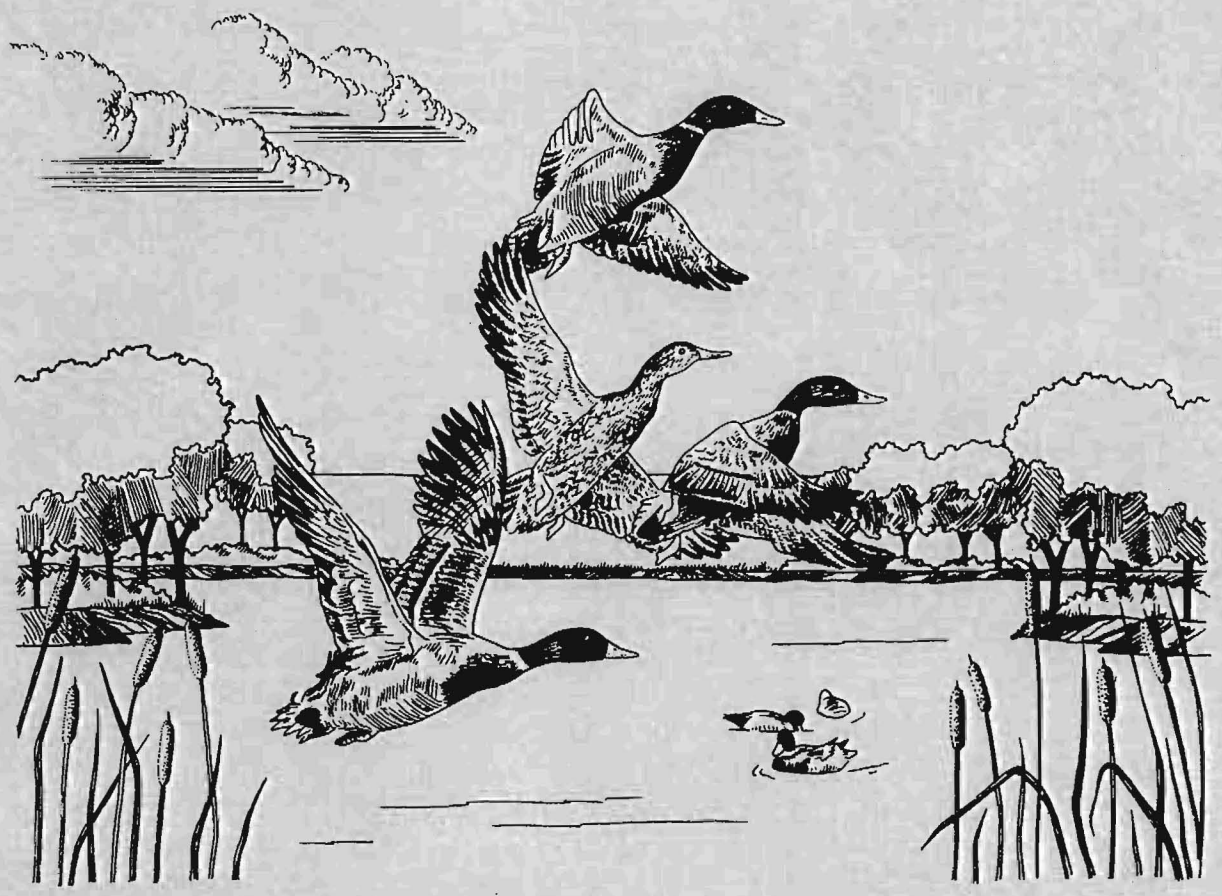
NEC – 87/17
JULY 1987

MODELING POTENTIAL IMPACTS OF THE GARRISON DIVERSION UNIT PROJECT ON SAND LAKE AND ARROWWOOD NATIONAL WILDLIFE REFUGES: A FEASIBILITY ANALYSIS



Fish and Wildlife Service

U.S. Department of the Interior

NEC-87/17
July 1987

MODELING POTENTIAL IMPACTS OF THE GARRISON DIVERSION UNIT PROJECT ON SAND LAKE AND ARROWWOOD NATIONAL WILDLIFE REFUGES: A FEASIBILITY ANALYSIS

by

David B. Hamilton
Gregor T. Auble
Adrian H. Farmer
James E. Roelle
National Ecology Center
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, CO 80526-2899

Results of a Workshop Sponsored by
U.S. Bureau of Reclamation
U.S. Fish and Wildlife Service
and
North Dakota Game and Fish Department

National Ecology Center
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This report should be cited as:

Hamilton, D.B., G.T. Auble, A.H. Farmer, and J.E. Roelle. 1987. Modeling potential impacts of the Garrison Diversion Unit project on Sand Lake and Arrowwood National Wildlife Refuges: a feasibility analysis. U.S. Fish Wildl. Serv., National Ecology Center, Fort Collins, CO. NEC-87/17. 79 pp.

EXECUTIVE SUMMARY

The Garrison Diversion Unit (GDU) of the Pick-Sloan Missouri Basin program was authorized in 1965, with the purpose of diverting Missouri River water to the James River for irrigation, municipal and industrial water supply, fish and wildlife habitat, recreation, and flood control. The project was reauthorized in 1986, with the specification that comprehensive studies be conducted to address a variety of issues. One of these ongoing studies addresses potential impacts of GDU construction and operation on lands of the National Wildlife Refuge (NWR) system, including Arrowwood and Sand Lake Refuges (the Refuges) on the James River. A number of concerns at these Refuges have been identified; the primary concerns addressed in this report include increased winter return flows, which would limit control of rough fish; increased turbidity during project construction, which would decrease production of sago pondweed; and increased water level fluctuations in the late spring and early summer, which would destroy the nests of some over-water nesting birds.

The facilitated workshop described in this report was conducted February 18-20, 1987, under the joint sponsorship of the U.S. Bureau of Reclamation, the U.S. Fish and Wildlife Service, and the North Dakota Game and Fish Department. The primary objectives of the workshop were to evaluate the feasibility of using simulation modeling techniques to estimate GDU impacts on Arrowwood and Sand Lake Refuges and to suggest enhancements to the James River Refuge monitoring program. The workshop was structured around the formulation of four submodels: a Hydrology and Water Quality submodel to simulate changes in Refuge pool elevations, turnover rates, and water quality parameters (e.g., total dissolved solids, turbidity, dissolved oxygen, nutrients, water temperature, pesticides) due to GDU construction and operation; a Vegetation submodel to simulate concomitant changes in wetland communities (e.g., sago pondweed, wet meadows, deep and shallow marsh); a Fish submodel to estimate changes in abundance or biomass of rough fish (carp, buffalo) and sportfish (northern pike); and a Wildlife submodel to calculate indices of waterfowl abundance or habitat suitability (e.g., for mallards, western grebes, migrating diving ducks, white-faced ibis, egrets, over-water nesters). Submodels considered weekly to monthly changes in pools within a Refuge over a time horizon of 30-50 years.

Based on workshop discussions and past experience with impact analysis modeling, a phased modeling approach was recommended for the James River Refuges analysis. The first phase would involve two modeling efforts. The

existing Sand Lake hydrology model, and a similar one developed for Arrowwood NWR, would be validated and used to predict changes in pool elevations and winter inflows to each pool for a variety of GDU alternatives. Outputs from simulations would then be evaluated in terms of potential fish and wildlife impacts. For example, the models could generate indices comparing the magnitude and timing of winter inflows for pre- and postproject conditions; fisheries biologists could then use these indices to better quantify their concerns relative to potential changes in the frequency of rough-fish control. The other modeling effort in the first phase would involve developing a sago pondweed growth model to integrate Refuge monitoring data and existing literature and perhaps to address some questions concerning turbidity impacts. A second phase of simulation modeling would be undertaken only if the initial analyses of hydrologic outputs indicated significant potential problems and if monitoring and research projects had clarified some of the biological and physical processes that cannot be modeled reliably at the present time (e.g., resuspension of sediments by carp, immigration and winter mortality of fish, loss of waterfowl nests due to wave action). The second phase would attempt to develop an integrated impact assessment model.

In order to address some of the biological and physical processes that presently are not well understood, a number of studies and enhancements to the Refuge monitoring program were suggested. The Hydrology and Water Quality workgroup recommended increasing turbidity and dissolved oxygen sampling, dropping expensive analysis of some trace elements, adding more pesticide analysis (including some biological monitoring), and developing better area-capacity data for the Sand Lake hydrology model. The Vegetation workgroup suggested expanding the number of monitoring stations, monitoring photosynthetically active radiation by depth, and modifying the biomass sampling procedure and schedule. Also suggested were additional analyses of existing Refuge monitoring data and additional field studies concerning sago growth under a variety of environmental conditions and effects of rough fish density on sago. A careful examination of Refuge narrative reports was recommended by the Fish workgroup to characterize conditions that lead to various rates of winter-kill. Monitoring enhancements related to a better understanding of fish population dynamics included increasing dissolved oxygen monitoring, continuing present monitoring of fish movement upstream from Jamestown Reservoir into Arrowwood NWR, initiating similar efforts for upstream movement into Sand Lake NWR and downstream movements into both Refuges, and augmenting the present gillnetting program (or replacing it) with sampling for population and age/size structure estimates. The Wildlife workgroup suggested estimating the relative density of mallard nests in over-water and wet meadow nesting areas, estimating the number of western grebe nests lost due to wave action, delineating wet meadows on the Refuge vegetation maps, estimating annual tuber consumption by birds, and monitoring insect/macroinvertebrate abundance. The workgroup also suggested research studies to better understand the relationships between food supplies and the growth and survival of ducklings and young grebes.

The workshop discussions also helped identify some suggestions for modifying project features that, if feasible from an engineering and operational standpoint, would reduce impacts on Refuge lands. These suggestions included: designing drains with control structures or small "reregulation" reservoirs to hold winter return flows that might adversely affect rough fish control, spreading construction activities over a number of years to reduce potential impacts of turbidity on sago pondweed in any single year, scheduling construction to occur after the spring sprouting and elongation growth stages to reduce impacts on sago pondweed, and installing "quick acting" control structures at Arrowwood NWR to reduce pool level fluctuations that might destroy nests of some over-water nesting waterfowl.

CONTENTS

	Page
EXECUTIVE SUMMARY	iii
FIGURES	vii
TABLES	viii
INTRODUCTION	1
Background	1
Objective	5
Approach	5
SCOPING	10
Bounding	10
Model Structure and Submodel Interactions	13
HYDROLOGY AND WATER QUALITY	16
Model Conceptualization	16
Implications for Monitoring and Research	24
VEGETATION	26
Model Conceptualization	26
Alternative Approaches	37
Implications for Monitoring and Research	38
FISH	42
Model Conceptualization	42
Alternative Approaches	51
Implications for Monitoring and Research	54
WILDLIFE	57
Model Conceptualization	57
Implications for Monitoring and Research	69
CONCLUSIONS	71
Simulation Modeling	71
Monitoring and Research	73
Project Features	75
REFERENCES	76

FIGURES

Number		Page
1	Arrowwood National Wildlife Refuge	2
2	Sand Lake National Wildlife Refuge	2
3	Garrison Diversion Unit	3
4	Looking Outward Matrix for the James River Refuges analysis	15
5	Hydrology model for Sand Lake National Wildlife Refuge	18
6	A simple model of light intensity by depth	31
7	A conceptual model of sago growth	33
8	A possible, incremental approach to assessing potential changes in cover types and their inundation resulting from altered hydrologic regimes	39
9	Hypothetical relationship between the proportion of available biomass of carp gaining access to Arrowwood Refuge and the difference in water levels above and below the control structure at DePuy Marsh	48
10	Conceptual model illustrating factors that influence winter mortality of fish	53
11	Hypothetical relationships between change in stage elevation and nest loss for mallards	61
12	Hypothetical relationship between water level change and loss of western grebe nests	66
13	Hypothetical relationship between water level change and loss of redhead nests	68

TABLES

Number		Page
1	Management actions and consequences of GDU operation discussed at the James River workshop	11
2	Performance indicators discussed at the James River workshop	12
3	Growth stages of sago pondweed assuming presence of viable tubers	28
4	Observations concerning sago pondweed	29
5	Indicator species, performance measures, and driving variables discussed by the Wildlife workgroup	58
6	Hypothetical parameter values for percent of renesting females and mean clutch size by month of nest loss	62
7	Hypothetical parameters for renesting attempts by western grebes	66
8	Hypothetical parameters for renesting attempts by redhead	68

INTRODUCTION

BACKGROUND

The James River originates in Wells County, North Dakota, and extends for 260 river miles in North Dakota and 450 river miles in South Dakota. The river is generally slow-moving and shallow in a broad and gently sloping floodplain. The headwaters portion of the James River extends approximately 125 miles to Arrowwood NWR. This reach is characterized by a series of intermittent pools for much of the year, and flow is normally low or non-existent. Arrowwood NWR (Figure 1) consists of four shallow impoundments making up a broad marshy area of 5,379 acres, with average depths of 3-5 feet. Jamestown Reservoir is immediately downstream from Arrowwood. Below Jamestown Reservoir, the slope flattens and the river meanders within the confines of a broad valley. Near the North Dakota-South Dakota border, the river enters the broad plain of glacial Lake Dakota. Dakota Lake NWR in North Dakota and Sand Lake NWR (Figure 2) in South Dakota lie in the low glacial lake bed. Control structures in both refuges maintain pools in the river valley. The last 295 miles of the James River extend to the confluence with the Missouri River near Yankton, South Dakota.

The Garrison Diversion Unit (GDU) of the Pick-Sloan Missouri Basin program was authorized in August 1965. The purpose of the program was to divert Missouri River water (from Lake Sakakawea), through a series of canals, to the James, Souris, and Sheyenne Rivers (Figure 3) to provide for: (1) the irrigation of 250,000 acres, (2) municipal and industrial water, (3) fish and wildlife, (4) recreation, and (5) flood control. A Final Supplemental Environmental Statement (U.S. Department of the Interior 1983) was filed with the Environmental Protection Agency in July 1983. Subsequently, the Secretary

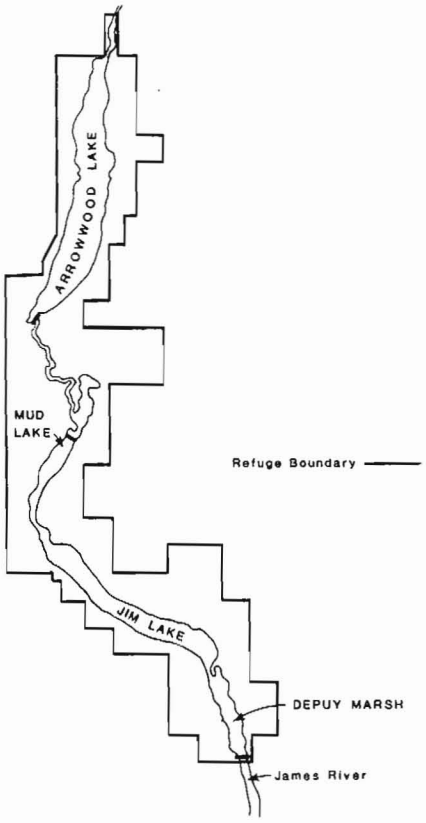


Figure 1. Arrowwood National Wildlife Refuge.

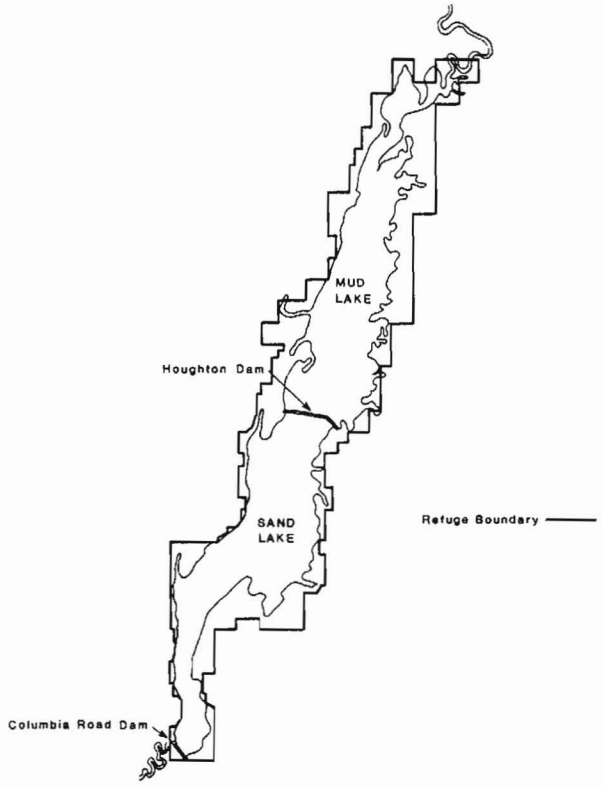


Figure 2. Sand Lake National Wildlife Refuge.

of the Interior appointed a Garrison Diversion Unit Commission to review the controversy surrounding the project, evaluate water needs of North Dakota, and make recommendations on development of the project. Their report (Garrison Diversion Unit Commission 1984) recommended major changes to the GDU project. The project was reauthorized in May 1986 (Garrison Diversion Unit Reformulation Act of 1986). The associated "Draft Scope of Study" specified eight studies to address various issues raised in the reformulation act; these studies are being developed and directed by an interagency study team including participants from the U.S. Bureau of Reclamation (USBR), the Fish and Wildlife Service (FWS), the North Dakota Game and Fish Department (NDGF), the U.S. Geological Survey (USGS), the State Water Commission, the Garrison Diversion Conservation District, and the South Dakota Department of Water and Natural Resources. One of these studies addresses potential impacts on National Wildlife Refuge (NWR) system lands, with specific objectives to:

1. identify potential riverine and NWR system impacts;
2. provide the requirements and methodology to be used for verification of these impacts;
3. provide a comparative impact analysis of baseline and alternative operating scenarios;
4. tabulate impacts by specific land categories; and
5. provide an impact analysis on the riverine system that lies outside dedicated wildlife area boundaries, but within the James River floodplain.

Specific concerns at Arrowwood and Sand Lake Refuges (the Refuges) on the James River that are addressed in this report include increased winter return flows, which would limit rough fish control; increased turbidity during project construction, which would decrease sago pondweed production; and increased water level fluctuations in the late spring and early summer, which would destroy the nests of some over-water nesting birds. This study will be based partly on a number of engineering studies (e.g., aquifer recharge, stabilization, hydrology) and data from the Refuge monitoring program conducted over the last 3 years. At the conclusion of the study, the FWS will submit a compatibility analysis according to 50 CFR, Parts 29 and 80 (U.S. Government

Printing Office 1985) that will identify mitigation required to offset impacts to the Refuge system. Unquantified impacts will be identified by a continuing biological/hydrological monitoring program.

OBJECTIVE

The interagency committee sponsored a workshop on February 18-20, 1987, to: (1) evaluate the feasibility of using simulation modeling techniques to estimate impacts on Arrowwood and Sand Lake National Wildlife Refuges, and (2) suggest enhancements to the James River Refuge monitoring program. This report documents the results of that workshop.

APPROACH

The facilitated modeling approach that was initiated at the workshop was developed by environmental scientists and systems analysts at the University of British Columbia and the International Institute for Applied Systems Analysis in Austria (Holling 1978). The approach is organized around a series of 3- to 5-day workshops that define information needs and promote a common understanding of the issues. These workshops are followed by periods of information collection, analysis, and synthesis. The workshops are attended by participants from key agencies and interests, who collectively represent a range of scientific expertise, management responsibility, and decisionmaking authority. These individuals are both involved in the workshops and also undertake some of the key tasks of information collection, analysis, and guidance that occur between workshops.

The focus of these workshops is the construction and refinement of a quantitative, dynamic simulation model of the system under study. Early in a particular application, the <u>process</u> of building the model is usually of greater benefit than the model itself. Some of the benefits of the model building approach include the following:

1. The development of a simulation model enables participants to view their expertise in the context of the whole system, thereby promoting interdisciplinary and interagency communication, understanding, and collaboration.

2. The model building process focuses attention on the interrelationships and indirect connections between components of the resource system. These connections often represent the points at which various agencies and interests must interface in their attempts to deal with the complexities of the resource issue.

3. Model building forces identification of the assumptions being made, both stated and unstated, in day-to-day management and decisionmaking activities. A clear statement of assumptions and their implications to other workshop participants provides better understanding, and perhaps better support, of management decisions and represents a set of clearly stated questions or hypotheses for analysis.

4. The simulation model provides a logical framework for synthesizing a variety of existing information.

5. Finally, the attempt to quantify environmental, economic, and social processes associated with the resource issue quickly and objectively identifies gaps in data or conceptual understanding of the system, which can be translated into research priorities.

With sufficient refinement, models can provide a reasonable representation of future consequences of various management or decision alternatives. The involvement of managers and decisionmakers in the model building process helps ensure that potential users understand the strengths and weaknesses of the resulting tool.

Participants at the workshop included the following individuals.

Charles R. Berry, Jr.
South Dakota Cooperative
Fishery Research Unit
South Dakota State University
P.O. Box 2206
Brookings, SD 57007
(605) 688-6121

Bill Bicknell
U.S. Fish and Wildlife Service
1500 Capitol Avenue
Bismarck, ND 58501
(701) 255-4011, ext. 492
FTS 783-4492

Clarence Covert
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58502
(701) 255-4011, ext 723
FTS 783-4723

Lawrence R. DeWeese
Patuxent Wildlife Research
Center
U.S. Fish and Wildlife Service
Laurel, MD 20708
(301) 498-0276

Gene Van Eeckhout
North Dakota Game and Fish Dept.
1014 - 16½ St. NE
Jamestown, ND 58401
(701) 252-4634

Tim Fay
State Water Commission
900 East Boulevard
Bismarck, ND 58501
(701) 224-2753

John Foster
Arrowwood NWR, RR1
Pingree, ND 58476
(701) 285-3341

Bob George
U.S. Bureau of Reclamation
Engineering and Research Center
P.O. Box 25007, DFC
Denver, CO 80225
(303) 236-3777
FTS 776-3777

Greg Gere
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58501
(701) 255-4011 ext 554
FTS 783-4554

Steve Grabowski
U.S. Bureau of Reclamation,
Code D-1522
P.O. Box 25007
Denver, CO 80225
(303) 236-6006
FTS 776-6006

Robert Green
U.S. Fish and Wildlife Service
P.O. Box 25486, DFC
Denver, CO 80225
(303) 236-5322

Randy Hill
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58501
(701) 255-4011, ext 721
FTS 783-4721

Greg Hiemenz
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58501
(701) 255-4011, ext 724
FTS 783-4724

Steve Hoetzer
American Construction and
Engineering Co.
1100 Industrial Dr.
Bismarck, ND 58501
(701) 258-5926

Bob Houghton
U.S. Geological Survey
821 E. Interstate
Bismarck, ND 58501
(701) 255-4011, ext 607
FTS 783-4607

Hal Kantrud
Northern Prairie Wildlife
Research Center
P.O. Box 2096
Jamestown, ND 58401
(701) 252-5363

Ron Koth
South Dakota Game, Fish and Parks
Anderson Building
Pierre, SD 57501
(605) 773-5511

Karen Kreil
U.S. Fish and Wildlife Service
1500 Capitol Avenue
Bismarck, ND 58501
(701) 255-4011, ext 492
FTS 783-4492

John R. Little
U.S. Geological Survey
Federal Building
Huron, SD 57350
(605) 353-7176

Jeffrey M. Lucero
U.S. Bureau of Reclamation
MB-730
P.O. Box 36900
Billings, MT 59107
(406) 657-6590
FTS 585-6590

Dick McCabe
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58502
(701) 255-4011, ext 721
FTS 783-4721

Mike McEnroe
114 19th Street
Devils Lake, ND 58301
(701) 662-8611

Bob Morgan
North Dakota Game and Fish Department
100 N. Bismarck Expressway
Bismarck, ND 58501
(701) 221-6330

Duane Murphey
South Dakota Dept. of Wildlife
and Natural Resources
Joe Foss Building
Pierre, SD 57501
(605) 773-4216

Fred L. Nibling, Jr.
U.S. Bureau of Reclamation
Attn: D-1522
P.O. Box 25007
Denver, CO 80225-0007
(303) 236-6017
FTS 776-6017

John Peterka
Zoology Dept.
North Dakota State University
Fargo, ND 58105
(701) 237-8449

John Peters
Environmental Protection Agency
999 - 18th St.
Denver, CO 80202
(303) 293-1585
FTS 564-1585

Scott Peterson
North Dakota Game and Fish Dept.
100 N. Bismarck Expressway
Bismarck, ND 58501
(701) 221-6345

Frank Pfeifer
U.S. Fish and Wildlife Service
RR #1
Valley City, ND 58072
(701) 845-3482

Marynell Redman
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58502
(701) 255-4011 ext 723
FTS 783-4723

Norm Roth
U.S. Bureau of Reclamation
P.O. Box 1017
Bismarck, ND 58502
(701) 255-4011, ext 556
FTS 783-4556

Fred Ryckman
North Dakota Game and Fish Dept.
100 N. Bismarck Expressway
Bismarck, ND 58501
(701) 221-6342

Al Sapa
U.S. Fish and Wildlife Service
1500 Capitol Avenue
Bismarck, ND 58501
(701) 255-4011, ext 481
FTS 783-4481

Bob Strand
U.S. Bureau of Reclamation
P.O. Box 25007, DFC
Denver, CO 80225
(303) 236-3780
FTS 776-3780

Mike Sauer
North Dakota State Dept. of Health
1200 Missouri Avenue
Bismarck, ND 58505
(701) 224-2354

George Swanson
Northern Prairie Wildlife
Research Center
P.O. Box 2096
Jamestown, ND 58401
(701) 252-5363

Douglas Searls
U.S. Fish and Wildlife Service
South Dakota Field Office
P.O. Box 986
Pierre, SD 57501
(605) 224-8693

Sam Waldstein
Sand Lake NWR
RR1, P.O. Box 25
Columbia, SD 57433
(605) 885-6320

Ronald D. Shupe
U.S. Fish and Wildlife Service
Denver Federal Center
Denver, CO 80228
(303) 236-8151

Gary Williams
U.S. Bureau of Reclamation
D-150
P.O. Box 25007, DFC
Denver, CO 80225
(303) 236-8401
FTS 776-8401

Terry Steinwand
North Dakota Game and Fish Dept.
100 N. Bismarck Expressway
Bismarck, ND 58501
(701) 221-6313

Steve Young
Sand Lake NWR
RR1, P.O. Box 25
Columbia, SD 57433
(605) 885-6320

These individuals contributed the vast majority of the ideas and information contained in this report. In documenting the results of the workshop, we have attempted to retain both the content and sense of the discussions, but accept full responsibility for errors of fact or interpretation. We would especially like to thank Dick McCabe, Al Sapa, and Terry Steinwand for hosting the workshop and allowing the use of background information, descriptions, and maps from previous study plans and reports.

SCOPING

BOUNDING

Combined operational, development, and resource management issues, such as those associated with the GDU and the James River Refuges, typically involve complex interactions among a variety of economic, social, and environmental factors. Although some individual components of such a system may be well understood, the complexity of component interactions generally results in poor understanding of the system as a whole. Simple representations of poorly understood systems often provide valuable insight into system behavior under different management or development alternatives, although they may not provide sufficient detail and credibility for actual decisionmaking. The representation used in a simulation model must, therefore, be sufficiently detailed and flexible to address all concerns adequately, yet must remain simple enough to be understandable. Problem simplification for better understanding is stressed in the early phases of the workshop process; addition of realistic complexity is stressed in later phases to provide a level of detail consistent with management and decision needs.

The process of bounding the Refuge analysis was approached at the workshop and a previous scoping meeting through group discussions of actions (those activities that management can undertake to manipulate the system toward some desired end) and indicators (those performance measures used to evaluate the response of the system). Because indicators are the links between the simulation model and participants' perceptions of the system, it is important to compile a comprehensive list that represents the concerns of all interests. The actions and indicators identified at the scoping meeting and workshop are shown in Tables 1 and 2. For the purposes of this report, they are organized into the groups that became major workgroups at the workshop.

Table 1. Management actions and consequences of GDU operation discussed at the James River workshop.

Subgroup	Action
Hydrology and Water Quality	- pool level manipulations - new and replacement water control structures - channel work in Refuge pools - winter return flow changes - water quality changes - instream flow maintenance - bypass canals
Vegetation	- chemical or mechanical vegetation control[a]
Fish	- rough fish control • winter drawdown • fish barriers • mechanical removal
Wildlife	- muskrat management[a] - construction of nesting islands[a] - predator control[a]

[a]The action was identified but not discussed in detail due to lack of time or information.

Table 2. Performance indicators discussed at the James River workshop.

Submodel	Indicator
Hydrology and Water Quality	- pool elevations - turnover rate of pools - flow below Refuge - water quality • dissolved oxygen • total dissolved solids • turbidity • nutrients (nitrogen and phosphorus) • pesticides
Vegetation	- sago pondweed - emergent vegetation
Fish	- abundance of rough fish (carp and buffalo) and sport fish (northern pike)
Wildlife	- waterfowl and colonial nesting bird use (mallard, western grebe, migrating diving ducks, white-faced ibis, egret, over-water nesters)

After identifying actions and indicators, the spatial and temporal resolution necessary to represent the components and processes implied by this set of actions and indicators were discussed. Spatial resolution concerns the geographic extent of the model, as well as the degree to which that geographic area needs to be subdivided into smaller units in order to represent the dynamics of the processes involved. Temporal resolution refers to the basic time-step of model calculations and the number of iterations needed to cover the time horizon of interest.

On the basis of actions and indicators and associated discussions, it was decided that a simulation model should represent an individual Refuge subdivided into pools. For any run of the model, the number and characteristics of pools would be parameterized to represent Arrowwood NWR or Sand Lake NWR. Considering the projected life-time of the GDU project, a time horizon of approximately 30-50 years was chosen for the model. A daily, weekly, or monthly time-step would be required to predict effects of the project on vegetation, fish, and wildlife.

MODEL STRUCTURE AND SUBMODEL INTERACTIONS

The system defined by the actions, indicators, spatial scale, and temporal framework was divided into four submodels for purposes of discussion by participants.

1. Hydrology and Water Quality--considered approaches for predicting changes in pool levels and turnover rates, flow velocity, and water quality.

2. Vegetation--considered approaches for predicting changes in abundance of sago pondweed and acres of various vegetation types based on hydrologic and water quality changes and habitat management practices.

3. Fish--considered approaches for predicting changes in abundance of carp, buffalo, and northern pike based on changes in hydrology, water quality, and vegetation.

4. Wildlife--considered approaches for predicting changes in abundance or habitat suitability for mallards, western grebes, diving ducks (migration only), white-faced ibis, egrets, and over-water nesters (e.g., redhead ducks) based on changes in hydrology, vegetation, and fish.

Following submodel definition, the linkages or information transfers between the submodels were defined. These are depicted in a Looking Outward Matrix (Figure 4) in which submodels are arrayed as both row and column headings. For each element of this matrix, participants identified what they needed to know from other submodels in order to meet their responsibilities for quantifying indicators and for providing needed information to other submodels. In addition to identifying linkages between the model components, this exercise was useful in promoting interdisciplinary communication and understanding. Workshop participants were forced to look carefully at the kinds of information that they could reasonably expect to obtain from other disciplines (i.e., how their submodel dynamics would be influenced by other submodels) and the kinds of information other disciplines expected from them (i.e., how their submodel would be influenced by the dynamics of the other submodels). Note that the question asked in this exercise (What information is needed from other disciplines?) was qualitatively different from the more common one that asks what information each discipline can provide.

Following this exercise, the workshop participants met in smaller workgroups, one for each major component, to discuss a conceptual model representing the internal dynamics of that component. The basic charge of each workgroup was: given a set of actions (identified in the bounding exercise) that you must represent in a model and a set of inputs provided by other workgroups (Figure 4), describe the mechanisms and processes (rules for change) that occur in your component to produce the set of indicators (from the bounding exercise) you must represent and the outputs that other workgroups require from you (Figure 4). In cases where the workgroup concluded that modeling was not feasible or was not an effective expenditure of resources, they were asked to discuss alternate approaches for generating the indicators of GDU impacts and for acquiring needed information. Descriptions of the approach discussed in each workgroup are presented in the following sections of this report.

Information from this submodel...	...to this submodel			
	HYDROLOGY	VEGETATION	FISH	WILDLIFE
HYDROLOGY		Water depth Turbidity Flow velocity Nitrogen and phosphorus Water temperature Sedimentation	Dissolved oxygen (weekly in winter) Water temperature (monthly mean) Pool turnover rate (winter) Pool elevation Turbidity (April to October)	Change in pool elevation (weekly)
VEGETATION	Area of clear channel Biological oxygen demand due to vegetation at ice-up		Sago pond weed (acres) Inundated upland grasses and weeds after ice-out (acres)	Sago pond weed (acres) Wet meadow (acres) Deep and shallow marsh (acres) "Wave action" or high energy zones
FISH	Management targets for pool elevation (monthly) Biological oxygen demand due to fish at ice-up	Number of rough fish by size class		Fingerlings (abundance) Macro-invertebrates - associated with sago in the top 18" - at the water surface
WILDLIFE	Management targets for pool elevation (monthly) Biological oxygen demand due to wildlife at ice-up	Sago tuber consumption		

Figure 4. Looking Outward Matrix for the James River Refuges analysis.

HYDROLOGY AND WATER QUALITY

MODEL CONCEPTUALIZATION

Approach

The Hydrology and Water Quality workgroup was responsible for discussing modeling approaches to predict changes in Refuge pool elevations (stages) and turnover rates, flow velocities, and associated water quality changes due to GDU operations. Initial discussions of the workgroup focused on modeling efforts already underway by the FWS, USBR, and the USGS. These models are described in detail in James River Technical Committee (1986).

The James River model studies involved the development of four computer models. The first model simulates the GDU in North Dakota from the Snake Creek Pumping Plant to the New Rockford Irrigation area. The model also simulates operation of facilities on the James River, including Jamestown and Pipestem Reservoirs, to the North Dakota-South Dakota border. The Sand Lake model utilizes border flows from the first model and operates pools in Sand Lake NWR. The third model simulates the James River from Sand Lake NWR to the Missouri River using flows from the Sand Lake model. These models require monthly unregulated discharges at 13 locations along the James River (in North and South Dakota) as input. The USGS compiled, and extended where necessary, discharges for each station for the period of record 1953-1983. A mass-budget salinity model was also developed; it uses output from the three flow models to provide discharge data.

Hydrology modeling for Refuge analyses. The modeling approach considered by the workgroup for conducting the Refuge analyses was to use the Sand Lake model (and a similar model for Arrowwood NWR), with little modification, to address the hydrologic actions, indicators, and information transfers identified during the scoping exercises. The following section briefly describes the conceptual structure of these models using Sand Lake NWR as an example (Figure 5).

Sand Lake NWR contains two pools, Mud Lake and Sand Lake. Water levels in each lake are regulated by control structures (Houghton Dam and Columbia Road Dam) to provide for waterfowl habitat in the spring and fall and for rough fish control in the winter. This means passing spring runoff through the Refuge until May at which time Refuge pools are filled for the first waterfowl nesters. Stable water levels are maintained, to the extent possible, through the nesting season. Pools are drawn down 1-ft below full pool by late November; this results in significant rough fish control every 3-4 years, but maintains about 2 feet of free water under the ice for muskrats at the south end of Sand Lake. Primary water management concerns to be addressed by the Sand Lake hydrologic model include the magnitude of winter inflows to each pool (as they affect rough fish control), the fluctuation of Refuge pool elevations (either as a consequence of passing project water or to prevent destruction of waterfowl nests), and the possibility of downstream flooding from Refuge releases (>60 cfs from Sand Lake). Arrowwood NWR has similar water management concerns to be addressed by a hydrology model with the exception that refuge managers would like to draw some pools down more than 1-ft below full pool in the fall.

The Sand Lake hydrology model simulates the volume of water in a lake monthly by adding surface water inflows and precipitation to the existing volume and subtracting evaporation and outflows through the control structure. Inflows are generated by the James River model, and the Sand Lake model provides an option for passing all or part of that inflow around the Refuge in a bypass canal. Outflows are determined based on user-specified target water

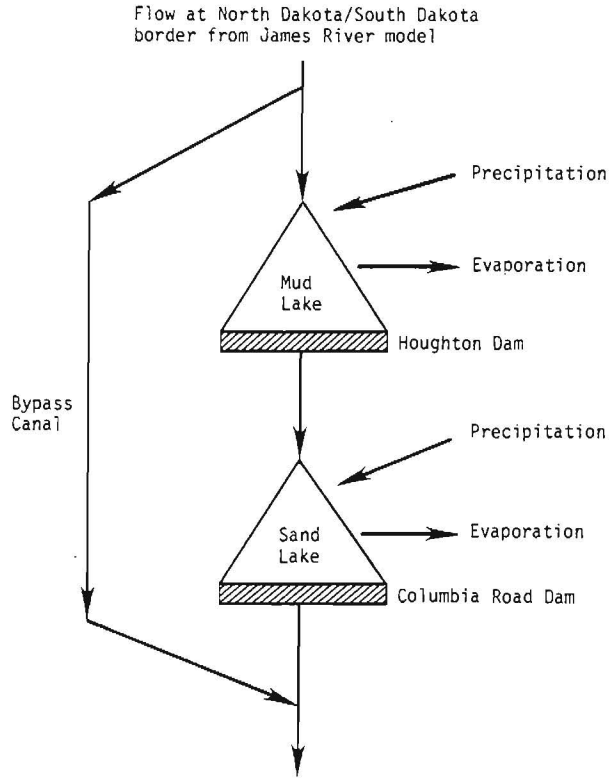


Figure 5. Hydrology model for Sand Lake National Wildlife Refuge.

levels for each pool to achieve management objectives (e.g., Sand Lake at 1287.3-1286.6 feet above mean sea level [ft msl] from April 1 to November 30 and 1286.3-1286.6 ft msl from December 1 to March 31), on user-specified instream flow requirements below the Refuge, and a spillway discharge curve for the outflow structure. The discharge curve relates discharge (cubic feet per second) to pool elevation and considers the effects of backwater during high flow conditions. Backwater is common at both Sand Lake and Arrowwood Refuges. Once the volume of water stored in a lake has been simulated for a month, the corresponding lake elevation is calculated from an area-capacity-elevation table.

Water quality modeling for Refuge analyses. The approach considered by the workgroup for modeling water quality parameters involved using the existing James River salinity model (George and Mueller 1985) for total dissolved solids (TDS) and developing new models for turbidity, dissolved oxygen (DO), nutrients (nitrogen and phosphorus), water temperature, and pesticides. A

limitation associated with any water quality modeling effort would be the very limited baseline data on James River water quality.

The James River salinity model is a mass-budget accounting procedure that computes solute load in a stream reach as the sum of inflow loads (stream flow, surface runoff, baseflow, irrigation return flow, precipitation) minus any outflow loads (withdrawal, downstream outflow). Solute loads are determined by multiplying flow by its TDS concentration using output from the three hydrologic flow models to provide discharge data. The salinity model uses the node structure of the discharge models to define reaches. The salinity model presently works with the Sand Lake model and would work with a similar model for Arrowwood NWR. The model routes a conservative substance (TDS) and thus could be used to model a number of dissolved ions; it cannot be used to model transport of dissolved substances that undergo decay with time (e.g., nutrients, pesticides, biological oxygen demand) or substances whose concentration may be controlled by chemical equilibrium or adsorption to sediments (e.g., trace metals, bicarbonate).

One of the most important water quality parameters considered at the workshop was turbidity, because of its effects on sago pondweed production. However, modeling such a nonconservative parameter (i.e., one that cannot be estimated simply from inputs and outputs of material) is difficult. There are four primary sources of turbidity at Arrowwood and Sand Lake Refuges: suspended solids in river inflow, plankton, resuspension of sediments by wind, and resuspension of sediment by carp. Even though several sources of turbidity are not expected to change with GDU operation (e.g., some workshop participants felt that postproject sediment loads may be as low or lower than at present due to stabilization projects, the fetch of Refuge pools will be unchanged), all sources would have to be modeled in order for a vegetation model to predict sago pondweed abundance. Models exist to estimate bed load transport of suspended solids, plankton blooms, and resuspension of sediments by winds (Nolen et al. 1985). However, resuspension of sediments by carp cannot be modeled reliably because of a lack of quantitative information relating increased turbidity to abundance of carp.

Another important water quality parameter considered was dissolved oxygen, especially in the winter, because of its importance in achieving periodic rough fish kills (ammonia, especially from waterfowl feces deposited just prior to ice-up, was also considered as a cause for rough fish mortality). Several approaches for modeling DO were discussed. The simplest approach would be to assume DO is at saturation just before ice-up and use a DO decay coefficient (calculated from existing monitoring data) to compute the decrease in DO during the time there is an ice cover. If models for vegetation, fish, and wildlife could provide an estimate of biological oxygen demand (ultimate BOD would be required but it could probably be extrapolated from 5-day BOD), then a slightly more sophisticated approach using a BOD decay coefficient could be used ($DO_{time\ t} = DO_{initial}$ - BOD decay coefficient x ultimate BOD). The DO contribution from winter return flows would have to be added to the estimates from either model; DO contribution from algae under the ice may be small enough to ignore. More sophisticated approaches, such as a Streeter-Phelps model (Velz 1984), could also be used to estimate dissolved oxygen; however, the increased complexity of these approaches may not be warranted and the results might be harder to defend because of all the assumptions that would be required.

Modeling nutrients (various forms of nitrogen and phosphorus) was considered because of their potential role in triggering algal blooms, which in turn can inhibit growth of sago pondweed. While nutrient dynamics models could be developed, joint discussions with the Vegetation workgroup concluded that such modeling was probably not worth the effort. This conclusion was based on three factors: (1) nutrients are abundant in most North Dakota lakes and reservoirs and may not limit algal growth (although nutrient increases might cause earlier, longer, and perhaps multiple blooms); (2) nutrient increases from GDU would be associated with fertilizer use during the irrigation season, which occurs after the critical spring period of initial sago growth (although nutrients may accumulate in the sediments of Refuge pools); and (3) a major field effort (staff time and costs) would be required to collect the data on nutrient levels and loadings for the models.

Predictions of water temperatures would be required by a vegetation submodel to simulate sprouting of sago pondweed in the spring and by a fish submodel to estimate metabolic rate, which, in conjunction with predicted DO, would be used to predict fish kills. A number of approaches for modeling water temperature are available. If precise temperatures on a daily basis (or diurnal fluctuations in temperature) were needed, then a stream temperature model such as Theurer et al. (1984) would be required. This model requires daily meteorologic and hydrologic data, and stream geometry information. If less precise estimates of water temperature are sufficient, then a relatively simple equilibrium model based only on ambient air temperature (perhaps monthly average temperatures) could be used. The problem with all of the models mentioned above is that they are not applicable when ice cover is present. Furthermore, most models with calculations for heat transfer through ice have been developed for large river systems or assume a single ice cover; there is some question whether these complex models would be applicable for the James River, which is relatively small and can have freezing conditions these models don't handle (e.g., anchor ice, freezing to the bottom). If extremely precise winter water temperatures are not needed by the Fish workgroup, then perhaps it would be sufficient to assume that the temperature is generally between 0° and 2 °C when ice cover is present (or supercooled to -1/2 °C when some open water is present amidst a general ice cover).

Although predictions of pesticide (as well as trace element and heavy metal) concentrations cannot be used directly by the Wildlife workgroup for simulating GDU impacts on waterfowl, pesticides were listed as an important indicator by workshop participants. The primary concern is that pesticides applied directly to project drains, canals, laterals, and agricultural fields, might accumulate in Refuge pool sediments and eventually reach levels that are toxic to waterfowl. This is of particular concern for materials that, under anaerobic conditions typical of winter months, would be converted to forms readily available to waterfowl in the spring. A number of models are available for studying nonpoint source pollutants in agricultural runoff (e.g., Donigian et al. 1976, 1977; Williams and Hahn 1978; Knisel 1980; Haith and Tubbs 1981) and subsequent transport in streams (Delos et al. 1984). However, these models require extensive input and calibration data and were developed for use on relatively small areas.

Feasibility

Hydrology modeling. The Sand Lake NWR hydrologic model can be used with little modification (improved area-capacity-elevation data would be necessary, conversion to a weekly time-step would be desirable), to estimate effects of GDU operation. The hydrologic actions listed in Table 1 can be implemented in this model by specifying instream flow requirements, existence and capacity of a bypass canal, monthly pool level targets (for each pool), and spillway discharge curves for new or modified control structures. Changes in winter return flows would be reflected in inputs from the James River model. Channel work in Refuge pools can effectively be ignored by assuming that channels would be designed with capacities the same as or greater than the downstream control structure (i.e., the channels would not limit flow). The hydrologic indicators listed in Table 2 are either computed by this model (pool elevations, flow below control structures) or could be easily added (e.g., turnover rate).

A similar model could be developed for Arrowwood NWR. Aside from the obvious differences (e.g., four pools instead of two), the Arrowwood model would likely have to use two inputs from the James River model: predicted flow at the Grace City node to determine upstream input to the Refuge and predicted flow and stage at the Pingree node to determine if Jamestown Reservoir was backing up into the Refuge. It might also be useful to add a node to the James River model between Grace City and Pingree to more accurately divide up the reach gains and losses and provide a better estimate of inflows to Arrowwood.

Water quality modeling. The James River salinity (TDS) model presently works in conjunction with the Sand Lake hydrologic model. The same model could also be used with a similar hydrology model for Arrowwood NWR.

Turbidity cannot be modeled reliably because of uncertainties associated with modeling resuspension due to carp. However, some factors affecting turbidity are not expected to change appreciably with GDU operation; for example, winds across Refuge pools. There was some disagreement among workshop

participants concerning the extent to which algal blooms might be affected and whether suspended solids will increase only during construction, then decrease below pre-construction levels. Estimates of the construction phase increase will be available from the James River Stabilization study and from data already collected during bridge construction in the Oakes test area (5-fold increase during construction). Such estimates might be used in an uncoupled sago growth model [see discussion in VEGETATION--ALTERNATE APPROACHES] to assess potential turbidity impacts on sago pondweed.

Dissolved oxygen can be modeled within about ±50% using a simple decay model and within ±20% if a nutrient/algae model is included. However, it is possible that DO does not have to be modeled explicity in order to predict fish kills [see discussion in FISH--MODEL CONCEPTUALIZATION--Approach--Winter Mortality]. For example, there seems to be a sufficiently good correlation between winter inflows to Sand Lake NWR and fish kills to make modeling DO unnecessary; it is not clear whether similar data are available for Arrowwood NWR.

Reasonable nutrient models for nitrogen and phosphorus could be developed. However, discussions with the Vegetation workgroup indicated such an effort was probably not warranted, because nutrients may not generally limit algal blooms in North Dakota lakes, and project related increases each year would occur after the critical spring period of sago growth.

Water temperatures are not expected to change dramatically due to GDU operation because ambient air temperature is the primary controlling factor except for immediately downstream of a reservoir. Water temperatures can be predicted with a relatively simple equilibrium model for periods without an ice cover; when an ice cover is present, water temperature can be specified as somewhere between 0 and 2 °C rather than utilizing extremely complex heat transfer calculations.

While models exist to predict agricultural nonpoint source pollution, the Hydrology and Water Quality workgroup recommended using a screening procedure to determine if such an extensive modeling effort is warranted. Current

loadings of pesticides, trace elements, and heavy metals should be determined and estimates made of additional project loadings. Some of these estimates could be generated from monitoring already done at the Oakes test area. If the project-related increases are not significant, then pesticide modeling should not be done. It is possible that the increased loadings will be small because channels will probably not be treated with pesticides and till barriers in most areas will prevent surface runoff from agricultural fields from directly entering drains and channels, thus allowing some decay of pesticides before they appear in return flows.

IMPLICATIONS FOR MONITORING AND RESEARCH

Present monitoring stations along the James River are collecting information hourly on temperature, pH, conductivity, and dissolved oxygen; information is collected on pesticides, toxic materials, and trace elements every 6 weeks (and two samples at high flow, one at low flow, and one following a rainfall event). The Hydrology and Water Quality workgroup suggested six modifications to the present monitoring program.

1. Additional turbidity monitors should be added in order to better separate the various sources of turbidity. These extra monitors should provide stratified sampling of high vs. low wind energy areas, high vs. low or no carp areas, high vs. low or no inflow areas, and high vs. low productivity (e.g., algae) areas.

2. Some sampling for dissolved oxygen and temperature should be conducted in deeper water areas, since these are the areas most likely to overwinter rough fish.

3. Some of the trace elements presently being analyzed should be dropped from the monitoring program. These analyses are expensive (up to $400 per sample) and 20% of the trace elements (e.g., thalium) have not shown up in the first 2-3 years of sampling.

4. Some additional pesticides should be included in the monitoring program. A list of these pesticides has been developed, but they have been too expensive to add because they would require development of a standard reference spectra for each. These pesticides might be added after North Dakota State University develops the associated best management practices for the Oakes test area.

5. Composite or sequential samplers might be added to some monitoring stations for pesticides, toxic materials, and trace elements. Composite samplers collect samples proportional to time or flow. Samples would be picked up monthly and analyzed to see if any major release events had occurred. Sequential samplers are triggered (and can notify the user) whenever a prespecified event has occurred. Thus, a sequential sampler with an ORP ion probe could be used to collect a sample when it is likely that pesticides might have been released into the river.

6. Biological monitoring stations could be added downstream from project drains as an additional check for pesticides, heavy metals, and trace elements. If added, the species used (perhaps a marsh invertebrate) should be chosen carefully because of differential sensitivity to pollutants. This biological monitoring would be in addition to the pre- and postproject analysis of coots and carp conducted by the FWS Patuxent Wildlife Research Center.

In addition, the workgroup recommended that better area-capacity data be developed for Sand Lake; this might be accomplished either through surveying additional transects or analysis of existing aerial photographs if they were taken at different water level elevations. Subsequent to the workshop, it was suggested that the West Oakes test area be added to the Refuge monitoring program.

VEGETATION

MODEL CONCEPTUALIZATION

Approach

In an integrated simulation model, a vegetation submodel would calculate variables needed by other submodels (as specified in the Looking Outward Matrix, Figure 4) and general output variables (Indicators as specified in Table 1) on a weekly, monthly, or yearly basis. At the workshop, these variables were identified as the area of sago pondweed (*Potamogeton pectinatus*) beds; areas of wet meadows, emergent marsh vegetation, upland grasses and weeds inundated after ice-out, and deep and shallow marsh; the biological oxygen demand from decomposing vegetation at ice-up; the area of clear channel for estimating channel roughness; and a specification of zones of high wave energy for estimating destruction of nests in emergent vegetation.

The Vegetation workgroup considered its task in terms of two basic issues:

1. simulating or analyzing effects on area or production (biomass) of sago pondweed; and

2. simulating or analyzing general changes in cover types (e.g., open water, emergent marsh, or moist upland types) and their inundation (i.e., water depth) over time.

Most of the attention was focused on sago pondweed because of its importance in the James River Refuge systems.

Ecology of sago pondweed. Several aspects of the ecology of sago pondweed were discussed and noted as background for constructing a simulation model. Important growth stages in an annual cycle starting with viable tubers are summarized in Table 3. The workgroup concentrated on vegetative propagation and growth from overwintering tubers, rather than reproduction from seed, because this "perennial" mode was judged to be by far the most important at the James River Refuges. Observations from literature sources (mostly provided by H. Kantrud), monitoring at the James River Refuges, and personal experience of the participants concerning distribution and growth of sago pondweed in response to environmental variables and concerning effects of rough fish (dominately carp) on sago pondweed are listed in Table 4. Many of these observations can be most easily integrated by a consideration of light availability. A simple model of light intensity by depth in a water body represents the light intensity, I_z, at a depth z as a fraction of the surface light intensity, I_0, where the fraction is an exponentially decreasing function of depth according to an extinction coefficient, n (Figure 6). The extinction coefficient is strongly related to turbidity. Factors that contribute to increased turbidity (e.g., algal blooms; increased dissolved organic matter or color; and increased suspended sediments due to sediment inflows, wind-generated resuspension, or carp feeding activity) generally produce a more rapid extinction of light with depth. The specific relationship between an extinction coefficient and a particular measure of turbidity, however, can be complex and dependent on the spectral distribution under consideration, as well as on the distributions of particle sizes and shapes and absorbance characteristics of the chemical compounds involved.

Nonetheless, a model that assumes the fraction of light at a given depth, and thus the light available for photosynthesis at that depth, is largely a function of turbidity integrates many of the types of observations in Table 4. Plant growth occurs when photosynthesis exceeds respiration. As available light decreases, there is a point (compensation point) where the rate of photosynthesis at that light level just balances the rate of respiration. The depth at which this occurs, under a given extinction coefficient or turbidity level, separates the water column into a euphotic zone where light conditions

Table 3. Growth stages of sago pondweed assuming presence of viable tubers.

Stage	Time[a]	Notes
Dormant tubers	overwinter	freezing and physical disruption at breakup when entire water column is frozen may kill tubers
Sprouting	late March to early April	water-soil temperature = 10 °C, tubers generally viable for 3-4 years with some fraction sprouting each year
Elongation	early April to early May	sago can probably grow 30-60 cm before reaching 4%-5% light, utilizing tuber reserves
Full development of near-surface leaf array, lateral belowground spread, secondary elongation (additional stems)	early May	when stem approaches water surface
Flowering (water pollinated at surface)	mid-May to mid-July	
Seed production	June to July or early August	
Increased tuber production	July-August	
Senescence	August-September	

[a]Based on growing season of 129 days.

Table 4. Observations concerning sago pondweed.

Subject	Observation (source)
Distribution and growth	
	1. Generally no aquatic macrophytes where light at bottom <2% (Hutchinson 1975).
	2. Wind-generated turbidity over clay-silt bottoms limited submerged plants in water over 1.7 m deep (Chamberlain 1948).
	3. Sago grew where light at bottom was as low as 2.5-5% (Jensen 1940; Howard-Williams and Liptrot 1980).
	4. Sago was absent in streams where turbidity >153 JTU (Kulberg 1974).
	5. Sago was not found in portions of a Manitoba lake where water depth was >1.2 m and fetch exceeded 600 m (Anderson 1978).
	6. Sago biomass was higher in a year with lower water depth even though turbidity was slightly increased with lower water depth (Bailey and Titman 1984).
	7. Phytoplankton blooms limited sago to water depths <1.5 m (Crum and Bachmann 1973; Andersen 1976; Jupp and Spence 1977).
	8. Sago was absent at sites with Secchi disk depths <20 cm, sago was abundant at sites with Secchi disk depths around 60 cm (Jenkin 1936).
	9. Sago production decreased at water depths >0.5 m on a clay-sandy clay substrate, even though turbidity was somewhat less at greater depths (Robel 1961a).
	10. In moderately turbid water, optimum water depth for sago is <2 m; in highly turbid water, optimum water depth is <1 m (generalization from many studies).

Table 4. (Concluded)

Subject	Observation (source)
	11. Sago biomass can vary annually by an order of magnitude, even in the absence of effects attributable to rough fish (James River Refuge monitoring data, especially Hyatt Slough sites).
	12. Sago is absent or less abundant in a narrow, near-shore zone and (less clearly) in the eastern sections of pools on the James River (James River Refuge monitoring data and vegetation maps).
Rough fish (carp) effects	
	1. Uprooting especially important when plants are young (King and Hunt 1967).
	2. Little adverse impact on sago when fish are <2-3 years old (generalization from studies on carp production ponds containing sago).
	3. Inclosure and exclosure experiments provide specific estimates of sago production under different densities of carp (Robel 1961b; King and Hunt 1967).
	4. Carp increase their use of sago for food as other foods become scarce (Sigler 1958).

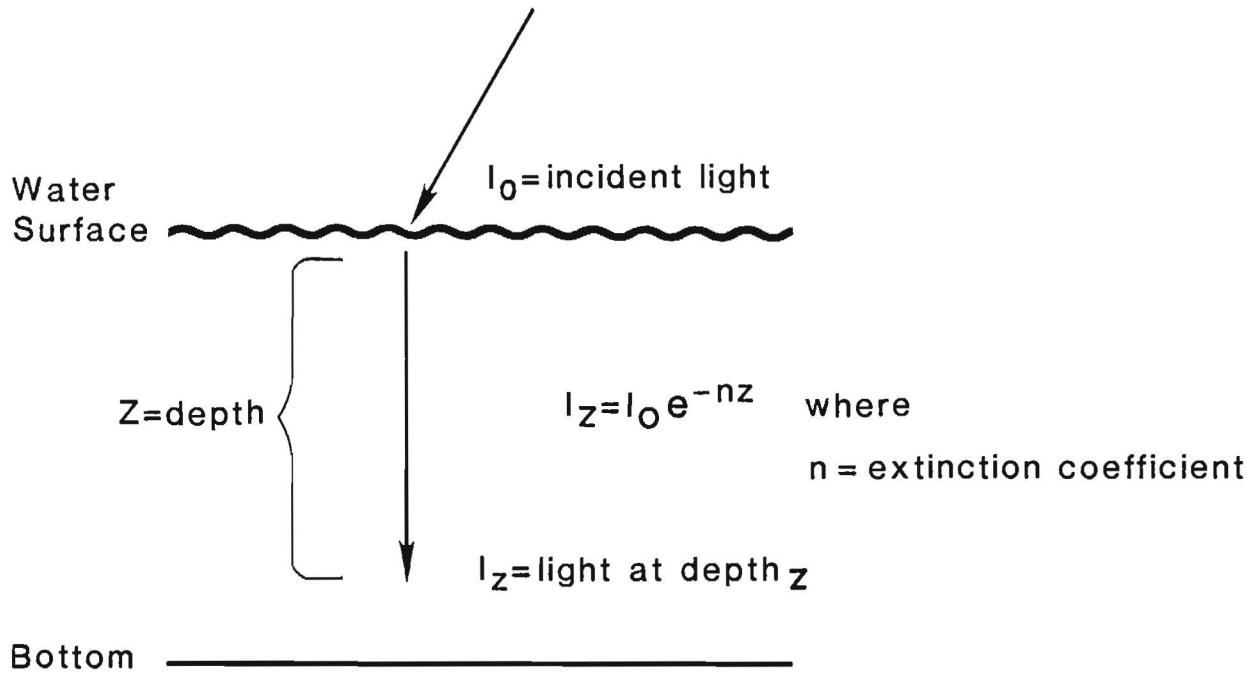


Figure 6. A simple model of light intensity by depth.

are favorable for primary production from a lower zone where light conditions are unfavorable. The light intensity at the compensation point is somewhere in the range of 1%-5% of incident light. Thus, because sago grows up from roots at the bottom of the water column, a first approximation would be that sago would not be found in situations where water depth and turbidity (or extinction coefficient) combine by the model of Figure 6 to produce light intensities at the bottom that are <1%-5% of incident light.

Unfortunately, the situation is likely somewhat more complex. In a perennial mode, sago sprouts from overwintering tubers that represent an energy reserve. This energy reserve can support some early vertical growth of stems and production of long leaves in cool waters in early spring at depths

where available light is not sufficient. Leaves are then arrayed near the surface after the plant has grown vertically into the euphotic zone. At this point, photosynthate from the near-surface leaf array of one stem may even be translocated to roots to support secondary stems starting from the bottom until the secondary stems reach the euphotic zone. Despite these complications, the capacity to overcome low intensities of available light at the bottom is limited because of the finite overwintering energy reserve and ultimate structural constraints and energetic constraints to producing and maintaining a very large supporting structure for a near-surface leaf array in very deep, turbid water. The above considerations do point to the importance of light availability during the critical early growing season when tuber energy reserves are being utilized. Thus, wind-generated resuspension and the related factors of wind velocity and fetch, carp-related resuspension, and the timing of algal blooms would be expected to be especially important early in the growing season.

Several additional factors influence light availability for sago. The most obvious is self-shading by sago itself, which might ultimately limit sago production in an optimal site. Other factors include other macrophytes, periphyton, animals that graze the periphyton, and mineral encrustation of leaf surfaces.

Sago growth model. The Vegetation workgroup devoted considerable energy to conceptual development of a simulation model of sago pondweed. The most promising approach appeared to be a plot-based growth model that would simulate changes in sago biomass on a daily or weekly time scale (Figure 7). Plot size (probably between 1 m^2 and 100 m^2) would be chosen to achieve reasonable intra-plot homogeneity and correspondence with the James River Refuge monitoring sites and to reduce edge effects (i.e., the need to consider lateral growth of sago into or out of the plot). The time scale would be a compromise between the relatively short (e.g., hourly) time scales that are most appropriate for the dynamics of photosynthesis and respiration and the longer time scales (e.g., monthly) on which driving variables and monitoring information are generally available.

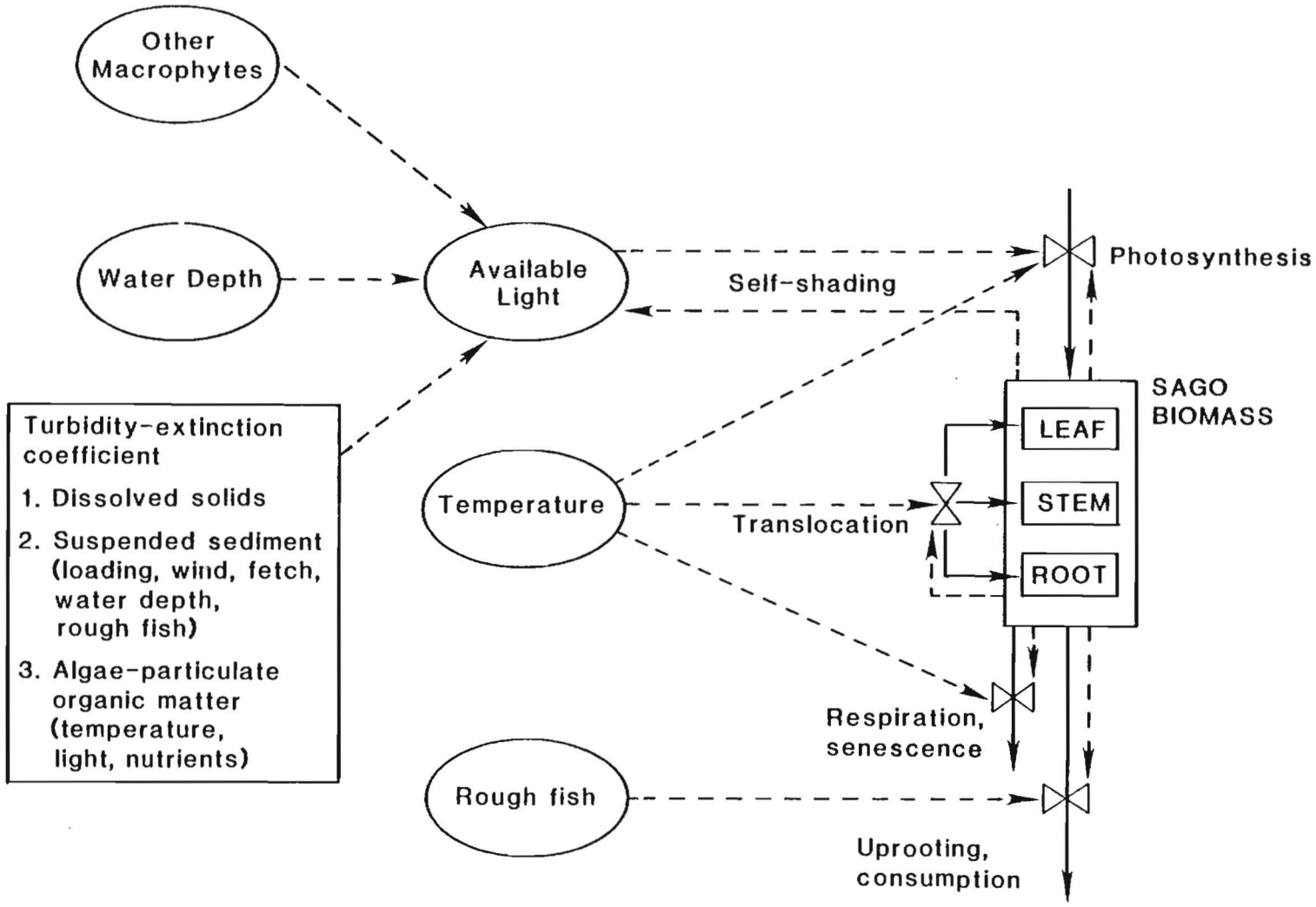


Figure 7. A conceptual model of sago growth. Solid lines indicate material flow and dashed lines indicate control or information flow. Important influences on turbidity-extinction coefficient are indicated parenthetically rather than as control flows. Leaf coatings such as periphyton and mineral encrustation may significantly alter self-shading.

The sago growth model of Figure 7 would update biomass in three compartments (leaf, stem, and root) every time-step based on calculations of net production (balance of photosynthesis and biomass losses) and translocations among compartments as sago moved through the growth stages outlined in Table 4. The principal driving variables would be available light as determined by water depth and turbidity, temperature, and density of rough fish or carp. Rough fish would influence sago both by direct consumption and uprooting and indirectly by increasing turbidity as a result of resuspending sediment through activity.

The type of plot-based simulation model described above could be used by applying it to a number of different plots in various subdivisions of each Refuge pool being considered. Criteria for defining subdivisions would likely include elevation (and hence, water depth at a given pool stage) and some differentiation of high or low "energy" zones representing the intensity of resuspension energy. High "energy" zones would probably be defined based on a delineation of a shallow, near-shore area and areas with long fetch in the direction of dominant (in early growing season) winds. Parameter adjustment and validation would be accomplished by running the model for each of the monthly sampling stations in various years of the James River Refuge monitoring effort.

General changes in cover types. Changes in hydrologic regime (depth and timing of inundation and soil saturation) could produce changes in the general distribution of both wetland and nearby upland cover types. For example, consistently deeper inundation might lead to thinning or loss of existing emergent stands; extending the period of soil saturation in wet meadows might shift community composition closer to a shallow marsh. Even in the absence of significant shifts in vegetation, a change in the pattern or amplitude of water level fluctuation might result in a change in rates of nest destruction (e.g., flooding of nests by rapid increases in water levels).

The basic information required to simulate such changes in cover types and depths of inundation by cover type includes the initial distribution of cover type patches over the landscape and simulated future hydrologic regimes for each of the patches. As a first approximation, hydrologic regimes might be estimated by relating simulated, monthly pool stages to an overlay of cover types by elevation.

The workgroup did not discuss in any detail the algorithms that might be used to simulate quantitative changes in cover types. A qualitative analysis could be conducted by comparing simulated hydrologic regimes for each cover type patch with the ranges of hydrologic regimes in which each cover type is generally found. The quantitative dynamics of cover type shifts have been simulated in several other marsh systems (Sklar et al. 1985; Hamilton et al. 1986), and a similar approach could be applied to the James River pools. Some difficulties and limitations of such models are discussed in the following section.

Feasibility

Integrated simulation for impact assessment. One approach to assessment of potential impacts from operation of GDU would be to simulate on a weekly or monthly basis movement of water, water quality, changes in biomass or areal extent of sago and other cover types, and fish and wildlife populations. Impacts would be assessed by comparing runs representing no-project to various with-project scenarios. A critical limitation of this approach is the ability to simulate changes in turbidity and rough fish that would connect a vegetation submodel of sago pondweed to the rest of the model (Figure 7) and ultimately to project actions. For reasons described in the Hydrology and Fish and Wildlife sections, it does not appear feasible in the short term to simulate turbidity or rough fish density with any confidence. Thus, it does not seem feasible to base an impact assessment on the development of an integrated simulation model of hydrology, vegetation, and fish and wildlife in the near future.

Sago growth model. Development of a plot-based sago growth model as outlined in an earlier section might provide considerable benefits even in the absence of tight integration with simulated turbidity and rough fish density. Such a model could be run by providing turbidity and rough fish input directly either from James River Refuge monitoring data or as hypothetical scenarios. Possible benefits include: (1) integration and interpretation of the extensive data on sago growth and concomitant environmental variables developed in the James River Refuge monitoring study, and (2) sensitivity analysis and "what if" gaming to address possible changes in the driving variables (e.g., what response in sago would be expected if an observed time series of turbidity was increased by a factor of five?).

The strongest reasons for expecting that a modeling effort focused on sago pondweed growth would be reasonably successful are the following:

1. the large amount of time series, field data collected in the James River Refuge monitoring study that could be used for parameter estimation and validation; and

2. the seemingly strong (e.g., Table 3) determination of sago distribution and growth by available light.

Potential difficulties in modeling sago pondweed growth include the following:

1. large variability in sago biomass both at the micro-scale (among individual replications at a "site") and year-to-year;

2. conversion of turbidity measurements to extinction coefficients;

3. lateral extension of both leaves and roots;

4. carbon partitioning and translocation among leaf, stem, and root components; and

5. representing effects of rough fish, and, in particular, separating direct uprooting from effects mediated by increased turbidity.

General changes in cover types. There are two general approaches to simulating changes among cover types. The first is to represent individual species tolerances (e.g., limits of inundation) and interactions (e.g., competition). Although this approach has been successfully applied to forested communities (e.g., Phipps 1979), it is difficult to use for marsh communities because of the large number of species with complex, and often poorly known, life histories, ecological tolerances, and interactions. The second approach is to treat various cover types as units (e.g., shallow, marsh, or wet meadow) and to develop rules for transitions between the units. Difficulties with this approach include the following:

1. establishing well-defined and homogeneous cover type classes;

2. the wide ranges and overlaps of environmental conditions associated with given cover types;

3. distinguishing between conditions suitable for continued existence of a cover type and conditions required for initial establishment (e.g., drawdown might be required for establishment from seed but not for maintenance of a perennial community); and

4. properly estimating rates of transition and community development.

ALTERNATIVE APPROACHES

Sago Pondweed

The most promising alternative to constructing an integrated simulation model for impact assessment appears to be to develop a sago growth model that would respond to directly specified inputs of turbidity and rough fish. Such a model might then be used to examine the effects of potential changes in these driving forces in the absence of detailed simulations of turbidity or rough fish densities. Another approach for impact assessment on sago pondweed would be to apply general results from inclosure or exclosure experiments conducted elsewhere (e.g., Robel 1961b) that relate fish density to a percentage reduction in sago production. Some estimates of fish density both

with and without the action to be evaluated (i.e., representative densities pre- and postproject) would be required in units that could be related to the experiments conducted elsewhere.

General Changes in Cover Types

With the possible exception of submerged aquatic vegetation (i.e., sago), the most likely determinant of changes in cover types and their patterns of inundation will be an altered hydrologic regime as expressed by changes in pool stages. Rather than immediately tackling the difficult problems of modeling transitions between cover types, a more incremental approach might be more efficient. This type of approach (Figure 8) would start from a comparison of pool stages (on a monthly or more frequent time scale for several decades) without (from historical records or hydrologic simulation) and with (from hydrologic simulation) the GDU in operation. More and more detailed consideration of cover type changes could be undertaken if the results of a preceding step of the analysis suggested that there are likely to be significant impacts. It is worth noting that one of the pieces of information required at a relatively early stage is reasonably detailed elevational data or topographic mapping. This information is available for Arrowwood Refuge, but questions were raised at the workshop regarding the quality of available topographic information for Sand Lake Refuge.

IMPLICATIONS FOR MONITORING AND RESEARCH

Based on the discussions of vegetation models and analyses, the workgroup developed suggestions for monitoring and research in the three areas of sampling or monitoring, data analysis, and possible laboratory or experimental studies.

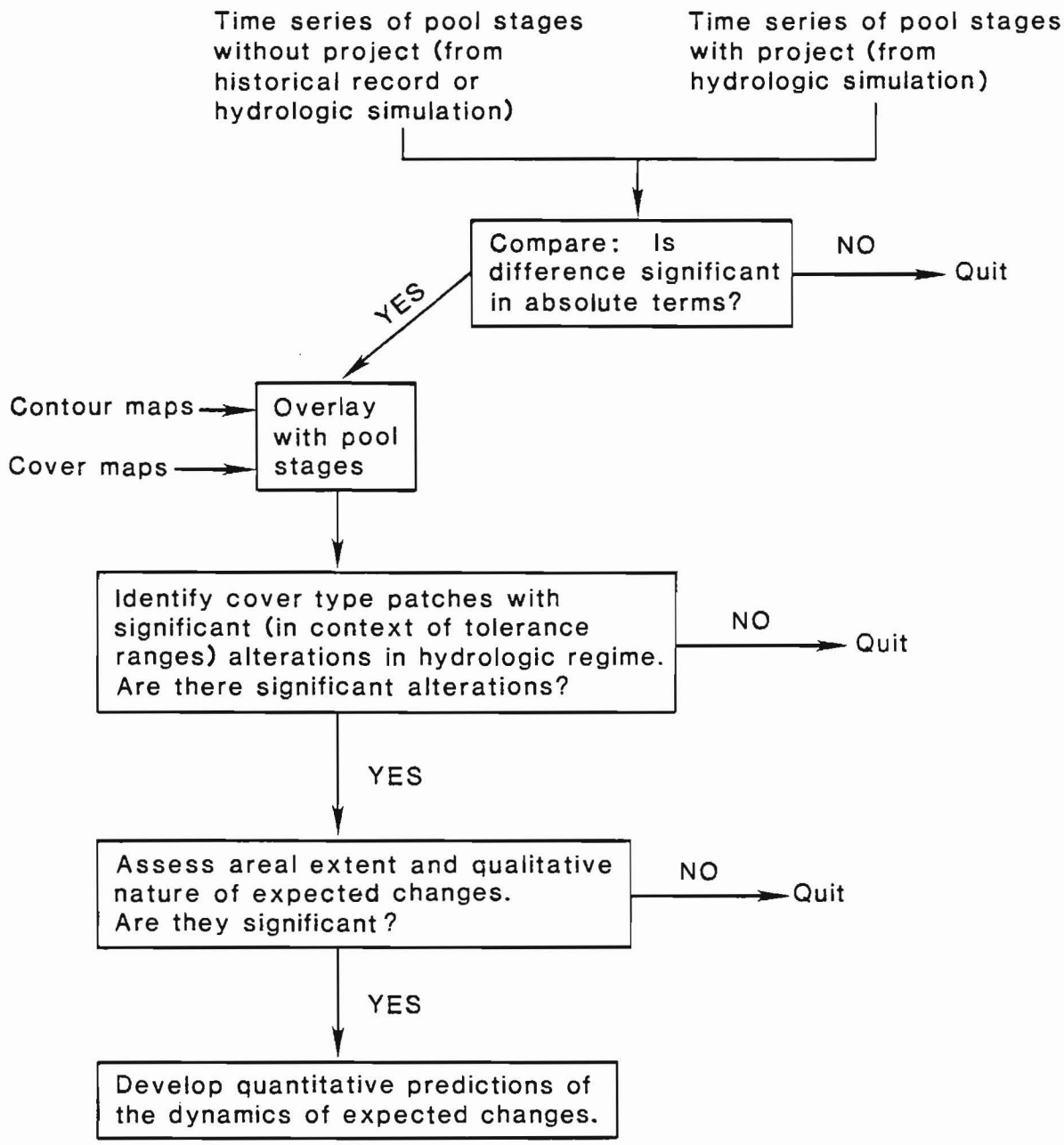


Figure 8. A possible, incremental approach to assessing potential changes in cover types and their inundation resulting from altered hydrologic regimes.

Monitoring

Examination of preliminary results from the James River Refuge monitoring study, as well as general discussions, indicated the importance of long-term monitoring, in large part because of substantial year-to-year variation. The source of this variability was not immediately obvious from the preliminary data and may involve a combination of weather, water depth, turbidity, rough fish, algal blooms, and changes in sampling methodologies or timing of aerial photography. More specific suggestions are listed below.

1. Expand number and upgrade "permanent" stations.

    a. add photosynthetically active radiation (PAR) by depth in order to calculate extinction coefficient
    b. locate in both high and low "energy" (wind, wave, fetch) zones

2. Stratify regular plot sampling by "energy" zones after considering implications of such stratification on the ability to estimate at the "whole pool" level.

3. Consider obtaining replicate biomass samples at each regular plot sampling site at each sampling date.

4. Consider modifying (e.g., use clipping method) biomass collection procedure.

5. Consider shifting regular plot sampling schedule by:

    a. dropping September date, which occurs after peak biomass
    b. adding an early growing season date because of suspected sensitivity of sago at this stage

6. Survey areas that are "unusual" with respect to sago distribution (e.g., patches that always or never seem to have sago).

Data Analysis

These suggestions focus on potential analyses of data collected as part of the James River Refuge monitoring study. Development of a sago growth model should be considered primarily under this heading rather than as an integrated impact assessment procedure. It is also possible that data from

other sites (e.g., Cottonwood Lake) could be used to supplement the James River Refuge monitoring information (e.g., using continuous sediment temperature records to help interpolate between fixed sampling dates).

1. Correlate euphotic zone or fraction of light at bottom (as estimated by various combinations of direct measurements of light extinction, water depth, and turbidity) with sago production.

2. Compare Hyatt Slough sites (no carp) to "sheltered" (similar expected wind generated resuspension) sites in pools with carp.

3. Compare sago in years with high and low carp densities.

4. Conduct multivariate discriminant function analyses to predict sago presence-absence.

5. Conduct multivariate regression analyses to predict level of sago biomass.

6. Develop conversions (regression analyses) between various turbidity measurements.

Laboratory and Experimental

These types of studies were suggested as providing potentially useful information. However, a comprehensive review of existing literature should certainly be conducted before initiating new studies in these areas.

1. Conduct greenhouse experiments to evaluate sago growth under various combinations of driving variables.

   a. temperature
   b. water level fluctuation
   c. available light (turbidity, water depth)

2. Conduct field exclosure-inclosure experiments to evaluate effects of rough fish density.

FISH

MODEL CONCEPTUALIZATION

The task of the Fish workgroup was to attempt to conceptualize a model that, if constructed, would be useful in analyzing the impacts of the Garrison Diversion Unit on the fishery resources of Arrowwood and Sand Lake National Wildlife Refuges. Workgroup members felt that, ideally, such a model should be able to address three key questions with respect to fish.

1. How will rough fish populations, and hence sago pondweed and waterfowl, be impacted?
2. How will the forage base for fish-eating birds be impacted?
3. How will the sport fishery be impacted?

While not specifically discussed at the workshop, there is also concern that the Garrison Diversion unit may affect distribution of other species such as gizzard shad (*Dorosoma cepedianum*).

Carp (*Cyprinus carpio*) and bigmouth buffalo (*Ictiobus cyprinellus*) are the most important fish species with respect to impacts on sago pondweed, and northern pike (*Esox lucius*) is the most important species in the sport fishery. Fingerlings of all three of these species are probably taken by fish-eating birds, though other species may also be important as a forage base. Workgroup members felt that a useful model would ultimately have to consider all three of these species but, due to availability of information and expertise, focused most of their attention on carp.

To construct a model of the dynamics of these fish populations, workgroup members requested the following information from other workgroups (Figure 4): dissolved oxygen concentrations, temperatures, and exchange rates in the Refuge pools (important in determining winter survival of fish); water surface elevations (important in determining movement of fish into Refuge pools from outside sources); turbidity (may influence foraging efficiency of northern pike); and acreages of sago pondweed (important as nursery habitat) and inundated upland grasses and weeds (important as spawning habitat for northern pike). Dissolved oxygen concentrations and water temperatures would be required on a time scale as short as possible (preferably daily, but weekly would probably suffice). A monthly time-step would probably be sufficient for other variables. In addition, management actions that impact the survival and movement of fish (e.g., installation of fish screens or other barriers, and chemical or mechanical control measures) would be important components of a useful model.

Information concerning fish and their management requested by other workgroups included management "targets" (e.g., desired pool elevations), number of rough fish by size class, and number of fingerlings available as forage for fish-eating birds. In addition, Wildlife workgroup members requested information on the number of macroinvertebrates in the top 18 inches of the water column and on the surface of the water; however, it was not completely clear that the Fish workgroup should be responsible for providing such information.

Approach

Workgroup members discussed two basic approaches for representing fish population dynamics in a simulation model: in terms of numbers of fish in a series of size or age classes, or in terms of biomass per unit area. The first of these approaches would produce outputs most consistent with the kinds of information requested by other workgroups (e.g., numbers of fingerlings, numbers of rough fish by size class). However, due to the large numbers of individuals present during early life stages, the behavior of models of this

nature tends to be dominated by very small differences in assumptions concerning egg and fry survival. Because there is little or no information available concerning egg and fry survival at Arrowwood and Sand Lake Refuges, workgroup members decided to try to represent fish populations in terms of biomass per unit area, realizing that this would not provide exactly the information requested by other workgroups. However, this approach was judged to be most feasible, and it was also noted that carp abundance has been measured in terms of biomass in most of the experimental work on interactions between carp and sago pondweed (e.g., Robel 1961b). As noted above, most of the discussions focused on carp due to the relatively larger amount of information and expertise available.

Changes in the biomass of carp from one year to the next were discussed in terms of six processes: winter mortality, immigration, recruitment, growth, other mortality (i.e., not due to winter-kill), and emigration. The following sections summarize workgroup discussions on these topics.

Winter mortality. Winter mortality of fish at Arrowwood and Sand Lake Refuges is largely a function of pool levels, inflows, and dissolved oxygen concentrations. Periodic winter-kills are important mechanisms for controlling carp and thus reducing their impacts on sago pondweed. If operation of the Garrison Diversion Unit alters the frequency with which effective kills of carp can be achieved during the winter, alternate control measures will likely be necessary.

Several approaches for estimating winter mortality were discussed by the workgroup. Perhaps the simplest would be to try to relate mortality rates directly to inflows during the winter. For example, observations at Sand Lake Refuge indicate that the combination of a 1-ft drawdown in the fall and winter inflows of 2-3 cfs or less is sufficient to produce a "significant" fish kill. Given sufficient time to examine Refuge records (e.g., annual narrative reports) and gaging station data, it might be possible at least to characterize winter mortality under a given set of conditions as either high, medium, or

low and then subjectively assign a mortality rate to each of these three classes. This approach would have the virtue of not requiring extensions to the current water quality and hydrologic modeling.

More complicated approaches to estimating winter mortality would require, at a minimum, that the water quality portion of the model simulate dissolved oxygen concentrations. Furthermore, monthly average dissolved oxygen concentrations would not be particularly useful, because mortality rates are more likely a function of minimum dissolved oxygen concentrations for relatively short periods of time (perhaps a few days). If the minimum dissolved oxygen concentration in any month could be estimated, it might be possible to develop a relationship to mortality based on information available in the literature.

Perhaps the most promising approach for estimating winter mortality would involve treating the Refuge pools as raceways and drawing on information available from the fields of fish culture and hatchery management. Although specific examples were not available at the workshop, relationships describing the biomass of a given species that can be supported per unit volume of water as a function of inflows, dissolved oxygen concentrations, and temperature are apparently relatively common in these fields. In a simulation model of Refuge pools, biomass in excess of that which can be supported would be removed as mortality. Participants were not certain however, that such relationships would be applicable at very low dissolved oxygen levels. Furthermore, in hatchery situations it is probably reasonable to assume that fish are the only consumers of dissolved oxygen, or at least that other factors that reduce dissolved oxygen (e.g., oxidation of unutilized food) are controllable. In the Refuge situation, other sources (e.g., photosynthesis) and sinks (e.g., oxidation of dead plant material) would either have to be estimated or explicitly ignored. In addition, if a multispecies model were developed, it would be necessary to develop an approach for allocating available oxygen among species. For example, such an approach might involve ranking the species according to their ability to survive low oxygen levels and then assuming that the species most tolerant of low oxygen levels are able to satisfy their needs first. Although an approach of this nature would clearly be the most difficult, it would also likely be the most credible.

Immigration. Movement of carp and other fish into Arrowwood and Sand Lake Refuges is an important mechanism for reestablishing populations following winter-kills and for augmenting populations in other years. Immigration occurs largely during the spring and early summer (spawning season) and includes both desirable (e.g., northern pike) and undesirable (e.g., carp) species. It is believed that the most significant movements tend to be upstream; that is, from Jamestown Reservoir into Arrowwood Refuge and from the lower channel of the James River into Sand Lake Refuge. However, little is known about movements from the James River downstream into Arrowwood or from Dakota Lake Refuge downstream into Sand Lake. The relative timing of winter-kills and significant immigrations is thus an important factor in determining how long carp populations remain below densities at which sago pondweed is impacted. Any changes in immigration patterns as a result of the Garrison Diversion Unit could have significant impacts on sago pondweed and use of the refuges by waterfowl.

The biomass of carp immigrating upstream into a Refuge was conceptualized as being a function of the biomass available and access. Biomass available, which was loosely defined as the biomass of fish moving upstream to a point where they would potentially have access to a Refuge, was considered to be a function of attractant flows, the size of the source population, and the proportion of that source population having a tendency to migrate. The North Dakota Game and Fish Department has collected some data on the number and size of fish moving upstream below Arrowwood Refuge. These data, which in essence are the net result of all three of the factors that influence the biomass available, could be examined to see if there is a relationship between flows and the biomass of fish moving upstream. If such a relationship exists, it could then be used with flows produced by the hydrology portion of a simulation model to estimate the number of fish moving upstream in any particular year. In the absence of such a relationship, the biomass of fish moving upstream would have to be considered a constant or a random variable, either of which could be estimated from the distribution of data collected by the North Dakota Game and Fish Department. Any of these approaches would implicitly assume that the relationship between the biomass of fish moving upstream and the source population in Jamestown Reservoir is unknown.

Similar information on upstream fish movements is apparently not available for Sand Lake Refuge. Likewise, there is apparently no information on downstream movements of fish into either Refuge.

The other factor in the immigration function, access, was conceptualized as depending on a variety of factors, including differences in water surface elevations at control structures, the nature of the control structures themselves, the depth of water in the take-off pool, and the depth and velocity of water moving over the control structure. Of course, the efficiency of any barriers specifically installed to limit fish movement would also have to be taken into account in estimating access.

At Arrowwood Refuge, the most significant limitation to movement of fish upstream is the control structure at the lower end of DePuy Marsh. Access of fish to Arrowwood at that structure might be estimated using a function such as that depicted in Figure 9. Thus, a difference in water surface elevation of 1 ft would represent no impediment to movement of carp, while an 8-ft difference (the maximum impediment at DePuy Marsh is only about 4 ft) would completely preclude immigration.

Although a function of this kind ignores many of the factors that probably influence access, it does represent both the physical configuration of the control structure and general understanding of the ability of carp to move over impediments of various heights. A similar function could probably be estimated for the control structure at the lower end of Sand Lake. Barriers installed specifically to limit carp movement could be represented as modifiers of these functions. Again, however, there is apparently no information on movements of carp downstream into the Refuges. This process would probably have to be ignored in the construction of a model, which would limit its utility.

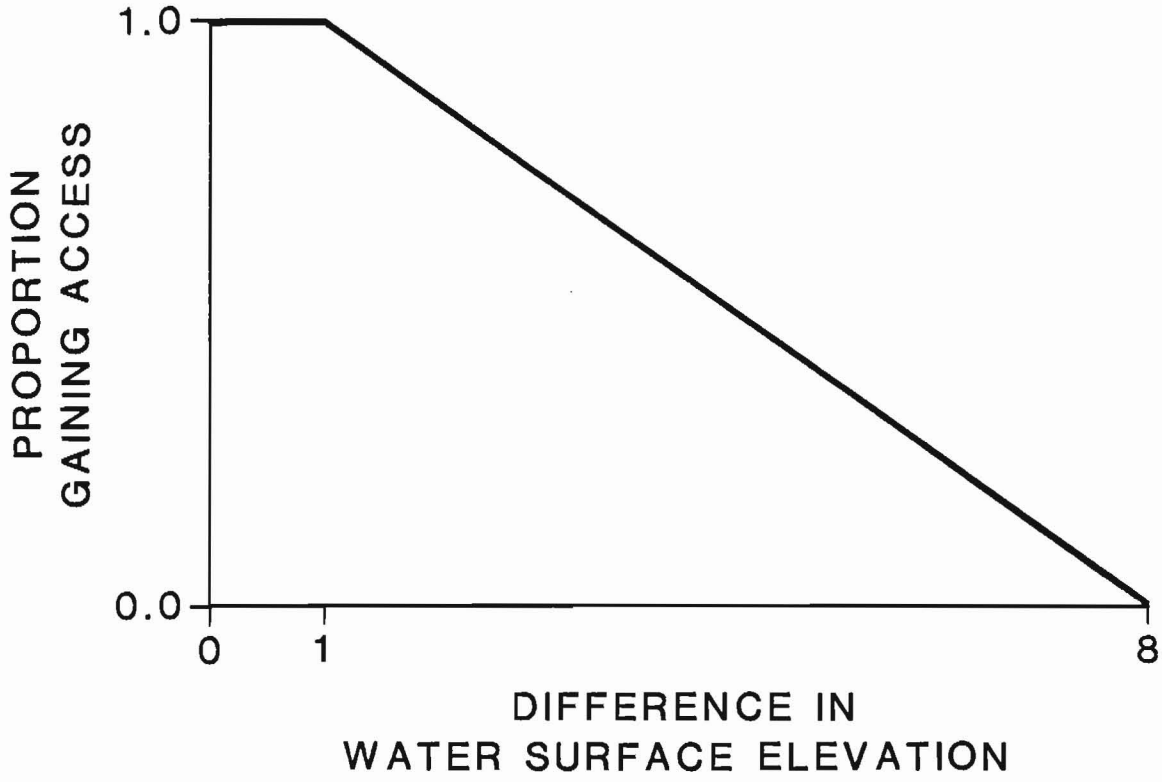


Figure 9. Hypothetical relationship between the proportion of available biomass of carp gaining access to Arrowwood Refuge and the difference in water levels above and below the control structure at DePuy Marsh. The relationship assumes that there are no barriers installed specifically to limit fish movement.

The final step in modeling the immigration process would be to estimate how carp gaining access to a Refuge distribute themselves among the various pools. Assuming that control structures (either existing or planned) between pools do not impede movements, it would probably be reasonable to calculate distribution simply as a function of available habitat, perhaps estimated by surface acreage.

Recruitment, growth, and other mortality. There is little or no information available concerning rates of recruitment, growth, or other (i.e., non-winter) mortality of carp at Arrowwood and Sand Lake Refuges. Furthermore, the potential for the Garrison Diversion Unit to impact these processes is probably less than the potential for it to impact winter mortality and immigration. Therefore, for purposes of constructing a simulation model, it seemed reasonable that all of these processes might be aggregated into a single parameter representing the rate of increase in biomass of carp from spring to fall. To be useful, this growth rate would have to be expressed as a function of biomass present in the spring (i.e., would have to be density-dependent). Presumably, at high densities of carp, growth rates decline (eventually to zero) as resources become limiting or as large fish interfere with survival of smaller fish.

Two methods for estimating growth rates of this kind were discussed. First, existing literature on carp could be examined for information that would be useful in constructing such a growth function. European literature on commercial culture of carp might be particularly valuable. If sufficient data are available, it might even be possible to limit consideration to information obtained from situations (e.g., latitude, water temperatures, water depths) similar to Arrowwood and Sand Lake Refuges. The obvious difficulty with this approach is that data of this kind from the literature are likely to be highly variable depending on a variety of other site-specific factors.

A second approach would be to try to develop a growth rate curve based on experiences at the two refuges. For example, Refuge managers find that carp can begin to impact sago pondweed 2 years after a significant winter-kill (in the absence of significant immigration), and that damage can be severe if 4 years elapse between winter-kills. In comparison Robel (1961b) found that carp stocked at rates of approximately 200, 400, and 600 lb/acre reduced sago pondweed production approximately 30%, 60%, and 75%, respectively, although sago production at a stocking rate of 200 lb/acre was not significantly different from that in a control area. King and Hunt (1967) also found that

carp affect aquatic vegetation at standing crops on the order of 400-500 lb/acre. It might therefore be reasonable to assume that densities on the order of 200, 400, and 600 lb/acre can be achieved 2, 3, and 4 years following a winter-kill, respectively. This would imply growth rates of 100% at a standing crop of 200 lb/acre and 50% at a standing crop of 400 lb/acre, assuming negligible immigration during the period. Growth rates at lower densities could then be estimated by assuming some standing crop immediately following a significant winter-kill (say, for example, 25 lb/acre) and calculating the growth rate that would be necessary to reach 200 lb/acre in 2 years (approximately 283% per year). Growth rates at higher densities could be estimated by assuming a maximum standing crop that might be expected in a situation like that on the refuges, and then assuming that the growth rate declines linearly between 50% at a standing stock of 400 lb/acre and 0% at the maximum density.

An approach of this nature, of course, ignores many specific factors (e.g., size-specific fecundity and growth rates) that are important in recruitment to and growth of a carp population. It also ignores the fact that a given biomass of carp probably has a greater impact on sago pondweed if it is composed of a few large fish rather than many small fish. However, more detailed representations would be even farther beyond the amount of information and understanding currently available.

Emigration. Emigration of carp from the Refuges was not discussed in any detail at the workshop, because the main concern is usually with movements into the Refuges. However, there is some potential that the Garrison Diversion Unit would allow greater numbers of carp to move out of Arrowwood Refuge to Jamestown Reservoir and out of Sand Lake Refuge to the lower reaches of the James River.

Feasibility

A relatively simple model of carp biomass dynamics could probably be constructed for Arrowwood and Sand Lake Refuges using the approaches described

above. However, construction and use of such a model to analyze the impacts of Garrison Diversion Unit would be hampered by the following factors.

1. Considerable extentions of the water quality modeling currently in progress would be required to represent dissolved oxygen concentrations adequately.

2. Much of the data to construct a model would have to be drawn from other locations, thus raising the question of their applicability to the James River situation.

3. A biomass dynamics model would not allow effective consideration of several factors (e.g., size structure of the population) that are important in the interactions between carp and sago pondweed. A more complex model incorporating size structure of the population would be even more dependent on data from other locations.

4. A truly credible model would have to consider other species of fish in addition to carp, and interactions between species (e.g., predation on carp by northern pike). Data on other species and species interactions are likely to be more scarce than information on carp.

Given these limitations, it is unlikely that construction of a model explicitly integrating hydrology and fish population dynamics would be a wise expenditure of resources at this time. Alternative approaches, some of which are described below, might be more useful in making a preliminary assessment of the probable magnitude of impacts and in directing acquisition of additional information. If these efforts indicate that there is a high probability of large impacts, and if significant additional information is collected, it may be worth reconsidering construction of a model of fish populations at some time in the future.

ALTERNATIVE APPROACHES

Perhaps the most useful approach that could be taken in the short term would be to incorporate into existing hydrologic models some output variables that could be interpreted more easily from a biological perspective. Specific examples of these kinds of outputs mentioned at the workshop include the following.

1. Comparisons of the magnitude and timing of winter inflows for pre- and postproject conditions, perhaps in the form of histograms, would be useful in assessing opportunities for winter-kills of fish. If some threshold criteria could be defined, the length of intervals between opportunities for significant winter-kill might be calculated.

2. Differences in water surface elevations above and below control structures at the outlets from the Refuges might be a useful index to access. Frequency distributions comparing these heights for pre- and postproject conditions could probably be produced quite easily. If keyed to specific time periods during which various species tend to move, such information might even be useful in assessing differential impacts to individual species. The utility of this approach would depend on how much water surface elevations differ from year to year.

3. The frequency with which the water surface elevation in Jamestown Reservoir is at or above the elevations of the stop-log structure or spillway at DePuy Marsh might provide another index to access to Arrowwood Refuge.

4. Pre- and postproject comparisons of the depths of inundation and acreages of various vegetation types might provide a useful index of changes in spawning habitat for individual fish species.

These are undoubtedly not the only types of outputs that might be desirable. Hopefully, they illustrate the kinds of approaches that might be taken to ensure that information generated by the hydrologic models is of maximum utility in the impact assessment process.

Another useful analytical tool would be a series of conceptual models, in the form of box and arrow diagrams, representing specific impact hypotheses. In the case of carp, the fundamental population processes discussed above (e.g., winter-kill, immigration) might form the basis for these models. A preliminary example, developed at the workshop, is shown in Figure 10. Winter mortality of carp is depicted as being a function of available oxygen, which in turn depends on the balance of factors that add (inflows, photosynthesis, surface aeration) or remove (biochemical oxygen demand) oxygen. Inflows can be either from surface water (e.g., return flows) or from underground springs. Ice and snow cover can affect both photosynthesis and surface aeration. In Refuge pools in the winter, decomposition of organic material may well be the major oxygen demand other than respiration by fish.

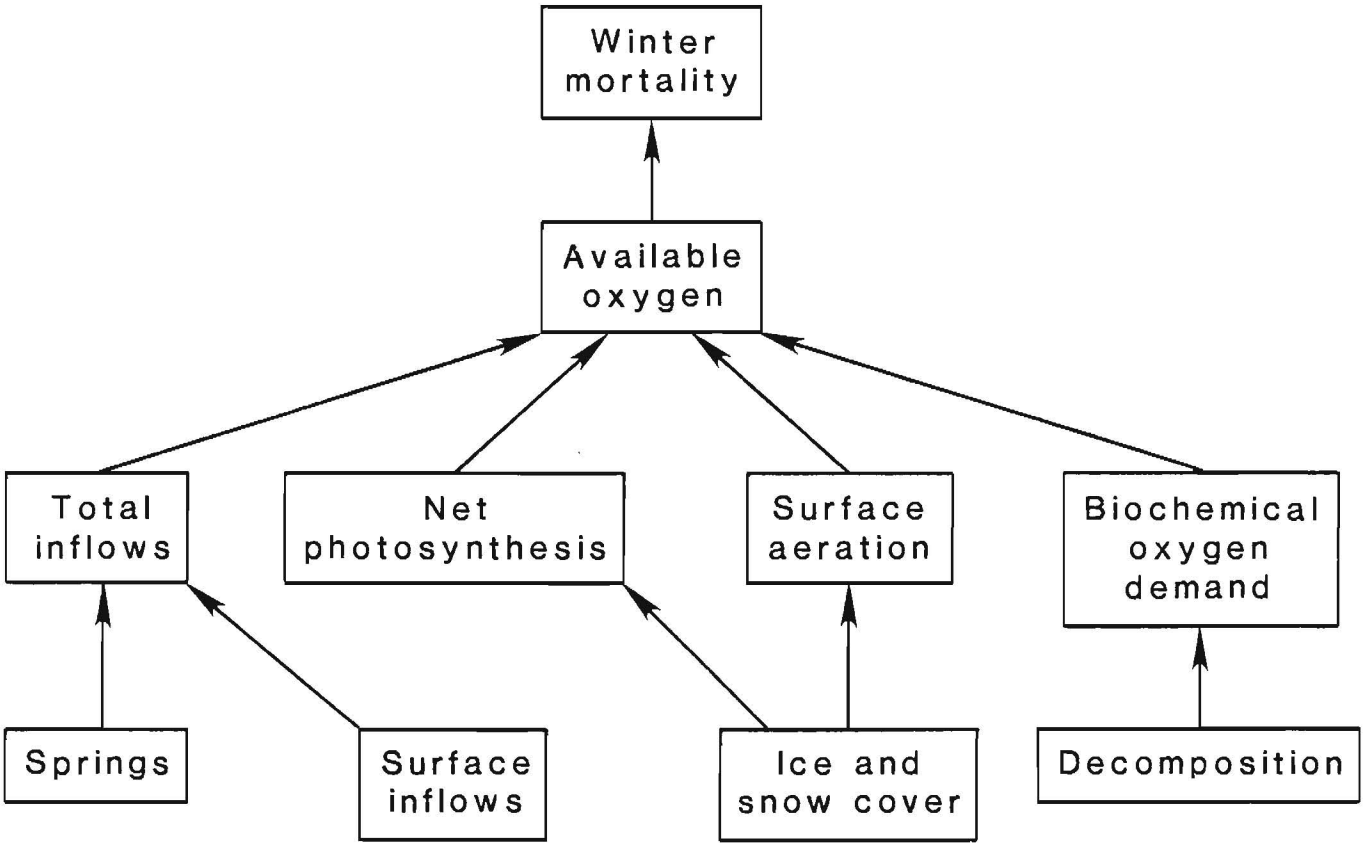


Figure 10. Conceptual model illustrating factors that influence winter mortality of fish.

Conceptual models of this nature can be useful in a variety of ways. First, they provide a clear and explicit statement concerning hypotheses about impacts and causal connections. They thus help to ensure thorough consideration of all possible impacts and are a convenient mechanism for communicating with other individuals or groups. Second, they provide a framework for organizing existing information and, conversely, for identifying areas where additional information or understanding is required. For example, at the workshop the diagram illustrated in Figure 10 prompted discussions concerning the possibility that winter inflows might cause ice-free areas of open water that would be significant sources of surface aeration. Third, such models can themselves be used to conduct a relatively crude impact assessment by using the best available information to estimate the direction and relative magnitude of change in each component or process as a result of a project. Fourth, such conceptual models may suggest additional ways of interpreting hydrologic variables from a biological perspective. And finally, conceptual models of all of the population processes important to fish, along with a description of available information relevant to those processes, would provide a sound and convenient basis for reassessing the potential for constructing a computerized simulation model at some time in the future.

IMPLICATIONS FOR MONITORING AND RESEARCH

Discussions at the workshop reiterated the importance of two processes, winter mortality and immigration, in determining the overall dynamics of fish populations at Arrowwood and Sand Lake Refuges. Winter mortality is apparently governed by dissolved oxygen concentrations, which are in turn largely a function of inflows and their dissolved oxygen content. Assessment of this aspect of the impacts of Garrison Diversion Unit will thus depend heavily on accurate estimates of these two parameters. However, at this point in time it appears that the critical need is for better information concerning what kinds of conditions produce what levels of winter mortality. Careful examination of Refuge narrative reports, in combination with gaging station records on inflows, might shed some light on this problem. Even a relatively crude

characterization of the kinds of conditions that lead, say, to high, medium, and low rates of mortality, and the frequency with which those conditions have occurred, would be useful. Additional monitoring information on dissolved oxygen levels, particularly in a year in which high mortality occurs, would also be desirable. The potential for holding winter flows in drainage canals or small reservoirs should also be explored. If this is physically possible, concerns about impacts on winter mortality would be reduced considerably. However, the benefits of this action would have to be carefully weighed against requests for winter flows in South Dakota.

Immigration is an important process by which fish populations on the refuges are reestablished following significant winter mortality. Current efforts to monitor movement of fish upstream from Jamestown Reservoir to Arrowwood Refuge should be continued. In addition, a similar effort should be initiated to monitor upstream movements into Sand Lake Refuge and, if possible, downstream movements into both Refuges. Consideration should also be given to monitoring factors (i.e., flow, water temperature) that may account for year-to-year variations in these movements.

Understanding of the dynamics of fish populations on the Refuges is also currently hampered by lack of information on the actual number and size of fish present. The present gillnetting program provides only an index to the abundance of relatively large fish. At the very least, the present program should be supplemented in two ways. First, additional sampling gear should be added to obtain information on the number and species composition of smaller fish, especially if impacts to these fish are of concern from the perspective of fish-eating birds. Second, population estimates (number, size, and species composition) should be obtained periodically. Such estimates would be useful both for correlating indices obtained through gillnetting with population size and for comparing populations with those known from experimental studies to cause damage to sago pondweed.

Ideally, of course, it would be desirable to abandon gillnetting entirely in favor of techniques that provide population estimates. For example,

estimates of population size in both spring and fall over a number of years would provide a great deal of information concerning growth, recruitment, and winter mortality under a variety of conditions. Although a program of this kind would probably be more expensive than the current monitoring effort, the information obtained would probably be considerably more useful in assessing the potential impacts of the Garrison Diversion Unit.

WILDLIFE

MODEL CONCEPTUALIZATION

The Wildlife workgroup conceptualized a modeling approach for use in assessing the impacts of the Garrison Diversion Unit on the wildlife of Sand Lake and Arrowwood National Wildlife Refuges.

There was considerable discussion concerning the indicator wildlife species that should be modeled. Waterfowl and other waterbirds were considered most important and species in these groups have been identified in management plans for both Arrowwood and Sand Lake Refuges. Species considered by the workgroup included the redhead duck (*Aythya collaris*), ruddy duck (*Oxyura jamaieensis*), mallard (*Anas platyrhynchos*), white-faced ibis (*Plegadis chihi*), black-crowned night heron (*Nycticorax nycticorax*), western grebe (*Aechmophorus occidentalis*), cormorants (*Phalacrocorax* spp.), egrets (*Egretta* spp.), white pelican (*Pelecanus erythrothynchos*), and muskrat (*Ondatra zebethica*).

Because there is overlap in habitat use, the workgroup believed that it was necessary to model only a subset of the above species. The list of species was reduced to four indicator species (Table 5) that were believed to represent different habitat use strategies and were thought, collectively, to be sensitive to land and water changes expected as a result of the Garrison Diversion project.

Table 5. Indicator species, performance measures, and driving variables discussed by the Wildlife workgroup.

Indicator species	Performance measure	Driving variables
Mallard	number of young fledged per pond	Water level fluctuations Area (surface area) of wet meadow Abundance of macro-invertebrates
Western grebe	number of young fledged per pond	Water level fluctuation Wave action (location of high energy zones) Area of submerged vegetation Abundance of macro-invertebrates Abundance of small fish
Diving ducks (fall migrants)	number of bird-days per pond	Area of submerged vegetation (sago pond-weed)
Redhead	number of young fledged per pond	Water level fluctuation Wave action (location of high energy zones) Area of emergent wet-land Abundance of macro-invertebrates

Approach

The workgroup members decided to represent populations of the four indicator species in the model using the performance measures listed in Table 5. The mallard, western grebe, and redhead reproduce on both Arrowwood and Sand Lake Refuges, and the suggested measures are indices of annual production. These production indices were defined on a pool basis because it was intended that the model structure be applicable to both Refuges by developing different parameter values for each separate pool. The performance measure for the diving ducks (fall migrants) was the number of bird-days per pool, measured during a defined fall period each year.

The performance measures were perceived to be sensitive to several variables associated with proposed irrigation return flows into the James River (Table 5). These driving variables are characteristics of the water column, vegetation, and fish populations and were requested from the other workgroups that dealt with these aspects of the James River system (Figure 4). Water level fluctuations would be required on at least a weekly time-step, whereas, for the other variables, a monthly time-step would be frequent enough. The Wildlife workgroup was asked, by the Vegetation workgroup, to provide estimates of sago tuber consumption by ducks, so that sago production could be modeled.

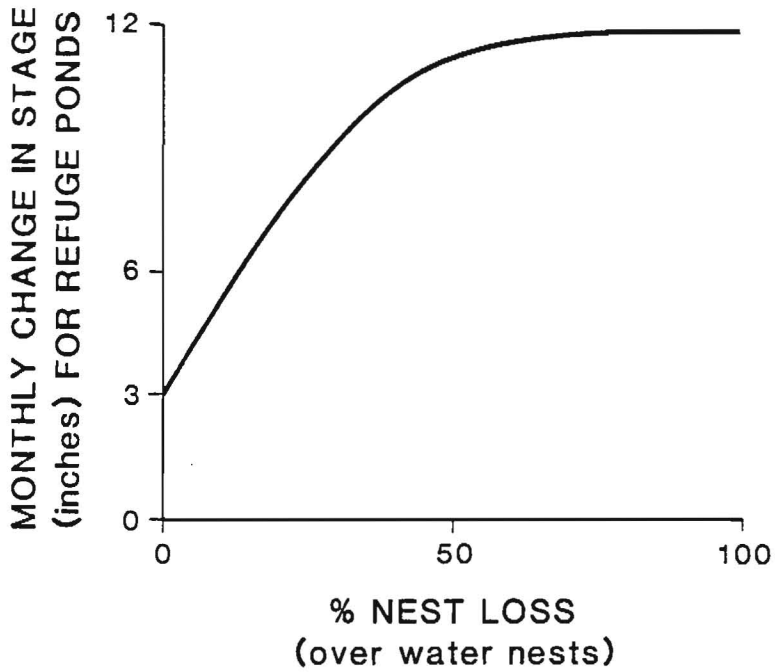
Mallard. Mallard production from year to year was conceived to be a function of processes occurring during three time periods: (1) prenesting; (2) nesting, including egg laying and incubation; and (3) growth and survival of ducklings to flight age.

The number of females at a production area during the prenesting period is a function of the size of the spring population, which is influenced by many variables that were beyond the scope of this modeling exercise. There was a consensus of the workgroup that areas with more suitable nest sites and food supplies would attract and hold a relatively higher number of breeding females. However, the forms of the relationships between nest and food suitability and the number of nesting females were not known. Instead, the

workgroup decided that it would be reasonable to assume a fixed number of females per pool at the beginning of each spring. Thus, the model would provide an index of production per female that could be compared from year to year to assess trends resulting from the proposed irrigation return flows.

Several factors influence production during the nesting period. First, the number of eggs per clutch is a function of the physiological condition of the female. Second, the percent of eggs that hatch (from a successful nest) is a function of weather conditions and physiological condition of the female, which is partially a function of water quality. Third, a number of nests are destroyed each year, particularly by predators. However, it did not seem feasible to model these factors because of the lack of data about the actual functional relationships. Instead, it seemed reasonable to focus the model on variables related to the proposed irrigation return flows. Specifically, the workgroup was willing to assume that the return flows would not alter (directly or indirectly) physiological condition of females, local weather patterns, or predator numbers and success. The model would incorporate fixed parameter values for clutch size, hatching percentage, and percentage of nests lost to predators. These parameter values would be determined from available data on both Refuges.

Given the preceding assumptions, the model would focus on nest losses caused by a change in the water surface elevations due to the irrigation flows. Mallards nest in three distinct areas: (1) over-water nesting in palustrine emergent wetlands, (2) ground nesting in wet meadows, and (3) ground nesting in upland cover types. It was assumed that water level fluctuations would have a negligible effect on the upland segment of the nesting population. Only females nesting over-water or in wet meadows would be subject to nest losses due to a change in water surface elevation. Nest losses could be estimated using functional relationships as depicted in Figure 11. These relationships indicate that nest losses occur only for <u>increases</u> in surface elevation; decreases in elevation were not believed to be significant. In order to estimate the total nest loss, percent loss (Figure 11) would be multiplied by an assumed nest density for both over-water and wet meadow areas and the products summed across both.



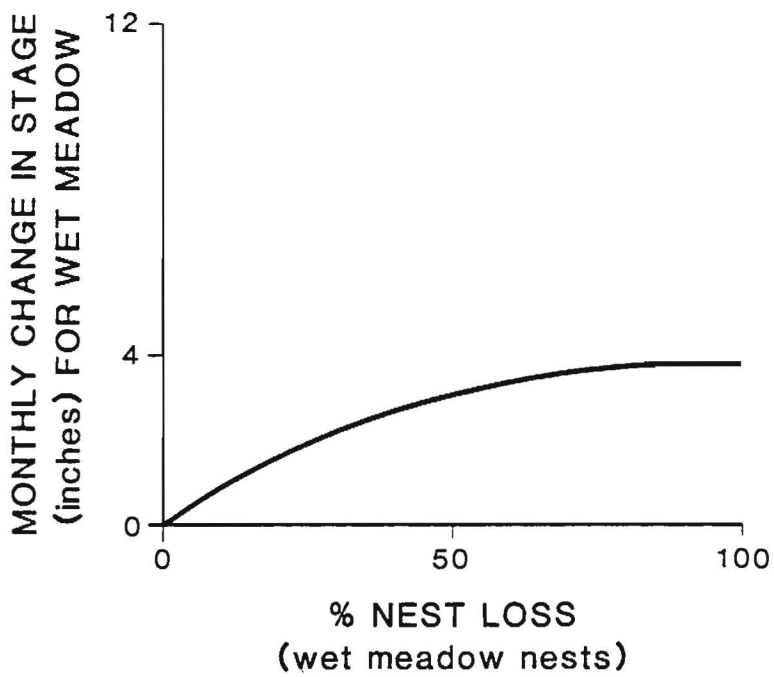


Figure 11. Hypothetical relationships between change in stage elevation and nest loss for mallards.

The functional relationships as depicted in Figure 11 estimate percent nest loss for a single time-step. However, mallards will renest depending on the time period. The proportion of females that will renest declines as it gets later in the year; and the mean clutch size declines with successive renesting attempts. The parameter values concerning renesting attempts shown in Table 6 are hypothetical and could be refined by using data available from nesting records in the study area. The renesting parameters in Table 6 combined with the nest loss functions in Figure 11 are combined as follows to yield an index of the number of young hatched.

1. Each nesting season begins in April with a given number of nests (e.g., 100).

2. Nest losses are computed at each time-step (assumed to be monthly). Those nests not lost to inundation are assumed to produce young during the time-step. Successful females do not renest that year.

3. Unsuccessful females renest depending on the parameters given in Table 6.

4. Step 2 is repeated for succeeding time-steps until all nests hatch or there is no renesting.

5. The annual production of hatchlings is the cumulative total of all successful nests (corrected for clutch size and hatching percentage) for all time-steps between April and July.

Table 6. Hypothetical parameter values for percent of renesting females and mean clutch size by month of nest loss.

Month of nest loss	Percent renest	Mean clutch size
April	100	12
May	100	12
June	50	10
July	0	--

The third production period that would be addressed by the model incorporates those variables that influence the survival of hatchlings to flight age. A large number of variables affect duckling survival, and the intent during the workshop was to address only the variables most strongly related to the proposed irrigation return flows. The Wildlife workgroup believed that the dominant link between return flows and duckling survival was the variation in the abundance of macroinvertebrate foods. Macroinvertebrate populations could potentially be affected directly (by changes in either water quantity or quality) or indirectly through decline in submerged vegetation on which invertebrates depend for food and cover.

There was little expertise in the Wildlife workgroup concerning macroinvertebrates. Consequently, the Fish workgroup was asked to provide information on invertebrate abundance, although it was not clear that they were in any better position to provide this data than was the Wildlife workgroup. The needed data were: (1) the abundance of macroinvertebrates in the top 18 inches of the water column, and (2) the abundance of invertebrates on the water surface (insects primarily). This information was discussed only in general terms, thus no units of measure were specified. Presumably, estimates of biomass per unit area (or volume) would be adequate. However, model limitations are related more to how this data would actually be used to estimate duckling survival.

The Wildlife workgroup could not develop a relationship between invertebrate abundance and duckling survival. Also, the opinion was that there were little available data concerning baseline abundance of invertebrates in both Refuges. Moreover, neither the Fish nor the Wildlife workgroup was able to develop relationships between invertebrate abundance and environmental changes that may occur as a result of irrigation return flows. Because of all the unknowns, the Wildlife workgroup could only make a plea for additional monitoring to measure baseline invertebrate populations and additional research to better understand the relationships between duckling survival and invertebrates.

Western grebe. Western grebe production from year to year was conceived to be a function of processes occurring during three time periods: (1) prenesting; (2) nesting, including egg laying and incubation; and (3) growth and survival of young to flight age. The structure of a model encompassing these time periods would be very similar to the mallard model previously described. Also, the data limitations and simplifications identified for the mallard model were the same for the western grebe model. Notably, the key assumptions were:

1. The number of prenesting females attracted to the Sand Lake system would be a function of the amount and suitability of nest sites and food resources. Instead of trying to model these variables, it seemed acceptable to assume a given number of females beginning each year. The beginning number would be determined by the following equation:

$$N_i = ND_{SL} \times A_{SL}$$

where N_i = the initial number of nesting females in May each year (assume all females initiate nests in May)

ND_{SL} = the empirically derived nest density in the Upper Sand Lake

A_{SL} = the area of palustrine emergent wetland in the Upper Sand Lake system.

This equation assumes that nest density is constant rather than a function of population size. Also, it was assumed that the principal western grebe production comes from a definable geographic area in Upper Sand Lake.

2. The survival of young from hatchling to flight age would be a function of food availability, defined as fish less than or equal to 3 inches in length. However, no data are available relating fish abundance to survival of juvenile grebes. Consequently, this time period was not addressed other than by recommendations for more research, data collection, and monitoring.

The workgroup developed a model for the nesting time period using the same concepts developed for the mallard model. Western grebe nests could be destroyed by rising water levels, and a hypothetical relationship is shown in Figure 12. Western grebes will renest if their nest is destroyed early in the time period, although clutch size will decrease for successive nesting attempts. Hypothetical parameters defining renesting are given in Table 7, and these could be replaced with actual data from nesting records. Each spring the model would compute the number of grebe hatchlings produced as follows.

1. In May (for Sand Lake) the number of nests potentially initiated would be computed by the preceding equation based on the area of palustrine emergent wetland that year (this is a potential number of nests based entirely on the amount of nesting habitat, and ignores other factors).

2. Each month, beginning in May, the number of nests lost to flooding would be computed using the relationship shown in Figure 12.

3. The cumulative total of all successful nests (corrected for clutch size) summed for May through July would be the total hatchling production each year.

There was some discussion about the possibility that wave action could destroy grebe nests in localized high energy zones. Specifically, there are two definable zones in Upper Sand Lake where emergent vegetation, at the edge of open bays, is subjected to prevailing winds between May and July. The amplitude of the waves in these zones is highly dependent on the amount of sago pondweed. When there is abundant sago (≥80% of the bays are covered by sago) the wave action is dampened, and grebe nest losses are negligible. However, when the coverage by sago drops below 20%, nest losses approach 50% in the high energy zones. The precise locations of the zones is variable from year to year due to variation in emergent vegetation patterns, but they were conceptually defined as 50 yard buffer strips of emergent vegetation along the windward side of Upper Sand Lake. The Refuge Manager at Sand Lake could delineate these zones if this concept were to be included in a model.

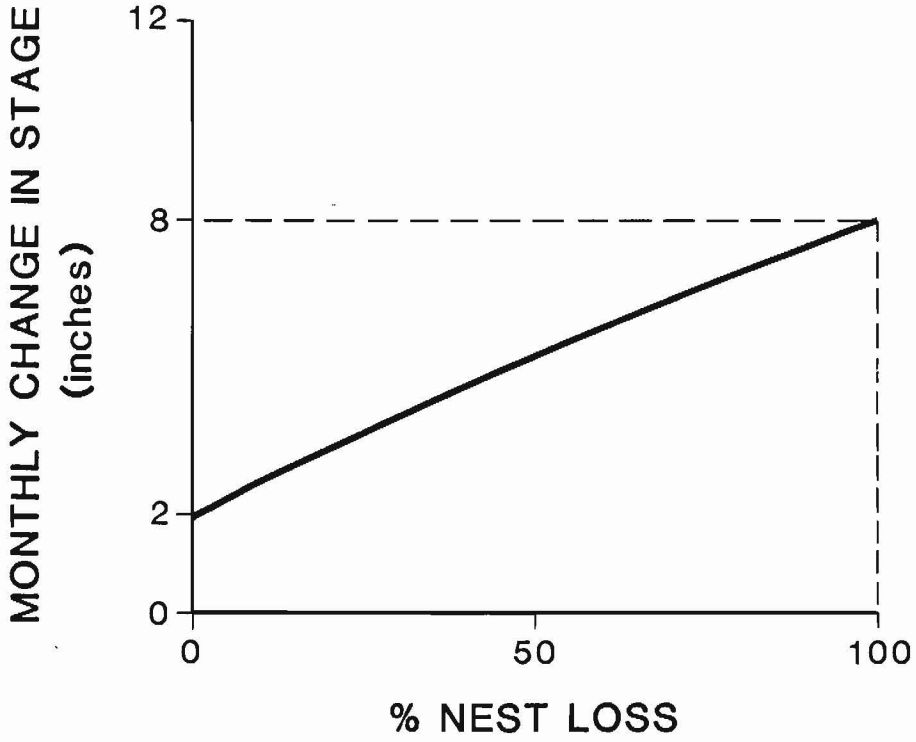


Figure 12. Hypothetical relationship between water level change and loss of western grebe nests.

Table 7. Hypothetical parameters for renesting attempts by western grebes.

Month of nest loss	Percent that renest	Mean clutch size
May	100	3
June	50	2.5
July	0	--

Redhead. The structure of the redhead model was identical to the mallard model in the sense that production was divided into three time periods: (1) pre-nesting, (2) nesting, and (3) survival and growth of hatchlings to flight age. Only the nesting period was modeled, the other two periods being subject to the same data limitations discussed previously for the mallard model.

Redheads are over-water nesters whose nests are subject to destruction by rising water levels. The hypothesized relationship between water level change and nest losses is shown in Figure 13. Redheads, like the previous two species, may also renest if a nest is lost to rising water levels. Example parameters depicting renesting rates and clutch sizes are given in Table 8.

The computations for estimating the annual production of hatchlings would follow the sequence outlined for the mallard. Each pool would start the nesting period (May) each year with a standard number of nesting females, all of which are assumed to initiate nests during the first month. Nest losses would be computed at each monthly time-step, and successful nests would be cumulatively totaled for the entire nesting season.

Diving ducks (fall migration). This indicator group is composed of four species: lesser scaup, greater scaup, redhead, and canvasback. The performance measure defined for these species was the total number of bird-days during the fall period (the actual months were not specified during the workshop). These four species are attracted to pools in the fall to feed primarily on sago pondweed. The plants are partitioned as follows: the scaup and redhead generally eat aboveground plant parts, and canvasbacks generally feed on the tubers.

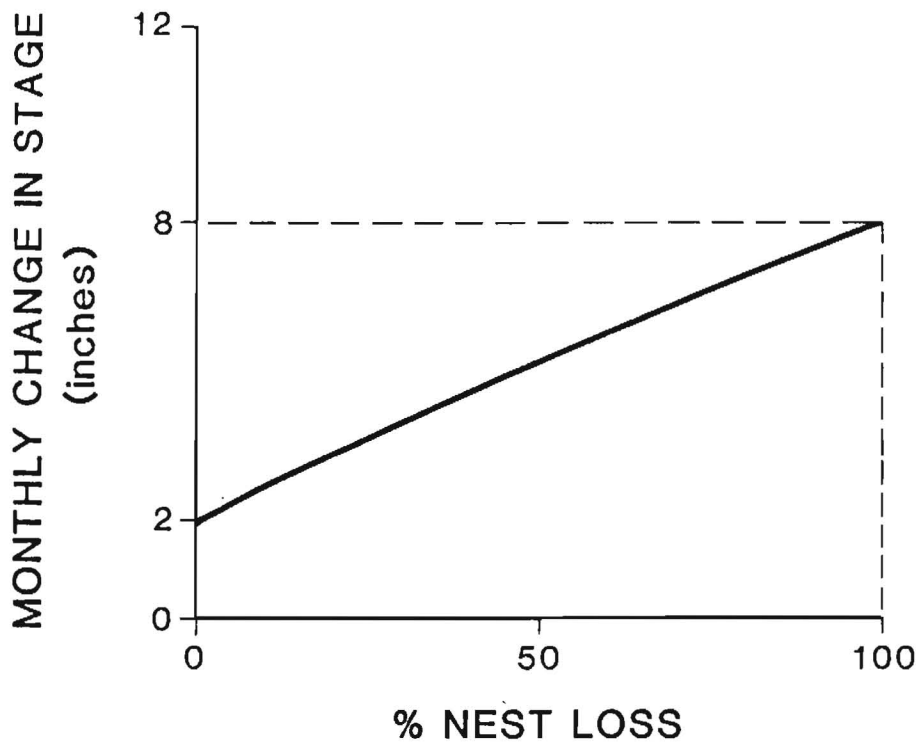


Figure 13. Hypothetical relationship between water level change and loss of redhead nests.

Table 8. Hypothetical parameters for renesting attempts by redheads.

Month of nest loss	Percent that renest	Mean clutch size[a]
May	75	--
June	35	--
July	0	--

[a]Not estimated; would be available from nesting records.

Workgroup participants believed it would be possible to develop a relationship between bird-use days and sago production using one of two possible strategies. First, it should be possible to construct an empirical relationship by collecting data on bird-use and sago abundance as part of the monitoring plan. The empirical approach was favored, but it also seemed feasible to develop a theoretical relationship based on annual production estimates for sago, energetics, and daily requirements of individual birds. The theoretical approach could be implemented more quickly if the model were to be constructed before further monitoring data could be collected.

The Vegetation workgroup requested that the Wildlife workgroup provide an estimate of the annual consumption of tubers by birds (Figure 4). This information was needed to model the annual dynamics of sago pondweed. The Wildlife workgroup believed that this information could be provided based on either: theoretical estimates of tuber consumption rates by canvasback or by conducting additional monitoring studies to estimate tuber depletion rates during the fall periods.

IMPLICATIONS FOR MONITORING AND RESEARCH

Monitoring needs. Several additions to the current monitoring plan were suggested in order to acquire data useful for implementing the conceived wildlife model.

1. Mallard nest density--need to have an estimate of the relative density of mallard nests in both over-water and wet meadow nesting areas. This data would be used to compute total nest losses due to water level rises and is needed because nests in the two areas show a different sensitivity to a given change in stage.

2. Wave action--need data on actual numbers of western grebe nests lost due to wave action, in specified areas, during years of high and low sago abundance.

3. Wet meadow delineation--need to add the delineation of wet meadows (mallard nesting area) to cover type maps so that the affects of different water regimes on mallard production can be more accurately estimated.

4. Tuber consumption--need to estimate annual tuber consumption by birds (principally canvasback). This could be accomplished by using exclosures and/or by sampling tubers prior to the arrival and after the departure of fall populations.

5. Insect/macroinvertebrate abundance--need to monitor invertebrates to detect changes that may occur with introduction of irrigation return flows.

Research needs. Several research needs were identified by the workgroup. These research efforts would help fill data gaps identified during the modeling exercise. These research studies would be long-term in nature and might not produce results timely for construction of a model for the James River study.

1. Invertebrate abundance vs. mallard and redhead duckling growth and survival--research is needed on duckling diets (size and species of food items), consumption rates, and indices relating insect availability to duckling growth and survival. Earlier studies performed by the Northern Prairie Wildlife Research Center have provided some information on this subject.

2. Fish abundance vs. growth and survival of young western grebes--this research would provide information similar to the above research on mallard and redhead ducklings.

CONCLUSIONS

A facilitated workshop was used to evaluate the feasibility and efficacy of developing a computer simulation model to estimate impacts of the Garrison Diversion Unit on Arrowwood and Sand Lake NWR's. The workshop brought together expertise and information from affected agencies and interest groups. The model building discussions also helped identify potential modifications to the monitoring program as well as some general suggestions concerning project features.

SIMULATION MODELING

Based on workshop discussions and past experience with impact analysis modeling, we recommend a phased modeling approach for the James River Refuges analysis. The first phase would involve two modeling efforts: (1) developing (or modifying) Arrowwood and Sand Lake NWR hydrology models and (2) developing a sago pondweed growth model.

The existing (or slightly modified) Sand Lake hydrology model, and a similar one to be developed for Arrowwood NWR, would be validated and used as a screening tool for potential impacts and the need for additional modeling. The Refuge models would predict weekly or monthly changes in pool elevations (and water depths), inflows to each pool, and other hydrologic indicators for six to eight GDU alternatives. The James River hydrology model would be used to generate the library of six to eight input files for these models. The output of each Refuge hydrology model run would then be evaluated in terms of potential fish and wildlife impacts. For example, the models could generate indices comparing the magnitude and timing of winter inflows for pre- and

postproject conditions. Fisheries biologists could then use these indices to better quantify their concerns relative to potential changes in the frequency of rough-fish kills. Similarly, fisheries biologists could compare historical data to predicted elevation differences between DePuy Marsh and the James River to determine possible changes in the frequency with which rough fish would be reintroduced into Arrowwood NWR. The Refuge hydrology models could also generate indices of the proportion of years with a >3 inch rise in water level during the nesting season, which waterfowl biologists could use to determine potential increases in nest destruction. A frequency distribution of water depths in various elevation bands in a pool could also be generated by a hydrology model. Wetland vegetation experts could compare such frequency distributions from pre- and postproject model runs and determine if there are likely to be long-term changes in the vegetation communities dominating those elevation bands. It might be useful to convene a small workshop of fisheries and wildlife biologists and Refuge staff to identify a set of these biologically relevant hydrologic indices to be generated by the Refuge hydrology models.

A sago pondweed growth model could be developed to integrate the James River Refuge monitoring data and existing sago literature. Initially, this model would run independently from the various hydrology models. This model development would be a useful exercise even if such a model were never incorporated into an overall impact analysis model. In addition to analyzing monitoring data and synthesizing literature, such a model might be used to address certain impact questions. For example, the model could be used to address the potential impacts of increased turbidity on sago during project construction (e.g., what might happen to sago if turbidity increases 5-fold over a 1-year period vs. what might happen if turbidity increases only 2-fold but over a 5-year period).

A second phase of simulation modeling would be undertaken only if the initial analyses of hydrologic outputs indicated significant potential problems and if monitoring and research projects had clarified some of the biological and physical processes that cannot be modeled reliably at the present time

(e.g., resuspension of sediments by carp, immigration and winter mortality of fish, loss of waterfowl nests due to wave action). Such an effort would develop an integrated impact assessment model with linked submodels for hydrology and water quality, vegetation, fish, and wildlife.

MONITORING AND RESEARCH

In order to address some of the biological and physical processes that are not presently well understood, the workgroups suggested a number of enhancements to the Refuge monitoring program. The Hydrology and Water Quality workgroup suggested increasing the number of turbidity monitors, sampling water temperature and dissolved oxygen in deeper water areas most likely to overwinter rough fish, dropping expensive analysis of some trace elements that have not been detected in the first 3 years of sampling, analyzing samples for some additional pesticides once best management practices for the Oakes test area have been developed, adding some composite or sequential samplers, and adding some biological monitoring stations as an additional check for pesticides, heavy metals, and trace elements. The workgroup also recommended that better area-capacity data be gathered for use in the Sand Lake hydrology model.

The Vegetation workgroup suggested modifying the monitoring program by: expanding the number of "permanent" monitoring stations and upgrading those stations to measure photosynthetically active radiation at several water depths; stratifying regular plot sampling by energy zones (wind, wave, fetch); modifying the biomass sampling procedure (e.g., use clipping) and replicating biomass samples at each sampling site; dropping the September sampling date, which occurs after peak sago biomass, and adding an early growing season date because of suspected sago sensitivity at this time; and surveying areas that are unusual with respect to sago distribution (e.g., patches that always or never seem to have sago). Also suggested were additional analyses of the Refuge monitoring data and data from other sites (e.g., Cottonwood Lake). These analyses would include: correlating euphotic zone with sago production,

comparing Hyatt Slough sites to sheltered sites in pools with carp, comparing sago in years with high versus low carp densities, conducting multivariate discriminant analyses to predict sago presence-absence, conducting multivariate regression analyses to predict sago biomass, and developing conversions between various turbidity measurements. Finally, the workgroup suggested two research studies: (1) greenhouse experiments to evaluate sago growth under various combinations of temperature, water level fluctuation, and available light; and (2) field exclosure-inclosure experiments to evaluate effects of rough-fish density on sago.

The Fish workgroup suggested a careful examination of Refuge narrative reports, in combination with gaging station records on inflows, to characterize the kinds of conditions that lead to various rates of winter-kill. Suggestions concerning the monitoring program focused on a better understanding of fish population dynamics, especially winter mortality and immigration. These included: increasing monitoring of dissolved oxygen levels, particularly in a year in which high mortality occurs; continuing to monitor fish movement upstream from Jamestown Reservoir into Arrowwood NWR and initiating similar efforts for upstream movement into Sand Lake NWR and downstream movements into both Refuges; and augmenting the present gillnetting program with sampling for smaller fish and periodic population estimates, or more preferably, replacing the gillnetting with techniques that provide population estimates.

The Wildlife workgroup suggested several additions to the present monitoring program. These included: estimating the relative density of mallard nests in over-water and wet meadow nesting areas; estimating the number of western grebe nests lost due to wave action, especially comparing differences between years of high versus low sago abundance; delineating wet meadows on the Refuge vegetation maps; estimating annual tuber consumption by birds, especially canvasback; and monitoring insect/macroinvertebrate abundance. The workgroup also suggested research studies to better understand the relationship between invertebrate abundance and the growth and survival of ducklings and the relationship between fish abundance and the growth and survival of young western grebes.

PROJECT FEATURES

Several general suggestions concerning modifications to project features can be made as a result of discussions at the workshop. These modifications, if feasible from an engineering or operational standpoint, would reduce impacts on Refuge system lands.

The success of Refuge attempts to periodically control rough fish is largely determined by the extent of inflows to Refuge pools during the winter months. The concern is that increased winter return flows from irrigated lands will prevent rough-fish control. If winter return flows could be held in the drains with small control structures or if a small "reregulation" reservoir of several thousand acre-feet capacity could be constructed above each Refuge, then the potential for rough-fish control would be unchanged or perhaps even enhanced. The benefits of such strategies should be carefully weighed against potential impacts on groundwater acquifers.

Another Refuge concern is increased turbidity in Refuge pools during project construction (downstream turbidity increased 5-fold during bridge construction in the Oakes test area) and its effect on sago pondweed production. It is possible that spreading construction activities over a number of years, with small increases in turbidity each year, would be less detrimental to sago than current construction plans, which could result in much more dramatic turbidity increases over a shorter time frame. Impacts on sago pondweed might also be reduced by scheduling construction to occur after the sprouting and elongation growth stages of sago in the spring. The possible benefits of such strategies might be explored with the sago growth model discussed previously (see CONCLUSIONS--SIMULATION MODELING).

The Refuges are also concerned that release of GDU project water in the late spring and early summer months will increase fluctuations of pool levels and destroy the nests of some over-water nesting birds (e.g., redhead ducks). This problem could be minimized or eliminated if the new structures to be installed at Arrowwood NWR were designed to be "quick acting" structures to reduce pool level fluctuations.

REFERENCES

Andersen, F.O. 1976. Primary production in a shallow water lake with special reference to a reed swamp. Oikos 27:243-250.

Anderson, M.G. 1978. Distribution and production of sago pondweed (Potamogeton pectinatus L.) on a northern prairie marsh. Ecology 59:154-160.

Bailey, R.O., and R.D. Titman. 1984. Habitat use and feeding ecology of postbreeding redheads. J. Wildl. Manage. 48:1144-1155.

Chamberlain, E.B., Jr. 1948. Ecological factors influencing the growth and management of certain waterfowl food plants on Back Bay National Wildlife Refuge. Trans. N. Am. Wildl. Conf. 13:347-355.

Crum, G.H., and R.W. Bachmann. 1973. Submersed aquatic plants of the Iowa Great Lakes region. Iowa State J. Res. 48:147-173.

Delos, C., W. Richardson, J. DePinto, R. Ambrose, P. Rodgers, F. Rygwelski, J. St. John, W. Shaughnessy, T. Faha, and W. Christie. 1984. Technical guidance manual for performing wasteload allocations, Book II streams and rivers, Chapter 3: Toxic substances. EPA 440/4-84-022.

Donigian, A.S., Jr., D.C. Beyerlein, H.H. Davis, Jr., and N.H. Crawford. 1977. Agricultural runoff management (ARM) model version 2: refinement and testing. EPA-600/3-77-098. U.S. Environ. Protection Agency, Athens, GA.

Donigian, A.S., Jr., and N.H. Crawford. 1976. Modeling nonpoint pollution from the land surface. EPA-600/3-76-083. U.S. Environ. Protection Agency, Athens, GA.

Garrison Diversion Unit Commission. 1984. Final Report.

Garrison Diversion Unit Reformulation Act of 1986, H.R. 1116, 99th Congress, Second Session. April 24, 1986.

George, R.L., and D.K. Mueller. 1985. Predicting dissolved solids concentrations in the James River, North and South Dakota. Hydrology Branch, Engineering and Research Center, U.S. Bureau of Reclamation, Denver, CO.

Haith, D.A., and L.J. Tubbs. 1981. Operational methods for analysis of agricultural nonpoint source pollution. Search: Agriculture. Cornell Univ. Agric. Exp. Sta. 1b, Ithaca, NY. 20 pp.

Hamilton, D.B., G.T. Auble, R.A. Ellison, and J.E. Roelle. 1986. Effects of flood control alternatives on the hydrology, vegetation, and wildlife resources of the Malheur-Harney Lakes Basin. NEC-86/20. National Ecology Center, U.S. Fish Wildl. Serv., Ft. Collins, CO. 85 pp.

Holling, C.S., ed. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York. 377 pp.

Howard-Williams, C., and M.R.M. Liptrot. 1980. Submerged macrophyte communities in a brackish South African estuarine-lake system. Aquat. Bot. 9:101-116.

Hutchinson, G.E. 1975. A treatise on limnology. Vol. III: limnological botany. John Wiley and Sons, New York. 660 pp.

James River Technical Committee. 1986. James River model studies.

Jenkin, P.M. 1936. Reports on the Percy Sladen Expedition to some Rift Valley lakes in Kenya in 1929-VII. Survey of the ecological results with special reference to the alkaline lakes. Ann. Mag. Nat. Hist. Ser. 10, 18:133-181.

Jensen, G.H. 1940. The relation of some physical and chemical factors of the soil to the productivity and distribution of certain waterfowl food plants at the Bear River Migratory Waterfowl Refuge. M.S. Thesis. Utah State University, Logan. 30 pp.

Jupp, B.P., and D.H.N. Spence. 1977. Limitations on macrophytes in a eutrophic lake, Loch Leven. I. Effects of phytoplankton. J. Ecol. 65:175-186.

King, D.R., and G.S. Hunt. 1967. Effect of carp on vegetation in a Lake Erie marsh. J. Wildl. Manage. 31:181-188.

Knisel, W.G., ed. 1980. CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. Conserv. Res. Rep. 26. Sci. and Education Adm., U.S. Dept. Agric., Washington.

Kulberg, R.K. 1974. Distribution of aquatic macrophytes related to paper mill effluents in a southern Michigan stream. Am. Midl. Nat. 91:271-281.

Nolen, S.L., J. Wilhm, and G. Howick. 1985. Factors influencing inorganic turbidity in a great plains reservoir. Hydrobiologia 123:109-117.

Phipps, R.L. 1979. Simulation of wetlands forest vegetation. Ecol. Model. 7:257-288.

Robel, R.J. 1961a. Water depth and turbidity in relation to growth of sago pondweed. J. Wildl. Manage. 25:436-438.

_____. 1961b. The effects of carp populations on the production of waterfowl food plants on a western waterfowl marsh. Trans. N. Am. Wildl. and Nat. Resour. Conf. 26:147-159.

Sigler, W.F. 1958. The ecology and use of carp in Utah. Utah State University, Logan Agric. Expt. Sta. Bull. 405. 63 pp.

Sklar, F.H., R. Costanza, and J. Day. 1985. Dynamic spatial simulation modeling of coastal wetland habitat succession. Ecol. Model. 29:261-281.

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish Wildl. Serv. FWS/OBS-84/15. v.p.

U.S. Department of the Interior. 1983. Final Supplemental Environmental Statement, Garrison Diversion Unit, Pick-Sloan Missouri Basin Program, North Dakota. Bureau of Reclamation, INT FES 83-35, Bismarck, ND.

U.S. Government Printing Office, Office of the Federal Register, National Archives and Records Administration, "Title 50: Code of Federal Regulations," October 1, 1985, as revised.

Velz, C.J. 1984. Applied stream sanitation, 2nd ed. Wiley, New York, NY. 800 pp.

Williams, J.R., and R.W. Hahn, Jr. 1978. Optimal operation of large agricultural watersheds with water quality constraints. Tech. Rep. 96. Texas Water Resour. Inst., Texas A&M Univ., College Station, TX.