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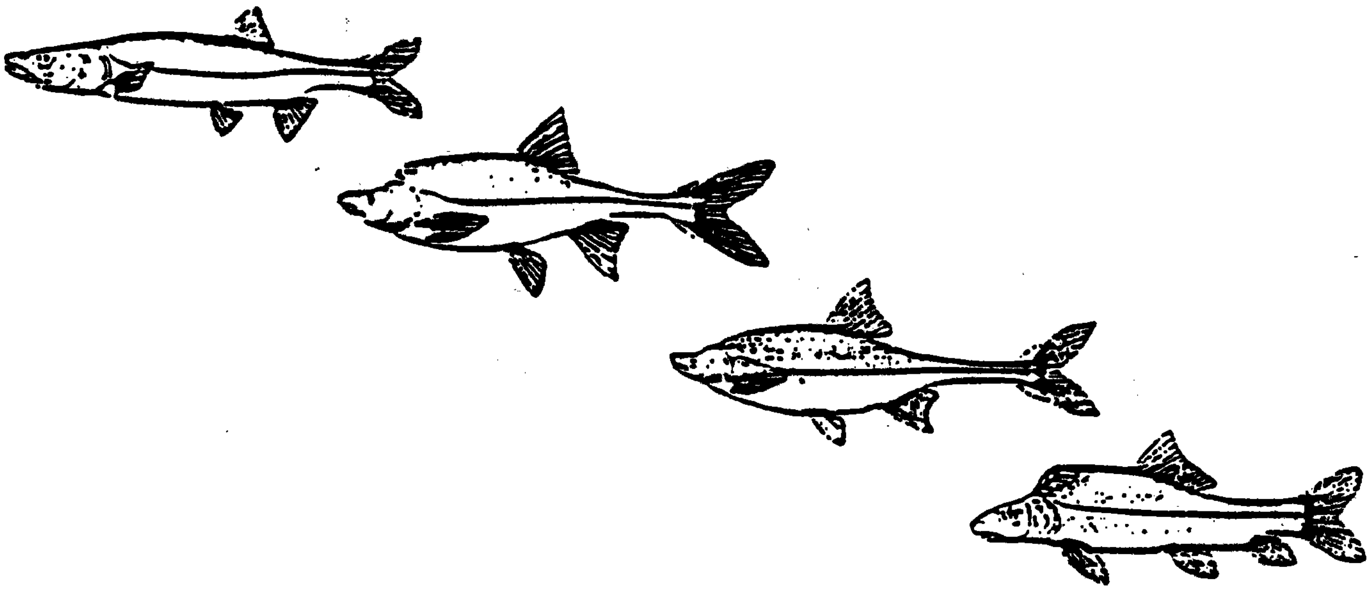
State of Colorado Hatchery Feasibility Study for Endangered Fishes of the Upper Colorado River Basin

Volume I Final Report



Prepared for:

Colorado Water Conservation Board

Prepared by:

URS Consultants, Inc.
FishPro, Inc.
Bio/West, Inc.
Leonard Rice Consulting Water Engineers, Inc.

September 1993

CO Water Cons. Board
1993

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Hatchery Feasibility Study
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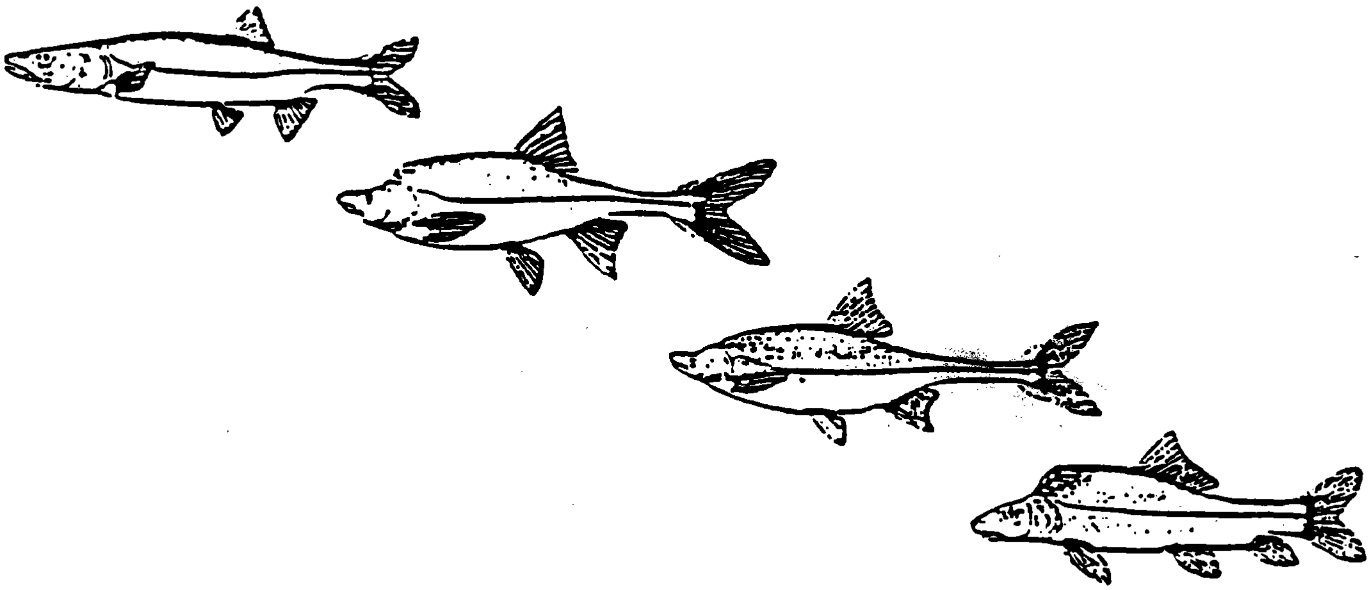

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TABLE OF CONTENTS

STUDY CONCLUSIONS

EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 LITERATURE REVIEW AND REVIEW OF EXISTING PROPAGATION FACILITIES

2.1 INTRODUCTION
2.1.1 Methodology
2.1.2 Conduct Field Visit to Dexter National Fish Hatchery
2.1.3 Work Product

2.2 SUMMARY OF PAST CULTURE TECHNIQUES
2.2.1 Brief History

2.3 CURRENT CULTURE TECHNIQUES
2.3.1 Extensive Fish Culture
2.3.2 Intensive Fish Culture

2.4 KEY CULTURE ISSUES AND DATA
2.4.1 Water Source
2.4.2 Water Temperature and Quality
2.4.3 Site-related Biological Design Criteria
2.4.4 Proximity to Fish Habitat
2.4.5 Geologic Considerations and Availability of Land
2.4.6 Design/Engineering Requirements
2.4.7 Construction Requirements
2.4.8 Land Ownership and Ease of Acquisition
2.4.9 Effluent Water Treatment Requirements
2.4.10 Site Accessibility
2.4.11 Utility Availability
2.4.12 Availability of Community Services
2.4.13 Incorporation into Existing Facility
2.4.14 Operation and Maintenance Costs

3.0 BIOLOGICAL DESIGN AND CULTURE TECHNIQUES

3.1 INTRODUCTION
3.1.1 Methodology
3.1.2 Factors to be Evaluated

TABLE OF CONTENTS (con't)

3.2 FISH REQUIREMENTS
- 3.2.1 Broodstock and Refugia Needs
- 3.2.2 Research and Augmentation Needs

3.3 BIOLOGICAL PERFORMANCE DATA
- 3.3.1 Water Quality
- 3.3.2 Species Performance
- 3.3.3 Culture Facilities

3.4 SPECIES PRODUCTION OPTIONS
- 3.4.1 Hatchery Modeling

3.5 FISH HEALTH
- 3.5.1 Documented Diseases
- 3.5.2 Disease Epizootiology, Treatment and Control
- 3.5.3 Nutritional Diseases
- 3.5.4 Miscellaneous Health Factors
- 3.5.5 Other Diseases of Concern
- 3.5.6 Regulations and Permits
- 3.5.7 Disease Control

3.6 OTHER FISH PRODUCTION CONCERNS
- 3.6.1 Predation
- 3.6.2 Escapement
- 3.6.3 Security
- 3.6.4 Genetic Monitoring

4.0 SITE IDENTIFICATION AND INITIAL SCREENING

4.1 INTRODUCTION
- 4.1.1 Background
- 4.1.2 Methodology

4.2 SITE IDENTIFICATION

4.3 SCREENING CRITERIA
- 4.3.1 Site Selection Factors

4.4 DATA COLLECTION
- 4.4.1 Data Sheet Development, Distribution and Results

4.5 SITE SCREENING

TABLE OF CONTENTS (con't)

5.0 SITE EVALUATION AND FINAL SCREENING

5.1 INTRODUCTION
- 5.1.1 Methodology

5.2 POTENTIAL HATCHERY SITES
- 5.2.1 Sites for Final Screening
- 5.2.2 Site Data Collection

5.3 SELECTION CRITERIA

5.4 SITE SCREENING
- 5.4.1 Methodology

6.0 HATCHERY DESIGN AND ESTIMATED COSTS

6.1 INTRODUCTION
- 6.1.1 Background
- 6.1.2 Methodology
- 6.1.3 Work Products

6.2 HATCHERY FUNCTIONS

6.3 DESIGN CRITERIA
- 6.3.1 Projected Site Conditions
- 6.3.2 Fish Production Facility Requirements
- 6.3.3 Broodstock and Refugia Facility Requirements
- 6.3.4 Research Facility Requirements
- 6.3.5 Visitor and Educational Opportunities
- 6.3.6 Disease Control and Quarantine Facilities

6.4 WATER TREATMENT PROCESS
- 6.4.1 Surface Water
- 6.4.2 Well Water
- 6.4.3 Effluent

6.5 FACILITY LAYOUT

6.6 COST ESTIMATES

7.0 ISSUES AND PERMITS

GLOSSARY OF TERMS

LIST OF TABLES

2.1 Library of Pertinent Culture Information on the Colorado River Endangered Fish
2.2 A List of Contacts and Summary of Responses on Culture-Related Information
2.3a-e A Summary of Past Culture Efforts for Colorado Squawfish
2.4a-e A Summary of Past Culture Efforts for Humpback Chub
2.5a-d A Summary of Past Culture Efforts for Bonytail Chub
2.6a-f A Summary of Past Culture efforts for Razorback Sucker
2.7 Summary of Extensive Culture Techniques for the Four Colorado River Endangered Fish
3.1 Hatchery Research and Production Needs
3.2 Threatened and Endangered Broodstock Requirements
3.3 Incubation Timing and Fry Size Relative to Optional Incubation Temperature
3.4 Survival Percentages for Colorado River Endangered Species
3.5 Numbers, Sizes and Species of Fish to be Cultured Under Six Scenarios
3.6 Hatchery Simulation Model - Input Descriptions
3.7 Productions Scenario 1 - Flow and Rearing Unit Requirements - Constant Temperatures
3.8 Production Scenario 1 - Flow and Rearing Unit Requirements - Average River Temperatures
3.9 Production Scenario 2 - Flow and Rearing Unit Requirements - Constant Temperatures
3.10 Production Scenario 2 - Flow and Rearing Unit Requirements - Average River Temperatures
3.11 Production Scenario 3 - Flow and Rearing Unit Requirements - Constant Temperatures
3.12 Production Scenario 3 - Flow and Rearing Unit Requirements - Average River Temperatures
3.13 PWG Production and Research Request Scenario 4 - Flow and Rearing Unit Requirements - Constant Temperatures
3.14 PWG Production and Research Request Scenario 4 - Flow and Rearing Unit Requirements - Average River Temperatures
3.15 Production Scenario 5 - Maximum Efficiency - Flow and Rearing Unit Requirements - Elevated Temperatures and Photoperiod Control
3.16 Production Scenario 6 - Intensive/Extensive Culture - Flow and Rearing Unit Requirements - Constant Temperatures
3.17 Production Scenario 6 - Intensive/Extensive Culture - Flow and Rearing Unit Requirements - Average River Temperatures
3.18 Pathogens Positively Identified in Artificially Cultured Colorado Squawfish
3.19 Pathogens Positively Identified in Wild Colorado Squawfish
3.20 Pathogens Positively Identified in Artificially Cultured Humpback Chub
3.21 Pathogens Positively Identified in Wild Humpback Chub
3.22 Pathogens Positively Identified in Artificially Cultured Bonytail Chub
3.23 Pathogens Positively Identified in Wild Bonytail Chub
3.24 Pathogens Positively Identified in Artificially Cultured Razorback Sucker

LIST OF TABLES (con't)

3.25 Pathogens Positively Identified in Wild Razorback Sucker
3.26 Summary of Diseases and their Therapy and Control
3.27 Diseases and Pathogens of Related Species
4.1 Study Site List - Original Sites Included in Hatchery Feasibility Study
4.2 Sites Not Included in the Hatchery Feasibility Study
4.3 Site Selection Criteria
4.4 Data Sheet Summary
4.5 Final Screening Site List
4.6 Deleted Site List
5.1 Final Screening Site List
5.3 Site Evaluation Matrix
6.1 Flow and Rearing Unit Requirements - Intensive Culture
6.2 Flow and Rearing Unit Requirements - Extensive Culture
6.3 Threatened and Endangered Broodstock Requirements
6.4 Broodstock Location Summary
6.5 Capital Cost Estimate of Nutrition Laboratory
6.6 Costs and Required Land - Scenario 2 - Warm Well Water
6.7 Costs and Required Land - Scenario 2 - Cold Well Water
6.8 Costs and Required Land - Scenario 2 - Surface Water
6.9 Capital Cost Estimate Comparison for Total Recovery Facility
6.10 Capital Cost Estimate Comparison for Core Facility

LIST OF FIGURES

2.1 Approximate Time Schedule for Culture of the Colorado River Endangered Fist at the Dexter National Fish Hatchery
5.1 Site Location Map
6.1 Nutrition Laboratory
6.2 Surface Water - Flow Diagram
6.3 Cold Well Water - Flow Diagram
6.4 Warm Well Water - Flow Diagram
6.5 Effluent Treatment Plan Schematic

APPENDICES TABLE OF CONTENTS

Appendix A: Annotated Bibliography of Pertinent Culture Information on the Colorado River Endangered Fish

Appendix B: File of Personal Communications with Key Fish Culturists
Site Visits:
Dexter National Fish Hatchery
Logan Experimental Fish Hatchery
Utah Cooperative Fishery Research Unit (USU)

Appendix C: Computerized Retrieval System for Culture of the Colorado River Endangered Fish

Appendix D: Site List Owners/Contacts Names and Addresses

Appendix E: Site Data Collection Sheet

Appendix F: Final Screening Site Descriptions

Appendix G: Facility Design Requirement Bioprograms

Appendix H: Facility Layout Drawings

Appendix I: Estimates of Probable Costs

HATCHERY FEASIBILITY STUDY

STUDY CONCLUSIONS

- A major difference between sites is whether warm ground water, cold ground water, or surface water is available.

- The type of water supply and the water temperature significantly affect land area requirements, facility layout and ultimately construction and operation costs.

- Development costs are significantly affected by the number of fish produced and whether a total recovery facility or only a core facility is built.

- This feasibility study should be the basis for discussion between the State of Colorado, the U.S. Fish and Wildlife Service, and other Recovery Program participants on the following issues:

  a. Should an endangered fish hatchery/recovery facility be built?

  b. Where in Colorado should such a facility be located?

  c. What components should such a facility include?

  d. How should such a facility be funded?

  e. Who should operate the facility?

  f. If a decision is made to proceed with the development of a hatchery/recovery facility in Colorado, the screening criteria and assumptions of culture techniques, fish production numbers and other design factors need to be re-evaluated and finalized.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY
TABLE OF CONTENTS

Page

Introduction 1

Review of Existing Literature and Facilities 2

Biological Design and Culture Techniques 2

Site Identification and Initial Screening 3

Site Evaluation and Final Screening 4

Recovery Facility Design 7

Costs 13

Issues and Permits 19

Site Descriptions 20

Glossary of Terms 23

HATCHERY FEASIBILITY STUDY
EXECUTIVE SUMMARY

INTRODUCTION

In 1989, the Colorado Legislature authorized the Colorado Water Conservation Board (CWCB) to prepare a feasibility study of fish culture techniques[1] and fish hatchery construction and operation for the propagation in Colorado, of endangered fish of the Upper Colorado river basin. The four endangered species are the Colorado squawfish *(Ptychocheilus lucius)*, humpback chub *(Gila cypha)*, bonytail chub *(Gila elegans)*, and razorback sucker *(Xyrauchen texanus)*.

The purpose of this Executive Summary is to provide a brief overview of the Final Report of this study. The Final Report and technical appendices include more detailed site information as well as hatchery simulation model printouts, design layouts and various tabulations of facility design information and costs. The proposed facility, which is cumulatively known as a recovery facility, could ultimately consist of a propagation component, a broodstock and refugia holding facility, and a research facility.

This study addresses only biological, technical and engineering design issues. Economic, social and philosophical issues related to the propagation and augmentation of endangered fish populations are beyond the scope of this study. However, these issues should be considered in deciding whether an endangered fish recovery facility should be built and where such a facility should be located.

The study evaluated sites in Colorado for a recovery facility and included a feasibility level design that will aid the State of Colorado and the Recovery Program in determining where a site should be located and what its construction and operation costs will be. This study is a unique undertaking as such a facility would provide propagation, research, broodstock holding, refugia and public educational opportunities for endangered fish species. There are uncertainties about culture and large scale production techniques for these fishes, therefore some assumptions were made as to how this type of facility should be developed and operated.

The study was performed by a team of consulting engineers and biologists and a Technical Advisory Committee (TAC). The TAC was responsible for overall direction of the study and was composed of staff representatives from the CWCB, Colorado Division of Wildlife (CDOW) and the U. S. Fish and Wildlife Service (USFWS). The Consultant Team consisted of URS Consultants, Inc., the prime contractor and responsible for site evaluation and engineering; Fish Pro, Inc., specializing in fish biology and hatchery design; Bio/West,

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[1]Culture techniques - a definition of this and other scientific terms used in this Executive Summary are included in the glossary.

Inc., specializing in fish biology and life history techniques and Leonard Rice Consulting Water Engineers, specializing in the investigation of the water supply aspects of the study.

The primary study tasks are briefly described in the following sections and are as follows:

- Review of Existing Literature and Facilities
- Biological Design and Culture Techniques
- Site Identification and Initial Screening
- Site Evaluation and Final Screening
- Recovery Facility Design
- Costs
- Issues and Permits

REVIEW OF EXISTING LITERATURE AND FACILITIES

The purpose of this task was to gather, review and analyze available literature and other information relevant to fish culture, propagation techniques and facility design for these four endangered fish species, as there was no centralized data base for culture information prior to this study. Information was compiled from: 1) personal and public sources identified by the study team; 2) local, state and federal agencies; 3) a field visit to the USFWS-Dexter National Fish Hatchery; 4) visits and interviews with propagation specialists from the USFWS, the CDOW, and the State of Utah; and 5) telephone interviews with key contacts identified by the TAC and members of the Consultant Team.

The information and data collected from these sources were assembled into five work products designed to document and provide ease of access to the available information. These work products include:

1) an alphabetized list and annotated bibliography of pertinent literature;
2) a catalogued library of pertinent literature;
3) a file of personal communications with key fish culturists;
4) a computerized data retrieval system with key culture data and subject issues; and,
5) a study report which presents pertinent information.

BIOLOGICAL DESIGN AND CULTURE TECHNIQUES

This study task evaluated factors to be used as specific design criteria for a recovery facility capable of providing for propagation, research, refugia and broodstock facilities for the four endangered fish species. The hatchery design criteria were developed through the following:

1) agency and study team consultation;
2) interpretation and analysis of available literature and information;

3) development of a hatchery simulation model to predict preliminary siting and design criteria. The model uses hatchery production goals, water supply and water quality parameters to produce output information of water flow needs, required number of rearing ponds, feed volumes, and other facility requirements to meet specific production goals;
4) compilation of known and suspected fish diseases for each of the endangered species and related species; and,
5) integration of prior experience on fishery facility design and utilization of concepts to provide state-of-the-art methodologies for creating a fully integrated recovery facility.

SITE IDENTIFICATION AND INITIAL SCREENING

The TAC and the Consultant Team compiled a list of 33 potential recovery facility sites located throughout the state. The 33 sites included existing hatchery facilities and undeveloped sites that had potential for recovery facility development. An information request form was mailed to each of the contacts for the 33 sites. Site information was requested, including: available water sources; flow rates; water quality parameters for temperature, dissolved solids and pH; water rights information; description of land and improvements; potential hazards such as flooding and availability of community services. Development of the information request form and site screening methodology was based upon technical issues related to biological, engineering and operational considerations.

Site selection criteria and screening factors were developed as the basis to review the 33 sites, and included: water source, flow rate, water quality, site physical characteristics, biological considerations, locational factors, and the estimated cost range for construction, operation and maintenance for a hatchery facility.

The initial screening methodology originally was intended to be based on a numerical rating system applied to each of the general site selection criteria factors described above, using the data obtained from the information request forms and other preliminary independent investigations. Due to incomplete or unavailable data, application of the numerical rating criteria for site screening was not feasible. Therefore, each of the sites was objectively reviewed and evaluated by the Consultant Team and the TAC, and, based on the relative rating with the site selection criteria, the initial 33 sites were screened to 16, and are listed in Table 1 and shown in Figure 1. The Site ID numbers included in the table were randomly assigned prior to the study and do not indicate any ranking of the sites. A brief description of the 16 potential sites is provided at the end of this Executive Summary.

TABLE 1

STUDY SITE LIST FOLLOWING THE INITIAL SCREENING

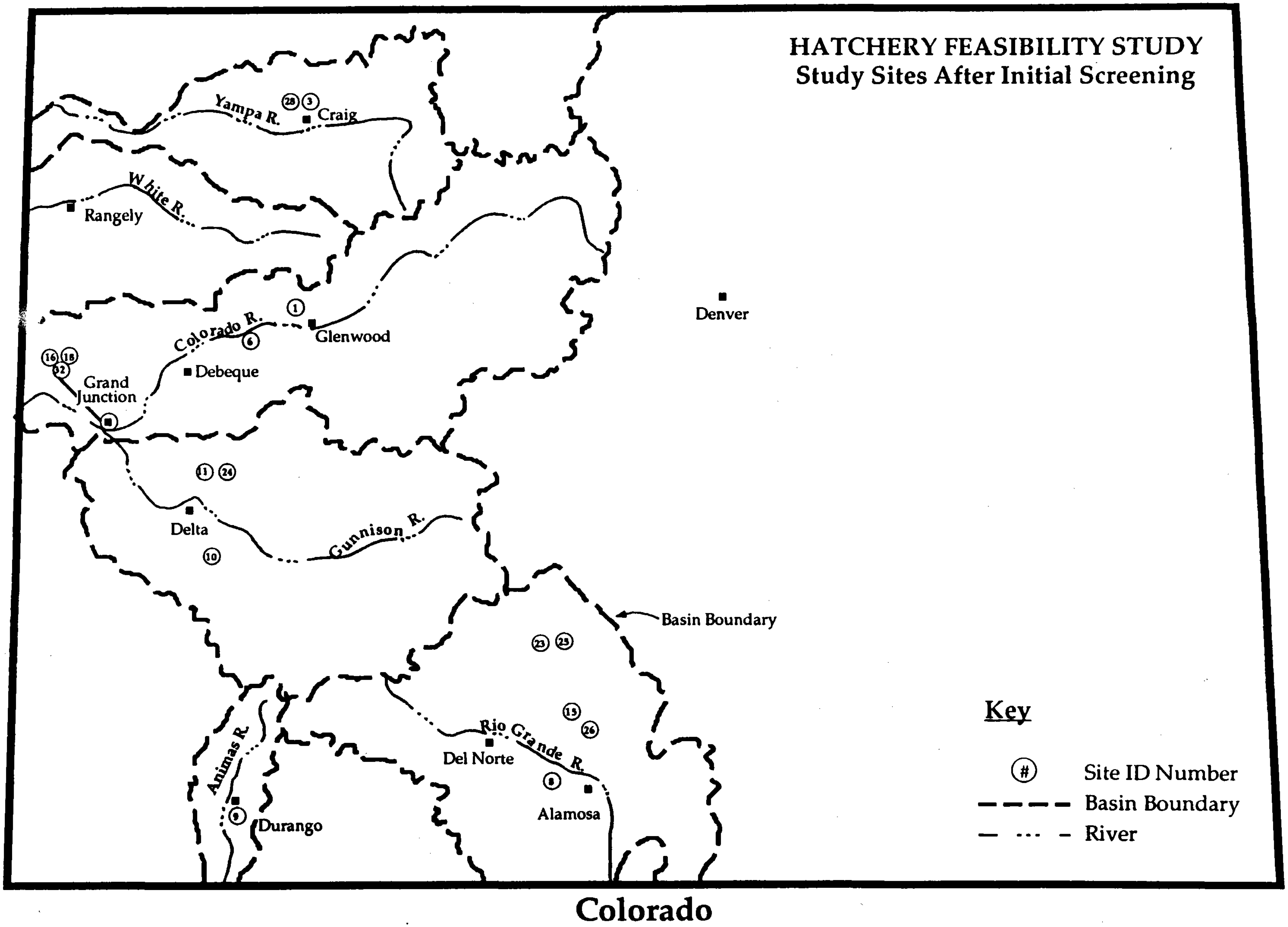
Site ID Number	Site Name and Location
1.	Glenwood Desalinization Facility (near Glenwood Springs, CO)
2.	CO-Ute Plant/CIRG Site (near Craig, CO)
6.	Rifle Falls SFH (near Rifle, CO)
8.	Clines Fish Hatchery (Monte Vista, CO)
9.	Putnam Fish Hatchery (Durango, CO)
10.	Silver Springs Trout Farm (Montrose, CO)
11.	McMillan's Trout Farm (Hotchkiss, CO)
15.	Crystal Properties (near Hooper, CO)
16.	Horsethief Site (near Grand Junction, CO)
18.	Walter Walker State Wildlife Area (Grand Junction, CO)
23.	Rangeview Trout Ranch (Saguache, CO)
24.	Crystal Springs Ranch and Trout Farm (near Hotchkiss, CO)
25.	Russell Lakes SWA (Saguache, CO)
26.	Closed Basin Project (near San Luis Lake, CO)
28.	Wastewater Treatment Plant (near Craig, CO)
32.	Grand Junction Site #1 (Summerville Ranch, CO)

SITE EVALUATION AND FINAL SCREENING

The purpose of the site evaluation task was to screen the 16 sites listed in Table 1 to the three highest ranking sites for which feasibility level hatchery/recovery facility designs would be developed in a later task. As with the initial site screening task, the site evaluation and screening criteria used for evaluating these remaining 16 sites was based on input from the TAC and Consultant Study Team. The following screening methodology was used:

- Each of the potential sites was visited to confirm and supplement site information gathered from the information request forms and other sources.
- More detailed site criteria were developed in the areas of water supply, water temperature and water quality, site physical factors, biological considerations, site location factors and estimated construction and operation costs.
- A system was developed for evaluating and rating each of the potential sites against technical criteria. The sites were then ranked based on the evaluation results.

FIGURE 1


HATCHERY FEASIBILITY STUDY
Study Sites After Initial Screening
Yampa R.
Craig
White R.
Rangely
Colorado R.
Glenwood
Debeque
Grand Junction
Denver
Gunnison R.
Delta
Basin Boundary
Animas R.
Durango
Rio Grande R.
Del Norte
Alamosa
Key
Site ID Number
Basin Boundary
River
Colorado

The evaluation criteria were grouped into six major categories: water source; water quality, including temperature; site physical factors; biological considerations; locational factors and probable cost. Key guidelines used in setting the value for each of the criteria were that the maximum possible point total for any site was set at 100, and the criteria categories (e.g. water source, water quality, etc.) were weighted, such that there was a limit to the maximum number of points which could be received for any criteria category or subcategory. In addition, a site could receive a fatal flaw rating if a site condition was determined to be not acceptable. Site descriptions are provided at the end of this report, including the basis of any fatal flaw determinations. The six rating categories and the point values assigned to each category are shown in Table 2.

TABLE 2

RATING FACTOR CATEGORIES

Factor Category	Maximum Point Value
Water Source	25
Water Quality	20
Site Physical	20
Biological Considerations	15
Locational Factors	10
Probable Cost	10

The type of water source was the highest rated criteria category due to its impact on the development of a hatchery/recovery facility and the propagation of fish. Groundwater is preferred for rearing hatchery fish because it is generally free of fish diseases which are prevalent in surface water supplies. This is extremely important to hatchery operations, especially for a hatchery dedicated to the holding and propagation of endangered species. For this reason, groundwater supplies were given higher point values than surface water supplies. However, surface water supplies tend to provide the most genetically compatible water supply as it more closely resembles natural conditions.

Water temperature was also a highly rated criteria because of the importance of water temperature at different life stages and growth rates. Warm water is also a preferred water source because the endangered fish need warm water for spawning. Warm water also provides improved survival and enhances growth rates under intensive culture conditions. Geothermal warm water offers a significant operational cost advantage over heating cold water supplies.

A matrix was developed to tabulate the rating criteria, allowable rating points and the evaluation scores for each of the sites. The matrix is presented as Table 3. Site scores for each criteria are totaled at the bottom of the matrix. Sites which best meet the evaluation factors have higher scores.

TABLE 3

SITE FACTOR MATRIX

SITE NAME AND NUMBER		GLENWOOD	COL UTE	RIFLE FALL	CLINES	PUTNAM	SILVER SPG	MCMILLANS	CRYSTAL PR	HORSETHIEF	WALTER WLK	RANGEVIEW	STROH	RUSSELL L	CLOSED BAS	CRAIG	GRAND JUNC
CRITERIA	POINT VALUE	1	3	6	8	9	10	11	15	16	18	23	24	25	26	28	32
A 0 WATER SOURCE (GPM)	**MAX 25**	**14**	**6**	**8**	**20**	**12**	**9**	**19**	**18**	**10**	**8**	**6**	**22**	**20**	**18**	**11**	**2**
A a 1 GROUND OVER 1500	15–20				20	16		19	20				18	20	20		
A a 2 GROUND 501-1500	10–15	14					11					10					
A a 3 GROUND 0-500	0–10		0	0						0	0					3	0
A 1 SURFACE OVER 1500	7–10			10						10	10		8			10	4
A 2 SURFACE 501-1500	4–6		6					4									
A 3 SURFACE 0-500	0–3	0			0	0	0		0			0		0	0		
A c 1 WATER RELIABILITY	FF,–6 TO 0	FF	FF	–2	0	–4	–2	–4	–2	0	–2	–4	–4	0	–2	–2	–2
B 0 WATER QUALITY	**MAX 20**	**11**	**12**	**5**	**14**	**2**	**3**	**2**	**15**	**8**	**5**	**10**	**6**	**15**	**16**	**10**	**6**
B a 1 TEMP 68-74	6–10	10			9				9								
B a 2 TEMP 50>68	1–5		3	1		1	1	1		1	1	3	2	5	1	1	0
B a 3 TEMP >74 ONLY	0																
B a 4 TEMP <50 ONLY	0																
B a 5 WARM WATER POTENTIAL	0–10	0	4	1	1	1	1	1	1	1	1	4	1	5	9	4	1
B 1 TDS 1100-4100	3–4																
B 2 TDS <1100	0–2	0	1	1	1	1	1	1	2	2	0	1	1	1	3	2	0
B 3 TDS >4100	0																
B c 1 pH 7.2-8.2	3–4		4	4	3		3		3	4	4		4	4	4	4	4
B c 2 pH <7.2	0–2	2				2		2				2					
B c 3 pH >8.2	0–2																
B 1 POTENTIAL FOR CONTAMINATION	FF,–5 TO 0	–1	0	–2	–1	–3	–3	–3	–1	0	–1	–1	–3	–1	–1	–1	0
B e 1 EFFLNT TRTMNT NEEDS	0–2	0	0	0	1	0	0	0	1	0	0	1	1	1	0	0	1
C 0 SITE PHYSICAL	**MAX 20**	**11**	**8**	**12**	**15**	**15**	**13**	**8**	**15**	**8**	**10**	**15**	**10**	**16**	**15**	**12**	**13**
C a 1 LAND AREA >40 ACRES	4–5				4	5			5			5	4	5	5	4	5
C a 2 LAND AREA 20-40 ACRES	2–3	2	FF	2			3	4		2	2						
C a 3 LAND AREA <20 ACRES	FF																
C 1 LAND AVAILABILITY	FF, 0–3	2	1	3	2	2	2	2	2	1	2	2	2	3	3	3	3
C c 1 LAND ACCESSABILITY/USEABILITY	FF, 0–2	2	2	2	2	2	2	FF	1	0	2	2	0	2	1	2	0
C 1 EXISTING FACILITIES	0–2	1	1	1	1	1	1	0	1	1	1	1	0	1	1	0	0
C e 1 DESIGN/CONSTRUCTION	0–2	0	0	0	2	1	1	0	2	0	0	1	1	1	1	1	1
C f 1 GEOLOGIC FACTORS	FF–2	2	2	2	2	2	2	0	2	1	0	2	1	2	2	0	2
C 1 ELEV <4000 FT	4																
C 2 ELEV 4000-5000 FT	3									3	3						
C 3 ELEV >5000 FT	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2
D 0 BIOLOGICAL CONSIDERATIONS	**MAX 15**	**9**	**8**	**7**	**3**	**8**	**8**	**7**	**7**	**6**	**6**	**3**	**7**	**3**	**2**	**7**	**7**
D a 1 HABITAT PROXIMITY TO BASIN	0–3	3	3	3	0	3	3	3	0	3	3	0	3	0	0	3	3
D 1 ESCAPEMENT	0–5	2	2	1	3	2	2	1	5	1	1	3	2	3	0	1	1
D c 1 PREDATION	0–5	4	3	3	0	3	3	3	2	2	2	0	2	0	2	3	3
E 0 LOCATIONAL FACTORS	**MAX 10**	**10**	**9**	**7**	**8**	**10**	**9**	**8**	**7**	**9**	**10**	**8**	**8**	**8**	**9**	**8**	**8**
E a 1 THREE PHASE POWER	0–2	2	2	2	2	2	1	1	2	2	1	1	1	1	2	2	1
E 1 NATURAL GAS	0–2	2	2	1	0	1	1	1	1	0	1	1	1	1	1	2	1
E c 1 COMMUNITY SVCS	1–2	2	2	1	2	2	2	1	1	1	2	2	2	2	2	1	1
E 1 INFO & ED OPPURTUNITIES	0–3	3	2	1	2	2	2	2	1	1	3	2	1	2	2	2	1
E e 1 CLIMATIC FACTORS	0–5	4	1	2	2	4	3	3	2	5	5	2	3	2	2	1	4
F 0 PROBABLE COST	**MAX 10**	**6**	**8**	**4**	**8**	**5**	**5**	**2**	**8**	**3**	**3**	**5**	**3**	**6**	**5**	**4**	**2**
F a 1 CONSTRUCTION	0–5	3	4	1	4	3	3	0	4	2	2	3	1	3	3	2	1
F 1 OPERATION AND MAINTENENCE	0–5	3	4	2	4	2	2	2	4	1	1	2	2	3	2	2	1
F c 1 MULTIPLE USE OF FACILITY	0–1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL POINTS		**61**	**51**	**43**	**68**	**52**	**47**	**46**	**70**	**44**	**42**	**47**	**56**	**68**	**65**	**52**	**38**
RANK				**10**	**2**	**6**	**8**		**1**		**11**	**8**	**5**	**2**	**4**	**6**	**12**
FATAL FLAW RATING		FF	FF					FF		FF							

NOTES:

1. SITE 8 LAND AREA IS FF IF A PORTION OF ADJACENT LAND IS NOT AVAILABLE. CURRENT SCORE ASSUMES LAND IS AVAILABLE.
2. SITE 18 LAND AREA MAY BE FF IF PROPOSED REFUGE PONDS USE UP AVAILABLE LAND.
3. SITE 24 GEOLOGIC FACTORS MAY BE FF. REQUIRES ADDITIONAL GEOLOGIC INVESTIGATION IF SITE IS CONSIDERED FURTHER.
4. MATRIX INCLUDES POINTS FOR POTENTIAL WARM WATER AT THE SITE, BASED ON SITE GEOLOGY AND RECORDS OF AREA WELLS.

RECOVERY FACILITY DESIGN

The operational requirements for the proposed facility are complex in relation to traditional fish hatcheries due to the unique constraints of working with rare and endangered fish stocks. An overriding concern in developing a facility design was the high degree of risk associated with artificial propagation of endangered stocks at critically low population levels. This problem is compounded because the facility will be receiving and releasing fish that may be genetically unique, from multiple sources and watersheds. These factors necessitate that all practical measures are taken to protect fish health and guard against disease outbreaks and transfer among various populations. Potential disease threats to each of the four species have been reviewed, so that features which will minimize the threats to fish health can be incorporated in the facility design. Other design characteristics which must be emphasized, due to the unique character of endangered fish species culture, are methods which will minimize or eliminate predation, escapement and theft or vandalism. Genetic segregation, as well as the quality and quantity of water available, have been given high priority with a resulting marked influence on design.

The purposes of the proposed propagation facility, broodstock and refugia holding facility, and research facility, which are cumulatively referred to as the recovery facility, are to meet the endangered fish recovery goals of propagation of endangered fishes, augmentation of native populations, refugia and broodstock holding and to provide facilities for research. During the initial development of the scope of work, the CWCB staff selected, for the purposes of this study, a range of hatchery production goals for each species. These production scenarios, for each species, are as follows: Scenario 1 - 150,000 fish per year, Scenario 2 - 300,000 fish per year and Scenario 3 - 600,000 fish per year. These production goals were estimated to meet the needs of both augmentation and research and were selected because there was no firm estimate of the number of fish needed for the recovery program.

The original scope of the design phase of the study was to prepare a recovery facility design for each of the three highest ranked sites. This design concept was later modified because the three sites with the highest rankings were similar sites located in the same geographic region, the San Luis Valley of the Rio Grande Basin, which is outside of the native habitat of the four endangered fish. The high rankings for these sites resulted primarily from availability of naturally occurring high temperature (70° to 118°F) groundwater, that is preferred for spawning and growth and offers a significant cost advantage over heating a cold water supply. However, to provide for greater flexibility in the ultimate selection of a hatchery site, the CWCB staff, with agreement of the TAC, decided to revise the study scope and prepare feasibility level designs for each of the for three types of water sources: warm groundwater, cold groundwater and surface water.

The three different production quantities of 150,000, 300,000, and 600,000 fish of each species, as specified by the scope of work, were considered for each of the water supply types. A total of nine design scenarios were developed, including an estimation of construction and operation and maintenance costs. The design effort was focused on the 300,000 fish production scenario, with extrapolation of design and cost information to the 150,000 and 600,000 production scenarios.

Standardization of the design of the production units was done as much as possible to allow flexibility in production quotas for each of the four species. This flexibility would also permit the facility to be used for propagation of fish, other than the four endangered fish, should the need arise. The initial production quotas were used as a basic criteria for total biomass[2] and a target for design which can be related to maximum, average and minimum water flows and various configurations of rearing systems. The general overall size and generic layout of the facility were designed to meet these initial production targets.

A state-of-the-art recovery facility was developed from the conceptual modeling effort, incorporating the latest technologies while considering the special needs for propagating rare and endangered species. The design effort included development of a hatchery simulation model which utilized input variables such as water flow rates, water temperature, production goals and site conditions and determined the required number and type of rearing ponds, tanks, feed rates and the general size of the facility.

To protect broodstock and refugia stocks from potential disease outbreaks, the TAC recommended that only one-half of all brood and refugia stocks for the four species be held at this facility. The remaining half would held at various other state and federal facilities. Additionally, as established by the TAC, rearing methods for each species were to be equally divided between intensive and extensive culture methods. A layout of the facility configured for a warm well water source and 300,000 fish production level is illustrated on Sheet 1. Facility layouts for the other design combinations are included in the Final Report.

A nutritional strategy was developed for extensive culture of augmentation stocks and refugia which is designed to stimulate a natural feeding response as a means of enhancing survival and ultimately genetic diversity. Accommodating this strategy requires natural feed production facilities, which have been incorporated in the design. Nutritional requirements for intensive culture of augmentation stocks will be satisfied through a diet of manufactured feed.

Flow requirements for extensive culture are based on oxygen consumption data and an acceptable level of water turnover rate for extensive culture. Flow requirements for intensive culture (using various water types and production scenarios) have been calculated by computer modeling based on oxygen consumption data for Colorado squawfish. Tables 4 and 5 identify the maximum requirements for flow, start tanks and

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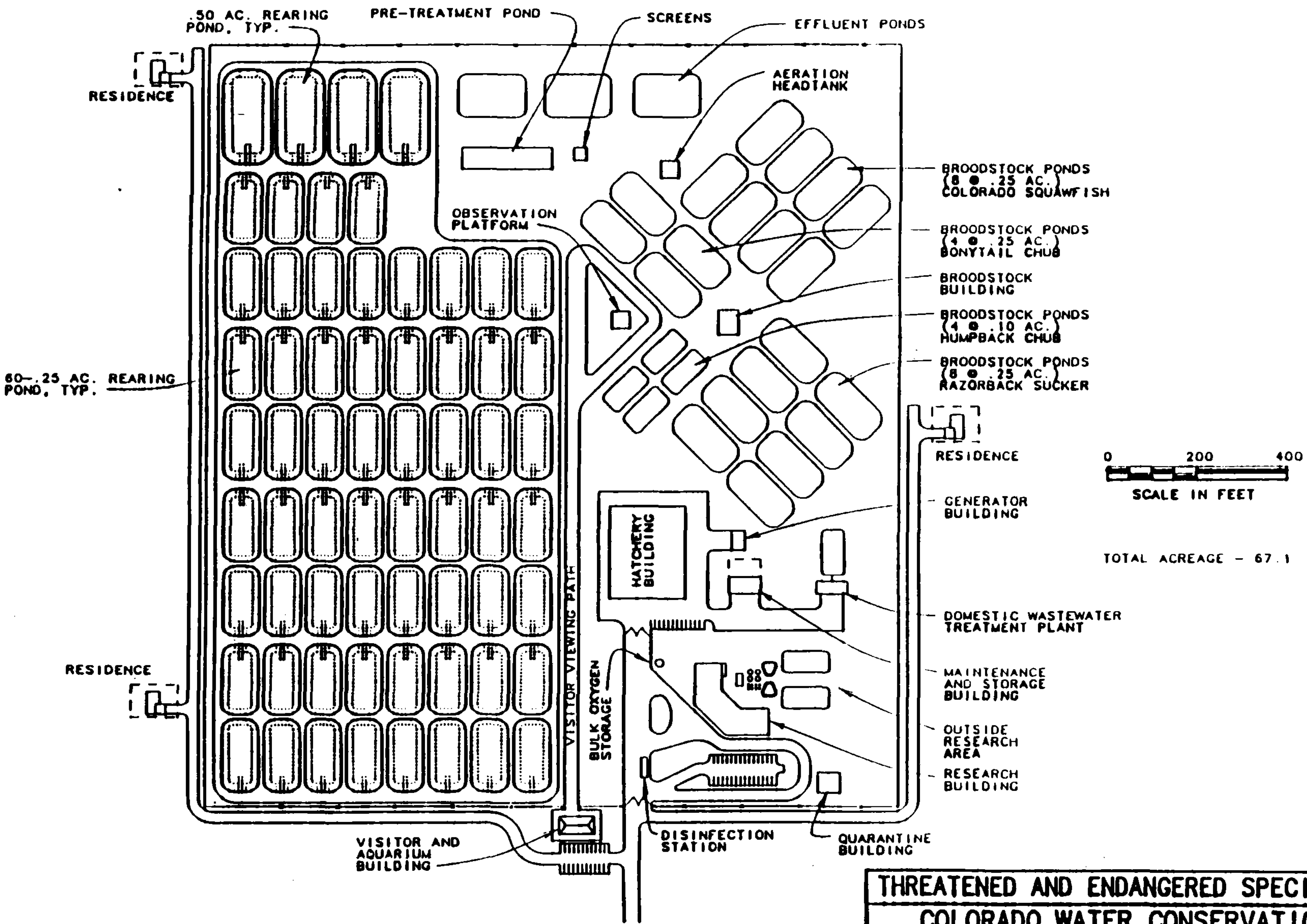
2 Defined in Glossary.



THREATENED AND ENDANGERED SPECIES FACILITY

COLORADO WATER CONSERVATION BOARD

SITE PLAN-SCENARIO 2-WARM WELL WATER

DESIGNED KF/ED DRAWN AB CHECKED KF	FISHPRO, INC. PREPARED FOR THE URS TEAM	DATE 7/17/92 SHEET NO. 1

TABLE 4

FLOW AND REARING UNIT REQUIREMENTS

(Warm Well Water Supply - 69°F)

INTENSIVE CULTURE

SPECIES	PRODUCTION LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Colorado Squawfish - 4"	150,000												
Total Flow Requirement (GPM)		295	317	411	459	540	672	37	66	98	142	182	240
Total Trough Requirement							2	10	28				
Total Circular Requirement		3	4	5	6	7	8			1	1	2	2
Razorback Sucker - 6"	150,000												
Total Flow Requirement (GPM)		3143	3827	94	30	205	667	780	1088	1385	1811	2151	2666
Total Trough Requirement				3	50								
Total Circular Requirement		33	42			1	2	4	6	9	13	19	25
Bonytail Chub - 4"	150,000												
Total Flow Requirement (GPM)						110	269	708	1256	1171			
Total Trough Requirement						3							
Total Circular Requirement							1	2	4	8			
Humpback Chub - 4"	150,000												
Total Flow Requirement (GPM)						76	472	1023	1815	1721			
Total Trough Requirement						3							
Total Circular Requirement							1	2	5	11			
SUBTOTALS INTENSIVE													
FLOW REQUIREMENT (GPM)		3438	4144	505	489	931	2080	2548	4225	4375	1953	2333	2906
TROUGH REQUIREMENT		0	0	3	50	6	2	10	28	0	0	0	0
CIRCULAR REQUIREMENT		36	46	5	6	8	12	8	15	29	14	21	27

Note: Table is for Scenario 2 - Total production of 300,000 per species, with intensive culture of 150,000.

TABLE 5

FLOW AND REARING UNIT REQUIREMENTS

(Warm Well Water Supply - 69°F)

EXTENSIVE CULTURE

SPECIES	PRODUCTION LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Colorado Squawfish - 4"	150,000												
Total Flow Requirement (GPM)		185	185	201	87	87	185	185	174	174	174	174	174
Total Trough Requirement				4									
Total Pond Requirement		17	17	18	8	8	17	17	16	16	16	16	16
Razorback Sucker - 6"	150,000												
Total Flow Requirement (GPM)		152	152	4	87	76	152	152	152	152	152	152	152
Total Trough Requirement				3									
Total Pond Requirement		14	14		8	7	14	14	14	14	14	14	14
Bonytail Chub - 4"	150,000												
Total Flow Requirement (GPM)						4	68	68	148	148			
Total Trough Requirement						3							
Total Pond Requirement							6	6	13	13			
Humpback Chub - 6"	150,000												
Total Flow Requirement (GPM)						4	65	65	141	141			
Total Trough Requirement						3							
Total Pond Requirement							6	6	13	13			
SUBTOTALS EXTENSIVE													
FLOW REQUIREMENT (GPM)		337	337	205	174	171	470	470	615	615	326	326	326
TROUGH REQUIREMENT		0	0	7	0	6	0	0	0	0	0	0	0
POND REQUIREMENT		31	31	18	16	15	43	43	56	56	30	30	30
TOTAL INTENSIVE AND EXTENSIVE													
FLOW REQUIREMENT (GPM)		3775	4481	710	663	1102	2550	3018	4840	4990	2279	2659	3232
TROUGH REQUIREMENT		0	0	10	50	12	2	10	28	0	0	0	0
CIRCULAR REQUIREMENT		36	46	5	6	8	12	8	15	29	14	21	27
POND REQUIREMENT		31	31	18	16	15	43	43	56	56	30	30	30

Note: Table is for Scenario 2 - Total production of 300,000 per species, with extensive culture of 150,000.

rearing ponds to produce 300,000 fish of each species (150,000 intensive culture and 150,000 extensive culture) using warm (64°F) well water.

The objective in the design for the broodstock and refugia portion of the facility is to simulate natural fish habitat in an environment with very low loading density. This is used as a means of reducing hatchery-induced stress and to help maintain genetic integrity. Broodstock and refugia facilities are designed to house a total of 5,100 adult fish, whose numbers are divided between the four endangered species. The broodstock ponds also incorporate features to function as refugia for these fish. A broodstock building has been incorporated into the design to accommodate tagging, spawning and recovery of broodstock.

A state-of-the-art research facility has been incorporated into the design to satisfy the special requirements of the Recovery Program. Primary research needs focus on genetics, fish health, and population/environment interaction. Research laboratories devoted to genetics, physiology and pathology are housed together in a building along with support facilities such as a library, photography laboratory, and conference and computer rooms. An outdoor research space is supplied with a variety of water types and drainage facilities to support a variety of rearing tank configurations for conducting fish behavioral experiments.

A hatchery building is located central to the facility. Incubation and culture to first feeding for all stocks will take place at the hatchery building. The hatchery building will also house all intensive culture facilities for up to one-half of total augmentation stocks. Sixty augmentation ponds are provided for extensive culture.

The facility includes a visitor center containing aquaria and informational exhibits to enhance the public awareness of the facility operation, Recovery Program efforts, and provide general background information on the endangered fish. Walkways are also provided to allow public access to certain areas of the facility.

Quarantine facilities are strategically placed to receive all incoming live fish and/or eggs. All biological products will be screened for diseases and quarantined prior to entrance to the remainder of the facility. Access to all facilities is secured behind locking gates.

Water conditioning functions have been designed for all three water types. Heating or cooling requirements will be a function of the temperature of the incoming supply and the specific life stage needs of the various fish stocks. In addition, the design incorporates water treatment facilities for degassing, aeration, screening and disinfection. Wastewater from all research, brood and culture operations will be adequately treated to prevent escapement and to remove solids prior to discharge. Research facility effluent water will be directed to a pretreatment pond prior to screening to allow for special treatment, such as removal of pathogens, prior to discharge to settlement ponds. All quarantine water will be disinfected prior to discharge to the effluent disposal facility.

A maintenance and storage building is located near the hatchery and research complex. A warehouse space is provided to store equipment and supplies. Emergency equipment is provided for low oxygen, loss of power and general alarm conditions. Three domestic residences are strategically placed outside the facility perimeter security fence at locations which allow for observation into critical areas of the hatchery complex by off-duty facility workers and their families.

COSTS

The feasibility level design prepared for this study includes a hatchery building, rearing ponds for propagation and augmentation stocks, ponds for holding broodstock and for refugia, a research building and outside research facilities, three on-site residences for hatchery workers, a visitor center and aquarium building, and other related facilities. This design represents a state-of-the-art facility. The design includes specific design and cost information for the key components of the facility. This information could be used to assist in the final selection of specific recovery facility components, therefore it is not anticipated that final costs for a facility would equal the totals presented in Tables 6 through 10. The cost components could also serve as a starting point for the preliminary design.

Estimated costs for capital construction were developed on the basis of feasibility level design information for a comparable unit or system basis and are shown in Tables 6, 7, and 8. The tables are for production Scenario 2 - 300,000 fish, for each of the three water supply types. The estimates are in 1992 dollars. The costs are segregated into the three major components of the recovery facility: the fish hatchery; the broodstock and refugia holding ponds and the research facility. These cost estimates do not include acquisition costs for land or improvements, including any existing hatchery facilities.

Estimated operation and maintenance costs have been developed and are also presented in Tables 6, 7 and 8. These costs represent all functions to be performed on-site with the exception of the research program. Details on the extent of research programs, due to changing priorities over time prevent accurate estimates of costs. These estimates would remain relatively constant regardless of site selection. Operation and maintenance costs for the research building which are associated with water quality, pathology and other services connected with the propagation of fish are included.

Full time personnel requirements for the facility have been estimated for each production scenario. Personnel categories include: facility manager, assistant facility manager, laboratory technician, fish culturist, maintenance engineer, plant engineer and receptionist. The estimated number of full time equivalent personnel are 6, 9, and 10 for production scenarios 1, 2 and 3 respectively.

Tables 6, 7 and 8 present the relative costs for the major components of the recovery facility and the total cost for each of the water supply types for production scenario 2 - 300,000 fish. Table 9 presents the estimated total cost for the recovery facility for each of the three production scenarios for each water supply type. Table 10 presents the estimated cost for just the core facility for each of the three production scenarios for each water supply type. Costs listed in Tables 9 and 10 are total capital construction costs plus a 25 percent contingency factor.

TABLE 6

COSTS AND REQUIRED LAND
WARM WELL WATER SUPPLY (SCENARIO 2 - 300,000)

	Recovery Facility Components					
	Core Facility	Refugia/Broodstock	Research	Total	Operation and Maintenance	Required Land (b)
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs (a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Labratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$15,567,000	$2,603,000	$3,011,000	$21,181,000	$756,000	67

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
A/E Fees (9.5% of Total)
Permits (.5% of total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 7

COSTS AND REQUIRED LAND

COLD WELL WATER SUPPLY (SCENARIO 2 - 300,000)

	Recovery Facility Components			Total	Operation and Maintenance	Required Land (b)
	Core Facility	Refugia/Broodstock	Research			
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs (a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Labratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$19,551,000	$2,664,000	$3,010,000	$25,225,000	$979,000	81

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
Additional cost for heaters and heat exchangers
A/E Fees (9.5% of Total)
Permits (.5% of total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 8

COSTS AND REQUIRED LAND
SURFACE WATER SUPPLY (SCENARIO 2 – 300,000)

	Recovery Facility Components				Operation	Required
	Core Facility	Refugia/Broodstock	Research	Total	and Maintenance	Land (b)
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs (a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Labratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$21,739,000	$3,027,000	$3,080,000	$27,846,000	$1,032,000	87

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
Additional costs for heaters, heat exchangers and disinfection equipment
A/E Fees (9.5% of Total)
Permits (.5% of total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 9

CAPITAL COST ESTIMATE COMPARISON FOR TOTAL RECOVERY FACILITY

PRODUCTION SCENARIO	WATER		
	WARM WELL	COLD WELL	SURFACE
1 (150,000)	$16,492,000	$18,149,000	$19,836,000
2 (300,000)	$21,181,000	$25,225,000	$27,846,000
3 (600,000)	$31,080,000	$39,167,000	$43,685,000
Note: Cost breakdown for the core facility, refugia/broodstock facility, and the research facility, for each scenario are presented in the Final Report			

TABLE 10

CAPITAL COST ESTIMATE COMPARISON FOR CORE FACILITY

PRODUCTION SCENARIO	WATER		
	WARM WELL	COLD WELL	SURFACE
1 (150,000)	$9,946,000	$12,754,000	$14,388,000
2 (300,000)	$15,567,000	$19,551,000	$21,739,000
3 (600,000)	$24,919,000	$33,049,000	$37,950,000

ISSUES AND PERMITS

Technical and biological issues have been raised which may affect the site evaluation and design process and must be considered as the site selection is made and the design of the recovery facility is completed. These issues are briefly described below. An expanded description of these issues can be found in the full text of this study.

Issues

- The need for a recovery and/or research facility for the recovery of the endangered fishes;
- The need and level of production for augmentation and for research;
- The role of the recovery facility for broodstock holding or refugia;
- Determination of the numbers of genetically individual sub-populations for each species;
- Use and mix of intensive and extensive fish culture techniques;
- Type of hatchery water supply and the impact on fish growth, health, genetics, imprinting, survivability in the wild, and hatchery capital and operation costs;
- Hatchery location and proximity to native habitats;
- Role of the proposed hatchery and research facility in the overall recovery program;
- Responsibility for construction of the hatchery and research facility;
- Responsibility for operation of the hatchery and research facility;

Permits

In siting and constructing a hatchery or the complete recovery facility, a number of permits from federal, state and local agencies will be required. Given that the current scope of the study is for a conceptual design and is not based on a specific site, it is not possible to determine the specific permits which would be required for a specific site. The following are descriptions of permits which could possibly be required and should be evaluated for compliance as necessary.

- Environmental Assessment
- Environmental Impact Statement
- Colorado NPDES permit
- Colorado wastewater discharge permit
- Construction dewatering permit
- Corps of Engineers 404 Permit
- Zoning permit
- Building permits
- Water Rights
- Endangered Fish Permit

SITE DESCRIPTIONS

This section provides brief descriptions of the 16 proposed sites evaluated in the final screening effort. The Final Report includes more detailed description of these sites.

1. Glenwood Desalinization Facility (near Glenwood Springs, CO):

This proposed hatchery site is located west of Glenwood Springs in a canyon south of I-70. The site was proposed in conjunction with a proposed desalinization plant project. The concept is to use the waste heat from the desalinization plant to heat hatchery water. The site is undeveloped. The site received a fatal flaw for: Water Reliability - The hatchery warm water supply would be contingent on the operation of the desalination plant. The site is also located downstream of a solid waste landfill operation.

2. CO-Ute Plant/CIRG Site (near Craig, CO):

This proposed hatchery site is located near Craig, on private property. The site was proposed as part of a larger site development project for industries which would use waste heat from the power plant, in this case, to heat the hatchery water. This site received a fatal flaw for: Water Reliability - With current information, the hatchery warm water supply would be contingent on the operation of the power plant. There may be the possibility of geothermal water at the site. The area of available land is small.

6. Rifle Falls SFH (near Rifle, CO):

This proposed hatchery site is located near Rifle, on property partially occupied by the existing Colorado Division of Wildlife - Rifle Falls Fish Hatchery. The water supply for the site would be cold surface water. Existing cold well water is used by the Rifle Falls Hatchery.

8. Clines Fish Hatchery (Monte Vista, CO):

This proposed hatchery site, located within the San Luis Valley, is currently the site of an existing private fish hatchery. The existing hatchery has an artisan geothermal well water supply. Acquisition of farm land adjacent to the Clines property would be required for the site to be feasible. The existing hatchery rearing ponds are generally small.

9. Putnam Fish Hatchery (Durango, CO):

This proposed hatchery site is currently the site of an existing private fish hatchery. The existing hatchery has a cold water supply from springs. The site has a large area of available land in addition to the area occupied by the hatchery. The site has good topographical relief for reaeration of water. The rearing ponds are generally small and grouped on different terraces across the site.

10. Silver Springs Trout Farm (Montrose, CO)

This proposed hatchery site is currently the site of an existing private fish hatchery. The existing hatchery has a cold water supply from springs. The existing hatchery rearing ponds are medium in size.

11. McMillan's Trout Farm (Hotchkiss, CO)

This proposed hatchery site is currently the site of an existing private fish hatchery. The existing hatchery has a cold water supply from springs. This spring water is likely mixed with surface runoff due the configuration of the existing water collection system. The site is situated on a small bench adjacent to the Gunnison River. The rearing ponds are small. This site received a fatal flaw for: Land Accessibility/Useability - The site is small and is relatively inaccessible.

15. Crystal Properties (near Hooper, CO)

This proposed hatchery site, located within the San Luis Valley, was formally the site of a private fish hatchery and a hot pool resort. Some remnants of both businesses remain. The property has a warm artisan well water supply. Effluent from the hatchery would be to open ground.

16. Horsethief Site (near Grand Junction, CO)

This proposed hatchery site is within a State Wildlife Area. This site received a fatal flaw for: Land Area - All available land has been used by existing rearing ponds.

18. Walter Walker State Wildlife Area (Grand Junction, CO)

This proposed hatchery site is within a State Wildlife Area. The site would have a surface water supply, from the Colorado River. The site is within the floodplain of the Colorado River.

23. Rangeview Trout Ranch (Saguache, CO)

This proposed hatchery site, located within the San Luis Valley, is currently the site of an existing private fish hatchery. The existing hatchery has an artisan geothermal well water supply. There may be additional geothermal water available at the site. The size of existing hatchery raceways and rearing ponds range from medium to small.

24. Crystal Springs Hatchery (near Hotchkiss, CO)

This proposed hatchery site is currently the site of an existing private fish hatchery. The existing hatchery has a cold water supply from springs and a surface water supply. The surface water supply is from water canals. The hatchery is adjacent to the former USFWS Chipeta Springs Hatchery, which was destroyed by a landslide. The existing hatchery rearing ponds are generally small.

25. Russell Lakes SWA (Saguache, CO)

This proposed hatchery site, located within the San Luis Valley, is within the State Wildlife Area. The property has a warm partially-artisan well water supply from a number of small wells. There may be additional geothermal water available at the site. The site has previously been used as a hatchery and currently is being used by the Rangeview Trout Ranch to raise fish.

26. Closed Basin Project (near San Luis Lake, CO)

This proposed hatchery site, located within the San Luis Valley, is on property which is part of the Bureau of Reclamation Closed Basin Project. The water supply would be ground water pumped from the Closed Basin Wells. There also may be geothermal water available at the site. Land is available for the proposed hatchery.

28. New Wastewater Treatment Plant (near Craig, CO)

This proposed hatchery site is located at the site of the City of Craig new wastewater treatment plant. While the plant site does not have adequate land area, there is open land adjacent to the site. The water supply would be surface water from the Yampa River. There also may be geothermal water available at the site.

32. Grand Junction Site #1 (Summerville Ranch, CO)

This proposed hatchery site is located southeast of City of Grand Junction. The water supply would be surface water, from the City of Grand Junction raw water supply system. There is available land for the proposed hatchery.

GLOSSARY OF TERMS

Augmentation Stock - Those fish which are released for the purpose of increasing the existing fish population.

Biomass - The pounds of fish which are either maintained or produced at the recovery facility. The capacity of the facility to hold and grow fish is expressed in terms of pounds of fish or total biomass.

Broodstock - Fish of a particular species, represented by both sexes which are held in captivity until and during maturity for the distinct purpose of crossbreeding. The genetic history is usually known for these animals and they are usually bred according to strict protocols designed to maintain a level of genetic diversity in the progeny. For the purposes of this facility, refugia and broodstock populations are considered the same.

Culture Techniques - Different methodologies which are used to hatch and produce fish. For this report, the two categories of culture techniques are intensive culture and extensive culture.

Extensive Culture - A culture methodology which emphasizes more natural rearing conditions for fish that are reared in an artificial environment. Under extensive culture conditions fish are reared at low density in outdoor ponds. Rearing is conducted at ambient temperatures and natural feed items are encouraged to grow in the pond environment. This strategy is employed to alleviate hatchery induced pressures which may work selectively on the genetic diversity of the fish being cultured. This method requires less water and more land than intensive culture.

Intensive Culture - A culture methodology designed to achieve maximum productivity for fish held in artificial culture environments. The fish are held at higher densities in tanks or raceways and fed an artificial diet. Rearing temperatures are held at values which are known to achieve maximum growth rates. Water flow rate are high to maintain water quality by carrying away waste products, and excess feed. The primary goal of intensive culture is to achieve maximum fish production levels for a given rearing space while maintaining healthy stocks of fish.

Refugia - Individual fish representing genetically distinct stocks of a particular species held in captive habitat. Usually held in reserve for use as future broodstock and to provide an environment for protection and survival of declining number of endangered fish in the wild. The purpose is to maintain the genetic diversity of a species by maintaining representative examples of distinct, genetically diverse strains from specific native habitats.

SECTION 1.0

INTRODUCTION

1.0 INTRODUCTION

Background and Study Description

In 1989, the Colorado Legislature, through Senate Bill 85, authorized the Colorado Water Conservation Board (CWCB) to prepare a study of the propagation in Colorado of endangered fish of the Upper Colorado River Basin. The scope of the study was to review available information on fish culture techniques[1], investigate and evaluate potential sites in Colorado for a fish hatchery facility, and to develop design concepts for an endangered fishes hatchery. The four endangered species are the Colorado squawfish *(Ptychocheilus lucius)*, humpback chub *(Gila cypha)*, bonytail chub *(Gila elegans)*, and razorback sucker *(Xyrauchen texanus)*.

The study describes and references available information pertinent to fish culture, propagation techniques and hatchery design for the four endangered fish species. This information was assembled by reviewing available literature and contacting local, state and federal experts in the field. As part of the study, a list of 33 sites in Colorado was developed as being potentially feasible to locate a hatchery facility. These sites were evaluated through a screening process, in which the sites were rated and ranked according to criteria developed for the study. Finally, the study included the development of a feasibility level design for the hatchery and support facilities.

The study addressed issues limited to biological, technical and engineering design concerns. Economic, social, philosophical and political issues related to the propagation and augmentation of endangered fish populations were not addressed and were considered beyond the scope of this study. However, these issues should be considered in the final decision process to determine the need and location for a hatchery facility.

The information contained in the study will aid the State of Colorado and the Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin (Recovery Program) in determining the need for such a facility, it's final location and design, and construction and operation costs. This study is a unique undertaking, as such a facility

[1] **Culture techniques - a definition of this and other scientific terms used in this report are included in the Glossary of Terms section of the report.**

would provide propagation, research, broodstock holding, refugia and public educational opportunities for endangered fish species, which has not been attempted previously in this region. Due to current uncertainties about culture and large scale production techniques for these fishes, it was necessary to make some assumptions during the course of the study on the development and operation of the hatchery facility. The proposed facility could ultimately consist of a fish hatchery, a broodstock and refugia holding facility and a research facility, as deemed necessary by the Recovery Program.

The study was performed by a team of consulting engineers and biologists and a Technical Advisory Committee (TAC). The TAC was responsible for overall direction of the study and was composed of staff representatives from the CWCB, Colorado Division of Wildlife (CDOW) and the U. S. Fish and Wildlife Service (USFWS). The Consultant Team consisted of URS Consultants, Inc., prime contractor, with major responsibility for the site evaluation and engineering; Fish Pro, Inc., specializing in fish biology and hatchery design; Bio/West, Inc., specializing in fish biology and life history needs, and Leonard Rice Consulting Water Engineers, specializing in the investigation of water supply aspects of the study.

The study tasks are grouped into six categories as listed below:

- Literature Review and Review of Existing Propagation Facilities
- Biological Design and Culture Techniques
- Site Identification and Initial Screening
- Site Evaluation and Final Screening
- Recovery Facility Design and Cost Estimates
- Issues and Permits

During the course of the study the TAC and the Consultant Team made modifications to the study scope and direction, as the study progressed and knowledge was gained. At the completion of each major task, a task report was prepared to present the findings and conclusions of the task. This Final Report serves two purposes: 1) to assemble in a summary report containing a description of each of the completed tasks, the final conclusions and associated technical appendices; and 2) to present a record of the study direction and progress toward completion. In general, the interim task reports were compiled and revised to prepare this final report.

Final Note

Subsequent to the completion of the feasibility study, the CWCB, Colorado Division of Wildlife and the Colorado Department of Natural Resources revised the concept of the function of the proposed hatchery facility, and are investigating the benefits of constructing a native Colorado aquatic species facility that would be available for culture and protection of not only the four endangered Upper Colorado River Basin fishes, but native aquatic species whose populations are in decline. This would aid in the efforts to protect and enhance these populations before they become federally listed as threatened and endangered species. The information provided in this study will be used as the basis for future decisions made by the State of Colorado in determining the need, and development of such a facility.

SECTION 2.0

LITERATURE REVIEW AND REVIEW OF EXISTING PROPAGATION FACILITIES

SECTION 2.0

LITERATURE REVIEW AND REVIEW OF EXISTING PROPAGATION FACILITIES

2.1 INTRODUCTION

The objective of this study task was to review all available literature pertinent to fish culture, propagation techniques, and hatchery design for the four endangered fish species; Colorado squawfish (Ptychocheilus lucius), humpback chub (Gila cypha), bonytail chub (Gila elegans), and razorback sucker (Xyrauchen texanus). This task was conducted by Bio/West, Inc.

2.1.1. Methodology

Literature pertinent to the culture of the endangered fish was assimilated and reviewed using the following five approaches:

1. research personal and public sources;
2. acquire information from local, State, and Federal agencies;
3. conduct a field visit to Dexter National Fish Hatchery (NFH) (later renamed the Dexter National Fish Hatchery and Technology Center);
4. visit and interview Propagation Specialists for the Colorado Division of Wildlife (CDOW) and the U.S. Fish and Wildlife Service (USFWS); and
5. conduct telephone interviews with key contacts.

The following is a description of each approach.

Research Personal and Public Sources

Bio/West personnel have been involved in work with the Colorado River endangered fish species for over 20 years. A library maintained at the Logan, Utah office, as well as personal contacts were valuable sources of information. The Utah State University Merrill Library and the College of Natural Resources Library were also researched. This search accounted for most of the library assimilated, which contains 100 literature sources pertinent to the culture of the Colorado River endangered fish.

Acquire Literature From Local, State, and Federal Agencies

Additional literature was solicited from key personnel from the following agencies:

a. Colorado Division of Wildlife
b. U.S. Fish and Wildlife Service
c. Utah Division of Wildlife Resources
d. Utah State University
e. Arizona Game and Fish Department
f. National Park Service

Conduct Field Visit to Dexter National Fish Hatchery

A field visit was conducted to Dexter NFH in southeastern New Mexico on September 12-13, 1990. The following project personnel participated in this visit: Richard Valdez and Bill Masslich (Bio/West), Bill Wemmert (URS), Sue Uppendahl (CWCB), Ken Ferjancic (FishPro), and Holt Williamson (USFWS).

The purpose of the visit was to view the facility and to discuss culture techniques with Hatchery Manager, Buddy Jensen. Personnel at Dexter NFH have cultured all four species of Colorado River endangered fish, and have developed most of the techniques for extensive culture of the species.

Visit and Interview Propagation Specialists for CDOW and USFWS

Propagation specialists for the CDOW and USFWS were visited on October 4, 1990. The following project personnel participated in this visit: Richard Valdez and Bill Masslich (Bio/West). The purpose of the visit was to discuss with Mr. Larry Harris, Propagation Specialist for CDOW, and Dr. Holt Williamson, Propagation Specialist for USFWS, additional culture techniques for these species. The interview with Mr. Harris provided observations of the current techniques for intensive culture of the endangered fish and to secure information on the procedures. Dr. Williamson provided insight into the USFWS's propagation program. Dr. Ron Goede of the Utah Division of Wildlife Resources Experimental Fish Hatchery in Logan, Utah and Dr. Tim Modde of the Utah Cooperative Fishery Research Unit at Utah State University, Logan, Utah were also visited. Dr. Goede is an authority on fish health and culture techniques, and Dr. Modde has maintained Colorado squawfish and bonytail chub at the University facility.

Conduct Telephone Interviews with Key Contacts

Telephone interviews were conducted with 33 key people involved in culture-related aspects of the Colorado River endangered fish. These interviews were preceded by a letter sent to a total of 73 people requesting additional culture-related information. A list of literature assimilated by Bio/West was included with the contact letter for people to reference information already assimilated. People were encouraged to contact Bio/West and send copies of publications, reports, files, and notes, or to notify Bio/West regarding personal communications.

2.1.2. Work Products

The following five work products were developed as part of the Literature Review and Review of Existing Propagation Facilities task. These include:

1. an alphabetized list and annotated bibliography of pertinent literature;
2. a catalogued library of pertinent literature;
3. a file of personal communications with key fish culturists;
4. a computerized retrieval system with key culture data and issues; and,
5. this task summary which describes all the work products.

Alphabetized List and Annotated Bibliography of Pertinent Literature

A total of 100 sources of written information were assimilated pertinent to the culture of these four endangered fish. Most of the information was in the form of publications and reports available through scientific journals and agency files. An alphabetized list of literature is provided in Table 2.1. Each of the literature sources identified in Table 2.1 was summarized in an Annotated Bibliography of Pertinent Culture Information on the Colorado River Endangered Fish. This document is included as Appendix A to this Final Report.

Catalogued Library of Pertinent Literature

Hard copies of the 100 literature sources listed in Table 2.1 were also assembled for this task. Each document was catalogued with a unique reference number, shown as the Ref # in Table 2.1. This number also corresponds to a computer retrieval system summarizing each of these sources.

A library of the pertinent culture information on the Colorado River endangered fish is housed at each of the following locations:

1. Colorado Water Conservation Board
   1313 Sherman Street, Room 721
   Denver, CO 80203
   303-866-3441
   Contact: Mr. Eugene I. Jencsok

2. Bio/West, Inc.
   1063 West 1400 North
   Logan, UT 84321
   801-752-4202
   Contact: Dr. Richard Valdez

File of Personal Communications with Key Fish Culturists

A total of 73 people working with the four endangered fishes were contacted with a letter requesting pertinent culture information. The purpose of this contact was to survey people familiar with the fish and to identify publications, reports, files, or personal communications that would add to our current knowledge. Key individuals from this list were further contacted by telephone to investigate additional information sources and document personal communications.

The complete list of people contacted by letter and telephone is provided in Table 2.2. Documentation of the phone conversations is provided in Appendix B of this Final Report. Documented interviews with Mr. Buddy Jensen, Mr. Larry Harris, Dr. Holt Williamson, Dr. Ron Goede, and Dr. Tim Modde were also included as part of Appendix B.

Computerized Retrieval System with Key Culture Issues and Data

A computer retrieval system was developed for this project by Bio/West to facilitate retrieving the literature assimilated for this project. The system is stored in dBASE III+ and is designed to retrieve documents through a search of species codes and key words. The computerized retrieval system for culture of the Colorado River endangered fish is described in Appendix C of this Final Report. One computer diskette containing this system is on file at the CWCB and at Bio/West.

Table 2.1 Library of Pertinent Culture Information on the Colorado River Endangered Fish.

REF. #	CITATION
2 -	Ammerman, L.K., and D.C. Morizot. 1989. Biochemical genetics of endangered Colorado squawfish populations. Transactions of the American Fisheries Society 118(4):435-440.
80 -	Arizona Game and Fish Department. 1988. Annual Hatchery Report 89-15. Phoenix, Arizona. pp 44-48.
81 -	Arizona Game and Fish Department. 1989. Annual Hatchery Report 90-2. Phoenix, Arizona. pp 55-58.
19 -	Beleau, M.H., and J.A. Bartosz. 1982. Acute toxicity of selected chemicals: data base. Pages 243-254 In W.H. Miller, J.J. Valentine, and D.L. Archer. (eds.) Colorado River Fishery Project Final Report: Part 3, Contract Reports. U.S. Fish and Wildlife Service for Bureau of Reclamation., Salt Lake City, Utah.
34 -	Berry, C.R. 1984. Hematology of four rare Colorado River fishes. Copeia 1984(3):790-793.
33 -	Berry, C.R. 1988. Effects of cold shock on Colorado squawfish larvae. Southwestern Naturalist 33(2):193-197.
77 -	Berry, C.R., and R. Pimentel. 1985. Swimming performances of three rare Colorado River fishes. Transactions of the American Fisheries Society 114(3):397-402.
41 -	Berry, C., R. Bulkley, D. Osmundson, and V. Rosen. 1985. Survival of stocked Colorado squawfish with reference to largemouth bass predation. Annual Report, Utah Cooperative Fishery Research Unit, Utah State University, Logan, Utah. 42pp.
90 -	Bestgen, K.R. 1990. Status review of the razorback sucker, Xyrauchen texanus (draft). Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado. 93 pp.
94 -	Black, T. 1982. Preferred temperature of Colorado squawfish (Ptychocheilus lucius) and its relations with age and growth rate. M.S. Thesis, Utah State University, Logan, Utah. 47 pp.

Table 2.1. Continued

REF #	CITATION
28 -	Black, T., and R.V. Bulkley. 1985a. Growth rate of yearling Colorado squawfish at different water temperatures. Southwestern Naturalist 30(2):253-257.
30 -	Black, T., and R.V. Bulkley. 1985b. Preferred temperature of yearling Colorado squawfish. Southwestern Naturalist 30(1):95-100.
72 -	Brooks, J.E. 1986a. Annual reintroduction and monitoring report for the razorback sucker Xyrauchen texanus, in the Gila River Basin, Arizona, 1985. Arizona Game and Fish Department, Phoenix, Arizona for U. S. Fish and Wildlife Service. 23 pp.
73 -	Brooks, J.E. 1986b. Reintroduction and monitoring of Colorado Squawfish (Ptychocheilus lucius) in Arizona, 1985. Arizona Game and Fish Department, Phoenix, Arizona for U. S. Fish and Wildlife Service. 15 pp.
11 -	Bulkley, R.V., and R. Pimentel. 1983. Temperature preference and avoidance by razorback suckers. Transactions of the American Fisheries Society 112(5):601-607.
21 -	Bulkley, R.V., C.R. Berry, R. Pimental, and T. Black. 1981. Tolerance and preferences of Colorado River endangered fishes to selected habitat parameters. Pages 185-241 In W.H. Miller, J.J. Valentine, and D.L. Archer (eds.). Colorado River Fishery Project Final Report: Part 3, Contract Reports. U.S. Fish and Wildlife Service for Bureau of Reclamation, Salt Lake City, Utah.
57 -	Burdick, B.D., and L.R. Kaeding. 1985. Reproductive ecology of the humpback chub and the roundtail chub in the Upper Colorado River. Proceedings of the Annual Conference of the Western Association of Fish and Game Agencies 65:163 (abstract).
26 -	Buth, D.G., R.W. Murphy, and L. Ulmer. 1987. Population differentiation and introgressive hybridization of the flannelmouth sucker and of hatchery and native stocks of the razorback sucker. Transactions of the American Fisheries Society 116(1):103-110.
86 -	Colorado River Fishes Recovery Team. 1984. Humpback chub (Gila cypha) recovery plan (agency review draft). U. S. Fish and Wildlife Service, Denver, Colorado. 40 pp.

Table 2.1. Continued

REF #	CITATION
87 -	Colorado River Fishes Recovery Team. 1984. Bonytail chub (Gila elegans) recovery plan (technical review draft). U. S. Fish and Wildlife Service, Denver, Colorado. 40 pp.
88 -	Colorado River Fishes Recovery Team. 1978. Colorado Squawfish (Ptychocheilus lucius) revised recovery plan, (original approval: March 16, 1978). U. S. Fish and Wildlife Service, Denver, Colorado. 52 pp.
13 -	Colorado State University. 1989. Research hatchery squawfish propagation report. June, 1989. Unpublished Report. Colorado State University, Research Hatchery. Fort Collins, Colorado. 3 pp.
76 -	Douglas, P.A. 1952. Notes on spawning of the humpback sucker, Xyrauchen texanus (Abbot). California Fish and Game 38:149-155.
71 -	Echelle, A.A. 1988. Review of genetic diversity and conservation genetics in fishes of U.S. Fish and Wildlife Service Region II, with a suggested program of conservation genetics. Department of Zoology, Oklahoma State University, Stillwater, Oklahoma. 42 pp.
20 -	Flagg, R. 1981. Disease survey of the Colorado River fishes. Pages 177-184 In W.H. Miller, J.J. Valentine, and D.L. Archer (eds.). Colorado River Fishery Project Final Report: Part 3, Contract Reports. U.S. Fish and Wildlife Service for Bureau of Reclamation, Salt Lake City, Utah.
6 -	Hamman, R.L. 1981a. Spawning and culture of Colorado squawfish in raceways. Progressive Fish Culturist 43(4):173-177.
7 -	Hamman, R.L. 1981b. Hybridization of three species of chub in a hatchery. Progressive Fish Culturist 43(3):140-141.
29 -	Hamman, R.L. 1981c. Transporting endangered fish species in plastic bags. Progressive Fish Culturist 43(4):212-213.
5 -	Hamman, R.L. 1982a. Induced spawning and culture of bonytail chub. Progressive Fish Culturist 44(4):201-203.

Table 2.1. Continued

REF #	CITATION
4 -	Hamman, R.L. 1982b. Spawning and culture of humpback chub. Progressive Fish Culturist 44(4):213-216.
31 -	Hamman, R.L. 1985a. Induced spawning of hatchery-reared razorback sucker. Progressive Fish Culturist 47(3):187-189.
32 -	Hamman, R.L. 1985b. Induced spawning of hatchery-reared bonytail. Progressive Fish Culturist 47(4):239-241.
27 -	Hamman, R.L. 1986. Induced spawning of hatchery-reared Colorado squawfish. Progressive Fish Culturist 48(1):72-74.
12 -	Hamman, R.L. 1987. Survival of razorback suckers cultured in earthen ponds. Progressive Fish Culturist 49(2):138-140.
3 -	Hamman, R.L. 1989. Survival of Colorado Squawfish cultured in earthen ponds. Progressive Fish Culturist 51(1):27-29.
98 -	Harris, L., T. Mandis, and P. Schler. 1990. Fish hatchery Bellvue, Colorado squawfish report 1989-90. 14 pp.
78 -	Haynes, C.M., T.A. Lytle, E.J. Wick, and R.T. Muth. 1984. Larval Colorado squawfish (Ptychochielus lucius Girard) in the Upper Colorado River Basin, Colorado, 1979-1981. Southwestern Naturalist 29(1):21-33.
52 -	Haynes, C.M., R.T. Muth, and T.P. Nesler. 1985. Identification of habitat requirements and limiting factors for Colorado squawfish and humpback chub. Job Final Report SE-3-4, federal aid in fish and wildlife restoration. Colorado Division of Wildlife, Denver, Colorado. 42pp.
67 -	Hendrickson, D.A. and L.H. Simons. 1988. Native fish - the long hard swim. Arizona Wildlife Views 31(2):4-7.
47 -	Holden, P.B., E.J. Wick. 1982. Life history and prospects for recovery of Colorado squawfish. Pages 98-108 In W.M. Miller, H.M. Tyus and C.A. Carlson (eds.). Fishes of the Upper Colorado River system: Present and future. American Fisheries Society, Bethesda, Maryland.

Table 2.1. Continued

REF #	CITATION

97 - Hubbs, C.L., and R.R. Miller. 1953. Hybridization in nature between the fish genera Catostomas and Xyrauchen. Michigan Academy of Science, Arts and Letters XXXVIII (1952):207-233.

18 - Inslee, T.D. 1981. Spawning of razorback suckers. Pages 145-157 In W.H. Miller, J.J. Valentine, and D.L. Archer (eds.). Colorado River Fishery Project Final Report: Part 3, Contract Reports. U.S. Fish and Wildlife Service, Bureau of Reclamation, Salt Lake City, Utah.

51 - Inslee, T.D. 1982. Spawning and hatching of the razorback sucker. Proceedings of the Western Association of Fish and Wildlife Agencies 62:431-432.

42 - Inslee, T.D. 1983. Spawning and hatching of Colorado squawfish (Ptychocheilus lucius). Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 17pp.

45 - Jensen, B.L. 1982. Operation of Dexter National Fish Hatchery, an endangered fishes facility. Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 15pp.

53 - Jensen, B.L. 1983a. Annual narrative report, calendar year 1983. Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 9pp.

44 - Jensen, B.L. 1983b. Culture techniques for selected Colorado River imperiled fishes. Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 7pp.

14 - Jensen, B.L. 1984. Annual narrative report, calendar year 1984. Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 9pp.

60 - Jensen, B.L. 1986. The role of fish culture in endangered fishes recovery. Proceedings of the Bonneville Chapter of the American Fisheries Society 1986:31-41.

69 - Jensen, B.L. 1987. Annual narrative report, calendar year 1987. Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 23 pp.

Table 2.1. Continued

REF #	CITATION

16 - Jensen, B.L. 1989. Dexter National Fish Hatchery (description). Dexter National Fish Hatchery, U.S. Fish and Wildlife Service. Dexter, New Mexico. 6pp.

40 - Johnson, J.E. 1983. Reintroducing the natives: razorback sucker. Proceedings of the Desert Fishes Council XIII:73-79.

50 - Johnson, J.E. 1985. Reintroducing the natives: Colorado squawfish and woundfin. Proceedings of the Desert Fishes Council XVII:118-124.

62 - Johnson, J.E., and B.L. Jensen. 1989. History and operation of endangered species hatcheries. U.S. Fish and Wildlife Service, Dexter National Fish Hatchery. Dexter, New Mexico.

58 - Kaeding, L.R., and M.A. Zimmerman. 1983. Life history and ecology of the humpback chub in the Little Colorado and Colorado Rivers of the Grand Canyon. Transactions of the American Fisheries Society 112(5):577-594.

95 - Keading, L.R., D.B. Osmundson, and C.R. Berry. 1985. Temperature as a resource limiting Colorado squawfish in the upper Colorado River Basin. U.S. Fish and Wildlife Service, Colorado River Fishery Project. Grand Junction, Colorado. 16 pp.

38 - Kaeding, L.R., and D.B. Osmundson. 1988. Interaction of slow growth and increased early-life mortality: an hypothesis on the decline of Colorado squawfish in the upstream regions of its historic range. Environmental Biology of Fishes 22(4):287-298.

93 - Knott, K. 1990. Intensive culture of Colorado squawfish to enhance growth and survival of fry. Colorado State University, Fort Collins, Colorado. 15 pp.

54 - Lanigan, S.T., and H.M. Tyus. 1987. Abundance, status, and rearing of razorback sucker (Xyrauchen texanus) in the Green River basin of Utah, USA. Proceedings of the Desert Fishes Council XIX:136-148.

63 - Loudermilk, W.E. 1981. Aspects of razorback sucker (Xyrauchen texanus, Abbott) life history which help explain their decline. Proceedings of the Desert Fishes Council XIII:67-72.

Table 2.1. Continued

REF #	CITATION
24 -	Marsh, P.C. 1985a. Effect of incubation temperature on survival of embryos of native Colorado River fishes. Southwestern Naturalist 30(1):129-140.
59 -	Marsh, P.C. 1985b. Razorback sucker management in Arizona. Proceedings of the Desert Fishes Council XVII:181 (abstract).
36 -	Marsh, P.C., and J.E. Brooks. 1989. Predation by ictalurid catfishes as a deterrent to re-establishment of hatchery-reared razorback suckers. Southwestern Naturalist 34(2):188-189.
39 -	Marsh, P.C., and D.R. Langhorst. 1988. Feeding and fate of wild larval razorback sucker. Environmental Biology of Fishes 21(1):59-67.
56 -	Marsh, P.C., and M.S. Pisano. 1985. Influence of temperature on development and hatching success of native Colorado River fishes. Proceedings of the Annual Conference of the Western Association of Fish and Game Agencies 62:59-67.
49 -	McAda, C.M., and R.S. Wydoski. 1980. The razorback sucker (Xyrauchen texanus) in the Upper Colorado River Basin, 1974-76. Technical Paper 99, U.S. Fish and Wildlife Service, Washington, D.C. 15pp.
22 -	Meffe, G.K. 1986. Conservation genetics and the management of endangered fishes. Fisheries 11(1):14-23.
85 -	Miller, R.R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6):22-38.
89 -	Mills, Lee. Undated. Plan for the propagation of threatened and endangered fishes of the Upper Colorado River Basin. U. S. Fish and Wildlife Service, Region 6, Lakewood, Colorado.
37 -	Minckley, W.L., and E.S. Gustafson. 1982. Early development of the razorback sucker Xyrauchen texanus (Abbot). Great Basin Naturalist 42(4):553-561.
1 -	Minckley, W.L., D.G. Buth, and R.L. Mayden. 1989. Origin of brood stock and allozyme variation in hatchery-reared bonytail, an endangered North American Cyprinid fish. Transactions of the American Fisheries Society 118(2):131-137.

Table 2.1. Continued

REF #	CITATION
75 -	Mpoame, M., and E.J. Landers. 1981. Ophiotaenia critica (Cestoda: Proteocephalidae), a parasite of the Colorado River squawfish. Great Basin Naturalist 41(4):445-448.
35 -	Mueller, G. 1989. Observations of spawning razorback sucker (Xyrauchen texanus) utilizing riverine habitat in the lower Colorado River, Arizona-Nevada. Southwestern Naturalist 34(1):147:149.
9 -	Muth, R.T., and T.P. Nesler. 1989. Marking Colorado squawfish embryos and newly hatched larvae with tetracycline. Southwestern Naturalist 34(3):432-436.
8 -	Muth, R.T., T.P. Nesler, and A.F. Wasowicz. 1988. Marking cyprinid larvae with tetracycline. American Fisheries Society Symposium 5:89-95.
74 -	Muth, R.T. 1990. Predator-prey interactions between selected non-native fishes of the Colorado River and larval Colorado squawfish and razorback sucker (Progress Report). Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado. 55 pp.
65 -	Osmundson, D.B. 1987. Growth and survival of Colorado squawfish (Ptychocheilus lucius) stocked in riverside ponds, with reference to largemouth bass (Micropterus salmoides) predation. M.S. Thesis, Utah State University, Logan, Utah. 191 pp.
79 -	Osmundson, D.B., and L.R. Kaeding. 1989. Colorado squawfish and razorback sucker grow-out pond studies as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. U.S. Fish and Wildlife Service, Colorado River Fishery Project. Grand Junction, Colorado. 57 pp.
15 -	Papoulias, D. 1986. Food availability and mortality for larval razorback sucker, Xyrauchen texanus. Proceedings of the Desert Fishes Council XVIII:210 (abstract).
99 -	Papoulias, D. 1988. Survival and growth of larval razorback sucker, Xyrauchen texanus. M.S. Thesis, Arizona State University, Tempe, Arizona. 83 pp.
10 -	Pimentel, R. and R.V. Bulkley. 1983. Concentrations of total dissolved solids preferred or avoided by endangered Colorado River fishes. Transactions of the American Fisheries Society 112(5):595-600.

Table 2.1. Continued

REF #	CITATION

68 - Rinne, J., V. Johnson, B. Jensen, A. Ruger, and R. Sorenson. 1986. The role of hatcheries in the management and recovery of threatened and endangered fishes. Pages 271-285 In R. Stroud (ed.). Fish culture in fisheries management. American Fisheries Society, Bethesda, M.D.

66 - Seethaler, K. 1978. Life history and ecology of the Colorado squawfish (Ptychocheilus lucuis) in the Upper Colorado River Basin. M.S. Thesis, Utah State University, Logan, Utah. 144 pp.

92 - Severson, S.H., C.A. Karp, H.M. Tyus, and G.B. Haines. 1990. Rearing of razorback suckers at Ouray, Utah. Proceedings of the Bonneville Chapter of the American Fisheries Society 1990: In Press. 4 pp.

96 - Thompson, J.M. 1989. The role of size, condition, and lipid content in the overwinter survival of age-0 Colorado squawfish. M.S. Thesis, Colorado State University, Fort Collins, Colorado. 87 pp.

23 - Toney, D.P. 1974. Observations on the propagation and rearing of two endangered fish species in a hatchery environment. Proceedings of the Annual Conference of the Western Association of State Fish and Game Commissioners 54:252-239.

25 - Tyus, H.M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979-1986. Transactions of the American Fisheries Society 116(1):111-116.

91 - Tyus, H.M., and S.H. Severson. 1990. Growth and survival of larval razorback suckers Xyrauchen texanus fed five formulated diets. Progressive Fish Culturist 52(3). In Press. 9 pp.

64 - Ulmer, L. 1980. Movement and reproduction of the razorback sucker (Xyrauchen texanus) inhabiting Senator Wash Reservoir, Imperial County California. Proceedings of the Desert Fishes Council XII:106 (abstract).

82 - U.S. Fish and Wildlife Service. 1987. Recovery implementation program for endangered fish species in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Region 6, Denver, Colorado. 82 pp.

Table 2.1. Continued

REF #	CITATION
83 -	U.S. Fish and Wildlife Service. 1989. Three year propagation/genetics management work plan. 23 pp.
17 -	Valdez, R.A. 1985. A review of the hatchery program for threatened and endangered fishes of the Colorado River. Colorado Water Congress Special Project on Threatened and Endangered Species. Tom Pitts and Associates, Loveland, Colorado. 29 pp.
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100-	Valdez, R.A. and A. Valdes-Gonzales. 1990. Field spawning of endangered humpback chub (Gila cypha). Technical Report. Bio/West, Inc. Logan, Utah. 2 pp.
61 -	Valentine, J. 1981. Hatchery and laboratory phase of the Colorado River endangered fishes study. Proceedings of the Bonneville Chapter of the American Fisheries Society 1981:111-117.
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Table 2.1. Continued

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Table 2.2 A List of Contacts and Summary of Responses on Culture-Related Information.

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Table 2.2 Continued

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Table 2.2 Continued

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Table 2.2 Continued

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Table 2.2 Continued

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a- Indicates contact made by Bio/West
L=Letter
P=Phone call
V=Visit.

b- Indicates response by contact
L=Letter
P=Phone call
V=Visit.

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2.2 SUMMARY OF PAST CULTURE TECHNIQUES

This section provides a summary of culture techniques used on the four species of Colorado River endangered fish. The summary begins with a brief history of the culture of these endangered fish and a synthesis of techniques employed. A more detailed description of current techniques for extensive and intensive culture of these fish species is presented in Section 2.3.

2.2.1. Brief History

Culture of Colorado River endangered fish began when 8 adult Colorado squawfish were taken from the Yampa River in July 1973 and transferred to Willow Beach NFH in Arizona. Seven of the fish survived and in July 1974, these spawned naturally in gravel-lined concrete troughs to produce 5,000 to 10,000 young squawfish (Toney 1974). After that initial transfer, 51 more adults were captured in the wild and sent to Willow Beach NFH. This includes 14 adults captured in November 1975 from the Colorado River near Grand Junction, Colorado, and 8 adults from the Green River near Jensen, Utah, in May 1976. In April and May, 1978, 11 adults were transferred from the Colorado River near Grand Junction and 11 from the Green River near Jensen. In October and November 1979, 3 fish were transferred from the Green River near Jensen and 4 from the Colorado River near Moab, Utah. A total of 58 adults were transferred from Willow Beach NFH to Dexter NFH in 1980, and since then, 12 more wild squawfish have been taken to Dexter NFH by the end of 1990.

Razorback suckers were first brought into captivity for propagation in 1974 when 40 adults were transferred from Lake Mohave, Arizona to Willow Beach NFH. The first transfers of humpback chub were in 1979 and 1980 when a total of 33 fish were brought to Willow Beach from the Little Colorado River, Grand Canyon, Arizona, and from Black Rocks, Colorado River, Colorado. The first bonytail chub were transferred to Willow Beach in 1979 and 1980 when 12 adults were taken from Lake Mohave, Arizona (Hamman 1981a).

Willow Beach NFH was the primary culture facility for these fish from 1974 to 1980, at which time the program was transferred to Dexter NFH near Roswell, New Mexico. Since that time, Willow Beach NFH has been phased out of endangered fish culture and propagation, and Dexter NFH has assumed the role as the principal endangered fish hatchery for the Colorado River Basin.

A variety of fish culture techniques have been used on the four species of Colorado River endangered fish since 1974. The following is a summary of past culture and propagation techniques used on each of the four species of fish (Tables 2.3, 2.4, 2.5 and 2.6). These techniques are presented for each of the developmental stages, including egg procural, egg incubation, swim-up fry, fry (Phase I), fingerling (Phase II), and fingerling (Phase III).

Colorado Squawfish

A summary of culture efforts for Colorado squawfish is presented in Table 2.3. Both human chorionic gonadotropin (HCG) and carp pituitary (CP) have been used as hormones to induce timely ovulation of females (Table 2.3a). Toney (1974) injected HCG intraperitoneally at a rate of 900 i.u./lb and found eggs in the gravel raceway 1 week later as a result of natural spawning by wild fish. Hamman (1981a) injected acetone-dried CP at rates of 4 mg/kg and 8 mg/kg of body weight and nearly doubled egg production of wild females (injected = 55,000 eggs vs. uninjected = 25,000 eggs). Jensen (1983b) used CP (2 mg/lb) on females and HCG on males (150 i.u./lb). Hamman (1986) used acetone-dried CP on 9 and 10-year old fish at a rate of 4 mg/kg. These fish ovulated in 18 - 20 hours and 20 - 24 hours, and produced an average of 77,400 and 66,185 eggs per female, respectively. Hamman (1989) also injected wild females with CP and obtained an average of 82,576 eggs per female. The Arizona Game & Fish Department (AGF 1988, 1989) injected females with CP at a rate of 150 i.u./lb and produced averages of 29,946 and 39,130 eggs per female.

Hamman (1981a) incubated eggs at 22 - 24°C, 20 - 21°C, and 12 - 13°C with 67, 59, and 30% hatching success, respectively (Table 2.3b). Hatching times at these temperatures were 90 - 130 hours, 90 - 120 hours, and 145 - 180 hours, respectively. Jensen (1983a) reported 59% hatching success with eggs held in Heath Trays and 66% with eggs held in McDonald Jars. Hamman (1986) found that eggs held at the same temperature (20 - 22°C) and the same flow rate (15 - 23 l/min) exhibited similar hatching times of 100 - 144 hours for 9-year old females and 96 - 144 hours for 10-year old females. Fourteen-hour eggs incubated at Colorado State University (CSU) (1989) at 21°C hatched in 80 - 110 hours (total incubation time of 94-124 hours) while eggs incubated at 11.4°C died and disintegrated. AGF (1988, 1989) reported hatching times of 48-72 hours at 68°F (20°C).

Swim-up fry have been held in concrete troughs (Hamman 1981a, 1989) at 20 - 21°C for 2 - 3 days (Table 2.3c). Fry at CSU (1989) were held in small pans suspended in rectangular troughs. The fry were concentrated in small pans to increase feeding efficiency and to reduce time and labor in cleaning the much larger trough. AGF (1988, 1989) held fish from sac-fry to swim-up in hatchery troughs before placing them in outdoor earthen ponds.

Colorado squawfish fry (Phase I) were held in fertilized recirculating systems (Hamman 1981a) and in earthen ponds 0.89 - 0.98 surface acres (Hamman 1989). Stocking rate in the earthen ponds was 105,316 - 137,438 fry per surface acre with a survival rate of 32.8% after 50 days (Table 2.3d). AGF (1988, 1989) stocked fry in heavily fertilized ponds in June at the Bubbling Pond Hatchery where the fish were held until October with variable survival and growth ranging from 2.1 to 2.9 inches. Fry have also been held in small pans suspended in troughs (CSU 1989) under intensive culture.

Colorado squawfish fingerlings (Phase II) have been cultured extensively in earthen ponds, 0.98 - 1.08 surface acres (Hamman 1989). These fish fed on the natural zooplankton which was supplemented with commercial fish food starter, #1 and #2 granules (Table 2.3e). Survival of the fish in earthen ponds was 92.7% after 88 days. Phase II fingerlings have also been cultured intensively in small rectangular troughs (CSU 1989) where the fish were fed brine shrimp, Biokyowa, Ziegler's larvae, and Rangen's trout diet as part of feeding experiments to evaluate this culture technique.

Humpback Chub

Fewer humpback chub have been cultured and propagated in a hatchery than any of the other three species of Colorado River endangered fish. A summary of past culture efforts for humpback chub is presented in Table 2.4. Culture techniques for this species are similar to those used for the closely related bonytail chub.

Hamman (1982a, 1982b) used acetone-dried CP injected intraperitoneally at a dose of 4 mg/kg of body weight to induce ovulation of wild humpback chub (Table 2.4a). Seventeen fish produced an average of 2,523 eggs per female. Highest hatching success (84%) of humpback chub was with eggs held at 19 - 20°C, while warmer temperatures of 21 - 22°C yielded slightly lower success of 79%. Incubation temperatures of 16 - 17°C resulted in 62% hatching success while only 12% of the eggs hatched that were incubated at 12 - 13°C (Table 2.4b). Hatching time at 19 - 20°C was 115 - 160 hours.

Hamman (1982b) also held swim-up fry in concrete troughs at 21 - 22°C, 19 - 20°C, 16 -17°C, and 12 - 13°C, and found survival rates of 99, 95, 91, and 15%, respectively (Table 2.4c). Fry held at 21 - 22°C were 36.9 - 47.5 mm long in 56 days (Table 2.4d). No information was available for humpback chub held as Phase II (Table 2.4e).

In the only effort to procure eggs from humpback chub in the wild, Valdez and Valdes-Gonzales (1991) successfully stripped and fertilized 18,000 eggs from three females following multiple injections of acetone-dried CP. The three fish yielded 4,000, 4,000, and 10,000 eggs. These fish were among 18 adults captured in Black Rocks, Colorado River, Colorado on June 2, 1980, held in live pens in the river for 5 days, and released. The river temperature at the time of capture was 11.5°C. The eggs were transferred to Willow Beach NFH.

Bonytail Chub

Little variation in technique has been used in culturing bonytail chub. A summary of past culture efforts for this species is presented in Table 2.5. All brood stock in existence are from Lake Mohave, Arizona, in the Lower Colorado River Basin. Although some wild fish have recently been captured in the upper basin, none have been transferred to hatchery facilities.

Acetone-dried CP has been used in all efforts to procure eggs of bonytail chub (Hamman 1982a, 1985b, Jensen 1983a). The injection rate was 4 mg/kg of body weight, and ovulation occurred in 18 - 20 hours (Table 2.5a). Wild bonytail chub produced greater numbers of eggs per female than domestic fish, perhaps because of age and fish size. Hamman (1982a) reported 25,090 eggs per female from 6 wild Lake Mohave fish, while Hamman (1985b) reported only 4,990 and 16,464 eggs per female for 2 and 3-year old fish, respectively. Similarly, Jensen (1983a) reported an average of 4,677 eggs per female for 2-year old hatchery fish. The lower fecundity of hatchery fish may be caused by the relatively young age (2 and 3-year old fish) and smaller size of the hatchery fish.

Ninety percent of eggs hatched from wild Lake Mohave bonytail chubs that were incubated at 20 -21°C, while 55% hatched at 16 - 17°C, and only 4% hatched at 12 - 13°C (Hamman 1982a). Hatching times at these temperatures were 99 - 174 hours, 170 - 269 hours, and 334 - 498 hours, respectively (Table 2.5b). Hamman (1985b) also found that only 17.1% of eggs hatched from 2-year old hatchery reared fish and 37.7% hatched from 3-year old fish, while Jensen (1983a) reported 67.5% hatching success of eggs from 2-year old domestic fish.

Bonytail fry (Phase I) were held in lightly fertilized circulating troughs, while fed on natural zooplankton for 21 days, followed by a commercial trout starter (Table 2.5d). The size of these fish was 18.1 mm in 28 days and 49.5 mm in 70 days, with a survival rate of 71% in 70 days (Hamman 1982a).

Razorback Sucker

The first recorded efforts at culturing razorback suckers were by Inslee (1981, 1982) at Dexter NFH. A summary of past culture efforts for razorback sucker is presented in Table 2.6. Using wild fish from Lake Mohave, Arizona, he injected females intraperitoneally with HCG (50 and 100 i.u./lb) and CP (2 mg/lb) to accelerate timely maturation of eggs (Table 2.6a). The fish produced eggs in several days with samples of 130 eggs per gm and 233 fry per ml. Jensen (1983b) also injected female razorback suckers with 100 i.u. HCG per lb at 24-hour intervals with successful ovulation in several days. He also found that males could be injected once with 300 i.u. HCG per lb to insure a viable and timely production of milt. Hamman (1985b) used HCG at a rate of 220 i.u. per kg at 24-hour intervals, and reported successful ovulation after several days.

Egg production by females varied considerably, from 63,674 for hatchery-reared fish (Hamman 1985a, Jensen 1984) to 123,110 for wild fish (Jensen 1984). McAda and Wydoski (1980) estimated fecundity of wild fish at 24,490 - 76,576 eggs per fish.

The eggs of razorback suckers have been incubated in a variety of ways and under a variety of temperatures (Table 2.6b). Inslee (1981) incubated eggs at 16.6°C, while Minckley and Gustafson (1982) incubated eggs at 14 - 15°C with hatching times of 5.3 - 5.5 days (127 - 132 hours). Eggs incubated at 21°C (Jensen 1983b) hatched in 96 - 144 hours. Hamman (1985a) held eggs at 20 - 22°C with 38.1% hatching in Heath Trays and 54.7% in McDonald Jars.

Swim-up fry were generally removed from the hatching trays or jars and held in small porous trays or containers during the 4 - 5 days of yolk-sac absorption (Table 2.6c). Approximately 4 days after hatching, and as the yolk sac was being absorbed and the mouth parts developing, the fry were transferred to larger holding units with feed. Inslee (1981) placed fry in 6-foot circular tanks lined with gravel and fed them a diet of trout starter four times a day (Table 2.6d). The fish were then transferred to 0.1 surface acre ponds and allowed to feed on natural zooplankton.

Hamman (1987) transferred the fry to specially prepared and fertilized outdoor earthen ponds ranging in size from 0.34 to 1.08 surface acres, at a density of 101,000 - 109,000 fry per surface acre (71,000/lb). The fry fed on natural zooplankton in the pond at variable water temperatures of 9 - 22°C, with a survival rate of 87.8 - 98.6% after 69 - 78 days (Table 2.6d). At the end of Phase I, or with the fish 1.5 - 2.0 inches long, the fingerlings were transferred to earthen ponds 0.86 - 0.98 surface acres to feed on natural zooplankton supplemented with #1 and #2 granules of a commercial trout diet. At a stocking rate of 51,000 - 58,000 fish per surface acre (724 - 549/lb), survival was 92.7 - 95.8% after 51 - 70 days (Table 2.6e). Razorback suckers at Dexter NFH were often carried through a third rearing cycle (Phase III) in earthen ponds (Table 2.6f).

Table 2.3a	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Colorado squawfish					
Life stage:	Egg procural					
CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	HORMONE INJECTION	INJECTION RATE	EGG PRODUCTION (PER FEMALE)	EGG DIAMETER (mm)
Toney 1974	023	7 wild - Yampa River	chorionic gonadotropin	900 units/lb	eggs in gravel 1 week later	-
Hamman 1981a	006	13 wild - Colorado River 14 wild - Green River[-a] • 39 hatchery-reared[-a] • 39 hatchery-reared[-a]	Allowed to spawn naturally Acetone-dried carp pituitary (40 mg) in oxytetracycline hydrochloride (10ml)	• 4 mg/kg • 8 mg/kg	wild uninjected=25,000 wild injected=55,000	- - - -
Jensen 1983a	053	26 hatchery-reared females	carp pituitary	-	77,436 (57,766-113,341)	-
Jensen 1983b	044	• Hatchery-reared became mature in the 6th year	• females - carp pituitary • males - human chorionic gonadotropin	• 2 mg/lb • 150 iu/lb	-	-
Jensen 1984	014	9 domestic	-	-	66,185	-
Hamman 1986	027	• 24 9-year-old females[-a] • 9 10-year-old females[-a] from wild 1974 stock	• acetone-dried carp pituitary • acetone-dried carp pituitary	• 4 mg/kg-ovulated in 18-20 hours • 4 mg/kg - ovulated in 20-24 hours	• 77,400 (55,533/kg) • 66,185 (45,451/kg)	- -
Jensen 1986	060	18 females	-	-	82,778 (22,921/lb)	-
Hamman 1989	003	25 females	acetone-dried carp pituitary		82,576	
AGF 1988	080	Bubbling Pond - Pond 31 • 30 females • 60 males	acetone-dried carp pituitary	150 iu/lb females only	29,946 eggs/female 712,897 eggs/26 females	-
AGF 1989	081	Bubbling Pond - Pond 31 • 30 females • 60 males	acetone-dried carp pituitary	150 iu/lb females only	39,130 eggs/female 900,000 eggs/23 females	-

[a]- Fish were anesthetized before stripping.

Table 2.3b A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Colorado squawfish

Life stage: Egg incubation

CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	FLOW RATE	TEMP. (°C)	HATCHING TIME (h)	PERCENT HATCHED	LARVAL SIZE (mm)
Toney 1974	023	7 wild - Yampa	200 gal/min	-	-	-	-
Hamman 1981a	006	wild injected-[a]	-	20-21	90-120	59	6.5-7.5
Hamman 1981a	006	hatchery injected	-	12-13	145-180	30	6.5-7.5
Hamman 1981a	006	hatchery injected	-	20-21	90-120	59	6.5-7.5
Hamman 1981a	006	wild injected-[b]	-	22-24	90-130	67	6.5-7.5
Hamman 1981a	006	wild uninjected	-	-	96-144	30	6.5-7.0
Jensen 1983a	053	26 hatchery-reared females	-	-	-	• Heath Trays = 59% • McDonald Jars = 66%	-
Jensen 1983b	044	hatchery-reared	-	-	96-144	-	-
Jensen 1984	014	9 domestic-[d]	-	-	-	19.8% to swim-up fry	-
Marsh 1985, Marsh & Pisaro 1985	024	Willow Beach Hatchery	1 l/hour	20	78-108	27	5.5
Marsh 1985; Marsh & Pisaro 1985	024	Willow Beach Hatchery	1 l/hour	25	63	-	5.6
Hamman 1986	027	24 9-year-old females ('83) 9 10-year-old females ('84)	15-23 l/min 15-23 l/min	20-22 20-22	100-144 96-144	- -	- -
Jensen 1986	060	18 females ('85)	3 gal/min	25°F	-	-	-
CSU 1989	013	Dexter:14-hour eggs	22.7 l/min	21	94-124	-	-
CSU 1989	013	Dexter:14-hour eggs	22.7 l/min	11.4	-[c]	-	-

Table 2.3b	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.						
Species:	Colorado squawfish						
Life stage:	Egg incubation						
CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	FLOW RATE	TEMP. (°C)	HATCHING TIME (h)	PERCENT HATCHED	LARVAL SIZE (mm)
AGF 1988	080	Bubbling Pond - Pond 31 • 30 females • 60 males	-	20	48-72	50% visual estimate • vertical tray incubator	-
AGF 1989	081	Bubbling Pond - Pond 31 • 30 females • 60 males	-	20	48 - 72	50% visual estimate • vertical tray incubator	-

[a]- Eggs incubated in trays.

[b]- Fish allowed to spawn naturally in raceways.

[c]- It was determined that squawfish eggs cannot successfully be incubated at 11.4°C.

[d]- Asian tapeworms treated with Di-N-Buth-Tin-Oxide in gelatin capsules; results unknown.

Table 2.3c	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Colorado squawfish					
Life stage:	Swim-up fry					
CITATION	REFERENCE NUMBER	HOLDING UNIT	FLOW RATE	TEMP (°C)	HOLDING TIME (DAYS)	PERCENT SURVIVAL
Hamman 1981a	006	Concrete troughs (30 x 2.4 x 1.2 m)	-	20-21	2-3	-
Hamman 1989	003	Concrete troughs (30 x 2.4 x 1.2 m)	-	20-21	2-3	-
CSU 1989	013	Small pans (15" x 12" x 15") suspended in trough	22.7 l/min	21	-	-
AGF 1988	080	Sac-fry in troughs until swim-up	-	20	Sac-fry to swim-up	-
AGF 1989	081	Sac-fry in troughs until swim-up	-	20	Sac-fry to swim-up	-

Table 2.3d A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Colorado squawfish

Life stage: Fry (Phase I)

CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	TEMP (°C)	PERCENT SURVIVAL
Hamman 1981a	006	Fertilized recirculating[a] system @ 23-24°C	-	-	-	-	-
Hamman 1989	003	Earthen ponds 0.89 - 0.98 ac. ave. depth = 3 feet	105,316 - 137,438/ac.	95,340 - 104,420/lb	natural zooplankton supplemented with commercial trout starter	23-24	32.8% @ 50 days
CSU 1989	013	Small pans (15"x12"x5") suspended in trough	-	-	-	-	-
AGF 1988	080	Earthen ponds - 2 ponds • 50 lb 16-20-0 • 1 gal Diquat, 28 lb $CuSO_4$	100,000	-	natural zooplankton supplemented with 2-3 lbs trout food daily	20	8%-pond 1[b] 22.4%-pond 5 (June 15-Oct)
AGF 1989	081	Earthen Pond - 3 ponds • 80 lb alfalfa pellets • 50 lb cottonseed meal • after filling: 120 lbs alfalfa pellets, 75 lbs cottonseed meal • 55 lb 18-46-0 • 11 gal liquid fertilizer • 1 gal/ac Diquat • 2 gal/ac Cutrine	50,000	-	natural zooplankton supplemented with 2-3 lbs trout food daily	20	0%-pond 23[c] 5.3%-pond 24[d] 40.8%-pond 26[e]

[a]-Temperature drop of 10°C over 10 minutes tolerated by fish; O_2 depletion of 9.9 to 1.5 mg/l caused 60% mortality.

[b]-Low survival rates attributed to cannabalism, mean size in October=2.1".

[c]-June 9 - September 22, no squawfish harvested, 17 smallmouth bass present.

[d]-June 9 - September 21, mean size=2.7".

[e]-June 0 - September 20, mean size=2.9".

Table 2.3e	A Summary of Past Culture Efforts for the Colorado River Endangered fish.					
Species:	Colorado squawfish					
Life stage:	Fingerling (Phase II)					
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	PERCENT SURVIVAL
Black & Bulkley 1985	028	-	-		Fish gained 0.3 gm @ 15°C, 0.9 gm @ 20 & 30°C, 1.7 gm @ 25°C during 12 weeks	-
Hamman 1989	003	earthen ponds 0.98 - 1.08 acre ave depth = 3 ft.	52,978 - 55,424/ac.	980 - 1088/lb	natural zooplankton[-a] supplemented by Fish Food #1 & #2 granules	92.7% @ 88 days
CSU 1989	013	small rectangular troughs	-	-	• brine shrimp[-b] • Biokyowa • Ziegler (larvae) • Rangen's trout diet	- - - -

a- Clam shrimp created excessive turbidity and were controlled with Masoten (trichlorfon) at 0.25 ppm - contributed to low fish survival.

b- All feeds performed equally at 20°C; fish were more active on Biokyowa at 15.5°C.

Table 2.4a	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Humpback chub					
Life stage:	Egg procural					
CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	HORMONE INJECTION	INJECTION RATE	EGG PRODUCTION (PER FEMALE)	EGG DIAMETER (mm)
Hamman 1982b	004	17 wild	Acetone-dried carp pituitary	4 mg/kg	2,523	-

Table 2.4b	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.						
Species:	Humpback chub						
Life stage:	Egg incubation						
CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	FLOW RATE	TEMP. (°C)	HATCHING TIME (h)	PERCENT HATCHED	LARVAL SIZE (mm)
Hamman 1982b	004	17 wild	-	21-22	102-146	79	-
Hamman 1982b	004	17 wild	-	19-20	115-160	84	-
Hamman 1982b	004	17 wild	-	16-17	167-266	62	-
Hamman 1982b	004	17 wild	-	12-13	304-475	12	-

Table 2.4c A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Humpback chub

Life stage: Swim-up fry

CITATION	REFERENCE NUMBER	HOLDING UNIT	FLOW RATE	TEMPERATURE	HOLDING TIME (DAYS)	PERCENT SURVIVAL
Hamman 1982b	004	Concrete troughs	-	21-22[a]	-	99
Hamman 1982b	004	Concrete troughs	-	19-20	-	95
Hamman 1982b	004	Concrete troughs	-	16-17	-	91
Hamman 1982b	004	Concrete troughs	-	12-13	-	15

a- Size doubled in 21-28 days.

Table 2.4d	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.						
Species:	Humpback chub						
Life stage:	Fry (Phase I)						
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	TEMPERATURE (°C)	PERCENT SURVIVAL
Hamman 1982b	004	Concrete troughs	-	36.9-47.5[a]	-	21 - 22°	-

[a]- Sized attained 56 days after hatching.

Table 2.4e A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Humpback chub

Life stage: Fingerling (Phase II)

CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	PERCENT SURVIVAL
No available information.						

Table 2.5a A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Bonytail chub

Life stage: Egg procural

CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	HORMONE INJECTION	INJECTION RATE	EGG PRODUCTION (PER FEMALE)	EGG DIAMETER (mm)
Hamman 1982a	005	Lake Mohave '79-'81 (6 females)	Acetone-dried carp pituitary	4 mg/kg - ovulated in 18-20 hours.	25,090 (21,514/kg)	-
Jensen 1983a	053	Hatchery-reared 24 females (2-year-old)	acetone-dried carp pituitary	-	4,677 (1,015-10,384)	-
Hamman 1985b	032	Hatchery-reared • 24 females (2-year-old) • 11 females (3-year-old)	• acetone-dried carp pituitary • acetone-dried carp pituitary	• 4 mg/kg- ovulated in 18-20 hours • ovulated in 20 hours	• 4,990 • 16,464	- -

Table 2.5b A Summary of Past Culture Efforts for the Colorado River Endangered Fish.

Species: Bonytail chub

Life stage: Egg incubation

CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	FLOW RATE	TEMP. (°C)	HATCHING TIME (h)	PERCENT HATCHED	LARVAL SIZE (mm)
Hamman 1982a	005	Lake Mohave '79-'81 (6 females)	7.5 l/min	12-13	334-498	4	6.8
Hamman 1982a	005	Lake Mohave '79-'81 (6 females)	7.5 l/min	16-17	170-269	55	6.8
Hamman 1982a	005	Lake Mohave '79-'81 (6 females)	7.5 l/min	20-21	99-174	90	6.8
Jensen 1983a	053	Hatchery-reared 24 females (2-year-old)	-	-	-	67.5	-
Hamman 1985b	032	Hatchery-reared • 24 females (2-year-old) • 11 females (3-year-old)	• 11 l/min • 11 l/min	• 20-22 • 20-22	- -	• 17.1 • 37.7	- -

Table 2.5c A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species: Bonytail chub					
Life stage: Swim-up fry					
CITATION	REFERENCE NUMBER	HOLDING UNIT	FLOW RATE	TEMPERATURE (°C)	HOLDING TIME (DAYS)
No information available.					

Table 2.5d	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.						
Species:	**Bonytail chub**						
Life stage:	**Fry (Phase I)**						
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	TEMPERATURE	PERCENT SURVIVAL
Hamman 1982a	005	Lightly fertilized circulating tanks (30 x 2.4 x 1.2 m)	-	18.1 mm @ 28 days 49.5 mm @ 70 days	Natural zooplankton for 21 days then commercial trout starter (0.25 - 0.5 kg/day)		71% @ 70 days

Table 2.6a	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Razorback sucker					
Life stage:	Egg procural					
CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	HORMONE INJECTION	INJECTION RATE	EGG PRODUCTION (PER FEMALE)	EGG DIAMETER (mm)
McAda & Wydoski 1980	049	wild fish	-	-	24,490-76.576-[a]	-
Inslee 1981	018	136 wild - Lake Mohave	• chorionic gonadotropin • carp pituitary	• 50 iu/lb • 2 mg/lb	-	-
Inslee 1982	051	wild - Lake Mohave	human chorionic gonadotropin	100 iu/lb	-[b]	-
Jensen 1983b	044	-	human chorionic gonadotropin	• females with 100 iu/lb ● 24 hr intervals • males with 300 iu/lb	-	-
Jensen 1984	014	25 wild	-	-	123,110	-
Jensen 1984	014	70 domestic	-	-	63,674	-
Hamman 1985	013	Hatchery-reared 70 females (3-year-old)	chorionic gonadotropin	220 iu/kg ● 24 hr intervals	63,645	-
Lanigan & Tyus 1987	054	11 wild females - Green River	-	-	-	-
Severson et al. 1990	09	wild fish - Green River	human chorionic gonadotropin	females with 150-300 iu/kg	-	-

a- Estimated fecundity of wild fish.

b- Sample counts revealed 130 eggs/g and 233 fry/ml.

Table 2.6b **A Summary of Past Culture Efforts for the Colorado River Endangered Fish.**

Species: **Razorback sucker**

Life stage: **Egg incubation**

CITATION	REFERENCE NUMBER	BROOD STOCK SOURCE	FLOW RATE	TEMP. (°C)	HATCHING TIME (h)	PERCENT HATCHED	LARVAL SIZE (mm)
Inslee 1981	018	136 wild - Lake Mohave	10 l/min[a]	16.6°F	-	-	-
Inslee 1982	051	wild - Lake Mohave	-	-	-	27.7-61.1	-
Minckley & Gustafson 1982	037	-		14-15	127-132	-	6.8-7.3
Jensen 1983b	044	-	3 gal/min	21°F	96-144	-	-
Jensen 1984	014	70 domestic	-	-	-	39.8	-
Jensen 1984	014	25 wild	-	-	-	51.7	-
Hamman 1985	031	Hatchery-reared - 70 females (3-years-old)	4-11 l/min	20-22	-	• Heath Trays=38.1 • McDonald Jars=54.7	-

[a]- Fish spawned naturally in 6-foot circular tanks lined with 1/2-3" rock, 22" deep.

Table 2.6c	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Razorback sucker					
Life stage:	Swim-up fry					
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	SIZE	TEMPERATURE	PERCENT SURVIVAL
Inslee 1981	018	Gravel-lined 6-foot circular tanks	-	-	-	-
Hamman 1987	012	Indoor concrete troughs	-	-	20-21	-

Table 2.6d	**A Summary of Past Culture Efforts for the Colorado River Endangered Fish.**						
Species:	**Razorback sucker**						
Life stage:	**Fry (Phase I)**						
CITATION	**REFERENCE NUMBER**	**HOLDING UNIT**	**STOCKING RATE**	**FISH SIZE**	**FOOD SOURCE**	**TEMPERATURE (°C)**	**PERCENT SURVIVAL**
Inslee 1981	018	Gravel-lined 6-foot circular tanks	-	-	Trout starter 4 times daily	-	-
Hamman 1987	012	Fertilized earthen ponds 0.34-1.08 ac.	101,000-109,000/ac	71,000/lb	Natural zooplankton	9-22	87.8-98.6 @ 69-78 days

Table 2.6e	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Razorback sucker					
Life stage:	Fingerling (Phase II)					
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	PERCENT SURVIVAL
Inslee 1981	018	Fertilized earthen ponds 0.1 ac.	-	-	Natural zooplankton	-
Hamman 1987	012	Fertilized earthen ponds 0.86 - 0.98 ac.	51,000 - 58,000/ac	724-549/lb	Natural Zooplankton + #1 & #2 granules commercial trout diet	92.7 - 95.8 @ 51-70 days

Table 2.6f	A Summary of Past Culture Efforts for the Colorado River Endangered Fish.					
Species:	Razorback sucker					
Life stage:	Fingerling (Phase III)					
CITATION	REFERENCE NUMBER	HOLDING UNIT	STOCKING RATE	FISH SIZE (mm)	FOOD SOURCE	PERCENT SURVIVAL
Hamman 1987	012	Fertilized earthen ponds 0.98 ac, 3 feet deep	26,000 - 27.000/ac	158/lb	Commercial trout diet #2 or #3 granules	96.2

2.3 CURRENT CULTURE TECHNIQUES

The four species of Colorado River endangered fish are cultured using two different methods; extensive culture and intensive culture. Extensive culture involves rearing fish at low to moderate densities in outdoor earthen ponds on natural planktonic food with supplemental feedings of artificial foods. Intensive culture involves rearing fish at high densities in indoor, temperature-controlled tanks or troughs on artificial diets. The following is a description of the techniques currently in use for each of the two methods.

2.3.1. Extensive Fish Culture

Extensive fish culture of the Colorado River endangered fish has been practiced at several facilities. Currently the method is employed at the Dexter NFH in southeastern New Mexico and at the Bubbling Pond Hatchery near Sedona, Arizona. The following is a summary of extensive culture as practiced at Dexter NFH with insights to variations at the Bubbling Pond Hatchery. Figure 2.1 is presented to illustrate the approximate time schedule for propagation of razorback sucker, bonytail chub, and Colorado squawfish at the Dexter NFH. Humpback chub have not been cultured at Dexter NFH as frequently as the other three species, but limited experience with the species suggests a schedule similar to that of bonytail chub. Table 2.7 is presented as a tabular summarization of extensive culture methods for the four Colorado River endangered fish. Figure 2.1 and Table 2.7 are located at the end of Section 2.3.

Colorado Squawfish

Egg Maturation. Colorado squawfish brood stock are held in outdoor earthen ponds at Dexter NFH. Hatchery-reared males and females usually mature at 5 and 6 years of age, respectively. Wild fish usually mature a year later than hatchery fish. Unlike razorback sucker and bonytail chub, Colorado squawfish do not cause high turbidity in holding ponds, which indicates a more open-water behavior and pelagic feeding mode. These brood fish are fed commercial trout food (.25-inch pellets), supplemented with fingerling rainbow trout, to insure that all elemental needs are fulfilled for this large piscivore.

Colorado squawfish mature later in the season than the other three species of Colorado River endangered fish. Gonadal maturation at Dexter NFH generally occurs in late May and early June, while maturation at Bubbling Pond is generally in early June. Maturation in the wild, as indicated by estimated spawning time, ranges from mid-May to late August, depending on the timing and duration of spring run-off. Colorado squawfish have not been observed to spawn naturally in outdoor earthen ponds, although natural reproduction was reported in gravel-lined raceways at Willow Beach NFH following injection with HCG (Toney 1974).

The period for gonadal maturation of Colorado squawfish is less than that of the other three species. Resorption of eggs in this species limits the available time for hormonal injection to 10 - 14 days.

In a manner similar to handling brood stock of the razorback sucker and bonytail chub, adult Colorado squawfish are transferred from earthen ponds to indoor covered concrete troughs. Following one day of adjustment, each female is injected intraperitoneally with 4 mg/kg of acetone- dried CP. This hormone is preferred for cyprinids (bonytail chub, humpback chub, and Colorado squawfish) over HCG, which is used on razorback suckers. Like bonytail chub, Colorado squawfish are generally injected only once and usually ovulate 20 - 24 hours after injection. Caution is advised in using CP since it can kill a fish with insufficient gonadal development. For this reason, personnel at Dexter NFH are particularly careful to thoroughly examine each brood fish. Secondary sex characteristics are examined prior to injection to prevent loss or injury to the fish. For example, Colorado squawfish must be tubercled, males more pronounced than females. Females must have a softened abdomen anterior to the vent with the tissue around the vent "flowery" and swollen, and the genital papillae swollen. Personnel at Bubbling Pond Hatchery use similar criteria for selecting fish to spawn and also use CP to induce ovulation.

<u>Egg Procural/Fertilization</u>. Eggs are procured and fertilized using the "wet method" at both Dexter NFH and Bubbling Pond Hatchery. Eggs are stripped with gentle pressure to the abdomen. Females are not "force-stripped" or stripped multiple times to maximize the percentage of ripe eggs. This reduces stress to the fish, minimizes the number of "green" eggs, and maximizes the percentage of viable eggs. Colorado squawfish consistently produce about 18,000 eggs per pound of body weight, so that a 10-pound female is expected to produce about 180,000 eggs.

All egg-holding facilities (Heath Trays, McDonald Jars, etc.) are thoroughly washed in formalin and allowed to dry before any eggs are taken. The eggs are stripped directly into porcelain pans containing sperm diluent and the milt of at least two males is added. Eggs and milt are alternately added to insure complete mixing and enhance fertilization. Water is added immediately to the egg/milt mixture to activate the sperm. Viable eggs are sticky even before fertilization, therefore they are constantly and gently stirred with a feather to prevent adhesion. Viable eggs are more adhesive than unfertilized eggs, and are light yellow in color. One minute after fertilization, a mixture of bentonite (commercial drilling slurry) is added to the egg/milt mixture to further prevent adhesion and clumping of the eggs. The mixture is continually stirred with a feather.

The eggs are then poured into floating egg baskets to loosen the clumps of bentonite and wash the eggs. The eggs are allowed to water harden in the egg baskets. Water-hardening is complete about one-half hour after fertilization, and the eggs are enumerated gravimetrically. A small sample of about 1 g of eggs is weighed and counted to determine the number of eggs per gram. Then all the eggs are weighed to estimate total numbers.

Incubation. The eggs are incubated in Heath Trays and McDonald Jars at 20 to 21°C. The water supply at Dexter NFH is 17.6°C, and is heated to 21°C and passed over the eggs at a flow rate of about 3 gallons per minute. The water supply at Bubbling Pond is 68°F (20°C).

Approximately 100,000 eggs (about 500 g) are placed in each Heath Tray and up to 500,000 eggs are incubated in each McDonald Jar at Dexter NFH. That facility has 12 McDonald Jars and 28 Heath Trays with a combined capacity of about 8.8 million eggs. The eggs held in McDonald Jars are aerated by the gentle agitation of water circulating through the jar. The dead eggs or "ringers" rise to the top of the egg mass and are removed by siphoning.

Eggs incubated in Heath Trays at Dexter NFH are spread evenly over the suspension screen to allow for aeration through water circulation. Eggs are not placed in the upper tray to prevent formation of large air bubbles which hamper proper aeration. Thus, seven trays of each of four stacks are used. The eggs continue to be slightly adhesive following water hardening, and have to be gently stirred with a feather 3 - 6 hours after being placed in the trays. The eggs are not normally treated for fungus during incubation since the disease is not usually a problem because of short hatching time, good water quality, and good egg quality. The eggs of Colorado squawfish held under these conditions at 21°C generally hatch in 90 - 120 hours.

Swim-Up Fry. When fry in the McDonald Jars begin hatching, the entire contents (fry, partially-hatched fry, and advanced eyed eggs) of the jar are poured into a 350-gallon concrete trough where the fry are held until swim-up. The fry are held at a density of 600,000 - 800,000 per trough and at a water temperature of 21°C with a trickle flow rate of about 3 gallons per minute.

The fry in the Heath Trays are all allowed to hatch before being transferred from the catchment basins to the concrete troughs. Most fry drop through the screen of each tray into the catchment basin, although a few are passed into the next lower tray. Survival of viable eggs is generally 67 - 70%, but can be as low as 35 - 37% if the eggs are stripped prematurely, fertilized improperly, or become clumped.

Swim-up fry are held in concrete troughs for 3 - 4 days at which time the mouth becomes well-formed and the yolk sac is absorbed. Egg shells and dead fry are siphoned from the bottom of the troughs to prevent fungus problems. Swim-up fry of Colorado squawfish behave differently than fry of razorback sucker or bonytail chub which school loosely. Colorado squawfish fry tend to school closely in corners of the troughs where they may suffocate and die in large numbers. As a precaution, fry of all species are held in indoor concrete troughs for only about 3 days.

Colorado squawfish fry are removed from the concrete troughs using a small dip net made of very fine soft mesh (pantyhose) with approximately 560 micro openings. A small sample of fry is weighed and counted to determine the number of fry per gram. Then, all the fry are weighed in order to estimate total numbers. The fry are then allowed to acclimate from the 21°C incubation temperature to the 17.6°C temperature of the source water before being transferred to outdoor earthen ponds. Approximately 8 days pass from the time of stripping to the transfer of fry into outdoor ponds, which generally occurs in early June (Figure 2.1). The fish are held in outdoor ponds through the fry and fingerling stages (Phases I and II), each phase corresponding to a rearing cycle in a separate holding pond. Swim-up fry at Bubbling Pond Hatchery (AGF 1988, 1989) are released into heavily fertilized ponds (alfalfa pellets and/or N-P-K) and left in the same pond from early June to October with survival rates of 0 to 40% (Table 2.3d).

Fry (Phase I). Colorado squawfish fry are first placed in outdoor earthen ponds at Dexter NFH in early to mid-June at a density of about 125,000 fry per surface acre. Following about 6 weeks in this pond, or by about mid to late July, the fish are 1 - 1-1/2 inches long. A description of the earthen ponds is presented in the subsection: **Preparation of Earthen Ponds.**

Fingerling (Phase II). Phase II for Colorado squawfish at Dexter NFH generally begins in mid-July and extends to the end of September, at which time the fish are transferred from the hatchery as 2.5 - 3 inch fish. Young Colorado squawfish are generally not held over-winter at Dexter NFH for several reasons. The pelagic behavior of these young fish makes them highly susceptible to predation by birds. At Dexter NFH, seagulls are a particular problem in the fall, winter, and spring. Grebes, cormorants, mergansers, and ospreys also prey on these fish. A severe example of this predation is the reduction of 87,000 to 220 young Colorado squawfish in a 1-acre pond from fall to spring. Cannibalism can occur if the fish are concentrated, not graded by size, or taken off feed. Young Colorado squawfish will consume others their own size and smaller in the absence of sufficient food. Natural attrition can also account for about a 10% loss of fish. Similar problems with cannibalism and bird predation were observed in holding Colorado squawfish for extended periods at Bubbling Pond Hatchery.

Bonytail Chub

Hatchery personnel at Dexter NFH report that bonytail chub are among the more difficult fish to culture. They react well to manual spawning, hatching, rearing, handling, and feeding. They also exhibit the greatest growth rate of the four species of Colorado River endangered fish.

Brood Stock. The brood stock of bonytail chub are also held in outdoor earthen ponds at Dexter NFH. Hatchery-reared males and females mature at 2 and 3 years of age, respectively, which is one year earlier than wild fish. Unlike Colorado squawfish, bonytail chub cause high turbidity in holding ponds which indicates benthic feeding as routine behavior. Adult bonytail chub were also observed remaining in a small tight swarm, particularly in the fall, winter, and spring.

Gonadal maturation of bonytail chub at Dexter NFH generally occurs in early to mid-May. Bonytail chub spawn readily along the shoreline of earthen ponds and need to be sorted by sex prior to full gonadal development if induced spawning is anticipated.

In a manner similar to the handling of Colorado squawfish, bonytail chub brood stock are transferred from earthen ponds to indoor covered concrete troughs. Following one day of adjustment, each female is injected intraperitoneally with 4 mg/kg of acetone-dried CP. This hormone is preferred for cyprinids (bonytail chub, humpback chub, Colorado squawfish) over HCG, which is used on razorback suckers. Bonytail chub are generally injected only once and usually ovulate 18 - 20 hours after injection. Caution is advised in using CP as it can kill a fish with insufficient gonadal development.

Egg Procural/Fertilization. Eggs of bonytail chub are procured and fertilized using the same techniques and precautions as described for Colorado squawfish. The eggs are fertilized in the same manner and also treated with bentonite to prevent clumping. A female in full gonadal development may only produce about 5,000 eggs, although production of larger fish may exceed 25,000 eggs.

Incubation. The eggs of bonytail chub are incubated in the same manner as the eggs of Colorado squawfish, using Heath Trays and McDonald Jars. They usually hatch in 99 - 174 hours at 20 - 21°C.

Swim-Up Fry. Swim-up fry of bonytail chub are handled in the same manner as razorback sucker fry. The fry of bonytail chub do not aggregate as tightly as fry of Colorado squawfish. These young fish are held in concrete troughs through their first 3 - 4 days of life, during yolk-sac absorption and mouth development. Fry of bonytail chub often position themselves in contact with the sides and bottom of the trough, suggesting a behavioral mechanism that may account for an absence of extensive drift by this species (i.e. the fry remain adjacent to structure preventing themselves from being transported downstream by river currents). This same behavior is suspected in humpback chub.

Fry (Phase I). Bonytail chub fry are first placed in outdoor earthen ponds at Dexter NFH in mid to late May at a density of about 125,000 fry per surface acre. After about 6 weeks in the first rearing pond, or by about the first of July, the fish are 1.5 - 2 inches long.

Fingerling (Phase II). Phase II for bonytail chub at Dexter NFH generally begins in early July and extends to the first of September, at which time the fish are transferred from the hatchery as 4 - 5-inch fingerling. Fish held into mid-September grow to 5 - 6 inches in length, which is the fastest growth rate of any of the four species of Colorado River endangered fish. Young bonytail chub are generally not held over-winter at Dexter NFH.

Razorback Sucker

Brood Stock. Razorback sucker brood stock at Dexter NFH are held in outdoor earthen ponds up to about 1 surface acre in size. It has been observed that ponds holding razorback suckers are generally turbid, indicating a high level of benthic activity in either a feeding mode or routine behavior.

Gonadal maturation of razorback suckers at Dexter NFH occurs predictably between February 25 and March 10, and from early to mid-March at Bubbling Pond Hatchery. Prior to this time, males and females at Dexter are placed in separate ponds to prevent natural spawning (razorback suckers have been observed constructing redds and spawning along the shoreline of the small earthen ponds). During the period from February 25 to March 10, the Dexter brood stock is brought indoors and placed in small covered concrete troughs.

Following one day of adjustment, each female is injected intraperitoneally with 150 i.u./lb of HCG. The females are injected daily with the same dosage for 3 - 4 days until ovulation occurs. Males are not normally injected, but a dosage of up to 300 i.u./lb may be administered if maturation is judged incomplete. This dosage takes effect with males in 2 - 3 days. Carp pituitary is not used with razorback suckers. A typical schedule for razorback suckers may be:

Friday	-	transfer brood stock from the outdoor earthen pond to the indoor covered concrete troughs
Saturday	-	allow fish to adjust undisturbed
Sunday	-	inject 150 i.u. HCG/pound
Monday	-	inject 150 i.u. HCG/pound
Tuesday	-	inject 150 i.u. HCG/pound
Wednesday	-	strip eggs

Egg Procural/Fertilization. Eggs of razorback suckers are procured and fertilized using the same techniques and precautions as described for Colorado squawfish and bonytail chub. The eggs are fertilized in the same manner and also treated with bentonite to prevent clumping. Female razorback suckers generally produce about 18,000 eggs per pound of body weight. Thus, a 5 pound fish is expected to produce about 90,000 eggs.

Incubation. The eggs of razorback suckers are incubated in the same manner as the eggs of Colorado squawfish and bonytail chub using Heath Trays and McDonald Jars. Razorback suckers usually hatch in 90 - 110 hours at 20 - 21°C.

Swim-Up Fry. Swim-up fry of razorback sucker are handled in the same manner as the fry of bonytail chub. These young fish are held in concrete troughs through their first 3 -4 days of life during yolk-sac absorption and mouth development.

Fry (Phase I). The fry are transferred from the indoor concrete troughs to specially prepared earthen ponds (see subsection: **Preparation of Earthen Ponds**) at a density of about 125,000 fry per surface acre. They are maintained in the pond for 6 - 10 weeks, depending on the decline of the zooplankton population and on the rate of invasion by aquatic plants. The fish are 1.5 - 2 inches long at the end of Phase I which is generally about late May or early June.

Survival during Phase I is very critical to total production and is generally 60 - 70%, although it can vary as much as 0 - 98%. In late May or early June, the young are moved to a second pond to initiate a new rearing cycle, Phase II. Prior to this transfer, the fry are introduced to an artificial diet of Trout Starter #1 to condition the fish to feed readily on artificial as well as natural diets.

Fingerling (Phase II). Phase II for razorback suckers at Dexter NFH generally spans from late May or early June until late August. The fish feed on natural zooplankton in the ponds and are also fed #2 granules. By the end of Phase II in late August, the young razorback suckers are 4 - 4.5 inches long, at which time they are transferred to a third earthen pond to begin Phase III.

Fingerling (Phase III). Young razorback suckers are generally transferred from Dexter NFH in late September or early October when the fish are 5 - 5.5 inches long. They may therefore be in a Phase III pond for only a month or so. It is noted that the size variation of razorback suckers is the greatest of any of the four endangered species. Seven-month old razorback suckers (by the end of October) may vary in length from 3 to 10 inches. Young fish are generally not held over-winter at Dexter NFH, but those that have been held grew only about 1 inch in the 6-month period from about October 1 to April 1.

Preparation of Earthen Ponds

Dexter NFH. Pond culture has been practiced for many years with a variety of warm-water species. The concept has been successfully adapted for culturing the endangered Colorado River fishes at Dexter NFH. Successfully rearing fish in earthen ponds depends on establishing a viable community of zooplankton as a food source for the fish, combined with supplemental feeding. Fish are kept in earthen ponds on a rotation system of 4 to 6 weeks. This is the period of time in which zooplankton populations peak and before growth of aquatic plants (e.g. *Chara* sp.) begin to choke the pond.

Dexter NFH has 47 earthen ponds that vary in size from 0.143 to 1.082 surface acres. All are rectangular in shape, ranging from 85 to 410 feet in length and 31 to 182 feet in width. The average water depth of these ponds is 3 or 4 feet with a maximum depth of 6 feet. None of the ponds are lined, and hatchery personnel report loss of water through seepage and problems with the aquatic plant, *Chara* sp.

The ponds are specially prepared prior to introducing young fish. They are generally drained in late summer and disked once in the fall and then allowed to remain dry over winter to minimize survival of diseases, parasites, and aquatic plants. The ponds are disked again in the spring to enhance aeration and to bring nutrient-rich soil to the surface. The soil in the pond is leveled and "floated" with a large drag and then compacted with a heavy packer while there is still some soil moisture content. This enhances soil compaction to reduce water loss.

When the ponds are filled, each is fertilized with 300 to 350 pounds of alfalfa pellets and 50 pounds of triple superphosphate (inorganic 0-46-0 granules N-P-K) per surface acre. Each pond is then fertilized weekly with 100 to 150 pounds per surface acre of alfalfa pellets during the 4 to 6 weeks that the fish are in Phase I. The resulting zooplankton community is generally dominated by rotifers, then copepods, and finally cladocerans. Fertilization is stopped when the zooplankton become dominated by cladocerans. Water flows through the ponds at Dexter NFH at a rate of about 1.5 - 2 cfs.

Phase I fry (< 1.5 inches long) are held at a density of 125,000 per surface acre. Reduced fish growth was observed when 200,000 fry were held per surface acre. Phase II fingerlings (< 3 inches long) are held at densities of 25,000 - 50,000 per surface acre.

The length of a rearing cycle in earthen ponds at Dexter NFH is generally 4 - 6 weeks, depending on the amount of invasion by *Chara* sp. and the decline of the zooplankton community. Lined ponds could enable managers to hold fish longer in a given pond and therefore reduce handling and the need for additional ponds. Lined ponds would minimize the problem with aquatic vegetation while reducing water loss through seepage. Fertilization rates would have to be adjusted for lined ponds for lack of a soil-water interface to supplement nutrients. Lined ponds may be warmer than unlined ponds if the black liner is left exposed.

Bubbling Pond Hatchery. The earthen ponds at Bubbling Pond Hatchery are prepared in a similar manner to the ponds at Dexter NFH. Each pond is filled with water and fertilized with 50 pounds of 16-20-0, or with 13 gallons of liquid fertilizer and 20 pounds of 18-46-0. Other ponds are fertilized with 50 pounds alfalfa pellets and 50 pounds cottonseed meal before filling, and with 70 pounds alfalfa pellets, 50 pounds cottonseed meal, and 25 pounds soybean meal after filling.

2.3.2. Intensive Fish Culture

Intensive culture of the four species of Colorado River endangered fish has been practiced in a variety of locations and conditions. In nearly all cases, fish used in intensive culture were hatched from eggs originally shipped from Dexter NFH for specific research purposes. Much work has been done in the Lower Colorado River Basin with intensive culture of these fish (Personal communication with W.L. Minckley, Arizona State University, October, 1990). Much of the data from this research was collected recently and has not been analyzed or reported.

Significant research with intensive culture is currently being conducted by the USFWS at the Experimental Endangered Fish Hatchery (EEFH) at Ouray National Wildlife Refuge (Personal communication with Harold Tyus, USFWS, November 1990) and by CDOW at the Fish Research Hatchery (FRH) at Bellvue, near Fort Collins, Colorado (Personal communications with Larry Harris, CDOW, September 1990). The Ouray facility is working with razorback suckers and the Bellvue facility with Colorado squawfish. A synopsis of the methods employed by these two facilities is provided as an example of intensive culture to contrast with the extensive culture methods used at Dexter NFH.

Colorado Squawfish - Fish Research Hatchery at Bellvue

The FRH conducted research on intensive culture of Colorado squawfish in 1989 (CSU 1989, Harris et al. 1990) and 1990 (Knott 1990). The purpose of the research was to determine if Colorado squawfish could be intensively reared. The primary objective of the 1989 work was to determine minimum temperature requirements and acceptable diets for the species under intensive culture, while the 1990 research was designed to identify the diet that enhanced survival and growth rates of Colorado squawfish under intensive culture.

<u>1989-1990 Research</u>. The only Colorado River endangered fish species under intensive culture at the FRH is the Colorado squawfish. This facility does not house brood stock for this species, and procures eggs from Dexter NFH.

On May 31, 1989, the FRH received approximately 150,000 (41 ounces @ 3,660/ounce), 14-hour old fertilized Colorado squawfish eggs from Dexter NFH. The eggs were shipped in water inside oxygenated air bags placed in styrofoam boxes. The water temperature upon arrival was 70°F (21°C). The eggs were distributed evenly among 11 Heath Trays with a screen size of 16 squares per inch, and a water flow of 6 gallons per minute. Ten trays of eggs were incubated at 70°F (21°C) and one was incubated at 52.6°F (11.5°C) (normal temperature of the well water entering the facility). The eggs in 70°F water began hatching in 80 hours (68.7 temperature units [T.U.]). Hatching was complete by 96 hours (82.4 T.U.). Most fry were collected in the screened trays. The eggs incubated at 52.6°F failed to hatch. Microscopic examination revealed that embryo development had stopped soon after the eggs were placed in the colder water. The physical appearance of the eggs did not change for 5 days, but deterioration of the egg shells began on the 8th day, and the eggs were completely disintegrated by the 12th day.

Approximately equal numbers of newly-hatched fry were reared at the FRH and at a wet lab at CSU. Water for the FRH is supplied from a ground well at a temperature of 52.6°F. The water is warmed with three Fasto-matic model V450NG demand water heaters and mixed with well water to attain the desired temperature. The CSU water is pumped through a series of underground steam ducts and reaches the wet lab at 68°F (20°C).

The sac fry held at the FRH were initially distributed into the lower half of six troughs, each measuring 5'x7"x19" with a capacity of 4.6 cubic feet and screened at top and bottom with 16 squares per inch mesh. The fry transferred to CSU were held in troughs measuring 5'x1'x6" with a capacity of 2.5 cubic feet. Because it was difficult to monitor the fry, and escapement became a problem at both FRH and CSU, the fry were placed in clear plastic pans (15"x12"x5" with a capacity of 0.5 cubic feet) in which openings were cut on each side and screened with 16 squares per inch mesh. To prevent crowding and suffocation of fry, a white masonite base was placed beneath the clear plastic pans to disperse the fish more evenly.

At the FRH, fry in four of the six troughs were held at 52.6°F (11.5°C) and fry in the remaining two troughs were held at 60°F (15.5°C). Both groups began feeding 2 days after swim-up. The fry held in the four troughs at 52.6°F were fed separate diets including live brine shrimp (control), Biokyowa, Ziegler's larva, and Rangen's trout diet. The fry held in the two troughs at 60°F were fed live brine shrimp (control) and Biokyowa. After 5 days, all fry held in 52.6°F became lethargic, stopped feeding, and mortality increased. The surviving fry were placed in one trough at 60°F and fed brine shrimp. By the 12th day, the fry were vigorous and feeding, and the water temperature was again lowered to 52.6°F and the diet switched to Rangen trout diet.

The group of fry held at 60°F was divided equally into two pans after the 14th day, and the diet was gradually switched to dry feed, Rangen trout diet to one and Biokyowa to the other. Initially, the fish were fed brine shrimp twice daily and their respective dry diet once daily, then the dry diet was introduced twice daily and the brine shrimp only once until the fish switched exclusively to the dry diet.

The fry at CSU were held in four troughs at 68°F (20°C) and fed separate diets of live brine shrimp (control), Biokyowa, Ziegler's larva, and Rangen's trout diet. The prescribed diets were fed twice daily.

As the fish became crowded in the screened pans, they were released into the open trough space. Space and water flow became a limiting factor at CSU, and the fish were placed in circular tanks 4 feet in diameter with a water depth of 17 inches.

After 4 months, scoliosis (spinal deformity) was observed in groups of fish on the commercial trout diet (Rangen's) at both the FRH and CSU. The Fish Cultural Development Center in Bozeman, Montana conducted histological examinations of the fish and determined that the scoliosis was probably associated with a vitamin C deficiency. Scoliosis was not observed in the group of fish fed the encapsulated Biokyowa.

Harris et al. (1990) acknowledged that the original feeding experimental design could not be closely followed because of a lack of supply of test foods, variable fish health, and failure by fish to accept certain diets because of low water temperature. Thus, growth rates were erratic in all groups fed for the 356-day period. It was determined that a minimum water temperature of 64°F (18°C) is needed to have productive growth, although fry accepted feed at lower temperatures of 52.6 (11.5°C) and 60°F (15.5°C). Biokyowa was the preferred dry diet to start fry because (1) it did not cause scoliosis, (2) it was easily ingested by the fry (other trout diets were too large and impacted the gills of the fish), (3) it appeared to induce aggressive feeding, and (4) it facilitated the switch to a semi-moist or trout diet.

It was also determined from this research that a density of greater than 1.5 pounds per cubic foot in rearing troughs resulted in decreased fish growth (Personal communication with Larry Harris, CDOW, December 1990). Cannibalism was not a problem under intensive culture as long as the fish were graded to similar size, fed regularly, and not excessively crowded. Mortality of fish due to high nitrogen levels (107.2% from the auxiliary well at the FRH and 110% at CSU) was alleviated by passing water through packed columns. Since Biokyowa was the preferred dry diet of the three tested--and the most expensive--it was computed that raising 10,000 Colorado squawfish to 5 inch size would cost approximately $7,000 for feed alone.

1990 Research. The main objective of the research in 1990 was to compare Silver Cup and Biokyowa diets to determine which diet enhanced survival and growth rates of Colorado squawfish under intensive culture.

Approximately 135,000 eggs were obtained from Dexter NFH on May 31, 1990. Only 14,000 fry survived (10.3%) during hatching and on June 7, 1990, an additional 48,000 fry were shipped from Dexter to compensate for the loss. Both eggs and fry were from the same broodstock (Knott 1990).

The fry were evenly distributed in troughs and holding pans in the same manner as in 1989 (Harris et al. 1990) except that mosquito netting (30 squares per inch) was used instead of screen with 16 squares per inch, and air stones were added to the troughs to insure adequate oxygenation. All fry started feeding within one week after hatching. The fry remained in the pans for about one month before being released into the troughs. The water temperature in the troughs varied between 65°F (18.3°C) and 70°F (21°C) because of complications with the temperature control.

Fry were fed a combination of brine shrimp and Biokyowa-250, a fine-textured commercial feed. Fry were alternately fed these diets hourly, eight hours per day, seven days per week. Two weeks after hatching, the fry in two troughs were switched to Silver Cup starter diet, while the remaining five troughs received only the Biokyowa-250 diet. At 6 weeks post-hatching, the fish in the two troughs receiving Silver Cup diet began swimming erratically (from scoliosis) and were switched to a combination of brine shrimp and Biokyowa-250.

This aspect of the research determined that survival rates of Colorado squawfish varied between 90 and 99.8% between troughs. Biokyowa-250 yielded the greatest survival and growth. Scoliosis was observed in fry fed the Silver Cup diet, and higher mortality was also prevalent. The monthly temperature units (M.T.U.) required for one inch of growth varied from 69.82 - 77.00 for the five troughs at average temperatures of 68.8 - 70.5°F (21 - 22°C), whereas fry in the trough with an average temperature of 65.2°F (18.5°C) required 118.57 M.T.U.'s to achieve one inch of growth. Cannibalism was not directly observed during this research.

Preliminary results from the research at the FRH showed that brine shrimp did not provide an advantage over the commercial feeds, and required additional culture efforts to maintain a source of live brine shrimp. Biokyowa provided the most favorable results in terms of acceptance by the fish, response to feeding, and growth, but it was the most expensive feed tested. Fish fed with Biokyowa were more aggressive during feeding, fed more readily, and therefore grew faster. Ziegler's larvae was not viewed as a favorable diet. Fry fed Rangen's

Trout Formula were not as aggressive and did not feed as well as fry fed with Biokyowa. Hatchery biologists observed that individual granules of Rangen's Trout Formula were visible moving through the gut of the fish with little disintegration and became lodged in the gills of the fry causing fungus infections.

Since the FRH at Bellvue is located at nearly 6,000 feet elevation with a water source of 52.6°F (11.7°C), outdoor pond culture was limited to a short period in the summer when ambient temperatures could warm ponds sufficient for fish growth. Since the facility is primarily a cold-water hatchery, available pond space was limited.

Razorback Sucker - Experimental Endangered Fish Hatchery at Ouray

The USFWS established the EEFH at Ouray, Utah in 1987 to develop techniques for rearing and propagation of razorback suckers (Severson et al. 1990). The efforts were concentrated on refining streamside fertilization techniques, intensive culture of larvae, establishment of brood stock from fry of wild-fish parentage, and stocking of young fish. Fertilized eggs were secured from wild fish captured in the Jensen area of the Green River in 1987, 1988, and 1989. The eggs were incubated and the young reared at the EEFH to evaluate growth and survival of fish in ponds, and of fish fed one of five commercial diets in tanks.

Fertilized eggs collected from the wild were kept separate for each female stripped to keep track of parentage. Fish that did not release eggs afield were taken to the facility and injected with 150-300 i.u. HCG/kg body weight to induce ovulation. These eggs were incubated at 20°C in Heath Trays. In 1987, all swim-up fry were placed in earthen ponds previously fertilized with alfalfa. The diet was supplemented with a commercial trout diet and the fry were transferred to indoor tanks in October. The fish were returned to outdoor ponds in April and released into the nearby Green River in September 1988.

Beginning in 1988, an evaluation was initiated of intensive culture methods for razorback sucker using commercial diets (Tyus and Severson 1990). Eggs collected from wild fish and placed in Heath Trays at 20°C hatched in 112 - 145 hours. The sac fry were held 4 days in a 76 liter aluminum tank at 21°C and a flow rate of 18.95 liters/min. On the 5th day, 40 fry were placed in each of 15 aquarium breeder baskets (2.5 liters) made of 10 micron nylon net with plastic frames and suspended in 29 liter compartments at 20.3°C. Each test diet was fed to triplicate lots of fish for 40 days. The five diets were AP-100 (Zeigler Bros., Inc., Gardners, PA), LIV (Farm and Wildlife Products, Inc., Omaha, NE), 4200 (Bio-Marine, Hawthorne, CA), and A-250 and B-250 (Biokyowa, Inc., St. Louis, MO). Fish were fed 5% of their body weight per day, which was divided into eight feedings per day, Monday-Friday, and six per day on Saturday and Sunday.

A-250 and 4200 produced the highest weight gain (0.092 and 0.066 g, respectively), but the lowest survival rate (32 and 20%, respectively). Fish on LIV and B-250 had the highest survival rate (78%) but the lowest weight gains (0.026 and 0.031 g, respectively). AP-100 produced intermediate results with a survival of 59% and weight gain of 0.036 g. The results of this study recommend the use of diets producing maximum survival (LIV or B-250) as first foods for razorback sucker larvae.

Future plans for the Ouray facility starting in 1991 include development of a diverse razorback sucker brood stock for augmentation of Green River stocks. The EEFH also planned to expand the facility to accommodate additional research on razorback suckers and other endangered Colorado River fishes to aid recovery efforts.

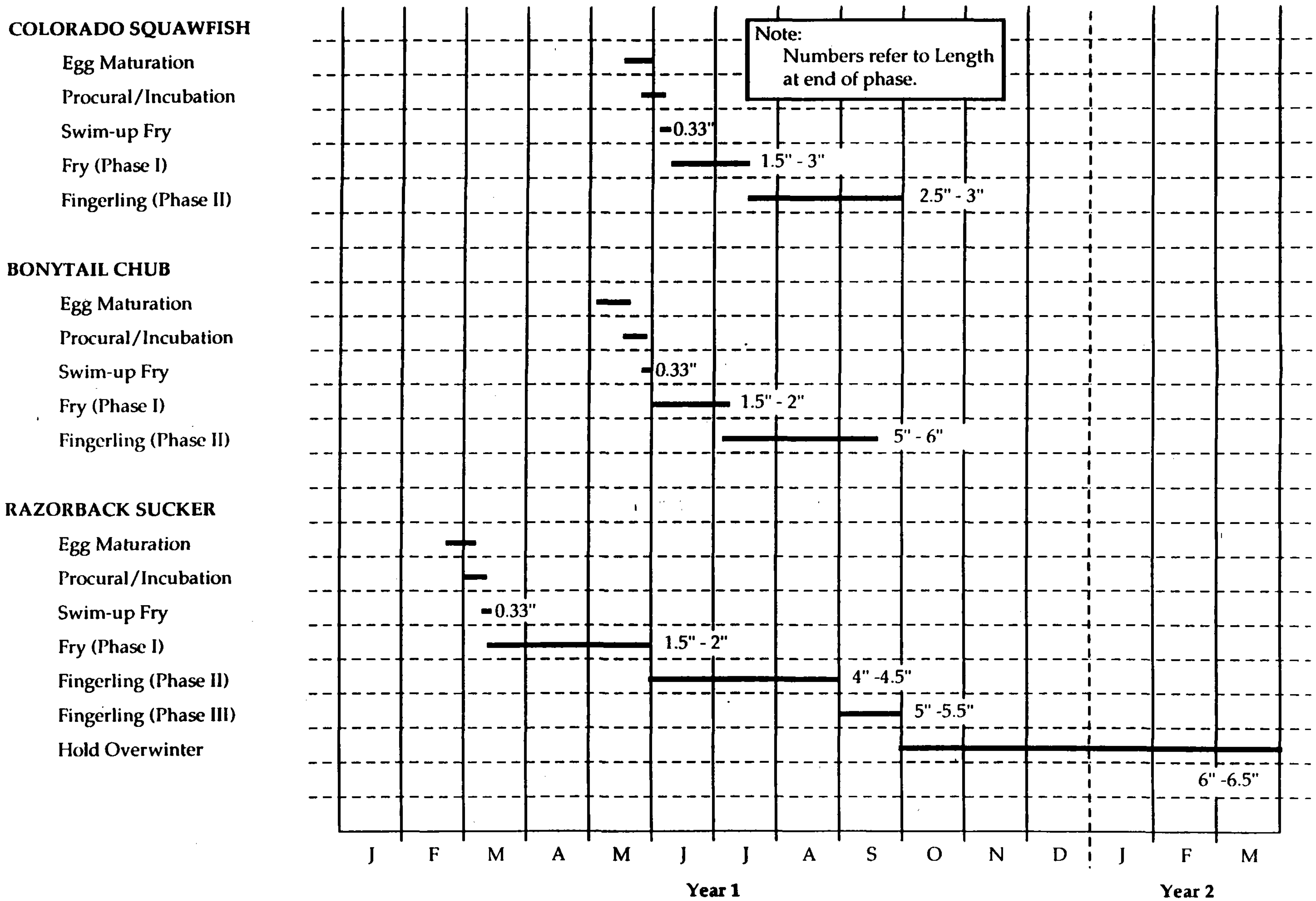

Figure 2.1 Approximate time schedule for culture of the Colorado River endangered fish at the Dexter National Fish Hatchery.

Table 2.7 Summary of Extensive Culture Techniques for the Four Colorado River Endangered Fish.				
	COLORADO SQUAWFISH	**BONYTAIL CHUB**	**HUMPBACK CHUB**	**RAZORBACK SUCKER**
EGG MATURATION **BROOD STOCK**	Held in outdoor earthen ponds. Fed fingerling rainbow trout & commercial trout diet #3 & #4. Transfer to indoor covered troughs 1 day before injection. Males mature at 5 years, females at 6 years.	Held in outdoor earthen ponds. Fed commercial trout diet #2 and #3 granules. Separate males from females near maturation. Transfer to indoor covered troughs one day before injection.	Held in outdoor earthen ponds. Fed commercial trout diet #2 and #3 granules. Transfer to indoor covered troughs 1 day before injection. Males mature at 2 years, females at 3 years.	Held in outdoor earthen ponds. Fed commercial trout diet #2 and #3 granules. Separate males from females near maturation. Transfer to indoor covered troughs 1 day before injection.
HORMONAL INJECTION	Acetone-dried carp pituitary, females injected once with 2 mg/lb, ovulate in 20-24 hours.	Acetone-dried carp pituitary, females injected once with 4 mg/kg, ovulate in 18-20 hours.	Acetone-dried carp pituitary, females injected once with 4 mg/kg.	Chorionic gonadotropin, females injected daily with 150 iu/lb for 3-4 days.
PROCURAL/INCUBATION **FECUNDITY (NO./FEMALE)**	Wild: 55,000 - 82,576 Domestic: 2,014 - 77,436 (18,000/lb)	Wild: 25,090 Domestic: 4,577 - 4,990	wild: 2,532	Wild: 123,100 Domestic: 63,645 - 63,674 (18,000/lb)
EGG DIAMETER	1.9 - 2.2 mm	-	2.2 - 2.9 mm	2.5 - 2.8 mm
INCUBATOR	100,000/Heath Tray 500,000/McDonald Jar	100,000/Heath Tray 500,000/McDonald Jar	100,000/Heath Tray 500,000/McDonald Jar	100,000/Heath Tray 500,000/McDonald Jar
FLOW RATE	15 - 23 l/min.	15 - 23 l/min.	15 - 23 l/min.	15 - 23 l/min.
OPTIMAL INCUBATION TEMP.	20 - 21°C	20 - 21°C	19 - 20°C	20 - 21°C
HATCHING TIME	90 - 120 hours	99 - 174 hours	115 - 160 hours	96 - 144 hours
SWIM-UP FRY **LARVAL SIZE**	6.5 - 7.5 mm	6.8 mm	6 - 7 mm	6.8 - 7.3 mm
LARVAL HOLDER	Fry are held for 2-3 days after hatching in concrete troughs; crowding suffocates fry if held longer.	Fry are held for 3 - 4 days after hatching in concrete troughs.	Fry are held for 3 - 4 days after hatching in concrete troughs.	Fry are held for 3 - 4 days after hatching in concrete troughs.
FRY (PHASE I) **FRY HOLDER**	Earthen ponds about 1 ac. Fertilized to culture zooplankton bloom.	Earthen ponds about 1 ac. Fertilized to culture zooplankton bloom.	Earthen ponds about 1 ac. Fertilized to culture zooplankton bloom.	Earthen ponds about 1 ac. Fertilized to culture zooplankton bloom.
FRY STOCKING RATE	105,316 - 137,438/ac.	≈120,000/ac.	≈120,000/ac.	101,000 - 109,000/ac.
FRY SIZE AT STOCKING	95,340 - 104,420/lb.	≈70,000/lb.	≈70,000/lb	71,000/lb.
FEED	Natural zooplankton, introduce trout starter.	Natural zooplankton, introduce trout starter.	Natural zooplankton, introduce trout starter.	Natural zooplankton, introduce trout starter.
SIZE AT END OF PHASE I	1 - 1½ inches	1½ - 2 inches	1½ - 2 inches	1½ - 2 inches
HATCHING TO END OF PHASE I	6 - 7 weeks	4 - 6 weeks	4 - 6 weeks	6 - 10 weeks

Table 2.7 Summary of Extensive Culture Techniques for the Four Colorado River Endangered Fish.

	COLORADO SQUAWFISH	BONYTAIL CHUB	HUMPBACK CHUB	RAZORBACK SUCKER
FINGERLING (PHASE II) FINGERLING HOLDER	Earthen ponds about 1 ac. Fertilized to culture zooplankton bloom.	Earthen ponds about 1 ac. Fertilized to culture zooplankton blooms.	Earthen ponds about 1 ac. Fertilized to culture zooplankton blooms.	Earthen ponds about 1 ac. Fertilized to culture zooplankton blooms.
FINGERLING STOCKING RATE	52,978 - 55,424/ac.	≈50,000/ac.	≈50,000/ac.	51,000 - 58,000/ac.
FINGERLING SIZE AT STOCKING	980-1,088/lb.	≈700/lb.	≈1,000/lb.	724 - 549/lb.
FEED	Natural zooplankton plus commercial trout diet #1 & #2 granules.	Natural zooplankton plus commercial trout diet #1 & #2 granules.	Natural zooplankton plus commercial trout diet #1 & #2 granules.	Natural zooplankton plus commercial trout diet #1 & #2 granules.
SIZE AT END OF PHASE II	2½ - 3 inches.	5 - 6 inches	≈3 - 4 inches	4 - 4½ inches
HATCHING TO END OF PHASE II	13 - 15 weeks	13 - 14 weeks	13 - 14 weeks	22 - 23 weeks

2.4 KEY CULTURE ISSUES AND DATA

A number of key culture issues were identified as a result of the literature review and review of existing propagation facilities. These key issues as understood and identified at this first phase of the feasibility study are briefly discussed in this Section. Those issues were later refined, and are presented in the later chapters of this report. A synopsis of pertinent culture information and key issues is vital to the planning of a hatchery facility for the Colorado River endangered fish.

2.4.1. Water Source

The volume of water available on a year-round basis is the most important consideration for a hatchery facility. The actual volume needed will depend on whether the facility is primarily under intensive or extensive fish culture, and the growth rates of the fish. A disease-free source of water is necessary for indoor facilities such as spawning, incubation, and fry rearing. This source can be either from a well, a spring, or treated surface water. Outdoor facilities (i.e. earthen ponds) can be supported with recirculated water or disease-free surface water. (Dexter NFH has a supply of 1,800 gallons per minute from three wells at 64°F (17.8°C). This water is used to supply the indoor facilities as well as 1 - 1.5 cfs to 47 one-acre earthen ponds (not all filled at once), without the need to recirculate. The Bubbling Pond Hatchery is comprised of 17 ponds supplied with 8 cfs of 68°F (20°C) water.) An untreated surface water source will introduce unwanted diseases and parasites into a hatchery facility which can be devastating. Any surface water source must be treated before the water can be used for hatchery purposes.

2.4.2. Water Temperature and Quality

Water temperature is a very important consideration with the Colorado River endangered fish. All four species are considered warm-water fish, and therefore require warm temperatures for gonadal maturation, spawning, incubation, rearing and growth. Desirable gonadal maturation temperatures for all four species ranged from 18 - 20°C (64.4 - 68°F) with the highest hatching success at 20 - 21°C (68 - 69.8°F). Preferred water temperatures for growth were identified as 20 - 25°C (68 - 77°F). Thus, a water source is preferred which is either naturally heated or can be heated inexpensively (i.e. ambient heating).

Water quality is equally important. Mortality of fish has been observed with nitrogen saturation in excess of 103% at both Dexter NFH and the FRH at Bellvue. The natural nitrogen level from source wells at these locations is about 110%. Nitrogen is removed from the water at these facilities using stacked columns.

Dissolved oxygen has generally not been a problem with the endangered fish except with very young fry that tend to crowd and clump in corners of troughs. This has been a problem, particularly with Colorado squawfish, but has been resolved at Dexter NFH by removing the fry from troughs before the schooling behavior is exhibited. Airstones in the troughs and white backgrounds have alleviated much of this problem at the FRH at Bellvue. Standard aeration techniques for well water are practiced at all facilities to maintain good water quality.

All four species have exhibited a high tolerance to total dissolved solids (TDS). The TDS avoidance levels of Colorado squawfish (4,400 mg/l), humpback chub (5,100 mg/l), and bonytail chub (6,600 mg/l) are two to three times as high as the highest levels found in the Upper Colorado River Basin (Pimental and Bulkley 1983).

Colorado squawfish show a high sensitivity to mercury and to various chlorinated hydrocarbons such as DDT and dieldrin (Beleau and Bartosz). Consideration needs to be given to possible pollutants in the source water, particularly near agricultural areas.

2.4.3. <u>Site-Related Biological Design Criteria</u>

A very important criterion for site selection will be the suitability of the site for the target fish. Since the Colorado River endangered fish are warm-water species, high elevation sites may not be suitable or desirable because of the cost of heating water and low growth rates from a shortened growing season. Climatic conditions can also dictate timing of maturation and availability of eggs. Sufficiently prolonged warm temperatures may enhance fecundity (egg production) of females and thus total fish production, survival and growth. Any efforts at outdoor pond culture will need to consider climate and elevation of the site and their effect on seasonal ambient temperature. Because of the large volume of water needed for outdoor pond culture, in the absence of a heated water source, ambient temperature will have to be sufficiently high to maintain ponds above 20°C (68°F) for several months to yield adequate fish growth.

2.4.4. Proximity To Fish Habitats

The hatchery site location will affect the transportation distance and have time to receiving waters. Fish generally become stressed with extended periods in hauling tanks which must be considered in the site selection process and operation of the hatchery and the planting of fish. Another consideration for site location is that fish may be stressed by a difference in water quality between the rearing facility and the receiving waters. A benefit of locating a hatchery facility near fish habitats is easier access to the fish and most endangered fish biologists are based close to wild populations.

Two sources of brood stock for the four species are identified; one is the hatchery-reared fish and the second is the wild fish. Hatchery-reared brood stock are available for Colorado squawfish, bonytail chub, and razorback sucker from the Dexter NFH. Brood stock for humpback chub could also be readily secured from a number of locations. Genetics studies of many different fish species strongly advocate periodic mixing of wild stocks with domestic stocks to maintain genetic integrity and diversity (Ammerman and Morizot 1989). Wild Colorado squawfish are available from only the Upper Basin, while bonytail chub are available from only the Lower Basin. There are bonytail chub in the Upper Basin, however they are very rare and are not used because of the likelihood of hybridization. Razorback suckers are available in the wild from both the Upper and Lower Basins, although their numbers seem increasingly limited. Wild humpback chub are available from both the Lower and Upper basins.

2.4.5. Geologic Considerations and Availability of Land

Once a reliable source of quality water is identified, a vital consideration is the geologic stability of the site and the availability of relatively flat or workable land to provide the space needed for buildings, ponds and associated facilities. Geologic instability (e.g., fault zones, potential mud slides, exposure to floods) is a vital consideration prior to investment of large sums of money into design and construction. Availability of relatively level land will minimize earth removal or filling, which is costly and can lead to future problems with settlement, water seepage, etc. Sufficient land area is a primary factor when considering outdoor pond culture. Adequate space is needed to accommodate a pond rotation system and to provide sufficient space to raise the target numbers of fish.

A large amount of area may be necessary for this facility to accommodate the necessary brood stock. Present knowledge of the Colorado River endangered fish suggests the existence of different genetic stocks in each sub-basin. It is estimated that there could be seven stocks of Colorado squawfish (Upper Colorado River, Gunnison River, Yampa River, Upper Green River, Lower Green River, White River, and San Juan River), six stocks of razorback suckers (Upper Colorado River, Gunnison River, Yampa River, Upper Green River, Lake Mohave, and San Juan River), six stocks of humpback chub (Black Rocks, Westwater Canyon, Desolation Canyon, Cataract Canyon, Yampa Canyon, and Little Colorado River), and one stock of bonytail chub (Lake Mohave). A hatchery facility would need sufficient holding capacity to accommodate holding various genetic stocks. Recent developments in linevasive marking techniques (Passive Integrated Transponder, PIT tags) allow for holding different identifiable genetic stocks together. More than one holding facility is desirable for endangered species so that a catastrophic event (e.g., loss of water heater, chemical spill, predators) does not eliminate the only available genetic stock of a species. Backup refugia may be needed at a single facility or through the use of multiple facilities.

2.4.6. Design/Engineering Requirements

This criterion goes hand in hand with **Section 2.4.5** **Geologic Considerations and Availability of Land** above. Geologic considerations and land availability will dictate specific design and engineering requirements. Land located in a narrow canyon will require a very different design of buildings, ponds and raceways than more open level terrain. Many engineering requirements are also determined by specific water warming and treatment needs (e.g. solar heating systems, screening devices, effluent disposal). Special facilities may also be needed to insure fish health. Quarantine facilities are recommended to treat all incoming fish as well as to insure that workers and visitors do not inadvertently introduce diseases to the facility. Quarantined fish may be held for a few days to allow sufficient time for pathogens to manifest themselves or it may be necessary to hold fish through a complete reproductive cycle to reveal pathogens of the reproductive organs capable of devastating an entire brood stock (Personal Communication with Ron Goede, Logan Experimental Fish Hatchery, October 1990).

2.4.7. Construction Requirements

Construction requirements are vital to consideration of site selection. Modifying land features and terrain may be extensive on some sites and escalate costs beyond practicality. Severe climatic conditions (e.g., cold winters) will require additional insulation of water systems and buildings to insure security and stable environment for the fish. Specific features will have to be incorporated to prevent future problems, such as designing ponds against bird predation. Large numbers of fish of all sizes are lost annually to avian predators. The Imperial Valley Warmwater Hatchery near Niland, California, was closed in 1990 because bird predation could not be controlled on the large earthen ponds. Small ponds with netting, lines, or water spray generally have less predation by birds.

2.4.8. Land Ownership and Ease of Acquisition

Land ownership and ease of acquisition is a very important consideration once the site is found to be suitable based on preliminary water quality analysis, land stability, and engineering requirements. Ideally, the site should be purchased outright with a minimal of difficulty in acquisition. This project must proceed carefully with this element because it deals with public and private interests and ownerships.

2.4.9. Effluent Water Treatment Requirements

Treatment of effluent water from a hatchery facility is a major consideration. The type of treatment and disposal of waste-water may vary depending on water quality of the waste-water and the receiving stream. Land application is also a disposal option. In reviewing the treatment alternatives, the possibility for releasing diseases and parasites into wild populations must be reviewed. Coordination with regulatory agencies will be necessary to obtain necessary permits for discharge of effluent waters.

2.4.10. Site Accessibility

Roadways into the site and proximity to major transportation systems is also an important consideration to site selection. The cost to build and maintain all-weather roads can be a major expense if these are not available.

2.4.11. Utility Availability

Utility services (i.e., electrical power lines, natural gas, telephone services, sewage and water systems) may be a major expense if these are not already available at a site. Of equal consideration is the necessity for specific power phasing to operate hatchery equipment.

2.4.12. Availability of Community Services

A hatchery facility will require on-site residence of caretakers or a hatchery manager. Ideally, the majority of employees should live on or near the site. Acquisition of capable personnel may be contingent upon the availability of community services and proximity to medical services, schools, churches, food stores, shopping centers, etc. A developed community nearby would be beneficial in providing airline, train, and truck delivery services.

2.4.13. Incorporation Into Existing Facility

Many aspects must be considered before deciding to use all or part of an existing facility either by take over or by joint use with a current operation. The objective or purpose of the existing facility must be defined and determined if it is consistent with the needs for rearing endangered fish. A full examination of the physical facilities will also be necessary to determine if these fulfill the specific requirements of rearing the target species. Using existing hatchery personnel for rearing endangered fish must also be considered, as well as interfacing endangered fish operations with ownership and control of the existing facility.

2.4.14. Operation and Maintenance Costs

Operation and maintenance costs are vital considerations but are difficult to assess at the site identification/screening phase. Most of these costs will be related to the efficiency of the engineering design and construction. Another consideration will be the design of a complete, reliable, and simple alarm system to monitor water quality and quantity, to insure quarantine facilities, and provide site security.

SECTION 3.0

BIOLOGICAL DESIGN AND CULTURE TECHNIQUES

3.1 INTRODUCTION

The objective of this study task was to evaluate factors impacting the culture of the endangered fish and develop design criteria for a fisheries facility capable of providing refugia, research and development, broodstock and rearing facilities for the Colorado squawfish, humpback chub, bonytail chub, and the razorback sucker.

During the course of conducting the feasibility study, some of the design criteria and information developed for this study task were revised, most notably in conjunction with the hatchery design task. Information presented in this section presents the revised biological design and culture technique information, as well as document the course of this study through the development of biological design and culture technique information and procedures.

3.1.1 Methodology

Specific methods used to develop this task are summarized below:

1. State and Federal Agency, TAC and project team consultation.
2. Interpretation and use of the previous task work: Literature Review and Review of Existing Propagation Facilities.
3. Development of a hatchery simulation model to predict preliminary siting and design criteria.
4. Compilation of known and suspected fish diseases for each of the target species and related species.
5. Integration of prior experience on fishery facility design concepts to provide state-of-the-art methodologies for meeting objectives.

3.1.2 Factors to be Evaluated

Fish Requirements

A projection of the number of fish to be held and cultured in the hatchery facility is necessary to continue the study into the design development phase. The number and size of each species to be cultured, for the purposes of this study, was established by the CWCB in the Study Scope of Work (Request for Proposal was dated February 23, 1989). The need for fish for broodstock, refugia, research and augmentation was broken down into a certain number of fish at different life stages. These requirements will vary from year to year and may change by the time actual production is realized. These numbers and sizes of fish may vary drastically as more is understood about their ability to survive and prosper in hatchery and natural environments.

The CWCB identified the number and size of fish to be cultured for the study because there was not a consensus within the resource agencies and the scientific community to establish a number of fish at this point in the recovery program development. It should be understood that the numbers and sizes of fish used in this study are not "locking in" a certain type of program or policy nor are these numbers necessarily those which would ultimately be used for the design of a hatchery. These numbers do provide a total biomass requirement for a facility, which can be used as a target for a conceptual facility design and estimation of maximum, average and minimum water flows and various configurations of rearing systems.

Biological Performance Data

It is essential to have a clear understanding of what is most desirable for the fish and what is the objective of the program prior to development of facilities and an analysis of the ability to produce fish possessing certain qualities and specifications. Water quality parameters established in this section are based upon data gathered during the literature review task. Anticipated fish performance guidelines are developed from previous experience in culture of these fish and observe actions in natural conditions.

Species Production Options

A hatchery model using extensive and intensive culture techniques was developed and tailored to the biological performance data for each of the four endangered species. Hatchery simulation modeling at various production levels defines a range of water and space requirements necessary to produce the numbers of fish required by the study scope of work. Information on intensive culture techniques used in the modeling is based primarily upon studies conducted by the Colorado Division of Wildlife.

Fish Health

The objectives of an endangered fish facility are complex in comparison to traditional fish hatcheries. The facility will likely be receiving and releasing fish from multiple watersheds. In addition, the facility will be dealing with endangered stocks which are at critically low levels in terms of population size. These conditions make it necessary to take all practical measures to prevent disease outbreaks or transmission of disease organisms from one population to another.

Fish and fish product transfer regulations for the states in the Colorado River Basin are identified in Section 3.5.6. This section includes a review of probable diseases which may be encountered, as well as the nature of these diseases and their control. A discussion of regulatory controls and facility controls is also presented to contribute to the decision making process for the facility design.

Other Fish Production Concerns

During development of a facility for endangered fishes, other concerns which must be addressed include methods to minimize or eliminate predation, escapement, and theft or vandalism. Genetic monitoring and segregation is very important and will influence the layout and process design for the facility. Possibly the most major factor influencing the hatchery siting and design is the quality and quantity of water available.

3.2 FISH REQUIREMENTS

3.2.1 Broodstock and Refugia Needs

Development of broodstock for the four Colorado River endangered fishes is one of the most critical aspects of the proposed facility. The origin for the broodstock will come from wild fish or from existing broodstock at state or federal hatcheries.

Wild fish must be acquired, as possible, from the wild, artificially spawning the females, and rearing the progeny for broodstock. Sufficient numbers of wild adult Colorado squawfish may be available from the Green River, Colorado River and White River, and also from the Gunnison River and San Juan River. Wild adult humpback chub may be available in greater numbers, depending on the population status. Sufficient numbers (10-20) for initiation of broodstock development could be captured from the Little Colorado River, Black Rocks, and Westwater Canyon. Fewer individuals would be available from Yampa Canyon, Desolation/Gray Canyon, and Cataract Canyon. The only confirmed bonytail chubs available are from Lake Mohave in the Lower basin, where 23 adults were taken from 1978-1988. Wild adult razorback suckers are available in small numbers from several locations. The best resource is the Green River, where 5-10 adults would likely be available. Fewer numbers may be available from the Gunnison River, San Juan River, Colorado River, and Lake Powell inflow regions. These numbers of the available adults are based upon estimates by Richard Valdez (Bio/West); based on his previous experience, beginning in 1975, as well as information gathered through conferences with other regional biologists.

Use of existing broodstock will depend on availability of an accurate genealogy of the fish. To maintain the integrity of presumed genetic stocks through hatchery augmentation, it is necessary to know the origin of the cultured fish. For example, augmenting Colorado squawfish in the San Juan River should be done with fish whose parents were spawned in that system. This process better insures adaptability to water quality, physical conditions, and recognition of chemoreceptor stimuli to spawning areas. Possible broodstock for Colorado squawfish, razorback sucker, and bonytail chub exist at several locations. Although small numbers of humpback chub are being held at several locations (e.g., Logan Experimental Fish Hatchery, Dexter National Fish Hatchery, Page Springs State Fish Hatchery), no provisions have been at this time made for developing a broodstock for this species.

The following paragraphs describe hatchery and refuge facilities holding endangered fish at the time of the drafting of this report. Subsequent to this initial investigation, a number of fish have been raised and relocated as part of the state and federal effort of managing these fish. Updated information from the time of printing of this report has been added in brackets [ ].

In 1992, Dexter National Fish Hatchery held 160 adult Colorado squawfish from the 1974 year class and 200 from the 1981 year class. These are first-generation progeny of wild fish taken from the Yampa River, Green River, and Colorado River, respectively. That facility plans to initiate a 1990 or 1991 year class broodstock from this stock that would be second generation fish. Potential sources of broodstock for Colorado squawfish are also available at the Page Springs State Hatchery in Arizona. However, these fish are second-generation from the wild fish at Dexter (progeny of the first-generation broodstock) and may have limited use because of reduced genetic variability. Small numbers of Colorado squawfish are also being held at various locations for experimental purposes with no intent or facilities to develop broodstock.

Dexter NFH also has 500+ adult razorback suckers from four separate year classes, which are also first-generation fish from the Lake Mohave wild stock. This is their primary source of broodstock from which over 10 million progeny have been released into tributaries of the lower basin. Broodstock for the razorback sucker are also being developed at the Ouray facility of the U.S. Fish and Wildlife Service in Utah. These stocks are first-generation fish from wild fish captured in the Green River near Vernal, Utah. Progeny from several year classes (1987, 1988, 1989) are being held separately to maintain identity of these fish to individual parentage. Broodstock for the razorback sucker are also available at the Page Springs State Fish Hatchery in Arizona. The Dexter NFH is also currently holding wild razorback suckers captured from the Colorado River near Grand Junction, Colorado and from the San Juan Inflow of Lake Powell in Utah, with plans to develop broodstock from these wild stocks.

Broodstock for the bonytail chub are also available from several sources including Dexter National Fish Hatchery and Page Springs Fish Hatchery. Dexter currently holds 500+ first-generation adults of one year class from Lake Mohave. Page Springs holds similar numbers of bonytail chubs and small numbers of wild adults from Lake Mohave.

[The following is updated information (June, 1993) provided by the US Fish and Wildlife Service and the Colorado Division of Wildlife concerning the location of the endangered fish held in hatcheries or refugia.

Wild adult razorback sucker and first generation offspring from the Colorado River and San Juan River Arms of Lake Powell, the Yampa River (Echo Park), and the Green River (Razorback Bar and Escalante Ranch) are at the Ouray facility. Additional wild adult razorbacks from the upper mainstem Colorado River are at the Horsethief refuge ponds near Grand Junction on the Colorado River. Their first generation offspring are being reared at the Bellvue Fish Culture and Research Facility (Bellvue). Wild adult San Juan River razorback sucker and their first generation offspring are at Wahweap ponds in Utah.

A Colorado squawfish refuge population and broodstock derived from an upper mainstem Colorado River population has been developed. Ten adults were taken to Dexter National Fish Hatchery and Technology Center in 1990 and spawned in 1991. Twenty-one unique family lots were produced, with the eggs being taken to Bellvue for incubation, hatching and rearing. Seventeen of these family lots survived. In 1993, first generation offspring were PIT-tagged and transported to the Horsethief refuge ponds. Other PIT-tagged offspring were kept at Bellvue for stocking into a second refuge facility while the remaining PIT-tagged offspring were returned to Dexter NFHTC to be incorporated into broodstocks at that facility. The Wray hatchery is involved in the endangered fishes program and is holding endangered fish which came from the Bellvue facility.]

Female Colorado squawfish generally mature at 6 or 7 years of age and males mature at 4 or 5 years of age. Thus, in order to develop a broodstock of Colorado squawfish from wild fish, progeny must be reared for at least 6 years before this species can produce eggs and young. Razorback suckers require only 2 years for males, and 3 years for females (based on Lower Basin fish) to become reproductively mature, while bonytail and humpback chub produce viable eggs at age 3.

Natural attrition of broodstock can be expected such that over a period of about 5 years, only 400 to 500 of the original 1,000 fish will survive. Mortality may occur from the stress of handling and spawning, disease, or bird predation.

The frequency of artificial spawning that a given female will tolerate and the maintenance of egg production is not known for these species. Fish of the 1974 year class at Dexter NFH were first spawned in 1982, and have been artificially spawned for nine consecutive years. Egg production has varied considerably, but there is no obvious sign of decreased fecundity. Personnel at Dexter NFH generally spawn only 30 to 60 of the 180 females, depending on egg and fish demand. A given female is not spawned 2 successive years in order to minimize stress to the fish. Each adult at Dexter NFH is uniquely identified with a PIT (Passive Integrated Transponder) Tag implanted intraperitoneally. At this time, these are the only Colorado squawfish brood being spawning at Dexter.

3.2.2 Research and Augmentation Needs

Preliminary estimates of hatchery research and production needs for the four Colorado River endangered fish species were developed and published by the Recovery Implementation Program in the "Blue Book". Table 3.1 is a reprint from the Blue Book. These estimates reflect anticipated needs for various studies (competition, bioassay, habitat improvement, entrainment, water quality, larval drift) as well as population augmentation. These annual estimates show initial needs of 1 million Colorado squawfish fry. Projected maximum needs of Colorado squawfish include 1,670,000 fry; 100,000 young of year; and 5,000 adults in the fifth production year. Long-term Colorado squawfish production is set at 250,000 young of year fish. Initial needs for humpback chub are set at 150,000 fry with maximum production of 265,000 young of year and 20 adults in year seven. The long-term production goal for humpback chubs is 125,000 young of year fish. Initial production for bonytail chub is set at 200 young of year, 100 juveniles and 1,400 adults. Maximum production needs for bonytail occur in year 4 with 100,000 fry; 200,000 young of year; and 2,000 juveniles. Long-term production goal for the bonytail chub is also 125,000 young of year fish. Initial razorback sucker requirements are 520,000 fry. Maximum razorback sucker production occurs in year 4 of the program with 1,170,000 fry and 5,000 adults. Projected long-term production needs for razorback suckers is 250,000 young of year fish. All fish species will be at least 4 inches in length at the time of release.

Stocking plans have not been identified or formalized for the upper Colorado River basin. Colorado squawfish fingerling (17,000 to 50,000) were being stocked into Kenney Reservoir on the White River, however all fish left the reservoir so stocking ceased in 1990. Planting records obtained from the USFWS show that 235,181 Colorado squawfish have been released in the vicinity of Grand Junction between 1980 and 1989. Over 10 million Colorado squawfish and razorback suckers have been released in the lower basin with very little survival (Osmundson and Kaeding, 1989). Studies are being conducted by Arizona Game and Fish Department (personal communication, Roger Sorenson, 1990) and Arizona State University (personal communication, Dr. W.L. Minckley, 1990) to evaluate these stockings, however detailed information is not available.

To insure adequate supply of young fish for research and augmentation, as well as adults for refugia and broodstock purposes, the suggested numbers of adult fish for a broodstock maintenance program are listed in Table 3.2. (Note: This table was changed during the hatchery design task as reported in Table 6.3.) The table illustrates the first generation groups as the spawning population and the second generation as replacement with an assumed 50% mortality. The broodstock needs reported in Table 3.2 were established by the Recovery Program Blue Book. The total number of brood required was back calculated, from the Blue Book number, to estimate the number of juvenile fish, predestined as brood animals. The following assumptions were made to calculate the total number of brood animals needed for each species:

- Given the stated Recovery Program projected broodstock needs.

Colorado squawfish	-	5,000 adults (sexually mature animals)
Humpback chub	-	20 adults
Bonytail chub	-	1,400 adults
Razorback suckers	-	5,000 adults

- Assume a conservative mortality estimate of 50% between the first and second generations of brood animals.

- Assume a 1:1 sex ratio.

For example: Final broodstock needs for Colorado squawfish = 5,000 adult fish. Given a 1:1 sex ratio, 2,500 males and 2,500 females are needed. To estimate second generation needs, 150 percent of the 5,000 adults is required, which sets the number of brood animals. This would give you at 7,500 (3,750 males and 3,750 females).

The above stated requirements for broodstock were used to prepare the study task described in this section of the Final Report. During the hatchery design phase of the study, the broodstock requirements were revised, and are described in Section 6 of the Final Report.

TABLE 3.1 HATCHERY, RESEARCH AND PRODUCTION NEEDS

Estimated numbers (x 1000) of Colorado River endangered fishes required for upper Colorado River Basin studies and reintroductions (f=fry; y=young of the year; j=juveniles; a=adults)

Study topic	Rating P-G[a]	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14
						Colorado Squawfish									
Passageways	1-III	20f	20f	20f	20f	20f 5a	5a	5a	5a	5a	5a				
Hatchery (biological)[b]	1-III	1,000f	1,000f	1,000f	1,000f	1,000f									
Hatchery (institution)[c]	2-III				220f	220f	220f								
Competition	2- II				100y	100y	100y	100y	100y						
Bioassays	3- II							20y	20y						
Habitat improvement[d]	3-III							100y	100y	100y	100y	100y			
Entrainment	3-III							10f 10y	10f 10y	10f 10y					
Turb/temp/salinity	4- II									40y	40y	40y			
Larval drift/habitat use	4- II									100f	100f	100f			
Reintroduction/fishery[e]	N.R.						250y	250y	250y	250y	250y	250y	250y	250y	250y
Totals	Fry	1,020f	1,020f	1,020f	1,670f	1,670f	650f	10f	10f	110f	100f	100f			
	YOY				100y	100y	350y	480y	480y	400y	390y	390y	250y	250y	250y
	Adults					5a	5a	5a	5a	5a	5a				
						Humpback Chub									
Hatchery (biological)[b]	1-III	150f	150f	150f											
Hatchery (institution)[c]	2-III				110f	110f	110f								
Hybridization	2- II				1j	1j									
Competition	2- II				20y	20y	20y	20y	20y						
Radio tracking	3- II							.02a	.02a	.02a					
Bioassays	3- II							20y	20y						
Habitat improvement[d]	3-III							100y	100y	100y	100y	100y			
Temp/salinity	4- II									20y	20y				
Reintroduction[e]	N.R.							125y	125y	125y	125y	125y	125y	125y	125y
Totals	Fry	150f	150f	150f	110f	110f	110f								
	YOY				20y	20y	20y	265y	265y	245y	245y	225y	125y	125y	125y
	Juvenile				1j	1j									
	Adult							.02a	.02a	.02a					
						Bonytail									
Hatchery (biological)[f]	1- I	0.2y 0.1j 1.7a	200j	200y	200y	200y									
Hatchery (institution)[c]	2-III				100f	100f	100f								
Taxonomy/hybrid/ident.	2- II				2j	1j	1j								
Bioassays	3- II							20y	20y						
Habitat improvement[d]	3-III							20y	20y	20y	20y	20y			
Radio tracking	3- II							.02a	.02a	.02a					
Reintroduction	N.R.							125y	125y	125y	125y	125y	125y	125y	125y
Totals	Fry				100f	100f	100f								
	YOY	0.2y		200y	200y	200y		165y	165y	145y	145y	145y	125y	125y	125y
	Juvenile	0.1j	200j		2j	1j	1j								
	Adult	1.4a						.02a	.02a	.02a					
						Razorback Sucker									
Hatchery (biological)[b]	1-III	500f	500f	500f	500f	500f									
Passageways	1-III	20f	20f	20f 5a	20f 5a	20f 5a	5a	5a							
Hatchery (institution)[c]	2-III				220f	220f	220f								
Reintroduction[e]	N.R.							250y	250y	250y	250y	250y	250y	250y	250y
Totals	Fry	520f	520f	520f	1,170f	1,170f	650f								
	YOY							250y	250y	250y	250y	250y	250y	250y	250y
	Adults			5a	5a	5a	5a	5a							

[a]Priority (P) Group (G) classification based on BSC Research prioritization document (9-85)
[b]Includes survival, recruitment, spawning, imprinting-homing, migration behavior, stocking success/life stage, aging techniques
[c]Includes culture technique research, disease testing, genetic variability analyses
[d]Includes growout ponds, backwaters, spawning areas for CSF, flow/temp manipulations for HBC and BT
[e]Refers to production phase of recovery plans (versus research phase), time line is not necessarily certain for start or duration.
N.R.=no rating
[f]Based on fish immediately available from California and Dexter NFH and proposed BT production at Dexter
(This document was prepared by the Upper Colorado River Biological Subcommittee.)

(reprinted from: Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin, USFWS, September 29, 1987)

TABLE 3.2 THREATENED AND ENDANGERED BROODSTOCK REQUIREMENTS

Species	First Generation[1]		Second Generation[2]		Total Brood on Station	
	Females	Males	Females	Males	Females	Males
Colorado Squawfish (6 substocks)	2,500	2,500	3,750	3,750	6,250	6,250
Humpback Chub (6 substocks)	128	128	192	192	320	320
Bonytail Chub (1 substock)	700	700	1,050	1,050	1.750	1,705
Razorback Sucker (6 substocks)	2,500	2,500	3,750	3,750	6,250	6,250

[1] Assumes 5 year-olds

[2] Assumes 2.5 year-olds

3 Number of substocks are shown in parentheses by each species

3.3 BIOLOGICAL PERFORMANCE DATA

Certain biological factors must be evaluated for each species to be cultured develop specific design criteria for an endangered fish hatchery. Factors such as preferred environmental conditions (water quality, habitat, etc.), growth, rate mortality, and feed requirements are all necessary to prepare specific design criteria that maximizes facility design success.

Data collected in the literature review study task were used as a basis for much of the initial performance data synthesis and establishment of input data for computer modeling of conceptual facility needs. Follow-up contacts were made with personnel active in culture of the fish to acquire additional insight to species performance in culture and specific culture techniques which have been proven successful.

The computer model predicts general hatchery design requirements (flow and rearing area) for each of the species to be cultured. Hatchery operational aspects such as production timing, feed requirements, and water quality constraints are also developed and presented in the model output. Results of the modeling effort allow evaluation and development of more specific hatchery design criteria. Design criteria presented in this section are further refined during the hatchery design study task, presented in Section 6 of this Final Report.

3.3.1 Water Quality

A significant amount of information exists on water quality preferences of the four target species. The following sections describe fish requirements for dissolved oxygen, ammonia, and temperature and how this information is used in the modeling. Other reported water quality data for: dissolved solids, pH, various pollutants and dissolved gasses are also discussed.

Dissolved Oxygen

As with the water quality parameters discussed above, dissolved oxygen (DO) is very important in successful fish culture. Dissolved oxygen physiological requirements have not been researched for the target species. Literature references and practice have shown that the target species are quite tolerant of reduced DO levels, down to 4 mg/L, and that culture requirements are generally met by pond surface tension aeration and low stocking densities.

In culture, the DO requirement typically determines the necessary water flows in respective culture tanks and ponds. Established and successful culture techniques have used a combined pond design with low stocking density and pond inflow rate equal to that necessary to replace seepage and evaporation losses. Stocking density determines the predicted rearing area requirement in the simulation model. Based on available literature and discussion with Dexter NFH personnel, it is desirable to maintain inflow DO levels at or near saturation, with acceptable DO fluctuations typical of pond culture operations. For modeling purposes, pond inflows with a maximum fish density of 5,500 pounds have been set to match a total pond changeover in water volume every 200 hours, or approximately 26 gpm per one acre pond per surface acre. An inflow oxygen content of 90% saturation has been assumed at an elevation of 5,000 feet, representative of the west slope Rocky Mountain area in Colorado. If the site selected for the proposed facility is at a different elevation, oxygen saturation can be changed accordingly when estimating final production capacities. Minimum DO content of rearing water has been set at or greater than 4 mg/L to insure adequate conditions in culture.

Ammonia

Ammonia-nitrogen and its unionized components are typically one of the most critical factors in developing water quantity and quality design criteria. Based on the water quality data collected and reported, the Colorado squawfish seems to be the least tolerant of the four target species; however, it is documented that they have survived excessive ammonia concentrations concurrent with pH 9.0 and a temperature of 23°C (Hamman, 1981a; Hamman, 1982a). This condition equates to an unionized ammonia concentration of 0.66 mg/L which is over 25 times above the chronic toxic level for trout and salmon species. Ammonia levels are not expected to constitute a significant culture limitation unless intensive culture methods are employed.

Temperature

Temperature is the most studied and reported environmental parameter for the target species. Spawning, incubation and rearing temperatures are well documented. All four species are adapted to natural conditions within the Colorado River Basin and therefore are acclimated to withstand water temperatures of 20-30°C in summer and 0°C in winter. Spawning occurs in all four species as temperatures approach 20°C. Razorback suckers have been reported to spawn at lower temperatures of 15-16°C in the wild (Tyus, 1987). Wild adult Razorback suckers from the Upper mainstem Colorado River (Etter Pond) spawned following injection of HCG when water temperatures reached 65°F. Incubation temperature studies have shown that incubation success is greatest between 20-26°C and was poor at temperatures below 15°C (Bulkley, et al., 1981; Hamman, 1981b). Swimup fry survival rates closely mirrored incubation results (Hamman, 1982b). The combined rearing temperature preference for all species ranged between 24-25.5°C (Bulkley, et al., 1981; Hamman, 1982a; Hamman, 1982b; Bulkley and Pimental, 1983).

For modeling purposes two temperature regimes have been evaluated for the three production scenarios presented in the scope of work and for the total production and research request prepared by the Biology Committee. One scenario represents an optimum groundwater supply of 20.5°C. The second scenario represents the average ambient temperatures of selected west slope rivers in Colorado: Yampa, White, Colorado, Gunnison, and Dolores river (USGS 1989 data). A third temperature regime was developed to include temperature and photoperiod control of broodstock to maximize production efficiency and minimize over winter rearing in the hatchery. Greater detail of these temperature regimes is provided in Section 3.4.

Other Water Quality Parameters

In general, the Colorado squawfish, humpback chub, bonytail chub and razorback sucker are hardy fish and are capable of withstanding significant variations in culture (Hamman, 1981a). Pimental and Buckley (1983) conducted total dissolved solids (TDS) preference-avoidance tests on Colorado squawfish, humpback chub and bony tail chub. Their results illustrated a clear gradation in species specific preference. Colorado squawfish preferred the lowest range of TDS at 560-1150 mg/L. Humpback chub preferred a TDS range of 1100-2500 mg/L and bonytail chub preferred the highest TDS range of 4100-4700 mg/L. This variance in preference may have hatchery water supply development implications. Therefore the avoidance levels of TDS are important to review. The respective species avoided TDS levels of 4400 mg/L, 5100 mg/L and <560 and >6600 mg/L. The wide TDS tolerance range of the bonytail chub allows culture of all three species with the same water supply. Based on these preference data, a water supply with a TDS range of 1100-4100 mg/L would be desirable. Although similar data are not available for the razorback sucker, its successful culture at Dexter NFH (Pimentel and Bulkley, 1983; Marsh, 1985a) suggests that this range would also apply to razorback suckers.

Some data also exist on pH tolerances of Colorado squawfish (Hamman, 1981a) and bonytail chub (Hamman, 1982a). These references report on instantaneous water quality reductions in culture in which Colorado squawfish survived pH 9.0 simultaneous with low dissolved oxygen and high ammonia levels. Preference tests for pH have not been accomplished to date. The pH at Dexter NFH ranges between 7.2 - 7.5 (Jensen, 1989) and is assumed to reflect conditions within the preferred pH range for the target species. Given the similarity of the species in water quality tolerance and culture success at various locations, the pH tolerance range for the target species is expected to be 7.0 - 9.0 standard units. USGS records for five west slope rivers show pH ranging from 7.8 to 8.7 standard units. The hatchery model calculates the ammonia production from fish culture based on pH and temperatures. A pH of 9.0 was input into the modeling program to evaluate hatchery ammonia levels assuming a "worst case" pH condition.

Acute toxicity measurements were made with bioassays on Colorado squawfish and humpback chubs (Beleau and Bartosz, 1982). Pollutants evaluated included thirteen metals and eight organic toxicants. Results further indicate that these two species are somewhat tolerant of degraded water quality conditions as compared to trout and catfish species. Pesticides appear to have the highest deleterious effect on these two species.

Observations of dissolved gas tolerance have been documented in the literature. Bonytail chubs were reported to have tolerated carbon dioxide levels in culture raceways of 1.8 - 4.4 mg/L (Hamman, 1982a). Colorado squawfish are reported to have survived extremely high carbon dioxide levels of 15.0 mg/L, concurrent with low dissolved oxygen, high pH and high ammonia nitrogen (Hamman, 1981a).

3.3.2 Species Performance

As previously mentioned, the success of any culture program is based on the ability to provide the proper species-specific environment. Hence, species performance data are directly affected by human activities and man-made habitat. The ability to understand the biological requirements of the species to be cultured ultimately dictates the level of success of a production program.

Much work has been done to improve understanding of the biological requirements for the Colorado squawfish, humpback and bonytail chubs and the razorback sucker. Literature and past hatchery practices regarding these species clearly point out that significant losses may result from poor planning, erroneous assumptions and over manipulation in the culture environment (Bulkley, et al., 1981; Valentine, 1981; Marsh, 1985a; Hamman, 1987; Arizona DF&G, 1988; Berry, 1988; and Arizona DF&G, 1989). This is not to say that significant improvements have not been made in recent years. It is the objective of this section to develop design criteria that provides an optimum environment for rearing populations of the four species of concern whether for refugia, research or augmentation.

Growth and Survival

Temperature appears to be the main factor in determining survival and growth. The target species will not spawn, survive incubation or grow unless appropriate temperatures are attained (McAda and Wydoski, 1980; Valdez and Clemmer, 1981; Valentine, 1981; Wick, et al., 1981; Jensen, 1983a; Jensen, 1983b; Haynes, et al., 1984; Black and Bulkley, 1985a; Hamman, 1985a; Marsh and Pisano; 1985; Jensen, 1986; Berry, 1988; and Kaeding and Osmundson, 1988). Survival also depends upon food availability and stocking density. Maintaining proper temperatures during spawning, incubation and early fry rearing is critical to the survival of the four species. Providing optimum temperatures and employing good culture techniques has resulted in long-term survival of these species in culture.

Growth and survival data were obtained from Dexter NFH for use as computer model input. Growth data (length and weight over time) were correlated to rearing temperatures to calculate a Monthly Temperature Unit requirement per inch of growth. In addition, the length-weight relationship or condition index was calculated for each species. These input parameters, with corresponding temperature information, allow the computer model to predict fish growth in a hatchery facility.

Feed

Current hatchery practices employ pond fertilization to generate a natural food base of rotifers, copepods and cladocerans. Artificial feed is often added to ponds as a supplement at a 5% body weight ration (Hamman, 1987; Hamman, 1989). Dexter NFH obtains a food conversion ratio of 2.3 (pounds of feed required to produce 1 pound of fish). This figure does not incorporate the natural food component to growth, but is useful in developing a similar supplemental feed regime based on fish biomass. A basic assumption for this study is that growth rate will be constant between current practices and the proposed facility.

3.3.3 Culture Facilities

Hatchery production of the four target species has primarily followed extensive culture practices. Eggs are typically incubated in large numbers. Newly hatched fry are reared in start tanks or small raceways for a short time before stocking into ponds for growout. Recent work has been conducted to investigate the intensive culture of these species focusing on fry and fingerling production. Data from these studies are limited and intensive culture applications on a production scale have not been attempted.

The CDOW proposed that intensive culture methods be considered as a means of production at the proposed hatchery, and presented information on crowding of Colorado squawfish based on work at the Belleview, Colorado Hatchery. They suggested that 2.5 pounds of fish be reared for every cubic foot of trough capacity, which would equate to 150 fish, at 5 inches in length, in a 4 X 6 X 12 foot trough, or 1,000,000 1/2 inch fish in the same trough.

Incubation

Current incubation techniques employ McDonald jars and stacked tray incubators. Prior to placement into the incubators the eggs are stripped from each female and fertilized by several males (Hamman, 1987). Sperm is mixed with a diluent to promote fertilization. As water hardening occurs, the eggs become quite adhesive. To prevent this, bentonite clay is added to the pan. The clay is washed away following water hardening (about 30 minutes) and the eggs are then placed into the incubators. McDonald jars are stocked with 500,000 eggs each. Tray incubators typically receive 100,000 eggs per tray and there are eight trays per stack.

Flow rates in McDonald jars are maintained at 4 L/min., whereas the tray incubator stack receives a flow between 8 and 11 L/min. Given that incubation temperature is critical to egg survival and hatching, incubation water supplies are typically mechanically heated to 20-21°C.

Incubation performance for each species was studied by Marsh (Marsh and Pisano, 1985). Temperature, hatch time, length at hatch, swim-up time, and length at swim-up were reported. Table 3.3 summarizes this data at optional incubation temperatures. Other studies concur with these results (Hamman, 1981a; Hamman, 1981c; Loudermilk, 1981; Hamman, 1982a; Hamman, 1982b; Minckley and Gustafson, 1982; Jensen, 1983a; Jensen, 1983b; Hamman, 1985a; Marsh, 1985a; and Colorado State University, 1989).

Survival percentages for various lifestages were obtained from data collected for this study. Table 3.4 presents a summary of the survival percentage used (for all species combined) to calculate total egg take requirements.

Fry Rearing

Swimup fry are typically reared in start tanks or small raceways for approximately one week. Past and current practices have employed placing fry in full size raceways (30 X 2.4 X 1.2 m) (Hamman, 1982b), directly into earthen ponds (Hamman, 1987), small raceways (2.75 X 0.75 X 0.75 m) (Hamman, 1986), and 2 m circular tanks (Inslee, 1981). Flow rates in these fry rearing units ranged from 10-22 L/min. A start tank size of 2.75 X 0.75 X 0.75 m with a flow rate of 15 L/min. was selected as input to the bioprogram (Hamman, 1985b). Prior to stocking the swimup fry into rearing units, the rearing vessel was fertilized to develop a zooplankton food base. Commercial starter diets have also been used as a supplement to the fertilizer and natural food production. The required number of start tanks varies with production scenarios.

Fry have been experimentally cultured under intensive conditions with some promise of success. Swimup fry are held in various sizes of hatchery troughs and fed artificial diets. Colorado squawfish have been reared to over 3 inches in these experiments (Knott, 1990; Harris, et al., 1990).

TABLE 3.3 INCUBATION TIMING AND FRY SIZE RELATIVE TO OPTIONAL INCUBATION TEMPERATURE (FROM MARSH, 1985)

Species	Incubation temp. (°C)	Time to last hatch (hours)	Length at hatch (mmTL)	Time to swimup (hours)	Length at swimup (mmTL)
Razorback Sucker	20	312	7.5-8.6	146	8.4
Bonytail Chub	20	131	6.0	217	8.6
Humpback Chub	20	133	5.5	249	8.5
Colorado Squawfish	20	135	5.5	267	7.9

TABLE 3.4 SURVIVAL PERCENTAGES FOR COLORADO RIVER ENDANGERED SPECIES

Lifestage	% Survival	Reference
Green Egg to Hatch	50	Bulkley, et al. (1981), Inslee (1983), Inslee (1982)
Hatch to Swim-up	75	Hamman (1982b), Hamman (1985a), Hamman (1985b), Jensen (1983b)
Phase I - Fry	80	Hamman (1982a), Hamman (1987)
Phase II - Fingerling	90	Hamman (1987)
Phase III - Fingerling	90	Hamman (1987)

Fingerling Ponds

Earthen ponds of varying sizes have been used to culture the target species (Valentine, 1983). Generally, ponds have ranged in size from 0.25 - 2.0 surface acres. Smaller ponds, from 0.1 to 025 surface acre are desirable because they are easier to manage. Smaller ponds allow better prediction and control the pond environment, make it easier to control bird predation, maintain genetics and they provide increased capacity for research. Pond inflow has varied, dependent on pond seepage and design. Inflow has been typically set to maintain a constant pond depth accounting for evaporation and seepage. Stocking levels for fingerling ponds ranged between 100,000 and 150,000 fry stocked per surface acre for Phase I rearing, and following approximately 6 weeks, fish were split into new ponds. Stocking density for Phase II rearing was typically 55,000 fish/surface acre. Flows and feeding rates were maintained from Phase I rearing. Input to the bioprogram was standardized to the Dexter NFH rearing pond size of 0.98 surface acre (with a depth of 3-4 feet) with stocking densities of 120,000 fry and 50,000 fingerlings for the two rearing phases (Hamman, 1989). The required pond number as predicted by the spreadsheet bioprogram is shown in Section 3.4.1.

Broodstock Facilities

Dexter NFH currently maintains two year classes of broodstock employing a varying number of ponds. The actual broodstock facility need at the new hatchery will be determined by the selected production program. Based on the fecundity of the four target species, relatively few broodstock are required to meet production needs. However, the broodstock are extremely important in their genetic representation of endangered species populations. Their health and genetic integrity must be maintained. It is assumed that the new hatchery will maintain two year classes of adult fish, each year class split into two smaller ponds of 0.10 surface acre (Inslee, 1982). Sixteen 0.10 surface acre broodstock/refugia ponds are recommended to accomplish program goals. Water inflows to broodstock/refugia ponds would be similar to production ponds. An increased number of rearing/holding units will be required should broodstock segregation involve specific subpopulations. Design options are available to reduce the large area necessary for pond culture. Adults may be held in raceways or circular tanks instead of ponds. Section 6, on hatchery design, presents more specific criteria for moderate levels of broodfish holding facilities. The suggested holding capacities are based on design for 5,000 pounds of biomass or approximately 1,000 fish at 5 pounds each.

Controlled Spawning Facilities

Controlled spawning is best conducted indoors. At Dexter NFH brood fish are brought from outdoor earthen ponds into indoor concrete raceways. The fish are held in these covered raceways for 1 day to allow for adjustment, then the females are injected with hormones to induce ovulation. All egg-taking is conducted indoors where the eggs can be placed in a controlled temperature and flow. This allows personnel to constantly observe the fish during hormone injection and allows for immediate action in case of stress or problems with a fish. It also reduces stress minimizing disease concerns with reliable results. It is recommended that the proposed hatchery consider indoor spawning facilities to accommodate the above issues.

3.4 SPECIES PRODUCTION OPTIONS

Six fish production scenarios were used to simulate preliminary hatchery design requirements using the hatchery simulation model. The modeling of these production scenarios was done to develop an understanding how different conditions impact production and how the type and level of production relates to facility size and facility requirements. Information from this preliminary modeling was refined during the hatchery design task described in Section 6.

Scenarios 1 through 3 were provided by the CWCB. Scenario 4 is the hatchery research and production needs as identified in the Recovery Program Blue Book. Scenario 5 was developed to illustrate a "maximum efficiency" hatchery in terms of space and flow requirements. Fish production was set at 300,000 fish to use as a comparison to Scenario 2. This necessitated the presumed use of controlled temperature and photoperiod for broodstock and controlled temperature for production to meet the size requirement prior to depressed winter temperatures. The general scenario plan involves obtaining eggs at the earliest possible time by environmental control to maximize the first summer rearing period. Rearing temperatures would be maintained at 25°C during the primary growth period to maximize growth. An acclimation period will be necessary prior to outplanting allowing fish to acclimatize to ambient water temperatures and is illustrated in the model output. Scenario 6 was prepared following discussions with CDOW biologists interested in predicting early lifestage intensive culture conditions. Fish production was set at 300,000 fish to use as a comparison to Scenario 2. Specific model input data were provided by CDOW and intensive culture research records from hatchery facilities rearing the fish of concern. Table 3.5 tabulates the numbers and sizes of fish for each of the production scenarios.

Each scenario was run under two temperature regimes in the hatchery spreadsheet model. The first temperature regime was a constant 69°F (20.5°C), which illustrated hatchery performance and requirements based on an optimum ground water hatchery supply. The second temperature regime represented an average of ambient conditions of five Colorado west slope rivers. Riverine temperature data for 1989 was obtained from USGS, Denver office.

TABLE 3.5 NUMBERS, SIZES AND SPECIES OF FISH TO BE CULTURED UNDER SIX SCENARIOS

Scenario 1		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	150,000	4-6 inches
Razorback Sucker	150,000	6-8 inches
Humpback Chub	150,000	4-6 inches
Bonytail Chub	150,000	4-6 inches
Scenario 2		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	300,000	4-6 inches
Razorback Sucker	300,000	6-8 inches
Humpback Chub	300,000	4-6 inches
Bonytail Chub	300,000	4-6 inches
Scenario 3		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	600,000	4-6 inches
Razorback Sucker	600,000	6-8 inches
Humpback Chub	600,000	4-6 inches
Bonytail Chub	600,000	4-6 inches
Scenario 4		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	1,000,000	4-6 inches
Razorback Sucker	520,000	6-8 inches
Humpback Chub	150,000	4-6 inches
Bonytail Chub	100,000	4-6 inches
Scenario 5		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	300,000	4-6 inches
Razorback Sucker	300,000	6-8 inches
Humpback Chub	300,000	4-6 inches
Bonytail Chub	300,000	4-6 inches
Scenario 6		
Species	**Numbers**[1]	**Sizes**[2]
Colorado Squawfish	300,000	4-6 inches
Razorback Sucker	300,000	6-8 inches
Humpback Chub	300,000	4-6 inches
Bonytail Chub	300,000	4-6 inches

1 = These numbers include production, refugia, and broodstock populations.
2 = The size and numbers of the fish to be cultured were revised during the course of the study upon consultation with the Technical Advisory Committee.

Monthly data for the Yampa, White, Colorado, Gunnison and Dolores rivers were averaged to develop the input temperature regime. This procedure best simulates an overall average ambient surface water supply to the hatchery prior to selection of a preferred site.

A summary table was prepared for each computer simulation identifying rearing unit and flow requirements. These tables do not include broodstock and incubation needs. Broodstock and incubation facility requirements were calculated based on the production program output and known species fecundity. Broodstock requirements are discussed in Section 3.2. To produce the desired numbers of fish as shown in the project scope of work, production Scenario 1 will require 625,000 eggs/species; Scenario 2 - 1,250,000 eggs/species and Scenario 3 - 2,500,000 eggs/species. The resultant total egg incubation capacities for scenarios 1-3 will be 2,500,000; 5,000,000; and 10,000,000 respectively.

3.4.1 Hatchery Modeling

Model Assumptions

As with any predictive tool, computer models are only as reliable as the data used for input information. For this reason, as much empirical data as available were used to accurately predict the baseline siting and design criteria for the Upper Colorado River Basin Rare and Endangered Species Hatchery. Unfortunately, some data were lacking or less complete than desired and some input assumptions were made based on agency discussions and technical experience. The literature review and existing hatchery visitations accomplished as part of this feasibility study proved quite helpful in preparing the hatchery simulation models. Table 3.6 contains a listing of all necessary model input parameters. An entry has been provided indicating the source of the input data or assumption. This table is organized in order of calculation occurrence in the spreadsheet output for ease of interpretation and review.

Model Simulation Results

Results of simulations were closely tied to desired goals. For example, in Scenario 1, 150,000 razorback suckers are to be produced in the 6 to 8 inch range. With these goals and the previous assumptions entered into the model, an estimate was made of the number of months necessary to achieve this goal and the number of fry initially required. For each of the first four scenarios results were obtained for both a constant temperature water supply and an average ambient river temperature.

Summary tables of all scenarios depict the number of raceways, ponds and flow (gpm) required by month to raise the target species to their required release size (Tables 3.7 through 3.17). All data are presented per species per month as well as totaled at the bottom of each table. In all cases, it took a longer timeframe, higher flows and number of both raceway and ponds when ambient river temperatures were simulated. These tables do not include broodstock or refugia ponds which are described in Section 3.3. Broodstock Facilities.

Table 3.6 Hatchery Simulation Model
Input Descriptions

Input Parameter	Data Source
Timing and Growth Rate (monthly temperature units per inch of growth)	References: 003, 005, 006, 012, 013, 014, 025, 027, 028, 035, 038, 042, 047, 048, 049, 058 Personal communications: Buddy Jenson, Roger Hamman, Holt Williamson, Larry Harris, Roger Sorenson
Temperature	Temperatures were set as described in Section 4.0 and vary with scenario. Life history, spawning requirements, and growth conditions were considered in developing the various temperature regimes (see references under timing).
Conditions Index	Hatchery records from Dexter National Fish Hatchery were used to calculate the condition index for each species.
Mortality Rate	References: 065, 079, 080, 081 The simulation model assumes a constant mortality rate over time. An overall average monthly mortality rate was calculated based on Dexter National Fish Hatchery records.
Stocking Densities	References: 003, 012, 065, 079, 080, 081
Feed Requirements	References: 003, 005, 012, 013, 018, 080, 081 Feed requirememets are limited to supplemental supply to augment pond fertilization. A supplemental feeding rate of 5% body weight per day has been used in the model.
Nitrogen Loading and Ammonia Calculation	References: 006, 024 These portions of the spreadsheet address the Nitrogen component delivered in the supplemental feed only. Pond fertilization and pond dynamics are not modeled.
Elevation	An average elevation of 5000 feet was input to be representative of western Colorado.
Container Size and Flow Rate	References: 003, 006, 007, 013, 018, 027, 031 Personal communications: Buddy Jenson, Roger Hamman, Larry Harris, Roger Sorenson. Flow rates for incubation and fry rearing are well established. Pond flows are typcially set at rates equal to evaporation and seepage losses. The model has been set to provide flow rates that allow pond turnover every 200 hours.

TABLE 3.7 PRODUCTION SCENARIO 1

Flow and Rearing Unit Requirements

CONSTANT TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number			4									
	Raceway Flow (gpm)			16									
	Pond Number	4	4	2	2	2	4	4	4	4	4	4	4
	Pond Flow (gpm)	106	106	53	53	53	106	106	106	106	106	106	106
Colorado Squawfish	Raceway Number						4						
	Raceway Flow (gpm)						16						
	Pond Number	4	4	3	3		2	2	2	4	4	4	4
	Pond Flow (gpm)	106	106	80	80		53	53	53	106	106	106	106
Humpback Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Bonytail Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Total Flow Requirement (gpm)		212	212	149	133	183	281	265	371	424	424	212	212
Total Raceway Requirement (gpm)		0	0	4	0	10	4	0	0	0	0	0	0
Total Pond Requirement (gpm)		8	8	5	5	6	10	10	14	16	16	8	8

TABLE 3.8 PRODUCTION SCENARIO 1

Flow and Rearing Unit Requirements

AVERAGE RIVER TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number					5							
	Raceway Flow (gpm)					21							
	Pond Number	5	4	4	4	7	7	9	14	14	14	5	5
	Pond Flow (gpm)	133	106	106	106	186	186	239	372	372	372	133	133
Colorado Squawfish	Raceway Number						5						
	Raceway Flow (gpm)						21						
	Pond Number	4	4	4	4	3	7	6	6	5	5	5	4
	Pond Flow (gpm)	106	106	106	106	80	186	160	160	133	133	133	106
Humpback Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Bonytail Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Total Flow Requirement (gpm)		239	212	212	212	417	499	505	744	717	717	266	239
Total Raceway Requirement (gpm)		0	0	0	0	11	5	0	0	0	0	0	0
Total Pond Requirement (gpm)		9	8	8	8	14	18	19	28	27	27	10	9

TABLE 3.9 PRODUCTION SCENARIO 2

Flow and Rearing Unit Requirements

CONSTANT TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number			8									
	Raceway Flow (gpm)			33									
	Pond Number	7	7	4	4	4	8	8	8	8	7	7	7
	Pond Flow (gpm)	186	186	106	106	106	213	213	213	213	186	186	186
Colorado Squawfish	Raceway Number						9						
	Raceway Flow (gpm)						37						
	Pond Number	7	7	6	6		4	4	4	8	8	7	7
	Pond Flow (gpm)	186	186	160	160		106	106	106	213	213	186	186
Humpback Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Bonytail Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Total Flow Requirement (gpm)		372	372	299	266	316	516	479	691	798	771	372	372
Total Raceway Requirement (gpm)		0	0	8	0	12	9	0	0	0	0	0	0
Total Pond Requirement (gpm)		14	14	10	10	10	18	18	26	30	29	14	14

TABLE 3.10 PRODUCTION SCENARIO 2

Flow and Rearing Unit Requirements

AVERAGE RIVER TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number					9							
	Raceway Flow (gpm)					37							
	Pond Number	9	8	8	8	13	12	11	17	17	16	9	9
	Pond Flow (gpm)	239	213	213	213	346	319	292	452	452	425	239	239
Colorado Squawfish	Raceway Number						10						
	Raceway Flow (gpm)						41						
	Pond Number	8	8	7	7	7	12	11	11	10	9	9	8
	Pond Flow (gpm)	213	213	186	186	186	319	293	293	266	239	239	213
Humpback Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Bonytail Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Total Flow Requirement (gpm)		452	426	399	399	779	839	745	1117	1090	1036	478	452
Total Raceway Requirement (gpm)		0	0	0	0	21	10	0	0	0	0	0	0
Total Pond Requirement (gpm)		17	16	15	15	26	30	28	42	41	39	18	17

TABLE 3.11 PRODUCTION SCENARIO 3

Flow and Rearing Unit Requirements

CONSTANT TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number			16									
	Raceway Flow (gpm)			66									
	Pond Number	13	13	7	7	7	16	16	15	15	14	14	14
	Pond Flow (gpm)	346	346	186	186	186	426	426	399	399	373	373	373
Colorado Squawfish	Raceway Number						17						
	Raceway Flow (gpm)						70						
	Pond Number	13	13	12	12		8	8	8	16	15	14	14
	Pond Flow (gpm)	346	346	319	319		213	213	213	426	399	373	373
Humpback Chub	Raceway Number					12							
	Raceway Flow (gpm)					49							
	Pond Number					6	6	6	13	13	13		
	Pond Flow (gpm)					160	160	160	346	346	346		
Bonytail Chub	Raceway Number					12							
	Raceway Flow (gpm)					49							
	Pond Number					6	6	6	13	13	13		
	Pond Flow (gpm)					160	160	160	346	346	346		
Total Flow Requirement (gpm)		692	692	571	505	604	1029	959	1304	1517	1464	746	746
Total Raceway Requirement (gpm)		0	0	16	0	24	17	0	0	0	0	0	0
Total Pond Requirement (gpm)		26	26	19	19	19	36	36	49	57	55	28	28

TABLE 3.12 PRODUCTION SCENARIO 3

Flow and Rearing Unit Requirements

AVERAGE RIVER TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number					19							
	Raceway Flow (gpm)					78							
	Pond Number	17	16	16	15	14	13	22	34	32	31	18	17
	Pond Flow (gpm)	452	426	426	399	638	612	586	905	852	825	479	452
Colorado Squawfish	Raceway Number						21						
	Raceway Flow (gpm)						86						
	Pond Number	16	15	14	14	13	22	21	21	19	18	17	16
	Pond Flow (gpm)	426	399	373	373	346	585	558	558	506	479	452	426
Humpback Chub	Raceway Number					12							
	Raceway Flow (gpm)					49							
	Pond Number					6	6	6	13	13	13		
	Pond Flow (gpm)					160	160	160	346	346	346		
Bonytail Chub	Raceway Number					12							
	Raceway Flow (gpm)					49							
	Pond Number					6	6	6	13	13	13		
	Pond Flow (gpm)					160	160	160	346	346	346		
Total Flow Requirement (gpm)		878	825	799	772	1480	1603	1464	2155	2050	1996	931	878
Total Raceway Requirement (gpm)		0	0	0	0	43	21	0	0	0	0	0	0
Total Pond Requirement (gpm)		33	31	30	29	39	47	55	81	77	75	35	33

TABLE 3.13 PWG PRODUCTION AND RESEARCH REQUEST SCENARIO 4

Flow and Rearing Unit Requirements

CONSTANT TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number			14									
	Raceway Flow (gpm)			58									
	Pond Number	11	11	7	6	6	14	14	13	13	13	12	12
	Pond Flow (gpm)	293	293	186	160	160	373	373	346	346	346	319	319
Colorado Squawfish	Raceway Number						28						
	Raceway Flow (gpm)						115						
	Pond Number	21	20	15	10		12	12	12	25	24	23	22
	Pond Flow (gpm)	559	532	399	266		319	319	319	665	639	512	585
Humpback Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Bonytail Chub	Raceway Number					2							
	Raceway Flow (gpm)					8							
	Pond Number					1	1	1	3	3	3		
	Pond Flow (gpm)					27	27	27	80	80	80		
Total Flow Requirement		852	825	643	426	260	887	772	851	1197	1171	831	904
Total Raceway Requirement		0	0	14	0	5	28	0	0	0	0	0	0
Total Pond Requirement		32	31	22	16	9	29	29	32	45	44	35	34

TABLE 3.14 PWG PRODUCTION AND RESEARCH REQUEST SCENARIO 4

Flow and Rearing Unit Requirements

AVERAGE RIVER TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number					16							
	Raceway Flow (gpm)					66							
	Pond Number	15	14	14	13	21	21	19	29	27	27	16	15
	Pond Flow (gpm)	399	373	373	346	559	559	505	771	719	719	426	399
Colorado Squawfish	Raceway Number						34						
	Raceway Flow (gpm)						140						
	Pond Number	25	24	23	22	21	35	34	24	30	29	28	27
	Pond Flow (gpm)	665	639	612	585	559	931	905	639	798	772	745	718
Humpback Chub	Raceway Number					3							
	Raceway Flow (gpm)					12							
	Pond Number					2	2	2	4	4	4		
	Pond Flow (gpm)					53	53	53	106	106	106		
Bonytail Chub	Raceway Number					2							
	Raceway Flow (gpm)					8							
	Pond Number					1	1	1	3	3	3		
	Pond Flow (gpm)					27	27	27	80	80	80		
Total Flow Requirement (gpm)		1064	1012	985	931	1284	1710	1490	1596	1703	1677	1171	1117
Total Raceway Requirement (gpm)		0	0	0	0	21	34	0	0	0	0	0	0
Total Pond Requirement (gpm)		40	38	37	35	45	59	56	60	64	63	44	42

TABLE 3.15 PRODUCTION SCENARIO 5 - MAXIMUM EFFICIENCY

Flow and Rearing Unit Requirements

ELEVATED TEMPERATURES AND PHOTOPERIOD CONTROL

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Raceway Number			9									
	Raceway Flow (gpm)			37									
	Pond Number	8	8	11	11	11	17	16	9	9	9	8	8
	Pond Flow (gpm)	213	213	292	292	292	452	425	239	239	239	213	213
Colorado Squawfish	Raceway Number				7								
	Raceway Flow (gpm)				29								
	Pond Number				4	4	3	7	7	6	6		
	Pond Flow (gpm)				106	106	80	186	186	160	160		
Humpback Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Bonytail Chub	Raceway Number					6							
	Raceway Flow (gpm)					25							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Total Flow Requirement (gpm)		213	213	329	427	608	692	771	797	771	771	213	213
Total Raceway Requirement (gpm)		0	0	9	7	12	0	0	0	0	0	0	0
Total Pond Requirement (gpm)		8	8	11	15	21	26	29	30	29	29	8	8

TABLE 3.16 PRODUCTION SCENARIO 6 - INTENSIVE/EXTENSIVE CULTURE

Flow and Rearing Unit Requirements

CONSTANT TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Start Tank No.						2	16					
	Start Tank (gpm)						14	112					
	Circular Number								1	2			
	Circular Flow (gpm)								117	235			
	Pond Number	7	6	6	6						7	7	7
	Pond Flow (gpm)	931	1579	1756	2235						373	373	745
Colorado Squawfish	Start Tank No.						2	10					
	Start Tank (gpm)						14	70					
	Circular Number								1	1	1		
	Circular Flow (gpm)								117	117	117		
	Pond Number	7	6	6	6							7	7
	Pond Flow (gpm)	373	479	639	798							186	261
Humpback Chub	Raceway Number					6							
	Raceway Flow (gpm)					13							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Bonytail Chub	Raceway Number					6							
	Raceway Flow (gpm)					13							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Total Flow Requirement (gpm)		1304	2058	2395	3033	186	188	342	606	724	862	559	1006
Total Start Tank Requirement (gpm)		0	0	0	0	0	4	26	0	0	0	0	0
Total Circular Requirement (gpm)		0	0	0	0	0	0	0	2	3	1	0	0
Total Raceway Requirement (gpm)		0	0	0	0	12	0	0	2	3	1	0	0
Total Pond Requirement (gpm)		14	12	12	12	6	6	6	14	14	21	14	14

TABLE 3.17 PRODUCTION SCENARIO 6 - INTENSIVE/EXTENSIVE CULTURE

Flow and Rearing Unit Requirements

AVERAGE RIVER TEMPERATURES

SPECIES	REARING NEEDS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Razorback Sucker	Start Tank No.						2	14					
	Start Tank (gpm)						14	98					
	Circular Number								1	2			
	Circular Flow (gpm)								117	235			
	Pond Number	7	7	7	7	7	6	6	6		8	7	7
	Pond Flow (gpm)	373	373	373	373	559	639	798	958		213	373	373
Colorado Squawfish	Start Tank No.						2	8					
	Start Tank (gpm)						14	56					
	Circular Number								1	1	1		
	Circular Flow (gpm)								117	117	117		
	Pond Number	7	7	7	7	7	6	6	6			7	7
	Pond Flow (gpm)	186	186	186	186	186	319	319	479			186	186
Humpback Chub	Raceway Number					6							
	Raceway Flow (gpm)					13							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Bonytail Chub	Raceway Number					6							
	Raceway Flow (gpm)					13							
	Pond Number					3	3	3	7	7	7		
	Pond Flow (gpm)					80	80	80	186	186	186		
Total Flow Requirement (gpm)		559	559	559	559	931	1132	1375	2043	724	702	559	559
Total Start Tank Requirement (gpm)		0	0	0	0	0	4	22	0	0	0	0	0
Total Circular Requirement (gpm)		0	0	0	0	0	0	0	2	3	1	0	0
Total Raceway Requirement (gpm)		0	0	0	0	12	0	0	2	3	1	0	0
Total Pond Requirement (gpm)		14	14	14	14	20	18	18	26	14	22	14	14

3.5 FISH HEALTH

Maintenance of healthy fish populations is best achieved by a program of good management and proper design. This involves maintaining the fish in an optimum environment with good nutrition and a minimum of stress. The difference between health and sickness depends on a delicate balance resulting from the interactions of the disease agent, the fish, and the environment. Although there are many disease agents, or pathogens, that are present continuously in a fish's environment, disease seldom occurs unless environmental quality or the defense systems of the fish have deteriorated.

Stress plays a major role in the susceptibility of fish to disease. In the wild, fish can usually alleviate stress by actively searching more hospitable habitat, therefore preserving the balance between host and pathogen. In culture, fish are exposed to many more stressors, these include fluctuations in water quality, physically handling the fish, and drug therapy, all which can weaken the host fish making them more susceptible to disease. High rearing densities as seen in intensive culture may be conducive to stress and to the spread of pathogens from one host to another.

Disease can be defined briefly as any deviation of the body from its normal or healthy state causing discomfort, sickness, or death. There are three main classes or types of disease; disease caused by foreign organisms, nutritional diseases, and diseases caused by environmental factors. Organisms that cause diseases in fish include viruses, bacteria, fungi, protozoans, and a wide range of invertebrate animals. Some organisms are highly virulent and can cause a disease outbreak, or epizootic, but most are commensalistic, and exist in or on their host, living and reproducing without causing undue harm.

There are two other categories of diseases that are important to the fish culturist. The first is nutritional in origin. Different fish species have specific nutritional requirements, which are normally met by normal forage supplies. In culture, the fish are usually fed a commercially prepared feed that may be lacking one or more important nutrients. This may predispose fish to various physiological anomalies, ranging from skeletal deformities, poor growth and even death. The second categories of disease relate to environmental factors, and in particular, water quality. Poor water quality, such as low dissolved oxygen, high concentrations of metabolic wastes, and high temperatures, can damage fish tissues, especially the extremely sensitive gill tissues, and cause mortality. Fish commonly become stressed because of poor nutrition or environment, and die of secondary infections by opportunistic pathogens.

Diseases have not been a major problem in wild fish populations of the four target species. This may be because they are living in a healthy or stress-free environment. This is demonstrated by the numerous reportings of the parasitic copepod, *Lernaea,* cyprinacea infesting apparently healthy wild fish. Epizootics in facility reared specimens usually result from some form of stress.

3.5.1 Documented Diseases

This section lists documented diseases and pathogens found in association with the four fish species. Fish health specialists and fish culturists from Colorado, Utah, Arizona, and New Mexico were interviewed for information about fish health problems which have been encountered. Their responses along with all pertinent information on fish health in the reference library was summarized and presented in Tables 3.18 through 3.25. These tables are divided into two sections; diseases identified in cultured fish and diseases identified in wild fish. Diseases or pathogens in cultured or wild fish were presented separately to identify diseases which can be a problem in future fish culture programs. Diseases or pathogens positively identified in cultured fish were usually causing a health problem and must be considered in future fish culture programs. Diseases or pathogens positively identified in wild fish were, for the most part, not causing health problems, so they may or may not cause health problems in cultured fish. In the tables, the location where the disease was specified is indicated either by: CRW, Common CRW, or a specific named drainage. CRW indicates the disease was found in an unspecified section of the Colorado River watershed, common CRW indicates the disease or pathogen is commonly found throughout the Colorado River watershed.

There are a few pathogens that are highly pathogenic or infectious under culture and conditions. From a review of available literature and interviews with fish health specialists, the following diseases were described to be most harmful to the four target species: Ich, Columnaris, and the Asian tapeworm.

The disease ICH is caused by the external protozoan parasite *Ichthyophthirius multifiliis* (Ich), a small single celled organism, is highly pathogenic to the four fish species, especially the Colorado squawfish and the chubs. This organism is common on wild fish but the parasite is usually not present in high enough numbers to affect the health of the fish. Once an infected fish is exposed to the stress of culture, a very rapid and deadly infection ensues. Columnaris Disease, caused by the bacterium *Flexibacter columnaris,* is reported to be highly pathogenic to cultured fish. Heavy losses have occurred at culture facilities that were reported to be due to handling or transporting stress. Some concern was also expressed about the Asian tapeworm *(Bothriocephalus acheilograthi)*, however it has not caused as significant of a health problem as the previously described pathogens.

Table 3.18 Pathogens Positively Identified in Artificially Cultured Colorado Squawfish (Ptychocheilus lucius)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. Comm. or Reference
Bacterial Pathogens				
Aeromonas hydrophila	Motile Aeromonas Septicemia	Logan Exp. St. Logan, UT	Post-hatch	Ron Goede
Aeromonas spp.		Common CRW* Ouray NFH	Post-hatch	Ron Goede, Jerry Landye Dennis Anderson Roger Hamman
Flexibacter columnaris	Columnaris Disease	Willow Beach NFH NM	All stages	Roger Hamman Joe Janish, Jerry Landye Dennis Anderson
Pseudomonas spp.		Common CRW	All stages	Dennis Anderson Ron Goede, Jerry Landye Roger Hammon
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens				
Saprolegnia	Saprolegniasis	Common CRW	All stages	R. Flagg, T. Inslee S. Lanigan, H. Tyus
Protozoan Parasites				
Ichthyophthirius multifiliis	Ichthyophthiriasis (Ich)	Dexter NFH NM Hotchkiss NFH CO Bubbling Ponds NFH AZ	Wild broodstock Adults	Roger Hamman Jerry Landye
Trichodina sp.	Trichodiniasis	Willow Beach NFH AZ	Wild broodstock	Roger Hamman Jerry Landye
Costia sp.	Ichtyobodiasis	Bubbling Ponds NFH AZ Ouray NFH	Post-hatch	Jerry Landye Harold Tyus
Myxosoma sp.		Willow Beach NFH AZ	Wild broodstock	K. Seethaler
Pleistophora sp.	Microsporiasis	Presumptive diagnosis at Logan Exp. Fac.	Post-hatch	Ron Goede
Platyhelmenthic Pathogens				
Dactylogyrus sp.	Gill fluke	Willow Beach NFH AZ	Wild broodstock	Roger Hamman
Bothriocephalus opsarichydis	Asian tapeworm	Bubbling Ponds NFH AZ	Post-hatch	Jerry Landye Roger Hamman
Opthiotania criticus		Willow Beach NFH AZ	Ad. H.	J. Valentine
Crustacean Parasites				
Lernaea cyprinacea		Dexter NFH NM	Post-hatch	Roger Hamman

* CRW = Non-specified area in Colorado River Watershed.

Table 3.19. Pathogens Positively Identified in Wild Colorado Squawfish (Ptychocheilus lucius)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. Comm. or Reference
Bacterial Pathogens				
Aeromonas hydrophila	Motile Aeromonas Septicemia	Common CRW*	Post-hatch	R. Flagg
Aeromonas liquefcans		Common CRW	Post-hatch	R. Flagg, Ron Goede
Aeromonas spp.		Common CRW	Post-hatch	R. Flagg Dennis Anderson Ron Goede, Jerry Landye Roger Hamman
Aeromonas punctata		Common CRW	Post-hatch	R. Flagg
Pseudomonas fluorescens	Pseudomonad Septicemia	Common CRW	Post-hatch	R. Flagg
Pseudomonas putrifaciens		CRW	Post-hatch	R. Flagg
Acinetobacter calcoaceticus		CRW	Post-hatch	R. Flagg
Morganella morganii		CRW	Post-hatch	R. Flagg
Escherichia coli		CRW	Post-hatch	R. Flagg
Enterobacter agglomerans		CRW	Post-hatch	R. Flagg
Enterobacter liquefaciens		CRW	Post-hatch	R. Flagg
Viral Pathogens				
	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens				
Saprolegnia	Saprologniasis	Common CRW	Post-hatch	R. Flagg
Protozoan Parasites				
Ichthyophthirius multifiliis	Ichthyophthiriasis (Ich)	Common CRW	Post-hatch	R. Flagg
Trichodina sp	Trichodiniasis	CRW	Post-hatch	R. Flagg, K. Seethaler
Myxobolus sp		CRW, Green R., UT	Post-hatch	R. Flagg
Platyhelmenthic Pathogens				
Otinthodiplostomum sp.		CRW	Adults	R. Flagg
Proteocephalus ptychocheilus		CRW	Post-hatch	R. Flagg
Proteocephalus ambloplites	Bass tapeworm	CRW	Post-hatch	K. Seethaler
Bothriocephalus opsarichydis	Asian tapeworm	Common CRW	Post-hatch	B. Jensen Jerry Landye, Roger Hamman
Crustacean Parasites				
Lernaea cyprinacea		Common CRW	Post-hatch	R. Flagg, B. Jensen, K. Seethaler

* CRW = Non-specified area in Colorado River Watershed.

Table 3.20 Pathogens Positively Identified in Artificially Cultured Humpback Chub (Gila cypha)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. Comm. or Reference
Bacterial Pathogens	There are no identifed bacteria pathogens found in cultured fish			
Viral Pathogens	There are no identified viral pathogens of warmwater fish *in the CRW**			
Mycotic Pathogens		CRW	Post-hatch	
Protozoan Parasites				
Ichthyophthirius multifiliis	Ichthyophthiriasis (Ich)	Hotchkiss NFH, CO	Adult	Neal Ward
Tetrahymena sp		CRW	Post-hatch	R. Flagg
Apiosoma sp.		CRW	Post-hatch	R. Flagg
Ambiphyra sp.		CRW	Post-hatch	R. Flagg
Chilodenella sp.		CRW	Post-hatch	R. Flagg
Tetrahymena pyriformis		CRW	Post-hatch	R. Flagg
Platyhelmenthic Parasites	There are no identified platyhelmenthic parasites found in cultured fish.			
Crustacean Parasites	There are no identified crustacean parasites found in cultured fish.			

* CRW = Non-specified area in Colorado River Watershed.

Table 3.21 Pathogens Positively Identified in Wild Humpback Chub (Gila cypha)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. comm. or Reference
Bacterial Pathogens				
Aeromonas hydrophila	Motile Aeromonas Septicemia	CRW*	Post-hatch	R. Flagg
Pseudomonas fluorescens	Pseudomonad Septicemia	CRW	Post-hatch	R. Flagg
Pseudomonas putrifaciens		CRW	Post-hatch	R. Flagg
Pseudomonas sp		CRW	Post-hatch	R. Flagg
Pseudomonas II - K2		CRW	Post-hatch	R. Flagg
Acinetobacter calcoaceticus		CRW	Post-hatch	R. Flagg
Morganella morganii		CRW	Post-hatch	R. Flagg
E. Scherichia coli		CRW	Post-hatch	R. Flagg
Enterobacter agglomerans		CRW	Post-hatch	R. Flagg
Bacillus mycoides		CRW	Post-hatch	R. Flagg
Erysipelothrix rhysiopathiae		CRW	Post-hatch	R. Flagg
Corynebacterium equi		CRW	Post-hatch	R. Flagg
Bacillus sp		CRW	Post-hatch	R. Flagg
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens				
Saprolegnia	Saprologniasis	CRW	Post-hatch	R. Flagg
Protozoan Parasites				
Amoebae sp	Gill amoeba	CRW	Post-hatch	R. Flagg
Trichodina sp	Trichodiniasis	CRW	Post-hatch	R. Flagg
Myxobolus sp		CRW	Post-hatch	R. Flagg
Myxidium sp		CRW	Post-hatch	R. Flagg
Platyhelmenthic Parasites	There are no identified platyhelmenthic parasites in wild fish.			
Nematoda				
Philometra sp				
Crustacean Parasites				
Lernaea cyprinacea		Common CRW	Post-hatch	R. Flagg

* CRW = Non-specified area in Colorado River Watershed.

Table 3.22 Pathogens Positively Identified in Artificially Cultured Bonytail Chub (Gila elegans)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. comm. or Reference
Bacterial Pathogens	There are no identified bacterial pathogens in cultured fish			
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW*			
Mycotic Pathogens	There are no identified bacterial pathogens in cultured fish			
Protozoan Parasites *Ichthyophthirius multifiliis*	Ichthyophthiriasis (Ich)	Willow Beach NFH NM Ouray NFH	Fry Adults	R. Hamman Harold Tyus
Platyhelmenthic Parasites	There are no platyhelmenthic parasites in cultured fish.			
Crustacean Parasites *Lernaea cyprinacea*	Lernaea	Dexter NFH NM	Wild broodstock	B. Jensen

* CRW = Non-specified area in Colorado River Watershed.

Table 3.23 Pathogens Positively Identified in Wild Bonytail Chub (*Gila elegans*)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. comm. or Reference
Bacterial Pathogens				
Pseudomonas fluorescens	Pseudomonad Septecemia	CRW*	Post-hatch	R. Flagg
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens				
Saprolegnia	Saprologniasis	Common CRW	All stages	
Protozoan Parasites				
Myxobolus sp		CRW	Post-hatch	R. Flagg
Myxidium sp.		CRW	Post-hatch	R. Flagg
Amobae sp.	Gill amoeba	CRW	Post-hatch	R. Flagg
Platyhelmenthic Parasites				
Bothriocephalus opsarichydis	Asian tapeworm	Imperial Valley State Warmwater Fish Hatchery Niland, CA	Post-hatch	Wayne Parker
Crustacean Parasites		Common CRW	Post-hatch	R. Flagg

* CRW = Non-specified area in Colorado River Watershed.

Table 3.24 Pathogens Positively Identified in Artificially Cultured Razorback Sucker *(Xyrauchen texanus)*

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. Comm. or Reference
Bacterial Pathogens				
Flexibacter columnaris	Columnaris	Bubbling Ponds NFH AZ	Post-hatch	Jerry Landye
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens	There were no myotic pathogens identified	ND**	ND	
Protozoan Parasites				
Ichthyophthirius multifiliis	Ichthyophthiriasis (Ich)	Willow Beach NFH AZ	Fry/fingerling	D. Toney
Myxobolus sp.		Willow Beach NFH AZ	Adult	D. Toney
Trichodina sp.	Trichodiniasis	Bubbling Pond NFH AZ	Post-hatch	Jerry Landye
Costia sp.	Costiaisis	Bubbling Pond NFH AZ	Post-hatch	Jerry Landye
		Ouray NFH	Post-hatch	Harold Tyus
Platyhelmenthic Parasites	There were no Platyhelmenthic parasites identified			
Crustacean Parasites				
Lernaea cyprinacea		Dexter NFH NM	Post-hatch	B. Jensen, D. Toney

* CRW = Non-specified area in Colorado River Watershed.
** ND = Not documented in text.

Table 3.25 Pathogens Positively Identified in Wild Razorback Sucker (*Xyrauchen texanus*)

Pathogen	Disease or Common Name	Location/ Occurrence	Lifestage	Pers. Comm. or Reference
Bacterial Pathogens				
Erysipelothrix rhysiopathiae		CRW*	ND**	R. Flagg
Viral Pathogens	There are no identified viral pathogens of warmwater fish in the CRW			
Mycotic Pathogens	There were no myotic pathogens identified in wild fish			
Protozoan Parasites				
Myxobolus sp		CRW	Post-hatch	R. Flagg
Platyhelmenthic Parasites	There were no platyhelmenthic parasites identified in wild fish			
Crustacean Parasites				
Lernaea cyrpinacea		CRW	Post-hatch	R. Flagg

* CRW = Non-specified area in Colorado River Watershed.
** ND = Not documented in text.

The following notes should be considered in using tables 3.18 - 3.25:

- The tables are summaries of confirmed identifications of diseases or fish pathogens and are not meant to be inclusive of every disease these fish may possibly get.
- There are several pathogens documented, which are found in specific lifestages, such as fry, fingerling, or adult, but it should be assumed that most, if not all lifestages would be susceptible to the pathogen as described.
- Because of the close genetic relationship of the four target species, and the similar habitat requirements, one can assume that all four fish species could be susceptible to any of the identified pathogens.
- Each disease or pathogen listed has been positively identified to be associated with the host but for the most part has not caused a health problem with the fish.

3.5.2 Disease Epizootiology, Treatment, and Control

Table 3.26 contains a summary of the life history of each documented pathogen, where it can be found in the environment, and what are the conducive factors to an epizootic, or disease outbreak. A subsection on Therapy and Control describes documented and suggested chemical and physical treatments and their methods of application that have been used to control epizootics in the four target fish and their related species. Documented treatments are defined as those identified in the reference library and through interviews with fish health specialists and fish culturalists. Suggested treatments are those treatments that may be used to treat epizootics in these species, and are those treatments documented to be the most commonly used on the specific pathogen. Current regulations governing the use of drugs for treatment of diseases must be reviewed before initiation of treatment.

Table 3.26 Summary of Diseases and their Therapy and Control

Disease/Pathogen	Epizootiology	Therapy and Control
Motile Aeromonad Septicemia *Aeromonas hydrophila* *Aeromonas punctata* *Aeromonas sp.*	Bacteria in the genus Aeromonas are commonly found in soils and water. Fishes may becomes hosts to Aeromonads when their defenses allow invasion. Most outbreaks in warmwater fish occur in spring and summer.	**Documented:** None **Suggested:** • Oxytetracycline treatment used in the food at the rate of 55 mg per Kg of fish (2.5 grams per 100 pounds) per day for 10 days. Sulfamerazine at 264 mg per Kg of fish (12 grams per 100 pounds) given in the food for three days, followed by 154 mg per Kg of fish (7 grams per 100 pounds) per day for 11 additional days, may also be an effective treatment (Post, 1987). • 2.5 - 3.5 grams active Terramycin (Oxytetracycline HCl) per 100 pounds of fish for 7-10 days (Piper, et al., 1986)
Pseudomonad Septicemia *Pseudomonas fluorescens* *Pseudomonas putrifaciens* *Pseudomonas II-K2* *Pseudomonas sp.*	Bacteria of the genus Pseudomonas are ubiquitous in the water. The disease among cultured fishes is usually a result of improper management or stress. Quite often there is no drug choice for treatment of the disease because there usually is a different species or strain of Pseudomonad associated with each epizootic.	**Documented:** None **Suggested:** • Same as suggested treatment for Motile Aeromonads Septicemia (Piper, et al., 1986) • A drug sensitivity test using a bacterial isolate from the epizootic may be of assistance to prescribe the most effective antibacterial. External bactericides may be used in conjunction if mortality cannot be reduced with systemic drugs (Post, 1987).
Miscellaneous Bacteria *Acinetobacter calcoaceticus* *Morganella morganii* *Eschexichia coli* *Enterobacter agglomerans* *Bacillus mycoides* *Erysipelothrix rhysiopathiae* *Corynebacterium equi* *Bacillus sp.*	Most of these bacterial species are either found as normal bacterial flora of the fish or in the soil or water. They should not represent a health problem unless, as seen with all other bacterial species, the host of fish becomes weakened due to excessive stress.	**Documented:** None **Suggested:** • Positively identify primary pathogen and treat with most effective antibacterial.

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
<u>Columnaris</u> *Flexibacter columnaris*	This disease usually results from injuries to the fish, or nutritional deficiencies. It most commonly involves external infections but can occur as an internal systemic infection with no visible external signs. Development of the disease is temperature related. In warmwater fish, most outbreaks occur when the water temperature is above 68°F, but the disease can occur anytime during the year. Flexibacteria are common inhabitants of soil and water, and are commonly found on fish.	**Documented:** Terramycin was used to Successfully treat Columnaris in Colorado Squawfish. The dosage prescribed for salmon and trout is suggested for use in these native fish. The dose is 3.75 grams active ingrediant per 100 pounds of fish for 14 days (personal communication, Roger Hamman). **Suggested:** External infections of Columnaris may be treated with: • Furanace as a bath at 1.5 ppm for one hour for one to three consecutive days is stated to be the most effective. The chemical is absorbed from the water, yielding therapeutic tissue levels as well as acting as a topical therapeutant (Piper, et al., 1986; Stickney, 1979). • Diquat at 8.4 to 16.8 ppm for one hour on three or four consecutive days (Piper, et al., 1986). • Terramycin as a prolonged bath at 15 ppm active ingredient for 24 hours (Piper, et al., 1986) • Copper sulfate has been used as a 20 minute dip at 40 ppm, a one minute dip at 500 ppm, a pond treatment at 0.5 ppm, or as an indefinite bath at 1 ppm in softwater and 2 ppm in hard water (Piper, et al., 1986; Post, 1987; Stickney, 1979) • Potassium permangenate, the most effective pond treatment for external Columnaris infections in warmwater fish, at the rate of 2 ppm. If the color changes in less than 12 hours it may be necessary to repeat the treatment (Piper, et al., 1986). • Oxolinic acid as a 24 hour bath at 1 ppm has been used (Post, 1987). • Internal or systemic infections may be treated with: 2.5 - 3.5 grams Terramycin per 100 pounds of fish per day for 7-10 days (Piper, et al., 1986; Post, 1987; Stickney, 1979). • Sulfamerazine will also prove somewhat effective when used at a rate of 264 mg per Kg of fish per day for three days then 154 mg per Kg for 11 days (Post, 1987).

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Viral Pathogens	As demonstrated by the literature review and summary in Section 5.1 through 5.4, there are, at this time, no identified viral pathogens found in the four target species of fish in the Colorado River watershed. This does not mean that there are not viruses that these fish are susceptible too though. There are well known viruses that are found in fishes in the same Family. For example, the spring viremia of carp virus that has been identified in common, bighead, and grass carp, guppy, fathead minnows and possiby tench, all of which are related to these four species of fish (Post, 1987). Another factor is that the fish may harbor a yet unknown viral species. As with bacteria, viruses infect a host and usually do not cause a disease unless the host's defenses are weakened. Intensive culture can sometimes stress a fish enough so that the virus is "expressed" and may cause a disease state. The four species we are examining may have not been exposed to the conditions needed to induce a viral disease in culture so one has not been observed. A viral epizootic may have occurred in the wild but the chances of recovering a moribund specimens for examination are probably very small.	
Mycotic Pathogens *Saprolegniasis* *Saprolegnia sp.*	The family Saprolegnia sp. is ubiquitous to fresh waters of the world. There are apparently no primary cases of Saprolegniasis among fishes. Malnutrition among cultured fishes has been and continues to be a primary cause of this disease (Post, 1987). Presence of toxic substances in food or water or physical damage to the fish from handling is highly likely to result in secondary invasions by Saprolegnia sp. Fungal invasions are commonly seen as secondary infections to external bacterial infections or parasitic infestations. It has been observed to infect necrotic host tissues, those which have been previously damaged. Most fish are susceptible to Saprolegniasis as well as their eggs. Most of the time only dead eggs can harbor the disease but live eggs may be killed by subsequent suffocation and invasion.	**Documented:** Daily flow through treatments of 1:100 (10,000 ppm) formalin for 10 minutes controlled fungal infestations on incubating eggs (Ref. 42). **Suggested:** • A 10 to 30 second dip in a 1:15,000 solution of malachite green has been used effectively (Stickney, 1979) • A one hour flush treatment at 1 ppm may also be effective on post-hatch fish (Stickney, 1979). • Formalin has been used with limited success at 250 ppm for one hour (Post, 1987). • Combining formalin, 100 ppm with 2.5 ppm malachite green solution and treating for one hour has been found to be effective in some cases (Post, 1987).

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
<u>External Protozoan Parasites</u> *Ichthophthirus mulitfiliis* Ichthyophthiriasis (Ich)	"Ich" is a large ciliated protozoan found worldwide, exclusively parasitic of fish. The feeding stages, or trophozoites, are found in the skin, gills, and fins. When mature adult parasites drop off the host and attach to the substrate, it secretes a gelatinous sheath or cyst and begins reproduction by fission, producing up to 1,000 tomites or infective bodies. The tomites burst from the cyst and must find a host within about 48 hours at 24 to 26°C or it will die. Generally fish with small or no scales are more susceptible to infection. Fish usually die from extensive damage to the gills or from a secondary pathogen that invades damaged fish. Colorado Squawfish are said to be highly susceptible to Ich. Ich is difficult to treat because the tissue inhabitating and encysted forms are resistant to treatment, only the free-swimming forms are vulnerable. This requires several treatments over a number of days.	**Documented:** • Adult wild broodstock heavily infected with Ich were treated with 25 ppm formalin and 0.05 ppm malachite green (Ref: 23). • Painting on a 1:1000 solution of potassium permangenate was ineffective (Ref: 23). • Formalin dissipates oxygen so ponds were first aerated then 25 ppm formalin plus 0.1 ppm malachite green was added to the ponds and allowed to dissipate over 6-8 hours. Ich was successfully treated (pers. comm. Roger Hamman). • Copper sulfate at 1.5 to 2.0 ppm depending on water hardness was successful in ponds and in race-ways 167 ppm formalin for one hour gave good results (pers. comm. Jerry Landye). • For fry, formalin baths at 15 ppm for one hour on three alternating days was believed to eliminate parasite. Weekly prophylactic treatments were continued (Ref: 5). **Suggested:** • Formalin at 15-25 ppm for two to four applications on alternate days is usually effective (Piper, 1986). • Malachite green at 1.5 ppm for 6 to 24 hour bath. • Flow through treatments in circular tanks are not effective against Ich at Ouray NFH (Hardness 440 mg/l). • Static treatments seem to be the most effective when water temperatures are elevated to 70°F so that the susceptible tomite lifestages are more rapidly released into the water column and can be exposed to the chemical therapeutant. Standard malachite green-formalin treatments are used.

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Ichtyobodiasis *Costia sp.*	Costia are very small flagellated ectoparasties. They are obligate parasites, which means thay thay cannot survive without the host. The organism is transmitted from fish to fish through the water. Ordinarily, the protozoan attaches to the skin or gills of the host fish where they occur in an apparently commensalistic state of symbiosis. The defenses of the host probably keep the protozoan populations down to acceptable levels. A change in the health of the host or environmental conditions, such as culture stress or poor water quality is usually conducive to an epizootic. Adverse environmental conditions may cause the trophozoites to encyst on the fish or free in the water until more favorable conditions exist. Mortality may result from gill damage or secondary infection of an opportunistic secondary pathogen.	**Documented:** None **Suggested:** • Pond treatments generally give good results, these include: formalin at 15-25 ppm; potassium permangenate at 2 ppm; or copper sulfate at safe recommended levels. For best results from formalin bath treatments, use 125 to 250 ppm depending upon water temperture, species and size of fish, and parasite load, for up to one hour (Piper, et al. 1986). • Acetic acid dip at 2-5% for one minute or less (Post, 1987). • Formalin one hour bath at 250 ppm or 10 to 15 minute dip at 400 ppm (Post, 1987). • Pond treatments that give good results include: formalin at 15-25 ppm; potassium permangenate at 2 ppm; or copper sulfate at safe concentrations. For prolonged bath treatments, 125 to 250 ppm for up to one hour.
Trichodiniasis *Trichodina sp.*	Trichodinids are saucer-shaped protozoans with cilia around the margins. They live on the skin, fins, and gills of fish. They are usually commensalistic but if these organisms become too numerous, they may be responsible for damage to skin and gills and then secondary infections may occur.	**Documented:** None **Suggested:** • Copper sulfate as an indefinite treatment at whatever concentration can be used safely in existing water chemistry. Potassium permangenate at 2 ppm as an indefinite pond treatment. Formalin at 15-25 ppm as an indefinite pond treatment. Formalin at 125 to 250 ppm for up one hour depending on tolerance of fish (Piper, et al., 1986).
Chilodonella sp	Small, oval, colorless ciliated protozoans which may be found in vast numbers on the skin, fins, and gills of fish. The epizootiology is similar to Trichodina sp., in that they are usually commensalistic until the general health of the host is jeopardized by physical or environmental factors.	**Documented:** None **Suggested:** Same as recommended for Trichodiniasis.

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Tetrahymena sp. *Ambiphyra sp. (scyphidia)* *Apiosoma sp.*	Ciliated protozoans with similar epizootiology as others in this class of organisms.	**Documented:** None **Suggested:** Same as those recommended for other external ciliated protozoan.
Gill Amoebae *Amoebae sp.*	Single celled polymorphous organisms that can be found on skin, fins and gills and occasionally in the intestines. Spontaneous or secondary amebasis has been reported but usually they are opportunistic pathogens to weakened host fish.	**Documented:** None **Suggested:** Same as those recommended for external protozoan parasites.
Internal Protozoan Parasite *Myxozoasis* *Myxobolus sp.* *Myxidium sp.* *Myxosoma sp.*	All members of this phylum are parasitic to other animals and commonly called myxosporeans. Many are found in the urunary and gall bladders of the host. Others are found in the parenchyma of soft tissues, but genreally within the inter-cellular spaces. Occassionally intracellular forms are found in muscle fibers. Most have evolved into a successful commensalistic relationship with the host; however, there are several that are significant pathogens. Spores are usually passed from fish through urine or feces but some are trapped in connective tissues and are released when the fish dies. There is little doubt that the transmission is orally in most cases. Birds or mammals may be involved in transmission cycles. Fish surviving early stages of the disease continue to carry the spores for life. Mortality is due to damage of gills, internal organs, or secondary infections or opportunistic pathogens.	**Documented:** None **Suggested:** Prevention is the only method of control because no chemical treatment is effective. The disease can be reduced or eliminated by quarantine and restriction of movement, test and slaughter, and sanitation and disinfection.

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Microsporiasis *Pleistophora sp.*	The microsporans are intracellular parasites with a tremendous reproductive capacity. The only transmitting entity is spores. Microsporiasis is a chronic condition is which masses of developing spores form tumor like cysts with host tissues. Disintegration of infected tissues release spores. Ingestion of infected fishes by other fishes also releases spores from the host. Mortality occurs due to damage to vital organs or secondary infections of opportunistic pathogens.	**Documented:** None **Suggested:** Microsporeans are similar to Myxosporeans in that there is no known chemical treatment. Similar control measures must be taken to control the spread of the pathogen.
Platyhelmenthic Parasites Gill Flukes *Dactylogyrus sp.*	Species of the family Dactylogyridae are found commonly on the gills of fish. Dactylogyrids lay eggs and have eye spots, one pair of anchor hooks and 16 marginal hooklets; they are common on warmwater fish. These worms lay eggs which may remain allocated to the host. The larvae are ciliated and actively swim in search of a new host. Once attached to a host they mature and begin to feed on the blood of the host. In large numbers they can cause serious damage to the gills of warmwater fish. Secondary infection is common.	**Documented:** None **Suggested:** • These parasites are easily controlled with Masoten (Dylox) at 0.25 ppm used as an indefinite pond treatment. Copper sulfate is also effective and formalin at 15-30 ppm is effective (Piper, et al., 1986). • A one hour formalin bath at 167-250 ppm every other day for three days (Post, 1987). • Also malachite green, acetic acid, sodium chloride or potassium permangenate can be used (Post, 1987).

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Tapeworms Asian Tapeworms *Bothriocephalus opsarichydis*	This type of parasite usually requires one or more animal hosts, in addition to fish, to complete their lifecycles. These parasites can be divided into two major groups; those that live in the fish as adults, producing eggs that leave the fish to continue the life cycle and those that penetrate the skin of the fish as larvae, usually encysted in the tissue, until the fish is eaten by the final host. Excessive numbers of either adult or plerocercoid (cysts) stages of the parasite in fishes may cause reduced growth, emaciation, anemia, and susceptibility to secondary infections.	**Documented:** • A size specific dose of Di-N-butyl Tin Oxide was placed in a gelatin capsule then injected into the stomachs of fish using a Bolus gun. The treatment was performed twice and there has been no re-occurrence of the tapeworm over the last five years (pers. comm. Roger Hamman) • Adult and three year old squawfish were fed DNBTO in an attempt to eradicate the tapeworm. The extent of control was unknown (Ref: 14). • Forage minnows are fed to infected squawfish to help physically remove the intestinal worms from the fish (pers. comm. Jerry Landye). • Tapeworms were recovered from fish treating once with Terramycin at a rate of 25 mg/Kg fish. **Suggested:** • DNBTO at 0.5 to 0.6% of the diet for three days or 250 mg per Kg fish. • Yomesan, or plenasal added to the diet fed at the rate of 50 mg per Kg of fish for three days. • Phenothiazine in the diet at one gram per Kg of fish body weight three times at two day intervals.

Table 3.26 (con't.)

Disease/Pathogen	Epizootiology	Therapy and Control
Crustacean Parasites *Lernaea cyprinacea*	The female L. cypriniacea becomes an adult on the host fish following fertilization by the male. The female metamorphosizes and the head region penetrates the skin or gills of the host then the head develops anchors which assist in holding the organism in place on the host. The fertilized attached female develops egg sacs that are shed when mature. The eggs hatch and the nauplii break out of the eggs. The nauplii matures to a copepodid then must find a host and repeat the cycle. They are commonly found on warmwater fish. This is demonstrated by the fact that this was the most common parasite to be observed on all of the four target species. Heavy infestations have caused massive mortality in carp and goldfish populations. The damage caused by the parasite is associated with loss of blood and exposure to secondary infections.	**Documented:** None **Suggested:** Masoten (Dylox) at 0.25 ppm as a pond treatment, repeated four times at weekly intervals gives good control. Inconsistent results are obtained at temperatures above 80°F and pH values above 9.

3.5.3 Nutritional Diseases

There are many diseases among fishes directly related to nutritional deficiencies and excesses. Also, malnutrition is implicated in many diseases involving pathogenic organisms. Formulations of complete rations are based on the quantitative expression of nutrient requirements of fishes and availability of the nutrients as well as the digestibility of the feed. Formulation of a complete diet must be followed by ration preparation, analysis, and actual feeding of the fish to be assured all nutrients are available.

The physiological functions of a fish, such as growth and reproduction, govern its metabolism and, in turn, determine its nutritional requirements. Apart from feed, water temperature is probably the single most important factor affecting fish growth and, in turn, nutritional requirements. As water temperatures reach optimal levels for the species, caloric and nutritional needs increase resulting in an increase in the fishes' appetite. During cooler winter, or ambient, temperatures fish generally have lower metabolic rates. Spawning and seasonal changes with the onset of sexual maturity affect the rate of metabolism. At this point, energy, instead of being funneled into building body tissues, is channeled into the formation of eggs and sperm.

Nutritional deficiencies and excesses may cause health problems such as reduced or impaired growth, lethargy, malformed or enlarged organs, organ damage, and skeletal deformities. It is very common that nutritionally compromised fish succumb to secondary infections. Factors such as water flows, water chemistry, and pollution can put added stresses on fish, and result in increased metabolic rates in relation to the severity of the stress. Crowding, disease, and culture practices also affect the metabolism and well being of the fish.

A demonstration of health problems suspected due to a nutritional deficiency was described by Harris, et al. (1990). After four months of feeding Rangen brand commercial trout diets to Colorado squawfish fry, scoliosis was observed in several fish. Histological examination revealed that the scoliosis was probably associated with a Vitamin C deficiency. The encapsulated diet in Biokyowa brand did not produce fish with scoliosis.

Many nutrients are heat, moisture, and/or air liable, and although most nutrients are often stabilized against deterioration, diets should be stored in a cool, dry place to prevent degradation. In most cases only sufficient diet is purchased to accommodate the needs over a few months. In no case should feed be stored for longer than a single growing season unless that feed is stored frozen. Still, some forms of Vitamin C are shown to rapidly degenerate in frozen feeds over three months.

3.5.4 Miscellaneous Health Factors

These fish show high sensitivities to mercury, copper and to various chlorinated hydrocarbons such as DDT and dieldrin (Beleau and Bartosz, 1982). Source water from agricultural areas should be evaluated for these pollutants. Colorado squawfish generally appear to be more tolerant of organic and inorganic compounds than the channel catfish or the fathead minnow. Razorback suckers are very sensitive to nitrogen gas saturation levels. It is best to keep nitrogen gas saturation below 102% especially during early lifestages of fish (personal communication, Larry Harris, Harold Tyus, 1990). Nitrogen gas supersaturation (107.2%) caused gill problems in Colorado squawfish fry. Treating with a combination of 3% salt solution one day and the next day a treatment of 2 grams per gpm chloramine-T helped reduce mortality (personal communication, Larry Harris, 1990).

Fungus on gill filaments was noticed on Colorado squawfish fry in hatchery troughs (Harris, et al., 1990). Microscopic examinations showed particles of food lodged in the gill filaments. Feed size was reduced and this problem was alleviated.

Another problem noted in the culture of Colorado squawfish was that when fry were placed in transparent screen pans, they would crowd into corners and suffocate (Knott, 1990). To alleviate this problem, pieces of white Masonite board were placed under each pan. This helped disperse the fish more evenly throughout the pan and reduce mortality (personal communication, Larry Harris, 1990).

Roger Hamman at Dexter NFH stated that high incidences of scoliosis is sometimes observed in Colorado squawfish if the fish are hatched in cold water conditions (≤60°F).

3.5.5 Other Disease of Concern

A further review of fish genetically related to the four target species was conducted to better evaluate future fish health issues, due to the limited information on the disease history and pathogens of the four target species. The majority of this group of genetically related fish share similar life histories and habitat requirements.

For the purposes of this report, other diseases that have been documented in genetically related species may be of concern in the culture of the four target species. Related species is defined here as fish species which belong to the taxonomic Order of *Cypriniformes;* the four target species belong to this Order. The Order *Cypriniformes* is made up of three Families of fish containing over 250 distinct species. The Family *Characidae* contains one species, the Mexican tetra. The Family *Cyprinidae* includes all squawfish, chubs, carps, dace, minnow, and shiner species. The Family *Catostomidae* includes all suckers, buffalo fish and redhorse fish species.

Fish health specialists were interviewed for information on diseases of related species. Information from these interviews and available literature were reviewed and is summarized in Table 3.27. It must be clarified that although one fish species is susceptible to a disease, one cannot assume that all fish in the same order, family or genus is also susceptible. The information contained in Table 3.27 is only to quantify the possible types of pathogens (i.e., bacteria, intestinal tapeworms, etc.) one may encounter in the culture of the four target species and not to delineate or describe all possible diseases.

3.5.6 Regulations and Permits

To control unauthorized release of fish and the spread of pathogens, state and federal agencies have standards and regulations regarding the transport of fish and fish reproductive products (i.e., eggs, sperm). Usually there is more attention focused on the transfer of coldwater fish, such as trout and salmon, than on warmwater fish. This may be due to the economic status of salmonids and/or because most species of warmwater fish and their pathogens are found throughout the United States. Information pertaining to fish transport was gathered from fisheries or wildlife agencies in Arizona, Colorado, New Mexico, and Utah, and the USFWS regarding the transport of warmwater species throughout the Colorado River watershed. The regulations and permits are described as follows:

Arizona

The Arizona Game and Fish Commission shall issue a stocking permit or deny the application for stocking aquatic wildlife not previously introduced within six months of receiving the application; such applicants shall be advised within ten calendar days of application if the extended time period will be required. For all other applicants, the Department shall issue a permit or deny the application within 30 calendar days. Authorization will not exceed 20 days and is valid only during the dates shown on the permit.

Live fish and eggs, fertilized eggs, and sperm imported into the state must be certified free of the following diseases and causative agents when applicable to the species involved. The verification shall be based on a physical inspection of the fish farm of origin within the 12 months preceding the shipment. The inspection shall be conducted by a fish health inspector or fish pathologist certified by the American Fisheries Society. A copy of the certifications shall accompany each shipment.

Live fish and eggs, fertilized eggs, and milt:

- Viral Hemorrhagic Septicemia of Salmonids
- Infectious Hemtopoietic Necrosis of Salmonids
- Infectious Pancreatic Necrosis of Salmonids
- Ceratomyxa shasta
- Proliferative Kidney Disease Agent
- Spring Viremia of carp

According to Post (1987), the four target species are not shown to be susceptible to any of these pathogens, except for the Spring Viremia of Carp Virus (SVCV). The four target species are genetically related to the carps, so we can assume that they also may be susceptible to SVCV. However, SVCV has never been reported in the U.S. Certification is required in this case only when the original origin of the shipment is from outside the United States (Arizona Game and Fish Commission. Live Wildlife Rules. Effective date April 28, 1989).

Table 3.27. Diseases and Pathogens of Related Species .

Disease/Pathogen	Fish Species		Location	Reference
Bacterial Pathogens				
Motile Aeromonads Septicemia				
Aeromonas hydrophila	Flannelmouth Sucker	Catostomus latipinis	CRW	#20
	Roundtail Chub	Gila robusta	CRW	#20
	Goldfish	Carassius auratus	North America	Piper, et al., 1986
	Common Carp	Cyprinus carpio	Worldwide	Piper, et al., 1986
	All freshwater fish species		Worldwide	Post, 1987
Aeromonas punctata	Same as A. hydrophila			
Furunculosis				
Aeromonas salmnonicida	Common Carp	Cyprinus carpio	Worldwide	Piper, et al., 1986, Post, 1987
	Goldfish	Carassius auratus	Worldwide	Piper, et al., 1986
	Chubs	Gila sp.	Worldwide	Post, 1987
	Dace	Clinostomous sp.	Worldwide	Post, 1987
	Salmonid species		Yampa R., CO	Larry Harris
Pseudomonad Septicemia				
Pseudomonas fluorescens	Flannelmouth Sucker	Catostomus latipinis	CRW	#20
Pseudomonas putrifaciens	Roundtail Chub	Gila robusta	CRW	#20
	Probably all species of fishes susceptible		Worldwide	Post, 1987
Columnaris				
Flexibacter columnaris	All freshwater fish		Worldwide	Post, 1987
	Baitminnows Family	Cyprinidae		
	Common Carp	Cyprinus carpio		
	Goldfish	Carassius auratus		
Pleisomonas shigelloides	Flannelmouth Sucker	Catostomus latipinis	Worldwide	#20
Finrot or Coldwater Disease				
Cytophaga psychrophilia	Probably all coldwater and coolwater fishes		Worldwide	Post, 1987
	Several sucker species Family	Catostomidae		
	Common Carp	Cyprinus carpio		
Bacterial (Environmental) Gill Disease				
Bacteria of mixed etiology	All species of fish. Fishes which have evolved in water supplies rich in detritus and organic matter seem to be more resistant.		Worldwide	Post, 1987

Table 3.27 (con't.)

Disease/Pathogen	Fish Species		Location	Reference
Mycobacteriosis Mycobactyerium marinum M. fortuitum	Probably all species of fish.		Worldwide	Post, 1987
Flavobacteriosis Flavobacterium sp.	Probably all fishes are susceptible to secondary infections of Flavobacterium sp.		Worldwide	Post, 1987
Streptococcus Septicemia Streptococcus sp.	Golden Shiners Not in Goldfish Not in Bigmouth Buffalo	Notemigonus crysoleucas Carassius auratus Ictiobus cyprinellus	USA	Post, 1987 Ribeline and Migaki, 1975
Viral Pathogens Lymphocystis Disease	Probably most of the bony (Osteichthyes) aquarium fishes are susceptible.		Great Lakes Region, USA Several Regions Worldwide	Post, 1987; Davis 1953
Spring Viremia of Carp (Abdominal dropsy) Rabdovirus carpio	Common Carp Bidhead Carp Grass Carp	Cyprinus carpio Ctenopharyngodon idella	Not known in USA Enzootic over Europe	
Mycotic Pathogens Ichthyophonus Disease Ichthyophenus hoferi	Probably all fish species are susceptible to infections of I. hoferi		Worldwide	Post, 1987
Branchiomycosis Branchiomyces sanguinis	Probably all freshwater fish are susceptible to Branchiomycosis specifically: European Carp Crucian Carp Golden Shiners		Worldwide	Post, 1987
Protozoan Parasites Ichtyobodrasis Costia sp.	All species of freshwater fish.		Worldwide	Post, 1987
Hexamitiasis Hexamita salmonis H. truttae H. intestinalis	Golden Shiners Goldfish	Notemigonus crysoleucas Carassius auratus	Probably Worldwide	Post, 1987; Davis 1953

Table 3.27 (con't.)

Disease/Pathogen	Fish Species		Location	Reference
Protozoan Parasites (con't.)				
Amoebiasis				
Acanthamoeba sp.	Probably all fish species.		Worldwide	Post, 1987
Entamoeba sp.				
Volkampfia sp.				
Schizamoeba sp.				
Coccidiosis				
Eimeridae	Common Carp	Cyprinus carpio	Worldwide	Post, 1987
Adeleidae	Goldfish	Carassius auratus		
	Rudd	Scardinius erythrophthalmus		
	Tench	Tinca tinca		
	Amurs (Grass Carp)	Ctenopharyngodon idella		
Microsporasis				
Pleistophora sp.	Neon tTtra	Astyanax sp.	Worldwide	Post, 1987
Nosema sp.	Golden Shiner	Notemigonus crysoleucas		Piper, et al., 1986
Glugea sp.	Fathead Minnow	Pimephales promelas		Ribelin and Migake, 1975
Thelohania sp.				Ron Goede
Mxyosoasis				
Primary Pathogens	Probably most fish are susceptible to one or more of these pathogens			
Myxosoma cerebralis			Worldwide	Post, 1987
Ceratomyxa shasta	Flannelmouth Sucker	Catostomus latipinis	CRW	#20
Henneguya sp.	Roundtail Chub	Gila robusta	CRW	#20
Myxobolus argentens	Bluehead Sucker	Catostomus discobolus - Myxobolus sp.	CRW	#20
Myotoulus notemigoni				Ribelin and Migaki, 1975
				Piper, et al., 1986
Secondary Pathogens				
Myxidium sp.				
Sphaeromyxa sp.				
Sphaerospora sp.				
Unicapsula sp.				
Averbachia sp.				
Thelohanelus sp.				
Chloromyxum sp.				
Kudoa sp.				
Unicauda sp.				
Hexacapsula sp.				
Chilodonella sp.	All freshwater fish are particularly susceptible to infestations.		Worldwide	Post, 1987
Trichodina sp.			CRW	#20
Epistylis sp.				Ribelin and Migaki, 1975
Trichohyra sp.				Piper, et al., 1986
				Davis, 1953

Table 3.27 (con't.)

Disease/Pathogen	Fish Species		Location	Reference
Platyhelmenthic Parasites				
Flukes				
Dactylogyridus sp.	Probably all marine and aquatic fishes of the world.		Worldwide	Post, 1987
Gyrodactylus sp.				
Cleidodiscus sp.				Piper, et al., 1986
Diplostonum spathaceum	Three species of suckers, one species of shiner and chub species.		Utah Lake, UT	Post, 1987
Pothodiplostamum minimum	100 species in N. America. Found especially in warmer climates over must of the USA.			Post, 1987
	Flannelmouth Sucker	Catostomus latipinis	CRW	#20
	Roundtail Chub	Gila robusta	CRW	#20
Linguia intestinalis	Suckers, minnows, shiners, chubs, dace.		Worldwide	Post ,1987
Uvalifer amboplitis	Roundtail Chub	Gila robusta	CRW	#20
Hunterella sp.	Flannelmouth Sucker	Catostomus latipinis	CRW	#20
Isoglari dacris sp.	Flannelmouth Sucker		CRW	#20
Acanthorephala Parasites				
Rhubdochona pellucida	Roundtail Chub	Gila robusta	CRW	#20
Philometra cylindracea	Red Shiner	Notropis lutrensis	CRW	#20
Hirudean Parasites				
Leeches	Leeches are non-host specific; on all freshwater fishes.		Worldwide	Post, 1987
Crustacean Parasites			Worldwide in cool and warmwater environments	Post, 1987
Lernaea cyprinacea	A variety of freshwater fishes including: carp, shiners, and minnows.			
	Red Shiner	Notropis lutrensis	CRW	#20
	Flannelmouth Sucker	Catostomus latipinis		
	Roundtail Chub	Gila robusta		
	Bluehead Sucker	Catostomus discobolus		
Fish Lice				
Argulus sp.	Parasitic on bony fish both fresh and salt water.		Widely distributed in N. America, Europe and Asia. Found most often in cool and warm water environmens	Post, 1987

Colorado

At this time there are no regulations in Colorado regarding the import or export of warmwater fish species. It would be ideal to have a fish health certification on each lot of fish being transported (personal communication, Larry Harris, 1990).

New Mexico

At this time there are no standard regulations in New Mexico regarding import or export of warmwater fish species. Everything is checked before it goes to Dexter NFH, especially for Asian tapeworm. If a site specific disease is present then the lot of fish will be examined before transfer (personal communication, Jim Hutheson, 1990).

Utah

Utah is mainly concerned with the import of fish that may harbor pathogens. There are no established requirements as of yet. It is suggested that a disease history be created for all fish being transferred not just into or out of Utah, but throughout the Colorado River watershed. For the target species hatchery in Colorado, this would be achieved by sharing acquired information between Ron Goede, Utah Division of Wildlife; Dennis Anderson, Director of the USFWS fish health laboratory in Fort Morgan, CO; and Peter Walker, USFWS Fish Health Specialist at Colorado State Fish Health Laboratory in Brush, CO (personal communication, Ron Goede, 1990).

USFWS

A Federal Fish and Wildlife Permit Application 3200 is required to collect and transport wild or cultured fish in the United States. This is an application for a blanket permit that covers all aspects of capture and transport on a case by case basis. The application may be obtained from a field office. Once the application is complete it is submitted to the field office, reviewed, stamped, and sent to the regional office where the actual permit is issued. Captive fish transferred from one USFWS facility to another may not require a permit if disease history is adequately known (personal communication, Max Schroeder, 1990). A USFWS permit is also required to propagate endangered fishes and may be required to stock them.

3.5.7 Disease Control

The most important factor in maintaining healthy stocks of fish is the implementation of good management and cultural techniques. This section on disease control describes basic management techniques that can reduce the incidence and spread of a disease or its pathogen, regarding water supply development, hatchery design or operations, and transfer of fish to and from the facility.

Water Supply

Groundwater generally is the best water source for hatcheries, particularly for intensive culture. Its flow is reliable, temperature stable, and is relatively free of pollutants and diseases. In areas that have highly porous soils and shallow water tables, there have been complications with pathogens being carried down through the bottom of earthen ponds and then being recycled up to the surface via shallow wells, effectively spreading a disease throughout the facility. Groundwater wells may be highly saturated with gasses. Supersaturation of nitrogen gas in hatchery water has been demonstrated to cause gas-bubble disease in small fish. The supersaturated gasses come out of solution inside the fish and form small bubbles that block capillaries that can eventually lead to death. Mechanical aeration effectively reduces nitrogen gas levels and raises oxygen concentrations in water.

Most fish culture facilities use surface water for much or all of their culture programs. The main problem in using surface water in culture facilities is that cultured fish are exposed to all of the pathogens, as well as environmental and water quality fluctuations of the watershed. To decrease the incidence of diseases in young fish, which are usually more susceptible to disease than older fish, groundwater is usually provided for incubation and early-lifestage rearing. If incoming surface water is used it is recommended that the supply be treated to remove pathogens and reduce variations in water quality. Filtration followed by ultraviolet radiation is one method for sterilizing hatchery water. Chlorine gas or hypochlorites can be used as sterilants, but they are toxic to fish and must be neutralized. Ozone is a more powerful oxidizing agent than hypochlorite, but it is extremely corrosive and can be a human health hazard if equipment is not designed properly. Ozonated water must be reaerated before use in fish culture. Examples of Best Management Practices (BMP) and design features to help achieve optimum culture conditions are listed below:

- Hatchery water supply should be of a pathogen-free source. If the facility runs on surface water, it should be sterilized before entering the facility and groundwater should be used for incubation and early lifestage rearing.

- When possible all effluent from a facility entering another body of water should be treated to improve water quality to meet state discharge standards.

- Any heated or ground water supplies (especially for early lifestage use) should be monitored for gas saturation and constancy.

Hatchery Design Requirements

BMP are those which reduce stress and adverse health, environmental, or nutritional factors while maintaining genetics management objectives and scheduled production programs. Consideration of BMP during the design planning results in a more comprehensive, long-term program that promotes fish health. This section suggests some practical programs and design requirements to effectively reduce the spread of pathogens throughout and between fish culture facilities.

One of the most common avenues of disease transfer within a facility is cross-contamination by hatchery personnel in their use of everyday equipment. By designing specific disinfection stations for trucks and hand-tools (dip nets, seines, hoses, incubators, etc.), cross-contamination can be minimized. The design must also include appropriate disposal of disinfection baths.

- Before placing a new lot of eggs or fish in a rearing vessel that previously contained fish, the rearing vessel should be completely disinfected.

- All culture tanks should have separate cleaning tools (i.e., brushes, mortality nets) that are disinfected after every cleaning then be allowed to dry.

- All earthen ponds should be drained, completely dried, covered with lime and tilled under between use. Many parasites have resistant spore or cyst lifestages that can survive long periods without a host.

- All grading and transport equipment must be disinfected before and after handling each group of fish.

- Mortalities should be disposed of properly, away from culture ponds and predator access to eliminate the possibility of cross-contamination.

- Fish should be kept in discrete areas throughout the facility according to species and brood year. This also allows fish to be quarantined if necessary to meet health regulations and requirements.

- All fish or eggs brought on the facility should be quarantined for a predetermined amount of time. These facilities should have separate water supplies and discharges.

- All people moving between facilities should completely disinfect shoes, boots, raingear, etc. before entering another facility.

- There should be a disinfectant foot bath at each hatchery entrance and between all "wet" rooms.

The practices described in this section emphasize that prevention of diseases is tied to proper management, facility design, and personnel awareness. By identifying the diseases that the four target species are susceptible to, and carefully planning prevention and management programs for them, losses by disease should not be a major factor in future endangered species production programs.

3.6 OTHER FISH PRODUCTION CONCERNS

3.6.1 <u>Predation</u>

Cannibalism

Young Colorado squawfish will consume others their own size and smaller in the absence of sufficient food (Arizona DG&F, 1988). Tom Mandis (CDOW) reports culturing Colorado squawfish since 1989. During, the first year, no cannibalism was observed. In the second year, when the larger fish reached 2 to 2.5 inches in length, they started to cannibalize the smaller fish in the culture tank. No fin or eye pecking was observed. Cannibalism was also a problem at Dexter NFH when fish over two inches long were produced. Cannibalism was observed in 30 mm (1.2 inch) fish in raceways at Willow Beach NFH, but the lot had an 80% survival from fry to fingerling (Valentine, 1983). Cannibalism in the other targeted fish species has not been documented.

Sorting and grading fish may reduce size variation and crowding. This, coupled with providing adequate feed, should reduce or alleviate the incidence of cannibalism (personal communication, Larry Harris). Losses due to cannibalism can occur if fish remain in culture ponds or drainpipes after harvest. After harvest all ponds and water pipes should be drained to prevent fish from reentering the pond later (personal communication, Jerry Landye). Design of the facility should consider these drainage concerns.

Predation by Other Fishes

The four target species are preyed upon by many different fish species in the Colorado River watershed. Most of these are of non-native origin. The fish most likely to prey on Colorado squawfish are channel and flathead catfish, largemouth bass, Northern pike, adult redshiners, and green sunfish (Berry et al., 1985; Brooks, 1986b; Muth, 1990). It is probable that the predatory fish listed here also prey on the humpback chub, bonytail chub, and razorback sucker (Marsh, 1985b; Brooks, 1986a; Marsh and Langhorst, 1988; and Marsh and Brooks, 1989). Northern pike have been reported in large numbers in the Yampa River, near Craig, Colorado, and are suspected of targeting Colorado squawfish (personal communication, Joe Theaman, 1991).

Predatory fish can enter a fish culture facility through connections to outside water sources. Surface water facilities, receive their water supply from a lake or river which is very likely to contain predators that may consume the fish in culture. Facilities that receive their water directly from groundwater sources usually would not have resident fish in their water supply. It is common for both groundwater and surface water facilities to discharge effluent to surface waters. Water supply, effluent pipes and ditches are usually equipped with screens or other mechanical or physical barriers to exclude fish from the cultural facility. These barriers must be able to exclude even the smallest lifestages of predatory fish. Unwanted fish can enter a facility during small lifestages directly invading culture ponds or may remain in connecting pipes and ditches where they may later enter culture ponds at larger sizes. Escapement of fish from one culture pond to another can also lead to predation losses. The water supply, effluent connections between ponds are also screened to prevent the escapement of fish. Improper screen sizes can allow smaller fish in a population to escape from a pond. The four target fish demonstrate extremely variable growth rates; that is, there is much size variation in any population of these fish. Screens and barriers must exclude the smallest size of fish in the population while ensuring proper water flows.

After removing fish from a culture pond, water should be completely drained to ensure that no fish remain in the pond. Usually netting or other techniques of fish removal or harvest are not 100% effective and fish may remain in the pond, or if drainpipes are not completely emptied, fish could remain in supply or effluent pipes and could re-enter the pond when filled for a new brood of fish.

Predation by Birds

Wading and aquatic birds pose the largest predation problems in fish culture facilities for these species (personal communication, Roger Hamman and Jerry Landye, 1990). The most common predator problem mentioned in the Colorado River watershed is with the great blue heron. These birds can take up to an 8-10 inch fish. Other birds that are a problem are mergansers, cormorants, seagulls, grebes, and pelicans. To a lesser extent bullfrogs, and snakes have been known to prey on fish in culture facilities (personal communication, Roger Hamman and Jerry Landye, 1990). Great blue herons and to a larger extent cormorants are the predators of importance at the Ouray NFH. No control measures are taken because the facility is located in a National Park (personal communication, Harold Tyus, 1990).

3.6.2 Escapement

There are two aspects of escapement that are critically important to the design of the Upper Colorado River Endangered Species Hatchery. First, all fish must be kept at the facility until time of transfer into the wild or to other rearing stations. Second, fish (including eggs and larvae) must remain segregated into specific culture vessels until controlled movement by hatchery personnel. These two escapement aspects have high importance because of the endangered status of the four species to be cultured and because of the research focus of the facility. Stock, lot, and group segregation is required for experimental design adherence to insure reliable results and maintain genetic integrity of fish in the facility.

To minimize escapement from and within the new facility several site-specific, design and operational factors must be considered. Sites within floodplains should be avoided. flood events may wash out ponds or cause premature release resulting in partial or total loss of the program. If floodplain areas are to be considered for hatchery siting, design efforts must include maximal flood protection.

Internal hatchery escapement problems may be minimized by careful design of piping and screen systems. This is especially important in early lifestage culture due to the size of the species. Harris, et al. (1990) determined the Colorado squawfish fry escaped through a screen mesh of 16 squares/inch but were unable to escape through mosquito netting (30 squares/inch). Each fry rearing vessel should be screened accordingly and observed frequently to prevent mesh clogging and vessel overflow.

Ponds and other culture vessels must be drainable. No water should remain in the drained vessel or piping system below the inlet following draining to avoid stock, lot, or group mixing. In addition, pond outlets must be screened to prevent wild fish species such as catfish or bass from entering the facility. Uncontrolled entry of predatory fish may lead to significant production losses (Arizona DG&F, 1989).

3.6.3 Security

The proposed hatchery facility will raise and maintain endangered fish species which may be politically sensitive. A variety of methods will need to be employed to ensure the safety of these fish from human intervention. Maximum security measures may include fencing the entire facility to prevent intruders from tampering with ponds located away from the main hatchery building in addition to motion sensitive lighting and alarm systems located throughout the facility. As an added security measure onsite, the valves which control inflow and outflow of water in the ponds should be keyed to reduce tampering.

Housing for hatchery personnel on the site should be located along the entrance road to the facility. These buildings should be located strategically within the hatchery grounds to monitor visitors to the site.

The security of the water supply may be the most difficult to maintain. If the hatchery is supplied completely with well water, security of the water supply would be less of a problem. However, if surface water is used as the water supply, the entire watershed could be susceptible to contamination or sabotage. Methods utilized to promote security could include complete enclosure of the intake structure and pipes from the river and restricted river access (fencing) in the vicinity of the intake.

3.6.4 Genetic Monitoring

Genetic monitoring can occur at the population level and at the individual level. Monitoring the genetics of a population will involve electrophoresis, cytogenetics, and perhaps mitochondrial DNA analyses to determine if genetic strains or subpopulations of these species occur in the wild. For example, it is possible that six subpopulations of Colorado squawfish occur in the wild: Green, Colorado, Yampa, White, Gunnison, and San Juan rivers. If this is the case, these genetic strains need to be segregated during propagation to maintain their genetic identity and unique morphological and behavioral characteristics of each. Six possible genetic strains also exist for razorback suckers in the Green, Colorado, and Yampa rivers; at the Lake Powell inflow regions of the Colorado and San Juan rivers; and in the lower basin from Lake Mohave. As many as six subpopulations of humpback chub may occur: Little Colorado River, Black Rocks, Westwater Canyon, Yampa Canyon, Desolation/Gray Canyon, and Cataract Canyon. The only genetic strain of bonytail is from Lake Mohave. It is estimated that there may be as many as 19 different genetic strains or subpopulations of the four Colorado River endangered fish, combined (Valdez, 1991).

Individual genetic monitoring means tracking and uniquely identifying the progeny of a given female in order to identify and maximize genetic diversity during future reproductive efforts and releases to the wild. The danger with highly-fecund species, such as Colorado squawfish and razorback suckers, is that it is possible to attain several hundred thousand eggs from a single female to support the needs of a given stocking. If the receiving waters are devoid of wild fish, this leaves a minimum of genetic diversity since all the progeny and potential spawners are from one female.

Maintaining segregation of genetic strains or subpopulations is vital to a propagation facility of this nature. This applies not only to the wild fish but to their progeny as well. Fish larger than 150 mm can be individually marked with PIT tags in order to identify parental source and can potentially be held with other strains. However, if the broodstock of each strain numbers 1,000 fish, sorting by strain during spawning could be problematic and cause unnecessary stress on the fish. Thus, it will be necessary to accommodate segregation of broodstock by genetic strain as well as segregation of progeny by parental stock. This could mean large numbers of small ponds or large circular troughs.

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SECTION 4.0

SITE IDENTIFICATION AND INITIAL SCREENING

4.1 INTRODUCTION

The objectives of this task were to identify hatchery sites within the State of Colorado that were potentially feasible to meet the needs of the proposed endangered species hatchery, to develop site selection criteria as a basis to review these sites, and to conduct an initial screening of the hatchery sites. This section summarizes the methodology and results of the site identification and initial screening process. The highest rated sites from this initial screening process were carried forward to a second phase screening process, which is described in Section 5.

4.1.1 Background

As background to development of this feasibility study task, it was anticipated at the beginning of the study that development of the facility design criteria would be completed and used in the site selection process and the initial screening of the potential hatchery sites. However, as work on the design criteria developed, it became apparent to the Technical Advisory Committee (TAC) and the consultant team that there were too many site and design variables to establish final design criteria prior to identifying the type of sites and resources available within the State of Colorado. Development of final design criteria was delayed until site information was obtained for each of the proposed sites. As a result, the initial site screening described herein was based upon generalized hatchery design criteria and site requirements.

4.1.2 Methodology

The methodology used to conduct the site identification and screening process were:

1. Development of the initial list of sites to be included in the hatchery feasibility study,

2. Selection of site screening criteria,

3. Collection of data for each of the proposed sites, and,

4. Evaluation and screening of proposed sites with a recommendation for those sites to be further evaluated during phase two of the evaluation and screening process.

4.2 SITE IDENTIFICATION

The identification of the potential sites to be evaluated during the study was made by the TAC, in consultation with other members of the CDOW and U.S. Fish and Wildlife Service staff and the consultant team. The proposed sites were selected, in part, based upon:

- The presence of an existing state, federal or private hatchery which could be converted, expanded, or rebuilt into an endangered species hatchery.
- The availability and quality of a water supply for hatchery processes.
- The availability of land for hatchery construction.

When the study scope of work was initially developed, it was anticipated that approximately 19 to 25 sites, located throughout the State, would be identified as potential hatchery sites and selected for evaluation during the initial screening study task. However, as the TAC members developed the list of potential sites, additional sites continued to be identified by state and federal agencies and municipalities. At the end of the identification process, the list of study sites totaled 33. These sites are listed on Table 4.1.

An additional 15 sites were initially identified for consideration, but were not selected by the TAC to be included on the list of study sites. These fifteen sites, shown on Table 4.2, were not selected for one of the following reasons:

1. The site location was not a specific parcel of property,
2. The site owners were was not interested in their property being considered, or,
3. There were anticipated issues related to water rights or property ownership/acquisition which were identified as probable fatal flaws.

TABLE 4.1

STUDY SITE LIST
ORIGINAL SITES INCLUDED IN HATCHERY FEASIBILITY STUDY

1. Glenwood Desalinization Facility (near Glenwood Springs, CO)
2. CC Craig Ranch (near Craig, CO)
3. CO-Ute Plant/CIRG Site (near Craig, CO)
4. Hayden Power Plant (near Hayden, CO)
5. Ross Ranch (near Hotchkiss, CO)
6. Rifle Falls SFH (near Rifle, CO)
7. Hotchkiss NFH (Hotchkiss, CO)
8. Clines Fish Hatchery (Monte Vista, CO)
9. Putnam Fish Hatchery (Durango, CO)
10. Silver Springs Trout Farm (Montrose, CO)
11. McMillan's Trout Farm (Hotchkiss, CO)
12. Steele Ranch (near Maybell, CO)
13. Cameo Power Generation Station (DeBeque Canyon near Grand Junction, CO)
14. Water Users Association #1 (near Rangley, CO)
15. Crystal Properties (near Hooper, CO)
16. Horsethief Site (near Grand Junction, CO)
17. Hereford Haven (Maybell, CO)
18. Walter Walker State Wildlife Area (Grand Junction, CO)
19. DeBeque Gravel Pit (Grand Junction, CO)
20. Etter Pond (Grand Junction, CO)
21. Una Pond (near Parachute, CO)
22. Humphrey's Pond (Grand Junction, CO)
23. Range View Trout Ranch (Saguache, CO)
24. Crystal Springs Ranch and Trout Farm (near Hotchkiss, CO)
25. Russell Lake SWA (Saguache, CO)
26. Closed Basin Project (near San Luis Lake, CO)
27. Moffet County Fair Grounds (near Craig, CO)
28. New Wastewater Treatment Plant (Craig, CO)
29. Old Wastewater Treatment Plant (Craig, CO)
30. Water Treatment Plant (Craig, CO)
31. Colorado Highway #394 Site (Craig, CO)
32. Grand Junction Site #1, Summerville Ranch, CO
33. Grand Junction Site #2, River Front Site

TABLE 4.2

SITES NOT INCLUDED IN THE HATCHERY FEASIBILITY STUDY

1. Grand Junction, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list.

2. Craig, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list.

3. Glenwood Springs, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list.

4. Durango, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list.

5. San Luis Valley, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list.

6. Juniper-Cross Mtn. Ranch, near Maybell, CO

   No water rights are associated with this property.

Table 4.2 (con't)

7. Brown's Park SWA (Northwest CO)

   No water rights are associated with this property and the majority of the area is in Utah.

8. Finger Rock, CO Area

   An existing hatchery has a cold water supply. Geothermal water does exist on an adjacent ranch however the availability of this warm water is questionable.

9. Meeker, CO Area

   This is a generalized area in which no specific sites were included on the preliminary site list. No geothermal water resources identified.

10. Pagosa Springs, CO Area

    This is a generalized area in which no specific sites were included on the preliminary site list. The only geothermal resources available are very small ($\approx$ 1 cfs) and are located within the town.

11. Kerr Site

    Potential problem with water rights. Water rights for this site were adjudicated for irrigation purposes. Water is currently being used to raise fish, but refining the water rights is deemed problematic.

12. Wildcat Canyon Site

    CDOW personnel indicated that this site is a private, small hatchery operation which raises trout. It was determined that the water is too cold and would not meet the needs of the proposed endangered fishes hatchery facility.

Table 4.2 (con't)

13. Buena Vista Site

    The CDOW has stated this facility is specifically geared for trout.

14. Chalk Cliff Site

    The CDOW has stated this facility is specifically geared for trout.

15. Radium State Wildlife Area

    This site is high up in the drainage, with poor access, according to CDOW officials, and would therefore not be a feasible location for the proposed hatchery.

4.3 SCREENING CRITERIA

The evaluation and screening of potential sites was based upon technical issues related to biological, technical, and engineering design concerns. Evaluation of economic, social, philosophical and political issues related to the propagation and augmentation of endangered fish populations were beyond the scope of this study.

The initial site screening criteria were developed based upon information from the review of available literature and existing propagation facilities, a review of culture techniques, and the biological and hatchery design experience of the TAC and consultant team. The site screening criteria developed for this initial screening was used as a base and was expanded and refined during the later phases of the feasibility study process.

4.3.1 Site Selection Criteria

The site screening criteria were developed around six major categories: water source, water quality, site physical characteristics, biological considerations, location factors and cost. The basic criteria are described below and are shown on Table 4.3, located at the end of this section.

Water Source

The source of water supply for hatchery operations is classified as either surface water or groundwater, and by the volume of water which is available on a reliable basis. The study team considered groundwater a preferred water source because it is free of fish diseases which are prevalent in surface water. As stated in Section 3, control of diseases is extremely important in culture facilities, especially for a facility designed for endangered species where the loss of fish is especially significant. Groundwater also provides a relatively constant temperature water supply and is generally of higher quality than surface water. A benefit of a surface water supply is that it is a more genetically compatible water supply, and more closely resembles natural conditions than does groundwater.

Water Quality

The water quality parameters used for site screening criteria include: water temperature, water chemistry and the potential for contamination of the supply. Temperature is important because various life stages of the endangered fish require a certain range of water temperature to survive and propagate. Temperature is also a significant because the growth rate of fish is highly dependent on temperature, which in turn impacts the design, operation and cost of the hatchery. Water temperature also impacts the health of the fish and fish mortality. Warm water is generally considered a preferred hatchery water supply source. Water chemistry parameters such as total dissolved solids, pH, ammonia and metals can also impact fish growth rates and fish mortality. Water chemistry parameters were used in the site screening process based on data supplied by the site representatives. More detailed site specific water quality data should be evaluated before the final site selection is made.

Site Physical Factors

The site physical factors or site characteristics used as screening criteria include: land area; land availability; property ownership - either private, state or federal; site accessibility - whether it is accessible for anticipated vehicle use with reasonable improvements; suitability of the site for construction of a hatchery - whether the topography is amenable for a reasonable layout of ponds, buildings and process hydraulics; geologic stability of the site - whether the site is susceptible to landslides, snow slides, settlement, expansive soils or flooding; and whether existing buildings or facilities present on the property are advantageous or disadvantageous to the proposed use as a hatchery site.

Biological Considerations

Site biological considerations used for site screening criteria include: the proximity of the site to the endangered species native habitat; the potential for fish to escape from the facility and what the ramifications of an escape would be; and the potential for predation by wildlife, especially birds.

Locational Factors

Locational factors used for site screening criteria include: the availability of utilities to serve the site; community services anticipated ability to provide necessary supplies for the hatchery and workers; the site proximity to educational centers and ability to provide public education on the endangered species; and site proximity research centers which could provide support services to the hatchery operation.

Probable Cost

The probable cost of hatchery facility used for site screening includes the cost to construct, operate and maintain a hatchery facility.

4.4 DATA COLLECTION

4.4.1 Data Sheet Development and Distribution and Results

Information used to conduct the initial site screening was based upon information provided by the owner or site representative for the site, and the knowledge of the study team. The site representative was requested to complete a site information form and return it to the consultant team for review. The form was designed to obtain information which would be required to apply the site selection criteria described previously. A sample form is included in Appendix E. Information obtained from the completed information form is summarized in Table 4.4.

4.5 SITE SCREENING

The purpose of the initial site screening was to evaluate the 33 proposed sites according to the site selection criteria and recommend approximately 10 sites for further evaluation as potential fish hatchery sites. The evaluation and screening of the sites was conducted jointly by the TAC and the consultant team. Information from the site data sheets, and the study team's knowledge of the sites were used to evaluate each site against the screening criteria. Based on this evaluation, the TAC developed a list of the 16 most favorable sites which warranted further evaluation during the final screening process. These 16 sites are listed in Table 4.5. The sites are listed in the order of previously assigned site numbers. The order does not represent any relative ranking of the sites. Table 4.6 lists those sites which are considered less favorable and are no longer under consideration as a potential hatchery site.

TABLE 4.3
SITE SELECTION CRITERIA

A. Water Source (availability, reliability)
   - **Groundwater**
   - Up to 500 gpm
   - 500 - 1,500 gpm
   - Above 1,500 gpm
   - **Surface Water**
   - Up to 500 gpm
   - 500 - 1,500
   - Above 1,500 gpm

B. Water Quality
   - Temperature
   - Chemical Parameters
   - Effluent Water Treatment Requirements

C. Site - Physical Factors
   - Land Area (size, ownership, availability, accessibility)
   - Use of Existing Facilities
   - Design and Construction Requirements
   - Geologic Factors

D. Biological Considerations
   - Proximity to Habitat
   - Escapement
   - Predation
   - Multiple Uses of Facilities/ Flexibility

E. Locational Factors
   - Utilities Availability
   - Community Services
   - Public Information and Education Opportunities
   - Climatic Factors

F. Probable Cost
   - Construction
   - Operation and Maintenance

In addition to the above screening factors, a site could receive a fatal flow for a given screening criterion. For example, a fatal flaw would be assigned if the land area of a site is too small to construct the proposed facility. This would cause the site to be dropped from further consideration.

TABLE 4.4
DATA SHEET SUMMARY

SITE NO.	SITE NAME	WATER SOURCE(S)	SOURCE TYPE	FLOW RATE (gpm)	TEMP WINTER (F)	TEMP SUMMER (F)	AVE TDS (PPM)	pH	WATER SOURCE NAME	DISCHARGE POINT	SALE/ LEASE/ DONATE	SITE AREA (AC)	ADJ AREA Y/N	TOPO G/N/P	ACCESS G/N/P	FLOOD PLAIN Y/N	ELEV	GEOL HAZARD Y/N	SUN Y/N	SEN HAB Y/N	UTILITY AVAIL W S E G
1	Glenwood Desalination		G	1388	160	160	3	7.00	SPRING	COLORADO		20	Y	G	G	N	6400	N	Y	N	W S E G
2	CC Craig Ranch																				
3	Co-Ute Plant/CIRG Site		S	162				8.00	YAMPA	YAMPA	L	10	Y	G	G	N	6400	N	Y	N	W S E G
4	Hayden Power Plant																				
5	Ross Ranch	1	G	17	100	100	3500	7.00			L	300		N	G	Y	5420	N	Y	Y	W S E G
5	Ross Ranch	2	S	3590		56			DITCH												
5	Ross Ranch	3	S	1346		59															
6	Rifle Falls SFH	1	G	6283	56	59	530	7.2	SPRING			700	N		G	Y	6750	Y	N	Y	W S E G
6	Rifle Falls SFH	2	S	9874	50	60	530	8.3	E RIFLE CR												
6	Rifle Falls SFH	3	G	224	52	54	600	7	SPRING												
7	Hotchkiss NFH			2800	56	56	690	7.80	SPRING		N	58.5	Y	G	G		5212		Y	N	E
8	Cline Fish Hatchery	1	G	1820	70	70	49				S/L	6+	Y	G	G	N	7500	N	Y	N	W S E
8	Cline Fish Hatchery	2	G	509	50	50	274														
8	Cline Fish Hatchery	3		579	50	50	274														
9	Putnam Fish Hatchery	1	G	673	48	58		9.00	LYMAN SPRING		Y	13	Y	N	G	N	6200	Y	Y	Y	W S E
9	Putnam Fish Hatchery	2	G	1122	48	58		9.00	LYMAN SPRING		Y	33									W S E G
10	Silver Springs Trout Farm	1	G	1000	50	63	350	7.30	SPRING		Y	36			G	N	5650	N	Y	N	W S E G
10	Silver Springs Trout Farm	2	G	400	54	54	350	7.00													
11	McMillan Trout Farm	1	S&G	583	40	60		7.00			Y	43	Y	P	N	Y	5300	N	Y	Y	W S E
11	McMillan Trout Farm	2	G	2244	40	60		7.00													
12	Steele Ranch																				
13	Cameo Power Plant	1	S	30000	50	71	790	8.00	CANAL						N	N	4780	N	Y	N	W E G
13	Cameo Power Plant	2	S		72	86	708	8.00													
14	Water Users Assoc #1		S	1000	34	72	600	8.40	HITE R, KENNEY		L	14	Y	G	G	Y	5213	N	Y	N	W S E G
15	Crystal Properties Site																				
16	Horsethief Site											1000		G	G		4550				
17	Hereford Haven										Y			G		Y	6300			Y	E
18	Walter Walker State													N			4510	N	Y	Y	
19	DeBeque Gravel Pit																				
20	Etter Pond											19									
21	Una Pond																				
22	Humphrey's Pond																				
23	Range View Trout Farm		G	1200	58	58		8.5	WELL		Y	80	Y	G	G	N	7800	N	Y	N	W S E G
24	J. Stroh (Crystal Sprgs R & TF)	1	G	2000	57	57		8	SPRING		Y	20	Y	N	N	Y	5250	Y	Y	N	E
24	J. Stroh (Crystal Sprgs R & TF)	2	S	1795		55			CANAL												
25	Russell Lake SWA																				
26	Closed Basin Hatchery																				
27	Moffat County Fairgrounds		S	0	34	70		8.00	WELL			1	N	G	G	Y	6189.2	N	Y	N	W S E G
28	New Wastewater Treatment		S	20196	34	67	436	7.90	YAMPA		D	5	Y	N	G	Y	6171	N	Y	N	W S E G
29	Old Wastewater Treatment		S	20196	34	67	436	7.90	YAMPA		D	40	Y		G	Y	6175	N	Y	N	W S E G
30	Water Plant	1	G	300	70	70	664	8.97	YAMPA		D	5	Y	G	G	Y	6174	N	Y	N	W S E G
30	Water Plant	2	S	20196	34	67	436	7.90	WELL		D										
31	Colorado Highway #394		S	20196	34	67	436	7.90	YAMPA		D	10	Y		G	Y	6181	N	Y	N	
32	Grand Junction																				
33	Grand Junction																				

Note: Summary of key data collected from the initial screening.

TABLE 4.5

FINAL SCREENING SITE LIST

6-5-91

1. Glenwood Desalinization Facility (near Glenwood Springs, CO)
3. CO-Ute Plant/CIRG Site (near Craig, CO)
6. Rifle Falls SFH (near Rifle, CO)
8. Clines Fish Hatchery (Monte Vista, CO)
9. Putnam Fish Hatchery (Durango, CO)
10. Silver Springs Trout Farm (Montrose, CO)
11. McMillan's Trout Farm (Hotchkiss, CO)
15. Crystal Properties (near Hooper, CO)
16. Horsethief Site (near Grand Junction, CO)
18. Walter Walker State Wildlife Area (Grand Junction, CO)
23. Rangeview Trout Ranch (Saguache, CO)
24. Crystal Springs Ranch and Trout Farm (near Hotchkiss, CO)
25. Russell Lakes SWA (Saguache, CO)
26. Closed Basin Project (near San Luis Lake, CO)
29. Wastewater Treatment Plant (near Craig, CO)
32. Grand Junction Site #1 (Summerville Ranch, CO)

TABLE 4.6

DELETED SITE LIST

6-5-91

2. CC Craig Ranch (near Craig, CO)

   No data. Appears that this site is not available and the warm water supply is owned by a second party.

4. Hayden Power Plant (near Hayden, CO)

   The site contact was interviewed by phone and did not return the data form due to the bankruptcy action of Colorado-Ute and lack of manpower. The contact suggested that the Co-Ute Plant/CIRG site was a better site for the proposed hatchery.

5. Ross Ranch (near Hotchkiss, CO)

   The hot water supply is rated at approximately 15 to 20 gpm and has shown evidence of periodic oil and gas contamination. There are no other associated ground water supplies for this site.

7. Hotchkiss NFH (Hotchkiss, CO)

   This hatchery is reserved for trout production.

12. Steele Ranch (near Maybell, CO)

    This site is no longer available for consideration.

13. Cameo Power Generation Station (DeBeque Canyon near Grand Junction, CO)

    The power generation plant may be out of service for extended periods of time at unscheduled intervals. This type of operation is not compatible with the operation of the hatchery. Public Service Company did not express interest in the hatchery project at the time of the study.

14. Water Users Association #1 (near Kenney Reservoir)

    The site water source is surface water.

17. Hereford Haven (Maybell, CO)

    This site was originally proposed as a hatchery site by the CDOW but was deleted due to proposed use of the site bird hunting.

19. DeBeque Gravel Pit (Grand Junction, CO)

    There was little information available on this site. The site is an old gravel pit which has filled with water and appears to be better suited for a potential refuge than a hatchery site.

20. Etter Pond (Grand Junction, CO)

    There was little information available on this site. The site is an old gravel pit which has filled with water and appears to be better suited for a potential refuge than a hatchery site.

21. Una Pond (near Parachute, CO)

    There was little information available on this site. The site is an old gravel pit which has filled with water and appears to be better suited for a potential refuge than a hatchery site.

22. Humphrey's Pond (Grand Junction, CO)

    There was little information available on this site. The site is an old gravel pit which has filled with water and appears to be better suited for a potential refuge than a hatchery site.

27. Moffat County Fair Grounds (Craig, CO)

    The area of this site is one acre, which is not considered adequate for the proposed hatchery.

28. New Wastewater Treatment Plant (Craig, CO)

    The area of this site is five acres, which is not considered to be adequate for the proposed hatchery. In addition, site 29 - Old Wastewater Treatment Plant site appears to be a more preferable site in the Craig area.

30. Water Treatment Plant (Craig, CO)

The area of this site is five acres, which is not considered to be adequate for the proposed hatchery. In addition, site 29 - Old Wastewater Treatment Plant site appears to be the most preferable site in the area.

31. Colorado Highway #394 (Craig, CO)

The area of this site is ten acres, which is not considered to be adequate for the proposed hatchery. In addition, site 29 - Old Wastewater Treatment Plant site appears to be the most preferable site in the area.

33. Grand Junction Site #2 Riverfront Site (Grand Junction, CO)

The water source for the site is surface water and municipally treated water. Land area and configuration is not compatible with the requirements of the proposed hatchery.

SECTION 5.0

SITE EVALUATION AND FINAL SCREENING

5.1 INTRODUCTION

The objective of this task was to further evaluate the 16 potential hatchery sites selected in the initial site screening and determine the three highest rated sites through a final screening process. The 16 sites included in the final screening process are listed in Table 5.1. This section summarizes the methodology used to conduct the final evaluation and final screening process.

5.1.1 Methodology

The methodology used to evaluate and screen the 16 potential hatchery sites is as follows:

1. Conduct a site inspection of each potential site to confirm and supplement information gathered during the initial site screening process,

2. Develop more detailed technical site evaluation criteria. These criteria were developed by the Technical Advisory Committee (TAC) and the consultant team for each of the categories identified during the initial screening (water supply, water temperature and water quality, site physical factors, biological considerations, site location factors, and estimated construction and operation costs),

3. Develop a system to evaluate and rate each of the potential sites against the revised technical criteria, and,

4. Rank the sites to identify the three highest ranking sites

5.2 POTENTIAL HATCHERY SITES

5.2.1 Sites for Final Screening

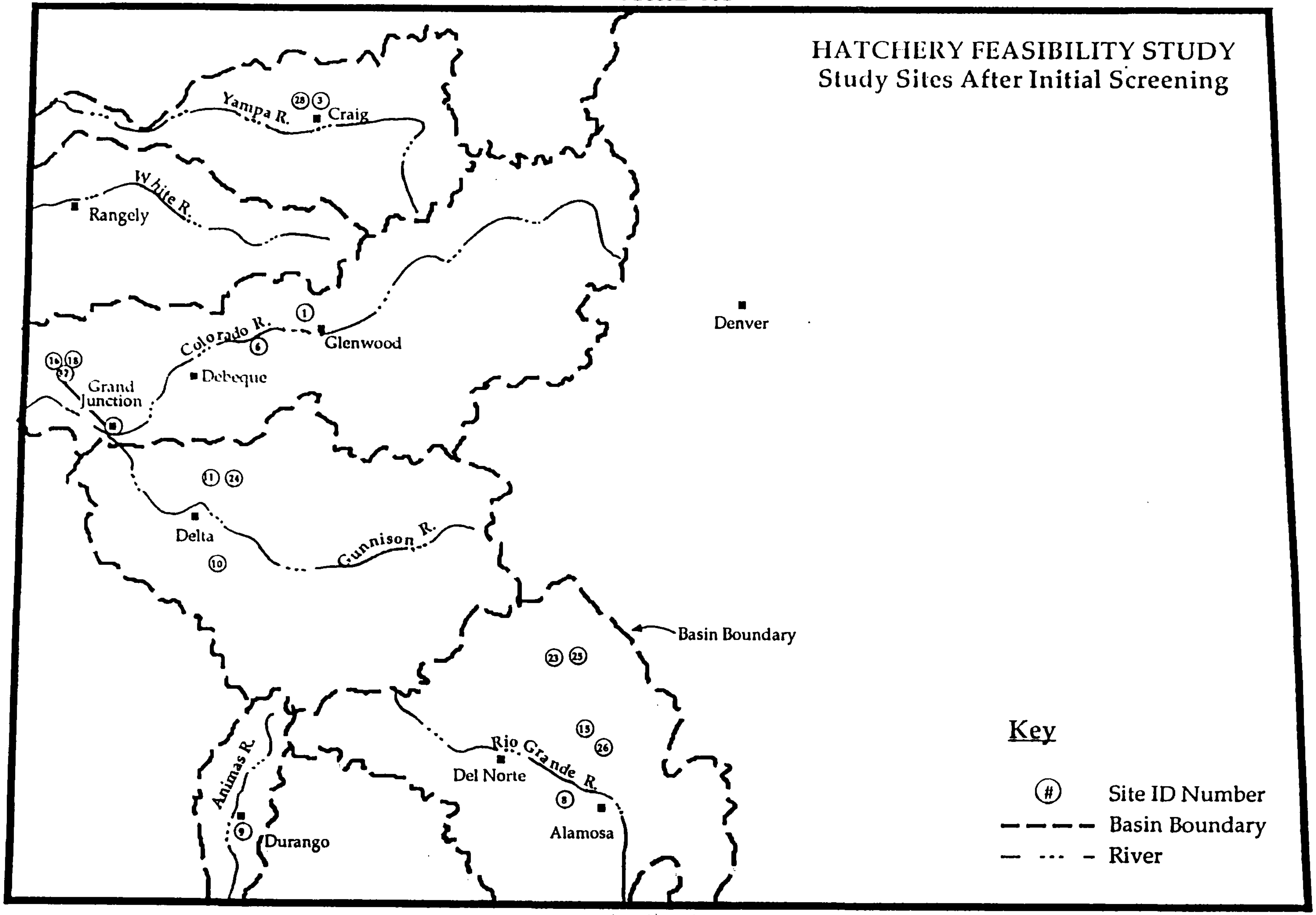
The 16 highest ranking sites determined by the initial screening task are listed in Table 5.1 and described in Appendix F. Figure 5.1 - Site Location Map, illustrates the location of each of the sites in the State of Colorado.

TABLE 5.1

FINAL SCREENING SITE LIST

1. Glenwood Desalinization Facility (near Glenwood Springs, CO)
3. CO-Ute Plant/CIRG Site (near Craig, CO)
6. Rifle Falls SFH (near Rifle, CO)
8. Clines Fish Hatchery (Monte Vista, CO)
9. Putnam Fish Hatchery (Durango, CO)
10. Silver Springs Trout Farm (Montrose, CO)
11. McMillan's Trout Farm (Hotchkiss, CO)
15. Crystal Properties (near Hooper, CO)
16. Horsethief Site (near Grand Junction, CO)
18. Walter Walker State Wildlife Area (near Grand Junction, CO)
23. Rangeview Trout Ranch (Saguache, CO)
24. Crystal Springs Hatchery (near Hotchkiss, CO)
25. Russell Lakes SWA (Saguache, CO)
26. Closed Basin Project (near San Luis Lake, CO)
28. New Wastewater Treatment Plant (near Craig, CO)
32. Grand Junction Site #1 (Summerville Ranch, CO)

FIGURE 5.1



Colorado

5.2.2 Site Data Collection

Each site was visited as the initial step in expanding available information. In June, 1991, representatives of the TAC, CWCB, CDOW, USFWS, and consultant team members: URS Consultants, Inc. and Fish Pro, Inc. visited each site. The visit included a general inspection of the site, inspection of the hatchery water supply, verification of the existing database and general discussion with the site representative. Hatchery operational issues were discussed at those sites with operating hatcheries. This helped the inspection team understand the existing hatchery operations, and characteristics of their water supply, etc. Specific topics addressed during the site visits included:

- Confirmation of the type and characteristics of the water supply source.

- Review of the overall site area, topography, geology, access and the impact of each on the hatchery design, construction and operation.

- Identification of the type and condition of existing hatchery facilities or buildings on the site, in order to determine the benefit or cost of these facilities or buildings to the project.

During the final screening task, study consultant team member Leonard Rice Consulting Water Engineers (LRCWE) conducted an analysis of the water supply at each of the sites. This investigation included an assessment of the physical availability and reliability of the water supply, a review of the legal availability of the water supply, estimates of water quality parameters and estimates of supply rates and volumes. The potential for development of warm water supplies, if not already existing, was also evaluated.

5.3 SELECTION CRITERIA

The TAC and consultant team revised the site screening criteria used in the initial screening to more fully evaluate and compare each of the 16 sites during the final screening process. The basic categories for site evaluation criteria (water source, water quality, site physical factors, biological considerations, location factors and probable cost) used in the initial site screening process were maintained, however for the final site screening, each criterion was subdivided and described in greater detail. The refined definition of the criteria allowed the study team to develop a detailed point system to evaluate the sites against the criteria. Key guidelines used in developing the point system were:

- The maximum possible point total for a given site was 100;
- The major criteria categories (e.g. water source, water quality, etc.) were weighted based on the relative significance of the category to the selection process. The points for each category were also set so that there is a maximum number of points which could be assigned to any criteria category and criterion. This maximum value for a given criterion was established so that no site could receive an inordinate number of points for a given criterion category and no single criterion could inordinately sway the total score for a site.
- Certain criterion could receive a fatal flaw rating if a site condition was determined to be not acceptable. Sites which received any fatal flaw were dropped from further consideration.

Each of the criterion used for the site evaluation is described below.

Water Source

Potential water sources for the proposed hatchery are either ground water or surface water. It was determined by the study team that the source of water for the hatchery facility was the single-most important criteria to evaluate the hatchery sites. The maximum points a site received for water source was 25 points, or 25 percent of the maximum possible site score of 100 points.

Points for water source were divided into subcategories consisting of: groundwater source, surface water source and water reliability.

Groundwater - To be considered a groundwater source, the water supply source must be beyond the immediate influence of surface waters. Groundwater sources were considered by the study team to be a superior to surface water because groundwater is generally free of the waterborne diseases associated with a surface water supply. Use of groundwater also provides protection from unwanted fish entering the facility. Points for a groundwater source ranged from 0 to 20 points, assigned by flow rate as follows:

Flow Rate (gpm)	Points	Flow Rate (gpm)	Points	Flow Rate (gpm)	Points
2400	20	1300	13	350	6
2250	19	1100	12	300	5
2100	18	900	11	250	4
1950	17	700	10	200	3
1800	16	500	9	150	2
1650	15	450	8	100	1
1500	14	400	7	50	0

Surface Water - Surface water sources were defined as streams, rivers or canals. Surface water sources were not as highly scored as groundwater sources because of the high potential for diseases to be present in surface water and the corresponding requirement to provide treatment before use. Points for a surface water source ranged from 0 to 10 points, assigned by flow rate as follows:

Flowrate (gpm)	Points	Flowrate (gpm)	Points
2400	10	835	4
2175	9	500	3
1950	8	375	2
1725	7	250	1
1500	6	125	0
1165	5		

Water Reliability - The water reliability rating was used to modify the score obtained for the water supply based upon the ability of the water supply source to provide a reliable quantity and quality of water. Water reliability factors and associated point values were assigned based on the following evaluation categories:

Water Reliability Category	Points
• Sites which lack multiple sources of water supply	- 2
• Physical dependability of the water supply flowrate is questionable	- 2
• Potential for legal problems in the water supply acquisition	- 2
• Water supply is not reliable. (A water supply received a fatal flaw if the water was supplied and controlled by an outside industry. The hatchery operation would be dependant on the industry operation.)	FF

Water Quality

The quality of the water supply is critical to the successful operation of the hatchery. Water quality impacts fish growth rate, fish health and mortality. The overall maximum point rating for the water quality category was 20 points. Water quality evaluation parameters and points associated with each are described below.

Temperature - The temperature of the water supply was considered to be significant because of the degree to which water temperature has an impact on the growth rate and health of the endangered fishes. Water temperature was assigned one-half of the total possible points for the water quality category. Possible points for temperature ranged from 0 to 10 points, assigned by temperature as follows:

Temperature	Points	Temperature	Points
74	10	67	5
72	9	65	4
70	8	61	3
69	7	57	2
68	6	53	1
		below 53	0

Total Dissolved Solids - Total Dissolved Solids (TDS) were selected as a water quality parameter because the endangered fishes have a preference range of TDS (Pimentel and Buckley, 1983) and there are TDS levels which should be avoided. Actual reported TDS values were used for scoring when data was available. If data was not available, TDS was estimated based upon similar water sources. Points values for TDS ranged from 0 to 4 points, assigned as follows:

TDS Value	Points
2101-4100 ppm	4
1101-2100	3
501-1100	2
301- 500	1
0- 300	0

pH - Water pH data submitted by the site representative was used when available. pH was estimated for sites where no data was provided. Point values for pH ranged from 0 to 4 points and were assigned as follows:

pH	Points
7.2 to 8.2	3 - 4
below 7.2	0 - 2
above 8.2	0 - 2

Potential for Contamination - The Potential for Contamination rating was used to modify the score for a water supply based upon the potential for the supply to become contaminated. Point values ranged from 0 to -3, including a fatal flaw rating, assigned as follows:

Surface water supply - where any contamination would likely be short-lived	0
Deep groundwater source - where the supply would be difficult to clean if contaminated	-1
Shallow groundwater source or groundwater source which is directly influenced by surface water.	-3

Effluent Treatment Needs - This rating addressed the relative level of hatchery effluent treatment which would likely be required prior to discharge. Effluent discharge to surface water was assigned 0 points. Effluent discharge to other then surface water was assigned 1 point.

Site Physical Characteristics

A number of factors were evaluated which were related to the physical site. These physical site characteristics included: Site area, land availability, type of access to the site, geologic stability and site elevation. Descriptions and point assignments for each are described below.

Land Area - Points for land area were assigned according to the reported acreage associated with the property. If adjacent land was necessary to construct the facility and the land appeared to be available, additional points were assigned.

Land Area (acres)	Points
above 45	5
40 - 45	4
30 - 40	3
15 - 30	2
below 15 with no potentially available adjacent land	FF

Land Availability - Points for land availability were assigned to indicate the anticipated effect of property acquisition. Land which would be donated or was State or Federally owned was assigned 3 points. Land which would likely be available through a normal fee simple acquisition process was assigned 2 points. Land which would be leased or which was shared was assigned 1 point. A Fatal Flaw was assigned for this factor if the available land area was determined to be inadequate.

Land Accessibility/Useability - Based upon field reconnaissance of the site, a determination was made on the relative ability to access the site and the ease of modifying the site to fit the needs of the hatchery. Between 0 and 2 points were assigned, including the option for a Fatal Flaw.

Existing Facilities - Based upon the site inspection, a determination was made as to whether existing facilities represented a benefit or a cost in converting the site for use as an endangered fishes hatchery. Between 0 and 2 points were assigned for this factor.

Design/Construction - Based upon the site inspection, a general determination was made of the relative impact the site topography and layout would have on the level of design and cost of construction of the hatchery. Between 0 and 2 points were assigned for this factor.

Geologic Factors - Based upon the site inspection, a determination was made as to the relative geologic stability of the site. Factors considered included the potential for slope instability, flooding, and erosion. Between 0 and 2 points were assigned for this factor, including the Fatal Flaw option.

Elevation - The elevation of the site has an impact on equipment, oxygen transfer, heating and cooling requirements and climate at the site. Points for this factor were assigned as follows:

Elevation (ft.)	Points
below 4000	4
4000 - 5000	3
above 5000	2

Biological Considerations

Three evaluation factors with a maximum potential point value of 15 points were categorized as biological considerations. These included: site proximity to native fish habitat, potential for harm due to escapement and potential harm due to predation.

Habitat Proximity to Native Habitat - Sites located within the native river basin for these fishes were given preference over sites outside the basin. Sites located within the basin were assigned 3 points. Sites located outside the basin received 0 points.

Escapement - This factor considered the loss of fish or eggs from the proposed hatchery to surface waters. A worst case scenario would be release of eggs or fish to waters not native to the species or species genetic strain. Such a release could result in hybridization. Points for this factor range between 0 and 5 where 5 points were assigned if there was no possibility for escapement and 0 points were assigned if there is significant threat of escapement to non-native waters.

Predation - This factor considered the loss and/or damage to fish due to predation. Point values for this factor ranged between 0 and 5 and were assigned based upon the site location and anticipated predation problems. Where a facility would be enclosed, with no threat of predation, 5 points were be assigned. If the site is not covered and is located near a bird refuge, 0 points were assigned.

Locational Factors

Five evaluation factors with a maximum potential point value of 10 points were categorized as locational factors. These factors addressed power and gas availability, proximity to service industries, educational opportunities and climate. Actual costs or plans for these services were not developed for this level of study, rather, the points represent a relative rating between the sites.

Power - This factor considered the proximity to three-phase electric power service. A point value of 2 was assigned if three-phase power was on-site. A point value of 1 was assigned if three phase was available, but not on-site.

Natural Gas - This factor considered the proximity of a site to natural gas service. A point value of 2 was assigned if natural gas was on-site. A point value of 1 was assigned if natural gas was readily available. A point value of 0 was assigned if the cost to obtain natural gas service was anticipated to be reasonable.

Community Services - This factor considered the proximity and access to community services such as fuel, service industry, retail stores, schools and churches. If services were within 5 miles of the site, 2 points were assigned. If community services were nearby but not within 5 miles of the site, a point value of 1 was assigned.

Information and Educational Opportunities - This factor considered the site location and anticipated ability to provide informational and educational opportunities to the public and access to higher education resources. Point values ranged between 0 and 3 and considered the site location, proximity to major roadways, and the proximity to population centers.

Climatic Factors - This factor considered the general climate found at the site and the anticipated impact on hatchery operation. Point values ranged between 0 and 5, where 5 was assigned if the site climate was most favorable to hatchery culture.

Probable Cost

Three factors were evaluated under this category, which considered the relative anticipated impact on the facility cost, associated with construction, operation and maintenance, and the benefit or non-benefit of a multiple use facility.

Construction - This factor considered the anticipated design and construction effort to place a hatchery on the site. The point value for this factor was between 0 and 5 and considered items such as site topography, location, availability of construction materials, and difficulty of site work.

Operation and Maintenance - This factor considered the anticipated operation and maintenance costs and efforts to run the hatchery. The point values assigned for this factor were between 0 and 5 and considered items such as a warm water supply versus the need to heat water, site location and access to supplies, and access to points of fish release.

Multiple Use of Facility - This factor considered the benefit of locating the proposed hatchery at or in conjunction with an existing facility. A point value of one was assigned for this factor if a benefit was anticipated.

5.4 SITE SCREENING

5.4.1 Methodology

A matrix was developed to document point values assigned to each site. The TAC and study team jointly reviewed each site and each criteria and assigned points as described herein.

Given the definition and rating point value for each of the site evaluation criteria, the consultant team and TAC reviewed and discussed each of the potential hatchery sites and assigned rating points for each site, for each of the site evaluation criteria. This information was entered into the Site Evaluation Matrix shown in Table 5.3. The sites are listed across the top of the matrix in order of their site number, which were assigned at random at the beginning of the study. Site Criteria are listed along the left side of the matrix, each with the associated potential rating point value. Site Scores are totaled at the bottom of the matrix. Sites which best meet the evaluation criteria have higher scores.

TABLE 5.3

SITE EVALUATION MATRIX

	SITE NAME AND NUMBER		GLENWOOD	COL UTE	RIFLE FALL	CLINES	PUTNAM	SILVER SPG	MCMILLANS	CRYSTAL PR	HORSETHIEF	WALTER WLK	RANGEVIEW	STROH	RUSSELL L	CLOSED BAS	CRAIG	GRAND JUNC
	CRITERIA	POINT VALUE	1	3	6	8	9	10	11	15	16	18	23	24	25	26	28	32
A 0	**WATER SOURCE (GPM)**	**MAX 25**	**14**	**6**	**8**	**20**	**12**	**9**	**19**	**18**	**10**	**8**	**6**	**22**	**20**	**18**	**11**	**2**
A a 1	GROUND OVER 1500	15–20				20	16		19	20				18	20	20		
A a 2	GROUND 501–1500	10–15	14					11					10					
A a 3	GROUND 0–500	0–10		0	0						0	0					3	0
A 1	SURFACE OVER 1500	7–10			10						10	10		8			10	4
A 2	SURFACE 501–1500	4–6		6					4									
A 3	SURFACE 0–500	0–3	0			0	0	0		0			0		0	0		
A c 1	WATER RELIABILITY	FF,–6 TO 0	FF	FF	–2	0	–4	–2	–4	–2	0	–2	–4	–4	0	–2	–2	–2
B 0	**WATER QUALITY**	**MAX 20**	**11**	**12**	**5**	**14**	**2**	**3**	**2**	**15**	**8**	**5**	**10**	**6**	**15**	**16**	**10**	**6**
B a 1	TEMP 68–74	6–10	10			9				9								
B a 2	TEMP 50>68	1–5		3	1		1	1	1		1	1	3	2	5	1	1	0
B a 3	TEMP >74 ONLY	0																
B a 4	TEMP <50 ONLY	0																
B a 5	WARM WATER POTENTIAL	0–10	0	4	1	1	1	1	1	1	1	1	4	1	5	9	4	1
B 1	TDS 1100–4100	3–4																
B 2	TDS <1100	0–2	0	1	1	1	1	1	1	2	2	0	1	1	1	3	2	0
B 3	TDS >4100	0																
B c 1	pH 7.2–8.2	3–4		4	4	3		3		3	4	4		4	4	4	4	4
B c 2	pH <7.2	0–2	2				2		2				2					
B c 3	pH >8.2	0–2																
B 1	POTENTIAL FOR CONTAMINATION	FF,–5 TO 0	–1	0	–2	–1	–3	–3	–3	–1	0	–1	–1	–3	–1	–1	–1	0
B e 1	EFFLNT TRTMNT NEEDS	0–2	0	0	0	1	0	0	0	1	0	0	1	1	1	0	0	1
C 0	**SITE PHYSICAL**	**MAX 20**	**11**	**8**	**12**	**15**	**15**	**13**	**8**	**15**	**8**	**10**	**15**	**10**	**16**	**15**	**12**	**13**
C a 1	LAND AREA >40 ACRES	4–5				4	5			5			5	4	5	5	4	5
C a 2	LAND AREA 20–40 ACRES	2–3	2	FF	2			3	4		2	2						
C a 3	LAND AREA <20 ACRES	FF																
C 1	LAND AVAILABILITY	FF, 0–3	2	1	3	2	2	2	2	2	1	2	2	2	3	3	3	3
C c 1	LAND ACCESSABILITY/USEABILITY	FF, 0–2	2	2	2	2	2	2	FF	1	0	2	2	0	2	1	2	0
C 1	EXISTING FACILITIES	0–2	1	1	1	1	1	1	0	1	1	1	1	0	1	1	0	0
C e 1	DESIGN/CONSTRUCTION	0–2	0	0	0	2	1	1	0	2	0	0	1	1	1	1	1	1
C f 1	GEOLOGIC FACTORS	FF–2	2	2	2	2	2	2	0	2	1	0	2	1	2	2	0	2
C 1	ELEV <4000 FT	4																
C 2	ELEV 4000–5000 FT	3									3	3						
C 3	ELEV >5000 FT	2	2	2	2	2	2	2	2	2			2	2	2	2	2	2
D 0	**BIOLOGICAL CONSIDERATIONS**	**MAX 15**	**9**	**8**	**7**	**3**	**8**	**8**	**7**	**7**	**6**	**6**	**3**	**7**	**3**	**2**	**7**	**7**
D a 1	HABITAT PROXIMITY TO BASIN	0–3	3	3	3	0	3	3	3	0	3	3	0	3	0	0	3	3
D 1	ESCAPEMENT	0–5	2	2	1	3	2	2	1	5	1	1	3	2	3	0	1	1
D c 1	PREDATION	0–5	4	3	3	0	3	3	3	2	2	2	0	2	0	2	3	3
E 0	**LOCATIONAL FACTORS**	**MAX 10**	**10**	**9**	**7**	**8**	**10**	**9**	**8**	**7**	**9**	**10**	**8**	**8**	**8**	**9**	**8**	**8**
E a 1	THREE PHASE POWER	0–2	2	2	2	2	2	1	1	2	2	1	1	1	1	2	2	1
E 1	NATURAL GAS	0–2	2	2	1	0	1	1	1	1	0	1	1	1	1	1	2	1
E c 1	COMMUNITY SVCS	1–2	2	2	1	2	2	2	1	1	1	2	2	2	2	2	1	1
E 1	INFO & ED OPPURTUNITIES	0–3	3	2	1	2	2	2	2	1	1	3	2	1	2	2	2	1
E e 1	CLIMATIC FACTORS	0–5	4	1	2	2	4	3	3	2	5	5	2	3	2	2	1	4
F 0	**PROBABLE COST**	**MAX 10**	**6**	**8**	**4**	**8**	**5**	**5**	**2**	**8**	**3**	**3**	**5**	**3**	**6**	**5**	**4**	**2**
F a 1	CONSTRUCTION	0–5	3	4	1	4	3	3	0	4	2	2	3	1	3	3	2	1
F 1	OPERATION AND MAINTENENCE	0–5	3	4	2	4	2	2	2	4	1	1	2	2	3	2	2	1
F c 1	MULTIPLE USE OF FACILITY	0–1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL POINTS			**61**	**51**	**43**	**68**	**52**	**47**	**46**	**70**	**44**	**42**	**47**	**56**	**68**	**65**	**52**	**38**
RANK					**10**	**2**	**6**	**8**		**1**		**11**	**8**	**5**	**2**	**4**	**6**	**12**
FATAL FLAW RATING			FF	FF					FF		FF							

NOTES:

1. SITE 8 LAND AREA IS FF IF A PORTION OF ADJACENT LAND IS NOT AVAILABLE. CURRENT SCORE ASSUMES LAND IS AVAILABLE.
2. SITE 18 LAND AREA MAY BE FF IF PROPOSED REFUGE PONDS USE UP AVAILABLE LAND.
3. SITE 24 GEOLOGIC FACTORS MAY BE FF. REQUIRES ADDITIONAL GEOLOGIC INVESTIGATION IF SITE IS CONSIDERED FURTHER.
4. MATRIX INCLUDES POINTS FOR POTENTIAL WARM WATER AT THE SITE, BASED ON SITE GEOLOGY AND RECORDS OF AREA WELLS.

SECTION 6.0

HATCHERY DESIGN AND ESTIMATED COSTS

6.1 INTRODUCTION

The objective of this phase of the feasibility study was to develop a feasibility level design for the proposed endangered species hatchery; broodstock and refugia holding facility; and research facility, cumulatively referred to as the recovery facility. This recovery facility would support the endangered fish recovery goals of: propagation of endangered fishes, augmentation of native productions, refugia and broodstock holding, and to provide facilities for research.

6.1.1 Background

The original scope of the design phase of the study was to prepare a recovery facility design for each of the three highest ranked sites. This design concept was later modified because the three sites with the highest rankings were all similar sites located in the same geographic region, the San Luis Valley of the Rio Grande Basin, which is outside of the native habitat of the four endangered fish. The high rankings for these sites resulted primarily from availability of naturally occurring high temperature (70° to 118°F) groundwater, that is preferred for spawning and growth and offers a significant cost advantage over heating a cold water supply. To provide for greater flexibility in the ultimate selection of a hatchery site, the CWCB Staff, with agreement of the TAC, decided to revise the scope of the design phase and prepare feasibility level designs for each of the for three types of water sources: warm groundwater, cold groundwater and surface water.

6.1.2 Methodology

Development of conceptual hatchery designs for this study task required the completion of a number of support tasks to finalize the hatchery design criteria and site information initially described in previous sections of the study. These support tasks included:

(1) identification of the functional goals of the hatchery facility;

(2) selection of design criteria for each function; and

(3) determination of representative site characteristics on which the design will be based. Once completed, this task information was used to develop the hatchery designs.

6.2 HATCHERY FUNCTIONS

There are a number of existing State and Federal hatcheries currently providing a refugia for the endangered fishes of the Upper Colorado River Basin and holding broodstock for limited fish production. None of these facilities has been specifically designed to meet the special requirements of these fishes nor are they dedicated solely for this purpose.

A goal of the CWCB in this study was to investigate the feasibility of providing a hatchery dedicated to assisting the recovery of these fish. This hatchery would be designed specifically to research and better understand these fish and to provide optimal facilities to hold the surviving members of the population and to assist in their propagation. Specifically, the hatchery would be designed to meet a number of objectives, as follows:

- **Fish Production**

Provide facilities for fish to augment existing populations to aid in propagation of the endangered fish in the wild. Due to the decline of these species, the CWCB believes that augmentation of wild populations with hatchery raised fish is an integral part of the program for recovery of these fish.

Provide facilities for fish production to meet the research needs of the endangered fishes. Because much of the information known about the fish is limited regarding their specific needs during different life stages, research on these fish is critical to increase the understanding of their specific needs and the ability to assist in their recovery.

- **Broodstock and Refugia**

Provide facilities for holding and protecting broodstock used in the recovery of the fish. The production of fish for research and augmentation of the wild population will require a number of separate facilities given the objective of maintaining separate genetic strains. Broodstock holding facilities must provide a natural environment which is secure from predators, and also allows for isolation of different genetic strains and year classes. Optimal broodstock holding and care are critical due to the declining ability to replace broodstock with fish from wild populations.

Provide facilities for a refugia for the endangered fish. Due to declining numbers of the endangered fish in the wild, a refugia for surviving members of the population is important. This facility would provide a refugia which would be designed to provide an optimal controlled environment for protection and survival.

- **Research**

Provide research facilities to broaden our understanding the fish and assist their recovery. Research on the endangered fishes is important to better understand their requirements during different life stages, determine reasons for their decline and to determine how best to produce these fish under hatchery conditions.

- **Visitor and Educational Opportunities**

Provide facilities for hatchery visitors for educational opportunities. Visitor and educational facilities located at the hatchery will assist in disseminating existing knowledge of these fish, promote activities which will improve chances of survival of wild populations, and encourage support for the Recovery Program.

6.3 DESIGN CRITERIA

6.3.1 Projected Site Conditions

To develop a hatchery design, it was desirable to have the hatchery design criteria represent actual site conditions as much as possible. To develop this criteria based on the final 16 sites, the potential sites were grouped into one of the three classifications of water supply source. Within each category, the average values for major hatchery design parameters were determined which were then used to represent a "generic" hatchery site. These design parameters included: water temperature, water flow rate, and site elevation. For example, the average water temperature for the potential hatchery sites with a cold water supply was 57°F. The design for a cold water hatchery was therefore based on a site with a water supply temperature of 57°F. Assumptions used for design criteria, development of the fish bioprograms and the conceptual hatchery design are tabulated at the end of each section of the report.

6.3.2 Fish Production Facility Requirements

One of the objectives of this study was to evaluate the hatchery requirements for different levels of fish production. Since the number of fish needed for augmentation of wild populations and research is difficult to determine, as stated previously, the CWCB estimated three levels of fish production to be used for the study. Production scenarios 1, 2, and 3 specify production of 150,000, 300,000 and 600,000 fish, respectively, for each of the four endangered fishes. Detailed hatchery requirements were developed for Scenario 2 (300,000) production. Scenario 2 information was halved or doubled to estimate hatchery requirements for Scenario 1 (150,000) and 3 (600,000) levels of production, respectively.

Results from the study task to determine design criteria and culture techniques provided the basis for the facility conceptual design criteria was established. Computer generated bioprograms were also used to assist with the development of design criteria. Production for augmentation and research is specified at 300,000 individuals per species, which is production Scenario 2, as provided by the CWCB. Discussions with CDOW staff (L. Harris, A. Kriss, P. Schler, 1992) identified data for intensive culture of Colorado squawfish. Analysis of these data yielded estimates for growth, condition factor, oxygen consumption, rearing space and flow needs.

Direction provided by the TAC finalized the desired components of the production program to be included in the conceptual design efforts. These components are described below and in Tables 6.1 and 6.2.

One-half of the production of each species (Colorado squawfish, razorback suckers, bonytail chub and humpback chub) is to be accomplished through intensive culture. The remaining production will follow extensive culture methods with initial fry rearing in the hatchery troughs. This combination will provide the most flexibility of rearing space as different culture methods for each life stage are developed. For this effort, intensive culture is defined as a controlled culture environment (inside a hatchery building) with water temperature maintained at 69°F. Extensive culture will be carried out in ponds using low densities, natural feed supplemented with artificial feed and minimal flows.

Rearing unit configuration and sizes have been selected with input from CDOW and the TAC. One-half of initial fry rearing will be conducted in 4 foot diameter white circular tanks, with other half in 4 x 1-1/2 x 1 foot troughs. This combination provides the hatchery manager with the maximum flexibility to adapt to changing culture technique developments. Intensive fingerling production will occur in 12 foot diameter circular tanks. The facility will also provide 100-200 glass aquaria with 50 gallon capacities. Approximately one-quarter of the rearing capacity in the hatchery building will be isolated from the remaining space to facilitate isolation of distinct stocks. Rearing ponds will be 0.25 surface acre, with an average water depth of 4 feet.

A nutritional strategy designed to simulate natural conditions and induce prey/predator behavior is recommended for extensive culture of augmentation stocks and refugia. This approach involves intensive production of natural live feeds to satisfy the diets of the four endangered species. These diets may vary by life stages. (Haynes, et al., 1985; Vanicek, 1967; Wick, et al., 1981). Natural feed production facilities will be housed in the hatchery building. These facilities consist of an algal room, zooplankton production room and live insect and fish production rooms. Insect production may include aquatic and terrestrial insects. Algae and insect production levels are intended to be sufficient to seed the augmentation pond complex. This starter will initiate natural feed level production which will sustain targeted growth of augmentation stocks. Pelleted feed may also be supplemented. It is intended that natural diets will also satisfy most, if not all, nutritional

TABLE 6.1

FLOW AND REARING UNIT REQUIREMENTS

(Warm Well Water Supply - 69°F)

INTENSIVE CULTURE

SPECIES	PRODUCTION LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Colorado Squawfish - 4"	150,000												
Total Flow Requirement (GPM)		295	317	411	459	540	672	37	66	98	142	182	240
Total Trough Requirement							2	10	28				
Total Circular Requirement		3	4	5	6	7	8			1	1	2	2
Razorback Sucker - 6"	150,000												
Total Flow Requirement (GPM)		3143	3827	94	30	205	667	780	1088	1385	1811	2151	2666
Total Trough Requirement				3	50								
Total Circular Requirement		33	42			1	2	4	6	9	13	19	25
Bonytail Chub - 4"	150,000												
Total Flow Requirement (GPM)						110	269	708	1256	1171			
Total Trough Requirement						3							
Total Circular Requirement							1	2	4	8			
Humpback Chub - 4"	150,000												
Total Flow Requirement (GPM)						76	472	1023	1815	1721			
Total Trough Requirement						3							
Total Circular Requirement							1	2	5	11			
SUBTOTALS INTENSIVE													
FLOW REQUIREMENT (GPM)		3438	4144	505	489	931	2080	2548	4225	4375	1953	2333	2906
TROUGH REQUIREMENT		0	0	3	50	6	2	10	28	0	0	0	0
CIRCULAR REQUIREMENT		36	46	5	6	8	12	8	15	29	14	21	27

Note: Table is for Scenario 2 - Total production of 300,000 per species, with intensive culture of 150,000.

TAB[illegible].2

FLOW AND REARING UNIT REQUIREMENTS

(Warm Well Water Supply - 69°F)

EXTENSIVE CULTURE

SPECIES	PRODUCTION LEVEL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Colorado Squawfish - 4"	150,000												
Total Flow Requirement (GPM)		185	185	201	87	87	185	185	174	174	174	174	174
Total Trough Requirement				4									
Total Pond Requirement		17	17	18	8	8	17	17	16	16	16	16	16
Razorback Sucker - 6"	150,000												
Total Flow Requirement (GPM)		152	152	4	87	76	152	152	152	152	152	152	152
Total Trough Requirement				3									
Total Pond Requirement		14	14		8	7	14	14	14	14	14	14	14
Bonytail Chub - 4"	150,000												
Total Flow Requirement (GPM)						4	68	68	148	148			
Total Trough Requirement						3							
Total Pond Requirement							6	6	13	13			
Humpback Chub - 6"	150,000												
Total Flow Requirement (GPM)						4	65	65	141	141			
Total Trough Requirement						3							
Total Pond Requirement							6	6	13	13			
SUBTOTALS EXTENSIVE													
FLOW REQUIREMENT (GPM)		337	337	205	174	171	470	470	615	615	326	326	326
TROUGH REQUIREMENT		0	0	7	0	6	0	0	0	0	0	0	0
POND REQUIREMENT		31	31	18	16	15	43	43	56	56	30	30	30
TOTAL INTENSIVE AND EXTENSIVE													
FLOW REQUIREMENT (GPM)		3775	4481	710	663	1102	2550	3018	4840	4990	2279	2659	3232
TROUGH REQUIREMENT		0	0	10	50	12	2	10	28	0	0	0	0
CIRCULAR REQUIREMENT		36	46	5	6	8	12	8	15	29	14	21	27
POND REQUIREMENT		31	31	18	16	15	43	43	56	56	30	30	30

Note: Table is for Scenario 2 - Total production of 300,000 per species, with extensive culture of 150,000.

requirements for broodstock. The small fish production facility in the hatchery building is intended to supply the diet for Colorado squawfish broodstock. Insect production will satisfy the dietary needs of humpback chub, bonytail chub and razorback sucker broodfish.

Flow was calculated by two methods in the bioprogram associated with both culture methods. Rearing flow for intensive culture is based upon CDOW (P. Schler) oxygen consumption data for Colorado squawfish. Average oxygen consumption reported by CDOW was 0.337 pounds of oxygen per pound of food fed per day. It was assumed that the three other species will exhibit similar oxygen consumption characteristics. Feed requirements were calculated based upon predicted monthly weight gain multiplied by an assumed feed conversion ratio of 2.0. Oxygen consumption was limited to a minimum discharge oxygen concentration of 5 ppm with an assumed inflow oxygen concentration at 95% saturation (adjusted for temperature and elevation) following conventional water supply aeration.

Extensive culture flow requirements were calculated based on one pond exchange per 475 hours to allow adequate water replacement, velocity and replacement oxygen. Minimum flow rate will not fall below 50 gal/min/acre. Oxygen exchange is assumed to be adequate based on surface tension with minimal inflow of water based upon Dexter NFH experience.

Tables 6.1 and 6.2, summarized from the bioprogram runs, identify the maximum requirements for flow, start tanks (4 foot circulars and 4.5 x 1.5 x 0.75 foot troughs), large tanks (12 foot circulars) and rearing ponds (0.25 surface acre) to produce 300,000 of each of the target species. Maximum flow requirement occurs in the months of September and October at 6,205 and 7,858 gpm, respectively. The large flow demand for intensive culture is a direct result of limited oxygen availability due to temperature and elevation. Supplemental aeration should be considered to include mechanical airlifts and/or oxygen injection during peak flow months. The maximum need for start tanks occurs in September with 32 units required. Peak large tank need is in February and October at 49 units. Maximum pond usage occurs in the months of August through October at 17 ponds. The facility conceptual design for production Scenario 2 (300,000 fish) has been based on 30 start tanks (which includes 26 troughs and 4 incubation tanks), 70 large tanks, and 64 rearing ponds to allow for grading, transfers, maintenance and program flexibility. Requirements for production Scenario 2 are shown on Drawings 1 through 14, and requirements for production Scenarios 1 and 3 are shown on Drawings 12 through 15 in Appendix H.

Assumptions made for development of design criteria as described in this section are as follows:

- One-half of species rearing for augmentation to be intensively cultured, and one-half to be extensively cultured.

- The bioprogram model uses a production scenario of 300,000 fish for each species.

- Spawning timing based upon previous data collected by BioWest and TAC information.

- Temperatures of well water supplies were from URS data.

- Surface water temperature based on average of five west-slope river systems (USGS data).

- Troughs are 4.5' x 1.5' x 0.75' (water depth).

- Start tanks are 4.0' diameter with 1.5' water depth.

- Growout tanks for intensive culture are 12' diameter circulars with 3' water depth.

- Growout ponds for extensive culture are 0.25 surface acre as set by TAC with an average depth of 4'.

- Initial lengths are based on literature (Hamman, etc.)

- Growth rates were determined from CDOW data for Colorado squawfish and BioWest data for other species. Humpback chub and bonytail chub assumed to have similar growout rates.

- Condition factors calculated from BioWest, and CDOW and USFWS data.

- Mortality rates based on Hamman 1987 and CDOW.

- Oxygen saturation assumed to be 95% with conventional aeration methods.

- Oxygen consumption set flow needs for intensive culture. CDOW provided oxygen consumption data for Colorado squawfish. No other data were available, therefore, oxygen consumption in other species was assumed to be similar to Colorado squawfish.

- Feed conversion was set at 2.0 for intensive culture (typical expected conversion from manufactured high energy diets). Extensive culture feed conversion set at 2.3, reflecting energy content of natural feeds.

- All swim-up fry to start in troughs until at least 1.2 inches.

- Growth goals are 4 inches in length for bonytail chub, humpback chub and Colorado squawfish. Razorback sucker to be grown to 6 inches in length.

- Change-overs per hour in extensive culture is set at twice the rate of Dexter National Fish Hatchery or one turnover per 475 hours.

- The average elevation of the sites under consideration was input into the program.

- Water quality of the water supplies was assumed to be adequate to sustain culture goals.

- Extensive culture may result in a large biomass load in the 0.25 acre ponds. A basic culture assumption of 1,000 lbs fish/acre + 10 lbs/gpm flow yields an expected loading between 2,500 and 3,000 lbs/acre. To increase the loading up to 4,000 lbs/acre, mechanical aeration or fish transfer to available ponds will be necessary.

6.3.3 Broodstock and Refugia Facility Requirements

Broodstock Requirements

The objective in the design of the broodstock portion of this facility was to simulate natural fish habitat within the hatchery environment. The purpose was to create complex and variable environmental conditions within controlled ranges, which provide fish with choices that require interaction. The intent was to enhance natural selective pressures on genetic traits, which may help maintain genetic variability in hatchery reared stocks (Eschelle, 1988).

Several strains of fish for each species come from quite different habitats (Haynes, et al, 1984; Douglas, 1952; Mueller, 1989; Tyus, 1987). It is felt that simulation of native habitat features will lessen hatchery-induced stress placed on these essentially wild fish being held in confinement. A reduction in hatchery related stress should improve genetic survivability (Eschelle, 1988).

Broodstock requirements have been determined for each species by the Recovery Program. Projected broodstock needs of sexually mature individuals of both sexes are listed in Table 6.3. A holding strategy was developed that takes into account the reduced risk of catastrophic loss by spreading of broodstock out to other existing offsite facilities. Holding facilities at this site will be designed to accommodate a total of 5,100 adults of all species. Recommendations regarding holding broodstock offsite includes 56% of total broodstock to be held at state and federal hatcheries and offsite refugia. Table 6.4 summarizes the distribution of broodstock at different locations for all species.

Broodstock holding and refugia were integrated together into a pond designed around what is currently known about preferred habitat for adults of each of the endangered species. Information about habitat and fish behavior was extracted from the reference library and personal communications. Adult and spawn habitat information from these sources was used to design a holding pond configuration which stimulates natural habitat conditions (Douglas, 1952; Haynes, et al; 1984; Haynes, et al., 1985; Tyus, 1987; Ulmer, 1980, Vanicek, 1967; Wick, et al., 1981).

Refugia designed into these holding facilities required that additional functions be incorporated into the design. Long-term (10 or more years) holding of certain critically depleted stocks was also taken into account. A decision was made on what loading density would be appropriate for ponds in which complex water flow, vegetation and natural feed production play significant interactive roles in the creation of natural fish habitat. Carrying capacity in wild habitat niches, such as those being created in the holding ponds, indicate that pond densities should be very low if the above features are to be effective towards creating self-maintaining long-term holding facilities. It was also decided that the carrying

TABLE 6.3 Threatened and Endangered Broodstock Requirements
Number of substocks are shown in parentheses by each species
First Generation[1]

Species	Average age of Broodstock (yrs)	Wt (lbs)[2] Females	Wt (lbs)[2] Males	Total
Colorado Squawfish (6 substocks)	10	2,500	2,500	5,000
Humpback Chub (6 substocks)	5	100	100	200
Bonytail Chub (1 substock)	5	700	700	1,400
Razorback Sucker	5	2,500	2,500	5,000
			Total	11,600

1 Assumes that stocking density reflects average 10 year-old fish weight for Colorado squawfish and 5 year-olds for remainder
2 Hamman, R. (1992), personal communication

Table 6.4 Broodstock Location Summary					
	Colorado Squawfish	Humpback Chub	Bonytail Chub	Razorback Sucker	Distribution (No. of fish)
CWCB Endangered Fish Hatchery	2,000	100	1,000	2,000	5,100
State & Federal Facilities or Offsite Refugia	3,000	100	400	3,000	6,500
Total Broodstock[1]	5,000	200	1,400	5,000	11,600

1 Total Broodstock - includes both males and females, with replenishment as required due to mortality.

capacity of natural living habitat features would be the main criteria for determining loading density, not fish density. As a starting point, 10.0 pounds for 10 year-old female Colorado squawfish was used as the maximum broodstock weight and a maximum loading density of 1,000 fish per acre was chosen to keep the number of ponds within reasonable limits (Williamson, 1992).

Assumptions made for the development of this section are as follows:

- Natural fish habitat assumed required for brood/refugia ponds as a means of reinforcing natural genetic selection pressures.

- Approximately 5,000 adults of all species/strains (both sexes) to be held onsite as specified by the TAC.

- Approximately 5,000 adults of all species/strains (both sexes) to be held offsite by other agencies to reduce risk of catastrophic loss.

- One pond habitat configuration designed for all species to allow flexibility in the numbers of broodstock maintained onsite.

- Ponds designed for long-term holding (10 years) to provide long-term refuge for seriously depleted strains.

- Broodstock replenishment on a 5 year cycle to replace mortality which is expected to approach 15% per spawn cycle (Hamman, 1992).

- Broodstock/refugia ponds sized so density does not exceed 1,000 fish/acre. Criteria determined by habitat requirements, not loading density.

- Species held separate and sexes separated after maturity; strains held together and differentiated by tagging.

- Starting broodstock weight variable depending on species.

Hatchery Broodstock Pond Requirements

A variable number of broodstock/refugia ponds were provided for each species depending on population numbers kept onsite, with the provision that fish density will not exceed 1,000 fish per acre and sexes will be held separate after maturity. Each population will be spread between at least two rearing unit pairs to reduce the risk of catastrophic loss should one pond fail. Pond requirements are as follows:

A. Colorado squawfish
Onsite broodstock population - 2,000
1,000 males; 1,000 females
Pond size - 0.25 acres
Total number of ponds - 8
Density - 1,000 fish/acre

B. Bonytail chub
Onsite broodstock population - 1,000
500 males; 500 females
Pond size - 0.25 acres
Total number of ponds - 4
Density - 1,000 fish/acre

C. Humpback chub
Onsite broodstock population - 100
50 males; 50 females
Pond size - 0.10 acres
Total number of ponds - 4
Density - 250 fish/acre

D. Razorback sucker
Onsite broodstock population - 2,000
1,000 males; 1,000 females
Pond size - 0.25 acres
Total number of ponds - 8
Density - 1,000 fish/acre

A review of the adult fish habitat information from the literature review study task (Douglas, 1952; Haynes, et al., 1984; Haynes, et al., 1985; Tyus, 1987; Ulmer, 1980; Vanicek, 1967; Wick, et al., 1981) indicated that the following features can be incorporated into broodstock pond design and will simulate features which are common to native habitat. Habitat components which are considered common for all four species and have been included.

1. Water Quality

   a. recirculate up to 80%
   b. controlled range of temperature (ambient - 69°F)
   c. flow velocity (0 - 1.0 ft/sec) past structures and obstructions
   d. TDS (500 - 4,500 ppm)
   e. dissolved gasses (oxygen > 4 ppm)
   f. turbidity

2. Substrate
   a. boulders (create eddies and turbulence)
   b. sand/gravel bars

3. Contours
   a. vary water depth
   b. turbulence

4. Vegetation
   a. enhance water quality
   b. provide shelter for fish and feed
   c. provide natural production of feed
   d. aesthetic appeal to visiting public

Description of Pond Characteristics for the Proposed Hatchery

Adult Colorado squawfish, bonytail chub and razorback sucker have been observed in similar shallow mid-channel bar habitats made up of various substrates. The broodstock/refugia ponds incorporate an elevated bar made up of coarse sand at the upstream end giving way to gravel at the downstream end.

The pond habitat is further enhanced with a sandy gravel substrate at the extreme inflow end and a cobble substrate at the outflow end. The design will incorporate a sediment flushing system beneath the substrate to maintain interstitial flow. Both of these features are characteristics noted to be associated with wild populations of all species except humpback chub. No literature is known which describes the habitat preference for adult humpback chub. Substrate at the upstream end of the ponds should support emergent vegetation which will aid in maintaining water quality and provide insect habitat for production of aquatic insect species as natural feed for resident broodstock. It is intended that introduced aquatic vegetation in the downstream cobble zone will also support water quality and live feed species. An overhang is provided around three sides of the broodstock/refugia ponds that is designed to give shade and shelter to the pond habitat and provide resident fish with hiding space. The pond design is intended to be flexible in order to meet varying needs for broodstock of different species over time. Some features can be added or removed depending on the type of habitat to be created. For instance, less vegetation may be desired for Colorado squawfish refugia because adults of this species prefer other smaller fish as prey, rather than insects. Obstructions can also be placed in the pond to create turbulence.

Flow Characteristics

Fish density in these broodstock/refugia ponds will be maintained below 1,000 fish per acre. As a result, the fish are not expected to have a significant impact on water quality. The criteria used to determine water flow, is to maintain habitat characteristic, not to replenish oxygen or remove metabolites. For example, a habitat feature directed towards bonytail chub is the creation of turbulence downstream of the bar region in the midsection of the ponds. This can be created by placing an obstruction in the current stream and will require considerably higher flow rates than would be necessary to carry away metabolites. For other species, such as the razorback sucker, flow rates can be slowed to produce laminar water flows, which is indicated in the literature to be a preferred habitat condition (Wick, et al., 1981, McAda and Wydoski, 1980). Recirculation up to 80% is provided, depending on flow requirements, to support habitat features. Recirculation will reduce total water requirements and allows for some temperature control. Each species will be on a separate recirculating system with the ability to isolate an individual pond should it be necessary. Each pond has the ability to receive new water.

Brood Building

A brood building has been incorporated central to the broodstock/refugia ponds designed to accommodate spawning of one species at a time. Access to the building is through wide roll-up doors located on along two opposing walls. Four circular holding tanks, 14 feet in diameter, by 3 feet deep occupy the middle area of the building adjacent to a spawning bench, which are intended to hold up to 50 hormone injected spawners. A recirculating water source is supplied to an anesthesia area adjacent to the spawning bench. Two 14 x 3 x 3 foot recovery tanks are provided. The spawning bench can also function for tagging requirements. Tagging apparatus and supply storage is provided under and over a standard laboratory bench along one wall. Three ancillary rooms are integral components of this building. These are:

A. Office to be used as a data collection point, equipped with a desk, shelving and a computer station.

B. Chemical and supply storage, containing a refrigerator and appropriate storage facilities for standard biological chemicals.

C. Mechanical/Electrical room, containing electrical service and other equipment necessary to operate the building. Water temperature control equipment is also provided for process water requirements.

6.3.4 Research Facility Requirements

The primary objective of the proposed endangered species hatchery is to facilitate the recovery of these fish species which are native to the Upper Colorado River Basin and have seriously declined in number. A strong research capability is essential to this goal because much of the knowledge needed to successfully recover these species remains unknown. Research is required to successfully improve hatchery based recovery programs. Many research needs have been identified which will aid in the development of a successful reintroduction program so these species can be cultured and returned to their natural environment (U.S. Fish and Wildlife Service, 1987).

In addition, major emphasis is being placed on maintaining the genetic integrity of different stocks of fish of the same species from different geographical regions of the basin. Another function of the hatchery is to produce robust and healthy fish which are able to cope and thrive once they are released back to the wild environment. Maintaining healthy fish in an intensive culture environment, where they are almost continually subjected to undue stress, requires an ability to closely monitor their pathology. The long-term success of the recovery program will also depend to a large degree on gaining knowledge of migration behavior, imprinting/homing, spawning, survival and reproduction, interaction with wild populations, population age structure and nutrition (Recovery Program, 1991). A comprehensive general biological research facility is needed to support these research functions.

Facility design is focused on genetics, general biology, and pathology, encompassing two laboratories directed specifically at these research functions. One laboratory is dedicated to genetics. Pathology and general biology are housed together in a second fully integrated laboratory. Many of the research priorities specified by the Recovery Program (USFWS, 1987) require access to fish culture facilities. A small research oriented rearing facility has been incorporated into the research design.

Because the hatchery is being designed as a regional focal point for research and propagation of these fish, space in the research facility has been set aside to accommodate and facilitate the research of visiting scientists and will provide a large scale venue for information transfer in the form of conference facilities.

The design of the research facility involved the input from several knowledgeable sources. Information gathered for this study identified foreseeable research requirements for which facilities should be provided. Experts in genetics and pathology were consulted for their ideas on what facilities would be needed to support these disciplines. The various research components were then proportioned and arranged in a coordinated manner so that a building concept could be laid out.

The research building is a highly integrated facility encompassing the major disciplines which are important to the development of a recovery program for the target endangered species. The right wing of the building is devoted to genetics and general biology/pathology research and their various support functions. The left wing houses employee accommodations, the museum, computer room and various ancillary functions. A culture room containing isolated incubation space, conference room and reception area occupy the central portion of the research facility.

The facility is designed to simultaneously accommodate and support up to three visiting researchers. Facilities management includes one shop/maintenance person and one receptionist. A full-time aquarium manager supports the operation of the culture room and outdoor research area as well as the visitor aquarium building. One visitor's office is included for use by transient researchers.

The computer facility houses a mini-main frame system interfaced with satellite terminals located throughout the hatchery. The library will house collections of texts, periodicals and reports pertinent to on-going research. Computer linkup with info-net services will be included. The design includes a conference room which can accommodate up to 30 conferees, reflecting the central focus of wide regional interest in these endangered species.

Genetics Laboratory

Up to six possible substocks are known to exist for each of the target species except bonytail chub, for which only one is identified, making a total of 19, possible substocks which will require genetic monitoring. Genetic screening is also necessary to determine if there are differences between substocks which will require their segregation in the hatchery during propagation. Maintaining genetic identity which reflects unique morphological and behavioral characteristics requires that genetically different substocks not be allowed to cross-breed. Thus, the primary function of the genetics laboratory will be to identify genetically distinct substocks of the target species.

The genetics laboratory has been separated into five physical spaces; two laboratories, one storage room, one office, and a karyotyping room. One of the labs is dedicated to protein electrophoresis. The other lab is dedicated to DNA electrophoresis. The protein electrophoresis lab will contain 6 electrophoretic units, a centrifuge, sample preparation area and incubator. The DNA electrophoresis lab will also contain 6 electrophoretic units, two centrifuges, two ultra-cold (-80°F) freezers, sequencer, shakers and water baths. Karyotyping work will be carried out in dedicated space housing a microscope room and prep area. An office space with computer facilities is provided for quantitative genetics. One room is provided as a storage area. Chemical storage as well as hazardous and flammable storage will be accommodated. The two laboratories will be provided with fume hoods and standard laboratory benches and sinks. The entire genetics facility will be designed to meet the requirements for radionuclide and biohazard use. Film processing and dark room facilities are designed to be shared with other research needs such as pathology.

General Biology and Pathology Laboratory

The pathology laboratory is divided into three individual work spaces, one storage space, and one office. A small mud room receives incoming field sample material and is designed with sinks, a bench, and floor drains. The purpose for this room is to perform initial sample preparations. A small tissue preparation room is also provided which doubles as a histology lab. This room can be darkened as required for immuno-fluorescent microscopy.

One small room is set aside as storage. This room will be equipped to store biohazardous materials and solvents. It also provides storage for general biology lab equipment and glassware. One third of the main room serves as the general pathology laboratory. This space will contain an island bench equipped with storage over and under, sink, research water supply and gas. The remainder of the room is devoted to general biological/physiological studies. Two fume hoods (biological and chemical), an incubator, autoclave, refrigerator, and benches with over and under storage are located centrally and along the perimeter walls.

The general biology/pathology laboratory is designed to facilitate onsite analysis of disease diagnosis in fish at the hatchery and to accommodate physiological studies as well as provide histological support. Taxonomic studies would also be conducted at this location. The laboratory is well equipped to also conduct analysis of hatchery water chemistry. Routine onsite water quality analysis will be performed at this location.

Culture Room

A small room with culture water supply, drains and controlled photoperiod will be provided in the research building. A small incubation room is included as part of this facility. The main hatchery room will have twelve 4 foot and two 12 foot circular rearing tanks with additional space and water outlets and drains for 50 gallon aquaria.

The culture room is designed to support the research needs for genetics and life history/habitat interaction studies. Generally, the facilities will be suitable for doing controlled flow studies, bioassay, and controlled water quality effects on the various life stages of the target species.

Outside Research Area

A comprehensive array of culture facilities is designed to facilitate behavioral and life history studies has been incorporated into the design of the research facility and includes five separate components:

1. Ponds - Two 0.10 acre ponds. The ponds are designed so that they can be readily configured with various habitat features. They are supplied with variable water flow and recirculation capability. Supplemental aeration is also available.

2. Current Tanks - Two laminar, variable flow and temperature current tanks are provided. Each of these are configured with up to three habitat zones. Observation ports will provide lateral views of fish interaction within each zone.

3. Culture Tanks (12 foot diameter) - Two 12 foot diameter culture tanks with variable temperature and flow capabilities are provided. Supplemental aeration will also be provided.

4. Culture Tanks (4 foot diameter) - Four 4 foot diameter culture tanks with variable temperature and flow, and aeration are provided.

5. Tank Set-up Slab - To add flexibility to the outdoor rearing facility, a space has been set aside for intermittent placement of multiple culture units. A concrete slab foundation with an integral curtain drain will support a row of up to 25 tanks or aquaria. Twenty-five individually controlled culture water stations will provide temperature controlled culture water and air above the slab.

Nutrition Research Requirements

A conceptual design and cost estimates for a nutrition analysis laboratory are shown in Figure 6.1 and Table 6.5 respectively and are included in this study should the research emphasis change to incorporate such a facility. These costs are not included in the overall facility cost estimates. It is currently assumed the nutritional research would be conducted at other facilities which are associated with the endangered species program. However, rearing facilities at this hatchery which are tailored to the culture of the four endangered species provide ideal rearing capability for conducting feeding trials associated with nutrition research.

The nutrition laboratory featured in the conceptual drawing provides for all aspects of nutritional analysis. The study of all nutritional components in diets and in the analysis of carcass composition can be accommodated. The special requirements associated with lipids analysis are provided in a closed room supplied with a positive pressure atmosphere to void toxic vapors. An instrument room is provided to house sensitive instrumentation associated with amino acid and fatty acid analysis. Protein analysis is provided for with an appropriate space. Diet formulation and feed manufacture has been provided for in a room with washdown features. Appropriate storage spaces provide optimum dry/cold storage capability for essential ingredients.

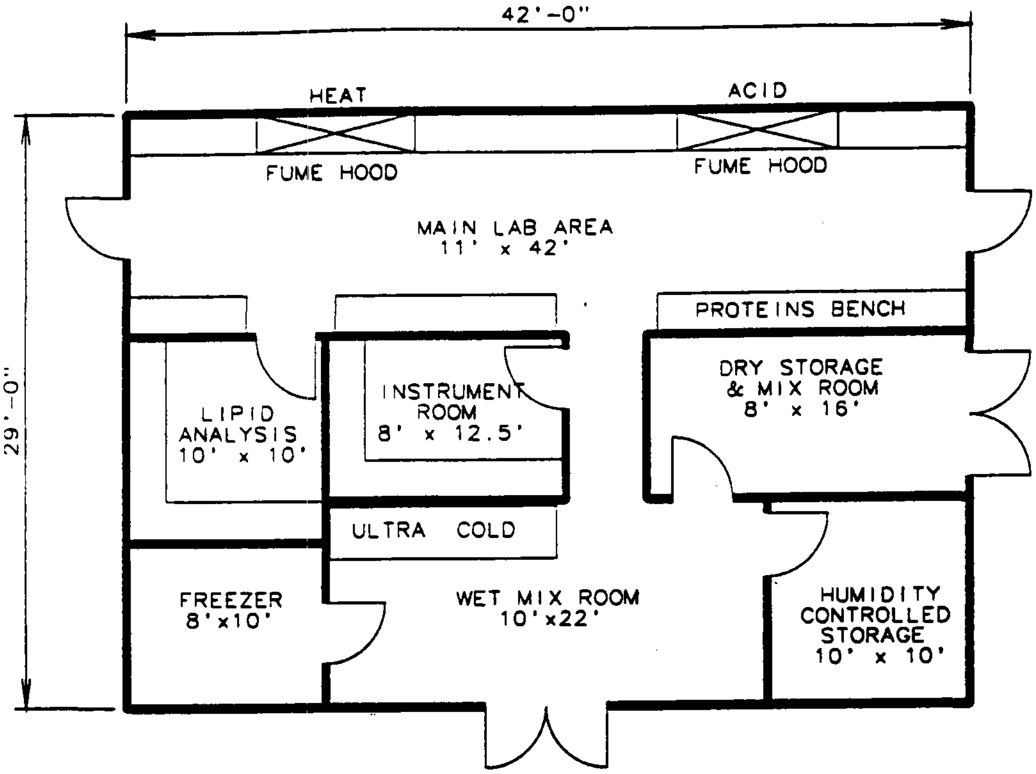
Analytical equipment needed to conduct protein, amino acid and fatty acid analysis such as gas chromatograph HPLC and protein analyzers can be found in most University research environments. As an alternative, the analyses of protein and fat components could be conducted offsite which would greatly reduce capital costs. The capital cost estimate presented in Table 6.5 includes the cost of high priced instrumentation.

Assumptions:

- Research is essential to the recovery process in order to expand our understanding of the propagation of these fish.

- Maintenance of genetic integrity of up to 19 possible substocks for all species is required.

- Fish health is a high priority to produce robust and healthy augmentation stocks.



NUTRITION LABORATORY

THE FACILITY WOULD ACCOMODATE THE FOLLOWING FUNCTIONS:

1. DIET FORMULATION AND FEED MANUFACTURE
2. PROXIMATE COMPOSITION ANALYSIS (I.E. PROTEIN, LIPID, CARBOHYDRATE, MOISTURE, DRYMATTER) FOR:
   - A. FEEDS
   - B. CARCASS
3. NUTRIENT ANALYSIS FOR:
   - A. AMINO ACIDS
   - B. FATTY ACIDS
   - C. VITAMINS
   - D. MINERALS
4. ENERGETICS
5. NUTRITIONAL PATHOLOGY

FISHPRO, INC.
PORT ORCHARD, WASHINGTON

FIGURE 6.1

Table 6.5 Capital Cost Estimate of Nutrition Laboratory

Facilities	
Laboratory Structure (29 X 42 feet)	$134,000
General Laboratory Equipment	25,000
Feed Preparation Equipment (pilot scale)	50,000
Subtotal	**$209,000**
Instrumentation	
HPLC	$100,000
GC	75,000
Protein Analysis	85,000
Subtotal	**$260,000**
TOTAL COST	**$469,000**

- Research support needs to focus on:

  a. genetics
  b. health and diagnostics
  c. migration behavior
  d. imprinting/homing
  e. spawning/reproduction
  f. survival
  g. stocks interactions
  h. aging

- Hatchery will be at the center of regional focus.

- Genetics analysis can be conducted in-house.

- A rapid disease diagnostics capability needs to be provided to head off disease outbreak.

- Flexibility in fish culture experimental design is accommodated within the research facility to provide the capability for a wide variety of behavioral and life history studies.

- A wetlab and disinfection room needs to be provided as the entry point for biological material to the research building. Initial sample preparations should be conducted in these spaces to reduce contamination risk to rest of research facility.

- A balance room provided to isolate sensitive instruments from moisture and vibration.

- The research and quarantine facilities are enclosed within a security compound which isolated them from the rest of the complex.

6.3.5 Visitor and Educational Opportunities

It is the intention of the Recovery Program to actively seek public participation and awareness in the fisheries restoration process. This will be done primarily through public education regarding the importance and current status of these endangered fishes, and tour access to the public of key facility components.

Public Access and Education

A 1,600 square foot visitor gallery is provided as the hub for visitor access and public education at the facility. The building is located in a public accessible area of the site and is serviced with adequate parking areas to accommodate buses and RVs, as well as ordinary automobile traffic. The building will be provided with handicap access and public restroom facilities. The main gallery will be a walk-through, light-controlled corridor complete with self-guided educational, and high interest features and aquarium displays. Information about the biology, and natural history of the fish will be conveyed by interpretive displays and reader boards. Foot traffic access to selected outdoor areas will be included in the public awareness program. Outdoor walking tours will be carefully confined to prevent potential vandalism and control the threat of fish disease transmission. Tour routes will be planned to limit public interference with routine staff activities. These foot tours may be staff or self-guided and will display interesting hatchery features such as reader boards describing the natural habitat refugia holding ponds and components of the operation of the hatchery.

Formal Education

The research facility of the hatchery has been designed to accommodate visiting scientific personnel and provide atmosphere and space to facilitate technology transfer through conferences, seminars, and collaborative research. Facilities which are provided to achieve these goals include: 1) in-house overnight living space for up to three visiting research personnel, 2) a conference room which can seat up to 30 people, appointed with audio and video aids, 3) a modern library housing collections of periodical literature relevant to on-going research and a computer data bank hook-up capability, 4) one office within the research and development building is set aside for visiting researchers use. These facilities should provide an attractive invitation to leading fisheries scientists and academics who are interested in research on endangered fish species.

Assumptions made for development of visitor and educational opportunities described in this section are as follows:

- Facilities are designed to provide self-guided educational exposure to the natural history of the endangered species.

- The education building and guided tour through interesting, outdoor features of the hatchery complex are designed to minimize the disturbance to routine hatchery operations.

- The doors to the public viewing gallery are placed to minimize daylight impact on fish.

- Public access to educational display facilities does not compromise hatchery security.

6.3.6 Disease Control and Quarantine Facilities

Disease Control

The introduction of a disease is a potential threat when fish are brought on station from off station locations, especially from the native environment. Hatchery operational strategies are generally designed around procedures which minimize cross-contamination of water and biological materials from one culture unit to another. A clean disease-free hatchery is based upon maintaining utmost cleanliness of facilities and implements which come in contact with culture water. The facilities of the endangered species hatchery have been designed with cleanliness in mind.

All wet areas within the facility are designed to be easily washed down. Floor drains will direct wash water away from culture areas. (Footbaths for disinfecting foot wear will be located in the hatchery and broodstock areas.) A policy of restricted access to the production and refugia components of the facility will limit the risk of disease transmission. Mortality and other biological materials disposal shall be accommodated by the installation and operation of a pathological incinerator.

Quarantine

It is the intent of the Recovery Program that the proposed endangered species hatchery be designed to facilitate a high standards of fish health and be maintained in disease-free condition so far as is possible. Elimination of pathogenic contamination from sources outside of the complex is of paramount importance to this goal. With this in mind, quarantine facilities have been incorporated into the hatchery design.

A quarantine area has been strategically placed near the main entrance to the hatchery complex to receive and hold all newly arriving fish stocks in isolation while they are screened for disease. A quarantine building houses four 12-foot diameter culture tanks and twenty-four 4.5 x 1.5 x 0.75 foot rearing troughs. Space is available for twenty 50 gallon aquaria. A sample preparation room is provided to prepare tissue samples for pathological analysis in the research building pathology laboratory. Quarantine facilities include an independent culture water supply and a drainage system which by-passes all other hatchery facilities and discharges directly to effluent treatment. Effluent coming from the quarantine facility will be chlorinated and dechlorinated prior to discharge. Aeration and emergency oxygen supplementation are available. The quarantine building and research facility are isolated from the rest of the hatchery complex by a perimeter fence. All vehicles which have access to the hatchery complex beyond the research/quarantine compound must pass through a disinfectant washdown station prior to entry. Effluent from vehicle washdown is tied into the dedicated sewer which services the quarantine facilities.

Assumptions made for development of disease and quarantine facilities as described in this section are as follows:

- Threat of disease outbreaks is always present under culture conditions.
- Routine washdown and disinfection facilities are an integral part of the hatchery design to maintain cleanliness.
- Quarantine facilities are necessary for protecting the hatchery complex against pathogenic contamination from outside sources.
- Quarantine facilities must be supplied with an independent water supply and effluent discharge system.
- Quarantine facilities must be isolated by distance from the rest of the hatchery complex culture areas.
- Standardized disinfection procedures must be implemented to isolate the quarantine area from the rest of the hatchery complex.

6.4 WATER TREATMENT PROCESS

As a part of the feasibility study, three different hatchery water supply sources were to be evaluated relative to treatment requirements and construction costs. Specifically, the three different supply sources are from a surface water source (river) and from two different well sources (warm - 69°F average and cold - 57°F average) were to be explored. The basic hatchery complex for this study was designed around the warm water well (69°F) as the least costly alternative.

Due to the water temperature requirements of the various life stages of the species held and reared at the facility, some temperature control may be an essential element for most of the water supply systems within the facility compound. Heating or cooling requirements will be a function of the temperature of the incoming supply and the needs of the specific life stages of the fish or the artificial conditions being created. To best achieve the flexibility necessary to meet the varied demands, the facility has been configured to provide heating and cooling units for each specific function where desired. The facility configuration also allows for the delivery of source water without tempering when conditions dictate or will allow for.

For surface and cold well water supplies, elevated water temperatures (69°F) are required for intensive rearing. This will be accomplished through the use of heating and heat exchange systems which will capture as much hat as possible from the effluent.

Heating water will create elevated dissolved nitrogen levels which are undesirable for fish rearing. Heated water must then be treated through the use of degassifica-tion/aeration columns to restabilize dissolved gas levels. Stabilization can be accomplished through the use of degassification columns located on or near the actual fish holding/rearing facilities.

The facility is intended to be a duel backup system controlled by the alarm/monitoring systems described in Section 5. These backup systems include emergency standby power generation sized to provide power to all essential facilities. Additional backup will be provided from the liquid oxygen system housed onsite. This system will activate upon interruption of water flow to any rearing unit onsite.

6.4.1 Surface Water

The use of a surface water supply must consider the potential for the introduction of undesired larval fish, bacteria and disease bearing organisms. Debris, organic matter and sedimentation can also be a problem during certain seasons.

The surface water supply system will include macroscreening at the river intake to exclude fish, debris and sediment. This will be followed by a sediment removal system and then a microscreen system to exclude all particles of a size greater than 100 microns. Following screening, water will be pumped to develop sufficient pressure for disinfection treatment by ozonation (through an ozonation tower and desaturator) followed by a pass-through aeration column to stabilize dissolved gases (specifically oxygen) at saturated levels. Figure 6.2 indicates the direction of the process water flow through the various rearing, holding and experimental units for a surface water facility.

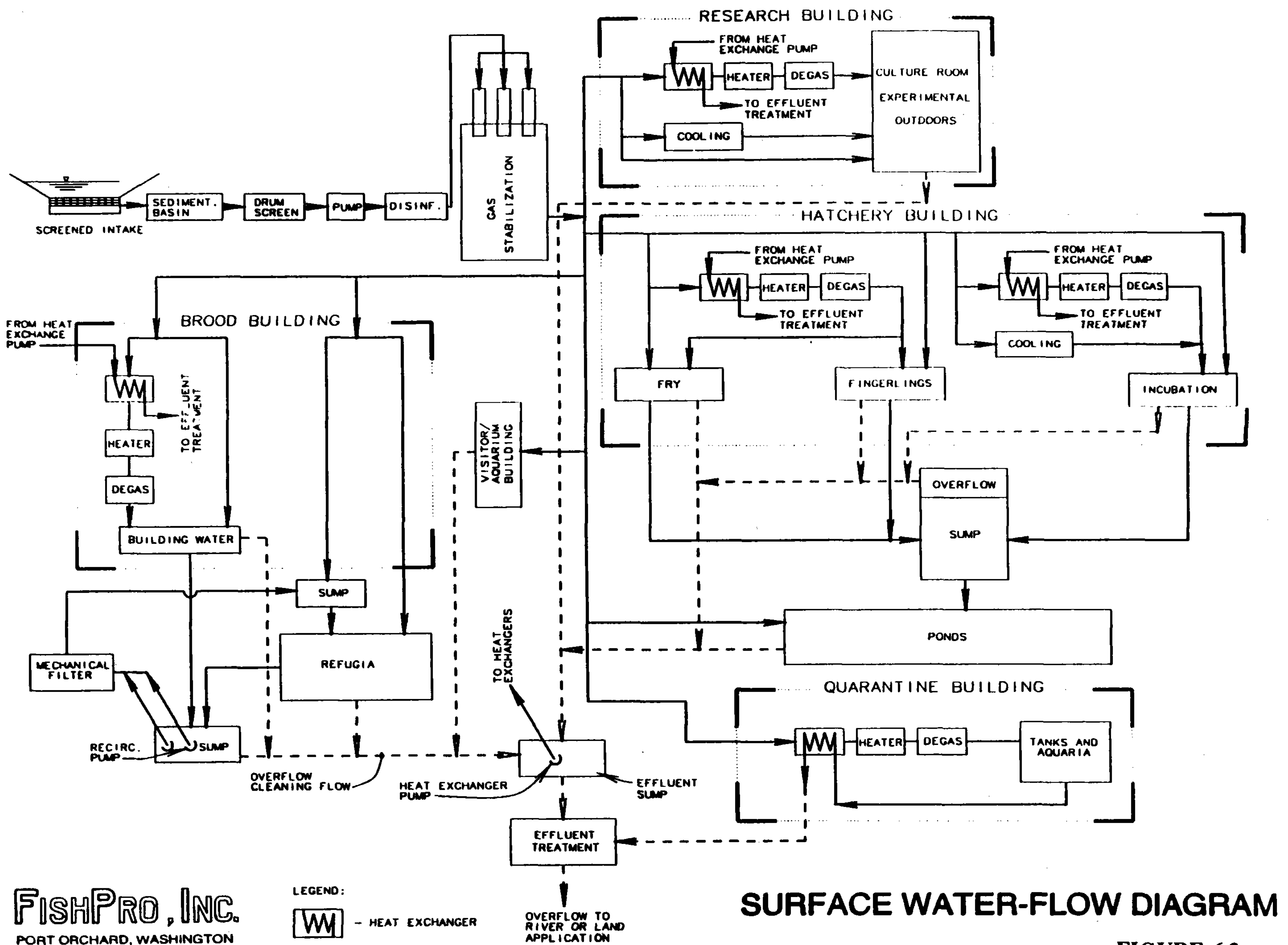
6.4.2 Well Water

Ground water supplies from wells do not require the same treatment considerations as surface water as there are no concerns with water-borne particulate matter. Ground water is typically supersaturated with nitrogen which must be removed through a degassification process involving a pass through a sealed column. After degassing, the ground water is then aerated to both stabilize the dissolved gases while allowing for dissolved oxygen levels to rise to near saturated conditions (95%). Figures 6.3 and 6.4 indicate the direction of the process water flow and the various treatments applied through the rearing, holding and experimental units for cold well water and warm well water supplied facilities. There are some ramifications, both economic and biological which depend on water source.

There is a significant O&M cost associated with heating and cooling process water to maintain ideal culture temperatures. The highest cost would be associated with heating cold well water where there is a large temperature differential between it and the desired culture temperature of 69°F.

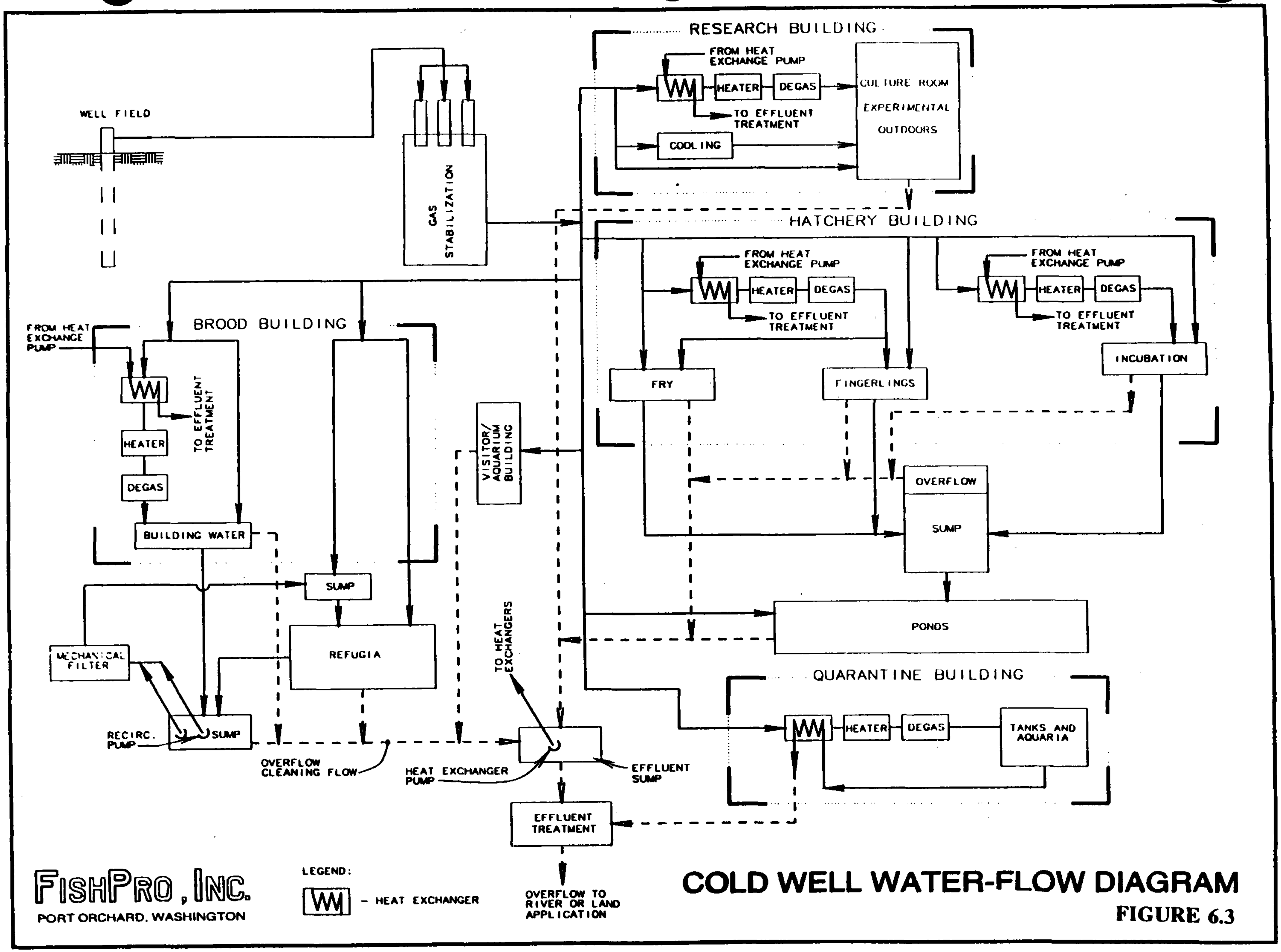
6.4.3 Effluent

Effluent treatment will consist of screening for removal of major solids, and ponds for removal of settleable solids. Discharge from the research building will be first directed to a pretreatment pond to allow for any special treatment (oxidation, chemical neutralization, disinfection) that may be required for conditions created by research programs. Flow which passes through the screen will be directed to a settling pond for eventual discharge. Screenings will be collected and directed to a pond for removal of settleable solids and to allow for sludge thickening (Figure 6.5).



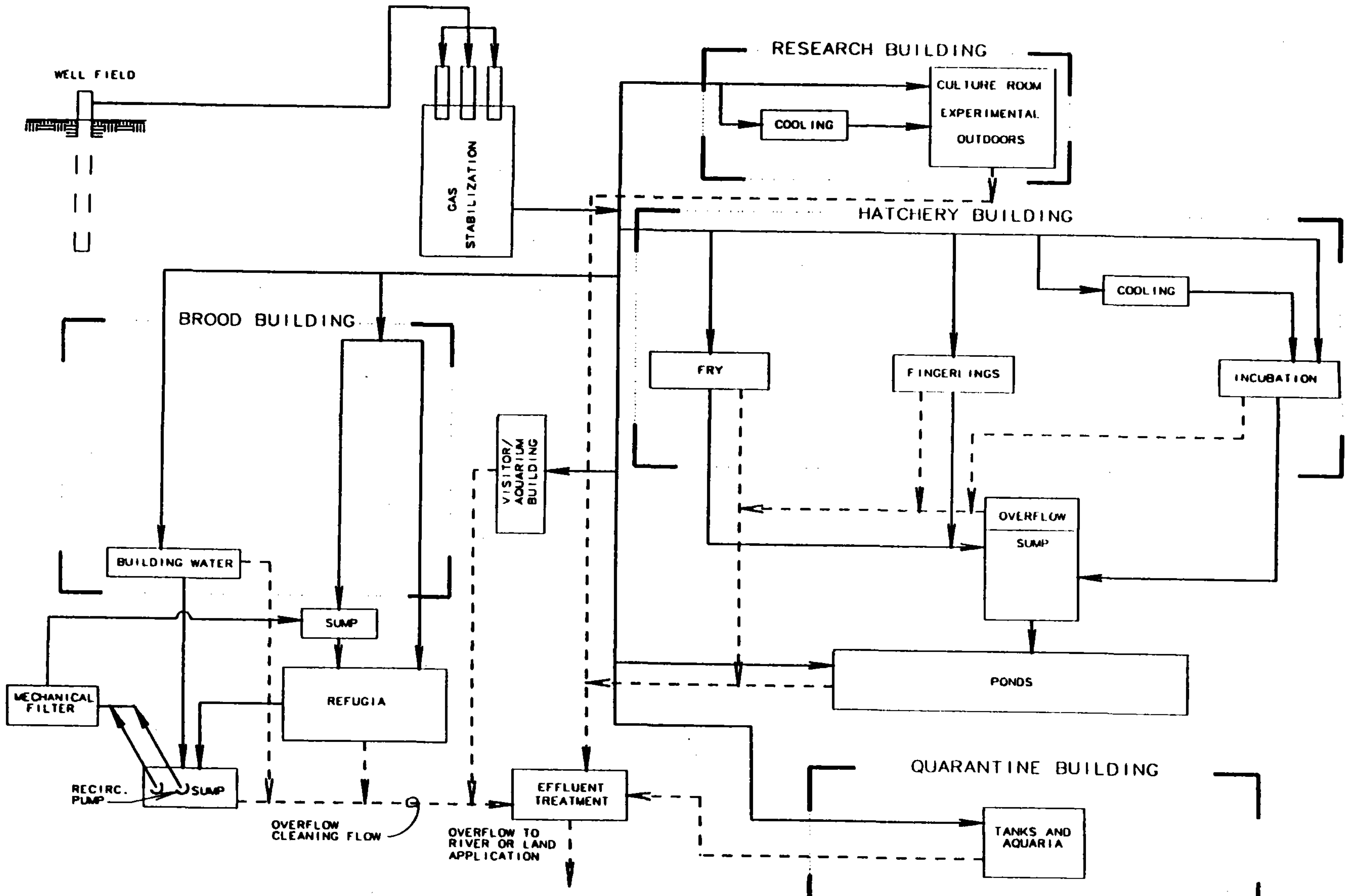
SURFACE WATER-FLOW DIAGRAM

FIGURE 6.2



COLD WELL WATER-FLOW DIAGRAM

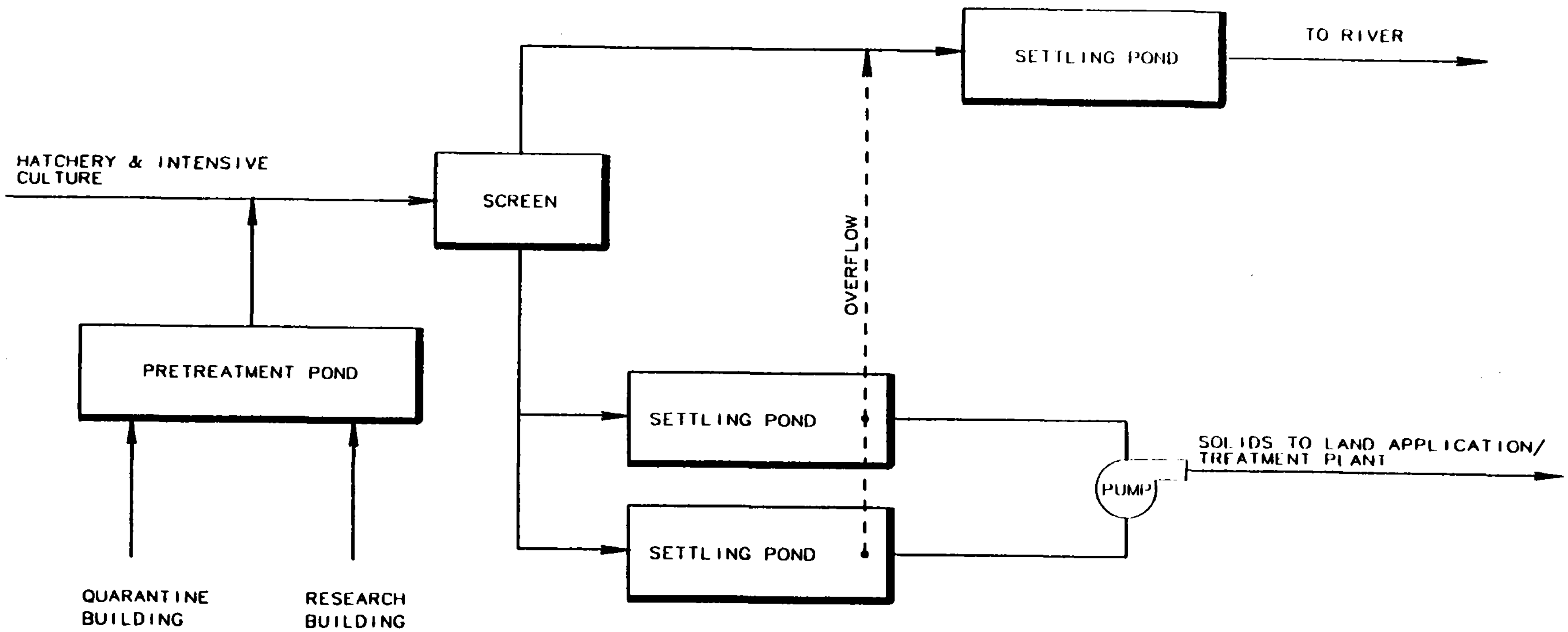
FIGURE 6.3



FISHPRO, INC.
PORT ORCHARD, WASHINGTON

WARM WELL WATER-FLOW DIAGRAM

FIGURE 6.4



EFFLUENT TREATMENT PLAN SCHEMATIC

FISHPRO, INC.
PORT ORCHARD, WASHINGTON

FIGURE 6.5

6.5 FACILITY LAYOUT

The general layout of the proposed endangered species facilities reflects intentional compactness and a logical organization of the various components. Specific hatchery components described in this section may vary, dependent on the selected hatchery site. The site is oriented with the visitor and education center at the front adjacent to the primary access into the facility. Augmentation ponds occupy approximately one-half of the facility space with all other components occupying the other half. Sheet No. 1 located on the following page, is a site layout for Scenario 2 (300,000 fish/species). Sheets No. 12 and 14 reflect Scenario 1 (150,000 fish/species) and Scenario 3 (600,000 fish/species) layouts respectively, and are part of the drawings prepared for this study which are located in Appendix H.

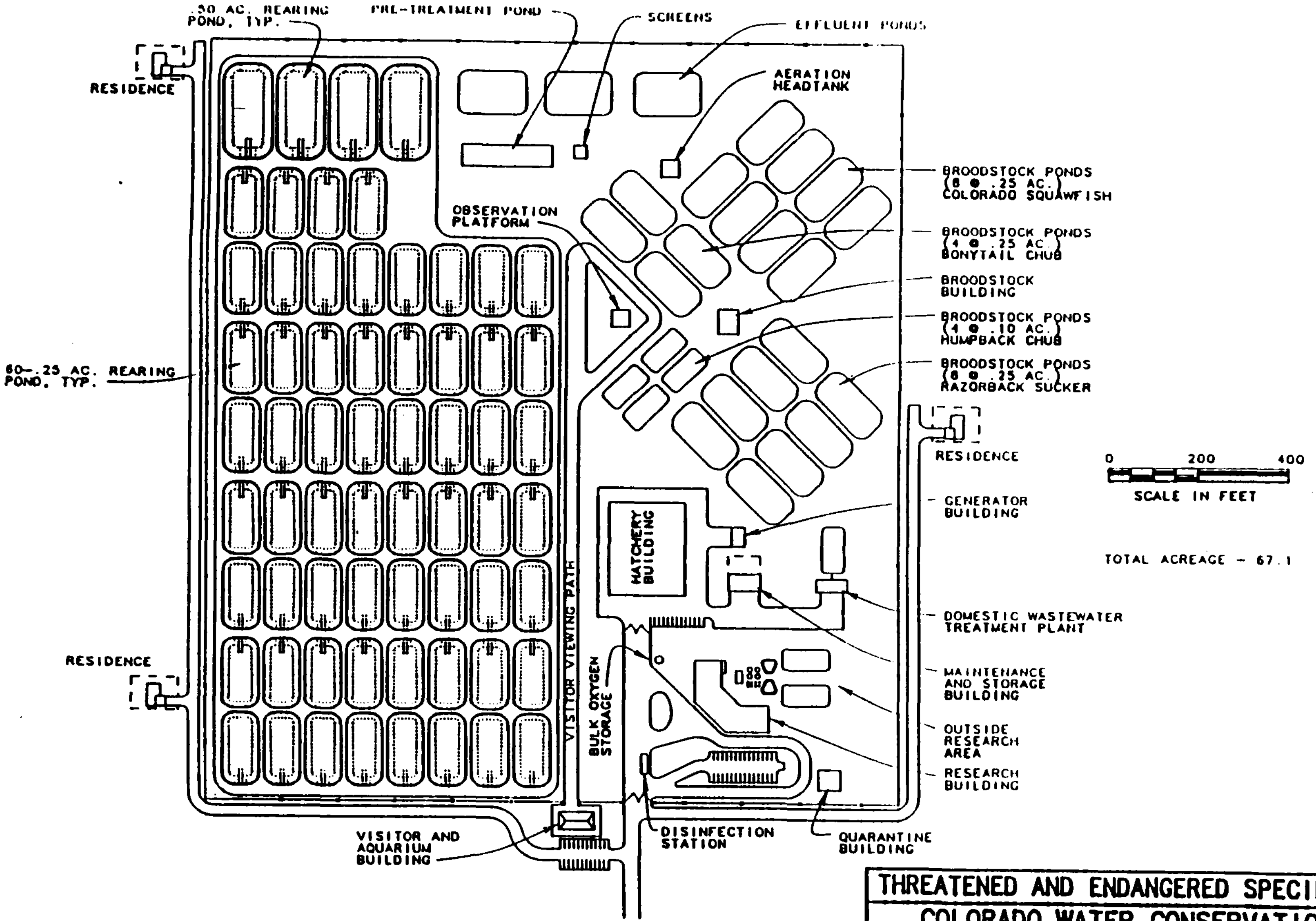
Security

Restricted access to the site is considered to be an important design feature. All production facilities are protected within a limited access enclosure. Controlled vehicular access is provided to the site. This provides for 1) decontaminating service vehicles, and 2) restricting contaminated vehicles which could introduce disease pathogens to the facility. Restricted access would also reduce the threat of vandalism and theft and prevent mammals which may prey on fish from invading the facility.

Security will be provided by a partially buried steel perimeter fence topped with barbed wire and locking passage gates. The main vehicle gates will be secured by cardlock system. Three single family bungalows will be constructed for the use of facility personnel. Besides providing onsite living space for employees these houses will augment the security of the facility by placing them adjacent to the outside of the perimeter fence at strategic points which overlook key areas within the site. Because these residences are situated outside the fence, personal visitation will not interfere with the security of the facility.

Parking

Three general parking areas are planned. The visitation and education center will be provided with a parking lot located outside the perimeter fence. This parking lot will be open to the public allowing unrestricted access. Parking spaces will be provided for general



THREATENED AND ENDANGERED SPECIES FACILITY

COLORADO WATER CONSERVATION BOARD

SITE PLAN—SCENARIO 2—WARM WELL WATER

DESIGNED KF/ED DRAWN AB CHECKED KF	FISHPRO, INC. PREPARED FOR THE URS TEAM	DATE 7/17/92 SHEET NO. 1

vehicles including buses and RVs. Inside the compound two designated parking areas are planned. Parking will be by permit only and will be provided to research staff, service vehicles, and for visiting scientists on a temporary basis. A decontamination vehicle washing station will be provided for service vehicles at a suitable location onsite. A hatchery parking area is provided for personnel of the hatchery and broodstock/refugia areas.

Main and Ancillary Structures

The primary components of the facility are housed in individual buildings onsite and are placed according to their function and relationship to the rest of the facility.

The hatchery building is the most centrally located structure on the site so that it is in close proximity to the brood facility as well as the augmentation ponds. The broodstock component consists of holding ponds situated radially to the broodstock building. The broodstock building is well placed in proximity to all brood holding ponds so that broodfish manipulations (e.g., feeding, treatment, tagging) and spawning functions can be easily accommodated. The open space arrangement of the brood holding ponds was designed to provide access for public viewing of the broodstock/refugia habitats, as well as to provide separation to limit the spread of disease pathogens.

The research building is positioned near the entrance to the facility primarily for its visual appearance and because it is the destination for most of the transient traffic coming to the facility. It is positioned so that there can be restricted access to the rest of the facility. An outside research area lies adjacent to the research building away from the augmentation ponds in order to lower the risk of cross-contamination. The quarantine facilities are also provided outside of the restricted access area of the hatchery complex to cut down on the risk of contamination from offsite.

An auxiliary electrical generation plant is provided in a position central to primary electrical consumption at the facility. The generation plant is sized to provide standby power for all areas in the facility which are essential to fish culture operations. The plant is completely self-contained including onsite fuel storage.

A maintenance/storage building is located central to the facility adjacent to the hatchery building. This building houses a work shop, two small vehicle, and one large tanker vehicle storage bay.

A domestic wastewater treatment plant providing tertiary treatment of domestic sewage is included. Primary and secondary treatment includes extended aeration and/or contact stabilization. Secondary treated effluent will be passed to a tertiary treatment pond onsite. Domestic wastewater from all buildings onsite and the visitor and education center will discharge to tertiary treatment. Aeration and supplemental oxygen are provided to all fish culture areas of the complex.

Potable Water

Potable water will be supplied from a separate well dedicated for domestic use or from a production well with separate independent chlorination treatment. All domestic water will be treated to drinking water standards. All potable water lines and valves will be independent and separate from those pipelines and valves which service the fish rearing facilities, in order to guard against accidental chlorination of rearing waters.

Escapement

All augmentation ponds are spaced a minimum of 12.5 feet apart to allow access and to limit escapement between ponds. There will be no stacking of culture vessels, tanks or troughs to limit accidental mixing of tank populations. All water lines entering and leaving ponds will be screened. All water lines coming from river sources and discharging to receiving rivers will be adequately screened to prevent escapement. Settling ponds will also be used to prevent escapement of fish eggs and larvae.

Bird Predation

Protection against bird predation will be provided by arrays of parallel spaced braided-strand stainless steel wire spanning the short width of the holding ponds. The wires will be spaced according to the types of predator birds present and will be permanently attached to the rim of the ponds.

Alarm/Monitoring Systems

It is intended that all rearing systems will be monitored for water level, flow and dissolved oxygen levels at critical points. This information will be recorded through a computer system and connected to an appropriate alarm sequence. Alarm systems will also include intruder monitoring. Alarms will activate in the occupied facilities, residences and through a telephone paging system (Drawing No. 11)

Assumptions:

- The site is laid out with a high degree of security to insure against loss of valuable endangered fish stocks.

- Controlled public access is provided to visitor and educationally oriented facilities to encourage public involvement in the endangered species recovery.

- Restricted access to the production areas of the hatchery is provided to insure the security of the complex.

- An integrated approach was used in the design of the hatchery which takes into account the special needs of an endangered species recovery program.

6.6 COST ESTIMATE

6.6.1 Construction Costs

The feasibility level design prepared for this study includes a hatchery building, rearing ponds for propagation and augmentation stocks, ponds for holding broodstock and for refugia, a research building and outside research facilities, three on-site residences for hatchery workers, a visitors center and aquarium building, and other related facilities. The design of this recovery facility provides design and cost information for those components and facilities which would be part of a model facility. This information can be used to assist in the final selection of the actual recovery facility components; selection of the site, and also serves as a starting point for preliminary facility design.

Conceptual design cost estimates presented here are preliminary; most details of the project will be determined in later preliminary engineering design phases after a site is chosen. In the present analysis, overall facilities costs are estimated on a comparable unit or system cost basis to provide an opinion of probable cost.

The basis for the projections in this section consist of the following:

- FishPro estimating data base; approximately nine years of comprehensive cost data from actual hatchery construction costs.

- Reference manuals; appropriate application of current Means and Dodge estimating manuals.

- Professional judgment; experienced engineers and design technicians take into account the specifics of this project, current changes in equipment/ construction costs, vendor information and any other unique relevant issues.

All material quantities were estimated from the scaled drawings developed and included in the appendix of this report. Where quantities are not directly measurable, they were developed from engineering experience with similar work. Unit pricing was developed from sources such as estimating handbooks, vendor contracts, awarded contract pricing and other similar current cost estimates.

Items or unit costs associated directly with onsite facilities such as refugia or the research building were itemized by sub-facility. Items such as site work, utilities and other similar items which are common to all sub-facilities were estimated using engineering judgment on a percentage basis. Costs are based on production Scenario 2 - 300,000 fish for each of the three water supply types, and are presented in Tables 6.6, 6.7 and 6.8. The estimates are given in 1992 dollars.

The costs are segregated into the three major components of the recovery facility: the fish hatchery; the broodstock and refugia holding ponds and the research facility. These cost estimates do not include acquisition costs for land or improvements, including any existing hatchery facilities.

Estimated operation and maintenance costs have been developed and are also presented in Tables 6.6, 6.7 and 6.8. Given the nature of this feasibility study, operation and maintenance costs are based on a number of different criteria. Considerable use was made of experience with hatchery operations elsewhere. Direct quotes of charge rates for utilities in the Upper Colorado region were factored into the analysis. Labor rates were established based on current standards which exist for various professional categories that apply to hatchery operations. The costs for material items were established based on quotes from manufacturers.

Key assumptions used for development of operation and maintenance costs include:

- Feed costs projected on annual basis.
- Feed cost of $0.71/lb (average of annual feed costs for FishPro Hatchery).
- Feed consumption for intensive culture at 2.2% body weight/day from bioprogram.
- Feed consumption for extensive culture at 0.2%/day.
- Feed consumption for refugia at 0.5%/day.
- Assume 6 ectoparasite treatments per growth cycle for all intensive culture tanks.

The operation and maintenance costs represent all functions to be performed on-site with the exception of the research program. Details on the extent of research programs, who will conduct them, and changing priorities over time prevent accurate estimates of costs. These estimates would remain relatively constant regardless of site selection. Operation and maintenance costs for the research building which are associated with water quality, pathology and other services connected with the propagation of fish are included.

Full time personnel requirements for the facility have been estimated for each production scenario. Personnel categories include: facility manager, assistant facility manager, laboratory technician, fish culturist, maintenance engineer, plant engineer and receptionist. The estimated number of full time equivalent personnel are 6, 9, and 10 for production Scenarios 1, 2 and 3 respectively. Land requirements for each type design are also including in the tables.

Cost estimates for Scenarios 1 and 3 were estimated by subtracting or adding components to Scenario 2 facilities and adjusting the cost using an appropriate percentage factor. Table 6.9 presents the estimated total cost for the recovery facility for each of the three production scenarios for each water supply type. Table 6.10 presents the estimated cost for just the core facility for each of the three production scenarios for each water supply type. Costs listed in Tables 9 and 10 are total capital construction costs plus a 25 percent contingency factor. The contingency figure includes variations for the level of detail at this stage of design, engineering fees and general permitting costs. Itemized cost tables and summaries have been prepared separately for the three production scenarios and for each of the three water sources and are presented in Appendix I.

TABLE 6.6

COSTS AND REQUIRED LAND
WARM WELL WATER SUPPLY (SCENARIO 2 - 300,000)

	Recovery Facility Components					
	Core Facility	Refugia/Broodstock	Research	Total	Operation and Maintenance	Required Land(b)
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs(a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Laboratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$15,567,000	$2,603,000	$3,011,000	$21,181,000	$756,000	67

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
A/E Fees (9.5% of Total)
Permits (.5% of Total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 6.7

COSTS AND REQUIRED LAND
COLD WELL WATER SUPPLY (SCENARIO 2 - 300,000)

	Recovery Facility Components					
	Core Facility	Refugia/Broodstock	Research	Total	Operation and Maintenance	Required Land(b)
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs(a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Laboratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$19,551,000	$2,664,000	$3,010,000	$25,225,000	$979,000	81

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
Additional cost for heaters and heat exchangers
A/E Fees (9.5% of Total)
Permits (.5% of Total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 6.8

COSTS AND REQUIRED LAND
SURFACE WATER SUPPLY (SCENARIO 2 - 300,000)

	Recovery Facility Components					
	Core Facility	Refugia/Broodstock	Research	Total	Operation and Maintenance	Required Land(b)
	Residences (3) Hatchery Building Maintenance/Storage Facility Visitor Aquarium Facility Production Ponds Brood Ponds (Augment Only) Rearing Water Supply Other Associated Costs(a)	Quarantine Building Broodstock Building Brood Ponds Broodstock Water Supply Other Associated Costs (a)	Research Building Outside Research Laboratory Equipment Other Associated Costs (a)	All Options	All Functions	Acres
Totals	$21,739,000	$3,027,000	$3,080,000	$27,846,000	$1,032,000	87

(a) Other associated costs may include some or all of the following:
Site work
Utilities
Emergency Power Generation
Gas Stabilization Tower
Miscellaneous Structures
Effluent Treatment
Yard Piping
Oxygen System
Monitoring and Alarm System
Fish Rearing Equipment
Process Water Conditioning
Additional cost for heaters, heat exchangers and disinfection equipment
A/E Fees (9.5% of Total)
Permits (.5% of Total)
Contingency (15% of Total)

(b) Land costs not included due to unspecified site location.

TABLE 6.9
CAPITAL COST ESTIMATE COMPARISON FOR TOTAL RECOVERY FACILITY

PRODUCTION SCENARIO	WATER SOURCE		
	Warm Well	Cold Well	Surface
1	$16,117,000	$17,905,000	$19,836,000
2	$21,181,000	$25,225,000	$27,846,000
3	$31,080,000	$39,167,000	$43,685,000

NOTE: Totals include 25% contingency.

TABLE 6.10
CAPITAL COST ESTIMATE COMPARISON FOR CORE FACILITY

PRODUCTION SCENARIO	WATER SOURCE		
	Warm Well	Cold Well	Surface
1 (150,000)	$9,946,000	$12,754,000	$14,388,000
2 (300,000)	$15,567,000	$19,551,000	$21,739,000
3 (600,000)	$24,919,000	$33,049,000	$37,950,000

Assumptions - The following assumptions were used in developing the conceptual level probable costs:

- Designs/layouts are configured to reduce O&M costs.
- Site is adequately sloped for a cut/fill balance so that no offsite borrow is required.
- No problems with groundwater table exist so that protective features are not required.
- Crushed rock, sand, structural fill, concrete and asphalt are available within a 25 mile radius of the site, so that long haul charges are not a concern.
- The main entrance and research building parking lots are to be asphalt paved. All other roads, driving surfaces/yard areas around sites, buildings, and ponds are to be crushed rock surfacing.
- Site is adjacent to river, but not in a floodplain that would require protective features.
- Adequate well and/or surface water is available for required flows.
- Soils are adequate for structural bearing without any requirements for special treatment measures.
- Landscaping costs (except residence sod) have not been included.
- Irrigation system costs have not been included.
- Site has adequate electrical power available and will not require extra expenditures to develop.
- Potable water is to be from a well and disinfection by ozonation or chlorination has been included.

- Sewage will be pumped from their source to a packaged treatment plant. This plant will handle sewage for all site facilities and residences.

- The site has telephone service available and will not require extra expenditures to develop.

- Process well water supply (if used) is onsite and would not require clarification and disinfection.

- Gravity flow is possible through the site with one river pump station providing required flow (for surface water).

- More costly disinfection system (ozone) is assumed, may be cheaper alternatives.

- Liners are included for all ponds, soils at certain sites may not require lining of ponds.

- Adequate construction time frame is provided.

- All heating systems are based on natural gas.

- Predation systems required for all rearing ponds.

- Construction unit prices include all contractor overhead, profit and mobilization costs along with all electric, HVAC, and plumbing.

- Yard piping same for well water or surface water supply.

- Site fire protection design not considered in water supply system, but should be included in the actual design of the facility independent on available services.

- Additional ponds are required for cold water and surface water options for each scenario.

- Warm water wells are assumed to be 1,000 feet deep and rated at 1,000 gpm each.

- Cold water wells are assumed to be 500 feet deep and rated at 1,000 gpm each.

- Process water cooling equipment is assumed to be with packaged units chillers, however, other methods are feasible and may be more cost effective depending upon the site.

- Process water heating equipment is assumed to be with packaged boiler units, however, other methods are feasible and may be more cost effective depending upon the site.

- Mitigation for any environmental issues are not included.

- Generator will be sized to provide power to operate process pumps, sewage pumps, essential water heating/cooling equipment and monitoring/alarm systems.

- Buildings are to be energy efficient and constructed to latest energy codes.

- Building costs do not include automatic fire extinguishing systems.

- Residences are of medium quality construction with 1,800 sq. ft. of living area (3 bedrooms, 2 baths) and will also include: attached 2-car garage, all kitchen appliances, concrete driveway/entrance walk, heat pump system and perimeter 4 foot high chainlink fence.

- No costs for land included.

- Nutrition laboratory construction costs not included.

SECTION 7.0

ISSUES AND PERMITS

7.0 ISSUES AND PERMITS

During the preparation of this study, technical and biological issues were raised which impact the site evaluation and design process and which must be considered in more detail as the site selection is made and the design of the recovery facility is initiated. These issues are briefly described below.

Issues

- The need for a hatchery and/or a research facility for the recovery of the endangered fishes;
- The need and level of production for augmentation and for research;
- The role of the recovery facility for broodstock holding or refugia;
- Determination of the numbers of genetically individual subpopulations for each species;
- Use and mix of intensive and extensive fish culture techniques;
- Type of hatchery water supply and the impact on fish growth, health, genetics, imprinting, survivability in the wild, and hatchery capital and operation costs;
- Hatchery location and proximity to native habitats;
- Role of the proposed hatchery and research facility in the overall recovery program;
- Responsibility for construction of the hatchery and research facility;
- Responsibility for operation of the hatchery and research facility;

Permits

Construction of a hatchery or the complete recovery facility, will require a number of permits from federal, state and local agencies. Given that the current scope of the study is for a conceptual design and is not based on a specific site, it is not possible to determine the specific permits which would be required for a specific site. The following are descriptions of permits which could possibly be required and should be evaluated for compliance as necessary.

- Environmental Assessment
- Environmental Impact Statement
- Colorado NPDES permit

- Colorado wastewater discharge permit
- Construction dewatering permit
- Corps of Engineers 404 Permit
- Zoning permit
- Building permits
- Water Rights
- Endangered Fish Permit

GLOSSARY OF TERMS

Augmentation stock - Those fish which are released for the purpose of increasing the existing fish population.

Biomass - The pounds of fish which are either maintained or produced at the recovery facility. The capacity of the facility to hold and grow fish is expressed in terms of pounds of fish or total biomass.

Bioprogram - A computer spreadsheet program based on empirical and published data to predict growth and culture requirements for fish. Species specific data and other input parameters are used to predict space, flow, feed and water quality conditions for fish culture facility planning.

Broodstock - Fish of a particular species and population or stock, represented by both sexes which are held in captivity until and during maturity for the distinct purpose of breeding. The genetic history of these animals, is usually known and they are usually bred according to strict protocols designed to maintain a level of genetic diversity in the progeny. For the purposes of this facility, refugia and broodstock populations are considered the same.

Culture Techniques - Different methods used to produce fish. For purposes of this study, the two types of culture techniques used are intensive culture and extensive culture.

Extensive Culture - A culture methodology which emphasizes natural rearing conditions for fish. Under extensive culture, conditions fish are reared at low density in outdoor ponds. Rearing is conducted at ambient temperatures and natural food items are encouraged to grow in the pond environment. This strategy may reduce undesirable genetic selective forces associated with intensive culture. This method requires less water and more land than intensive culture.

Intensive Culture - A culture methodology designed to achieve maximum productivity for fish held in artificial culture environments. The fish are held at higher densities in tanks or raceways and fed artificial food. Rearing temperatures are held at levels which achieve maximum growth rates. Water flow rates are high to maintain water quality by carrying away waste products, and excess feed. The primary goal of intensive culture is to achieve maximum fish production for a given rearing space, while maintaining healthy stocks of fish.

Refugia - Individual fish representing genetically distinct stocks of a particular species, held in captive habitat. These fish are usually held in reserve for use as future broodstock, and to provide protection for a declining number of endangered fish in the wild. The purpose of refugia fish is to maintain the genetic diversity of a species by maintaining representative examples of distinct, genetically diverse strains from specific native habitats. The term is also used to describe the place where these fish are held.