality levels of 5 attributes would yield 3125 permutations, a rather unwieldy number of judgements to ponder.

The question that each user or system builder must ask about the number of attribute quality levels is, "What number of habitat descriptions is justified?" Put another way, the question might become, "Is our knowledge of the relation between habitat attributes and the welfare of most successfully studied species sufficiently refined to warrant a large number of habitat descriptions?" With the present format of 243 descriptions, at least 4 hours were required to decide their meaning for a species. The judging panel (the authors) seldom felt that what is known about the relation between the species and the attributes justified more than three attribute quality levels.

The number of attributes may be more germane than the number of quality levels. This is particularly true if the pattern judgement method is extended to a diversity of existing habitat types (rivers, streams, natural lakes, and possibly terrestrial environments). We are, in effect, making inductions when constructing any model. One of the guidelines for generating inductions is that multiple attributes more convincingly support a generality about nature than do refined interpretations of one or two attributes. As with quality levels, the number of possible habitat descriptions increases rapidly as attributes are added.

In the system described in the body of this report the number of attributes is reduced by conflating 18 secondary attributes into five primary attributes (some might prefer to reverse the terms secondary and primary). We would have preferred to have maintained the separate identities of most of these 18 attributes, but this is impractical if not impossible. On the other hand, we could have conflated a greater number of secondary attributes by the same process. We think it is important not to combine secondary attributes so unrelated that the primary attribute loses meaning and becomes an abstraction. When this is done, the resulting primary attributes do not relate to the practical experience of fishery managers. Managers would thus have no basis for agreement. It should be noted that the process of combining secondary attributes is judgemental and can be altered simply by changing the numbers in the matrices representing attribute quality.

Most species of fish are not expected to prosper in large reservoirs and are not even considered as candidates for a reservoir population. Most darters, several suckers, dace, and minnows inhabiting small streams can be automatically removed from consideration. This also would be true for species of minnows or suckers adapted to large, swift, muddy rivers. Some species only found in small springs or shallow swampy waters are usually absent in reservoirs which have inundated their preferred habitat. This would include mudminnows (Umbridae), most killifishes (Cyprinodontidae), and specialized small centrarchids. Sporadically, individuals of species not usually reproducing and surviving in large reservoirs may turn up in extensive collections, presumably having drifted in from more suitable habitats on the drainage. It seems most practical in developing future habitat suitabilities from pattern judgements to consider first those species which, at least occasionally, develop significant reproducing populations in the set of reservoirs herein defined as being subject to pattern judgments. Species often maintained by stocking [e.g., rainbow trout, walleye (Stizostedion vitreum vitreum), and channel catfish (Ictalurus punctatus)] despite little hope of reproduction, would, of course, be included as expected reservoir species.

Descriptions of suitable habitats for one species may be similar to those for other species naturally occurring together. While this also is likely for many fish in a single genus it is not necessarily so. Suitable habitat for the black basses should differ little from that for black crappie, while white crappie (Pomoxis annularis) habit may be identical at the discrimination level of the descriptions. The foregoing observations suggest that grouping species according to similar habitat needs may make the development of new species suitability ratings an easier task than if fish with similar habitat needs were considered consecutively.

Cursory inspection of the 243 reservoir descriptions reveals that, although the permutations of three quality levels for each of the five attributes may progress in any of several possible orders of change, the sums or products of the quality levels do not.[1] The same sums or products of numerical quality levels are repeated for diverse suitability indexes. This characteristic precludes any simple scoring systems. Further experimenting with scoring systems based on simple polynomials or assignment of selective powers to quality levels according to their importance in determining habitat suitability levels also is precluded by the foregoing characteristics and the changing influence of quality levels as quality increases. To further complicate the attempt to convert judgements into formulae, a low quality level (e.g.) may occasionally be mitigated by a high level of another attribute. There may be procedures for converting some pattern judgement systems into scoring systems, but they would be difficult to discover and would vary for different species. While scoring systems that provide a single number rating for habitat suitability from a continuous scale of values have an appeal to users preferring a greater number of habitat suitability levels, they may preclude intuitive understanding of the reason for or meaning of differences in particular habitat suitability ratings. This in turn deprives the user of a simple field critique and rapid modification of the model in terms of his or her experience. The possibility exists that habitat suitability indices derived mathematically may never agree even approximately with pattern judgements for the same reservoirs even when using the same attributes. Possible interpretations of this situation are that both are equally incorrect, or that one or the other procedure leads to results more correct than the alternative. Results differing significantly cannot both be correct when habitat attributes are the same.

In the event that a statistically derived set of habitat suitability indices differs seriously from pattern judgements based on the same data, there is no intrinsic reason for presuming that either one is more correct because of the technique used. This seems to be apparent for judgements but not for statistical techniques. This is not the appropriate place for a detailed discussion on the misuses of statistics. Let it suffice here to point out that field data based on sampling can rarely, if ever, be conclusively analysed by multiple regression techniques. Confidence limits regarding predictions of some aspect of fish welfare (e.g., standing crop) can be calculated, but when the assumptions of the regression model are not reasonably met, estimates of the reliability of the predictions are illusions. When regression procedures are not legitimate, correlation often becomes a second best alternative. Correlation, unlike regression, is not capable of predicting the location of new points on a graph given new values of one or the other variable. This is so because the correlation coefficient (r) does not define a relationship between pairs of variables which can be used to draw a line on a graph. The absence of a line defining the most likely relationship between sets of variables also precludes the construction of confidence belts and therefore precludes statements of reliability about predictions for individual reservoirs. The fact that correlations are all we can derive in most comparative studies of habitat attributes and fish welfare does not give us license to misinterpret them. Their most legitimate use is to help make judgements.

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[1]None cause the habitat suitability indexes to progress in an ever improving fashion, a condition which could lead to a single formula system.

The habitat suitability levels predicted by pattern judgement models have no predictive confidence belts associated with them, but, as pointed out earlier, neither do correlation based models despite presumptions to the contrary. In effect, pattern judgements must be based on simple correlations and conjunctions recalled by working biologists with the aid of field notes, administrative reports, and the published literature. Published literature is often disappointing because of the scarcity of data needed for pattern judgements. Local input in constructing pattern judgement systems is therefore a necessity. Experienced fishery biologists often have a remarkably extensive record of reservoir attributes and past and present fish populations for a large number of waters. The ultimate pattern judgement system should be regional and based on modifications by users who have compared system output to their experience.

Despite the lack of predictive confidence information, ratings of the lowest habitat suitability (low) should be more likely to be correct than ratings of the upper three (low medium, high medium, and high) suitabilities. When hypotheses and data are presumed to be correct, the current concensus on the logic of science is that hypotheses forbidding something under certain relatively unchanging conditions are more justified than those predicting the occurrence of something. The presence of all permanent and predictable habitat attributes necessary for the welfare of a fish species is not sufficient to assure its welfare. The unpredictable but necessary attributes associated with the vagaries of the total population of fish in a reservoir and those of climate can decrease the actual degree of success of a species. In contrast, any necessary attribute for success of a species, when absent, becomes sufficient to justify a negative prediction.

Many of the foregoing explanations are intended to refute the notion that formal mathematical or logical procedures guarantee the correctness of prediction, and that intuitive judgements are not likely to be right. Respected statisticians consistently emphasize that statistics is only a system for guiding judgements and demonstrating that judgements are not hasty or emotional. Anyone who asks which method is the more scientific has only demonstrated a lack of familiarity with current views on the scientific method. There is no consenus among those writers recognized as authorities, but the most conservative of their views is that careful judgement well supported is the basis for accepting and rejecting all hypotheses. There is no method for absolutely proving or disproving any hypothesis. There is no way for a fishery manager to escape responsibility for his or her decisions or predictions. Fairly or unfairly, all decisions involve judgements and, as such, all have the possibility of being incorrect.

COMMENTS ON BIBLIOGRAPHY

To be consistent with the nontechnical style in which this report is written, original sources are not cited in the text of Appendix C. Writings about the logic of science also are frequently not amenable to understanding by reading a single paragraph or passage out of context. The bibliography was limited to the four sources which were the most helpful. The four books listed represent current mainstream views. Their listing in no way suggests that they are easy reading or are recommended for all resource biologists. They all emphasize the dominant role of professional judgement in present day science.

ANNOTATED BIBLIOGRAPHY OF SOURCES FOR IDEAS ABOUT JUDGEMENTS IN SCIENCE AND LOGIC

Barrett, W. 1979. The illusion of technique. Anchor Press/Doubleday. Garden City, NY. 392 pp.

Part 1 of this book is a popularized, well-written account of Ludwig Wittgenstein's attack on the use of logic and mathematics to "conclusively prove" reality. It emphasizes the unavoidability of subjectivity in all thinking even when we believe we are being objective. Wittgenstein is considered to have been one of the greatest influences on scientific logic in the 20th Century. Note that part II is not relevant to the subject of this report.

Brown, H. I. 1977. Perception, theory and commitment. The University of Chicago Press, Chicago. 203 pp.

Brown's book could also be called "Rise and Fall of Scientific Logic." It describes the birth and decline of logical positivism which was and often still is the basis for most introductory chapters of text books about ecology, fisheries, limnology, zoology, etc. written since 1940. It is well written and clear for the reader who perseveres. For those who find it too dry and detailed the last chapter is worth reading by itself.

Hull, D. L. 1974. Philosophy of biological science. Prentice-Hall, Inc. Englewood Cliffs, NJ. 148 pp.

As with the other books, it is not specifically about resource management but it does discuss ecology as part of a more intensive treatment of evolution and the logic that pertains to it. One plus is that all of the examples are not from physics, unlike most books on scientific method.

Lakatos, I. 1978. The Methodology of scientific research programmes: Philosophical Papers, Vol. I. Edited by J. Worrall and G. P. Currie. Cambridge University Press. 250 pp.

This is a rather uneven book; some parts will be fairly clear to an ecologist while others are confusing. It describes a practical way to proceed in science even though things are not developing as neatly as they do in physics and chemistry textbooks. Readers who find passages long and difficult will be encouraged to see that Lakatos includes succinct, italicized summary statements that make it worth reading. Lakatos, who died in 1974, is a well-respected philosopher of science whose ideas still represent the current middleground. His most important ideas emphasize not rejecting an hypothesis because of one apparent falsification but also not claiming proof because of one validation.

APPENDIX D. RESULTS OF A TEST OF THE ORIGINAL LOW EFFORT MODEL

This appendix examines the overall ease of use of the original low effort model (McConnell et al. 1982), identifies limits to its application, and recommends improvements which might enhance its usefulness. Discussions are based on a test accomplished by applying the model to a dam and reservoir site under construction on the White River in western Colorado.

STUDY AREA

Construction of the Taylor Draw Dam, located on the White River near Rangely, Colorado, at an elevation of about 1,615 m, began in 1982 and is scheduled for completion in 1984. This site was selected for model testing because it was typical of many dam sites being proposed on large rivers in the intermountain West in response to regionwide energy development activities.

At this location the White River has a TDS of about 2,000 mg/L with bicarbonate/carbonate complex being about 200 mg/L. The surface area of the proposed reservoir is 2.5 km^2, which is slightly smaller than the minimum of 3 km^2 recommended by McConnell et al. (1982) for use in the model. This slight deviation from the model requirements was not considered significant in terms of model testing. Although quite turbid at times, the river meets the model assumption of not being grossly polluted and has a diverse fish population, including the endangered Colorado River squawfish. Taylor Draw Dam will maintain the reservoir at a nearly constant level with fluctuations not expected to exceed 1 m per year.

ORIGINAL MODEL

In the original model, reservoir habitat suitability is determined on the basis of a composite "score" of the same five primary reservoir attributes described in the main text of this report. The value of each primary attribute is determined from one or more "secondary" attributes, which can be directly obtained from published documents, maps, reservoir plans, and on-site inspections of the proposed reservoir basin prior to construction. The five-digit reservoir description derived in this manner represents a unique combination of the primary attributes. It is specific for the species/temperature classification group of concern. The three species/temperature classification groups (warmwater, coolwater, and coldwater) are the same here as in the original model. The unique 5-digit description is compared to each of 243 lake descriptions which have been designated as having one of four levels of suitability for each species. The suitability of the lake for a particular species is then read directly from suitability rating lists.

COLLECTION AND DOCUMENTATION OF SECONDARY ATTRIBUTES

Growing Season

Identifying a value for this attribute requires knowledge of the number of days between the last frost in the spring and the first frost in the fall at the reservoir site. This type of information is available for most weather stations. The suggested references listed in McConnell et al. (1982) were adequate but two others were found to be easier to locate and use. These include:

U.S. Department of Commerce, Environmental Services Administration, Environmental Data Service. Climatography of the United States. No. 60-5.

Siemer, Eugene C. 1977. Colorado climate. Colorado Experiment Station. (It is likely that similar documents exist for States other than Colorado.)

Both of these documents contained extensive records for the stations used in this model test.

In comparing temperature data between two weather stations in the vicinity of the reservoir site it was apparent that in areas of elevational diversity, climates can change considerably in a relatively short distance in response to local topography. At the two nearest weather stations [Rangely (8 km) and Little Hills (48 km)] growing seasons were 60 days and 111 days, respectively. Mean July air temperatures were 22.8° C and 19.2° C, respectively. Because temperature is one of the more important attributes in determining reservoir habitat suitability, it is critical that it be measured at or as near to the reservoir site as possible. Where weather stations are widely scattered it may be necessary to establish on-site temperature recording devices to obtain this information.

Mean July Air Temperature

July air temperatures were easily obtained from all sources referenced in McConnell et al. (1982) as well as the two sources cited above. The problems associated with obtaining growing season information also apply to mean July temperatures. The closer to the reservoir site the better when seeking representative temperature data.

Storage Ratio

The environmental impact statement for the Taylor Draw Project and personal communications with the chief project engineer proved to be the simplest way to determine the ratio of reservoir volume to annual discharge. Discussions with the construction engineers helped to fine tune the initial estimates made from the EIS, but the two estimates were not sufficiently different to alter the model outcome.

Depth of Outlet

Outlet depth was determined directly from construction plans provided by the construction company. This information may not be available early in the planning process, making any judgements about this attribute a "best guess" situation.

Maximum Fetch

Maximum fetch is easily obtained from a map of the reservoir site. The fetch distance should be measured parallel to the direction of predominant winds at the reservoir site.

Mean Depth

Reservoir surface area and volume used to calculate mean depth (Vol./Area = D) were obtained from reservoir descriptions found in a memorandum of agreement between the Water Uses Association, Colorado Division of Wildlife, and the U.S. Fish and Wildlife Service.

Mineral Turbidity

The White River at Taylor draw is noted for its high turbidity levels, which would tend to suggest that the reservoir also would be somewhat turbid. However, the storage half-life of the reservoir is estimated at 30 years, indicating that a substantial amount of silt will be deposited in the reservoir annually. There were no other reservoirs in the vicinity that could be used as a comparison for predicting turbidity levels in Taylor Draw Reservoir. Because of these factors and as a result of discussions with several engineers involved on the project, an intermediate turbidity level of 0.5 to 1 m secchi disk depth was chosen to represent probable conditions in the proposed reservoir. The amount of fetch and the relatively shallow depth also influenced the decision to select the mid-level turbidity figure.

Mineral turbidity proved to be one of the more difficult attributes to estimate. It is a single variable primary attribute, thus it is important that it be estimated as accurately as possible. Even with the best available information, estimation may become a "best guess" proposition.

It is suspected that the value for the middle range (corresponding to a score of 2) of estimated Secchi disk readings could be made wider and still not alter the use of the mid-range score in the model.

Areal Extent of Bottom Covered by Structural Units

About 15% of the bottom of the Taylor Draw Reservoir site has been or will be burned or scraped to mineral soil. Very little of the remaining reservoir bottom contains anything that resembles a structural unit as defined in the model. A site visit and discussions with project engineers provided the information needed to estimate this attribute.

Percent Structural Units on Deepest Half of Bottom

A reservoir map and a site visit are all that are needed to derive this attribute.

Mean Height of Structural Units as a Percent of Mean Depth

Structural units in existence at Taylor Draw Reservoir do not exceed 1 m in height and average somewhat less than this. A site visit is essential and direct measurement may be necessary to accurately depict this attribute because the height of a structural unit is difficult to determine when viewed from a distance.

Mean Density of Structural Units

Structural units covered about 10 ha of the reservoir bottom. In these areas densities exceeded 100/ha; however, when expanded to the entire lake basin, structural unit density probably did not exceed 5/ha.

Linear Extent of Structure in Deepest Half of Reservoir

A wheeled map measurer was used to determine the length of the middepth contour line directly from a reservoir map. Middepth elevation was determined by dividing the reservoir depth by two and subtracting this figure from the surface elevation. The reservoir map used had narrow contour intervals (10 ft) which faciliated identification of the middepth contour.

This is probably the most confusing of the original model attributes to measure. The user is instructed to measure and sum the lengths of all contours adjacent to or below the middepth contour which have slopes > 45°. The fact that this depends entirely on the contour frequency of the map used was not mentioned. We used a map with 10 ft (3 m) contours. U.S. Geological Survey (USGS) 15-minute quadrangle maps have 40 ft (12.1 m) contour intervals. USGS maps are the most readily available of all maps, thus it would seem appropriate to base all map measurements on this series. However, had a USGS map been used at the Taylor Draw site, the several attributes derived from maps would have been very difficult to estimate accurately due to the shallowness of the reservoir (1,609 m in front of outlet structure and only 1,621 m at upper end of reservoir). Only one or two contour intervals would have occurred in the reservoir basin. It is recommended that a frequent interval contour map (if available) be examined during a site visit to allow the user to make a value judgment regarding this attribute. The question is, "Is there a lot of structure or not very much?" It is a case of considering extremes and these should be evident if they exist at the reservoir site.

Linear Extent of Structure at Full Basin

The problems associated with measuring this attribute are the same as noted with the preceding attribute. There is some probability of making large errors in this attribute if its measurement is treated casually. When estimating this attribute during a site visit, one of the authors (Bergersen) estimated its value at about 40%. When recalculated with a 10 ft (3 m) contour map, the structure made up less than 1% of the full basin contour length. The actual value was probably between these two extremes but closer to the lower estimate. Examination of a detailed contour map during a site visit should aid in estimating the variable. Practice observing slopes known to exceed 45° would enhance one's ability to identify slopes of these dimensions in the field.

Mean Height of Cliffs or Shoals as a Percent of Mean Depth

Mean depth of the reservoir was estimated at about 6.8 m. In the few places where they existed, the height of cliffs and shoals were equal to or exceeded the mean depth. Again, using a detailed contour map during a site visit should make identification of cliffs and shoals quite straightforward.

Extent of Maximum Drawdown

Taylor Draw Reservoir will be maintained at full basin level except during low flow periods when levels may drop as much as 1 m. Sometime during the first 10 years of operation, the lake may be drained to expose and clean trash racks on the outlet structure. Values for this and the following attribute were obtained during discussions with project engineers.

Time of Maximum Drawdown

Normally, 0.3 to 1.0 m drawdowns can be expected during midwinter (November to February).

Shoreline Development Factor (D_L)

This attribute is calculated as follows:

$$D_L = \frac{L}{2\sqrt{\pi A}}$$

where L = shoreline length

A = surface area

Using Appendix B in McConnell et al. (1982), the D_L for Taylor Draw Reservoir was estimated to be less than 5.0. Calculating D_L using the above formula resulted in a value of 3.7. Use of the lake outlines and known D_L's in Appendix B was sufficient for the purposes of the test, although the calculation is simple enough once shoreline length and area are known.

MODEL RESULTS AT TAYLOR DRAW RESERVOIR

The tested model (McConnell et al. 1982) classifies habitat suitability into the same four levels described in this publication: low; low medium; high medium; and high; based on unique species/reservoir descriptions. The species/reservoir descriptions derived for the Taylor Draw Reservoir site are shown in Table D-1. Environmental data are summarized in Table D-2.

The results suggest that the habitat conditions which will exist in Taylor Draw Reservoir will be most favorable for the common carp and less for the other species considered, although black crappie and white suckers (probably suckers in general) are also likely to do reasonably well. These results are virtually in complete agreement with the opinions expressed in the Draft EIS regarding the fish populations likely to occur in Taylor Draw Reservoir.

Table D-1. Species/reservoir descriptions.

	Primary attribute				
Species	Temperature	Turbidity	Cover	Drawdown	Cove frequency
Black crappie	2	2	1	3	2
Carp	2	2	1	3	2
White sucker	3	2	1	3	2
Yellow perch	3	2	1	3	2
Rainbow trout	2	2	1	3	2

As an example, the habitat description for Taylor Draw Reservoir for the carp is 22132.

HSI values for these species/reservoir descriptions are as follows:

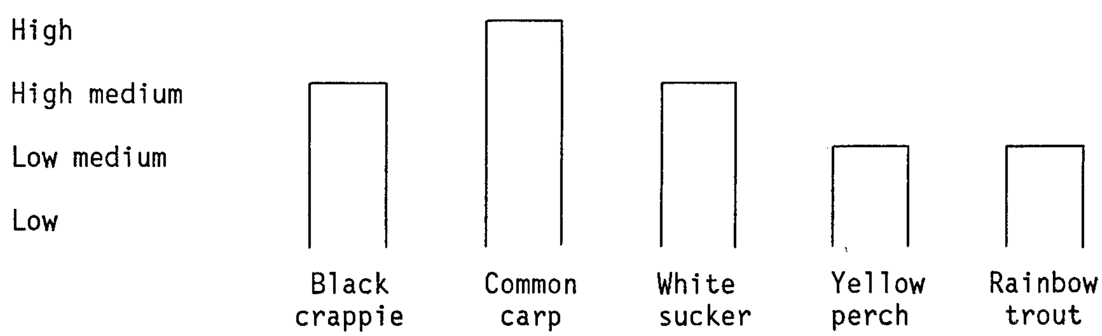

Table D-2. Secondary attribute values used in the Taylor Draw Reservoir Test.

Growing season	111 days (8-yr period of record - Rangely)
Mean July air temperature	22.8° (21-yr period of record)
Storage ratio (acre feet)	$\frac{13,800}{490,000} = 0.0282$
Depth of outlet in relation to mean depth	Below middle 1/3 of z $\bar{z} \simeq 6.8$ m, $z_{max} \simeq 15.2$ m
Maximum fetch	5.028 km
Mean depth	$\simeq$ 6.8 m
Mineral turbidity (Secchi disk)	0.5 to 1 m
Areal extent of structure	< 10%
Percent structure units on deepest half of bottom	< 10%
Mean height of structural units	< 1 m
Mean density of structural units	5 units/ha
Linear extent of structure in deepest half of reservoir	< 10%
Linear extent of structure at full basin	< 1%
Mean height of cliffs or shoals as percent of mean depth	Approached 100%
Extent of maximum drawdown	< 2 m/yr
Time of maximum drawdown	November to February
Shoreline development factor	< 5.0 calculated at 3.745

DISCUSSION

Although a few minor "gray areas" have been identified in the model mechanics, all can be overcome by employing the user's best judgment and common sense without lessening the model's usefulness.

Timing may be a critical factor in the use of the model. Information to estimate several attributes may not be readily available until site selection is well advanced. While "best guess" estimates can be used at any time prior to site selection, it is advisable to use this model during planning activities occurring not more than 5 years prior to the beginning of construction. Alternative construction scenarios developed during this period will allow the user to make model predictions most consistent with probable future habitat conditions.

It is appropriate and desirable to seek out opinions of knowledgeable local experts when working with this model. In the test reported here, the project designer and chief engineer proved to be some of the best sources of information for rapidly identifying model input attributes. Others familiar with various aspects of the river, fish populations, hydrology, and engineering were also helpful in verifying or refuting the original variable estimates.

Once the user fully understands the model it can be refined to better reflect unique local environmental situations that might exist. A revision of the three mineral turbidity attribute ranges is an example of this type of refinement.

To reduce problems with user recall, it is quite helpful to photograph physical features of the reservoir site. Attributes related to structure abundance and density are particularly well suited to photographic documentation.

SUMMARY

The model tested here is indeed a low-effort system for determining the fish habitat suitability of a proposed reservoir site. It is a very rapid and easy to use model (travel to and from the test site took longer than the on-site visit or determination of the species/reservoir descriptions); the resulting fish habitat suitability predictions appear to be reasonable.

In its present form, the model has somewhat limited use due to the small number of fish species it considers. Expansion of the species lists to include a greater diversity of native and non-native species might be helpful.

REFERENCES

McConnell, W. J., E. P. Bergersen, and K. L. Williamson. 1982. Habitat suitability index models: A low effort system for planned coolwater and coldwater reservoirs. U.S. Fish Wildl. Serv. FWS/OBS-82/10.3. 47 pp.

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16. Abstract (Limit: 200 words)

A technique is described for measuring reservoir habitat suitability based on a composite score for five primary reservoir attributes (temperature, turbidity, nonliving cover, drawdown, and shallow cove frequency). The value of each primary attribute is determined from secondary attributes, which are easily obtained from published data and on-site inspection of the proposed reservoir basin. Subsequently, the use of primary attribute scores to determine reservoir habitat suitablity for five selected fish species is described. This approach has the advantages of procedural simplicity and ready availa-ability of input data. The intended use is during the early planning stages of reservoir construction projects, when the outcomes of alternative plans are being evaluated.

This is one in a series of publications describing the applications of Habitat Suitability Indices (HSI's), a corollary to the U.S. Fish and Wildlife Service's Habitat Evaluation Procedures.

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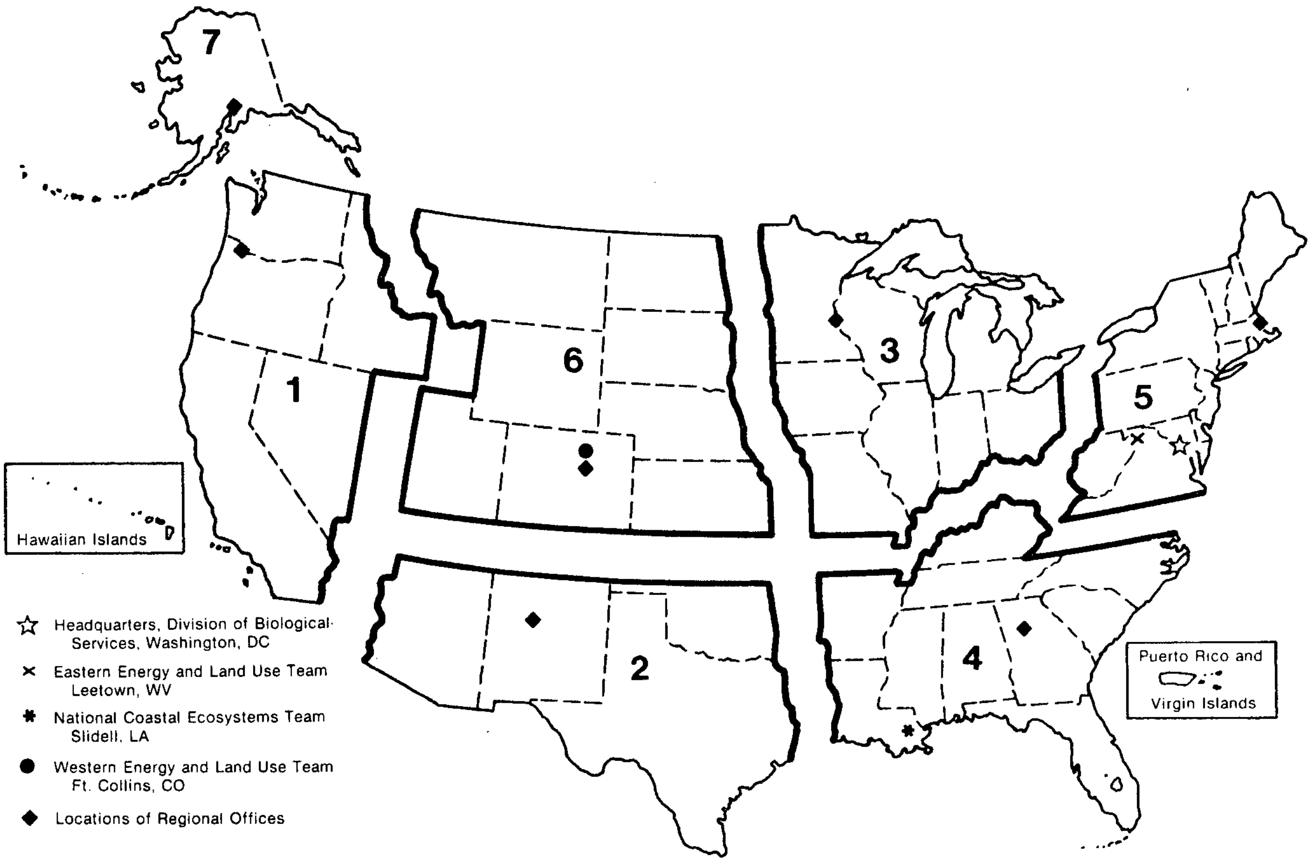

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