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COMPILATION REPORT ON THE EFFECTS OF RESERVOIR RELEASES ON DOWNSTREAM ECOSYSTEMS

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16. ABSTRACT
Most of the dams built by the Bureau of Reclamation were completed before environmental regulations such as the Clean Water Act, National Environmental Protection Act, or Toxic Substances Control Act existed. The management and operation of dams was instituted under conditions where the ecology of the downstream habitat was unknown and largely ignored. Changing or modifying structures, flow regimes, and land use patterns are some of the efforts being pursued by the Bureau to reconcile or mitigate the effects of impoundment to comply with these environmental policies and to maximize the potential for recreation, fisheries, and water quality in tailwater habitats for the water resource users. The purpose of this report is to provide a reference document intended to aid in the management, compliance, and problem solving processes necessary to accomplish these goals in Bureau tailwater habitats.

This report was organized by categorizing each reference with the Bureau region in which the information originated. Each of the five regions is discussed in a separate section, with each section containing a complete bibliographic reference for each literature citation. Included with each bibliographic entry is additional information about the State, county, dam, and drainage associated with the literature. A subject code is also listed that categorizes the literature into one of five main subject categories, and one or more letters that may indicate specific subcategories.

Each regional section of this report begins with a discussion of the information available for that region, problem tailwater areas, and a discussion of the literature covering the five subject categories. This will allow the user to locate a tailwater by region, State, county, or drainage; and to determine if any literature is available for that tailwater and what subjects that literature covers.

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CONTENTS

INTRODUCTION

The term "tailwater" has two distinct meanings depending on whether the water flowing from an impoundment is being viewed hydrologically or ecologically. Hydrologically, the tailwater may be considered to be the segment of a stream below an impoundment that can be affected by changes in the velocity, volume, depth, and frequency of discharge. This segment is relatively short and may consist only of the tailrace, stilling basin, or an afterbay. Ecologically, the tailwater is the segment of a stream below an impoundment that is hydrologically, physicochemically, and biologically altered by the presence and operation of the impoundment. The ecological tailwater may be relatively long, persisting downstream to the confluence of an unregulated water source.

Tailwaters are intrinsically different from unregulated streams and rivers. Four sources of general information discussing these differences are: (1) *The Ecology of Regulated Streams* (Ward and Stanford, 1979) [140][1]; (2) *Effects of Reservoir Releases on Tailwater Ecology: A Literature Review* (Walburg, *et al.*, 1981) [135]; (3) *Environmental Effects of Dams and Impoundments* (Baxter, 1977) [11]; and (4) *Improving Reservoir Releases* (Tennessee Valley Authority, 1984) [127].

Impoundments usually alter a stream or river both physically and biologically. Physical alterations include changes in naturally occurring flow regimes. Flows below many impoundments differ from naturally occurring flows and generally exhibit less fluctuation. Although flows in a tailwater may increase and decrease, the change in a flow may occur over a longer time period. Flooding is also less likely to occur in a regulated tailwater system. In the desert Southwest, water may be present in stream channels year round when, before a dam was built, stream channels carried flows intermittently.

Turbidity in streams and rivers below impoundments is reduced because the reservoir behind the dam acts as a settling basin for fine sediments. Water temperatures in the tailwater may be reduced relative to naturally occurring thermal regimes depending on the level of water releases from the reservoir behind the dam. Water quality parameters such as dissolved oxygen concentration, pH, and nutrient and trace metal concentrations may also be affected by changes occurring within the reservoir.

[1] Numbers in brackets refer to entries in the Bibliography for this section.

Biological differences between tailwaters and unregulated systems result from the physical changes in the stream or river that resulted from impoundment. Stabilization of flows and reduction of turbidity in the water below the dam may result in armoring of the streambed and may reduce the abundance of invertebrates, unless rooted aquatic weeds or filamentous algae provide habitat.

Macroinvertebrates life cycle cues are often dependent on the physical conditions that exist in natural streams. The seasonal changes in temperature and flow, and the presence of spates and/or turbidity may be required elements for growth and reproduction for many species. After a dam is closed, a permanent change in the macroinvertebrate population occurs because the species no longer receiving the proper environmental cues to grow and reproduce, disappear from the tailwater habitat.

Other ecological changes that may occur following stream impoundment in the tailwater habitat include the following:

- The reduction of turbidity and increased nutrient concentrations in water releases may promote the growth of attached algal species such as *Cladophora*, resulting in nuisance quantities of this algae, which reduces the carrying capacity of the stream.
- Conversely, sediment loading below an impoundment that increases or stays the same can result in sedimentation of the substrates in the streambed below the dam, which may reduce or eliminate the habitat necessary for successful fish spawning or macroinvertebrate occupation.
- Rapidly fluctuating flows or flow regimes that are unsuitable during critical fish spawning periods may decrease nesting success, egg and fry survival, decrease macroinvertebrate productivity and community stability, and cause mortality of fish by stranding.
- A major change occurs when a thermal regime is stabilized because many organisms require a certain range or threshold temperature before reproduction, emergence, and molting can occur.
- A reduction of dissolved gases in water releases below a dam, specifically dissolved oxygen, may directly limit the species of biota which can survive in the tailwater environment.
- An increase in dissolved gases such as nitrogen may result in the phenomenon of gas supersaturation, which can cause gas-bubble disease in fish and macroinvertebrates.
- A dam may create a barrier to fish migration upstream for spawning and downstream for

movement toward the ocean, which is a requirement for many salmonid fish species to complete their life cycles.

When the Tailwater Ecology Project was initiated in 1983, it soon became apparent that the Bureau of Reclamation had already responded to many concerns about the ecology or water quality in tailwater areas throughout the 17 Western States. Other agencies such as the COE (Corps of Engineers) and the TVA (Tennessee Valley Authority) have developed management guides for tailwater habitats or have published definitive reports for managing and improving tailwater ecology. The purpose of this report is to provide a reference document for those persons actively concerned with management and improvement of Bureau tailwater environments.

The Bureau differs from both the TVA and COE in that our principal function for impoundment has been irrigation deliveries of water to previously arid farming regions. Flood control, municipal water supply, and power generation have been secondary purposes for impounding rivers and streams in the West. Most of the dams built by the Bureau were completed before environmental regulations such as the Clean Water Act, National Environmental Protection Act, or Toxic Substances Control Act existed. The management and operation of dams was instituted under conditions where the ecology of the downstream habitat was unknown and largely ignored. Changing or modifying structures, flow regimes, and land use patterns are some of the efforts being pursued by the Bureau to reconcile or mitigate the effects of impoundment to comply with these environmental policies and to maximize the potential for recreation, fisheries, and water quality in tailwater habitats for the water resource users. The information provided in this report is intended to aid in the management, compliance, and problem solving processes necessary to accomplish these goals in Bureau tailwater habitats.

This report was organized by categorizing each reference with the Bureau region in which the information originated. Each of the five regions is discussed in a separate section, with each section containing a complete bibliographic reference for each literature citation. Included with each bibliographic entry is aditional information about the State, county, dam, and drainage associated with the literature. A subject code is also listed that categorizes the literature into one of five main subject categories, and one or more letters that may indicate specific subcategories. These subject categories and subcategories are shown in table 1, and a sample bibliographic entry is shown on figure 1.

Table 1.- Subject category and subcategory codes used in bibliographic references.

Code Number	Subject Category	Code Letter	Subject Subcategory
1	Water Quality	a.	Physical-chemical parameters such as temperature, dissolved oxygen, pH, major ion concentration, trace metals concentration, and nutrient concentration.
		b.	Gas supersaturation
		c.	Aeration effects
2	Aquatic Ecology	a.	Macroinvertebrates
		b.	Fish
		c.	Zooplankton
		d.	Phytoplankton
		e.	Algae/aquatic weeds
		f.	Habitat constraints
3	Stream Regulation	a.	Peaking powerplant effects
		b.	Dam operation changes
		c.	Dam or structure modifications
		d.	Water release regime
		e.	Instream flow requirements
4	Modeling		
5	Wildlife	a.	Loss
		b.	Habitat
		c.	Mitigation

[Number] Author (s), Title of publication, article, document, etc; Edition; Agency or organization producing publication; Volume; Pages;Publisher; Location of Publisher (City); and copyright date or date of publication.

Region: State, County, Dam, River, etc.
Subject Code

Example:

[1] Hannan, H.H, "Chemical Modification in Reservoir-Regulated Streams," In: *The Ecology of Regulated Streams*, J. V. Ward and J. A. Stanford(editors), pp. 79-84, Plenum Press, New York, NY, 1979.

Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Code 1a.

Figure 1.- Sample bibliographic entry used in this report.

Each regional section of this report begins with a discussion of the information available for that region, problem tailwater areas, and a discussion of the literature covering the five subject categories. This will allow the user to locate a tailwater by region, State, county, or drainage; and to determine if any literature is available for that tailwater and what subjects that literature covers. This report should be especially useful for problem solving, contracting processes, design of structure modifications or aerators, evaluating proposed changes in operation, and determining future tailwater ecology needs.

A representational listing of literature on tailwater ecology is included in this introductory section to introduce the general concepts of this report and to show the extent of research activities in the subject area. The structure of the discussion in this introductory section will be followed throughout the report for each region's tailwater ecology literature.

Water Quality

The relationship between the physical-chemical parameters of water and the ecology of fishery resources is the main focus of almost all multidisciplinary tailwater investigations. Walburg, *et al.*, (1981) [135] state that three major physical modifications occur following the impoundment of a natural stream: (1) seasonal temperature changes are delayed, and natural fluctuations may be reduced; (2) high natural streamflows are reduced or eliminated and replaced by more uniform discharges; and (3) less sediment is transported. Thus, special attention has been paid to temperature, turbidity, and flow as potentially significant factors affecting the productivity and health of tailwater fisheries. Other physical-chemical factors that have received considerable attention are dissolved oxygen, nutrient and trace metals, and significant major ions.

In their general discussion on temperature in reservoirs, Smalley and Novak (1978) [114] state that temperature is the most important environmental factor to change significantly from impoundment construction, and that temperature is a primary influence on the resulting changes in physical, chemical, and biological events in the reservoir. The effect of discharge temperatures on tailwater fisheries is often dependent on the level within the reservoir from which the water is released and on the type of fish present. For example, cold discharges from a hypolimnetic release reservoir may stress downstream warmwater fish, while warm epilimnetic releases may stress downstream coldwater fish (Walburg, *et al.*, 1981) [135].

The effects of temperature on fish are addressed in several references in this introductory section. Adams, *et al.*, (1975) [1] discuss reduced salt water survival by steel head trout in moderate water temperatures. Cherry, *et al.*, (1975) [30] reported temperatures selected and avoided by fish at various acclimation temperatures. Coble (1967) [32] investigated the relationship of temperature to total annual growth in adult smallmouth bass. Coutant (1977) [39] presented comprehensive results on the temperature preferences of many fishes. Coutant and Carroll (1980) [40] discussed temperatures occupied by 10 ultrasonic-tagged striped bass in freshwater lakes. England and Fatora (1977) [52] reported on the effect of low-head impoundments on ambient trout stream temperatures. Gibbons and Sharitz (1974) [61] edited the proceedings of a symposium on thermal ecology that contains many papers on thermal tolerance, adaptation, population ecology, behavioral ecology, community ecology, productivity, diversity, and modeling of temperature. Richards, *et al.*, (1977) [104] presented an overview, with procedural recommendations, of temperature preference studies in environmental impact assessments. Smalley and Novak (1978) [114] discussed natural thermal phenomena associated with reservoirs. Stabler, *et al.*, (1976) [118] reported on the effects of altered flow regimes, temperatures, and river impoundment on adult steelhead trout and chinook salmon. Swink (1982) [122] presented the problems and promises of tailwater trout fisheries and included temperature as a variable. Walburg, *et al.*, (1981) [135] thoroughly discussed the effects of temperature on many fish species in their literature review on the effects of reservoir releases on tailwater ecology. Topics from these papers include temperature preferences of numerous fish species and the effect of temperature on salmonid ecology; e.g., spawning and migration, growth rates, distribution, and food resources.

Many documents in this introductory section contained significant information on the influence of temperature on invertebrates. The development of blackfly larvae (*Simulium vittatum*) at thermal increments from 17 to 27 °C was reported by Battelle Northwest (1973) [10]. Coutant (1967) [38] investigated the effect of temperature on the development rate of bottom organisms. The effect of temperature on the hatching time by mayflies (*Baetis rhodani*) was presented by Elliott (1972) [51]. Temperature effects on invertebrates are included in the proceedings of a thermal ecology symposium, edited by Gibbons and Sharitz (1974) [61]. Macan (1960) [79] evaluated the effect of temperature on the mayfly (*Rithrogena semicolorata*). Nebeker (1971) [89] discussed the effect of temperature at different altitudes on the emergence of aquatic insects from Big Cottonwood Creek, Utah. In 1973, Nebeker [90] reported the temperature requirements and life cycle of the midge *Tanytarsus dissimilis*. Spence and Hynes (1971) [116] included temperature effects in a report on the differences in benthos upstream and downstream of an impoundment. Walburg, *et al.*, (1981) [135] also included the effects of temperature on invertebrates in their literature review on the effects of reservoir releases on tailwater ecology. Ward (1975) [139] reported the effects of thermal constancy and seasonal temperature displacement on the community structure of stream invertebrates. Effects of temperature on invertebrates is also included in the volume on the ecology of regulated streams by Ward and Stanford (1979) [140]. Young, *et al.*, (1976) [152] reported the influence of a deep storage reservoir on the species diversity of benthic macroinvertebrate communities of the Guadalupe River in Texas. These papers included research on the characteristics of invertebrate populations that indicate a thermally stressed community; invertebrate temperature requirements; effect of temperature alterations from impoundments on emergence, development, respiration, and growth rates; and the effects of thermal constancy and seasonal temperature displacement on invertebrate community structure.

Tailwater research on turbidity emphasized reduced sediment transport from dams, resulting from sedimentation within the reservoir. Increased turbidity is possible by erosion from unstable riverbeds and stream banks during high discharge periods. General effects of erosion below dams is discussed by Taylor (1978) [125]. Other general treatments include a study by Flaxman (1966) [54] that describes the variables that influence rates of reservoir sedimentation, and a paper by Webster, *et al.*, (1979) [144] that presents a sediment transport model. The effects of sedimentation on fish include an investigation of reduced trout spawning capabilities and cover habitat from increased silt (Saunders and Smith, 1965) [108], a description of the direct effect of turbidity on fish (Wallen, 1951) [137], and a discussion of fish and invertebrate population fluctuations in response to varying inorganic sediment concentrations (Gammon, 1970) [59].

Several significant studies focused on sedimentation influences of invertebrate communities. Brusven and Prather (1974) [25] and Cummins and Lauff (1969) [42] investigated the effect of sedimentation on invertebrate distribution, and Corning (1970) [36] researched the benthos of eroding and sedimenting environments by evaluating the effects of suspended sediments and streambed load movements on invertebrate seasonal abundance and biomass. Cummins and Lauff (1969) [42] also determined microhabitat preferences of invertebrates by analyzing the importance of substrate particle size on their distribution.

Research on the effects of sedimentation on algae and zooplankton includes a description of a mathematical model to determine turbidity influence on algal productivity (Murphy, 1962) [88], and a study on the relationship between suspended materials and reproduction rates of zooplankton (Robinson, 1957) [106].

Studies on the effect of dissolved oxygen concentration on tailwater ecology include a general treatment of dissolved oxygen in streams and reservoirs (Bohac, 1982) [19], a discussion on the prediction and interpretation of reservoir hypolimnetic oxygen deficits (Cornett and Rigler, 1979) [35], and a study on the effect of reservoir hypolimnetic aeration on zooplankton distribution and fish production (Taylor, 1978) [125]. Dissolved oxygen levels in spawning gravels were frequently determined in fish spawning studies. Silver, *et al.*, (1963) [111] researched the differences in growth and survival of developing salmonid embryos in varying water velocities and dissolved oxygen concentrations.

One paper included in this introductory section emphasized water pollution. In 1974, the Bureau reported on a procedure development for predicting the mineral quality of return flow water from irrigated land (1974) [132]. Some papers discuss the use of invertebrates as indicators of water quality: Cummins, *et al.*, (1964) [43]; Hilsenhoff (1971) [66]; Spence and Hynes (1971) [116]; Whitaker, *et al.*, (1979) [150]; and Young, *et al.*, (1976) [152]. Marcus (1980) [82] researched algal response to chronic nutrient enrichment from a reservoir discharge.

Gas supersaturation can occur in the tailwater when water is spilled over the dam, and can result in gas-bubble disease in fish. Papers from this introductory section that address this problem included proceedings of a workshop on gas-bubble disease (Fickeisen and Schneider, 1976) [53]. This reference paper includes research presentations on the effects of long-term exposure to gas supersaturation, including alterations in blood chemistry and live-cage bioassays, as well as the effects of gas supersaturation on invertebrates and a review of monitoring and research methodologies. In addition, Rucker (1972) [107] conducted a critical review of gas-bubble disease in salmonids, and Katz (1980) [71] reviewed dissolved gas supersaturation literature in general. Schiewe (1974) [109] discussed the influence of atmospheric gas on swimming performance of juvenile chinook salmon.

Aquatic Ecology

Fish.-The most common tailwater ecology research considers the effect of dams on the quality and productivity of fisheries. Fishery management topics include creel censuses, stocking and introduction records, habitat analysis and enhancement, and fish mortality from man-made structures (e.g., fish screens, diversions, and turbines) and methods for preventing mortality. Studies on age-growth, length-weight, abundance, distribution, movement, and condition factors for fish are commonly reported in many documents. Baldes (1968) [7] reported on the microhabitat velocity occupied by trout. Barton, *et al.*, (1972) [9] presented a bibliography on the physical alteration (channelization) of aquatic habitats. The effects on fisheries is included by Baxter (1977) [11] in a report on the environmental effects of dams and impoundments. A bibliography of fish screens is presented by Bell (1978) [14]. Bell and DeLacy (1972) [15] presented a compendium on the survival of fish passing through spillways and conduits. Bell, *et al.*, (1976) [16] discussed the effects of peaking power on survival of juvenile fish at the Lower Columbia and Snake River Dams. Bentley and Raymond (1968) [17] reported on the collection of juvenile salmonids from turbine intake gatewells of major dams in the Columbia River system.

Dominy (1967) [45] presented information on the operation of Bureau reservoirs for recreational and fishery benefits consistent with other reservoir purposes. The relationship of lake population density to the size of young sockeye salmon (*Oncorhynchus nerka*) was discussed by Foerster (1944) [55]. Heman (1969) [64] investigated manipulation of fish populations to improve growth rates of largemouth bass in Little Dixie Lake, Missouri. The occurrence and distribution of larval fish in the Cumberland River was reported by Hess and Winger (1976) [65]. Holmes (1948) [67] presented comprehensive information on electric fish screens. Hubbell (1967) [69] presented a bibliography with abstracts from the literature on the ecology of impoundments. Kenyon (1981) [72] discussed the environmental effects of hydroelectric projects. Long (1968) [75] discussed diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. Long and Ossiander (1974) [76] reported on survival of coho salmon fingerlings passing through a perforated bulkhead on a spillway at Lower Monumental Dam on the Snake River, and Long, *et al.*, (1968) [77] researched fingerling mortality in kaplan turbines. The effects of river fluctuations resulting from hydroelectric peaking on invertebrates was discussed by MacPhee and Brusven (1973) [80].

The influence of reservoir discharge location on water quality, biology, and sport fisheries of reservoirs and tailwaters was reported by Martin and Stroud (1973) [83]. Mundie (1979) [87] presented information on regulated streams and salmon management. Pennak (1971) [97] discussed the effects of reservoirs on the classification of lotic habitats. Schoeneman, *et al.*, (1961) [110] reported on the mortalities of downstream migrant salmon at McNary Dam. The differences in benthos populations upstream and downstream of an impoundment was investigated by Spence and Hynes (1971) [116]. Stalnaker (1979) [120] discussed the use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Turner (1971) [131] speculated on the compatibility of dams and ecology in an article by the same name. The effects of impoundment on the fishery at Ft. Peck Reservoir, Montana was discussed by the Fish and Wildlife Service (1949) [134]. Walburg, *et al.*, (1981) [135] extensively reported on tailwater fisheries in their review of tailwater ecology literature. California's fish screen program is discussed by Wales (1948) [136]. Comprehensive data on fisheries investigations is included in Ward and Stanford's (1979) [140] book, *The Ecology of Regulated Streams*. Wegener and Williams (1974) [145] reported on fish population responses to improved lake habitat using an extreme drawdown of a reservoir as a management technique. Whalls, *et al.*, (1956) [149] presented information on a simplified rotary fish screen and an automatic water gate.

Reports on fish reproduction most frequently included the spawning ecology of various species (i.e., data on physical-chemical requirements, spawning behavior, fish morphology and physiology), the spawning success of individual fisheries, spawning habitat analysis and enhancement, patterns and problems with both upstream and downstream migration (Bell and DeLacy, 1972) [15]; (Bell, *et al.*, 1976) [16]; (Copp, 1968) [34]; and the exposure and inundation of spawning grounds by irregular releases (Becker, *et al.*, 1982) [12].

A compendium on the survival of juvenile fish passing through spillways and conduits was presented by Bell and DeLacy (1972) [15]. They discussed both biological variables (i.e., species, size and condition of fish, number of predators, effects of diseases, food availability, and behavior patterns) and physical variables (i.e., type of spillway, morphometry of stilling basin, distance of fall, velocity through the gate, temperature, turbidity, type of recovery gear, and water releases) influencing survival.

Invertebrates.-Tailwater research on invertebrates included general insect ecology studies as well as projects that focused on invertebrates as a food resource for fish. Many invertebrate studies investigated temperature requirements for development to occur and the effects of temperature on growth rates and life cycles of invertebrates, specifically on altering emergence or hatching times (Battelle Northwest, 1973) [10]; (Coutant, 1967) [38]; (Elliott, 1972) [51]; (Macan, 1960) [79]; (Nebeker, 1971, 1973) [89, 90]; and (Ward, 1974) [138]. An in-depth, comprehensive study of the thermal ecology of aquatic insects by Ward and Stanford (1982) [141] contained detailed discussions of thermal diversity and the influence of temperature on distribution, life cycles, behavior, trophic relationships, and growth of aquatic invertebrates.

Other papers that significantly examined invertebrates included studies on the effects of flow on drifting behavior (Brusven and Trihey, 1978) [26]; (Corrarino and Brusven, 1983) [37]; (MacPhee and Brusven, 1973, 1976) [80, 81]; (Waters, 1964, 1965) [142, 143]; colonization of the substrate (Gersich and Brusven, 1981) [60]; and (Waters, 1964) [142]; and the effects of sediments (Brusven and Prather, 1974) [25]; (Corning, 1970) [36]; (Cummins and Lauff, 1969) [42]; (Cummins, *et al.*, 1964) [43]; (Gammon, 1970) [59]; channel modification (Whitaker, *et al.*, 1979) [150]; and gas supersaturation (Fickeisen and Schneider, 1976) [53]. Spence and Hynes (1971) [116] discussed differences in species composition, relative abundance, and diversity of benthos above and below an impoundment. Young, *et al.*, (1976) [152] discussed the influence of a deep storage reservoir on diversity of benthic macroinvertebrates in the Guadalupe River.

Algae and Aquatic Weeds.-Since primary production is increased by several conditions common to tailwaters, such as increased light, temperature, and nutrients, algae were frequently studied in relationship to these physical-chemical parameters (Edmondson, 1956) [48]; (Marcus, 1980) [82]; (Murphy, 1962) [88]; and in relationship to other biotic factors such as zooplankton (Edmondson, 1962) [49]. Algae was also included in limnological studies (Harris and Silvey, 1940) [63] and (Pennak, 1955) [96]. An overview of algae in relationship to the environmental effects of large dams is presented by Bachman (1978) [6].

Most papers dealing with aquatic weeds emphasized that flow alterations had caused various species to proliferate and choke stream channels. Rhodes (1978) [103] presented a general review of problems and solutions for aquatic weed control in reservoirs.

Zooplankton.-Most zooplankton research examined their role as a food resource for fish (Applegate and Mullan, 1969) [3]; (Edmondson, 1962, 1965) [49, 50]; (Horst, 1980) [68]; (Robinson, 1957) [106]; and (Taylor, 1978) [125]. Edmondson (1962) [49] discussed the effects of temperature and phytoplankton production on zooplankton reproduction and age structure. Edmondson (1965) [50] discussed variations in the reproductive rate of rotifers in relationship to food, temperature, parasitism, and predation. Other significant research included a mathematical model to assess the effects of turbine passage on zooplankton populations (Horst, 1980) [68], and the effect of hypolimnetic aeration on vertical and temporal distribution of a zooplankton community in a small eutrophic lake (Taggart, 1984) [124].

Stream Regulation

Impoundments can drastically alter the flow characteristics in stream ecosystems. Tailwater flows may become relatively uniform or fluctuate frequently and dramatically; the results depend on the operation of the dam and the water requirements downstream (Walburg, *et al.*, 1981) [135]. The resulting alterations in flow can strongly impact downstream fishery resources. Flow is discussed frequently in relationship to its effect on physical-chemical parameters. Flow is often cited as a primary factor responsible for changes in temperature, turbidity, and dissolved gases. Desirable flows have been quantified in many regulated streams for the benefit of game fisheries.

In addition, substantial research and methodology investigations were conducted for determining instream flow requirements for fishery resources:

- Fraser (1972) [57]
- Milton (1972) [84]
- Montana University (1974) [86]
- Orsborn and Allman (1976) [91]
- Orsborn and Deane (1976) [92]
- Pacific Northwest River Basins Commission (1972) [95]
- Peters (1982) [99]
- Rhinehart (1975) [102]
- Singh (1982) [113]
- Stalnaker (1977) [119]
- Swink (1982) [122]
- Wesche (1973, 1974) [146, 147]

Some of the documents centered on the effects of flow on fish:

- Baldes (1968) [7]
- Campbell and Scott (1984) [28]
- Fraser (1972) [58]
- MacPhee and Brusven (1976) [81]
- Miracle and Gardner (1980) [85]
- Mundie (1979) [87]
- Orth (1978) [93]
- Peters (1982) [99]
- Stalnaker (1977) [118]

Topics in these documents included changes in fish behavior resulting from decreases in discharge; trout preferences for a specific water velocity in nesting microhabitats; effects of pumped-storage powerplant operation on fish; and effects of river fluctuations from hydroelectric peaking on fish abundance, feeding behavior, egg survival, upstream migration, and rate of stranding for adult fish.

Water-level fluctuations were frequently researched in terms of their effects on fisheries. Ploskey (1982) [101] presented a comprehensive paper on the general effects of water-level fluctuations on fisheries including algae, zooplankton, and water quality. Other topics on water-level fluctuations include the detrimental exposure of fish redds and the use of such fluctuations to control undesirable fish species. Wegener and Williams (1974) [145] discussed improving lake habitat by using extreme drawdown, and Heman (1969) [64] described manipulation of fish populations through reservoir drawdown.

The effects of flow on invertebrate populations is reported in several studies (Brusven and Trihey, 1978) [26]; (Corrarino and Brusven, 1983) [37]; (Gersich and Brusven, 1981) [60]; and (MacPhee and Brusven, 1973, 1976) [80, 81]. Topics include interacting effects of low flow and fluctuating shorelines on benthic insects, effects of reduced stream discharge on insect drift and stranding of near-shore insects, and colonization rates in near-shore regions subjected to peaking power discharges.

Modeling

Many studies used instream flow models to determine the minimum flows required to allow successful spawning and still supply enough habitat so that a healthy fishery could be maintained. Several papers described flow models or discussed guidelines for instream flow methodologies. Bovee (1978) [20] developed probability-of-use criteria for the family Salmonidae. A guide to stream habitat analysis using the Instream Flow Incremental Methodology was described by Bovee (1982) [21]. Bovee and Couchnauer (1977) [22] discussed the development and evaluation of weighted criteria and probability-of-use curves for instream flow assessments. Cuplin and Van Haveren (1979) [44] also described instream flow guidelines.

Gupta and Afaq (1974) [62] reported on numerical simulation of unsteady flow hydraulics of the Truckee River. Loftis (1981) [74] used modeling techniques to determine optimal control of reservoir discharge quality through selective withdrawl. Orsborn and Allman (1976) [91] and Orsborn and Deane (1976) [92] discussed instream flow needs.

Orth (1978) [93] presented computer simulation models for predicting population trends of large-mouth bass in a large reservoir. Nestler (1982) [94] discussed modeling efforts in an article entitled "Reservoir Releases: An Overview". Smith (1979) [115] edited the proceedings of a workshop on instream flow habitat criteria and modeling. Instream flow needs are also discussed by Stalnaker (1977) [119]. Tennant (1976) [126] reported instream flow regimes for fish, wildlife, recreation, and related environmental resources. Wesche (1973, 1974) [146, 147] and Wesche and Rechard (1980) [148] discussed minimum and/or suitable flows for trout habitat, and presented a summary of instream flow methods for fisheries and related research needs. A methodology for recommending stream resource maintenance flows for large rivers was proposed by White (1975) [151].

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GREAT PLAINS REGION

The Great Plains Region bibliographic information is available for the following tailwater areas:

- Arkansas River near Twin Lakes Dam and below Pueblo Dam
- Big Thompson River (Colorado-Big Thompson Project)
- Cache la Poudre River near Horsetooth Dam
- Colorado River below Granby and Shadow Mountain Dams and Grand Lake
- Willow Creek below Willow Creek Dam
- Fryingpan River below Ruedi Dam
- Lake Fork Creek below Sugar Loaf Dam
- Lower Blue River below Green Mountain Dam
- North Platte River below Seminoe, Alcova, Kortes, Glendo, and Guernsey Dams
- Beaverhead River below Clark Canyon Dam
- Bighorn River below Yellowtail Dam
- Marias River below Tiber Dam
- Missouri River below Canyon Ferry Dam
- Brazos River in Texas
- Stillwater Creek in Oklahoma
- Washita River below Foss Reservoir Dam
- Rock Creek below Arbuckle Dam
- Cimmaron River in Oklahoma
- Guadalupe River in Texas
- Rio Grande below Falcon Reservoir

Information on tailwaters and areas that are not part of the Bureau of Reclamation's area of responsibility include the following:

- North Poudre River below Dry Creek Dam
- Missouri River below Gavins Point, Big Bend, Fort Peck, Fort Randall, Garrison, Hauser, Holter, and Oahe Dams
- Niobrara River below Spencer Dam
- Sheyenne River below Lake Astabula
- South Platte River below Cheesman and Elevenmile Canyon Dams
- White River below Beaver and Bull Shoals Reservoirs
- Madison River below Madison River Dam and Hebgen Lake

Although no water development projects were mentioned, the following rivers were also cited in tailwater ecology documents for the Great Plains Region:

- Laramie River
- North St. Vrain Creek
- Blacktail Creek
- Clark Fork River
- Gallatin River on Lowline Canal
- Lower Big Hole and Jefferson Rivers
- Prickly Pear Creek
- Tongue River
- West Gallatin River
- Yellowstone River

Tailwater areas below Bureau dams in the Great Plains Region that were identified as having an ecological and/or water quality problem include the following:

- Arkansas River near Twin Lakes Dam and below Pueblo Dam
- Big Thompson River below Lake Estes
- Fryingpan River below Ruedi Dam
- Lake Fork Creek below Sugar Loaf Dam
- North Platte River below Guernsey Dam
- Beaverhead River below Clark Canyon Dam
- Bighorn River below Yellowtail Dam
- Marias River below Tiber Dam
- Missouri River below Canyon Ferry Dam

Water Quality

Studies that focus on physical-chemical parameters have been conducted on many tailwaters and impoundments in the Great Plains Region. Parameters such as water temperature, pH, dissolved oxygen concentration, conductivity, and redox are available for the following tailwaters, streams, impoundments, and/or lakes in the Great Plains Region:

- Shadow Mountain and Granby Reservoirs and Grand Lake (Environmental Protection Agency, 1970) [158][2]
- Pueblo and Ruedi Reservoirs, Turquoise Lake, and Fryingpan River (Nelson, 1984) [110]
- North Platte River below Guernsey Dam (Gray and Ward, 1982, 1984) [64, 65], (McDonald and McKnight, 1977) [94]; and (Peters, 1979) [124]
- South Platte River (Ward, 1974, 1976) [164, 167]
- White River (Mullan and Applegate, 1965) [102]
- Missouri River below Canyon Ferry Dam (Wright, 1958-61) [174-177]
- Missouri River below Garrison and Fort Randall Dams (Neel, *et al.*, 1963) [103]
- Lake Oahe (June, 1974) [81]
- Clark Canyon Reservoir (Berg, 1974) [5]
- Beaverhead River below Clark Canyon Dam (Smith, 1973) [147]
- Marias River below Tiber Dam (Stober, 1962, 1963) [155, 156]
- Bighorn River below Yellowtail Dam (Stevenson, 1975) [152]

[2] Numbers in brackets refer to entries in the Bibliogrpahy for this section.

Temperature is by far the most commonly studied physical-chemical parameter as it is included as an important ecological factor in almost all tailwater ecology and fishery studies. Temperature was the sole subject in several papers for the Great Plains Region documents. The effects of temperature on *Daphnia* egg development in Lake Astabula was reported by Knutson (1970) [85]. Temperature was investigated as a cause of fish deaths in the North Platte River below Kortes Dam by Kent (1963) [84]. Temperature is included in a comprehensive report on the limnology of the Colorado-Big Thompson Project reservoirs and lakes by Nelson (1971) [109]. Temperature data is available for the Niobrara River in a report by the Nebraska Game and Parks (1980) [151]. Pennak and van Gerpen (1947) [121] include temperature in a study of bottom fauna production and the physical nature of the substrate in North St. Vrain Creek. Other studies that included temperature and some other physical-chemical parameter data are: Burkhard (1977) [15] for the Taylor River below Taylor Park Dam; Horak and Tanner (1964) [75] for Horsetooth Reservoir; Nesler (1980) [115] for Twin Lakes, Colorado; and Simons, Li, and Associates, Inc. (1983) [146] for the Fryingpan River below Ruedi Dam.

The effect of Madison Dam on the Madison River stream temperature was reported by Heaton (1962) [70], and another study by Vincent (1981) [163] evaluated the impact of Madison Dam's warm tailwaters on wild trout populations. Lowham, *et al.*, (1975) [89] presented 23 years of temperature data for Wyoming streams. Temperature is included in a report of the effects of Clark Canyon Reservoir on the limnology to the Beaverhead River by Smith (1973) [147]. Stevenson (1975) [152] included temperature in a study of the trout fishery of the Bighorn River below Yellowtail Dam. Temperature preferences, Calhoun, *et al.*, (1981, 1982) [16, 17], and the effect of temperature on genetic variation, Zimmerman and Richmond (1981) [181], for several shiner species were analyzed in the Brazos River below Morris Sheppard Dam.

Temperature and other physical-chemical parameter data are included in fishery ecology studies for Clark Canyon Dam (Nelson, 1976, 1977) [105, 106]; Oahe Dam (Fogle, 1963) [49, 50, 51]; and the Missouri River below Fort Randall and Gavins Point Dams (Shields, 1957, 1958) [141, 142]. Temperature, pH, and dissolved oxygen were monitored in a study of sewage and impoundment effects on fish in Stillwater Creek (Cross, 1950) [24].

Herrmann and Mahan (1977) [71] examined the effects of Pueblo Dam impoundment on chemical concentrations in the Arkansas River, noting monthly variations and surface, spatial, and seasonal trends. Ward (1975) [166] evaluated hypolimnial releases from Cheesman Dam to determine the cause of temperature stress on invertebrates. The Public Health Service (1964) [130] issued a water pollution surveillance report for the Missouri River, that contained comprehensive data on water quality parameters, radioactivity, waste discharges, and coliforms. Mullan and Applegate (1965) [102] presented comparative water quality data for Beaver and Bull Shoals Reservoirs on the White River to determine why fisheries in new reservoirs are more productive than in older reservoirs. The EPA (1970) [158] reported nutrient concentration inputs from natural runoffs, wastewater inflows, and calculated nutrient loads for Granby and Shadow Mountain Reservoirs and Grand Lake.

Several studies from other disciplines, especially fishery investigations, contained general water quality research. These studies were conducted on Lake Astabula by Knutson (1970) [85], Peterka and Reid (1968) [123], and Peterka (1969) [122]; numerous streams in Colorado by the EPA (1970) [158]; the Arkansas River by Nesler (1982) [117]; the Frying Pan River by Nelson (1984) [110]; the Niobrara River by the State of Nebraska (1980) [151];, and the North Poudre and North Platte Rivers by Gray and Ward (1982) [64]. Topics included hydrogen sulfide pollution, heavy metals, and nutrients. In addition, three impact studies contained comprehensive water quality data for the Frying Pan River below Ruedi Dam by Simons, Li, and Associates, Inc., (1983) [146] and the Bureau (1975) [159]; and for the Arkansas River near Twin Lakes Dam, Colorado by LaBounty and Roline (1980) [87].

The Bighorn River below Yellowtail Dam and its impoundment were host to a 2-year study of physical-chemical and water quality parameters by Soltero, *et al.*, (1973) [148] and a study by Wright and Soltero (1973) [179] that included correlations between water quality and phytoplankton and between water quality constituents and turbidity. The Marias River Basin attracted a water quality inventory and management plan by Garvin and Botz (1975) [59] that included monitoring significant major ions, nutrients, iron, and total and fecal coliform counts from municipal sewage, industrial, and irrigation discharges. Other potential origins of water pollution identified were water treatment plants, mines, oil fields, and surface water drainage.

Limnology studies in the early 1970's on Clark Canyon Reservoir by Berg (1974) [5] and Yellowtail Dam by Smith (1973) [147] and Soltero and Wright (1974) [149] included data on nitrogen and phosphorus nutrients and chlorophyll *a*. Other studies that included water quality information were a study on the effects of Garrison and Fort Randall Reservoirs on water quality in the central Missouri River by Neel, *et al.*, (1963) [103]; a discussion of hydrogen sulfide as a cause of fish deaths in Clark Canyon Reservoir by Nelson (1976) [105]; and five papers reporting nitrogen supersaturation problems and gas-bubble disease in fish below Yellowtail Dam on the Bighorn River by Denson (1984) [36], Leathe (1985) [88], FWS (1981) [162],and White, *et al.*, (1987, 1986) [170, 171).

The effect of stabilized water levels on comprehensive physical-chemical data was determined for Falcon Reservoir by Cooke (1972) [23]. Salinity in Washita Creek, caused by brine discharge from the Foss demineralization plant, was reported in an invertebrate study by Magdych (1979) [91]. Sulfates and chlorides were monitored in a 3-year study of the effects of a demineralization plant on benthos below Foss Reservoir by Magdych (1979) [91].

Aquatic Ecology

Fish.-Little information on the ecology, distribution, or status of rare or native fish populations is presented in the Great Plains Region documents. Burkhard (1977) [15] researched the effects of flow on spawning areas of naturally reproducing brown trout populations in tailwater areas below Taylor Park Dam. An annotated bibliography of rare fish of the Upper Missouri River system by Joseph (1977) [80] is the only document specifically discussing rare fish. This document contains a list of species treated in its references. Paddlefish and cutthroat trout, which were included in several papers, were on this list; however, their legal status was not clarified in the list or in any other reference. Therefore, it is not clear which species are rare for the Upper Missouri River, or for specific tailwater areas.

Several documents included paddlefish and cutthroat trout research. A study of ages, lengths, and weights of paddlefish was completed for Gavins Point tailwaters by Boehmer (1973) [12]. A study of paddlefish movement, as related to flow in the Missouri River, was completed by Gardner and Berg (1982) [57] as part of an analysis of instream flow requirements for selected fish in that river reach.

Fish habitat research reported for the Great Plains Region often included instream flow modeling to recommend flows for maintaining trout habitat. A simulation model, PHABSIM, was used to evaluate percent changes in usable fish habitat below Ruedi Dam (Environmental Research and Technology, Inc., 1981) [40]. Cooper and Wesche (1976) [30] described and evaluated artificial stream channel modifications in Douglas Creek. Artificial structures were placed in the streambed to increase trout habitat under low flow conditions. Creating artificial meanders in a stream for habitat enhancement was recorded in two papers. This method was evaluated by Elser (1971) [38] in the East Gallatin River and Prickly Pear Creek in Montana by measuring stream morphometry and fish population changes. A Prickly Pear Creek habitat enhancement project reported by Workman (1974) [173] included a description of this method as well as results of experiments with rock and soil berms for controlling streambank erosion, results of revegetation experiments to determine which native shrubs were most suitable, and fish population estimates. Childress and Eng (1979) [19] described a wildlife enhancement project consisting of artificial marshes created for dust abatement near Canyon Ferry Dam. A plan for restoring wildlife habitat in the Garrison Unit was reported by Sapa (1979) [139].

Spawning ecology and loss of spawning habitat was a frequent topic of concern in Great Plains Region documents. Fish egg and young-of-the-year development, redd counts, spawning site inventories, distance traveled to spawn, and spawning movement were frequently studied. Additional topics included artificial spawning habitat, kokanee egg planting, egg mortality, and incubation and spawning periods. The effects of flow were often discussed as the major physical parameter impacting spawning activities. Documents mentioning spawning are available for Granby Reservoir by Finnell (1960) [43], Upper Arkansas by Nesler (1982) [117], Fryingpan by Hoppe and Finnell (1970) [73], and the Niobrara Rivers by the State of Nebraska (1980) [151]. The effects of flow on spawning were noted for the Upper Arkansas by Nesler (1982) [117] and the Fryingpan Rivers by Hoppe and Finnell (1970) [73].

Three papers discussed the effects of temperature on red and blacktail shiners below Morris Sheppard Dam on the Brazos River (Calhoun, *et al.*, 1981, 1982) [16, 17] and (Zimmerman and Richmond, 1981) [181]. In 1954, Hall, *et al.*, [67] determined the environmental factors affecting growth of black and white crappies in Oklahoma waters. Erickson, *et al.*, (1971) [39] described techniques for artificially spawning striped bass below Keystone Reservoir, and presented age and growth determination and length-weight relationships.

June (1979) [83] related atresia in northern pike in Lake Oahe to flow changes that interrupted spawning periods. Papers with significant spawning habitat research were done in the Missouri River below Canyon Ferry by Berg (1981) [6], at Hauser and Holter Reservoirs by Berg (1983) [7] and Berg and Lere (1983) [8], and at Tiber Dam on the Marias River by Gardner and Berg (1983) [58]. Decline in fish abundance was frequently related to loss of reproductive success, or specifically to a loss of spawning and nursery habitat from reduced water flows. Papers reporting declining fish abundance are available for Oahe Dam by June (1976) [82] and for four Missouri River reservoirs by Nelson and Walburg (1977) [112].

The food habits of fish were not specifically addressed in Great Plains Region documents; however, fish food data were presented in several studies on related subjects. Three reports discussed the relationship between food sources, feeding habits, and vertical distribution of fish in Horsetooth Reservoir by Goettl (1966) [61], Horak (1961) [74], and Horak and Tanner (1964) [75]. These studies included feeding methods and rates, stomach analyses, numbers of organisms consumed in relation to numbers available, and vertical depth of fish in relation to temperature, season abundance, and the vertical depth of plankton. Finnell (1968) [45] researched kokanee salmon food habits in Granby and Shadow Mountain Reservoirs and in Grand Lake on the Colorado River. Finnell reported percent of occurrence per item, location within the digestive tract, and volume of stomach contents.

Powell (1958) [129] correlated reductions in fish food production to reductions in fish production below Green Mountain Reservoir. Studies that included less detailed fish food data were by Finnell (1960, 1968, 1969) [43, 45, 46] and Finnell, *et al.*, (1975) [48]. For the Missouri River, Gardner and Berg (1982, 1983) [57, 58] investigated sauger food habits and flow requirements to maintain forage habitat, and studied invertebrates as a food source for mountain whitefish in the Marias River below Tiber Dam.

Several life history studies of species not clearly defined as native were reported in Great Plains Region documents. A life history and taxonomic comparison of sauger, walleye, and their hybrids in Garrison Reservoir was reported by Carufel (1961) [18]. These species of fish were described as important native game fish of North Dakota. Nelson and Walburg (1977) [112] discussed population dynamics and correlations between relative abundance and loss of habitat from reservoir impoundments for yellow perch, sauger, and walleye in Big Bend, Fort Randall, and Gavins Point Reservoirs, and Lake Oahe. A 7-year study of population trends, growth and movement of bigmouth buffalo in Lake Oahe by Moen (1974) [97], and an age-growth study of 13 species of fish by Nelson (1974) [114] in Lake Oahe all contained life history information. The Fish and Wildlife Service (1966) [161] presented life history information in a population ecology study of carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo in Lewis and Clark Lake.

Discussions of fish distribution and movement included a rainbow trout migration in Granby and Shadow Mountain Reservoirs and in Grand Lake by Finnell (1969) [46]; a study of fish movement in relation to low flows in the North Platte River by Cooper and Wesche (1976) [30]; several studies on vertical distribution in relation to fish food, season, and temperature in Horsetooth Reservoir by Goettl (1966) [61], Horak (1961) [74], and Horak and Tanner (1964) [75]; and fish distribution and abundance in the Arkansas River by Finnell (1983) [47] and Finnell, *et al.*, (1975) [48].

The loss of fish from dam operation is described in several papers for the Great Plains Region. This problem is usually attributed to flows that were too low or that contained high levels of sediment. Fish losses were reported for the Colorado-Big Thompson Project by Feast (1956) [42], Twin Lakes, Colorado by Finnell (1983) [47], Granby and Shadow Mountain Reservoirs and Grand Lake by Feast (1954([41], Niobrara River by the State of Nebraska (1980) [151], North Platte River by Kent (1963) [84], and the Upper Arkansas River by Nesler (1982) [117].

Fishery management documents often included creel census data and stocking records. Stocking schedules, fish egg planting procedures, harvest estimates, and fishing pressure assessments were among the topics discussed. Feast (1954) [41] presented creel census data for Grand Lake, Shadow Mountain, and Granby Reservoirs. Finnell (1960, 1960, 1968, 1969, 1983) [43, 44, 45, 46, 47] and Finnell, *et al.*, (1975) [48] reported creel census data for Grand and Twin Lakes and Granby and Shadow Mountain Reservoirs. Creel censuses, which reveal the rate and intensity of fishing use, were included in fishery investigations at Oahe Dam by Fogle (1963) [49, 50, 51], at Clark Canyon Dam by Miller (1972) [95] and Peterson (1971) [125], at Yellowtail Dam by Stevenson (1975) [152], and at Fort Randall Dam by Nelson (1962) [113]. The average catch rate, percent of catch per fish species, and fish yields were often determined in these previously mentioned documents. Stocking of rainbow trout in Canyon Ferry Reservoir was described by the Montana Department of Fish and Game (1956) [98], and stocking efforts in Clark Canyon Dam impoundments was reported by Miller (1972) [95]. Evaluation of four strains in rainbow trout fingerlings stockings in Black Hills reservoirs was reported by Ford (1978) [53].

Invertebrates.–The invertebrate ecology is frequently addressed in papers describing the effects of dam releases on general tailwater limnology and as an important food resource of fish. Flow, temperature, and especially sediment are characteristics of dam releases most often described as responsible for influencing invertebrate population dynamics. In food habit documents and in most invertebrate studies, the most common topics covered were relative abundance, distribution, dominance, and species composition.

Research on the effect of temperature on invertebrates below hypolimnial releases was emphasized in two studies in the literature. Ward (1974) [164] related changes in standing crop and diversity to the distance from Cheesman Dam in the South Platte River. In 1976, Ward [167] studied populations in highly regulated and unregulated streams to assess the effects of deep, hypolimnial release dams on invertebrates. Topics in this paper included standing crops, distribution, abundance, predation, competition, diversity correlated with regulation, restriction of taxa correlated with chemical limiting factors, and the effect of temperature on invertebrates.

An invertebrate study on the Yellowstone and Tongue Rivers by Newell (1976) [118] identified flow as the main parameter affecting fish and invertebrate populations. This paper reported data on standing crops in relation to discharge velocity, river current preference, and emergence and flight patterns of mayfiles, stoneflies, and caddisflies. Gore (1978) [62] described a technique for predicting instream flow requirements of invertebrates and applied it to the Tongue River. This in-depth study included tolerance ranges per species, conditions for faunal diversity, and invertebrates as indicators of adequate flow.

The effects of sedimentation and turbidity on invertebrates in tailwaters in the North Platte River below Guernsey Dam were reported by Gray and Ward (1982, 1984) [64, 65] and Peters (1979) [124]. Gray and Ward (1984) [65] included relative densities of invertebrates by genera, time, and longitudinal distance from the dam; speed of population recovery after sediment releases; and changes in invertebrate community composition, distribution, and relative abundance. In addition, Peters (1979) [124] described the effect of sediment release on rates of drift of aquatic insects in the North Platte River. Morris, *et al.*, (1968) [101] discussed the effects of turbidity resulting from channelization of the Missouri River below Gavins Point Dam, and compared invertebrate distributions between unchannelized and channelized river segments. This paper also estimated loss of invertebrate habitat and changes in standing crops from channelization. Turbidity/sediment loading effects of Spencer hydro-powerplant flushing on insect fauna in the Niobrara River was reported by the State of Nebraska (1980) [151].

Invertebrate habitat research was included in four studies in the Great Plains Region literature. Pennak and van Gerpen (1947) [121] reported on bottom fauna production and the physical nature of the substrate in North St. Vrain Creek, Colorado. Ward (1975) [166] investigated the bottom fauna-substrate relationships in the same stream in 1945 and again in 1974. Morris, *et al.*, (1968) [101], as previously discussed, evaluated the effects of channelization on invertebrates in the Missouri River below Gavins Point Dam. Ward and Short (1978) [168] reported on the macroinvertebrate community structure of four special lotic habitats,one of which was the South Platte River. Several fishery studies included significant invertebrate information: Fryingpan River by Simons, Li, and Associates, Inc. (1983) [146]; the North Fork Little Snake River by Binns (1977) [11]; Granby Reservoir by Finnell (1960) [43];, and Lake Oahe by Jones and Selgeby (1974) [79]. Edmonds and Ward (1979) [37] researched profundal benthos in Horsetooth Reservoir. Temporal and spatial distribution of benthic organisms, productivity estimates, percent composition, biomass in relation to depth, turn-over ratios, and mean annual density and biomass were discussed. This study also included limited invertebrate habitat analysis (percent organic matter, sand, silt, and clay).

Seven studies focused on invertebrate research, mostly on the Brazos River. Cloud (1973) [21] estimated drift density and nocturnal periodicity, and determined emergence patterns and seasonal peak densities. Cloud and Stewart (1974) [22] investigated the drift of mayflies in the Brazos River, including nocturnal periodicity and seasonal fluctuation, as well as the drift of exuviae as an indicator of mayfly emergence.

Stewart, *et al.*, (1973) [153] researched food habits of hellgramite larvae. Trophic position and interrelationship with other riffle insects were determined through the analysis of larval stomach contents and macroinvertebrate samples. The analyses yielded data on frequency and relative abundance of each food type, forage ratios, seasonal preference, and diurnal periodicity of feeding rates.

A detailed study of the substratum of the Brazos River was conducted to determine the nature and extent of vertical stratification of riffle insect communities, to compare populations sampled at different depths, and to assess stratification in relation to seasonal periodicity, insect life cycles, emergence peaks, size-class dominance, and changes in flow (Poole and Stewart, 1976) [127].

Rhame and Stewart (1976) [135] reported life cycles and food habits of three Trichoptera species below Possum Kingdom Dam. Standing crops, time of emergence, mating behavior, sex ratios, reproduction, larval morphology, pupation, and food preferences were investigated. The effects of brine discharge from a demineralization plant on the benthos of the Washita River were described by Magdych (1979) [91].

Algae and Aquatic Weeds.-Phytoplankton ecology documents in the Great Plains Region literature most frequently addressed topics such as relationships between water quality and physical-chemical parameters and phytoplankton, which included distribution, abundance, standing crop, species composition, dominance, and density estimates. The effects on plankton ecology from water project alterations of physical-chemical or water quality parameters is a common topic; in fact, many phytoplankton studies include physical-chemical data as a significant ecological factor. Water quality studies often include phytoplankton research because excessive algal growth can be a potential source of reservoir pollution.

Algae in Lake Astabula were researched in three reports. In 1968, Peterka and Reid [123] documented phytoplankton standing crops, production rates, and algal blooms in relation to temperature, pH, and Secchi depth. In addition, Peterka (1969) [122] correlated respiration rates and chlorophyll *a* concentrations with comprehensive water quality and physical-chemical data. Knutson (1970) [85] presented an in-depth phytoplankton ecology study that included research on relative seasonal dominance, net primary production, phytoplankton pulses, and ratios of chlorophyll *a* to algal cell volume.

A study on water quality changes in Horsetooth Reservoir attempted to correlate plankton standing crops, seasonal dominance, and annual productivity with temperature, oxygen, alkalinity, and total dissolved solids (Stimpfl, 1966) [154]. Two papers related phytoplankton to zooplankton ecology: Pennak (1955) [120] recorded ratios of phytoplankton to zooplankton in eight Colorado mountain lakes, as well as data on algal dominance, generic composition, and density; and Nelson (1971) [109] discussed primary productivity, relative seasonal dominance, and relative abundance of phytoplankton as related to the ecology of *Daphnia* in the Colorado-Big Thompson Project reservoirs and lakes.

One important set of papers focusing on primary production is a three-part limnological study of Canyon Ferry Reservoir conducted from 1958 to 1965 by Wright [174-178]. The author addressed the effects of physical-chemical parameters on photosynthesis and the relationship of chlorophyll with phytoplankton standing crops. This study also included a description of a method for estimating photosynthesis on the basis of various rates and coefficients of phytoplankton productivity. Wright and Soltero (1973) [179] conducted limnological research on Yellowtail Reservoir and the Bighorn River to examine primary production and chlorophyll *a* concentration in relation to distance from the dam.

Studies that related physical-chemical parameters to phytoplankton ecology were conducted in the impoundments or tailwaters of Canyon Ferry by Rada (1974) [132], Gavins Point by Hudson and Cowell (1966) [76], Lake Oahe by June (1974) [81], Tiber Reservoir by Stober (1962, 1963) [155, 156], and on Hebgen Lake by Martin and Arneson (1978) [92]. Phytoplankton research results were reported in several papers. Claffey (1955) [20] correlated the size of phytoplankton populations with turbidity and light penetration in Oklahoma waters. Otter Creek and Cimarron River algae were investigated in a study correlating stream order with species composition, diversity, biomass, and chlorophyll by Seyfer and Wilhm (1977) [140].

Several papers that focused on other disciplines contained information on algae in Grand Lake, Shadow Mountain and Granby Reservoirs (Feast, 1954) [41]; Pueblo and Ruedi Reservoirs and Turquoise Lake (Nelson, 1984) [110]; Twin Lakes, Colorado (LaBounty and Roline, 1980) [87]; Missouri River (Public Health Service, 1964) [130]; Niobrara River (State of Nebraska, 1980) [151]; and the North Platte and North Poudre Rivers (Gray and Ward, 1982, 1984) [64, 65]. Topics included dominance, biomass, primary productivity, chlorophyll *a* concentrations, changes in algal populations as indicators of water quality, and algal blooms.

In a stretch of the Guadalupe River that contains five impoundments, seasonal and diel changes in physical-chemical parameters were compared between impoundments and streams, and the productivity of phytoplankton was correlated with several parameters (Young, *et al.*, 1972) [180]. Primary productivity, in terms of its relationship to turbidity and light penetration, was investigated in numerous impoundments in Oklahoma (Claffey, 1955) [20]. Chlorophyll *a* data were included in an algae study on Otter Creek by Seyfer and Wilhm (1977) [140] and in a limnology study on the Guadalupe River by Young, *et al.* (1972) [180].

Aquatic plants were discussed in a paper by Childress and Eng (1979) [19] that described the wildlife habitat enhancement of Canyon Ferry Reservoir. Aquatic plants were evaluated as emergence sites for invertebrates in Fort Randall and Gavins Point Reservoirs in a report by Cowell (1967) [34].

Zooplankton.–Several studies in the Great Plains Region literature focused on the general ecology of zooplankton populations. These studies usually discussed vertical and seasonal distribution, relative abundance, species composition, and density or standing crops. In-depth ecology studies for *Daphnia* were conducted in Lake Astabula by Knutson (1970) [85], Colorado-Big Thompson Project reservoirs by Nelson (1971) [109], and Horsetooth Reservoir by Nelson (1970) [108]. Aspects of *Daphnia* populations discussed included culture procedures, clutch size variations, seasonal variations, birth and death rate estimates, and determinations of egg development, relative abundance, distribution, and generation time. Population ecology statistics were also correlated with physical-chemical parameters, predation, competition, and season. Wright (1965) [178] published research on population dynamics and production of *Daphnia* spp. in Canyon Ferry Reservoir, addressing ecological efficiency determinations, birth, population change, and mortality rates. This work also included a mathematical model that used chlorophyll *a* concentration, density of a predator species, and constant death rate to duplicate general features of a population curve for a *Daphnia* species.

A comparative limnological survey of eight Colorado mountain lakes by Pennak (1955) [120] contained comprehensive qualitative and quantitative data on zooplankton life cycles. This study included relative and seasonal abundance, density, dominance, standing crop, and the ratios of zooplankton to phytoplankton abundance. A limnological study to determine primary and secondary productivity of Canyon Ferry Reservoir correlated the rate of phytoplankton loss with the zooplankton population, determined the grazing coefficient and digestive efficiency of zooplankton, and studied assimilation as a percentage of net primary production (Wright, 1958) [174].

Ward (1975) [166] reported the effects of hypolimnetic releases from Cheesman Dam on downstream zooplankton populations in the South Platte River. Ward also determined changes in zooplankton density and composition and assessed the factors influencing changes and the resulting effects on the stream benthos community. This paper also discusses zooplankton as an invertebrate food source.

The ecology of *Mysis relicta* (opossum shrimp) was discussed in several documents in the Great Plains Region literature. An in-depth study by Nesler (1981) [116] related abundance of *Mysis* to time of day and depth in the water column. The report discussed limnological factors and impacts from the Mt. Elbert Pumped-Storage Powerplant, and evaluated the use of a benthic trawl for *Mysis* population estimates. In addition, three fish ecology reports contained pertinent *Mysis* information. Finnell, *et al.*, (1975) [48] discussed the importance of Mysis in Twin Lakes, Colorado as a food source for lake trout. LaBounty and Roline (1980) [87] addressed the impacts of pumped-storage powerplants on zooplankton. They discussed relative abundance and seasonal peak concentrations for zooplankton in general, and discussed *Mysis* as a fish food source in particular. Finnell (1983) [47] presented pre- and post-operational effects of the Mt. Elbert Pumped-Storage Powerplant on distribution, abundance, and density of *Mysis* in Twin Lakes.

Studies that focused on the general ecology of zooplankton populations were completed for the reservoirs created by Gavins Point and Fort Randall Dams (Cowell, 1967) [34] and (Siebrass, 1961) [145]. Gumtow (1955) [66] included zooplankton information in an investigation of periphyton in a riffle of the West Gallatin River in Montana. Smith (1973) [147] evaluated zooplankton abundance in the Beaverhead River relative to the distance downstream of Clark Canyon Dam, and Stober (1963) [156] presented similar information for the Marias River below Tiber Dam in Montana. Claffey (1955) [20] conducted a study in which zooplankton abundance was correlated with turbidities from soil and with light penetration in 40 impounded lakes and farmponds in Oklahoma.

Other zooplankton research that went beyond the usual ecology data included the Clark Canyon Reservoir study by Berg (1974) [5] that discussed the effect of temperature and chlorophyll *a* on zooplankton population dynamics, and a Lake Oahe study by June (1976) [82] that correlated zooplankton abundance with temperature, transmissivity, turbidity, and discharge.

Studies from other disciplines that contained general zooplankton data are available for the following impoundments in the Great Plains Region: Horsetooth (Goettl, 1966) [61]; (Horak, 1961) [74]; and (Horak and Tanner, 1964) [75]; Granby (Finnell, 1960) [43, 44], Gavins Point (Morris, *et al.*, 1968) [101], Guernsey (Peters, 1979) [124], Pueblo, Ruedi, and Sugarloaf (Nelson, 1984) [110]; and Twin Lakes (LaBounty and Roline, 1980) [87]. Besides presenting general population ecology research for zooplankton, Peters (1979) [124] also correlated zooplankton abundance with sediment releases from Guernsey Dam. Morris, *et al.*, [101] discussed the effect of channelization on zooplankton abundance.

Stream Regulation

The crucial role played by flow in tailwater ecology is dramatized by the frequency with which flow discharge and its influence on physical-chemical parameters, water quality, and aquatic life are included in tailwater documents in the Great Plains Region literature. Recommendations for minimum flow to maintain aquatic resources are frequently given. Two papers that focus on impacts of flow regime on tailwater ecology are Nehring (1979) [104] and Peterson and Leik (1958) [126]. Nehring [104] evaluated several instream flow methods by comparing, for each method, predictions of various environmental and flow patterns, reliability, accuracy, and cost. This study was conducted for water quantity need in numerous Colorado streams. Peterson and Leik [126] described results of test water releases from Alcova Dam to determine a water release schedule for North Platte River fisheries. This document provides photos, overlay diagrams, surface acreage, and average width of the stream for five different discharge levels to determine habitat changes.

Kent (1963) [84] reported results of test flows from Kortes Dam conducted to evaluate temperature, river width, and changes in total surface acreage. These experiments were performed to develop a minimal water release schedule that would restore the fishery downstream from the dam and prevent fish losses. Similar reports include a study of the effects of dewatering on trout in the Upper Arkansas River (Nesler, 1982) [117] and the effects of dewatering and sediment loading on invertebrates, fish eggs, and fish larvae in the Niobrara River (State of Nebraska, 1980) [151].

Two additional evaluations of instream flow methodologies applied to Great Plains Region streams are by Hilgert (1982) [72] for several Nebraska streams, and by the Montana Department of Fish, Wildlife, and Parks (1981) [99] for four trout rivers in southwest Montana. In addition, instream flow requirements were determined for fish in a wild and scenic portion of the Missouri River by Gardner and Berg (1982) [57] and for the Marias River fishery below Tiber Dam by Gardner and Berg, 1983 [58]. A technique for predicting instream flow requirements of invertebrates was applied to the Tongue River to determine minimum flow recommendations (Gore, 1978) [62].

Several papers present significant research on the effects of flow on the habitat, spawning, and loss of fish. Powell (1958) [129] evaluated the effects of fluctuating flows and water levels on turbidity, temperature changes, plankton, invertebrates, and fish below Green Mountain Reservoir. Data from the tailwaters and areas farther downstream from the dam were compared with data from river segments above the reservoir.

Other reports describing the effects of flow include recommendations on instream flow and impacts of flow, velocity, and dewatering on trout habitat in the North Fork Little Snake River (Binns, 1977) [11]; effects of stream flow patterns on spawning in the Taylor River (Burkhard, 1977) [15]; inflow, area, volume, depth, and flushing rates of Pueblo and Ruedi Reservoirs and Turquoise Lake (Nelson, 1984) [110]; and stream channel modifications to enhance trout habitat under low flow conditions in the North Platte River (Cooper and Wesche, 1976) [30]. This latter report included hydrology data (depth, discharge, velocity, and wetted perimeter) and flow requirements for spawning, food, and shelter for trout.

While numerous fishery studies included discharge data and discussed water-level fluctuation effects on fish populations, research that focused mainly on the influence of altered flow on fisheries is reported by Nelson (1976) [105] for the Beaverhead River below Clark Canyon Dam and in Clark Canyon Reservoir. A study of abnormal ovaries in northern pike populations caused by interrupted spawning from flow reductions from Oahe Dam is reported by June (1979) [83]. Two papers discuss the use of harmfully low flow during spawning to control problem fish species. Clothier (1957) [29] presented information on carp control through water drawdowns at Fort Randall and Gavins Point Dams on the Missouri River by dropping water levels immediately following carp spawning, thus exposing and killing the eggs. Shields (1958) [142] conducted a similar study below Fort Randall Dam.

Limnology papers usually contained pertinent flow information. A 1974 ecological study of final filling and impoundment above Oahe Dam by June [81] included discharge, level, water volume, and outflow rate data. Soltero and Wright (1974) [149], in a study of impoundment effects on water quality below and above Yellowtail Dam on the Bighorn River, included hydrological data such as net inflow, total discharge, and water exchange rates.

An invertebrate study identified taxa that are potentially useful as indicators of stable regulated flow (Ward and Short, 1978) [168], and a water pollution survey for the entire Missouri River included hydrologic and discharge data from records dating back 64 years (Public Health Service, 1964) [130].

Cooke (1972) [23] studied the effects of stabilized water levels on fish and invertebrates, and on physical-chemical parameters in Falcon Reservoir on the Brazos River.

Modeling

Most documents containing modeling information in the Great Plains Region literature concerned flow or physical-chemical parameters. Herrmann and Mahan (1977) [71] determined the water quality changes that would possibly occur after completion of Pueblo Dam. They also predicted water quality changes with respect to time and different dam operation practices. Instream flow modeling was conducted to recommend flows for maintaining trout habitat in the North Fork Little Snake River (Binns, 1977) [11] and in Colorado streams (Nehring, 1979) [104]. A simulation model, PHABSIM, was used to evaluate percent changes in usable fish habitat below Ruedi Dam (Environmental Research and Technology, Inc., 1981) [40]. Binns [11] also used the Habitat Quality Index Method to evaluate fluvial trout habitat in the North Fork Little Snake River. Gore (1978) [62] described a technique for predicting instream flow requirements of invertebrates and applied it to the Tongue River. This in-depth study included tolerance ranges of flow per species, conditions for faunal diversity, and invertebrates as indicators of adequate flow. Hamilton and Bergersen (1984) [68] reported on methods to estimate aquatic habitat variables. Nelson (1977,1980) [106, 107] used and/or evaluated instream flow methodologies in studies of the Beaverhead River and Clark Canyon Reservoir fisheries and in four trout rivers in southwestern Montana. Weber (1983) [169] presented information on accessing and using the Colorado stream data bank containing many variables such as flow, physical-chemical parameters, and water quality data as well as some biological or fisheries information on Colorado streams.

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Great Plains: Colorado, Chaffee County, Twin Lakes Dam, Arkansas River
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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
Codes 1a. and 2b.

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Codes 1a. and 2b.

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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
Codes 1a. and 2b.

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Great Plains: South Dakota, General
Code 2b.

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Great Plains
Code 2b.

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Great Plains: Texas, Palo Pinto County, Possum Kingdom Dam, Brazos River
Code 2b.

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Great Plains: Montana, Madison Dam, Madison River
Codes 1a. and 2a.

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Great Plains: South Dakota, Oahe Dam, Missouri River
Code 2b.

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Great Plains: Montana, Missouri River
Codes 2b. and 3e.

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Great Plains: Montana; Liberty, Hill, and Chouteau Counties; Tiber Dam, Marias River
Codes 1a., 2a., 2b., 2f., and 3e

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Great Plains: Montana, Marias River
Code 1a.

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Great Plains: Montana
Code 1a.

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Great Plains: Colorado, Larimer County, Horsetooth Dam, Cache la Poudre River
Code 2b.

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Great Plains: Montana, Tongue River
Codes 2a. and 3e.

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Great Plains: Colorado, Kansas, Oklahoma, Pueblo Dam, Arkansas River
Code 2

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Great Plains: Wyoming, Platte County, Guernsey Dam, North Platte River
Codes 1a. and 2a.

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Great Plains: Wyoming, Platte County; Colorado, Larimer County; Dry Creek Dam, North Poudre River, Guernsey Dam, North Platte River
Codes 1a., 2a., and 2d.

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Great Plains: Montana, Gallatin County, West Gallatin River
Codes 2d. and 2f.

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Code 2b.

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Great Plains
Codes 2f. and 4

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Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Code 1a.

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Great Plains: Montana, Madison Dam, Madison River
Code 1a.

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Great Plains: Colorado, Pueblo County, Pueblo Dam, Arkansas River
Code 1a.

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Great Plains: Nebraska
Code 3e.

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Great Plains: Fryingpan River
Code 2b.

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Great Plains: Colorado, Larimer County, Horsetooth Dam, Cache la Poudre River
Codes 1a., 2b., and 2d.

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Great Plains: Colorado, Larimer County, Horsetooth Dam, Cache la Poudre River
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Great Plains: South Dakota, Yankton County, Gavins Point Dam, Missouri River
Code 2d.

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Great Plains: Bonny Reservoir
Code 2b.

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Great Plains: Montana, Several streams
Code 1a.

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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
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Great Plains: General
Code 2b.

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Codes 1a., 2c., and 2d.

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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
Code 2b.

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Great Plains: South Dakota, Oahe Dam, Missouri River
Code 2b.

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Great Plains: Wyoming, Carbon County, Kortes Dam, North Platte River
Codes 1a., 2b., and 3e.

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Great Plains: North Dakota, Barnes County, Lake Astabula, Sheyenne River
Codes 2c. and 2d.

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Great Plains: Bighorn River
Code 1b.

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Great Plains: Montana, Yellowtail Dam, Bighorn River
Code 3a.

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Great Plains: Montana, Yellowtail Dam, Bighorn River
Code 1c.

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Great Plains: Wyoming, General
Code 1a.

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Great Plains: Montana, Elk Lake
Code 2b.

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Great Plains: Oklahoma, Custer County, Foss Reservoir Dam, Washita River
Codes 1a. and 2f.

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Codes 1a. and 2d.

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Codes 1a. and 2b.

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Great Plains: Wyoming, Platte County, Guernsey Dam, North Platte River
Codes 1a. and 2b.

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Great Plains: Montana, Beaverhead County, Clark Canyon, Beaverhead River
Code 2b.

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Great Plains: Montana, Lower Big Hole and Jefferson Rivers
Code 2b.

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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
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Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Code 2b.

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Great Plains: Montana
Code 3e.

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Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Codes 1a. and 2b.

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Great Plains: Nebraska, Gavins Point Dam, Missouri River
Codes 1a., 2a., and 2b.

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Great Plains: Beaver and Bull Shoals Reservoirs, White River
Code 1a.

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Great Plains: North and South Dakota, Garrison and Fort Randall Dams, Missouri River
Code 1a.

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Great Plains: Colorado,General
Code 3e.

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Great Plains: Montana, Beaverhead County, Clark Canyon Dam, Beaverhead River
Codes 1a., 2, 2b., and 3e.

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Great Plains: Montana, Beaverhead County, Clark Canyon Dam, Beaverhead River
Codes 1a., 2b., and 4

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Great Plains: Montana, General
Code 3e.

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Great Plains: Colorado, Larimer County, Horsetooth Dam, Cache la Poudre River
Codes 1a. and 2c.

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Great Plains: Colorado, Larimer and Weld Counties, Big Thompson River, 10 reservoirs
Codes 1a., 2c., 2d., and 3d.

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Great Plains: Colorado, Gunnison, Eagle, Lake, and Pueblo Counties; Ruedi Dam, Fryingpan River, Sugar Loaf and Pueblo Dams, Arkansas River
Codes 1a., 2c., 2d., and 3e.

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Great Plains: General
Codes 1a., 2a., 2b., 2f., and 3e.

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Great Plains: South Dakota, Big Bend, Fort Randall, Gavins Point, and Oahe Dams; Missouri River
Codes 1a. and 2b.

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Great Plains: South Dakota, Gregory and Charles Mix Counties, Fort Randall Dam, Missouri River
Codes 1a. and 2b.

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Great Plains: South Dakota, Stanley and Hughes Counties, Oahe Dam, Missouri River
Code 2b.

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Great Plains: Colorado, Chaffee County, Twin Lakes Dam, Arkansas River
Codes 2b. and 3a.

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Great Plains: Colorado, Chaffee County, Twin Lakes Dam, Arkansas River
Code 2a.

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Great Plains: Colorado, General, Upper Arkansas River
Code 2b.

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Great Plains: Montana, Yellowstone River
Code 1a.

[119] Office of Missouri River Basin Studies, Fish and Wildlife Service Staff, *A Three Year Fishery Investigation, Fort Peck Reservoir, Montana 1948-1950*, 47 pp., 1952.

Great Plains: Montana, McCone and Valley Counties; Fort Peck Dam, Missouri River
Code 2b.

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Great Plains: Colorado, General
Codes 1a., 2c., and 2d.

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Great Plains: North St. Vrain Creek
Codes 2a., 2b., and 2f.

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Great Plains: North Dakota, Barnes County, Lake Astabula, Sheyenne River
Codes 1a. and 2d.

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Great Plains: North Dakota, Barnes County, Lake Astabula, Sheyenne River
Codes 1a. and 2d.

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Great Plains: Wyoming, Guernsey Dam, North Platte River
Codes 1a., 2a., and 2b.

[125] Peterson, N., *1970 Summary of Clark Canyon-Beaverhead River Project*, Montana Dept. of Fish and Game, Fisheries Division, 19 pp., 1971.

Great Plains: Montana, Beaverhead County, Clark Canyon Dam, Beaverhead River
Code 2b.

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Great Plains: Wyoming, Natrona County, Alcova Dam, North Platte River
Codes 2b. and 2f.

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Great Plains: Texas, Palo Pinto County, Possum Kingdom Dam, Brazos River
Codes 1a. and 2a.

[128] Posewitz, J., *A Fish Population Investigation in the Marias River Below Tiber Dam*, Montana Dept. of Fish and Game, Job Completion Report, Project No. F-5-R-11, Job IIa, May 1, 1961-June 30, 1962, 9 pp., 1962.

Great Plains: Montana, Liberty and Hill Counties, Tiber Dam, Marias River
Code 2b.

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Great Plains: Colorado, Summit and Grand Counties, Green Mountain Dam, Lower Blue River
Codes 1a., 2b., 2c., 2d., and 2f.

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Great Plains: North Dakota and Missouri, General
Codes 1a. and 2d.

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Great Plains: Montana, West Gallatin River
Codes 1a. and 2b.

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Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Codes 1a. and 2d.

[133] Reed, E. B., "Plankton Productivity in a Fluctuating North-Central Colorado Reservoir," M.S. Thesis, 128 pp., Agricultural and Mechanical College, Fort Collins, CO, 1955.

Great Plains: Colorado, Larimer County, Horsetooth Reservoir, Cache la Poudre River
Codes 1a. and 2d.

[134] Reiser, D. W., and T. A. Wesche, *Determination of Physical and Hydraulic Preferences of Brown and Brook Trout in the Selection of Spawning Locations*, Water Resources Research Institute, Univ. of Wyoming, Water Resources Series No. 64, 96 pp., 1977.

Great Plains: Wyoming, Laramie River and several small creeks
Codes 2b. and 2f.

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Great Plains: Texas, Palo Pinto County, Possum Kingdom Dam, Brazos River
Codes 2a. and 2f.

[136] Rouch, R., *Effects of a Plains Irrigation Reservoir Upon a Colorado River*, 15 pp., 617 Peterson, Apt. 13, Fort Collins, CO, 1977.

Great Plains: Colorado, Pueblo County, Pueblo Dam, Arkansas River
Code 2a.

[137] Ruff, J. F., "Pressure Fluctuations Downstream From Valves," M.S. Thesis, 50 pp., Colorado State Univ., Fort Collins, CO, 1967.

Great Plains: Colorado, Larimer County, Horsetooth Reservoir, Cache la Poudre River
Code 3

[138] Sandoz, O., *A Pre-Impoundment Study of Arbuckle Reservoir, Murray County, Oklahoma*, Oklahoma Fishery Research Laboratory Report No. 77, 28 pp., Norman, OK, 1980.

Great Plains: Oklahoma, Murray County, Arbuckle Dam, Rock Creek
Codes 1a. and 2b.

[139] Sapa, A. J., "Restoration of Wildlife Habitat to Offset Project Losses, Garrison Diversion Unit, North Dakota," In: *Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats*, pp. 318-321, General Technical Report RM-65, Rocky Mountain Forest and Range Experimental Station, Forest Service, Fort Collins, CO, 1979.

Great Plains: North Dakota, Garrison, Unit, Missouri River
Codes 2e. and 2f.

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Great Plains: Oklahoma, Otter Creek, Cimmaron River
Code 2d.

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Great Plains: South Dakota, Gregory and Charles Mix Counties, Fort Randall Dam (Reservoir), Missouri River
Codes 1a. and 2b.

[142] ________, *Report of Fisheries Investigations During the Third Year of Impoundment of Gavins Point Reservoir, South Dakota, 1957*, South Dakota Dept. of Game, Fish, and Parks, Dingell-Johnson Project F-1-R-7, Jobs 1 and 4, 48 pp., 1958.

Great Plains: South Dakota, Yankton County, Gavins Point Dam, Missouri River
Codes 1a. and 2b.

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Great Plains: North and South Dakota; Garrison, Oahe, Big Bend, Fort Randall, and Gavins Point Dams; Missouri River
Codes 1a. and 2b.

[144] ________, "Experimental Control of Carp Reproduction Through Water Drawdowns in Fort Randall Reservoir, South Dakota," In: *Trans. Amer. Fisheries Soc.*, pp. 23-33, 87th annual meeting, Las Vegas, NV, 1958.

Great Plains: South Dakota, Gregory and Charles Mix Counties, Fort Randall Dam, Missouri River
Code 2b.

[145] Siebrass, H. H., "The Plankton of Two Large Artificial Impoundments of the Missouri River in South Dakota," M. A. Thesis, 57 pp., State Univ. of South Dakota, 1961.

Great Plains: South Dakota, Fort Randall and Gavins Point Dams, Missouri River
Codes 2c. and 2d.

[146] Simons, Li, and Associates, Inc., *Environmental Assessment of Water Marketing Program for Ruedi Reservoir, Colorado,* 125 pp., 1983.

Great Plains: Colorado, Pitkin and Eagle Counties, Ruedi Dam, Fryingpan River
Codes 1a., 2b., 2f., and 3e.

[147] Smith, K. M., "Some Effects of Clark Canyon Reservoir on the Limnology of the Beaverhead River

in Montana," M.S. Thesis, 62 pp., Montana State Univ., 1973.

Great Plains: Montana, Beaverhead County, Clark Canyon Dam, Beaverhead River
Codes 1a., 2c., and 2d.

[148] Soltero, R. A., J. C. Wright, and A. A. Horpestad, "Effects of Impoundment on the Water Quality of the Bighorn River," *Water Research*, 7:343-354, 1973.

Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Code 1a.

[149] Soltero, R. A., and J. C. Wright, "The Physical Limnology of Bighorn Lake-Yellowtail Dam, Montana: Internal Density Currents," *Northwest Sci.*, 48(2):107-124, 1974.

Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Code 1a.

[150] Sprague, J. W., *Report of Fisheries Investigations During the Fourth Year of Impoundment of Gavins Point Reservoir, South Dakota, 1958*, South Dakota Dept. of Game, Fish, and Parks, Dingell-Johnson Project F-1-R-8, Jobs No. 2, 4, and 5, 45 pp.,1959.

Great Plains: South Dakota, Yankton County; Nebraska, Cedar County; Gavins Point Dam (Reservoir), Missouri River
Codes 1a., 2, and 2b.

[151] State of Nebraska, *A Study of the Effects of Spencer Hydroflushing on Water Quality, Fishes, and Insect Fauna in the Niobrara River*, Nebraska Game and Parks, 41 pp., 1980.

Great Plains: Niobrara River
Codes 1a., 2a., 2b., and 2d.

[152] Stevenson, H. R., "The Trout Fishery of the Bighorn River Below Yellowtail Dam, Montana," M.S. Thesis, 67 pp., Montana State Univ., 1975.

Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Codes 1a. and 2d.

[153] Stewart, K. W., G. P. Friday, and R. E. Rhame, "Food Habits of Hellgramite Larvae, *Corydalus cornutus* (Megaloptera: Corydalidae), in the Brazos River, Texas," *Ann. Entomological Soc. Amer.*, 66:959-963, 1973.

Great Plains: Texas, Brazos River
Code 2a.

[154] Stimpfl, K. J., "Changes in the Quality of Water Impoundment in Horsetooth Reservoir," M.S. Thesis, 57 pp., Colorado State Univ., 1966.

Great Plains: Colorado, Larimer County, Horsetooth Dam, Cache la Poudre River
Codes 1a. and 2d.

[155] Stober, Q. J., "Some Limnological Effects of Tiber Reservoir on the Marias River," M.S. Thesis, 37 pp., Montana State Univ., Bozeman, MT, 1962.

Great Plains: Montana; Liberty, Hill, and Chouteau Counties; Tiber Dam, Marias River
Codes 1a. and 2d.

[156] _________, "Some Limnology Effects of Tiber Reservoir of the Marias River, Montana," *Proceedings of the Montana Acad. of Sci.*, 23:111-137, 1963.

Great Plains: Montana; Liberty, Hill, and Chouteau Counties; Tiber Dam, Marias River
Codes 1a., 2c., and 2d.

[157] Tash, J. C., G. A. Swanson, and R. E. Siefert, "A Report on the Occurrence and Distribution of Cladocera and Copepoda in Lewis and Clark Lake, South Dakota," *Univ. of Kansas Sci. Bulletin*, 12(11):425-432, 1966.

Great Plains: South Dakota, Yankton County, Gavins Point Dam, Missouri River
Code 2a.

[158] Environmental Protection Agency, *Water Quality Conditions in Grand Lake, Shadow Mountain Lake, and Lake Granby*, 61 pp., 1970.

Great Plains: Granby and Shadow Mountain Dams, Colorado River
Code 1

[159] Bureau of Reclamation, *Final Environmental Impact Statement for the Fryingpan-Arkansas Project, Colorado*, INT FES 75-43, approx. 507 pp., 1975.

Great Plains: Colorado, Pitkin and Eagle Counties, Ruedi Dam, Sugar Loaf Dam, Fryingpan River
Codes 1a., 2, and 3

[160] Fish and Wildlife Service, *Reservoir Fishery Investigations for Summer 1948-Fort Peck Reservoir, Montana*, Missouri River Basin Studies, Progress Report, 1949.

Great Plains: Montana, McCone and Valley Counties, Fort Peck Dam, Missouri River
Code 2b.

[161] ________, *Carp, River Carpsucker, Smallmouth Buffalo and Bigmouth Buffalo in Lewis and Clark Lake, Missouri River*, Bureau of Sport Fisheries and Wildlife, Research Report 69, 30 pp., 1966.

Great Plains: South Dakota, Yankton County, Gavins Point Dam, Missouri River
Code 2b.

[162] ________, *Bighorn River Nitrogen Supersaturation Study Final Report, February–August 1981*, 13 pp., 1981.

Great Plains: Montana, Yellowtail Dam, Bighorn River
Codes 1b. and 2b.

[163] Vincent, E. R., *Madison River Temperature Study*, Montana Dept. of Fish, Wildlife, and Parks, Job Progress Report No. F-9-R-28, IIb., April 1, 1979-March 31, 1980, 9 pp., 1981.

Great Plains: Montana, Madison County, Madison Dam, Madison River
Codes 1a. and 2b.

[164] Ward, J. V., "A Temperature-Stressed Stream Ecosystem Below a Hypolimnial Release Mountain Reservoir," *Archives fur Hydrobiology*, 74:247-275, 1974.

Great Plains: Colorado, Cheesman Dam, South Platte River
Codes 1a. and 2a.

[165] ________, "Downstream Fate of Zooplankton From a Hypolimnial Release Mountain Reservoir," *Verh. Internat. Verein. Limnol.*, 19:1798-1804, 1975.

Great Plains: Colorado, Cheesman Dam, South Platte River
Codes 1a. and 2c.

[166] ________, "Bottom Fauna-Substrate Relationship in a Northern Colorado Trout Stream: 1945 and 1974," *Ecology*, 56:1429-1434, 1975.

Great Plains: Colorado, North St. Vrain Creek
Code 2a.

[167] ________, "Comparative Limnology of Differentially Regulated Sections of a Colorado Mountain River," *Archives fur Hydrobiology*, 78:319-342, 1976.

Great Plains: Colorado, Elevenmile Canyon Reservoir, South Platte River
Code 2a.

[168] Ward, J. V., and R. A. Short, "Macroinvertebrate Community Structure of Four Special Lotic Habitats in Colorado, U.S.A.," *Verh. Internat. Verein. Limnol.*, 20:1382-1387, 1978.

Great Plains: Colorado; Four sites, including South Platte River
Codes 1a. and 2a.

[169] Weber, D., *Colorado Stream Data Bank User's Guide*, Colorado Division of Wildlife, DOW-R-M-8-83, 28 pp., 1983.

Great Plains: General
Code 4

[170] White, R. G., G. Phillips, G. Liknes, C. Sprague, J. Brammer, W. Connor, L. Fiddler, T. E. Williams, and W. P.Dwyer, *The Effects of Supersaturation of Dissolved Gases on the Fishery of the Bighorn River Downstream of the Yellowtail Afterbay Dam, 1986 Annual Report*, Montana Cooperative Fishery Research Unit, Montana State University, and Montana Department of Fish, Wildlife, and Parks, 181 pp., 1987.

Great Plains: Montana, Yellowtail Dam, Bighorn River
Code 1a.

[171] White, R. G., G. Phillips, G. Liknes, and S. Sanford, *The Effects of Supersaturation of Dissolved Gases on the Fishery of the Bighorn River Downstream of the Yellowtail Afterbay Dam, 1985 Annual Report*, Montana Cooperative Fishery Research Unit, Montana State University, and Montana Department of Fish, Wildlife, and Parks, 62 pp., 1986.

Great Plains: Montana, Yellowtail Dam, Bighorn River
Code 1a.

[172] Wipperman, A. H., *Effects of Dewatering on a Fish Population*, Montana Dept. of Fish and Game, Job Completion Report, Project No. F-9-R-17, Job No. IV., 6 pp., 1969.

Great Plains: Montana, Blacktail Creek
Codes 2b. and 3e.

[173] Workman, D. L., *Final Report Evaluation of Stream Improvements on Prickly Pear Creek, 1971-1973*, Montana Dept. of Fish and Game, 13 pp., 1974.

Great Plains: Prickly Pear Creek
Code 2f.

[174] Wright J. C., "The Limnology of Canyon Ferry Reservoir, I, Phytoplankton-Zooplankton Relationships in the Euphotic Zone During September and October, 1956," *Limnology and Oceanography*, 3:150-159. 1958.

Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Codes 2c. and 2d.

[175] _________, "The Limnology of Canyon Ferry Reservoir, II, Phytoplankton Standing Crop and Primary Production," *Limnology and Oceanography*, 4:235-245, 1959.

Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Code 2d.

[176] _________, "The Limnology of Canyon Ferry Reservoir, III, Some Observations on the Density Dependence of Photosynthesis and Its Cause," *Limnology and Oceanography*, 5:356-361, 1960.

Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Code 2d.

[177] _________, "The Limnology of Canyon Ferry Reservoir, IV, The Estimation of Primary Production From Physical Limnological Data," *Limnology and Oceanography*, 6:330-337, 1961.

Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Code 1a.

[178] _________, "The Population Dynamics and Production of Daphnia in Canyon Ferry Reservoir, Montana," *Limnology and Oceanography*, 10:583-590, 1965.

Great Plains: Montana, Lewis and Clark County, Canyon Ferry Dam, Missouri River
Code 2c.

[179] Wright, J. C., and R. A. Soltero, *Limnology of Yellowtail Reservoir and the Bighorn River*, Office of Research and Monitoring, Environmental Protection Agency, EPA-R3-73-002, 105 pp., 1973.

Great Plains: Montana, Bighorn County, Yellowtail Dam, Bighorn River
Codes 1a. and 2d.

[180] Young, W. C., H. H. Hannan, and J. W. Tatum, "The Physicochemical Limnology of a Stretch of the Guadalupe River, Texas, With Five Main-Stream Impoundments," *Hydrobiologia*, 40(3):297-319, 1972.

Great Plains: Texas, Guadalupe River, several impoundments
Codes 1a. and 2f.

[181] Zimmerman, E. G., and M. C. Richmond, "Increased Heterozygosity at the Mdh-B Locus in Fish Inhabiting a Rapidly Fluctuating Thermal Environment," *Trans. Amer. Fish. Soc.*, 110:410-416, 1981.

Great Plains: Texas, Palo Pinto County, Morris Sheppard Dam, Brazos River
Codes 1a. and 2b.

UPPER COLORADO REGION

Tailwater areas occur on many rivers in the Upper Colorado Region. The following areas are included in the available bibliographic material:

- Animas-La Plata Project
- Bear Lake on Bear River
- Black's Fork River near Meek's Cabin Dam
- Blue River below Green Mountain Dam
- Colorado River below Glen Canyon, Granby, Shadow Mountain, and Willow Creek Dams
- Emery County Project on the Huntington River
- Green River below Fontenelle and Flaming Gorge Dams
- Gunnison River below Blue Mesa, Crystal, Morrow Point, and Taylor Park Dams; and the Curecanti River Storage Project
- Provo River below Deer Creek Dam and Jordanelle Reservoir
- San Juan River below Navajo Dam
- Strawberry River below Soldier Creek Dam

Although no water development projects were mentioned, the following rivers were also cited in tailwater ecology documents for the Upper Colorado Region: Animas, Dirty Devil, Dolores, Escalante, Logan, Paria, Price, San Rafail, Virgin, White, and Yampa Rivers.

Tailwater areas reported as having problems include the following:

- Animas-La Plata Project
- Blue River below Green Mountain Dam
- Colorado River below Glen Canyon, Shadow Mountain, and Willow Creek Dams
- Emery County Project on the Huntington River
- Green River below Fontenelle and Flaming Gorge Dams
- Gunnison River below Blue Mesa, Crystal, Morrow Point, and Taylor Park Dams; and the Curecanti River Storage Project
- Provo River below Deer Creek Dam and Jordanelle Reservoir
- San Juan River below Navajo Dam
- Strawberry River below Soldier Creek Dam

The Animas and Yampa Rivers were also cited as problem areas.

Water Quality

Flaming Gorge Dam on the Green River has inspired more physical-chemical parameter research than any other project in the Upper Colorado River Basin. The hydrologic chemistry of Flaming Gorge Reservoir and its tailwaters has been investigated in many multidisciplinary studies from 1960 to the present. Some of the papers concentrating on this reservoir are:

- Annear, 1980 [5][3]
- Annear and Neuhold (1983) [6]
- Bolke (1979) [17]
- Bolke and Waddell (1975) [18]
- Bosley (1960) [19]
- Holden and Crist (1977) [72]
- King and Sartoris (1973) [87]
- Kramer (1979) [94]
- Madison and Waddell (1973) [100]
- Miller (1984) [111]
- Noyes (1981) [128]
- Pearson (1967) [132]
- Pearson, *et al.*, (1968) [133]
- Pearson and Franklin (1968) [134]
- Peters (1978) [136]
- Schmidt and Kramer (1980) [144]
- Schmidt, *et al.*, (1980) [145]
- Schmidt and Lund (1977) [146]
- Schmidt, *et al.*, (1979) [147]
- Starostka and Stone (1972) [160]
- Starostka, *et al.*, (1976) [161]
- Bureau of Reclamation (1976) [174]
- Utah State Division of Fish and Game and Wyoming Game and Fish Commission (1966) [178]
- Vanicek (1967) [181]
- Varley (1967) [184]
- Varley (1979) [186]
- Varley, *et al.*, (1970) [188]
- Woodbury (1960) [209]

Wydoski (1980) [214] summarized the biological impacts of flow and physical-chemical parameter changes resulting from water projects in the Upper Colorado River Basin. Special attention was paid to temperature, turbidity, and dissolved oxygen in tailwaters as potentially significant factors affecting the productivity of fisheries.

Temperature was often included in tailwater ecology research and was found to have a crucial impact on fishery ecology. Typically, studies from the Upper Colorado Region focused on the temperature differential between the discharge from dams and pre-impoundment flows, particularly the effect of colder, post-impoundment flows on the reproductive ability and food sources of warm-water fish and the resulting shift to cold-water fisheries in the tailwaters. The effects of temperature on fisheries was reported for the Gunnison River by Stanford and Ward (1983) [158], Williams (1951) [198], Wiltzius (1967, 1969, 1970, 1971, 1975, 1976) [201-206], and Woodbury (1962) [208]. The effects of

[3] Numbers in brackets refer to entries in the Bibliography for this section.

temperature on fisheries of the Green River below Flaming Gorge Dam was reported by Noyes (1981) [128]. The effects of temperature and dissolved oxygen were reported for Grand Lake (Shadow Mountain Dam) by Nelson (1980) [123]. Several papers focused on the biological effects of modifications to Flaming Gorge Dam that restored warmer water temperatures, which resulted in improved warm-water fisheries (Holden and Crist, 1977) [72], (Kramer, 1979) [94], (Larson and Bonebrake, 1982) [95], (Larson, *et al.*, 1980) [96], and (Peters, 1978) [136]. Holden and Crist (1981) [74] thoroughly discussed pre- and post-impoundment conditions of the Green River below Flaming Gorge Dam.

A few studies performed in the Upper Colorado Region looked at the reduction of sediment and consequent physical changes in banks and beds of rivers or at the alteration of suspended sediment dynamics of the tailwaters. Beach degradation downstream of Glen Canyon Dam on the Colorado River is reported by Carothers and Phillips (1981) [26] in a paper on the recreational impacts on riverine habitats in the Glen Canyon National Recreation Area. Laursen, *et al.*, (1977) [97] and Laursen and Silverston (1976) [98] also discussed beach degradation in the Grand Canyon in two reports on the effects of change in release regime below Glen Canyon Dam on the morphology of the Colorado River and the hydrology and sedimentology of the area, respectively. Sedimentation and turbidity changes resulting from upstream impoundments was discussed by Evans and Paulson (1983) [40] in a report on the influence of Lake Powell on the suspended sediment-phosphorus dynamics of the Colorado River inflow to Lake Mead. Andrews (1978) [2] presented similar information on the Yampa River Basin in a report on present and potential sediment yields. Everhart and Duchrow (1970) [41] discussed the effects of suspended sediment on the aquatic environment of the Gunnison River below Blue Mesa Dam. Eustis and Hillen (1954) [39] reported on stream sediment removal by controlled reservoir releases from Granby Dam on the Colorado River. Stanford and Ward (1983) [158] present thorough studies of the effects of mainstream dams on the physicochemistry of the Gunnison River below Taylor Park, Blue Mesa, Morrow Point, and Crystal Dams.

Physical-chemical parameter studies appear comprehensive for the multiyear investigations of the impacts of Blue Mesa Dam on the Gunnison River (Wiltzius, 1967, 1969, 1970, 1971, 1975, 1976) [201-206] and (Woodbury, 1962) [208]; the Glen Canyon Reservoir on the Colorado River (Stone, *et al.*, 1965) [165], (Stone and Miller, 1965) [166], (Stone, *et al.*, 1965) [167], (Utah State Division of Fish and Game, 1968) [177], and Flaming Gorge Reservoir on the Green River (Binns, 1967) [12], (Bosley, 1960) [19], (Dibble, 1960) [32], (Eiserman, *et al.*, 1966) [38], (Kramer, 1979) [94], (Larson and Bonebrake, 1982) [95], (Larson, *et al.*, 1980) [96], (Schmidt and Brayton, 1982) [142], (Schmidt, *et al.*, 1982) [143], (Schmidt and Kramer, 1980) [144], (Schmidt, *et al.*, 1980) [145], (Schmidt and Lund, 1977) [146], (Schmidt, *et al.*, 1979) [147], (Schmidt, *et al.*, 1980) [148], (Starostka, *et al.*, 1974) [159], (Starostka and Stone, 1972) [160], (Starostka, *et al.*, 1976) [161], (Starostka, *et al.*, 1977) [162], (Utah State Division of Fish and Game and Wyoming Game and Fish Commission, 1966) [178]. Typically, a reservoir was sampled regularly over several months at different depths for vertical variations and changes in stratification, and the tailwaters were analyzed at several points for physical-chemical changes in relation to distance from the dam. Seasonal variations were frequently discussed. Most post-impoundment studies and fishery surveys were as comprehensive as those mentioned above.

Two investigations addressed salinity problems in the Colorado River. Topics have included the natural salinity of the river as well as salinity policies for the Colorado River Basin. Miller, *et al.*, (1983) [112] included an overview of salinity patterns for the entire Colorado River Reservoir System. In 1979, wetlands of the lower Gunnison River Basin were inventoried extensively under the 1974 U.S. Salinity Control Act by Mustard and Rector [117].

Five documents focused on significant water quality research for the Upper Colorado Region tailwaters. Comprehensive research on water pollution and heavy metals was performed at the Animas River-Navajo Dam Area by Tsivoglou, *et al.*, (1959) [170] and the Public Health Service (1964) [139], and at Colorado River reservoirs by the EPA (1970, 1977) [175, 176]. Stone (1972) [164] reported on heavy metals and pesticides in the tailwaters below Glen Canyon Dam. Significant major ions were frequently included in water physical-chemical parameter studies performed for multidisciplinary investigations of fishery and water project surveys, such as a Gunnison River survey reported by Stanford and Ward (1983) [158]. Wright (1958) [211] presented a comprehensive paper on the water quality of the entire Upper Colorado River Basin in relation to Bureau of Reclamation projects. King, *et al.*, (1972) [86] presented the results of dissolved gas supersaturation tests below Navajo Dam.

Aquatic Ecology

Fish.–Many of the multidisciplinary studies of individual fisheries and the tailwater ecology of specific water projects in the Upper Colorado Region included studies of fish ecology in relation to dams. A particularly prominent example is the series of in-depth investigations of Flaming Gorge Reservoir conducted during the past 10 years by numerous researchers [142-148, 159-162, 168, 178, 188]. These reports were completely cited in the previous section. Fishery surveys were also performed for several years on the Green River below Fontenelle Dam by Banks, *et al.*, (1974) [8, 9], Binns (1967) [12]; and McKnight (1975) [108]. Fisheries in the Colorado River below Glen Canyon Dam were also extensively reported by Carothers and Minckley (1981) [24]; Gloss, *et al.*, (1973) [57], Gustaveson, *et al.*, (1980) [62], Hepworth, *et al.*, (1976) [66], Hepworth (1976) [67], McCall (1982) [107], Minckley and Blinn (1976) [115], Stone (1972) [164], Stone, *et al.*, (1965) [165], Stone and Miller (1965) [166], Stone, *et al.*, (1965) [167], and Utah State Division of Fish and Game (1968) [177]. Fishery surveys for several Gunnison River water projects were reported by Van Buren and Burkhard (1981) [180], Williams (1951) [198], and Wiltzius [201-206]. Fisheries below Navajo Dam (Graves and Haines, 1969) [61], (Olson, 1968) [129], (Olson and McNall, 1964) [130], Granby Dam (Feast, 1954) [45], (Federal Water Pollution Control Administration, 1968) [46], (Finnell, 1962, 1963, 1966, 1970) [47-50], and Shadow Mountain Dam (Feast, 1954) [45], (Finnell, 1970) [50], (Finnell and Woodward, 1969) [51], (Sharpe, 1956) [151], were surveyed less often.

Numerous documents focusing on the ecology and life history of indigenous fish populations of the Upper Colorado Region, and research on rare fish species has been increasing. Several recent papers on rare species have concentrated on distribution, current status, critical habitat, ecological requirements for spawning and reproduction, and competition with introduced fish. The principal objective of these studies was to determine the effect of impoundment and stream regulation on rare and native fish populations.

Holden (1973) [68] and Ecology Consultants (1978) [37] presented comprehensive distributional data on all rare fish known to occur in the Upper Colorado River Basin. Several papers discussed the impact of Flaming Gorge Dam on the distribution and reproduction of rare fish in the Green River (Holden, 1977, 1980) [70, 71], (Seethaler, *et al.*, 1979) [149], (Vanicek and Kramer, 1969) [183]. Investigations of rare species were also published for the San Juan River by Koster (1960) [91], Minckley and Carothers (1980) [114], the Dolores River by Holden and Stalnaker (1975) [76], the White River by Tyus and McAda (1984) [173], the Yampa River by Holden (1980) [71], Holden and Stalnaker (1975) [76], Seethaler, *et al.*, (1979) [149], Valdez and Wick (1983) [179], and the Colorado River by Binns (1977) [14], Holden (1973) [68], Kidd (1977) [85], McAda (1977) [103], McAda and Wydowski (1980) [105], Miller (1982) [113], Minckley and Carothers (1980) [114], and Valdez and Wick (1983) [179]. In addition, McAda, *et al.*, (1977) [104] surveyed seven previously unstudied streams in southeastern Utah for threatened and endangered fish. Tyus and McAda (1984) [173] studied migration, movements, and habitat preferences of Colorado squawfish in the Green, White, and Yampa Rivers. Kidd (1977) [85] summarized the current information on threatened and endangered species in relation to numerous Bureau of Reclamation projects on the Upper Colorado and Gunnison Rivers, including Granby and Shadow Mountain Dams.

Many fishery studies also discussed project impacts on fish species not designated as rare, especially those important to sports fisheries. Loss of habitat and competition from growing exotic fish populations are frequently cited problems for maintaining native fisheries. Research on competition between native and introduced species generally investigates declining native fish populations by concentrating on the ecology of native populations and comparing relative abundance, distribution, reproductive success, habitat, and diet requirements of native versus exotic fish. Competition between native and exotic species was reported for the Gunnison River by Middleton (1969) [110] and Pratt (1938) [137], Green River by McKnight (1975) [108], Vanicek (1967, 1970) [181, 182], and Wiley (1977) [194], and the Colorado River by Binns (1977) [14], Holden (1973) [68], Holden and Stalnaker (1975) [75], Miller (1982) [113], Minckley and Blinn (1976) [115], and Molles (1980) [116].

To enhance and protect both endemic and rare fish populations, more recent multidisciplinary fishery surveys frequently evaluate habitat in one of two ways; they either assessed habitat parameters and requirements of specific fish species, or presented descriptions of habitat development techniques. Research on native fishery habitat was performed on the Yampa River by Valdez and Wick (1983) [179], the Green River by Bosley (1960) [19], Dibble (1960) [32], Holden (1977, 1980) [69-71], Holden and Crist (1977) [72], and the Colorado River by Gosse (1981, 1985) [59, 60], Holden and Stalnaker (1975) [75], Miller (1982) [113], Minckley and Blinn (1976) [115], Molles (1980) [116], and Weber (1959) [190]. Papers that discussed habitat loss usually focused on the physical-chemical and hydrologic changes and destruction of spawning habitat resulting from dam operation. Habitat development techniques for Fontenelle Reservoir tailwaters on the Green River were reported by Snigg (1980) [155] and for the Black's Fork River by Wesche and Cooper (1974) [192].

Stomach content analysis is the most commonly reported method of evaluating fish diets, although invertebrate and plankton collections from varying depths are also employed. Most multidisciplinary fishery investigations for specific water projects in the Upper Colorado Region included information on dietary composition for important fish. These comprehensive papers were previously cited for the Colorado River below Glen Canyon Dam as references [24, 57, 61, 66, 67, 108, 115, 164-167, 177], for the Green River below Fontenelle and Flaming Gorge Dams [8, 9, 12, 108, 142-148, 159-162, 168, 178, 188], and the Colorado River below Granby Dam [45-50] and Shadow Mountain Dam [45, 50, 51, 152]. These comprehensive papers often discussed the composition, seasonal variation, and relative importance of various organisms important as fish food.

Many ecology and life history studies of individual fish species analyzed food habits in detail. Such studies correlated the distribution, abundance, and seasonal variations of fish foods (usually invertebrates and plankton) with subsequent variations in fish distribution and diet. Dietary differences between reservoir and tailwater populations were also compared; variations in fish diet and distribution were related to different habitat, competition for food between native and introduced fish were discussed; and diel movements were examined.

Several papers specifically addressed the diet of fish in Colorado River reservoirs. Finnell and Reed (1969) [52] investigated the diel vertical movement of kokanee salmon (*Oncorynchus nerka*) in Grandby Reservoir, Colorado. Hazzard (1934) [64] reported on studies of trout food in some Utah streams. Hepworth and Gloss (1976) [65] discussed the food habits and age-growth of walleye in Lake Powell, with reference to the introduction of threadfin shad. May (1973) [101] included fish diet in a report on seasonal depth distributions of rainbow trout in Lake Powell. May and Thompson (1974) [102] assessed the impact of threadfin shad (*Dorosoma petenense*) introduction on food habits of four centrarchids in Lake Powell. Papers on food habits of rainbow and brown trout in Flaming Gorge Reservoir are by Varley (1979) [185, 186] and Wiley and Varley (1969, 1978) [195, 196]. One fishery management study assessed the introduction of forage fish species into water systems to improve food availability and, thus, fish production in Lake Powell (Hepworth and Gloss, 1976) [65].

Almost all of the multidisciplinary fishery investigations mentioned at the beginning of this section contained biological assessments designed to recommend management practices. Fishery status is primarily evaluated by determining distribution, reproduction rates, size/growth estimates, migration, population estimates, and relative abundance for each species. In addition, creel census surveys and fingerling marking techniques were frequently used to obtain data on harvest rates, stocking success, and fishing pressure.

The stocking of new species was occasionally recommended and procedures described. The objectives of introducing new species depend on fishery requirements. To control problem fish, potential competitors or predators were added; to enhance the existing fishery, either new forage fish species were stocked to improve food resources, or additional sports fish were stocked. Introduction of threadfin shad into Lake Powell was reported by Hepworth and Gloss (1976) [65] and May and Thompson (1974) [102]. Finnell (1970) [51] discussed the introduction of silver salmon into Granby Reservoir. Graves and Haines (1969) [61] reported plantings of rainbow trout, Kamloops rainbow, and largemouth bass in Navajo Reservoir and tailwaters.

Invertebrates.–The invertebrate ecology of tailwater systems in the Upper Colorado Region is frequently discussed in multidisciplinary documents that investigate the effects of impoundments and stream regulation on fisheries. Because invertebrates are often an important food source for fish, many studies include baseline invertebrate surveys to determine species composition, relative abundance, and distribution in relation to fish food habits. While many invertebrate studies used benthic sampling and vertical sampling techniques, a majority of fishery investigations obtained data on relative abundance, frequency of occurrence, and species identification entirely from fish stomach samples. Invertebrate relative abundance and variation in relation to fishery quality were often discussed in water development and fishery surveys. Two studies determined invertebrate densities: one was done on Lake Powell by Hepworth (1976) [67] and one on the tailwaters of Flaming Gorge Dam by Pearson, *et al.*, (1968) [133].

The effect of physical and chemical factors on invertebrate populations in tailwaters was studied in several areas, including the San Juan River below Navajo Dam by Holden, *et al.*, (1980) [78]; below Flaming Gorge Dam on the Green River by Dufek (1967) [35], Holden and Crist (1981) [74], Kramer (1967) [92, 93], Pearson (1967) [132], Pearson, *et al.*, (1968) [133], below Glen Canyon Dam on the Colorado River by Blinn, *et al.*, (1985) [16], and the Gunnison River by Knight (1965) [90].

Algae and Aquatic Weeds.–Four documents relating to algae in the Upper Colorado Region specifically address the problem of controlling algal blooms in Deer Creek Reservoir, a primary source of drinking water for the Salt Lake City area. Funk (1963) [54] and Gaufin and MacDonald (1965) [56] studied physical and chemical factors influencing algal abundance, variation, and productivity with respect to efforts for controlling algal blooms. Funk and Gaufin (1965) [55] tested the effectiveness of several algacides on a variety of algal species under varying environmental conditions. They also addressed the ecological impacts of each algacide. Merkley (1966) [109] studied Deer Creek Reservoir phytoplankton for 3 years, primarily evaluating three methods for collecting and concentrating phytoplankton samples. Plankton types, seasonal distribution, and the physical and chemical factors influencing distribution were discussed.

Norton (1977, 1979) [126, 127] conducted two separate phytoplankton surveys in the Upper Colorado Region. In a 3-year study of lakes in several Colorado mountain ranges, Norton [126] identified phytoplankton species and discussed their relative abundance, distribution, and dominance. Later, Norton [127] identified phytoplankton species and noted relative abundance for the Colorado-Big Thompson system of reservoirs and canals.

Czarnecki, *et al.*, (1976) [31] completed a geographically extensive survey of algae in the Colorado River and its major tributaries. Relative importance, diversity, and distribution were determined. Only a few multidisciplinary documents discussed algae in relation to tailwater ecology.

Zooplankton.–Of the five documents that emphasize plankton research in the Upper Colorado Region, all but one focus on distributional patterns of plankton. In three papers, Varley (1967, 1979) [184, 185, 186], discussed the distribution, dominance, and abundance patterns of plankton in Flaming Gorge Reservoir. He researched physical, chemical, and biological factors influencing both zoo- and phytoplankton in Flaming Gorge Reservoir [184], studied impacts from trout grazing on zooplankton [185], and surveyed the reservoir for distribution and relative abundance of both zoo- and phytoplankton species [186].

Pennak (1944) [135] conducted a 2-year study of diurnal migrations of zooplankton in five northern Colorado mountain lakes. Quantitative data and distribution were determined for 17 zooplankton species, and physical and chemical factors were evaluated as possible influences on zooplankton movement. Research on fish ecology frequently included studies of zooplankton as a principal factor of fish movement and food habits. These studies usually provided a list of taxa, relative abundance, and relative horizontal and vertical distribution. Two Studies compared fish and zooplankton distribution in Lake Powell: (Gloss, *et al.*, 1973) [57] and (Gustaveson, *et al.*, 1980) [62].

Stream Regulation

Many multidisciplinary studies in the Upper Colorado Region included daily flow measurements in their data collections to evaluate the impacts of altered flows on fish ecology. In addition, several documents focused on the effects of flow changes for specific water development projects in the Upper Colorado Region. Banks, *et al.*, (1974) [8] and Johnson (1965) [84] both studied changes in flow regime from Fontenelle Dam on the Green River downstream and evaluated relationships between flow and aquatic habitat. The biological impacts of flow alterations were reported for research done on the Colorado River below Granby Dam by Weber (1959) [190], and below Glen Canyon Dam by McCall (1982) [107]. Alteration of flow in the Provo River below Jordanelle Dam was discussed by Gosse and Helm (1979) [58]. Flow alteration in the Gunnison River was reported by Wiltzius (1976) [206]. Holden (1980) [71] and Nehring (1980) [119] discussed altered flows in the Green and Yampa, and the Taylor and Fryingpan Rivers, respectively.

Two papers evaluated methodologies of estimating and analyzing the impacts of flow in the Upper Colorado Region. Holder (1960) [79] reevaluated the inflow-outflow equation for the Green River in Wyoming. Prewitt and Carlson (1977) [138] evaluated four instream flow methodologies that were used for fish in the Yampa and White Rivers.

Modeling

Modeling efforts in the Upper Colorado Region literature usually concerned flows or physical-chemical parameters such as temperature. Brittan (1960) [22] presented a probability model for integration of Glen Canyon Dam into the Colorado River system. Holder (1960) [79] evaluated a method of measuring water supply to determine allocation of Colorado River water for competing uses. Prewitt and Carlson (1977) [138] evaluated and compared the analytical effectiveness and flexibility of four different incremental analysis models tested on the Yampa and White Rivers. The models were used to approximate flows that would provide for optimum fishery conditions.

King and Sartoris (1973) [87] developed a temperature model that simulated temperatures in deep impoundments, with Flaming Gorge Reservoir as the test case. Warmer water temperature releases following modification of the outlet structure at Flaming Gorge Reservoir were modelled by Schmidt, *et al.*, (1979) [147].

Additional Information

The Bureau of Reclamation is presently evaluating the Colorado River below Glen Canyon Dam (Grand Canyon Recreation Area). In December 1982, the Secretary of the Interior directed the Bureau to initiate a multiagency study to address the concerns of the public and other Federal and State agencies about possible negative effects of the operations of Glen Canyon Dam on downstream environmental and recreational studies. The study goals were to investigate the impact of current dam operations on the Glen Canyon National Recreation Area and Grand Canyon National Park, specifically the effect of very high, very low, and strongly fluctuating releases from the dam. To accomplish the study goals, over 30 technical studies on biology, recreation, and sediment and hydrology were conducted. The results of these studies are summarized in "Glen Canyon Environmental Studies, Final Report–January, 1988," published by the Department of the Interior along with a listing of 32 technical reports available for various aspects of the studies.

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Code 2b.

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Code 2b.

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Upper Colorado: Utah, Daggett County; Wyoming, Sweetwater County; Flaming Gorge Dam, Green River
Codes 1a., 2b., and 3c.

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Upper Colorado: Utah, Daggett County; Wyoming, Sweetwater County; Flaming Gorge Dam, Green River
Codes 1a., 2b., 3c., and 4

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Upper Colorado: Utah, Daggett County; Colorado, Moffat County; Flaming Gorge Dam, Green River
Codes 1a., 2b., and 3c.

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Upper Colorado and Lower Colorado: Colorado River
Code 1a.

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Codes 1a., 2a., and 2b.

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Upper Colorado: Colorado River
Codes 1a., 2, 3e.

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Upper Colorado: Wyoming, Utah, Colorado, Flaming Gorge Dam, Green River
Code 2b.

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Upper Colorado: Colorado, Gunnison and Montrose Counties; Taylor Park, Blue Mesa, Morrow Point and Crystal Dams; Gunnison River
Code 1a.

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Code 2b.

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Codes 1a. and 2b.

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Upper Colorado: Utah, Daggett County; Wyoming, Sweetwater County; Flaming Gorge Dam, Green River
Codes 1a. and 2b.

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Upper Colorado: New Mexico, San Juan County; Navajo Dam, San Juan River
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Upper Colorado: Arizona, Coconino and Mohave Counties; Glen Canyon Dam, Colorado River
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Upper Colorado: Arizona, Coconino and Mohave Counties; Glen Canyon Dam, Colorado River
Codes 1a. and 2b.

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Upper Colorado: Glen Canyon Dam, Colorado River
Code 2b.

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Upper Colorado: Arizona, Coconino and Mohave Counties; Glen Canyon Dam, Colorado River
Codes 1a. and 2b.

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Upper Colorado: Utah, Daggett County; Wyoming, Sweetwater County; Flaming Gorge Dam, Green River
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Upper Colorado: Colorado, Summitt and Grand Counties; Green Mountain Dam, Blue River
Codes 2b., 3d., and 3e.

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Upper Colorado: New Mexico, Animas River
Code 1a.

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Code 2f.

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Upper Colorado: New Mexico, Utah, San Juan River
Code 2b.

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Upper Colorado: Colorado, Utah; Green, White, and Yampa Rivers
Codes 2b. and 2f.

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Upper Colorado: Utah, Daggett County: Colorado, Moffat County; Flaming Gorge Dam, Green River
Codes 1, 2, and 3c.

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Upper Colorado: Arizona, Coconino and Mohave Counties; Glen Canyon Dam, Colorado River
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Upper Colorado: Wyoming, Sweetwater County; Fontenelle Dam, Green River
Code 3d.

LOWER COLORADO REGION

The available bibliographic material contains information on the following tailwaters within the Lower Colorado Region's management area:

- Colorado River below Glen Canyon, Hoover, Davis, Parker, Headgate Rock, and Imperial Dams
- Virgin River above Lake Mead
- Salt River
- Little Colorado River

Tailwaters reported as having some ecological, water quality, or biological problems are all on the Colorado River below Glen Canyon, Hoover, Davis, Parker, Headgate Rock, and Imperial Dams.

Water Quality

Water temperature was the most common physical-chemical parameter discussed in tailwater ecology documents from the Lower Colorado Region. Temperature profile information from Lake Mead was recorded in several documents[4]:

- Anderson and Pritchard (1951) [3]
- Baker and Paulson (1980) [5]
- Baker and Paulson (1983) [7]
- Smith, *et al.*, (1960) [61]

A report on the feasibility of introducing rainbow trout in Lake Havasu by Ponder (1971) [49] discussed temperature and dissolved oxygen concentrations.

While the majority of tailwater ecology papers included temperature data, several papers specifically focused on temperature effects on aquatic life. These studies were conducted on Lake Havasu for fish by Ponder (1971) [49], on Lake Mohave for algae by Priscu (1978) [52], and in the Grand Canyon for invertebrates by Hofknecht (1981) [20]. Comprehensive physical-chemical data for Lake Mead, Lake Mohave, Colorado River in the Grand Canyon, and tailwaters of Hoover and Davis Dams are available in the following: Borland and Miller (1960) [9], Saiki (1976) [57], Johnson and Sanderson (1968) [23], and Priscu (1978) [52].

Comprehensive information on water quality and nutrient dynamics for Arizona streams can be found in Fisher and Grimm (1981) [16]. Paulson, *et al.*, (1979) [46] compiled nitrate data from 1940 to 1977 to determine possible causes of long-term changes in nitrate concentrations for Lake Mead. In 1981, Paulson [45] described impacts of nutrient loading on phytoplankton productivity of the tailwaters of Hoover Dam. This latter paper also included data on chlorophyll *a*, phosphorus, ammonia, and total nitrogen.

Water quality discussions are included in reports focusing on other disciplines. Portz (1973) [50] discussed water quality in a report on plankton pigment heterogeneity in seven reservoirs on the Colorado and Salt Rivers. Priscu (1978) [52] included water quality data for Lake Mohave. Lake Mead was also surveyed for heavy metal and phosphates in relationship to an invertebrate study by Melancon (1977) [30]. Significant major ions and nitrate data were obtained for the Virgin River in a fish ecology study by Cross (1975) [12]. Johnson and Sanderson (1968) [23] presented information on ions and nitrates for the Grand Canyon. Nutrient loading in Lake Mead was discussed by Baker and Paulson (1983) [7], Paulson (1981) [45], and Prentki, *et al.*, (1981) [51].

Aquatic Ecology

Fish.–In fishery studies, declines of endemic fish populations are frequently attributed to abiotic or biotic changes resulting from dam closure and impoundment formation, and to fishery practices such as the introduction of exotic fish. Several papers discuss rare and endemic fish in Lower Colorado Region tailwaters. Cross (1975) [12] reports the ecological distribution of fishes in the Virgin River. Minckley (1979) [33] is the most comprehensive fishery study for the lower 275 miles of the Colorado River, and gives indepth ecological information on fish and their habitats. Paulson, *et al.*, (1980) [44] also discussed endemic fish species in their report on the influence of dredging and high discharge on the ecology of Black Canyon, Lake Mead. Prentki, *et al.*, (1981) [51] discussed fish in a report on the chemical and biological structure of Lake Mead sediments. Rinne (1969) [53] comprehensively reported on cyprinid fish of the genus *Gila* from the lower Colorado River Basin. Saiki (1976) [57] performed an ecological evaluation of game fish at Deer Island Lake on the Lower Colorado River. Suttkus and Clemmer (1977) [64] investigated the ecology of the humpback chub, *Gila cypha*, in the Grand Canyon area of the Colorado River; and Wallis (1951) [67] reported on the status of the fish fauna of the Lake Mead National Recreational Area. Distribution and abundance of endemic and rare fish species were frequently discussed in this literature and competition between endemic and introduced fish species were documented, especially in the lower Colorado River.

Three papers specifically discussed food habits of fish, each for a different tailwater area. Competition for food was studied by Baker and Paulson (1983)

[4] Numbers in brackets refer to entries in the Bibliography for this section.

[7] at Lake Mead. Trophic interrelationships among introduced fish were researched by Minckley (1982) [34] below Davis Dam. McClain (1976) [29] investigated food habits of brook trout in the Little Colorado River.

Many fish ecology and fishery surveys included general food habit information as part of a general life history discussion or in relation to fishery management. The most common method for evaluating food habits is stomach content analysis, which provides information on species composition, frequency of occurrence for each food item, and relative abundance. Seasonal differences in food habits may also be included. Fish ecology studies that included food habit information related to Lake Mead and downstream of Hoover Dam are available in Allan and Roden (1978) [1]; Dill (1944) [14]; Jonez and Sumner (1954) [24]; Minckley (1979) [33]; Moffett (1942) [36]; and the Nevada Department of Wildlife (1972-76) [38-42]. This type of information for Lake Mohave [1, 24], for a backwater below Headgate Rock Dam (Saiki, 1976) [57], and the tailwaters below Davis Dam (Edwards, 1974) [15] is also available.

Fishery investigations almost always contain ecological assessments to recommend management practices. Fishery status is primarily evaluated by determining distribution, reproduction rates, size/growth estimates, migration, population estimates, and relative abundance of each species. In addition, creel census surveys and fingerling marking techniques may be used to obtain data on harvest rates, stocking success, and fishing pressure. Comprehensive fishery management surveys for Lake Mead and the tailwaters of Hoover Dam are reported by Dill (1944) [14], Jonez and Sumner (1954) [24], Marshall (1976) [27], Minckley (1979) [33], Moffett (1942) [36], and by the Nevada Department of Wildlife (1976) [42]. Similar information for the backwater below Headgate Rock Dam is reported by Saiki (1976) [57]. A general statewide aquatic resource survey for Arizona fisheries was reported by Novy (1978) [43].

The largemouth bass population in Lake Mead was the subject of fishery investigations reported by Allen and Romero (1974) [2], Baker and Paulson (1983) [7], Nevada Department of Wildlife (1972-76) [38-42], Prentki, *et al.*, (1981) [51], and Wallis (1951) [67]. Other tailwater areas surveyed for largemouth bass included the areas below Imperial Dam by Weaver and Ziebell (1976) [68], and below Lake Mohave by Baker and Paulson (1980) [6]. Other studies focused on stocking practices. Ponder (1971) [49] discussed physical-chemical impacts on the introduction and survival of rainbow trout in Lake Havasu. Edwards (1974) [15] evaluated the success of introduced striped bass in the lower Colorado River below Davis Dam. The Nevada Department of Wildlife (1972-76) [38-42] did a 5-year comprehensive study that evaluated and described salmonid stocking success in Lake Mead.

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Code 2b.

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Codes 1a. and 2b.

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Code 1

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Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Codes 1a. and 3c.

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Lower Colorado: Arizona, Mohave County; California, San Bernardino County: Davis Dam, Colorado River
Codes 1a., 2d., 3a., and 3c.

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Codes 3e. and 4

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Codes 1a., 2b., 2c., and 2d.

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Codes 1a., 2b., 2c., and 2d.

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Codes 2b. and 5

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Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
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Codes 2a. and 2b.

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Codes 1a. and 2b.

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Lower Colorado: Arizona, California, Hoover Dam, Yuma Valley, Colorado River
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Lower Colorado: Arizona, California, General, Lower Colorado River
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Lower Colorado: Arizona, Mohave County; California, San Bernardino County; Davis Dam, Colorado River
Code 2b.

[35] Morgensen, S. A., and C. O. Padilla, *The Status of the Black Bass Fishery in Lake Mead and a Program Toward Restoration and Enhancement*, Bureau of Reclamation Contract Report No. 7-07-30-X0028.

Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
Code 2b.

[36] Moffett, J. W., "A Fishery Survey of the Colorado River Below Boulder Dam," *California Fish and Game*, 28:76-86, 1942.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Codes 1a. and 2b.

[37] ________, "A Preliminary Report on the Fishery of Lake Mead," *North Amer. Wildlife Conf. Trans.*, 8:179-186, 1943.

Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
Code 2b.

[38] Nevada Department of Wildlife, *Lake Mead, Clark County*, Job Progress Rept., Project No. F-20-8, Job Nos. IV 1, 2, 3, 4, 5, and 6, January 1, 1972–December 31, 1972, 44 pp., 1972.

Lower Colorado: Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[39] ________, *Statewide Fisheries Program, Lake Mead, Clark County*, Job Progress Rept., Project No. F-20-9, Job Nos. IV 1, 2, 3, and 4, January 1, 1973–December 31, 1973, 45 pp., 1973.

Lower Colorado: Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[40] ________, *Statewide Fisheries Program, Lake Mead, Clark County*, Job Progress Rept., Project No. F-20-11, Job Nos. 304 1, 2, and 3, January 1, 1974–December 31, 1974, 76 pp., 1974.

Lower Colorado: Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[41] ________, *Statewide Fisheries Program, Lake Mead, Clark County*, Job Progress Rept., Project No. F-20-12, Job Nos. 304 1, 2, 3, and 4, 100 pp., 1975.

Lower Colorado: Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[42] ________, *Statewide Fisheries Program, Lake Mead, Clark County*, Job Progress Rept., Project No. F-20-13, Job Nos. 304 1, 2, 3, 4, and 5, 108 pp., 1976.

Lower Colorado: Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[43] Novy, J., *Job Progress Report, Federal Aid in Fish Restoration Act*, Federal Aid Project F-7-R-20, Job Nos. 1, 2, 3, 4, 6, and 8, Arizona Fish and Game Department, 79 pp., 1978.

Lower Colorado: Arizona, General
Codes 1a. and 2b.

[44] Paulson, L. J., T. G. Miller, and J. R. Baker, *Influence of Dredging and High Discharge on the Ecology of Black Canyon*, Lake Mead Limnological Research Center, Univ. of Nevada, Technical Rept. No. 2, 59 pp., Las Vegas, NV, 1980.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Codes 1a., 3a., and 3c.

[45] Paulson, L. J., *Nutrient Management With Hydroelectric Dams on the Colorado River System*, Lake Mead Limnological Research Center, Univ. of Nevada, Technical Report No. 8, 39 pp., Las Vegas, NV, 1981.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Codes 1a., 2d., and 3d.

[46] Paulson, L. J., J. R. Baker, and J. E. Deacon, "Potential Use of Hydroelectric Facilities for Manipulating the Fertility of Lake Mead," In: *The Mitigation Symposium: A National Workshop on*

Mitigating Losses of Fish and Wildlife, pp. 296-300, General Technical Rept. RM-65, Rocky Mountain Forest and Range Experimental Station, U.S. Forest Service, Fort Collins, CO, 1979.

Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
Codes 1a. and 2b.

[47] Paulson, L. J., and J. R. Baker, "Possible Causes for Long-Term Changes in the Nitrate Budget and Concentration in Lake Mead, Arizona-Nevada," Abstracts of Papers Submitted for the First Winter Meeting of the American Society of Limnology and Oceanography, Inc., Jan. 2-5, 1979, Univ. of Texas, Corpus Christi, TX, 1979.

Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
Code 1a.

[48] Polhemus, L. J., and M. S. Polhemus, "Aquatic and Semiaquatic Chaeteroptera of the Grand Canyon (Insecta: Hemiptera)," *Great Basin Naturalist*, 36:221-226, 1976.

Lower Colorado: Arizona, Hoover Dam, Colorado River
Code 2a.

[49] Ponder, G., *A Study of Temperatures and Dissolved Oxygen in Lake Havasu As They Pertain to a Catchable Rainbow Trout Fishery*, California Dept. of Fish and Game, Inland Fisheries Admin. Rept. No. 71-15, 21 pp., 1971.

Lower Colorado: Arizona, Mohave County; California, San Bernardino County; Parker Dam, Colorado River
Codes 1a. and 2b.

[50] Portz, D. E., "Plankton Pigment Heterogeneity in Seven Reservoirs of the Lower Colorado Basin," M.S. Thesis, 154 pp., Arizona State Univ., 1973.

Lower Colorado: Arizona, Hoover and Davis Dams, Colorado River
Codes 1a. and 2d.

[51] Prentki, R. T., L. J. Paulson, and J. R. Baker, *Chemical and Biological Structure of Lake Mead Sediments*, Lake Mead Limnological Research Center, Univ. of Nevada, Technical Rept. No. 6, 89 pp., Las Vegas, NV, 1981.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Codes 1a. and 2b.

[52] Priscu, J. C., Jr., "Primary Productivity and Related Limnological Factors in Lake Mohave (Colorado River)," M.S. Thesis, 154 pp., Univ. of Nevada, Las Vegas, NV, 1978.

Lower Colorado: Arizona, Mohave County; California, San Bernardino County; Davis Dam, Colorado River
Codes 1a. and 2d.

[53] Rinne, J. N., "Cyprinid Fishes of the Genus Gila From the Lower Colorado River Basin," M.S. Thesis, 77 pp., Arizona State Univ., Tempe, AZ, 1969.

Lower Colorado: Arizona, Lower Colorado River
Codes 2b. and 2f.

[54] Rinne, J. N., "A Limnological Study of Central Arizona Reservoirs with Reference to Horizontal Fish Distribution," Ph.D. Dissertation, 350 pp., Arizona State University, Tempe, AZ, 1973.

Lower Colorado: Arizona
Code 2b.

[55] Roline, R. A., and D. M. Lieberman, *Limnology and Water Quality of Lower Lake Havasu During Preoperation and Testing of the Havasu Pumping Plant*, Bureau of Reclamation, Special Report, 63 pp. plus appendixes, Denver Office, Denver, CO, August 1985.

Lower Colorado: Nevada, Colorado River, Lake Havasu
Codes 1a., 2c., and 2d.

[56] Saiki, M. K., D. M. Kennedy, and J. C. Tash, "Effects of Water Developments on the Lower Colorado River," In: *Cal-Neva Wildlife Transactions*, pp. 100-111, 1980.

Lower Colorado: Arizona, Lower Colorado River
Codes 1a. and 2b.

[57] Saiki, M. K., "An Ecological Evaluation of Game Fishes at Deer Island Lake, Lower Colorado River," Ph.D. Dissertation, 240 pp., Univ. of Arizona, 1976.

Lower Colorado: Arizona, Deer Island Lake, Headgate Rock Dam, Lower Colorado River
Cods: 1a., 2a., 2b., 2c., 2e., and 2f.

[58] Sharpe, F. P., M. Elkins, and P. Strauss, "A Case History–Unscheduled Fish and Wildlife Mitigation," PL 93-320, Title 1, Colorado River Basin Salinity Control Project, In: *The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife*, pp. 301-304, General Technical

Report RM-65, Rocky Mountain Forest and Range Experimental Station, U.S. Forest Service, Fort Collins, CO, 1979.

Lower Colorado: Arizona, California, Colorado River
Codes 1a. and 2b.

[59] Singer, M. A., "The Ecology of Sport Fish in Two Dredged Backwaters of the Lower Colorado River," M.S. Thesis, 57 pp., Univ. of Arizona, 1973.

Lower Colorado: Arizona, Colorado River
Code 2b.

[60] Slawson, G. C., Jr., "Water Quality in the Lower Colorado River and the Effect of Reservoirs," M.S. Thesis, 116 pp. plus appendixes, Univ. of Arizona, 1972.

Lower Colorado: Arizona, Nevada, Hoover Dam, Colorado River
Code 1a.

[61] Smith, W. O., C. P. Vetter, and G. B. Cummings, *Comprehensive Survey of Sedimentation in Lake Mead, 1948-49*, USGS Professional Paper 295, 200 pp., 1960.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Code 1a.

[62] Sommerfeld, M. R., R. M. Cisneros, and R. D. Olsen, "The Phytoplankton of Canyon Lake, Arizona," *Southwestern Naturalist*, 20(1):45-53, 1975

Lower Colorado: Arizona, Maricopa County; Mormon Flat Dam, Salt River
Code 2d.

[63] Stevens, J. C., "The Effect of Silt Removal and Flow Regulation on the Regimen of Rio Grande and Colorado Rivers," In: *Transactions of the Amer. Geophysical Union, Nineteenth Annual Meeting, Part II*, pp. 653-661, 1938.

Lower Colorado: Arizona, Nevada, New Mexico, Hoover Dam, Colorado River, Elephant Butte Dam, Rio Grande River
Code 1a.

[64] Suttkus, R. D., and G. H. Clemmer, "The Humpback Chub, *Gila cypha*, in the Grand Canyon Area of the Colorado River," Occasional Paper, Tulane Univ. Museum of Natural History, 30 pp., 1977.

Lower Colorado: Arizona, Grand Canyon
Code 2b.

[65] Bureau of Reclamation, *Riverflows Between Davis Dam and Yuma, Arizona: A Forecast of Conditions and Impacts for the Period 1977 to 1986*, Lower Colorado Region, Colorado River Front Work and Levee System, Arizona, California-Nevada, 20 pp. plus figures and appendix, 1976.

Lower Colorado: Arizona, Mohave County; California, San Bernardino County; Davis Dam, Colorado River
Code 3e.

[66] U.S. Geological Survey, "Water Resources Data for Nevada–Part 1, Surface Water Records and Part 2, Water Quality Records," 1969.

Lower Colorado: Nevada, General
Code 1a.

[67] Wallis, O. L., "The Status of the Fish Fauna of the Lake Mead National Recreational Area, Arizona-Nevada," *Trans. Amer. Fish Soc.*, 80:84-92, 1951.

Lower Colorado: Arizona, Mohave County; Nevada, Clark County; Hoover Dam, Colorado River
Code 2b.

[68] Weaver, R. O., and C. D. Ziebell, "Ecology and Early Life History of Largemouth Bass and Bluegill in Imperial Reservoir, Arizona," *The Southwest Naturalist*, 21(2):151-160, 1976.

Lower Colorado: Arizona, Yuma County; California, Imperial County; Imperial Dam, Colorado River
Codes 1a. and 2b.

PACIFIC NORTHWEST REGION

Among the numerous tailwater areas in the Pacific Northwest Region, the available bibliographic material contains studies on the following Bureau impoundments or rivers:

- Baker River below Baker Dam
- Columbia River below Grand Coulee Dam
- North Fork of Payette River below Cascade Dam
- Owyhee River
- Snake River below American Falls, Jackson Lake, and Minidoka Dams
- South Fork Boise River below Anderson Ranch Dam
- Umatilla River
- Yakima River
- Flathead River below Kerr and Hungry Horse Dams

Literature is available for the following areas that are not within the Bureau of Reclamation's authority:

- Alsea River Basin
- Bear River below Bear Lake
- Clearwater River, and below Dworshak Dam
- Columbia River below Bonneville, Chief Joseph, Dry Falls, John Day, McNary, North, Priest Rapids, Rock Island, Rocky Reach, The Dalles, Wanapum, and Wells Dams
- Deep Creek
- Little Deschutes River
- Little Snake River
- Logan River
- Metolius River
- Orofino Creek
- Powder River
- Quartz Creek
- Salmon River
- Snake River below Ice Harbor; Lower Granite, Lower Goose, and Lower Monumental Dams
- South Fork Snake River
- Spokane River
- Spring Creek
- Spring Rain Creek

Water Quality

Temperature was the most extensively researched physical-chemical parameter in papers from the Pacific Northwest Region, especially in the fish studies. Three papers focused on temperature in the Columbia River basin. In 1958, Sylvester [206][5] discussed temperature in relation to potential effects on fish production, examined temperature variations on a diel and monthly basis, and related temperature to the distance downstream from various dams on the Columbia River. In 1968, the U.S. Geologic Survey [215] reported temperature profile data below Bonneville Dam. These profiles showed minimum, mean, and maximum temperatures during all months, and indicate temperature trends according to season. Diel fluctuations in temperature were recorded for the Flathead River below Hungry Horse Dam by Graham, *et al.*, 1980 [64].

Comprehensive physical-chemical research was conducted on Banks Lake and the Spokane River. Karp (1975) [95] and Stober, *et al.*, (1975) [201] examined the effects of irrigation drawdown and pumped-storage development on the ecology of Banks Lake. They provided comprehensive chemistry data and discussed thermal stratification, temperature regimes, horizontal thermal gradients, and monthly temperatures. Bishop and Lee (1972) [9] determined the effects of water quality conditions in Long Lake on the physical chemistry of the lower Spokane River and Roosevelt Lake.

The effect of temperature on nitrogen supersaturation and temperature tolerances of fish were reported by Beiningen and Ebel (1970) [8], Ebel (1969) [42], Ebel and Raymond (1976) [43], and the Seattle Marine Laboratories (1974) [184]. Temperature profiles in Cascade Reservoir were reported by Casey (1962) [20] in a study on the life history of the northern squawfish. Temperature data in American Falls Reservoir is included in a study of selected nutrients on nuisance algal growth by Rose and Minshall (1972) [176]. Stober, *et al.*, (1977) [202] presented thermal profiles of Franklin D. Roosevelt Reservoir as part of an extensive survey of fisheries in the forebay.

The effects of temperature on fish growth and migration, spawning requirements and tolerance levels of various fish species were reported for numerous streams in Idaho; for the Clearwater, Columbia, Little Deschutes, Salmon, and Snake Rivers; and for rivers and streams within the Lower Willamette, Powder, and Umatilla River basins. Hiebert and Bjornn (1980) [80] evaluated maintenance of the fish resources below Minidoka Dam on the Snake River following enlargement of the powerhouse. Hunter (1973) [82] discussed the water requirements of game fish throughout the State of Washington. Hutchison and Aney (1964) [85] and Hutchison, *et al.*, (1966) [87] presented water requirements of fish and wildlife resources in the Willamette River basin in the State of Oregon. Hutchison and Fortune (1967) [86] did a similar study within the Powder River basin. Water needs for aquatic life in Idaho streams were determined by the Idaho Fish and Game Department (1969) [88]. Temperature effects on the growth rates of small-

[5] Numbers in brackets refer to entires in the Bibliography for this section.

mouth bass in the Snake, Clearwater, and Salmon Rivers in Idaho were studied by Keating (1970) [96]. The ecology and management of brown trout in the Little Deschutes River was evaluated by Lorz (1974) [108]. Meekin (1973) [122] presented temperature data in a study of the effects of controlled spilling at Chief Joseph Dam on dissolved nitrogen supersaturation in the Columbia River by Pettit (1976) [158]. Temperature data was part of an evaluation by Pettit (1976) [158] of game and rough fish populations below Dworshak Dam on the Clearwater River. Smith and Pitney (1973) [187] reported water requirements, including temperature, for fish and wildlife resources in the Umatilla River basin, Oregon. Whitt (1954) [228] reported the effect of temperature on the age, growth, and migration of steelhead trout in the Clearwater River, Idaho. The effect of temperature on the growth and development of the mayfly, *Trichorythodes minutus* Traver, in Deep and Spring Creeks, Idaho was evaluated by Newell (1976) [144].

The influence of water exchange and dissolved oxygen in redds on surivival of steelhead trout embryos in the Alsea River basin was studied by Coble (1961) [23]. Sams and Pearson (unpublished manuscript, 1963) [177] include dissolved oxygen measurements in a report on methods for determining suitable flows for spawning by anadromous salmonids in the State of Oregon.

Nitrogen supersaturation and the effects on fish in the Columbia River are the subject of numerous papers from the Pacific Northwest Region. The effects of nitrogen supersaturation on fish will be discussed in the following section of this report. An in-depth study by the State of Washington (1974) [197] reported nitrogen data from 1965 to 1971 that was collected at seven dams on the Columbia River. In addition, Beiningen and Ebel (1970) [8] reported nitrogen measurements taken in the Columbia River below John Day Dam, and the Seattle Marine Laboratories (1974) [184] reported data collected below Grand Coulee Dam. Information from these reports included peak percent saturation levels, peak times of saturation, changes in partial pressure during spills, nitrogen concentration changes in relation to water temperature, and nitrogen levels in relation to time of day, season, and amount of spillover.

Other water quality studies were reported by Craig and Townsend (1946) [28] in a comprehensive study performed below the Willamette Valley Project on the Willamette River. They examined the effects of pollution from sewage, industry, and municipalities on salmon spawning migration. Heggen (1980) [77] described and evaluated a reservoir cost allocation proposal for the Willamette River, and determined that water quality below dams can be improved at a lower cost by merely increasing flows, thus eliminating the cost of additional water treatment facilities. In 1958, Sylvester [206] completed a water quality study of the Columbia River basin that included the effects on fish of water quality changes from irrigation practices, pollution, domestic sewage, and industrial waste. Sylvester also briefly described the effects on fish from a host of pollutants such as toxic chemicals, pesticides, oil, and detergent.

Several studies of the microbiology and bacteria of Flathead Lake above Kerr Dam on the Flathead River were performed by Graham and Young (1934) [66], Hern (1970) [78], and Potter and Baker (1956, 1961) [163, 164]. In [164], Potter and Baker studied the microbiology of Flathead Lake that included baseline fungus research; vertical distribution, dominance, and comparative population counts by habitat for bacteria; and concentrations of nitrogen, phosphorus, and iron.

Sonstelie (1967) [189] studied the water quality of the Flathead River above Flathead Lake. Besides reporting physical-chemical and plankton data, Sonstelie also addressed sulfide concentrations, coliform densities per depth, fungi percent composition, and recommendations for pollution control. Hern (1970) [78] also discussed coliform counts in Flathead Lake.

Studies from other disciplines that also contained water quality data were conducted on Banks Lake by Karp (1975) [95] and Stober, *et al.*, (1977) [203], on Rufus Woods Reservoir by Erickson, *et al.*, (1977) [45], on Clearwater River below Dworshak Dam by Pettit (1976) [158], on the Snake River near Lewiston, Idaho by Potlatch Forests, Inc., (1971) [162], and on the Spokane River by Bishop and Lee (1972) [9].

Aquatic Ecology

Fish.–The Pacific Northwest is an important area for the spawning and migration of economically important anadromous fish, this may be why spawning and migration are the most common topics in the literature from the Pacific Northwest Region. Papers that focused on spawning ecology and the subsequent effects of barriers (dams) to spawning and migration were reported for the years between 1946 and 1980. Studies were performed on many of the rivers of the region, especially the Clearwater, Columbia, and Snake Rivers. Casey (1962) [20] researched the life history of the northern squawfish in Cascade Reservoir on the North Fork of the Payette River, Idaho. Craig and Townsend (1946) [28] investigated fish population maintenence problems in relation to the Willamette Valley Project on the Willamette River, Oregon. The life history of the cutthroat trout, *Salmo clarki* Richardson, in the Logan River, Utah was reported by Fleener (1951)

[56]. Fish and wildlife resources of the Owyhee Basin, Oregon and their water requirements were discussed by Fortune and Thompson (1969) [57]. Studies on the Snake River included work below Minidoka Dam by Hiebert and Bjornn (1980) [80], and by the Wyoming Game and Fish Commission (1966) [233], which prepared a report summarizing the life history and management studies on the Rocky Mountain whitefish. Information is available on the the Clearwater River, another frequently reported study area, in Hoss, *et al.*, (1976) [81] on salmon and steelhead populations; Pettit (1976) [158] on evaluating game and rough fish populations below Dworshak Dam; and Whitt (1954) [228] in a study of the age, growth, and migration of steelhead trout. Studies from the Columbia River include those by Raymond (1968, 1969) [167, 168], Raymond, *et al.*, (1974) [170], Stober, *et al.*, (1977) [202], and by the Corps of Engineers (1957) [207]. Information on the Willamette River basin is reported by Hutchison and Aney (1964) [85] and Hutchison, *et al.*, (1966) [87], and on the Powder River basin by Hutchison and Fortune (1967) [86]. Moore and Cadwallader (1979) [135] provided information on fish populations in the South Fork Boise River below Anderson Ranch Dam. Smith and Pitney (1973) [187] reported on the fish and wildlife resources of the Umatilla basin, Oregon.

Common topics in reports involving fish spawning included spawning time; redd counts; age, size, and sex composition of spawners; spawning reductions from temperature and flow changes; and destruction of habitat. The ecological requirements for spawning were emphasized, particularly for temperature, dissolved oxygen, gravel size and distribution, and velocity and depth of flow.

Papers that discussed the water requirements for spawning are available for the following rivers or river basins:

- Clearwater River by Pettit (1976) [158]
- Boise River by Moore and Cadwallader (1979) [135]
- Powder River basin by Hutchison and Fortune (1967) [86]
- Umatilla River basin by Smith and Pitney (1973) [187]
- Willamette River basin by Hutchison and Aney (1964) [85]

Two general references discussing water requirements for game fish in the States of Washington and Oregon are by Hunter (1973) [82], and by Sams and Pearson (unppublished manuscript, 1963) [177], respectively.

Research on spawning habitat was reported in several references beginning with Coble (1961) [23], who investigated the influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Spawning habitat was discussed in Hoss, *et al.*, (1976) [81] and Hunter (1973) [82] for streams in Idaho and Washington. Hutchison and Fortune (1967) [86] included spawning habitat in their report of the fish and wildlife resources of the lower Willamette River basin, Oregon. Keating (1970) [96] discussed spawning habitat for smallmouth bass in the Snake, Clearwater, and Salmon Rivers in Idaho.

Loss of spawning habitat was reported in the Clearwater River by Pettit (1976) [158], the Willamette River by Craig and Townsend (1946) [28], and in Franklin D. Roosevelt Reservoir by Stober, *et al.*, (1977) [202]. In 1964, Hutchison and Aney [85] conducted spawning gravel transects at different flows, and reported the percent of useable spawning gravel for the lower Willamette River basin. Hutchison, *et al.*, (1966) [87] conducted spawning ground fish population estimates and determined the distribution and density of spawning gravel in the upper Willamette River basin. The use of a spillway on Minidoka Dam on the Snake River as spawning habitat was reported by Hiebert and Bjornn (1980) [80]. The spawning of fish other than salmonids was discussed in two papers from the Pacific Northwest Region. Casey (1962) [20] examined the life history of the northern squawfish in Cascade Reservoir on the North Fork of the Payette River, Idaho. Topics included in this report were the sexual development, spawning concentration, and age of spawning squawfish. The Wyoming Game and Fish Commission (1966) [233] presented a summary of life history studies conducted between 1952 and 1964 on Rocky Mountain whitefish in the Snake River drainage. This summary included discussions of spawning habits and migration.

Research on migration can be divided into two categories: (1) research on salmonids moving upstream to spawn, and (2) on smolts migrating downstream towards the ocean. Upstream migration in the lower Columbia River was discussed by Laythe (1948) [103] as part of a fishery development program. The effects of hydroelectric development on the fishery resources, including upstream migration, in the Snake River was reported by Irving and Cuplin (1956) [89]. Moore and Cadwallader (1979) [135] included upstream migration in a report of fish population studies done in the South Fork Boise River below Anderson Ranch Dam. Upstream migration is discussed by Hutchison and Fortune (1967) [86] in a report on the water requirements of fish and wildlife resources in the Powder River basin, Oregon. Studies on the Willamette River reporting upstream migration of salmonids were performed by Craig and Townsend (1946) [28] and Hutchison and Aney (1964) [85].

Upstream migration information from the above reports included the speed of travel during migration, number of fish migrating, and factors such as temperature, flow, pollution, and physical obstructions that affect migration efforts. In 1954, Whitt [228] conducted a detailed study of steelhead trout that migrate long distances. Whitt determined age and growth characteristics, traveling speed, and overwintering habits of steelhead trout; and also designed a sampling system that estimated the annual populations of steelhead trout migrating up the Clearwater River. McMaster, *et al.*, (1977) [121] researched the effects of reduced flows on the upstream migration of chinook salmon and steelhead trout using mark-and-recapture and radiotelemetry methods. They also evaluated movement patterns, travel rates, and steelhead overwintering behavior.

Studies on downstream migration were done on the Columbia, Snake, Baker, and the North Fork Payette Rivers; however,most of these studies were done on the Columbia and Snake Rivers. Laythe (1948) [103] discussed downstream migration in the lower Columbia River. Mains and Smith (1964) [109] reported distribution, size, time, and current preferences of seaward migrating chinook salmon in both the Columbia and Snake Rivers. Marquette and Long (1971) [114] performed laboratory studies of screens for diverting juvenile salmon and trout from turbine intakes in both the Columbia and Snake Rivers. Raymond (1968, 1969, 1979) [167, 168, 169] extensively reported migration rates of yearling chinook salmon in relation to flows and impoundments on both the Columbia and Snake Rivers. Raymond, *et al.*, (1974, 1975) [170, 171], focused on the effects of peaking power operations on migration activity in the Columbia and Snake Rivers. The Corps of Engineers (1957) [207] reported the effects of structures on the Columbia River and certain other dams on downstream migration of fingerling salmon. Rees (1957) [172] described the vertical and horizontal distribution of seaward migrant salmon in the forebay of Baker Dam on the Baker River. Finally, Casey (1962) [20] included a discussion of downstream migration in a study of the northern squawfish in Cascade Reservoir on the North Fork Payette River.

Topics in the above reports included current and velocity preferences, size range of migrants, diurnal fluctuations in migration activity, and periodicity of annual and peak migration. Most migration studies emphasized research on the effect of various water projects on migration by examining migration rates in impounded versus freeflowing stretches of rivers. They also determined causes of mortality of migrant fish, correlated migration rates with discharge and velocity, and studied the effects of diel and weekly peaking discharges as well as the effects of holdover in reservoirs.

The effects of nitrogen supersaturation on fish were extensively investigated in the Pacific Northwest Region. Steelhead trout and salmon (primarily chinook) were the most frequently studied fish species. Nine papers reported nitrogen supersaturation effects on fish in the Columbia River, three of which also included the Snake River. Field observations commonly included fish mortality estimates:

- Beiningen and Ebel (1970) [8]
- Ebel (1969) [42]
- Ebel and Raymond (1976) [43]
- Ebel, *et al.*, (1975) [44]
- Raymond (1979) [169]
- Raymond, *et al.*, (1975) [171]
- Seattle Marin Laboratories (1974) [184]
- State of Washington Department of Fisheries (1974) [197]

Other reports discussing nitrogen supersaturation effects on fish included the effect on spring migration success and changes in fish depth distribution to compensate for high nitrogen levels [184, 197], tolerance of eggs and juveniles to nitrogen [8, 42, 44, 169, 197], lowered tolerance of juvenile fish to temperature increases [42], and observations of gas-bubble disease [9, 42, 43, 184, 197]. Studies reporting that spring migrant mortalities were increasing as a result of nitrogen supersaturation compounded with delays in fish traveling over the dams were done by Beiningen and Ebel (1970) [8], Raymond (1979) [169], and Raymond, *et al.*, (1975) [171].

Ebel and Raymond (1976) [43] presented significant research that correlated the level of nitrogen supersaturation to the severity with which fish were affected. This report included data on temperature and duration of exposure, physical condition, and swimming depth of fish. The authors also conducted caged fish studies to determine mean values of lethal exposure time, travel time estimates (migration rates), and percent of supersaturation relative to fish depth. In 1974, Newcomb [143] conducted lab experiments to assess blood chemistry changes of juvenile steelhead trout following exposure to nitrogen supersaturation. Serum samples were analyzed for numerous ions and biochemical constituents (e.g., calcium, sodium, cholesterol, glucose, urea, and enzymes) after exposing trout to different saturation levels of nitrogen mixed with argon gas.

Fish rearing studies were the subject of or included in several reports for the Pacific Northwest Region. Stober, *et al.*, (1977) [203] discussed fish rearing in a report on the operational effects of irrigation and pumped storage on the ecology of Banks Lake, Washington. This study investigated the development rates and survival of eggs and fry, and reported plantings of kokanee eggs. In a report on the fisheries resources in the forebay of Franklin D. Roosevelt Reservoir by Stober, *et al.*, (1977) [202], fish rearing information was also included. Casey (1962) [20] studied the life history of the northern squawfish in Cascade Reservoir and included fish rearing activities. White and Wade (1980) [227] included fish rearing information in a report of the fish and macroinvertebrate fauna in the South Fork Boise River, Idaho. Coble (1961) [23] presented detailed fish rearing data in a report on the influence of water exchange and dissolved oxygen in redds on the survival of steelhead trout embryos. Sams and Pearson (unpublished manuscript, 1963) [177] correlated levels of intragravel dissolved oxygen and stream velocity with coho and chinook salmon and steelhead trout egg survival.

Food habits of fish were the main subject of one report, but were included in 11 other studies in literature from the Pacific Northwest Region. Keating (1970) [96] focused on food habits of smallmouth bass in the Snake, Clearwater, and Salmon Rivers. This report discussed variations in food composition between different populations found in each river, variations in food abundance from each river, and percent occurrence of food items in the stomachs of each age class of fish. The other reports that included information on fish food habits are:

- Casey (1962) [20]
- Coon, *et al.*, (1977) [27]
- Erickson, *et al.*, (1977) [45]
- Fleener (1951) [56]
- Giger (1973) [61]
- Graham, *et al.*, (1980) [64]
- Hutchison and Fortune (1967) [86]
- Idaho Fish and Game Department (1969) [88]
- Lorz (1974) [108]
- Stober, *et al.*, (1975) [201]
- Stober, *et al.*, (1977) [202, 203]
- White and Wade (1980) [227]

In addition the more common data regarding food items (e.g., composition, relative abundance, frequency of occurrence), a few papers also provided more detailed information. Fleener (1951) [56] discussed seasonal variations in food habits of the cutthroat trout in the Logan River, Utah. In a report on feeding behavior of salmonids in relation to discharge level and velocity, Giger (1973) [61] associated differences in feeding behavior to time of day, season, and the size-class and species of fish.

Fish habitat for shelter and rearing was described in seven studies in the Pacific Northwest Region literature. Dalton, *et al.*, (1965) [34] included a discussion of habitat in their report on the distribution of sculpin, *Cottus extensus*, in Bear Lake, Utah-Idaho. Giger (1973) [61] determined shelter requirements for young fish by examining the effect of velocity on substrate use; describing overhead and submerged habitat as fish shelter; examining variations in shelter use according to the season, flow, time of day, and species of fish; and discussing microhabitat selection and territoriality. Jesperson (1979) [91] developed a model to predict trout standing crop from mean riffle velocity and available cover habitat, estimated habitat parameters, and determined fish losses during reduced flow periods. Keating (1970) [96] also included a discussion of fish habitat in a report on the growth rates and food habits of smallmouth bass in the Snake, Clearwater, and Salmon Rivers in Idaho. In 1974, Lorz [108] discussed the amount of vegetation on banks in relation to the size of fish populations and correlated cover quality to pounds of fish per acre. Munther (1970) [139] reported fish habitat information for smallmouth bass in the Middle Snake River.

Other fish ecology topics covered in Pacific Northwest Region literature included age-growth, length-weight relationships, growth rates, condition factors, abundance of fish, and distribution and movement. Whitt (1954) [228] examined the relationships between age-length and age-weight of steelhead trout, and reported on steelhead trout scale studies. Keating (1970) [96] studied growth rates of smallmouth bass in three rivers, the Snake, Clearwater and Salmon Rivers, by comparing growth rates according to age, class, river section, thermal criteria, and competition effects, and predicted changes in growth rates if tailwater temperatures were reduced by dam releases.

The abundance, distribution, and movement of fish were discussed in 18 papers from the Pacific Northwest Region literature:

- Coon, *et al.*, (1977) [27]
- Dalton, *et al.*, (1965) [34]
- Erickson, *et al.*, (1977) [45]
- Fleener (1951) [56]
- Fortune and Thompson (1969) [57]
- Hiebert and Bjornn (1980) [80]
- Hutchison and Aney (1964) [85]
- Hutchison and Fortune (1967) [86]
- Hutchison, *et al.*, (1966) [87]
- Kiefling (1972) [97]
- Lorz (1974) [108]
- Mains and Smith (1964) [109]
- Munther (1970) [139]
- Rees (1957) [172]
- Stober, *et al.*, (1975) [201]
- Stober, *et al.*, (1977) [202, 203]
- White and Wade (1980) [227]

Several of these studies correlated changes in abundance and distribution with the impacts of dam operation [108, 203, 227]. Munther (1970) [139] researched movement and distribution of smallmouth bass. Topics in this paper included characteristics of interpool movement and changes in movement by time of day, season, and density of fish. In addition, diel changes within a pool and the effect of temperature on fish distributions were assessed. Stober, *et al.*, (1977) [202] determined monthly fish abundance in Franklin D. Roosevelt Reservoir by using gillnets, townets, and acoustic surveys; and described the distribution patterns for each important fish species.

Documents with fishery management information such as creel census or stocking records were available for the Columbia, Owyhee, Snake, Bear, Clearwater, Little Deschutes, Logan, Salmon, and South Fork Boise Rivers, as well as the Panhandle, Southwest, Willamette, and Powder River basins. Information on creel census on the Logan River was presented in Fleener (1951) [56]. The Snake River creel census data is contained in Hiebert and Bjornn (1980) [80] and Irving and Cuplin (1956) [89]. Hutchison and Aney (1964) [85] reported creel census data for the lower Willamette River basin. Hutchison, *et al.*, (1966) [87] obtained creel census data for the upper Willamette River basin. Lorz (1974) [108] included creel census data for the Little Deschutes River. South Fork Boise River creel census data was reported in Moore and Cadwallader (1979) [135]. Pettit (1976) [158] included creel census information in an evaluation of game and rough fish populations below Dworshak Dam on the Clearwater River. Stocking records on the Owyhee River are available in Fortune and Thompson (1969) [57]. Snake River stocking records are reported by Hiebert and Bjornn (1980) [80] and by the Wyoming Game and Fish Commission (1966) [233]. Hutchison and Fortune (1967) [86] included stocking records for the Powder River basin. Stocking records for Banks Lake, Washington on the Columbia River were reported by Stober, *et al.*, (1975) [201] and for Franklin D. Roosevelt Reservoir by Stober, *et al.*, (1977) [202].

Invertebrates.-Several papers from the Pacific Northwest Region literature included comprehensive ecological data on invertebrates. In 1976, Newell [144] studied the effects of temperature on a mayfly species, *Tricorythodes minutus* Traver, in Deep and Spring Creeks in Idaho. Newell also studied temperature effects on growth, development, ecclosion, and survival, and noted whether the mayfly was multivoltine or bivoltine according to temperature constancy. This report also included life history information such as number of eggs per female, egg morphology and fecundity, and food and abundance. In addition, the development, distribution, length-weight relationship, and mortality of nymphs; and the morphology, mating habits, life span, and oviposition of adults were studied.

Hauer and Stanford (1982) [75] investigated invertebrate response to stream regulation. Collections obtained over a 5-year period resulted in information on population variance estimates, density of organisms between headwaters and main stem, and seasonal mean abundance of four species of caddisfly. Hauer (1980) [74] conducted ecological studies of Trichoptera and, besides the general topics of invertebrate ecology, included trophic dynamics, morphological, and ecological differences between larvae and ecological segregation of cogeneric species, larval specialization, and ecology of infrequently collected caddisflies. Perry and Graham (1982) [156] studied the impacts of Hungry Horse Dam on invertebrates by assessing density, biomass, and the effects of flow increases on insect drift and life history in the Flathead River. Stanford (1975) [191] studied hyporheic communities, temperature, and photoperiod as they affect growth and emergence, and the ecology of stoneflies in the Upper Flathead River.

Three papers presented significant data on the effects of changes in flow on invertebrate drift. Minshall and Winger (1968) [130] reported the effect of artificial reductions in discharge on invertebrate drift in the South Fork Snake River. They correlated invertebrate entry into the drift with changes in current velocity and depth. Walker (1972) [218] included research on population density, biomass, percent generic composition, drift rates in relation to time of day and season, peak times of drift, and drift variations in relation to changes in flow velocity. White and Wade (1980) [227] reported the effect on fish and macroinvertebrates of fluctuations in test flows in the South Fork Boise River below Anderson Ranch Dam during the winter. Topics related to invertebrates included species composition of catastrophic as opposed to behavioral drift, size of drift in relation to speed and volume of flow, and distribution and relative abundance. Giger (1973) [61] included less detailed information on invertebrate drift as part of a report on the streamflow requirements of salmonids. Two papers presented brief data on impacts to invertebrate populations from water projects. Bjornn (1977) [10] examined the effects of granitic sediments on invertebrates in the streams of Idaho. Another paper by Potlatch Forests, Inc. (1971) [162], classified invertebrate species in terms of their tolerance to pollution in the Snake River, Idaho. Topics from these two papers included data on the flow velocity and time of day in relation to drift and population density, and on the abundance of terrestrial insects in relation to the proximity of shoreline vegetation.

Only three papers researched invertebrate ecology without considering the potential effects of water projects. Anderson (1967) [1] reported on the productivity, diversity, and abundance of caddisflies in the drift and benthos of the Metolius River. For each species collected, Anderson discussed density, distribution, importance, diel periodicity, larval emergence, morphology, and peak periods of activity. Topics on drift ecology included species composition, species variations in drift tendency, variation in numbers during a 24-hour period, age-class distribution within the drift, and an evaluation of the drift-trap collection method. Smith (1968) [188] reported and described larval and adult forms of *Rhyacophila* collected over a 3-year period from the Salmon River. This study included, for almost every species, systematic, distributional, and ecological data. This report also discussed variations in seasonal occurrence and diurnal activity. Kroger (1974) [100] reported data on invertebrate drift in the Snake River. Drift indices, indicators of a species tendency to drift, for 25 taxonomic groups were calculated by the ratio of standing crop to drifting numbers. These indices were linked to conditions of competition among the invertebrate species and the carrying capacity of the river. Kroger also correlated life cycle stages and abundance with drifting numbers and discussed diel periodicities of drift.

Many fish studies include brief discussions of invertebrates as fish food. Usually, stomach analyses are conducted to obtain data on frequency of occurrence, relative abundance, and percent composition of invertebrate types. Fish studies that discussed invertebrates as fish food were:

- Casey (1962) [20]
- Coon, *et al.*, (1977) [27]
- Erickson, *et al.*, (1977) [45]
- Fleener (1951) [56]
- Keating (1970) [96]
- Lorz (1974) [108]
- Stober, *et al.*, (1977) [202, 203]
- White and Wade (1980) [227]
- Wyoming Game and Fish Commission (1966) [233]

Algae and Aquatic Weeds.–Only a few studies focused on algae in tailwaters of the Pacific Northwest Region. Most of these discussed phytoplankton as a significant limnological constituent or as an indicator of water quality. In 1967, Cushing [33] examined periphyton that were accumulating radionuclides in the Columbia River below the nuclear reactors at Hanford. Cushing correlated the net production rate and weight of periphyton to transport of radionuclides by the river, reported the quantity of radionuclides per gram of periphyton, and discussed concentration levels of radionuclides in periphyton in relation to the season. Walker (1972) [218] described pre-impoundment benthos and periphyton communities in Clearwater River prior to completion of Dworshak Dam. Seasonal population fluctuations related to flow, temperature, and life history dynamics were studied. Periphyton community composition and primary production were examined in selected riffles, and peak primary production was correlated with temperature.

Rose and Minshall (1972) [176] conducted a study in the Snake River below American Falls Dam to determine the feasibility of using polyethylene tubes as inplace culture chambers to assess the influence of several nutrients on algal growth. In a water quality study of the Spokane River, Bishop and Lee (1972) [9] also grew algal cultures to study growth relative to the river's water quality and nutrients; these experiments were performed in the lab. This study also included field observations of phytoplankton blooms, cell densities, and collections above and below industrial and municipal wastewater discharges. General phytoplankton data from papers focusing on other disciplines are found in:

- Erickson, *et al.*, (1977) [45]
- Karp (1975) [95]
- Kroger (1973) [99]
- Stober, *et al.*, (1977) [202, 203]

Stream Regulation

Because the Pacific Northwest Region includes coastal areas, it is a prime area for salmonid spawning migration, and numerous papers present discussions of the effect of flow changes on spawning ecology and migration. Studies that presented significant data on the effects of flow on migration, passage, spawning, and rearing were:

- Fortune and Thompson (1969) [57]
- Giger (1973) [61]
- Hunter (1973) [82]
- Hutchison, *et al.*, (1966) [87]
- Jesperson (1979) [91]
- Moore and Cadwallader (1979) [135]
- Pettit (1976) [158]
- Smith and Pitney (1973) [187]
- White and Wade (1980) [227]

These studies most often assessed the biological water requirements of fish (and sometimes wildlife) by conducting minimum streamflow studies to determine the flows required for spawning, rearing, and passage. Velocity and depth requirements for spawning were also reported.

Sams and Pearson (unpublished manuscript, 1963) [177] developed criteria, methods, and procedures to determine adequate spawning flows for anadromous salmonid spawning in the Willamette River basin. They used five methods of data analysis to calculate these flows that were used to develop criteria for egg survival and establish requirements of velocity and depth over salmonid redds on four streams. In addition, they evaluated the accuracy, versatility, and time and manpower requirements for each of the five flow-determining methods.

In 1977, Cochnauer [24] obtained data on flows from 13 Idaho streams to use in a Bureau water surface profile computer program. This program can predict velocities and depths over a range of flows. Cochnauer then compared the predicted values to the ecological requirements for fish and wildlife, including the velocity and depth requirements for spawning by each important fish species.

White (1975) [226] conducted an in-depth evaluation of flow methodology. This paper contains information gathered for use by the State of Idaho in their water plans that address the ecological requirements of select fish and wildlife species on 90 sections of 46 Idaho streams. White proposed a methodology that addressed the requirements for the passage, spawning, and rearing of various fish species. White also described a model developed by the Bureau that predicts channel morphometry and hydraulic characteristics at various discharges, and describes changes in stream habitat that can be determined from these predictions. This method was applied to the Snake River in recommending flows necessary to meet the ecological requirements of white sturgeon, smallmouth bass, and channel catfish.

Jesperson (1979) [91] conducted a study to determine the flows necessary to provide adequate habitat for maintaining sensitive trout populations in the North Fork and Roaring Fork drainages of the Little Snake River. A model was developed that could predict trout standing crop from mean riffle velocity and available cover habitat. Jesperson also used the model to predict fish loss from reduced flows. In 1976, Pettit [158] studied the effects of reduced flows on game and roughfish populations below Dworshak Dam on the Clearwater River. Decreased and fluctuating flows were found to reduce spawning and rearing habitat, and affect total harvests.

White and Wade (1980) [227] evaluated the effects of fluctuating flows on invertebrates and fish in the South Fork Boise River. Test flows, simulating winter operation, were used to determine the minimum discharge needed to protect and enhance fish, wildlife, and related recreational values. Flow impacts on insect drift, fish egg dislodgement and exposure, and fish displacement were evaluated.

Modeling

Simulation models for physical-chemical parameters and flow regimes are available in Pacific Northwest Region literature. Jaske and Goebel (1967) [90] described a mathematical model capable of predicting temperature and associated water quality variables. This model was used to evaluate the results of a program to minimize impacts from plant operations by reducing river temperatures. In 1984, Mueller and George [138] applied two streamflow transport simulation models to the Yakima River basin during low flows. These models were calibrated, verified, and evaluated to determine how accurately they predict temperature, dissolved oxygen, and biochemical oxygen demand. In 1969, the first application of a thermal model to the tailwaters of Hungry Horse Dam on the Upper Flathead River was completed by Water Resources Engineers, Inc. [222]. This generalized mathematical model was devised to predict thermal changes for a number of alternative reservoir operation conditions. Models for recommending minimum flow for the protection of fish discussed in the previous section are reported by Cochnauer (1977) [24], Jesperson (1979) [91], Pettit (1976) [158], White (1975) [226], and White and Wade (1980) [227].

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Pacific Northwest: Montana, Lake County; Kerr Dam, Flathead River
Codes 1a., 2c., and 2d.

[235] Zubik, R. J., and J. Fraley, *Determination of Fishery Losses in the Flathead System Resulting from the Construction of Hungry Horse Dam*, Bonneville Power Administration, DOE/BP-23638-1, 33 pp. plus appendixes, 1987.

Pacific Northwest: Montana, Hungry Horse Dam, Flathead River
Codes 2b. and 2f.

MID-PACIFIC REGION

Numerous studies have been conducted in the following tailwater areas in the Mid-Pacific Region:

- American River below Folsom Dam
- Cache Creek below Clear Lake Dam
- Carson River
- Delta-Mendota Canal in Central Valley Project
- Feather River below Oroville Dam
- Hallwood-Cordua Fish Screen in Yuba River
- Kings River below Pine Flat Reservoir
- Klamath River Basin
- Lake Tahoe
- Putah Creek below Monticello Dam
- Sacramento River below Anderson-Cottonwood Project; Keswick, Redding, and Shasta Dams; and Glenn-Colusa Irrigation Diversion
- San Joaquin River below Millerton Dam
- Shasta River below Lake Shastina
- Stanislaus River below New Melones Dam and below Beardsley, Donnells, and Tulloch Dams (Tri-Dam Project)
- Stevens Creek below Stevens Creek Dam
- Trinity River below Trinity Project and Lewiston and Trinity Dams
- Truckee River below Derby Dam and Pyramid Lake
- Ventura River below Casitas Dam

Tailwater areas below dams in the Mid-Pacific Region that were clearly identified as having some kind of water quality, fishery or ecological problem include the following:

- American River below Auburn (proposed) and Folsom Dams
- Cache Creek below Clear Lake Dam
- Delta-Mendota Canal in the Central Valley Project
- Feather River below Oroville Dam
- Klamath River Basin
- Sacramento River below Anderson-Cottonwood Project; below Keswick, Redding, and Shasta Dams; and the Glenn-Colusa Irrigation Diversion
- San Joaquin River below Millerton Dam
- Stanislaus River below New Melones Dam
- Trinity River below Trinity Project and below Lewiston and Trinity Dams
- Truckee River below Derby Dam and Pyramid Lake
- Ventura River below Casitas Dam
- Yuba River below Hallwood-Cordua Fish Screen

Water Quality

Many documents in the available literature from the Mid-Pacific Region discuss temperature as a physical-chemical parameter affecting tailwaters, and as a factor affecting fish, particularly salmon and trout. Most of these reports also include flow data because flow directly influences water temperature. A water temperature study on the Auburn-Folsom South Unit was done by Rowell (1968) [61][6]. Other studies on the Truckee River, (Rowell, 1975) [64], (Rowell, 1984) [69, 70]; Trinity Dam (Rowell, 1979) [65]; on the American River (Rowell, 1982) [67]; and at the proposed Auburn Dam (Rowell, 1980) [66], were also reported. Raphael (1966) [56] examined the effects of surface water intakes on temperature cycles in Oroville Reservoir, basing the study on a heat budget analysis for the impoundment. Weidlein (1971) [97] predicted water release temperatures based on projected water demand conditions for the year 2020. This study was conducted to determine if the Sacramento River, under maximum downstream water demand, would warm to the point of harming the salmon fishery. Temperature predictions were studied specifically with regard to spawning times and egg development.

A study on the effects of multiple level outlets at the proposed Auburn Dam was conducted by the Bureau of Reclamation (1968) [78] to determine the optimum number and location of penstocks necessary to maintain good discharge water quality. This study emphasized temperature and turbidity effects on both the proposed impoundment and in the tailwaters.

Many papers that involved research in other disciplines also included data on physical-chemical parameters, especially temperature and sedimentation. Boles (1981) [2] evaluated macroinvertebrate populations below Lewiston Dam on the Trinity River, which is a hypolimnial release reservoir. Curtis (1959) [15] reported changes in the physical characteristics of the Sacramento River following hydroelectric diversion. Gregory (1982) [28] studied the geomorphology of the Truckee River, and a report by Kaiser Engineers (1973) [35] presented comprehensive water quality survey results from the Truckee River.

The literature also includes information from significant physical-chemical studies. Particularly addressed were temperature and sedimentation. Also included were reports on salmonid fish and salmonid fisheries in the Mid-Pacific Region:

- California Resources Agency (1979) [11]
- Hooper (1973) [33]
- LaFaunce (1965) [41]
- McBrayer and Ringo (1975) [43]
- McGregor (1922) [44]

[6] Numbers in brackets refer to entries in the Bibliography for this section.

- Moffet (1949) [48]
- Needham, *et al.*, (1943) [50]
- Fish and Wildlife Service (1980) [88, 89]
- von Geldern (1964) [95]
- Weidlein (1971) [97]

The above papers contained mostly temperature data, although sedimentation and dissolved solids were often considered to be factors that affected spawning conditions and habitat degradation. Kaiser Engineers (1973) [35] reported historical and recent data on the water quality of the Truckee River. This report presented data on nutrients, significant major ions, and coliforms; included assays of selected bacteria that are pollution indicators; and described those factors that influence water quality. Fast (1979) [21] reported saturation ranges for nitrogen, oxygen, and argon during artificial aeration of the Ventura River below Lake Casitas Dam. Nowlin, *et al.*, (1980) [51] described multidisciplinary plans and designs for a river-quality assessment for the Carson and Truckee River Basins. The objectives were to identify the most significant resource management problems affecting water quality, and to develop and apply methodologies to assess these problems. The California Department of Public Health (1965) [7] examined the effects of storms on water quality in the Trinity and Central Valley Projects. The report emphasized turbidity data; however, it also included a discussion of the effects on the concentrations of nutrients, significant major ions, iron, manganese, and bacterial coliforms.

Significant water quality data for Clear Lake by Goldman and Wetzel (1963) [26], Shasta Lake by Weidlein (1971) [97], American River by the Bureau of Reclamation (1968) [78], Stanislaus River by the Water and Power Resources Service (1980) [94], and the Truckee River by Koch and Hainline (1976) [39], and McBrayer and Ringo (1975) [43] are available. Pollution and heavy metal concentration data was reported by Reclamation for the American River (1968) [78] and for the Trinity River (1978) [79]; the Truckee River by McBrayer and Ringo (1975) [43], and for Shasta Lake by Weidlein (1971) [97].

Aquatic Ecology

Fish.-Many documents from the Mid-Pacific Region are concerned with some aspect of fish or fish ecology. Two papers on native fish species are Baker (1977) [1] and Ebert and Summerfelt (1969) [18]. In 1977, Baker [1] determined the vertical and seasonal distribution, size composition, and relative abundance of the Lahontan speckled dace in Lake Tahoe. Field data were collected by shoreline rotenoning and minnow trapping. Baker correlated catch rates to month and temperature, and analyzed length-frequency data to determine age classes. Ebert and Summerfelt (1969) [18] investigated another species of native fish in Lake Tahoe, the Piute sculpin. Diet research analyzed variations in food composition according to season, sculpin size, depth of capture, and collection site. Age-growth studies of these fish revealed number of age groups, coefficients of condition, and length-weight relationships. Reproductive data presented in this report contained estimates of spawning times, mean number of eggs per female, and age at spawning. The discussion of parasites on the Piute sculpin population included parasite types and places of attachment.

Fish food habits were the main subject in two reports, Goodson (1965) [27] and Frantz and Cordone (1970) [24]. In 1965, Goodson [27] described variations in the diets of largemouth bass, black crappie, bluegill, and white catfish in Pine Flat Lake based on 1 year of stomach contents data. This study was conducted to determine which food organisms provide important forage to these fish species. Frantz and Cordone evaluated data from 1,389 stomachs to determine the diets of lake trout in Lake Tahoe. Diet was evaluated on the basis of size-class of fish, season, and year.

Significant data on the food habits of fish was included in Weidlein (1971) [97], Hooper (1973) [33], and Wigglesworth (1975) [99]. Weidlein presented data on food habits of lake trout as part of the Shasta Lake trout management investigations. Hooper discussed food production for resident trout populations in relation to flow, and included extensive invertebrate data. The report on the food habits of smelt in Lake Shastina by Wigglesworth included a discussion of zooplankton utilization relative to size-class of fish and the frequency of occurrence and percent volume estimates for several zooplankton taxa used as food sources by smelt.

Several papers focused on spawning research in the Mid-Pacific Region. LaFaunce (1965) [41] reported on a spawning bed survey designed to estimate the effects of Trinity and Lewiston Dams on abundance and area use by spawning Chinook salmon in the upper Trinity River. Farley (1965) [20] determined where and under what conditions striped bass spawn in the Sacramento-San Joaquin River systems by collecting eggs and larvae from various locations within the delta and its tributaries. Geographic origins of the eggs and larvae were estimated by determining individual ages and by using hydrologic and physical-chemical data to calculate where the eggs and larvae originated. Farley also determined the effect of total dissolved solids on spawning migration and activity, and related spring water warming patterns to limits of upstream spawning migration.

Menchen (1965, 1970) [45, 46] estimated spawning stock inventories of salmon in the Sacramento-San Joaquin River system by counting redds and both live and dead salmon. McBrayer and Ringo (1975) [43] discussed the environmental conditions affecting natural spawning of Lahontan cutthroat trout in the Lower Truckee River below Derby Dam. They evaluated the amount and general condition of the spawning habitat, conducted stream surveys, and analyzed gravel composition and sediment deposition. In addition, they estimated the total amount of spawning habitat available below Derby Dam. Mitchell (1982) [47] presented comprehensive data on the reproductive ecology of largemouth bass in Millerton Lake to determine how water level fluctuations limit nesting success; and described spawning time, behavior, and abundance of spawning fish, and survival of eggs and fry.

Spawning migration research literature includes papers discussing aspects relating to the Klamath-Trinity watershed (California Resources Agency, 1979) [11]; Feather River below Oroville Dam (Painter, *et al.*, 1977) [52]; Sacramento River below Shasta Dam (Needham, *et al.*, 1943) [50]; Redding Dam (McGregor, 1922) [44]; Keswick Dam (Reclamation, 1983) [82]; Trinity River below Lewiston Dam (Healey, 1970) [31]; and the Trinity River Project (Smith, 1976) [72]. These papers included discussions of stream barriers blocking both upstream and downstream migration, characteristics of seaward migration of salmonids, flow and temperature influences on migration, timing of juvenile migration, predation increases of downstream migrants at man-made structures, and patterns and timing of upstream and downstream migration as modified by alterations in temperature and flow.

Significant research on spawning habitat was presented in several papers: (California Resources Agency, 1970) [10]; (Farley, 1965) [20]; (Kier, 1964) [38]; (LaFaunce, 1965) [41]; (Leidy and Myers, 1984) [42]; and (Moffet and Smith, 1950) [49]. Flow was the predominant environmental factor considered in spawning habitat research. Callculations of avialable habitat are often dependent on flow releases. These calculations were done to estimate the available spawning habitat for king salmon in the lower Feather River below Oroville Dam by Kier (1964) [38], and to determine the number of available nests available for salmon and steelhead at various flows in the Trinity River below Lewiston Dam by Moffett and Smith (1950) [49]. In other studies, the total amount of spawning habitat available below Derby Dam on the Truckee River was estimated by McBrayer and Ringo (1975) [43], changes in spawning areas following operation of Trinity and Lewiston Dams were analyzed by LaFaunce (1965) [41], and loss of nursery and spawning habitat resulting from sedimentation by erosion and reduced flow were discussed by the California Resources Agency (1970) [10]. Effects of water projects on the development and survival of eggs and fry were described for the Central Valley Project by Calhoun and Woodhull (1948) [4], for Millerton Lake by Mitchell (1982) [47], the Truckee River below Derby Dam by McBrayer and Ringo (1975) [43], the Feather River below Oroville Dam by Painter, *et al.*, (1977) [52], and for the Sacramento River below Shasta Dam by Moffett (1949) [48]. These papers included discussions of the effect of changes in runoff and temperature on egg and fry development, percent of live eggs in surveyed redds, egg survival rates relative to the physical-chemical parameters of the spawning bed and density of spawners, hatching success of eggs in artificial redds, and the abundance and predation of eggs and fry.

Creel census data is an important part of fishery management activities. Creel censuses were reported for Lake Tahoe (Cordone and Frantz, 1966) [12], Lake Berryessa (Rawstron, 1972, 1975, 1977) [57, 58, 59], (Wigglesworth and Rawstron, 1974) [100], Shasta Lake (Healey, 1981) [32], (Weidlein, 1971) [97], for 23 Central Valley Project reservoirs (Leidy and Myers, 1984) [42], and for the Feather River below Oroville Dam by Painter, *et al.*, (1977) [52]. The census data emphasized angler success, total hours fished, types of fishing methods used, and length, weight, and taxonomic composition of harvested fish. The economic and harvest superiority of silver salmon and different strains of rainbow trout were documented in the studies on Lake Berryessa [57, 58, 59, 100] and Shasta Lake [32, 97].

Fish losses were described in numerous documents that discussed the following areas: Delta-Mendota Canal by Rhone and Bates (1960) [60]; Feather River by Painter, *et al.*, (1977) [52]; Klamath River by Rankel (1980) [55]; Sacramento River by Cramer and Oligher (1964) [14], Kabel (1974) [34], Needham, *et al.*, (1943) [50], Pickard, *et al.*, (1982) [54], and USBR (1983) [82, 83]; San Joaquin River by Stevens and Miller (1983) [75]; Trinity River by Healey (1970) [31]; and USBR (1978) [79]; and the Yuba River by Hall (1979) [30]. Several of these papers described potential and actual effectiveness of fish screens to mitigate fish losses (Hall, 1979) [30], (Kabel, 1974) [34], (Rhone and Bates, 1960) [60], (Spencer, 1936) [74], and (Wales, 1948) [96], as well as describing increased fish losses at fish screens resulting from increased predation pressure (Hall, 1979) [30] and (Pickard, *et al.*, 1982) [54]. Other causes of fish loss that were discussed include losses from habitat degradation and reduction in the Klamath River basin by Rankel (1980) [55], increased predation of seaward migrants at Keswick Dam by USBR (1983) [82], flow reduction mortality of salmon by stranding near Anderson-Cottonwood Dam by USBR (1983) [83], mortalities during transfer of migrating chinook salmon in the Sacramento River from Shasta Dam to Deer Creek by Needham, *et al.*, (1943) [50], and fish kills from copper pollution in the Sacramento River basin by USBR (1978) [79].

The status of fish populations in Folsom Lake and Lake Shastina were evaluated in two reports. The vertical and horizontal distribution of white catfish and rainbow trout in Folsom Lake were evaluated by von Geldern (1964) [95], who related changes in abundance of white catfish to month, depth of sampling station, and littoral area; and changes in abundance of rainbow trout to month, depth, water temperature, and to time and area of spawning. Wigglesworth (1975) [99] reported on age and growth studies, length-weight data, sex ratios per month, and stomach analyses for an introduced species of smelt in Lake Shastina.

Invertebrates.–Studies that contained significant research on invertebrates were conducted on the Trinity River by Boles (1981) [2] and Weidlein (1971) [97]; on the Truckee River by Cordone and Pennoyer (1960) [13] and Koch and Hainline (1976) [39]; on the Kings River by Goodson (1965) [27]; on Stevens Creek by Briggs (1948) [3]; on Lake Tahoe by Ebert and Summerfelt (1969) [18], and on Shasta Lake by Healey (1981) [32].

Two studies conducted on the Truckee River provided detailed information on the effects of silt pollution on the density, weight, and relative composition of benthic invertebrates (Cordone and Pennoyer, 1960) [13]. The effects of flow on stability, dominance, and diversity of invertebrate populations in the Truckee River was reported by Koch and Hainline (1976) [39]. They also included stomach analyses to establish fish preferences for invertebrates in the Truckee River.

In 1948, Briggs [3] examined the effects of a dam on the productivity of benthos in Stevens Creek by measuring the number and weight of organisms above and below the dam, and by correlating productivity and relative composition of invertebrates with flow and temperature. Boles (1981) [2] determined the effect of gravel replacement on invertebrate recolonization in the Trinity River below Lewiston Dam. Boles correlated differences in species diversity, density, and biomass with gravel sizes, and discussed the effect of temperature alterations on recolonization.

Fish stomach analyses data for food preferences were reported by Ebert and Summerfelt (1969) [18] for Lake Tahoe, by Healey (1981) [32] for Lake Shasta, and by Goodson (1965) [27] for the Kings River. These studies provided information on relative frequency of occurrence and on variations in invertebrate composition, and variations in invertebrate composition and abundance according to depth, season, size, and location of predator fish. A comprehensive study of tailwaters in general by Hooper (1973) [33] included an examination of the effects of flow on food production for trout. Aquatic invertebrate productivity was assessed in terms of several factors, such as velocity and depth of the water, substrate composition, organism relationships, drift rates and drift ecology, and drift organisms as indicators of productivity.

Algae and Aquatic Weeds.–The causes and possible methods for preventing riparian plant encroachment on fish habitat in the Trinity River below Lewiston Dam was discussed by Pelzman (1973) [53]. This study assessed propogation of riparian plants in controlled streams (both by vegetative and sexual reproduction), and determined what environmental factors influenced the level of encroachment. Lab studies determined seeding and germination times for willows, cattails, and *Baccaris* spp., and field surveys of 15 controlled streams determined the abundance of plants relative to the stability of flows and amount of soil moisture. Because soil moisture was correlated with the success of plant encroachment, decreasing the water level in a stream during critical periods for plant survival was suggested as a means of preventing this problem.

Information on aquatic and riparian vegetation is available for the Feather River below Oroville Dam by Fisher, *et al.*, (1964) [22], the Klamath-Trinity water sheds by the California Resources Agency (1979) [11], and the Trinity River below Lewiston Dam by the California Resources Agency, (1970) [10]. Almost all studies that included aquatic vegetation research emphasized the problem of encroachment as negatively impacting fisheries, and considered potential methods for controlling growth. However, one invertebrate study discussed periphyton coverage (Koch and Hainline, 1976) [39], and two others discussed the removal of bank vegetation and its relationship to fish habitat losses and increases in water temperature as related to aquatic vegetation (California Resources Agency, 1979) [11] and (Fisher, *et al.*, 1964) [22].

Stream Regulation

Two instream flow studies from the Mid-Pacific Region literature assessed flow requirements specifically for fish habitat. In 1964, Kier [38] evaluated king salmon streamflow requirements on the Lower Feather River below Oroville Dam, using 1 year of field data collections on the characteristics of 47 riffles. The study was conducted to preserve spawning salmon runs during critical spawning and egg incubation periods. Spawning areas were determined relative to four different flow levels. In 1980, the Fish and Wildlife Service [90] published the results of an instream flow study done on the Trinity River between Lewiston Dam and the North Fork to assess opportunities for improving habitat for salmon and steelhead by increasing flow releases from the dam. Flow schedules were developed to coincide with important life stages of the fish to optimize instream flows for spawning and downstream migration needs. This study used the Instream Flow Incremental Methodology.

The effects of water level fluctuations on tailwaters were frequently evaluated. Effects of water level fluctuations on invertebrate productivity and stability were described by Briggs (1948) [3] and Koch and Hainline (1976) [39]. The effects of water level fluctuations on fish productivity, reproductive behavior, nesting success, and egg and fry abundance and survival were reported by Delisle and Eliason (1961) [16]; Leidy and Myers (1984) [42]; Mitchell (1982) [47]; and the USBR (1978, 1983) [79, 83]. These studies were conducted on the Feather River [16], Central Valley Project reservoirs [42], San Joaquin River [47], Trinity River [79], and Truckee River [83].

Streamflow reductions have caused salmon losses from stranding in the Sacramento River below Anderson-Cottonwood Dam (USBR, 1983) [83]. Flow reductions have also resulted in the loss of spawning habitat in the Trinity River below Lewiston Dam (California Resources Agency, 1970) [10]; (Woodhull, 1970) [101], and in the Feather River below Oroville Dam (Delisle and Eliason, 1961) [16]. Flow reductions were also responsible for problems with migration success and fish mortality in the Trinity River (Healey, 1970) [31] and USBR (1978) [79]. Flow reductions were also associated with physical changes such as increases in water temperature (California Resources Agency, 1979) [11], sedimentation (California Resources Agency, 1970) [10], and pollution and salt intrusion (USBR, 1978) [79].

Papers that discussed flow changes in tailwaters were conducted on the Feather River below Oroville Dam by Delisle and Eliason, (1961) [16] and Painter, *et al.*, (1977) [52]; on the Sacramento River below Anderson-Cottonwood Dam by McGregor, (1922) [44] and USBR (1983) [83]; the Sacramento River below Keswick Dam by the USBR (1983) [82]; on the San Joaquin River below Millerton Dam by Stevens and Miller (1983) [75]; on the Stanislaus River below New Melones Dam by the USBR (1980) [80]; on the Trinity River below Lewiston Dam by the California Resources Agency (1970) [10]; Healey (1970) [31]; Moffett and Smith (1950) [49]; Smith (1976) [72]; and Woodhull (1970) [101]; on the Central Valley Project by the USBR (1978) [79]; and on the Truckee River below Derby Dam by Nowlin, *et al.*, (1980) [51] and Rowell (1975) [64]. These papers described the effect of flow on spawning success and habitat [10, 16, 47, 51, 72, 79, 101], predation [54, 82], fish abundance [75], temperature requirements for trout [64], salmon losses [83], migration success [31], and productivity [33]. Sediment transport and temperature changes resulting from flow releases were described for the American, Feather, Trinity, and Truckee Rivers [56, 61, 64, 66, 67, 69]. In 1983, Stevens and Miller [75] described the effects of river flow on the abundance of young chinook salmon, American shad, and longfin smelt in the Sacramento and San Joaquin Rivers. This paper emphasized correlations between fish abundance and flow levels. The authors also correlated flow reductions to exposure of redds and to predation increases resulting from greater clarity of the less turbid water. Both flow reductions and an increase in predation were related to mortality increases.

Modeling

Modeling efforts in the Mid-Pacific Region literature include papers on flow, temperature, water quality, and fish habitat. Gupta and Afaq (1974) [29] presented a modeling methodology to investigate the simulation capability of the unsteady flow regime in a mountainous stream using the Truckee River as a case study. They described geometric and hydraulic elements of the river at two locations, and conducted a sensitivity analysis. In addition, they reproduced flood hydrographs, streamflow hydrographs, flood routing of specific events, and routing studies of hydraulic surge propogation. In 1980, Nowlin, *et al.*, [51] planned and designed multidisciplinary river quality assessment studies for the Truckee and Carson River basins, including streamflow modeling studies for the analyses of water quality and fish habitat.

Some of the most extensive temperature modeling efforts in the Mid-Pacific Region were performed by Jack Rowell for the Sacramento River in 1972 [63], the Truckee River in 1975 [64], the Trinity River in 1979 [65], and the American River with regard to the proposed Auburn Dam in 1980 [66, 67]. Raphael (1966) [56] also used a model in a study of the annual temperature cycle in Oroville Reservoir. Weidlein (1971) [98] developed temperature approximations for the Sacramento and Trinity Rivers using estimated year 2020 water demand conditions. Cramer and Oligher (1964) [14] used a model in a study of fish passage through hydraulic turbines.

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Mid-Pacific: Nevada, Lake Tahoe
Code 2b.

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Mid-Pacific: California, Sacramento and San Joaquin River Systems
Code 2b.

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Mid-Pacific: California, Sacramento and San Joaquin River Systems
Code 2b.

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Codes 1 and 1a.

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Mid-Pacific: California, Trinity County; South Fork Trinity River
Code 1a.

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Mid-Pacific: California, Trinity and Humboldt Counties; Trinity River
Code 1a.

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Mid-Pacific: California, Trinity County; Lewiston Dam, Trinity River
Codes 1a. and 2b.

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Code 2b.

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Code 2b.

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Mid-Pacific: California, Central Valley Project
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The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

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