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LIMNOLOGICAL EFFECTS OF FERTILIZING BARE LAKE, ALASKA

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A REVIEW OF NUTRIENT DYNAMICS IN UNPERTURBED STREAM ECOSYSTEMS

Ph.D. Comprehensive Examination

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for

Dr. James V. Ward

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INTRODUCTION

Ecosystems are ultimately limited by two resources: energy, fundamentally as sunlight, and elemental nutrients (Odum 1971). Much of the dynamics of lotic systems must therefore revolve around the mobilization of energy and nutrient resources into organic compounds. Coupled with organic synthesis is the eventual dissipation of this biomass towards some physiochemical equilibrium and a regeneration of assimilated nutrients (Webster et al. 1975).

Emphasis on lotic processes has focused primarily on energy metabolism (Teal 1957; Nelson and Scott 1962; Minckley 1963; Minshall 1967; Coffman et al. 1972; Fisher and Likens 1973; Boling et al. 1975). If any unifying concept in stream ecology has emerged from these studies it is the generalization that the surrounding terrestrial community provides the primary energy input to small unperturbed woodland streams (Cummins 1974, 1979; Hynes, 1975). The same generalization also applies to stream nutrients (Bormann and Likens 1967; Cooper 1969; Hall 1972; Likens and Bormann 1972, 1974a; Saunders 1972; Hobbie and Likens 1973.).

Lotic system stability necessarily entails material inputs, internal processing, and material outputs. Because nutrient cycling is inexorably linked with ecosystem stability (Pomeroy 1970; Odum 1971) the concepts of input, processing, and output provide a logical review framework. Further specific approaches detailing land-water linkages, as espoused by Likens and Bormann (1974a), the river continuum concept (Vannote et al. 1980) and, the nutrient spiralling hypothesis (Wallace et al. 1977; Webster and Patten 1979) will serve as focal points for discussions of nutrient-stream interrelationships.

Saunders (1972) broadly defines nutrients in a manner suitable to the present context as, "elements and their organic derivatives necessary to stimulate and sustain the growth of flora and fauna in river ecosystems". He subdivides them into macro- and micro-nutrients according to the relative proportions required for plant growth. Macronutrients include: hydrogen, oxygen, carbon, nitrogen, phosphorous, potassium, calcium, magnesium and sulfur. Iron, manganese, cooper, zinc, boron, sodium, molybdenum, chlorine, vanadium, cobalt and silica are considered micronutrients. Since micronutrients are infrequently limiting to aquatic plants (Eyster 1964) they will not be appraised further. Hydrogen, particularly as it affects pH, and oxygen, necessary for respiration, are important elements in aquatic systems; however, they are generally treated under dissolved gases and not nutrients (Hynes 1970; Reid and Wood 1976). Carbon, although it may limit plant growth (Schindler et al. 1973; Wetzel 1975), is more often included with reference to flowing waters under the subject of energy transformation (i.e., as organic carbon) rather than under nutrient dynamics. Emphasis on nutrients in lotic waters centers on phosphorus and nitrogen as these are widely recognized as the primary nutrients limiting aquatic plant production (Blum 1956; Feth 1966; Keup 1968; Owens et al. 1972; Saunders 1972). Potassium (Hynes 1970) and calcium (Blum 1956) are also seen as important to aquatic plant growth although neither has been supposed to limit plant production. Potassium, calcium, magnesium and sulfur will be treated to the extent represented in the literature.

NUTRIENT DYNAMICS IN STREAMS: THE TERRESTRIAL-AQUATIC LINKAGE

Nutrient Inputs to Streams

Hynes (1975) summed up the association between a stream and its surrounding environment when he concluded, "that in every respect the valley rules the stream". Energy and nutrients from the terrestrial watershed are commonly illustrated (Fig. 1) as entering streams via meteorologic, geologic, and biologic vectors (Bormann and Likens 1967; Likens and Bormann 1972, 1974a; Likens 1975).

Meteorologic Inputs of Nutrients

Dissolved and particulate matter, including mineral ions, are added directly to streams as gases, aerosols, precipitation, and dust (dry fallout).

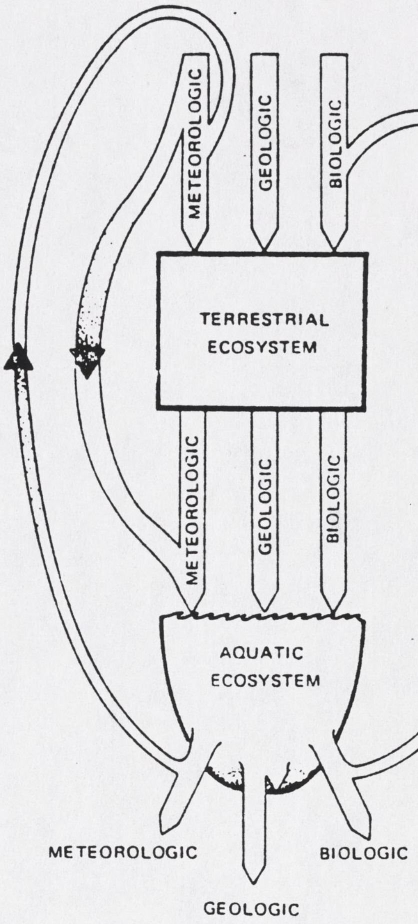

Figure 1. Diagrammatic model of the functional linkages between terrestrial and aquatic ecosystems. Nutrients may be moved across ecosystem boundaries by meteorologic, geologic, or biologic vectors (from Likens and Bormann 1974a).

The latter two sources, considered together as bulk precipitation (Whitehead and Feth 1964), have been most extensively investigated. Precipitation chemistry is highly variable both temporally and geographically (Likens 1975). Nutrient concentrations in rainfall frequently decrease with time within a single precipitation event and also over time between a series of closely spaced events. This suggests that much of the nutrients in precipitation are derived from "washout" of atmospheric particulates (Ångström and Högberg 1952a; Junge 1958; Junge and Werby 1958; Gorham 1961; Keup 1968; Brezonik 1972).

Phosphorus concentrations in rain and snow are typically low away from urban areas (Cooper 1969; Weibel 1969; Vollenweider 1971). Likens (1975) reports 1 to 5 μg P/l in precipitation at Hubbard Brook, NH, and 5 to 8 μg P/l at Ithaca, NY. Brezonik et al. (1969) found 9 μg P/l in north-central Florida and Pearson and Fisher (1971) recorded an average of 13 μg P/l in the northeast U. S. Values of phosphorus in precipitation from Minnesota were 21 μg P/l (Wright 1974) and from snow in the Sierra Nevada Mountains, CA, 10 μg P/l (Leonard et al. 1979). The highest value reported was by Weibel et al. (1966) of 80 μg P/l in Cincinnati rainwater.

Of the three nutrient input vectors, phosphorus derived from precipitation was of least importance (5%) to the phosphorus budget of Hubbard Brook (Meyer and Likens 1979). Peters (1977) has shown that a large fraction of the phosphorus (76%) in bulk precipitation southeast of Montreal, Quebec was dissolved, and of this at least half was biologically available.

Much of the research on the chemical composition of precipitation has dealt with nitrogen compounds (Eriksson 1952). Hutchinson (1944) listed the sources of atmospheric nitrogen to precipitation as: soil, oceans, electrical and photochemical fixation and industrial contamination. Many workers (Ångström and Högberg 1952a, Junge 1958, Gambell and Fisher 1964, Yaalon 1964) contend that electrical generation is insignificant. Also, values of NH_4^+ and NO_3^- were low near coastlines and over oceans compared with inland areas (Junge 1958). Yaalon (1964) showed a strong correlation between NH_4^+ content in rainfall and soil temperature. Furthermore, areas with low pH soils appear to absorb NH_3 and hence have low NH_4^+ concentrations in rainfall, while conversely, alkaline soil regions are associated with high NH_4^+ and NO_3^- concentrations in rainfall (Junge 1958). Tropical air masses contained 10 to 30 percent more nitrogen than polar air and twice the amount recovered from arctic air (Ångström and Högberg 1952b). These authors also found that in temperate regions (Sweden), nitrogen in precipitation peaked in spring which they attributed to photochemical oxidation of atmospheric ammonia. It is currently recognized that most of the non - anthropogenic nitrogen in precipitation is derived from this source (Hutchinson 1957). Human activities have produced a significant increase in nitrogen concentrations in precipitation. Since 1945 the increase has been fourfold in central New York, and since 1956, double in rural New Hampshire (Likens 1972, 1975).

These factors result in a wide variability of nitrogen concentrations in precipitation. Additionally, how much nitrogen present in rainfall enters a stream is dependent on many factors. Climate, precipitation chemistry, runoff characteristics, geology, soil type, watershed vegetation composition, and land use practices all influence precipitation nitrogen transport to streams.

Compared with phosphorus, concentrations of nitrogen in precipitation are quite high, no doubt due in part to its high solubility in water relative to phosphorus. Ammonia usually is the dominant form rather than nitrate. Feth (1966) and Vollenweider (1971) tabulated nitrogen concentrations in precipitation from early studies while Cooper (1969), Likens (1975), and Coats et al. (1976) detail more recent observations. Total inorganic nitrogen concentrations in precipitation of over 1.0 mg/l as N are not uncommon (Hutchinson 1957; Vollenweider 1971).

With such high levels of nitrogen in precipitation it is not surprising that many authors consider precipitation to be an extremely important non-biological source of nitrogen to watersheds and lentic waters (Hutchinson 1957; Feth 1966; Cooper 1969; Likens 1975). Coats et al. (1976) showed that nitrogen from bulk precipitation (snow) and biological nitrogen fixation were the two major nitrogen sources to streams feeding Lake Tahoe, California.

Levels of other inorganic nutrients in precipitation (K, Ca, Mg, S) are reviewed by Junge and Werby (1958), Gorham (1958, 1961), Whitehead and Feth (1964), Saunders (1972), and Likens (1975). Soils are the principal source of potassium and calcium which accounts for their high concentrations in bulk precipitation in arid regions where dust storms are common. Rainfall near oceans had higher potassium and sulfate concentrations than non-urban inland areas in the 1950's (Junge and Werby 1958) indicating the importance of seawater as a source of these minerals, particularly sulfate (Gorham 1961; Golterman 1975).

Unfortunately, atmospheric pollutants from man's combustion of fossil fuels, primarily as sulfur and nitrogen dioxides, have contaminated precipitation on a global scale (Likens et al. 1972, 1979; Likens and Bormann 1974b; Lewis and Grant 1980). Today, the nutrient dynamics of most streams can no longer be considered uninfluenced by anthropogenic activities. The insiduous toxic effects of decreased pH from acid rain far outshadow any beneficial impacts of industrially generated nitrogen and sulfur in rainfall.

Feth (1966) concludes that precipitation might be the most important single source of nitrogen for surface waters. Mineral contributions from precipitation to streams can also be significant, particularly in tropical regions of low relief and leached soils. Gibbs (1970) calculated that 81% of the Na, K, Mg and Ca carried by a tributary of the Amazon (Rio Téfe) were derived from precipitation. He generalized that nutrient loads of African and South American tropical rivers are precipitation, rather than geologically, dominated. Phosphorus inputs to watersheds from rainfall are variable but frequently low (Likens 1975).

Through the process of nitrogen fixation,atmospheric nitrogen, originally in a gaseous state, can enter aquatic ecosystems (Keeney 1973). Horne and Carmiggelt (1975) observed a high rate of nitrogen fixation in Nostoc, a common lotic algae. Nitrogen fixation in streams by aquatic bacteria on wood was demonstrated by Buckley and Triska (1978). They estimated that the nitrogen contribution to a Cascade mountain stream from this source was nearly fifty percent (0.70 g N/m^2 stream channel) of that from litterfall input. Although the source of nitrogen to stream nitrogen fixing algae and bacteria is atmospheric, it is important to recognize that nitrogen fixation in streams is mediated by biological processes and that it is also the only noncarbon autochthonous nutrient input.

Alder, a frequent riparian tree, also fixes atmospheric nitrogen and is an important litter source to stream ecosystems (Kaushik and Hynes 1971; Triska and Sedell 1976). Leonard et al. (1979) showed that the contribution of nitrogen to a Sierra Nevada mountain watershed from nitrogen fixation by alders and other terrestrial plants surpassed that from atmospheric precipitation and was potentially the largest single nitrogen source to Ward Creek.

Geologic Inputs of Nutrients

The geologic input of terrestrial nutrients dissolved into water and as particulate matter to streams is one of the most important land-water linkages in the biosphere (Likens and Bormann 1974a). Streams and rivers take on particular significance in this regard as the primary bond between terrestrial and lentic systems. Particulate matter (sediments) enters streams by erosion and surface drainage (particulate removal). Nutrients in rock and soil also become dissolved in surface and subsurface water by which they are then transported to streams as surface and groundwater runoff (solution removal) (Bormann et al. 1969).

Rock and soil composition, daily and seasonal variations in precipitation, topography, terrestrial vegetation composition, land use practices, and soil biological processes are all critical factors which determine the chemical composition, quantity, and size fraction of geologic nutrient inputs to lotic waters. Golterman (1975a) presents a thorough review of weathering processes involved in the dissolution of rock. Sedimentary rocks and their associated soils are the principal geologic source of calcium in streams (e.g. limestone). They are subject to rapid erosion according to the type of cement binding the rock particles into a matrix. Sedimentary rocks are also frequently the main supplier of inorganic sediments entering streams, where such sediments are subject to further dissolution. Igneous and metamorphic rocks are much more resistant to weathering, which is why rivers in basaltic or granitic areas are often poor in dissolved minerals.

Much of the non - anthropogenic phosphorus entering streams is derived from geologic sources. Wilde et al. (1949) list the percentage phosphorus contained in representative rocks as follows: sandstone, 0.02; diabase, 0.03; gneiss, 0.04; unweathered loess, 0.07; andesite, 0.16; and limestone, 1.32. Phosphorus content in topsoil fluctuates between 0.0 and 0.3 percent; lowest values being found in clay and sandy soil followed by silt and loamy soils (Vollenweider 1971).

Phosphorus binds tenaciously to soil particles which thereby minimizes its solution loss from terrestrial ecosystems. Its solubility is highly pH dependent, being most available to dissolution at pH values between 6 and 7. Two important factors governing phosphorus availability in water are adsorption on clays which can transfer phosphorus from an available solute fraction to an unavailable particulate fraction (see Table 5.1; Vollenweider 1971) and complexing of phosphorus with calcium, iron and aluminum which also make it unavailable for plant absorption. Griffith's et al. (1973) volume devoted exclusively to phosphorus presents more detail on its solubility chemistry.

Virtually no nitrogen compounds are contained in parent rock except in organogenic sedimentary strata, and these can be very rich in this nutrient (Vollenweider 1971). Nitrogen content of organic rich shales averaged 0.06 percent with a maximum of 0.86 percnet (Trask and Patnode 1942). Nitrogen content of lignite and bituminous coal from Chile ranged from 0.3 to nearly 2.0 percent (Clarke 1924). Formation of geologic deposits rich in nitrogen necessitates shelter from leaching. This can occur by location (e.g. caves), by deposition over impermeable basement strata, or where the climate is arid enough so that deposition exceeds leaching (Feth 1966).

Dissolution of potassium from parent rock is quite high, 0.2 to 4 percent (Vollenweider 1971), and the weathering of calcite, colomite, and gypsum are important sources of calcium, magnesium, and sulfate to streams.

Heavy rainfall, especially when concentrated in a short time period, transports enormous quantities of sediment to streams, but nutrient concentrations in solution are typically low. Particulate removal of nutrients from land to streams dominates at such times (Cooper 1969). This contrasts with periods when rainfall is low or absent. Long contact of ground water with soil and rock increases concentrations of dissolved nutrients and solution removal from the terrestrial ecosystem to streams predominates.

Topography also plays a crucial role in nutrient transport to streams. Regions of low relief exhibit high infiltration rates and low surface runoff. Consequently in such areas input of minerals in solution exceeds particulate transport to streams. As land gradient increases so does the potential for erosion and therefore sediment transport to flowing waters. Sheet erosion appears to be of greater importance for removing soil from hillsides than gully erosion (Keup 1968) and Cooper (1969) concluded that at steep gradients subsurface flow was more significant than surface runoff in transporting nutrients from land.

The significance of terrestrial vegetation and land use practices on nutrient movement from terrestrial to aquatic ecosystems has been repeatedly demonstrated. Most noteable has been research done at the Hubbard Brook Experimental Forest, New Hampshire (fifteen years of studies there are summarized in a volume by Likens et al. 1977) and at the Coweeta Hydrologic Laboratory, North Carolina (Webster and Patten 1979 refer to much of the work generated there). Forest cover regulates nutrient output to streams by storage in plant biomass and by influencing surface and ground water movement. What nutrients the stream gains the forest loses. Hence, a strategy of maximum retention and recycling of terrestrial nutrients minimizes "leakage" to streams (Johnson et al. 1969). In unperturbed forested ecosystems this leakage is very small (Cooper 1969). Vegetative cover impedes surface runoff and erosion thereby reducing particulate mineral losses. As intact terrestrial ecosystems mature they develop "tight" internal nutrient cycles which minimize losses of soluble nutrients to ground water (Likens and Bormann 1974a).

The effectiveness of terrestrial vegetation as a mechanism for nutrient retention has been well illustrated by forest removal (Bormann et al. 1969, 1974; Likens and Bormann 1972; Jordan et al. 1972; Hobbie and Likens 1973). Phosphorus losses in drainage water from the Hubbard Brook forest increased ten-fold, while inorganic nitrogen losses increased about fifty-fold, and potassium losses increased eighteen-fold. Because the effects of logging increased watershed nutrient losses to streams, it has been postulated that similar conditions would occur following forest fires. Support is lacking, however, as Johnson and Needham (1966) found no effect of fire on the ionic composition of Sage Hen Creek, California. They concluded that a combination of low post-fire rainfall and high exchange capacity for calcium, magnesium, and potassium characteristic of the region's acid soils were responsible for nutrient retention in the terrestrial environment.

Biologic Inputs of Nutrients

Only migrating animals are included under this category by Likens and Bormann (1974a). Donaldson (1967) believed decomposing sockeye salmon carcasses were an important biogenic phosphorus source to Alaskan lakes. From this Gregory and Donaldson (1972) suggested that stream spawning species of Pacific salmon (coho and chinook) could also provide substantial phosphorus loads periodically. They reported that most labled phosphorus in rainbow trout carcasses was leached out within 15 days and was incorporated into periphyton and invertebrates biomass. Terrestrial invertebrates falling into streams are important food for stream fishes and during summer may contribute 40 to 50% of trout diet (Hynes 1970). Vallentyne (1952) gives the nitrogen and phosphorus content of emerging aquatic insects from a lake as four and 0.16 percent respectively. These figures are likely appropriate for terrestrial insects as well.

My consideration of allochthonous nutrient inputs to streams has up to this point neglected a major source--litterfall. Fisher and Likens (1973) include leaf-litter organic inputs under meteorologic vectors, however, I do not concur with this classification, but believe that nutrients in terrestrial vegetation transported to streams should be considered a biologic input. It is correct that meteorological vectors (gravity, wind, rain) transfer nutrients bound in terrestrial plant biomass to streams, but the same is also true for nutrients bound in soil particles, and yet Likens includes these under the geologic vector. Since a unifying concept of stream ecology is that running water habitats are dependent for their major energy supply on terrestrial plant biomass, and such material is of biological origin, it seems more appropriate to relegate nutrient inputs to streams via terrestrial plants under this heading.

Although the magnitude of terrestrial organic matter inputs to streams is well documented (see Hynes 1975 for a literature summary), few authors have considered in depth the associated input of nutrients from terrestrial litterfall. Deciduous leaf-litter contains a moderate amount of phosphorus (Cowan and Lee 1973), and Meyer and Likens (1979) found that phosphorus in coarse particulate litter amounted to twenty-three percent of the total phosphorus budget of Bear Brook, New Hampshire.

Significant quantities of nitrogen are also contained in leaves, although concentration varies with tree species. Kaushik and Hynes (1971) reported the percent nitrogen content for five species of deciduous leaves after leaching as: maple, 0.70; beech, 0.73; elm, 1.02; oak, 1.20 and alder, 2.12. Coniferous needles contain less nitrogen than deciduous leaves, 0.64 percent nitrogen from unleached Douglas fir needles (Triska and Sedell 1976). The transport of nitrogen to streams by litterfall is significant. Buckley and Triska (1978) report a contribution of 1.35 g N/m^2 to a Cascade mountain streambed from fir-needles and deciduous leaves.

Webster and Patten (1979) evaluated litterfall calcium and potassium input to flowing waters and showed that their concentrations in litter varied by season and vegetation type but were substantial for both nutrients (see their Table 1).

Considering the moderate amounts of nutrients present in litterfall and the vast quantities of litter which enter streams, the dearth of research on the magnitude of this nutrient source to streams is astonishing (e.g. Likens et al. (1967) ignored this source in their mineral budget for Hubbard Brook). Certainly much of the nutrient content of leaf-litter is recycled within the terrestrial environment. Nevertheless, Thomas (1970) reported that for calcium the rate of loss was faster when leaves decomposed in water versus on land.

Nutrient Processing in Streams

From the preceeding discussion we can generalize that nutrients enter flowing-waters in three fractions: soluble, inorganic, and organic, and once in the stream may also be exchanged between these three compartments (Fig. 2). A fundamental difference between lentic and lotic waters is that nutrient cycling between these three compartments in lakes occurs in place (although a vertical, i.e. stratification-turnover component exists), while the defining feature of streams--unidirectional flow--precludes cycling at a single point (Webster and Patten 1979). Nevertheless, nutrient cycling is prominent in stream nutrient dynamics, but because a longitudinal component is incorporated such cycling has been more appropriately labled "spiralling" (Webster 1975; Wallace et al. 1977; Webster and Patten 1979).

A second feature which distinguishes stream nutrient dynamics from that of lakes is that feedback mechanisms are of limited significance in streams, again because their unidirectional flow limits inplace reuse of regenerated soluble nutrients (Webster and Patten 1979). Downstream nutrient export may be offset by two factors: import from upstream, and influx from the surrounding terrestrial environment. The magnitude of input by these sources requires no feedback control. These views of instream nutrient dynamics, though by no means new (Leopold 1949), contrast sharply with the "conduit concept" of streams often purported by engineers, whereby rivers merely serve as conveyances for fluids.

Nutrient cycling characteristics figure significantly in considerations of ecosystem stability (Webster and Patten 1979). Tight nutrient cycles imply strong system stability. Our unidirectional, nonfeedback view of stream nutrient dynamics suggests streams to be rather unstable systems. Contrasted

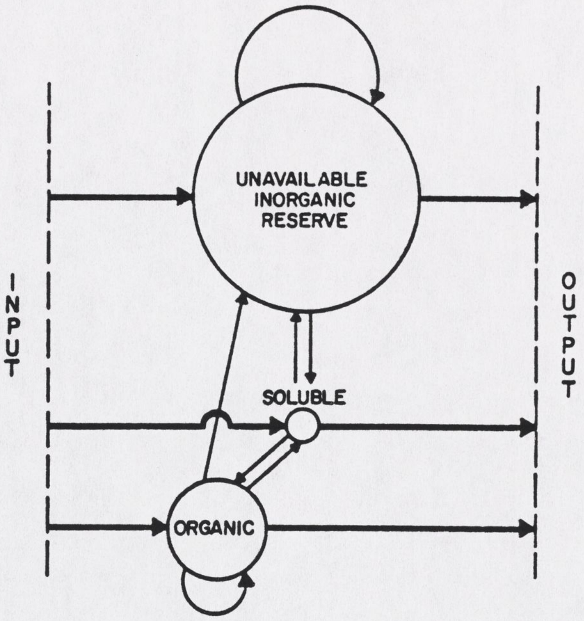

Figure 2. A simplistic model of nutrient storage and release in streams. Only soluble organic and inorganic nutrients are absorbed by microbes and plants. Although the solute fraction is small, turnover between it and the organic compartment is rapid. Most instream inorganic nutrients are unavailable for microbial or plant uptake because they are: bound in primary minerals, adsorbed on clays, or complexed with other ions.

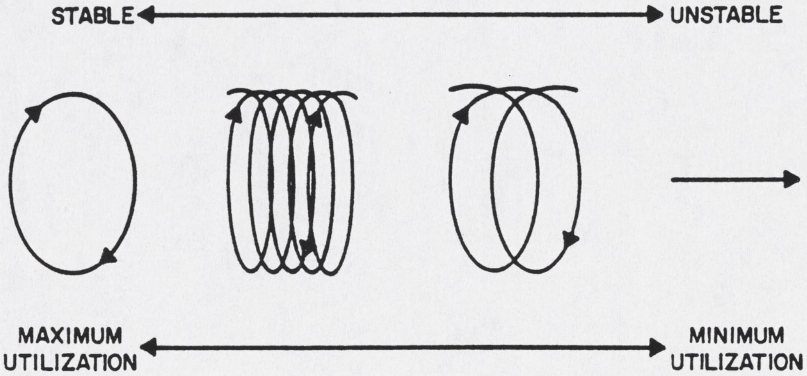

Figure 3. Schematic illustrating potential range of nutrient utilization within a stream reach. Maximum utilization (far left) corresponds to cycling in place (recycling), while minimum utilization is represented by unidirectional downstream transport (no cycling). The degree of nutrient spiralling between these extremes defines the efficiency of within reach nutrient reuse.

with a terrestrial climax forest this is undoubtedly true. However, several attributes characterize streams which function to delay downstream nutrient losses thereby enhancing overall system stability.

If nutrient <u>re</u>cycling in the traditional view (i.e., in place) is seen to represent maximum nutrient utilization efficiency (Fig. 3, far left) and unidirectional nutrient flow is accepted as representing minimum utilization efficiency (Fig. 3, far right), then the tightness of sprialling between these extremes defines the degree of nutrient reuse within hypothetical equal length stream reaches. Greater nutrient reuse within a reach moves the stream towards greater stability. Thus, strategies which shift spiralling towards the left in Figure 3 increase nutrient processing efficiency of the system while those shifting it to the right reduce efficiency.

The river continuum concept (Cummins 1977, 1979; Vannote et al. 1980) stresses structural and functional stream system attributes which lead towards minimum energy loss within a reach. Applied to instream nutrient dynamics, minimum energy loss translates to maximum spiralling (Webster 1975). According to the river continuum concept, reduced fluctuations in energy flow (i.e., stability) are achieved by resource partitioning of food, substrate, nutrients, etc. However, there exists a trade-off between the ideal of maximum energy (nutrient) utilization within a reach and a temporally uniform rate of energy (nutrient) processing (minimization of variation). Examples of the former include strategies which entrain nutrients such as pools, debris dams, efficient bacterial and algal nutrient uptake kinetics, selective particle size feeding by invertebrates, etc. Such mechanisms function to retard downstream energy and nutrient losses. A successsion of plant and animal species, each highly adapted to seasonal variations of a river's inorganic nutrient regime, distributes utilization of nutrient inputs over time.

An element central to the river continuum hypothesis is the dependence of downstream reaches on upstream processes (Cummins 1979). Seen in terms of a nutrient spiralling concept the storage-release cycle of flowing waters cascades nutrients down a river's course from headwater streams to the ocean.

The simplistic model in Figure 2 serves as a starting point with which to review the mechanics of nutrient storage and release in streams. Only a tiny fraction of the nutrients in water are in a soluble form, and thereby available for uptake (Feth 1966; Keup 1968; Golterman 1975b). Nutrient absorption into bacterial and plant biomass is rapid, but metabolic release of certain soluble forms (e.g. NH_4^+) may also be swift. Rates of phosphorus regeneration, and presumably that of other nutrients as well, are dependent on external concentrations and on the organism's metabolic activity (Pomeroy 1960; Hooper 1973). Nutrient uptake and release kinetics of bacteria and algae are a vast subject and not specific to lotic habitats, therefore, the reader is referred to detailed discussions on bacteria by Alexander (1971) and Skinner and Shewan (1977); on algae, Carr and Whitton (1973), Werner (1977); or for both groups, Goldman (1965), Golterman (1975b).

The largest fraction of mineral nutrients (i.e., non-nitrogen nutrients) resides in the unavailable inorganic compartment (see Fig. 2 for sources). Dissolution of primary minerals, disassociation and desorption are the principal modes of release. Dissolution of nutrients from sediments and rocks can, as on land, operate at a very slow rate. These processes are also general to the biosphere and are detailed elsewhere (Hutchinson 1957; Stumm and Morgan 1970; Golterman 1975a,b 1976).

Stream processing models usually concentrate on detritus (Boling et al. 1974, 1975; McIntire et al. 1975), but they present a paradigm applicable to nutrient dynamics with the exception of the just described inorganic nutrient storage fraction. Webster et al. (1975) illustrate a generalized ecosystem nutrient flow model which includes an inorganic reserve (Fig. 4, x_6). The left side of their model approximates Figure 2 while the remainder details biological interactions involving nutrients. Elwood et al. (1980) suggest that biological processes control nutrient spiralling dynamics in undisturbed streams, therefore it is these biotic nutrient transformations on which I will concentrate.

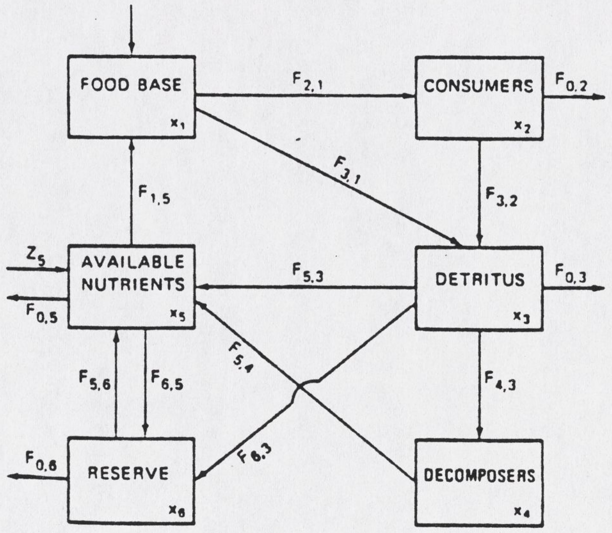

Figure 4. General nutrient-flow model of an ecosystem. x_i is the size of the ith compartment; z_i is inflow to compartment x_i; $F_{i,j}$ is the flow from x_j to x_i; and $F_{0,j}$ is the outflow to the environment from x_j. (From Webster et al. 1975.)

Phosphorus translocations in lotic ecosystems, observed through the use of radioactive tracers, have been most studied (Ball and Hooper 1963; Gardner and Skulberg 1966; Nelson et al. 1969; Gregory 1978). Labled phosphorus released into streams is rapidly taken up by aquatic plants, as much as 95 percent within 100 m of stream (Keup 1968). Gregory (1978) showed that epilithic algal communities (i.e., diatoms) had higher phosphorus sorbtion rates than filamentous algae; riparian trees were lowest. Phosphorus uptake rates by aquatic macrophytes were similar to periphyton (Ball and Hooper 1963), but concentrations in macrophytes have been reported to be both greater (Schoonbee and Swanepoel 1978) and less (Ball and Hooper 1963) than in benthic algae. Microbial communities attached to sediments and leaf-litter absorbed as much as three and seven times more phosphorus, respectively, than did identical substrates that were first sterilized (Gregory 1978). Gregory also demonstrated that biological phosphorus uptake (i.e., microbial and algal) was much more important to phosphorus translocation in streams than physical sorbtion.

Aquatic macrophytes and fine bottom sediments become more abundant in mid-sized rivers, primarily because of reduced stream velocity (Cummins 1977). Carignan and Kolff (1980) reported that aquatic macrophytes derive over seventy percent of their phosphorus from sediments and not from the water column. They and others (Hill 1979) characterize submergent macrophytes as pumps of phosphorus from sediments to open water.

From these studies and an understanding of lotic plant community succession we can generalize on soluble phosphorus uptake and spiralling along the river continuum. In low-light headwater streams attached microbial communities dominate as converters of soluble phosphorus into an organic form capable of ingestion by higher trophic level heterotrophs. As stream order increases and the water's surface receives more light, periphytic algae gain prominence and along with microorganisms become important for sorption of soluble phosphorus. With the appearance of macrophytes in larger rivers we see an evolution towards uptake strategies which mobilize sediment phosphorus, thereby cycling phosphorus back into the water column where an emerging phytoplankton community can exploit it. Such a spatial sequence of communities capable of utilizing soluble phosphorus illustrates the concept of maximum utilization of a nutrient by sprialling it between soluble and organic fractions along a river's course. Since most higher trophic levels cannot use nutrients in their soluble inorganic fraction but ingest them in an organic form, the repeated cycling of phosphorus through the microbial-plant community over a river's length provides a reservoir of useable phosphorus to higher trophic levels. Nitrogen, potassium and calcium uptake by plants is similar to that of phosphorus and all are represented in Fig. 4 by the vector $F_{1,5}$.

In terms of Webster's model (Fig. 4) nutrient leaching whether from allochthonous or autochthonous sources is included in vector $F_{5,3}$. Depending on the leaf species, up to thirty percent of its dry weight can be lost through solubilization within twenty-four hours after initial wetting (Petersen and Cummins 1973). Dramatic losses of nitrogen and phosphorus occur due to leaching during the first few days after leaves enter streams. As decomposition proceeds organic nitrogen concentration increases (and to a lesser degree so does phosphorus) as a result of microbial immobilization (Mathews and Kowalczewski 1968; Kaushik and Hynes 1971; Iversen 1973; Petersen and Cummins 1973; Triska et al. 1975; Triska and Sedell 1976). Microbes absorb many forms of organic nitrogen and through mineralization (ammonification) convert some to ammonium. Ammonium may be used in this form or nitrified before uptake to other bacteria and plants (Alexander 1971; Keeney 1973; Fenchel and Jorgensen 1977). The importance of nitrifying bacteria who derive energy by oxidizing ammonium to nitrate is well known and therefore need not be summarized further (see Hutchinson 1957; Keeney 1973; Wetzel 1975; Garland 1977). This transformation is included in vector $F_{5,4}$, Fig. 4.

Potassium is a very mobile cation and leaching is responsible for much of the loss of potassium to stream water. In one study on Appalacian streams quantities leached varied with the composition of terrestrial vegetation, being 89 percent from old-field detritus, 80 percent from hardwoods and coppice, and 50 percent from pine (Woodall and Wallace 1975). Potassium's general insignificance as a limiting nutrient in waters is likely a consequence of its high solubility. Woodall and Wallace (1975) and Webster and Patten (1979) believe that almost no leaching of magnesium and calcium from detritus occurs but that digestion by invertebrate consumers plays the major role in calcium and magnesium integration from terrestrial organic matter to the lotic food web. Although my treatment has been cursory, the significance of microbial mobilization and decomposition in nitrogen transformations should be apparent. (Saunders 1976, presents a more thorough review of organic matter decomposition in freshwaters.)

Once soluble nutrients are absorbed by autochthonous organic matter (microbes, periphyton, macrophytes) some may again spiral through the food base--detritus--available nutrient compartments, illustrated by vectors $F_{3,1}$, $F_{5,3}$, $F_{1,5}$, Fig. 4. Another pathway available is $F_{3,1}$, $F_{4,3}$, $F_{5,4}$, $F_{1,5}$ where the decomposers include, in addition to bacteria and fungi, invertebrate collectors and shredders. A third pathway also exists ($F_{2,1}$, $F_{3,2}$ . . .,) to stream consumers (invertebrate and vertebrate collectors, scrapers, shredders and predators).

This last pathway is more convoluted since it can incorporate portions of previous pathways. It is clear that translocation of nutrients through consumer and decomposer trophic levels quickly becomes complex and only a few studies have attempted to detail the various pathways. By far the most complete research has been by Woodall and Wallace (1975) and Webster and Patten (1979) for potassium, calcium, and magnesium in Appalacian streams (Fig. 5). Early studies on phosphorus by Ball and Hooper (1963) and Gardner and Skulberg (1966) have been updated by Hall (1972, Fig. 6) primarily for fish and by Schoonbee and Swanepoel (1978) for selected invertebrates. Nitrogen, unlike phosphorus, potassium, calcium, and magnesium, does not have a restricted biogeochemical cycle (Keup 1968; Keeney 1973). Exchange between aqueous and gaseous phases limits quantitative radioactive tracer studies and therefore little work has been done on non-microbial nitrogen translocations in lotic ecosystems. A thorough study of nitrogen cycling in flowing waters was conducted by Stanley and Hobbie (1981, Fig. 7) for the lower reaches of a North Carolina coastal river. They showed that high summer algal productivity is dependent on release and regeneration of nitrogen from organic sediments and the water column. Two nonbacterial sources of inorganic nitrogen regeneration in stream sediments appear to be tubificid worms (Chatarpaul et al. 1979) and chironomid larvae (Graneli 1979).

Nutrient Outputs from Streams

Corresponding to meteorologic, geologic and biologic input vectors are similar output vectors (Fig. 1). Sources of meteorologic nutrient outputs

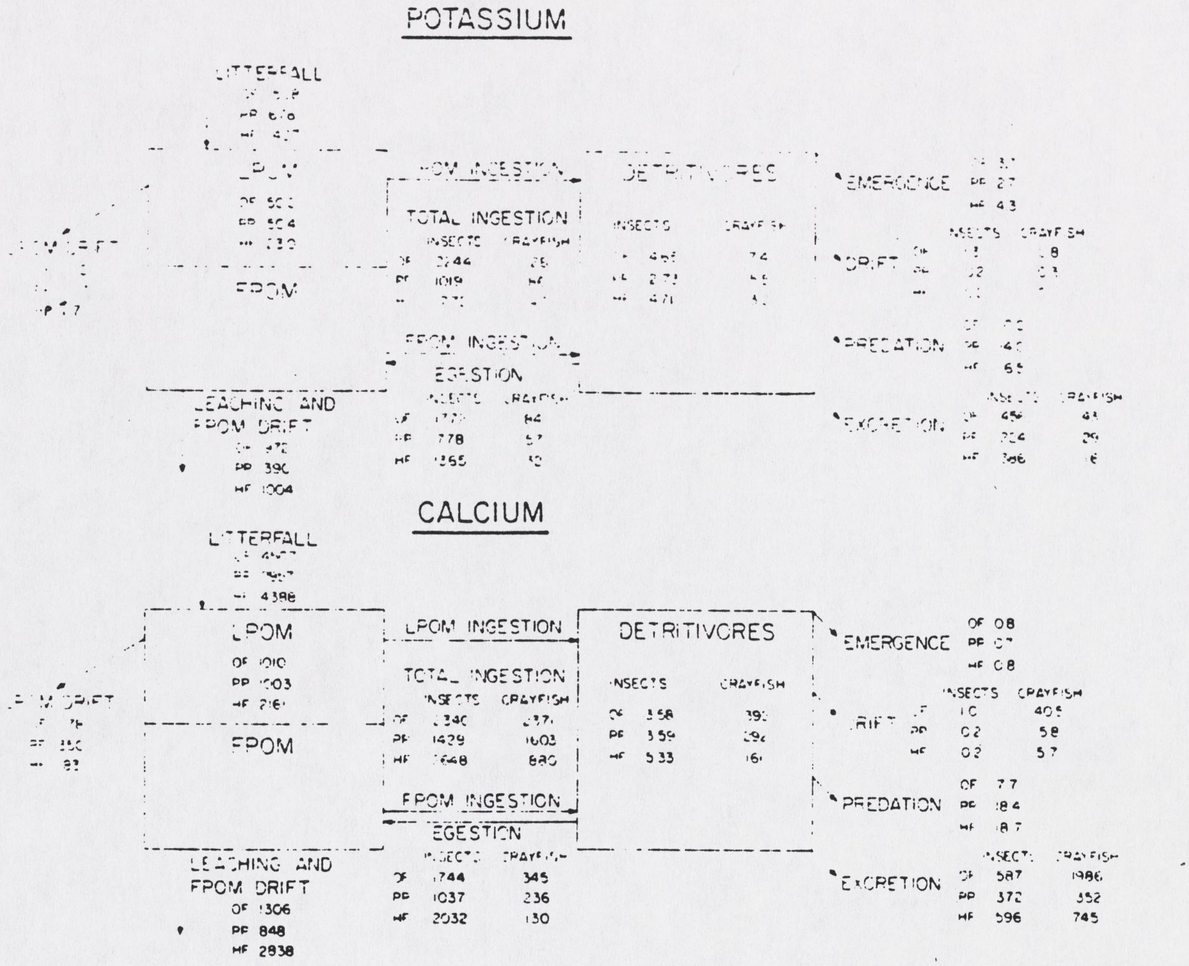

Figure 5. Potassium and calcium dynamics in the old field (OF), pine plantation (PP), and hardwood forest (HF) watershed streams. Standing crops are mg m^{-2}; flows are mg m^{-2} yr^{-1}. (From Webster and Patten 1979.)

are gaseous exchange, which is restricted to nitrogen as it is the only nutrient common in a gaseous form. Geologic outputs include overbank or downstream export of nutrients dissolved in stream water and carried as inorganic sediments or bedload. Emigrating animals consumption of aquatic organisms by terrestrial animals, and downstream export of nutrients contained in organic material constitute the biologic output vector.

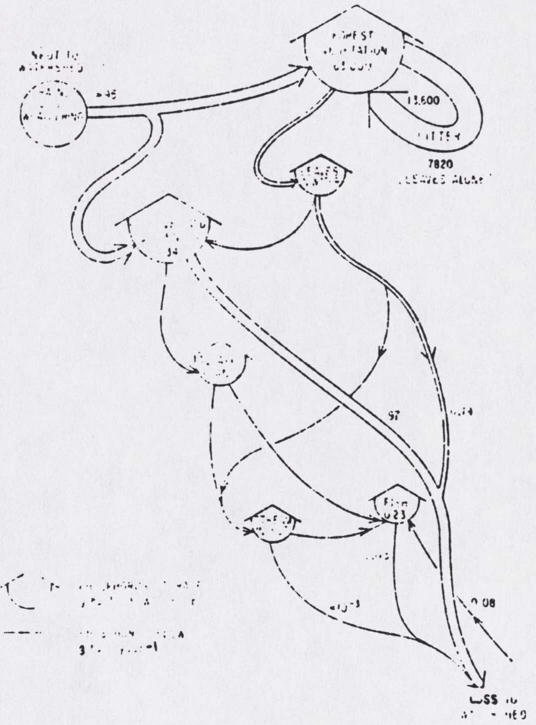

Figure 6. Some phosphorus storages and flows for New Hope Creek and surrounding watershed, based on studies from June 14, 1968, to June 13, 1969, and on literature values. (From Hall 1972.)

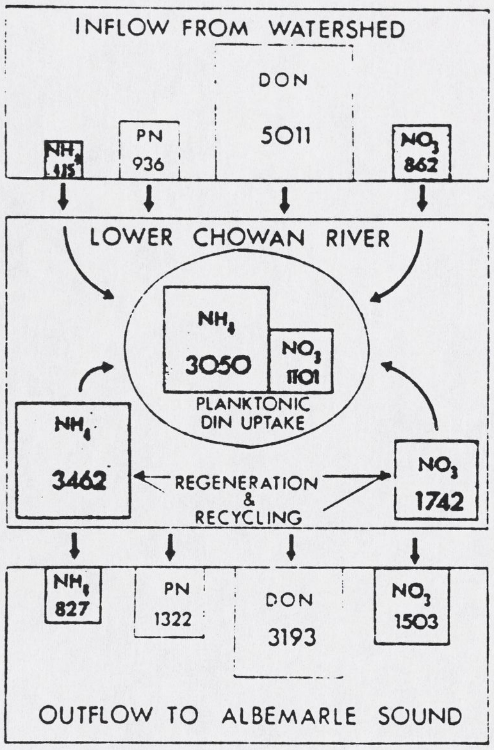

Figure 7. Total annual inflow, assimilation, and outflow (tonnes) of nitrogen for lower Chowan River between November 1974 and November 1975. (From Stanley and Hobbie 1981.)

Meteorologic Output of Nutrients

Small quantities of ammonia appear to be lost from water to the atmosphere by gaseous exchange. The magnitude is directly related to temperature, pH (up to 9.5), and surface turbulence or wind velocity (Stratton 1968; Weiler 1979). How significant this output is in streams is poorly understood.

Denitrification, herein defined as the biochemical reduction of nitrate-N or nitrite-N to gaseous nitrogen (N_2) is an important factor for meteorologic-biologic nitrogen export from lakes (Brezonik and Lee 1968, Chen et al. 1972, Keeney 1973). Its role in stream nitrogen dynamics is less well studied. Canadian workers (Kaushik and Robinson 1976, Sain et al. 1977, and Chatarpaul et al. 1979) concluded that denitrification was the dominant source of nitrate-N removal from a woodland stream. Hill (1979) reported that nitrogen losses by denitrification represented approximately seven percent of mean annual total nitrogen export from another Canadian river basin.

Biologic Output of Nutrients

It has been suggested that emerging aquatic insects are a means whereby nutrients are exported from streams and recycled back to the terrestrial ecosystem. Available evidence, however, lends little credence to this contention. Keup (1968) calculated that 5.4 trillion insects would have to emerge from the Pigeon River, North Carolina, to the surrounding land to effect a significant phosphorus loss by this vector. Inconsequential nitrogen and phosphorus export by emerging aquatic insects has also been suggested for a lentic water (Vallentyne 1958). Compared with calcium and potassium losses from several North Carolina rivers by dissolved materials, sediments,and particulate organic matter, insect emergence was calculated to be trivial (Webster and Patten 1979). Foraging birds (e.g. shorebirds, waders, dippers, etc.) and mammals (e.g. moose, hippopotami, mink, etc.) also likely remove insignificant quantities of nutrients from lotic waters. Phosphorus export by upstream migrating fish were reported by Hall (1972) to be about one-half that lost by leaves moving downstream but less than 0.1 percent of that lost in stream discharge (Fig. 6).

Another potential biologic loss of nutrients is uptake by riparian terrestrial plants whose roots remove water from the stream. Gregory (1978) found that riparian plants had lower phosphorus uptake rates than stream algae. He noted, however, that because of their high standing crops terrestrial plants represent a significant sink for stream nutrients. Presumably, after these plants die (annuals), shed their leaves, or high stream discharge erodes them from the bank, most of the minerals they removed from the stream would be recycled back to the aquatic system.

Geologic Outputs of Nutrients

During flood stage in large rivers (e.g. Mississippi, Nile, Amazon) massive quantities of previously deposited sediments may be resuspended and exported by overbank flow to the surrounding flood plain. Once in the flood plain river velocity decreases and the suspended sediment with its nutrient load is deposited (Keup 1968). Formation of unique igapós forests and várzea lakes are a consequence of the Amazon's annual flooding. Productivity may be high in várzea lakes and overbank nutrient loadings are important to the igapós forest community (Sioli 1975).

The importance of overbank flows from large rivers to flood plain fertility is common knowledge because of the intimate association of human cultural development with this recurrent event. The impact of annual Nile River deposition of over 50 million tons of sediment on Egyptian agriculture and its loss due to construction of the Aswan High Dam are discussed by Hammerton (1972) and Rzóska (1976).

The largest single loss of nutrients from a stream reach is by downstream export of inorganic and organic materials that are dissolved or suspended in water. (Likens et al. 1967 (Ca, Mg, K); Vollenweider 1971 (N,P); Hobbie and

Likens 1973 (P); Johnson et al. 1976 (P); Miller and Smith 1976 (N); Meyer and Likens 1979 (P); and Webster and Patten 1979 (Ca, K)). Quantities of nutrients exported in this manner are highly variable between streams and are dependent on numerous factors including,but not limited to: upstream loadings, stream order, gradient, channel morphometry, bank characteristics, instream retention devices (e.g. debris dams), and instream biological processes.

Our present view of streams as a continuum of physical and biological gradients from headwaters to mouth raises questions regarding the relevance of many published stream nutrient export studies to within stream processes. Many of the studies just referenced do not elucidate the efficiency of stream nutrient processing in relation to nutrient output,but rather relate to watershed export. Indeed, they evaluate throughput rather than output (Likens 1975). Similarly, most export studies consider outputs only in terms of a selected stream reach. Often a weir is constructed along the stream and materials passing the weir or collected behind it are quantified. Yet from a holistic viewpoint, nutrients discharged from one reach are input to the contiguous downstream reach. Little research on stream nutrient export to date has actually tested the river continuum hypothesis, instead most reflect a more parochial view defined by practical sampling constraints in lieu of attempting to integrate the multiplicity of nutrient utilization strategies.

Judgements concerning whole stream nutrient processing efficiency can logically be made only at points of discharge into lakes or eventually the ocean. Naiman and Sibert's (1978, 1979) studies demonstrating the dependence of juvenile salmon production in the Nanaimo Estuary on river energy inputs suggests the significance of whole river export. Stanley and Hobbie (1981, Fig. 7) show that nearly all nitrogen discharged from the Chowan River watershed to the lower Chowan River (7224 tonnes) is ultimately exported to Albermarle Sound (6845 tonnes export; which leaves 329 tonnes in storage). Extrapolating nitrate-N loadings into Lake Tahoe from Ward Creek to the entire Tahoe basin, Leonard et al. (1979) estimated a contribution of ~1 µg NO_3-N/l to Lake Tahoe's total volume. This loading rate was considered highly significant when related to the lake's average nitrate-N concentration of 13 µg/l. The magnitude and importance of river nutrient loadings to estuaries can be appreciated in view of Windom et al.'s (1975) report that fluvial inputs of inorganic phosphorus from nine southeastern rivers are adequate to supply the phosphorus demands of the appoximately one million acres of *Spartina* salt-marsh between Georgetown, S. C. and Jacksonville, Fla. Inorganic nitrogen inputs from these rivers could also account for twenty percent of salt-marsh vegetation requirements.

CONCLUSIONS

As Stanley and Hobbie (1981) showed, nutrient inputs into rivers are balanced by nutrient outputs. Were this not the case nutrient concentrations within undisturbed streams would increase or decrease over time as no feedback loop exists between instream levels and terrestrial loadings. One can conclude that factors which prolong retention of nutrients are the key to stream processing efficiency. The preponderance of attached rather than planktonic plant and animal communities in streams best illustrates this strategy of retention. Meanders, pools and debris dams are physical features which biological communities exploit to maximize nutrient retention. These and other factors define the extent of nutrient spiralling over a river's course. Because nutrient movement in streams is inexorably a downhill process, strategies which maximize spiralling (i.e., reuse over a defined reach) enhance stream processing efficiency and thereby system stability.

The most significant natural factor countering nutrient processing efficiency and contributing to high output-low spiralling is flooding. High discharges scour stream beds and remove reserves of organic and inorganic nutrients. Periphyton and benthic invertebrates may be detached and once in the water column can no longer restrain undirectional nutrient flow as they have themselves become part of it. Floods reset the stream ecosystem. Much material is exported, yet new materials are introduced from upstream reaches and the surrounding terrestrial environment. Debris dams are destroyed and new ones generated. Previously detached algae and invertebrates recolonize scoured bed materials. Webster et al. (1975) characterize ecosystems in terms of their resistance to displacement and their resiliency following displacement. As suggested by the impact of flooding on streams, they exhibit low resistance to perturbations. In fact, Webster et al. (1975) state that with respect to nutrient stability streams may be the least resistent ecosystem in the biosphere. They characterize an idealized stream as an ecosystem without large abiotic reserves, with low biotic localization of nutrients and with little or no nutrient recycling.

What stability streams do exhibit can be attributed to their resilience following disturbances (Webster and Patten 1979). Nutrients lost downstream during a flood are replaced by watershed inputs. Internal function is regained by retention mechanisms and organism recolonization and regrowth as was previously described. Notwithstanding these reset devices, Webster et al. still consider streams as low resilience ecosystems compared with oceans, marshes, lakes, tropical and temperate forests, tundra and grasslands. If one accepts their premise that high resistance and resilience equate to stability, then their proposition implies that streams are highly unstable environments. Such a conclusion gains support from the devastation wrought on lotic ecosystems by anthropogenic perturbations.

We cannot escape the conclusion that, on a global scale, lotic systems function primarily in the transport of nutrients from the terrestrial to the oceanic environment. Nevertheless, I hope to have demonstrated that the voyage is a circuitous one. Indeed, the evolution, diversity, and integrity of a stream's biotic community is at once both a cause and consequence of non-linear nutrient transport.

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Questions
23-25
27, 30, 31
43, 44, 45
46, 47, 48

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May 15, 1981

Behnke
EXHIBIT
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86

Mr. Roland C. Fischer
Colorado River Water
Conservation District
P.O. Box 1120
Glenwood Springs, CO 81601

Re: Juniper-Cross - Response to Data Request (0375C.02)

Dear Rolly:

Attached is a draft of our response to the pending FERC Data Request bearing the date 05/15/81 on each page to distinguish it from other versions which will evolve as we get more answers.

The major effort in this was to edit some of Bob Behnke's "Scenario" and then insert paragraphs from that Scenario in what seemed to me to be the appropriate spots in response to the various questions. So that you and Bob can see quite readily what I did with Bob's work I am enclosing a copy of the manuscript of his which I marked up for typing.

I believe you have a separate typing of Bob's full paper under way. He wanted that in order to cross check some of his data. I would request that when he has done that he makes sure that any necessary changes are made in the draft response to the data request so that we can keep that project moving.

If John Marr has any notions for supplementing some of Bob's comments with regard to vegetation I am sure he will let you know.

You will note in the left hand margin oppsite each question I have indicated the person or organization which is to get together a response. I am sending copies to all of those indicated and hope they will send me copies of any material in response which they send to you. We can then integrate that material in to the draft and recirculate it, as may be necessary, until we get a final, finshed product.

We should be visualizing a transmittal letter which I expect would probably be rather brief contianing whatever general comments we think desirable, probably signed by both you and John Bugas as the joint applicants.

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I will be out of the office until May 27, but will be in touch with you promptly on my return to assess our progress.

As I indicated at the Grand Junction meeting I think we should be as fully responsive as possible to each of the questions and that we should try to get the material back to the staff as much ahead of the July 9 deadline as we can, as long as we are satisfied that what we are getting together represents the best job we can do.

With best regards.

Sincerely,

McCARTY, NOONE & WILLIAMS

Robert L. McCarty

cc: Messrs Balcomb
Bugas
Wagoner
Christensen
Currier
Behnke
Marr
Irish

DRAFT

June , 1981

RESPONSE TO FERC STAFF DATA REQUEST OF APRIL 10, 1981 FOR JUNIPER-CROSS MOUNTAIN PROJECT

The following material is submitted in response to the Data Request attached to William W. Lindsay's letter dated April 10 (OEPR-DEA, Project No. 2757, Colorado), to Roland C. Fischer of the Colorado River Water Conservation District, received April 17. For ease of reference the questions have been repeated, with the response immediately following, referring to any supplementary data which may be appended.

C-U. Q. 1. Submit a completed copy of the attached pages from the DOE/FERC Annual Report (Form No. 1) for the year ended December 31, 1980. Data should be supplied for all system generating plants (disregard instructions for reporting only "large plants") for page 432, Steam-Electric Generating Plant Statistics (including any Combustion Turbine Plants); and page 433, Hydroelectric Generating Plant Statistics. Project data equivalent to that called for in Form No. 1 for the following planned expansions: (1) the proposed 800 Mw thermal coal-fired generating facility in the vicinity of Delta or Grand Junction (see Craig Daily Press, December 24, 1980) and (2) the proposed recapture of an additional 30 percent of Hayden Unit 2 in 1982 (see Exhibit U).

C-U Q. 2. For each generating plant described in Form No. 1, provide comparable unit data showing percent of ownership, generating units installed and dependable capacity, full and partial load heat rates, forced and planned outage rates, and generating unit response times.

C-U Q. 3. Provide data on the sequence in which the generating units would be dispacthed for all years between 1981 and 1995, and the order in which they have been dispatched during 1980.

C-U Q. 4. In addition to plant investment cost data in Form No. 1, provide a detailed cost breakdown of Craig Units 1 and 2, and the estimated cost of Craig Unit No. 3.

C-U Q. 5. Provide a breakdown of fixed charge rates (including cost of money, depreciation, insurance and taxes) for the most recently constructed Craig units, and a similar breakdown of estimated fixed charges for the Juniper-Cross Mountain Project.

C-U Q. 6. Provide a copy of all analytical studies (e.g., LOLP studies) performed by the Colorado-Ute Electric Association, Inc. (CUEA) justifying the reserve margin currently being used. On what basis were the reserve margin planning criteria chosen? What is the relationship between the reserve margin criteria and system reliability?

C-U Q. 7. Quanitfy energy and peak demand resources available via all transmission interconnections with other utilities, both on a long-term and on an emergency basis. What is the cost of such power? Note seasonal restrictions, if any. Submit data for each major transmission link separately. Describe all arrangements including pricing agreements that the CUEA has made with other electric utilities for purchases of power, including emergency power, over the period 1981-1995. At what price and quantity might additional power be available during this time period?

C-U Q. 8. What is the magnitude of load currently contracted for an interruptible basis and what is the probable mangnitude of this variable for the years 1981-1995. Also, show the controlled service loads for both water heating and air conditioning, and other types of loads.

C-U Q. 9. Provide any load management studies that CUEA has performed or considered and the conclusions reached respecting system energy consumption and peak demand.

C-U Q. 10. Provide a computer readable card deck (or magnetic tape) with the CUEA system hourly demand for 1980. In the absence of yearly ADP data substitute system load data for the specified weeks which will be reported in DOE/FERC Form No. 12, Power System Statement for the year 1980. In addition to the weeks specified in Form 12, include data for the two weeks during which the previous summer and winter peak loads occured.

C-U Q. 11. Provide estimates of spinning reserve required on peak for the years 1981-1995, and explain how these estimates were made.

C-U Q. 12. Provide data to show which generating units (both within and outside the CUEA system) currently provide the following operating functions: peaking power, power system regulation (load following), and reserve power capacity. Project which units will supply these functions for the years 1981-1995.

C-U Q. 13. Update or revise all load projections that were filed with the application for license so that these data may be coordinated with the 1980 Form 12, Power System Statement, Schedule 13, Demand on Generating Plants, Power Received, and Power Delivered, for Resale, at the Time of System Peak Load of the Year (copy attached).

C-U Q. 14. Submit the historical data used to support projected future rates of load growth and the options selected for satisfying them, including: historical production data (annual peak loads and annual energy production, 1970 to date), peak load growth rates and total energy for each major system component (distribution of ultimate consumers, by class), and location of past load centers and projected changes in location of future load centers.

IECO Q. 15. Describe the possible consequences downstream to property and life, using hypothesized situations such as slowly-developed failure and rapidly-developed failure for either or both dams at normal pool elevations.

WE Q. 16. Show the effects of evaporation losses from the reservoirs on power production and water rights downstream.

IECO Q. 17. Show the considerations and limitations used to develop the optimum dam heights.

IECO Q. 18. Describe the major factors that preclude development of a single-dam project in lieu of the proposed two dams.

IECO Q. 19. What is the feasibility of storing and using the waters of the Yampa River for a multipurpose development, including power, irrigation, and municipal industrial uses? Are these alternative uses of water incompatible with hydroelectric development? Do they offer less economic benefits overall than the proposed hydroelectric development?

WE Q. 20. What is the feasibility of irrigating currently dry lands to mitigate for losses that would occur on currently irrigated lands in the proposed reservoir basins? Indicate the quantity of water required for this purpose and the potential impacts on project power generation and reservoir recreation, the location of the lands to be irrigated, a description of their present use, and likely environmental impacts.

C-U Q. 21. Would the project require construction of a new 22-mile-long transmission line from Juniper switchyard to Craig? If so, provide data on tower design, alternative routes considered, environmental impacts, and mitigative measures.

WC, RD Q. 22. Provide estimates of salinity increases in mg/l at Imperial Dam that would result from evaporative losses and reservoir inundation of the Mancos shale. Indicate the surface area of the shale formation that would be: (a) in direct contact with the water, (b) covered by alluvial material and in indirect contact with the water, and (c) subject to cyclic fluctuation in reservoir levels. What effect would wet-dry cycles have on the formation? Would any increase in salinity be temporary or would weathering cycles cause continuous leaching of salts from the Mancos? Would salts be able to leach upward through any overlying alluvial materials?

A. Item No. 22 raises 5 questions. We will take them in order, as follows:

"Provide estimates of salinity increases in mg/l at Imperial Dam that would result from evaporative losses and reservoir inundation of the Mancos Shale."

Comment: In our judgment, the salinity increases would be negligible because the most likely dissolvable mineral in the Mancos Shale is gypsum and it does not readily redissolve on contact with cold, fresh water. We have checked with senior sources in both the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, and they confirm our assessment. They know of no documented situation in which reservoir-leached gypsum has contributed significantly to the salt content of the reservoir water or of the water released from the reservoir. The salinity of reservoir water is not significantly increased by the leaching of shales underlying the reservoir; consequently, increases in salinity caused by evaporative losses where the salinity is derived from leaching also should be negligible.

"Indicate the surface area of the shale formation that would be: (a) in direct contact with the water, (b) covered by alluvial material and in indirect contact with the water, and (c) subject to cyclic fluctuation in reservior levels."

Comment: Approximately 4,350 acres, 4,050 acres, and 3,200 acres, respectively. Note, however, that the shale typically is blanketed by residual and slopewash soils on the valley slopes, thus would note be commonly in direct contact with reservoir water.

"What effect would wet-dry cycles have on the formations?"

Comment: The Mancos Shales typically air slake, but do not dissolve or breakdown readily to their constituent clays when repeatedly wetted and dried. Within a short time the slaked material forms rubble-like armor on the shales, retarding further deterioration. This armor typically is a few inches to a few feet thick. Of equal importance to this question, however, the shales rarely crop out across the valley slopes within the reservoir area. They are mantled by residual soils and slopewash soils, mainly clays, and they should provide a large measure of protection from erosive attack. Finally, we know of no reported case of shale deterioration caused by wetting and drying that resulted in appreciable damage in a reservoir area or pollution of reservoir water.

A. 22 Cont.
"Would any increase in salinity be temporary or would weathering cycles cause continuous leaching of salts from the Mancos?"

Comment: As noted above, the increase in salinity of the reservoir waters due to solutioning of salts from the Mancos Formation shoud be negligible. Any influx of salts due to that process to the reservoir waters, moreover, is likely to be derived from surficial secondary deposits that would be leached very slowly over a long period of time, probably measured in hundreds to thousands of years. Once those salts are removed at a vitrually unmeasurably slow rate, the process would cease for lack of surficial materials.

"Would salts be able to leach upward through any overlying alluvial materials?"

Comment: Yes, but the process is slow and the quantity of material per unit time reaching the reservoir should be small because the leaching process is slow.

In summary, we conclude that the risk of pollution of the reservoir waters by salt leached from the Mancos Shale by those waters, is miniscule; and that the risk of significant deterioration of the shales as a result of exposure to the reservoir waters, followed by significant erosion, is also judged to be very small.

3B, RD Q. 23. Describe and compare projected water quality downstream vis-a-vis the preimpoundment water quality.

NOTE: Dr. Behnke has offered the following comments by way of perspective in connection with some of the data supplied for items 23-25, 30, 31 and 43-48:

CHANGING A LOTIC (FLUVIAL OR RIVER) ENVIRONMENT TO A LENTIC (LACUSTRINE OR LAKE) ENVIRONMENT.

The energy pathways in relation to converting raw material (nutrients) into organic matter by primary production (photosynthesis by plants) and through successive connections of the food web into fishes, is basically the same in the two environments. The organisms filling the various niches at different trophic levels change due to changes in depth, flow velocity, substrates, temperatures, and oxygen. The plot in these two plays in the theatre of life is essentially the same, only the actors change. Thus, it is important to understand the processes, the trophic-dynamic relationships (the plot) and not be concerned over species lists of plants and animals (the actors), which can vary enormously in time even in the same environment. A wide range of species can function at any particular trophic level to effectively move the energy flow to the next level. For example, green algae and diatoms are the main sources of primary production in the Yampa River. In a reservoir, green algae (although there will probably be a change from the genus Cladaphora to the genus Spirogy~~pus~~ra) and diatoms (benthic-pelagic species) will continue to exist, but the main source of primary production will be a diversity

A. 23. Cont.
of unicellular algae (phytoplankton). The same is true of the invertibrate animals that move the energy from primary production into fishes -- a variety of species function in various niches in the food web of different environments. It is only when we come to the fishes, in relation to endangered species or food and game fishes influencing recreational use that information on what species fill what niche becomes significant information. While for these reasons species of aquatic vegetation and macroinvertibrates have relatively little import they are catalogued ante at Q. 43.

For the following discussion, I have drawn on a wide range of material such as the book on the ecology of regulated streams (Ward and Stanford 1979) and WPRS publications on North Platte River reservoirs (La Bounty et. al. 1976, 1978), particularly in relation to Seminole Reservoir, Wyoming, which has close similarities to the proposed Juniper Reservoir -- 6357 feet elevation at maximum pool, 10,000 surface acres, and 1,011,000 acre feet of storage capacity. A full list of references is contained in the appendix.

WATER QUALITY

Total Dissolved Solids (TDS). This is the mineral or salinity content of water composed of various ions or forms of sodium, potassium, calcium, magnesium, chloride, sulfate, phosphorus, and nitrogen. Because the major nutrients governing primary production -- nitrogen and phosphorus -- are part of TDS, TDS is a key factor for predicting fish production in lakes. In general, the higher the TDS (within limits) the higher the fish production. This simple relationship does not hold for water in the Colorado River basin because, although TDS levels are high in various parts of the basin (from less than 100 in headwater tributaries to morethan 1000 in the mainstream during low flows and exceeding several thousand in some tributaries at low flow such as the Price and San Rafael rivers of Utah), the relative proportion of nitrogen and phosphorus are low in relation to the other molecules. Thus, nitrogen is typically the limiting factor for primary production in reservoirs of the Colorado River basin. Because some of the components of TDS are incorporated into living organisims in a reservoir and some components may precipitate out in reservoirs, the outflow water will typically have reduced TDS values from the inflow water (particularly if water is released from the surface), unless the flooded reservoir basin leaches additional minerals into the reservoir. Reservoir evaporation also increases TDS values (Juniper and Cross Mtn Reservoirs ~~is~~ are predicted to have an annual evaporation of less than 40,000 acre feet which may increase TDS levels by about 6%). The average annual TDS concentration in the Yampa River (at Maybell) is 178 ppm; however, this concentration will typically vary by about 10 fold from peak dillution flow to minimum low flow. The Juniper-Cross Mountain Project Environmental Assessment Report (p. W 3-18) based a prediction on post impoundment TDS levels on data from Flaming Gorge Reservoir where soil leaching increased TDS levels by 28%. Similar increases in Juniper and Cross Mountain reservoirs would increase the TDS in the outflow from Cross Mountain to about 290 ppm according to the report. There is no feasible way to predict accurately post impoundment TDS levels (the assessment report did not consider TDS loss to nutrient trapping in reservoir sediments and the often large differences

A. 23 Cont.
in TDS levels between reservoir releases from deep water (hypolimnion) as from Flaming Gorge, and from surface waters (lower TDS values), as would be the case with Juniper-Cross Mountain reservoirs).

It can be safely said, however, that an average increase in TDS levels in the Yampa River to a range of 200 to 300 pose no threat to aquatic life. On the contrary, if additional nitrogen is part of increased TDS values, primary production will increase leading to increased invertebrate and fish production both in the reservoirs and in the river downstream from Cross Mountain dam. Steele (1980, fig. 3) predicts that if Juniper Dam, Cross Mountain Dam, and other dams are constructed in the Yampa basin, the average annual TDS levels in the Yampa River at Echo Park will decrease from the present 309 ppm to 185 ppm and the fluctuations around the mean value will be much reduced after the impoundments are constructed.

Nutrients. As mentioned, the major nutrients governing primary production in water (as on land), nitrogen (nitrate) and phosphorous (phosphate) are part of the TDS. Concern is often expressed over eutrophication or the enrichment of water that greatly increases primary production (and subsequently fish production). It must be recognized that artificial enrichment or fertilization of water has been a fish cultural practice for 2000 years or more in China, and is a regular fish management practice in the United States. Nitrate nitrogen will likely be the limiting factor governing primary production in Juniper and Cross Mountain Reservoirs. Values of nitrate nitrogen in the Yampa River range from essentially zero at peak dilution flows to .9 ppm at minimum low flows, averaging about .2 ppm. This value in too low to produce eutrophic conditions (Typical eutrophic lakes, where phosphate is limiting, may have nitrate nitrogen values of 2.0 or higher. The most productive of the TVA reservoirs (greatest production of fish) is Cherokee Lake, which averages 2.7 ppm nitrate-nitrogen in its waters (Krenkle, et. al 1979).

Nutrient values in Juniper Reservoir can be expected to increase slightly soon after filling due to leaching and decomposition of flooded organic matter. The phytoplankton in the epilimnion (surface zone) of the reservoir will utilize much of the available nutrients. The stratification of the reservoir (due to water of different temperature and density forming layers -- epiliminion [upper], metaliminion or thermocline [middle], and hypolimnion [lower] will tend to concentrate nutrients in the hypolimnion. This differential concentration of nutrients by depth in a reservoir is dependent on the intensity of phytoplankton development in the epilimnion and the degree of completeness of stratification. Thus, the outflow from the surface zone of Juniper Reservoir can be expected to have reduced nutrient concentration and the similar process in Cross Mountain Reservoir should further reduce nutrients downstream. In any event, there should be no problems from eutrophication such as excessive growth of blue-green algae, oxygen depletions and fish kills, etc. Juniper and Cross Moutain reservoirs would be classified as mesotrophic bodies of water -- waters of moderate productivity. See generally W 3.18-20.

B, RD Q. 24. Water quality (bacterial) in the Yampa River below Craig is now reported to be unsuitable for body-contact recreation. What conditions are anticipated after impoundment?

A. 24. Bacteria are a necessary component in ecosystems to recycle energy from decompostion of organic matter, releasing nutrients and incorporating protien, carbohydrates, and fats into more bacteria that are consumed by various invertebrate animals (snails, detrital feeding insects and crustacean). Such energy recycling is not complete, however, as can be demonstrated by fossil fuel -- coal and oil -- that represents the incompletely recycled energy trapped in sediments many millions of years ago. The only concern in relation to bacteria for environmental assessments is that of pathogenic bacteria that cause disease. These mainly concern fecal coliform bacteria. Fortunately, fecal coliform bacteria can not survive for long periods outside of the digestive track or outside of feces. When washed into a stream or introduced into a stream from incomplete sewage treatment, their numbers dwindle rapidly downstream from the point source. Coliform bacteria are continually and ubiquitously introduced into waters from dung of wild and domestic animals (particularly livestock). Potential human health problems occur only near the source of raw or incompletely treated sewage effluent where pathogenic bacteria density is high. The sewage effluent from Las Vegas, Nevada, entered Lake Mead via Las Vegas Wash into Las Vegas Bay which created a potential health problem near the point source (Baker et. al. 1977). However, fecal bacteria numbers rapidly decline in Las Vegas Bay away from the Las Vegas Wash. Lake Mead receives enormous human use for swimming and water skiing. The Las Vegas Wash sewage input was beneficial to aquatic life by greatly increasing phytoplankton and zooplankton production (and ultimately fish) by its nutrient enrichment. The current fisheries management plan for Lake Mead is to change from a hypolimnion to an epilimnion release in order to retain nutrients and increase fish production. Undue alarm over human health without real basis in fact can cause great but needless expenditure of funds and reduce the quality of a fishery due to reduction of nutrient input. For example, the trout population in the North Branch of the Ausable River, Mighigan, was reduced in biomass by 70% and with much slower growth after the City of Grayling, Michigan, installed tertiary sewage treatment and reduced the nitrate nitrogen concentration in the river by 70% (Clark, et. al. 1980). Odell Lake, Oregon, was once a famous fishery for kokanee salmon. The Forest Service campgrounds received heavy use. It was feared that the septic system of human waste disposal was polluting the lake by leaching through the soil and the toilets were vaulted to prevent leakage. As a result, the nitrate nitrogen level in Odell Lake dropped by 20%, but this triggered reduced productivity and a decline in the catch of kokanee salmon by 80% (Oregon Department of Fish and Wildlife, Fishery Research Review and Planning Report 1977-78). The Oregon Department of Fish and Wildlife in cooperation with the U.S. Forest Service is now planning to fertilize the lake artificially to replace the nutrients lost from the septic seepage. The point is that nutrient enrichment is necessary for aquatic ecosystems to function. Problems arise when the enrichment carries pathogenic organisims or when enrichment reaches too high a level causing oxygen depletion, elevated levels of ammonia and fish kills (too much of a good thing).

BB, RD Q. 27. Expand and quantify the analysis and discussion of water temperature at the project reservoirs during filling, at equilibruim, and seasonally. Describe the planned project releases and operating mode, indicating the average monthly release temperatures. Estimate the monthly river temperatures above and below the Little Snake confluence, and above and below the confluence with the Green River. Assess the probable interactions with Green River and Flaming Gorge releases, and possible control options.

A. 27. The reservoirs will act to warm the Yampa River water earlier in the spring by exposing a great surface area to the atmosphere and solar radiation. As the cold water from spring snow melt enters the reservoir it will tend to sink to the bottom below the warmer surface layer. By July stratification should set in with a colder (45 degrees to 55 degrees F) hypolimnion, a transitional zone of rapid temperature change (metalimnion), and a surface zone or epilimnion that will be warmer than the Yampa River inflow in May and June, reaching equilibrium probably in July. During the hottest part of the summer, the surface waters will approximate the present temperatures in the river at low summer flows, sometimes slightly higher, sometimes slightly lower (ranging from about 70 degrees to 80 degrees F), depending on the ambient air temperatures -- but the daily fluctuation in temperatures will be dampened by the reservoir. That is, surface temperatures in the reservoir will warm and cool more slowly than present summer river temperatures at low flow due to the effect of volume and wind action.

The colder waters of the hypolimnion should experience only minor oxygen depletion. Because of the moderate productivity and relatively brief period of stratification (probably three months or less), bacterial decomposition of organic matter causing anoxic conditions should effect only a relatively small zone near the bottom. In most years it may be anticipated that 90% of the hypolimnetic volume will maintain dissolved oxygen levels of 4 to 5 ppm, suitable to allow fishes to live in the hypolimnion.

The overall temperature regime in the reservoirs will allow for "two story" fisheries -- warm-water fishes inhabiting the epilimnion during the summer and cold-water species living in the hypolimnion. The new temperature regime should benefit the endangered fishes. The reduction of the peak, scouring flow and warmer temperature in the late spring flow will act to induce earlier spawning in squawfish and humpback chub. Squawfish spawn at about 70-72 degrees F. This temperature is normally achieved in early to mid July in the lower Yampa River. The new thermal regime should produce spawning temperatures two to three weeks sooner. The longer period for growth during the first year of life should act to increase survival. The winter flows (from the hypolimnion) will increase normal winter temperatures. The temperature and flow regimes (evening out the annual cycle) will increase invertebrate production and provide more food for fishes in the lower Yampa (discussed in more detail below).

CO, C-U Q. 28. Provide a time-increment, monthly-projected hydrologic load curve (including both winter and summer estimates). Indicate the projected on-peak hours. What methodology was used to extrapolate stream flows on the Yampa River to the reservoirs (drainage-area ratio)?

C, RD Q. 29. Describe the landslide and slumping potential at the project. How would the impounded water affect the unstable Mancos shale formation?

A. 29. As stated in our [Woodward-Clyde] geotechnical report on the Juniper-Cross Mountain Project, we consider the reservoir induced landslide risk to be low. The Mancos Shale is weak, relative to other types of rock such as granite, gneiss or dense limestone, but is not necessarily unstable. Long, high, steep slopes underlain by shale strata that dip toward the reservoir present the best developed potential for reservoir water seepage-induced ground failures, whereas shallow slopes underlain by gently dipping shale beds tend to be stable. That latter condition predominates within the peripheral sections of the planned Juniper Reservoir underlain by Mancos Shales. Consequently, we have judged the risk of reservoir-induced landslides to be low.

Otherwise, landslides (large or small) are rare within the two reservoir areas. Landsliding does not appear to be one of the major methods of land erosion and degradation. This constitutes empirical evidence of a general well-developed slope stability. Generally low-angle slopes and neutral or slope stability-enhancing bedding dip orientations predominate. Consequently, we have judged the general risk of reservoir-induced landslides throughout the Cross Mountain and Juniper Reservoir areas to be low.

EB, RD Q. 30. Analyze and discuss seasonal turbidity and sediment in the Yampa River below the Little Snake confluence, and the likely effects of project releases during those months when the Little Snake is relatively clear.

A. 30. Sediment and consequent turbidity changes were noted at W. 3.19-20. Turbidity is the degree of opaqueness of water (inhibition of light penetration). Unless there is a non particulate source, such as acid bog water, to discolor water, turbidity is directly related to the suspended sediment load. The Yampa River is relatively low in sediment yield in comparision to other Colorado River basin tributaries. It yields 12% of the flow but only 1.5% of the sediment in the upper basin (Yorke 1980). The Yampa River at Maybell yields an average of 90 tons of sediment per square mile of watershed with an average suspended sediment load of 196 ppm (mg/l). The Little Snake River yields 295 tons per square mile of watershed at an average concentration of 1,790 ppm. Juniper and Cross Mountain reservoirs will effectively remove sediment from the Yampa River. The flow from Cross Mountain Dam wil be essentially free of sediment (but with some small contribution of turbidity from phytoplankton and particulate organic matter).

A. 24. Cont.

From the foregoing and as indicated in Exhibit W (W 3.23-24), the ~~local~~ fecal coliform bacteria from Craig are not expected to survive long enough to attain detectable levels in the reservoir ~~by~~ to cause alarm on matters of human health. Coliform bacteria in the reservoir will be mainly from submerged animal feces (particularly livestock feces) and from tributaries draining grazing lands. These coliform levels can be expected to be characteristic of natural waters in similar geographic areas.

BB, RD Q. 25. Analyze and discuss trace metal concentrations reported for the Yampa River in the Colorado West Area Council of Governments Plan, 1979.

A. 25. Some waters in Colorado have pollution problems from heavy metals -- zinc, copper, lead, mercury, aluminum, etc. The major source of metal pollution is draining from old mine tailings. Water quality data for the Yampa River, given in the environmental assessment report, give no indication of any problem from metal pollution. The diversity of fishes and invertebrates throughout the Yampa basin also is evidence for an absence of any threat from metal pollution.

The Colorado West Area Council of Governments Plan, 1979, has been reviewed for the Yampa River and gives no cause for concern. The concentration of most elements can be expected to be greatest at lowest flows, yet a diversity of plants and animals live throughout the ~~local~~ low flow period in the Yampa (actually the low flow summer period is the time of the greatest increase in production and biomass). If an aquatic toxiological problem exists it should have been very evident by now. Concentrations of metal ions will be reduced in reservoirs with suspended organic matter and ? PH above 7. Thus, the average concentrations of heavy metals will be much less in the reservoirs (averaging out the years flow, plus precipitation) than they are presently at low flow conditions in the Yampa.

WC, RD Q. 26. How would sanitary facilities at the proposed project recreation areas affect groundwater?

A. 26. The impact of sanitary facilities at the proposed project recreation areas on ground water would be dependent on the type of facility used. It could well be self-contained and could even be a recycling unit. Both would have no impact on the ground water regime. Standard ranch or farm-type privies might well result in pollution of the ground water, but this is not a certainty. It would depend on the geologic and ground water setting at each specific site. Valley bottom sites, where the ground water table is shallow, obviously present more of a risk than upland areas where the ground water level may be relatively deep. The point to be made, however, is that the sanitary facilities can be engineered to virtually eliminate pollution problems.

A. 30. Cont.

The Little Snake dumps a relatively enormous sediment load into the Yampa River, but virtually all of this sediment comes in May and June (and with flash floods at other times). Sediment transport in a river is a continually balanced process between aggradation (sediment deposition) and degradation (sediment transport). The sediment free water from Cross Mountain Dam will act to "degrade" the river bed by sediment transport, but this process will be greatly modified three miles downstream where the Little Snake enters. The reduced peak flows from Cross Mountain Dam can be expected to increase the rate of sediment deposition below the Little Snake River in May and June. Typically, the Little Snake river ceases to flow into the Yampa after mid July. At this time, the entire flow of essentially sediment free water from Cross Mountain Dam will act to transport the "surplus" sediment deposition of the May-June period with the end result, that by the fall-winter period, the dynamics will be similar to the present situation. The Little Snake contributes 3.5 times more sediment than the Yampa at present and the overall result will be about 25% reduction in total sediment yield in the Yampa River (at Echo Park).

Like nutrients, sediment is a natural part of flowing water but too much sediment from man-induced accelerated erosion (such as Little Snake River) is harmful to aquatic life, especially fishes. Sediment is also deposited at high flows along the margin of the river to provide substrate and nutrients for riparian vegetation (the early centers of human civilization in the lower Nile and lower Tigres-Euphrates Valleys depended on sediment deposition). This riparian deposition will continue to occur, but the overall sediment yield in the lower Yampa will be reduced by about 25% -- but still above virgin conditions, before man's land use produced increased rates of accelerated erosion.

The hydrologic term "degradation" is not entirely descriptive in relation to its impact on fishery values. "Degradation" of a stream channel, removing accumulated sediment down to boulders and bedrock ("armoring" of the substrate), deepens the channel and can create more fish habitat. Examples discussed in Ward and Stanford (1980) point to increased abundance of invertebrates and fishes below some TVA dams and below a dam on the Brazos River, Texas, where the "degradation" of sediment removal by sediment-free flows from the reservoir, deepened the channel and provided considerably more habitat than was there before impoundment. Some deeping of the Yampa River can be expected from "degradation", but the effects should be moderate in view of the fact that more than 70% of the present sediment load in the lower Yampa will continue to be provided by the Little Snake River. Also as indicated, the effect on the fishery is expected to be beneficial. Other examples include the outstanding trout fisheries on South Platte River below Cheeseman Dam (up to 800 lbs/acre standing crop) and the "Miracle Mile" of the North Platte River, below Seminoe Reservoir, even though these are in "degradaded" (in the hydrological sense) streams where sediment has been removed by reservoirs.

ECO, BB Q. 31. Describe the possibility of nitrogen supersaturation in project discharges and the potential for discharges drawn from lower reservoir levels where dissolved oxygen is low.

A. 31. Nitrogen supersaturation can be a problem, particularly with sensitive salmonid fishes in the Columbia River where a series of dams build up nitrogen and spillover during high flows (free fall of water over spillways) captures atmospheric nitrogen and plunges it into pools below dams. No comparable dam-dam-dam system without free flowing river between occurs on the Yampa River. Discussion with CDOW as to the occurence of nitrogen supersaturation problems in Colorado suggested that at certain times if the turbines were running at reduced capacity and air was jetted into them, the outflow below the dam would become supersaturated with nitrogen. Equalibrium levels would be reached 100-200 feet from the dam. No mortalities or stress on salmonid fishes were ever observed -- evidently they avoid the areas of supersaturation. No potential problem below Cross Mountain Dam is anticipated. Regarding oxygen, the environmental assessment report makes it clear that withdrawal will occur from the surface zone of the reservoirs (oxygen at saturation or above on sunny days from photosynthesis). Hypolimnion withdrawal would occur only after fall overturn and 0_2 saturation of the whole reservoir. The only possible problem from low 0_2 levels would be if considerable organic matter decomposed during the winter months in Cross Mountain Reservoir. As discussed above, this is not likely to occur to a point of serious oxygen depletion. If it could be a problem, the discharge could be changed back to a surface release.

SIGNS, WE Q. 32. Provide a list of all impoundments on the Yampa River above Juniper damsite, including all tributaries, the purpose(s) of these impoundments, and the possible interactions between these existing developments and the project. List all upstream waste discharges and all NPDES permits for development. Proposed water-related developments upstream should also be described.

R. MARR Q. 33. Would any plant species or special concern in the project and surrounding areas be affected by project construction or operation? If so, describe the potential impacts and mitigation measures. Plant species of special concern are those included on the Special Plant List of the Colorado Natural Heritage Inventory.

BB, MARR Q. 34. Assess the impacts of the project on the diversity, composition, and abundance of downstream riparian vegetation, including Dinosaur National Monument.

Ar nstrong	Q. 35. Estimate the wildlife losses that would result from the project due to habitat destruction or interrupted migration routes. Data available from the Colorado Division Wildlife should, in part, be utilized for this purpose.
A mstrong, BB	Q. 36. Describe the likely impacts on terrestrial wildlife from project-induced alteration of riparian habitat below Cross Mountain, including Dinosaur National Monument.
Ar nstrong, RD	Q. 37. Provide a detailed description of plans to mitigate for the loss of terrestrial wildlife habitat. The plans should be quantified and discussions should include the amount of private land, if any, to be included in the mitigation proposal.
Ar nstrong, RD	Q. 38. A detailed field survey for all cliff-nesting raptors, including the peregrine falcon and golden eagle, should be conducted during the early spring nesting season in Juniper and Cross Mountain Canyons and Dinosaur National Mounment. The results of this survey should be used to analyze the value of the potential loss of cliff nests due to inundation or detachment of rocks dur to project construction and operation.
C-U	Q. 39. Evaluate the probable impacts of the project on the bighorn sheep introduced on Cross Mountain, including the potential for stress-induced disease as reported in Waterton Canyon by the Colorado Division of Wildlife.

C-U Q. 40. Describe the impacts of the project on nearby greater sandhill crane staging and nesting areas (e.g. Big Bottom and Round Bottom).

C-U Q. 41. Describe the potential effects on wildlife from project-induced human encroachment (camping, hiking, recreational vehicle use, etc.) and home and business development on non-project lands adjacent to the proposed project.

Armstrong, RD Q. 42. How does this project and its proposed wildlife mitigation measures correspond with the Colorado Division of Wildlife's statewide management priorities for wildlife (e.g. planned wildlife population, numbers, harvest rates, and hunter days use)? Would hunting be allowed on project lands and waters? Would there be additional hunting opportunities at the project, such as for waterfowl, and, if so, who would manage and/or develop them?

E3, RD Q. 43. Provide a detailed description of existing aquatic vegetation and macro-invertebrates in the Yampa River at the project site, and how they would be changed by the project impoundments.

A. 43. Further references and substantial detail may be found at W 2.54-56 and W 3.26-27. While that data ~~is~~ are considered adequate, it may be added that Cummins (1974, 1980) discussed the functional aspects of the dynamic changes of life forms in a river from headwaters to large river environment -- the river continuum concept. When a dam is placed across a river, the continuum is disrupted, new life forms fill the reservoir and a new stage of the river continuum develops below the dam. Depending on the flow and temperature regime released from the reservoir the new condition can decrease or increase the abundance of invertebrates and fishes below the reservoir in comparison to preimpoundment conditions. In rivers, a considerable part of the organic matter (and food for invertebrates and fishes) may come from the terrestrial environment (allocthonous input). The processes the functional aspects of converting inorganic nutrients into living organisms and the movement of energy through various trophic levels into fishes is basically the same in rivers and in lakes, but the species filling niches at various trophic levels differ.

A. 43. Cont.

As has been noted, the primary producers in running water in streams with boulder, rubble substrate, are diatoms. Diatoms encrust rocks and produce a "slimy" texture to the substrate. Green algae, typically the genera Cladophora and Ulothrix are common in Colorado rivers, particularly in pools and at low flow when current velocities are low. They form filamentous mats that may reach considerable proportions. Carlson, et. al. (1979), notes that channel catfish in the Yampa River had mainly Cladophora in their stomachs. If nutrients could be extracted from Cladophora by catfish, this would be a most efficient feeding strategy, utilizing primary production directly without transferring the energy through invertebrate animals with subsequent loss to the ecosystem. It is doubtful, however, that the catfish derive much nutrition from the algae they consume. Only fishes with specialized teeth to break down the cellulose walls of plants can obtain nutrients from a plant diet. Catfish lack such teeth. Catfish digest the microorganisms that live in the green algae and actually obtain their nutrition from the animal and bacterial life associated with the algae. Other aquatic plants are relatively rare in the Yampa River. Elodea has been seen in quiet spring seep areas.

In a reservoir, the main primary producers will be unicellular algae (diatoms are unicellular algae), collectively called phytoplankton. Due to draw-downs (up to 65 feet) in Juniper Reservoir, macrophyte vegetation is expected to be very limited. From a fishery point of view, the great predominance of phytoplankton as the primary producers over macrophyte vegetation is desirable and fisheries management activities try to foster the favoring of phytoplankton over macrophytes. This is because the energy in phytoplankton is quickly passed on to zooplankton and fishes, whereas, macrophyte energy storage is a dead-end, until they decay and release nutrients, unless some animal consumes the living macrophyte. Virtually no fish or invertebrate feeds directly on living aquatic macrophytes except the grass carp. Filamentous green algae in reservoirs is typically of the genus Spirogyra. The earlier warming of spring flows, the reduction of peak scouring flows, which dislodge diatoms and green algae, and the higher base flows below Cross Mountain Dam will improve the physical environment for primary production in the lower Yampa River. If nitrate and phosphate levels are not seriously depleted in the reservoirs, the Juniper-Cross Mountain Project should result in increased primary production in the lower Yampa River.

In rivers, the great majority of invertebrate animals (the primary and secondary consumer trophic levels) are larvae of aquatic insects. Crustaceans are typically limited to quiet areas of a stream. Accordingy to the river continuum concept, the headwater areas are largely shaded by trees. Thus sunlight and primary production is limited. Leaf fall from trees into the water are coated with decomposi~~ng~~tion bacteria which provide a source of nutrition for insects that feed by shredding leaves, the debris, or particulate organic matter created by the feeding of the "shredder" group of insects creates a food source for insects that specialize in collecting organic particles (such as net spinning caddis larvae). Thus, headwater areas are typically dominated by species of insects that can be characterized by their feeding -- "shredders" and "collectors". Downstream as the river widens, sunlight and nutrient enrichment stimulate increased

A. 43 Cont.
primary production and a group of insect species that are specialized to graze or scrape the epilithic diatoms as a food source becomes important. Also with increased abundance and biomass of all insects, predatory insects (those feeding on other insects) increase. Fishes feed on all of these groups of insects.

In a reservoir, the major shift in the primary consumer trophic level is that of crustaceans replacing insects as the major converters of plant life into animal life. From comparable situations, it is very predictable that the primary zooplankton that would inhabit Juniper and Cross Mountain reservoirs are species of Cladocera (water fleas) and Copepods.

Insects would be represented mainly by chironomids (midge larvae) in the benthic zone and by free-swimming Coleoptera (beetles) and Hemiptera (water boatmen, backswimmers).

Crawfish have never been found to our knowedge in the Yampa River (they are very abundant in the Colorado River near Grand Junction where they provide an abundant food supply for channel catfish). Crawfish might be stocked into Juniper and Cross Mountain reservoirs. They are excellent food for game fish and convert energy from low trophic levels (living and dead plants, some animals) directly into fish.

Post impoundment downstream effects below Cross Mountain Dam on invertebrates would be largely beneficial. Many examples and discussions on invertebrate changes below dams are given in Ward and Stanford (1979) and personal information from Henry Zimmerman, C.S.U. graduate student currently conducting research invertebrate production above and below 36 Colorado reservoirs (Appendix A), lead to the following conclusions regarding post impoundment conditions for invertebrates in the lower Yampa. Flow changes that reduce peak scouring flow and elevate late season base flow, as would the Juniper-Cross Mountain Project, will act to increase total abundance and biomass of insects below a dam, even with daily fluctuations in flow from peaking power production (see Ward and Sanford 1979, and Holden and Crist 1980). This is largely due to beneficial changes in the physical habitat (reduced scouring, reduced sediment, more uniform flows and temperatures and more submerged habitat during low flow times of the year). A great increase in particulate organic matter (mainly phytoplankton) would be expected below the surface releases from Cross Mountain Dam and this would favor increased abundance of the collector group of insects (simulids and Hydropsyche).

BB, RD Q. 44. Describe the impacts on aquatic organisms due to project-induced flow fluctuations and temperature changes in the Green River downstream of its confluence with the Yampa, to Jensen, Utah, considering both reinforcing and cancelling effects of the Flaming Gorge Project.

A. 44. For our previous general discussion of this question see Ex. W at pp. W 3.17, 31-32 and Ex. S., p. 11. In addition, sections in Ward and Stanford (1979) reveal increased abundance and biomass of invertebrates below dams even with daily fluctuations. Ward and Stanford speculated that the positive

A. 44. Cont.
aspects of the long term stable flow and temperature regime overrides the negative impact of short term fluctuation.

Of interest in this regard is the work of Holden and Crist (1979, 1980) on the invertebrate fauna in the Green River downstream from Flaming Gorge Dam (which fluctuates flow at a much greater absolute magnitude and at a much greater relative rate of change than the flow currently proposed for Cross Mountain Dam).

Invertebrate sampling stations were set up at Little Hole (7 miles below Flaming Gorge Dam), Taylor Flats (16.5 miles below dam), Wade Curtis campground (49 miles below dam) and at Jensen, Utah (94 miles below dam and below mouth of Yampa). Invertebrates were also sampled at Lily Park and Box Elder in the Yampa River. Five samplings were made in 1978 and four samplings in 1979.

The following table summarizes the average number of invertebrates sampled per sampling period:

Location	Miles Below Flaming Gorge Dam	1978	1979
Green River			
Little Hole	7	20,000	25,000
Taylor Flats	16.5	11,000	29,000
Wade Curtis	49	7,500	3,500
Jensen	94	5,000	5,000
Yampa River			
Lilly		3,000	about 3,000
Boy Elder		2,000	less than 3,000

Sufficient detail is not given in the publications to discuss adequately the reasons for these differences, but one point is very obvious, and that is the clear indication that invertebrate abundance greatly increases in an upstream direction toward Flaming Gorge Dam. That is, the sites with greatest abundance are the sites exposed to the greatest flow fluctuation -- but also they are influenced by more stable water temperatures and probably higher nutrient level and organic particles originating in Flaming Gorge Reservoir. The sites in the Green River exposed to fluctuations greatly exceeding the proposed fluctuations from Cross Mountain Dam have a considerably greater abundance of invertebrates than found in the lower Yampa River sites.

A list of invertebrates is given in the environmental assessment report, taken from Carlson, et. al. (1979).

The Yampa River contributes about one third and the Green River two thirds of the total flow at their confluence. Diurnal fluctuations in the Yampa would be less than the fluctuations induced by Flaming Gorge Dam. Even if the peak high flow from the Yampa happened to coincide and reinforce peak high flows from Flaming Gorge, the maximum fluctuation at Jensen (for perhaps one or two ~~days~~ brief period a year) would be less than the everyday fluctuations at Little Hole and Taylor Flats where the greatest abundance of invertebrates are found.

BB, RD Q. ㊺ Describe the proposed reservoir fishery management plan. If the reserviors are to be stocked, provide species, stocking rates, expected forage base, annual cost, and management agency. If stocking is not planned, indicated species expected to populate the reserviors, potential for reproduction of each, and effects of projected water level fluctuations on each.

A. 45. Before discussing the potential reservoir fishery (introduced game fishes), the impact on the fishes presently inhabiting the Yampa River will be reviewed (endangered species are covered in a separate section).

From the above discussions regarding Project impacts predicted to increase primary production and invertebrate production because of changes in flow regime (reduced peak scouring flow, increased base flow) and temperature regime (earlier warming, more stable temperatures, higher winter temperatures) can only lead to the conclusion that fish production will also increase because they are the general trophic end points in the ecosystem and benefits accrued at lower trophic levels will be passed on to higher trophic levels.

If no fish are stocked into the reservoirs there will be a largely underutilized niche -- that of a pelagic zooplankton feeder. Fathead minnows, redside shiner, and to a lesser extent, speckled dace will occupy littoral areas around the reservoir. The creek chub, of rare occurence, may greatly increase its abundance in the reservoir without predation pressure. The native roundtail chub will probably greatly increase in abundance initially, utilizing both littoral and pelagic areas and consuming both insects and zooplankton (although its gillrakers are not well adapted to strain small zooplankton). Carp will flourish in the relatively few shallow bays, but because these areas are limited by reservoir morphometry and drawdown (and drawdown will likley effectively suppress carp reproduction in the reservoir), the carp will be only locally abundant, but at low overall abundance in consideration of reservoir volume. As in Flaming Gorge Reservoir, the native Flannelmouth sucker may be expected to maintain itself, and the bluehead sucker will likely be of rare occurence in the reservoirs. The sucker fauna will be dominated by the white sucker. The longnose sucker which now only occurs in the UpperYampa drainage (Trout Creek) will likely become established in the reservoirs and become abundant. When living together in a lake, the main foods of white and longnose suckers are zooplankton (mainly Cladocers) and chironomid larvae, but the longnose sucker is more of a zooplankton feeding specialists while the white sucker tends to prey more chironomids (Barton and Bidgood 1980). Particularly if longnose suckers and creek chub become abundant in the reservoirs along with the white sucker, they would create considerable competition with stocked hatchery trout.

Without stocking, some rainbow and brown trout (and whitefish) will migrate into the reservoir and attain a large size but they will be relatively scarce and seldom taken by anglers.

The channel catfish will increase in abundance and growth rate in the reservoir in comparison to present river conditions but will not attain a high abundance because it will be restricted to the warmer epilimnion zone and have a limited growing season.

A. 45. Cont.

Without any management, Juniper and Cross Mountain reservoirs would not be highly attractive to most anglers, but the occasional catches of trout and channel catfish would be much greater than the present catch of fish is in the river sections of the reservoir sites (essentially nil).

The direction that fisheries management should take to convert the reservoirs into productive and attractive sport fisheries would be to introduce predators to utilize the littoral forage (such as redside shiners) and the pelagic forage (suckers, roundtail chub) and a species to utilize pelagic zooplankton (forage species such as alewives or game species such as kokanee salmon). Seminoe Reservoir, Wyoming, has developed an excellent fishery for walleyes (prey mainly on suckers) and trout (feed on insects and zooplankton with some predation on forage fishes). Seminoe Reservoir provides 1.4% of the total fishing pressure for the state of Wyoming (La Bounty, et. al. 1976).

These matters are then presented in some detail at W 3.27-29 and on p. 12 of Exhibit S. While we continue of the strong belief that the fisheries management of the reservoirs is clearly the perogative of the state, as mentioned above, we would suggest the goal to be to create a "two story" fishery by introducing game fish species to fill underutilized niches. Largemouth and smallmouth bass (particularly smallmouth) would be stocked to utilize littoral and sublittoral forage. Wild strains (to better compete with nongame fishes) of brown, rainbow (such as Lake McConaughy rainbow) and cutthroat trout (Snake River cutthroat) would be stocked to compare growth and survival. Two or more species of trout stocked would also increase trout production by the phenomenon of ecological segregation (Troj~~an~~nar & Behnke 1974). If the trout make effective use of the zooplankton, the stocking of kokanee salmon, which are better adapted than trout to capture zooplankton, should be delayed. If trout do not survive and grow as expected due to severe competition from suckers, introducing walleye as a predation on suckers could be considered as could the introduction of a pelagic plankton ~~for~~ feeding forage fish (probably alewives). Trout stocking costs would be minimized by stocking fingerling fish. Essentially unlimited fishing pressure can be generated by heavy stocking of catchable-size trout (3000 hrs. per acre angling pressure in some Colorado waters), but the option is too expensive for large reservoirs.

Kokanee salmon are successful in fluctuating reservoirs, such as Dillon Reservoir which may fluctuate by more than 100 feet. The present decline in the kokanee fishery in Dillon, and the virtual lack of survival of stocked fingerling rainbow trout, is not due to the fluctuations of the reservoir, but due to the introduction of the opposum shrimp (Mysis relicta) by the Colorado Division of Wildlife in the belief (which appears mistaken) that Mysis would increase the food supply to trout. Mysis has virtually eliminated the zooplankton from Dillon Reservoir and its behavior of setting on the bottom of the deepest parts of the reservoir during the day, effectively removes it from being preyed on by trout.

Thus, after evaluating the results of the first few years of trout stocking, the probable consequences of stocking kokanee salmon should be considered. Rather than introduce Mysis, crawfish should be introduced.

BB, RD Q. 46. Describe the methodology, data and references used to estimate the numbers of angler days at the proposed project.

A. 46. It was there estimated ang~~u~~lar use at about 40 hrs per surface acre per year. This is a realistic estimate if quality fisheries management and stocking are applied. Each pound of fish caught in Colorado typically generates about two or three hours of angling use. Thus a catch of 20 pounds per acre would be expected to generate 40 to 60 hours per acre of angling pressure. It is obvious that there is a direct connection between angler use and catch which, in turn, depends on the production of the target species sought by anglers.

Ryder (1974) re~~ceived~~viewed the application of his morphoedaphic index to predict fish production (total dissolved solids [ppm of TDS] divided by average lake depth). Jenkins (1977) evaluated data from 166 reservoirs more than 500 acres in area. He broke the data down to consider hydropower separately from nonhydropower reservoirs and in relation to retention time of the reservoir and water chemistry types.

Dr. William McConnell, Colorado Cooperative Fishery Unit, has developed a model predicting habitat quality and fish species occurrence in planned reservoirs for the USFWS Western Energy and Land Use Team.

It is believed premature to devote further effort now to the construction of a reservoir model for fisheries until it is decided what fish species may be stocked (for example, should striped bass be stocked to eat the suckers?). In any event, there can be no doubt that the future reservoir fisheries, no matter how poor, will generate enormously greater angler use than the present river fishery, and a good fishery (yielding 40-50 pounds per acre) will generate much more use than the estimated 40 hrs./acre given in the assessment report.

Mullan (1976) presented data on angler use of 6 reservoirs along U.S. 40 in Utah. Juniper and Cross Mountain reservoirs would be near U.S. 40 and the distances from population centers (Salt Lake City and Denver) are comparable. These Utah Reservoirs (Strawberry, Starvation, Sandwash, Steinaker, Midview, and Bottle Hollow) generated from 37 to 153 hrs/acre/year angling pressure over several years. The catch ranged from about 1/4 to about 1 pound per hour of angling or averaging out at 2-3 hours of angling for each pound.

B, RD Q. 47. Describe the existing game fishery from the project area downstream to Dinosaur National Monument.

A. 47. There is only one site, at the mouth of Cross Mountain Canyon, that receives detectable fishing pressure at present. Over the course of 4 or 5 visits to this site no fishermen have been seen, but remnants of tackle, remains of cleaned fish, etc. have been noted. The fishery here is for channel catfish but the size-age structure of catfish sampled here is indicative of light exploitation (light fishing pressure). It is no more (and probably much less) than 100 person days of angling per year. The lack of angling pressure on the Yampa River is evident from the results of

A. 47. Cont.
angling in the pool at Lily Park about one mile downstream from Cross Mountain Caynon. Here, at a site where a vehicle can be driven to the edge of the river, Mr. Ed Wick and his assistants of the Colorado Division of Wildlife's Endangered Species Monotoring Team, have taken several large squawfish and northern pike of 5 to 9 pounds on artifical lures. It is obvious that this site is not used by anglers or such specimens would not be so readily available to the lure.

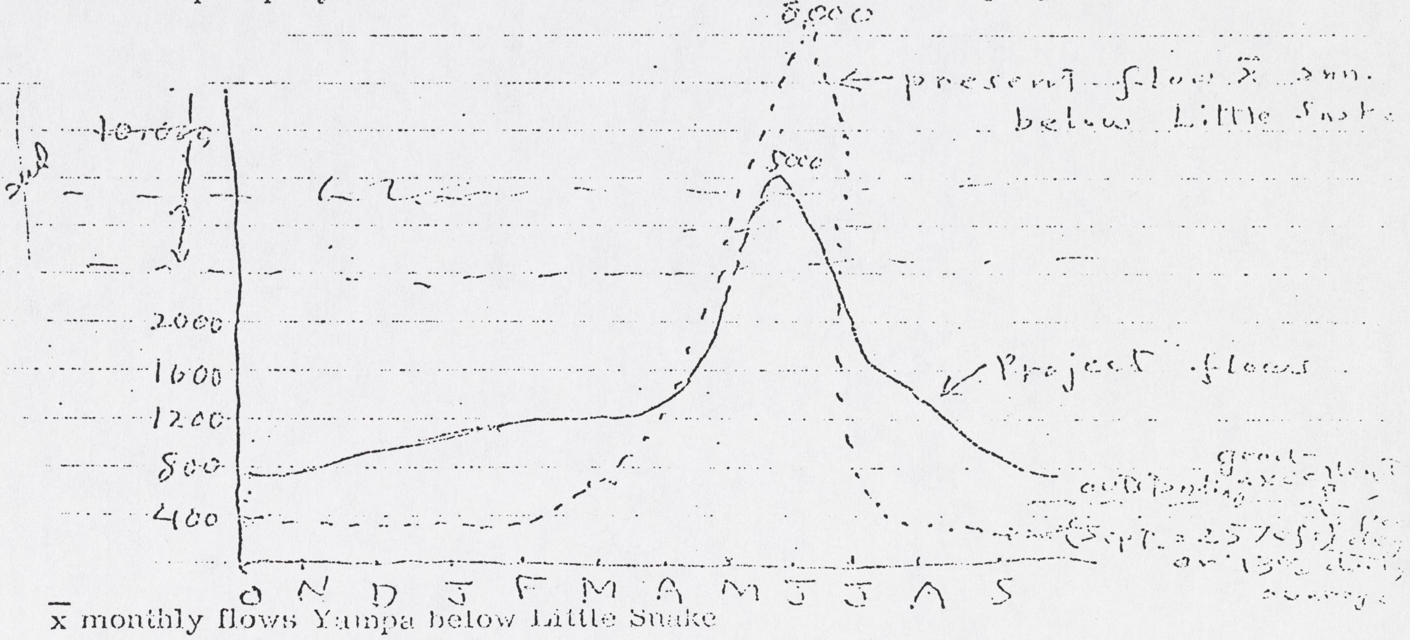
BB, RD Q. 48. Submit the methodology and supporting data for the statement (page ~~W3~~-17, Exhibit W) that proposed project flows are designated to maintain aquatic life.

A. 48. As the material in Exhibit W notes the flow conditions are to maintain recreational uses as well.

The methodology attempts to utilize that developed by Mr. Tennant of FWS (1976). He, in researching flows in relation to fish, developed a simple set of rules based on years of experience and study. "Optimum" flows (best for fish and invertebrate) are in the range of 60 to 100% of the average daily flow. "Outstanding" flows average 40% of the average daily flow from October to March and 60% from April to September. "Excellent" flows are 30% and 50% of average daily flows for these respective time periods, "Good" flows are 20% and 40% respectively, "Fair or degrading" flows , 10% and 30%, "poor or minimum" flows are 10% of the average daily flow, and less than 10% of the long term average daily flow is "severe degradation" according to Tennant (1976).

The significant information with respect to flows is included in Exhibit W. Basically, the rationale that project flows are an improvement for aquatic life over pre-project flows can be observed on the following figure.

Rolly - have this drawn and cleaned up



x̄ monthly flows Yampa below Little Snake

Average daily flow (23 yr. average) = 1986 cfs (round off to 2000 cfs), thus 60% = 1200 cfs, 40% = 800 cfs, 30% = 600 cfs, 10% = 200 cfs

A. 48. Cont.

Thus, as can be noted (see also Appendixes B and C) the present flow for most of the year falls in the poor or degrading range of flow in relation to aquatic life values. Post impoundment flows change these values into the excellent, outstanding and optimum range. Also, the great short term (week to week) and long term (year to year) fluctuations will be considerably dampened. These changes in the flow regime from dams that store peak runoff (reduce scouring flow) and release the stored flow later in the year (increase the late summer base flow from poor or degrading to excellent or outstanding) are the basic reasons for increased production of invertebrates and fishes in the many examples cited previously. Nehring (1979) compared the Tennant method of evaluating the effects of flow on fisheries with the USFWS "Instream Flow" method (the method currently being used to predict flows needed for squawfish in FWS study). Nehring evaluated the predictive success of the two methods by comparing actual biomass of trout in a stream with flow data. He found that in general the Instream Flow and the Tennant methods were in agreement. For instances where there was disagreement there was no conclusive evidence that the Instream Flow Method had superior predictive capabilities.

Prewitt and Carlson (1980) related flows at two areas of the Yampa River (Maybell and Lily Park) to factors enhancing squawfish habitat. The FWS Instream Flow computer complete model predicted that when flows are increased to the 1200 to 1500 cfs range, the environmental changes will begin to favor the squawfish over the channel catfish. This is precisely what the Cross Mountain flows would do -- replace catfish habitat with squawfish habitat if Prewitts and Carlson's conclusions are correct.

Wesche and Richard (1980) reviewed the various methods used to predict flows favorable to fishes. It should be clear that all methods have a considerable element of uncertainty. Comments found in Smith (1979) point to some serious logical flaws inherent in Instream Flow methods as an accurate predictor of the response of fishes to changes in flow. Orth (1980) could find no correlation between Instream Flow predictions and smallmouth bass abundance in an Oklahoma river.

The FWS Instream Flow model has been improved by the addition of more data input and probably offers the best approach for the ultimate determination of favorable endangered species flows. However, substantial experimentation is probably to be expected together with the evaluation of results over several years before the most optimum flow regime for endangered species can be established for any river section.

As mentioned, the peaking power fluctuations from Cross Mountain Dam are of a much reduced rate of change and of much less absolute magnitude than typical peaking power operations. The proposed Cross Mountain flow change would increase from 500 cfs to 3000 cfs over a 2.5 hour period. If no flow was coming from the Little Snake River (and no spill at Cross Mountain Dam) this translates into a rate of change between 750 cfs to 2000 cfs over a twelve hour period at the mouth of the Yampa in Echo Park, about 50 miles downstream, according to the assessment report. The attached figure (Appendix C) is based on data

A. 48. Cont.
from table 2.2-8 of the Exhibit W assessment report comparing stage flows relationships at three flows at three points in the lower Yampa. The data can not be precisely used to predict the stage flow changes from a change of flows from 750 cfs to 2000 cfs because of insufficient data points, and each river section would respond differently in relation to channel and bank morphology. In any event, comparable flows from Flaming Gorge Dam vary from 800 to 4100 cfs at Lodore Canyon, about 50 miles below Flaming Gorge. Thus, the magnitude of daily fluctuation impact is about 2 fold greater in the Green River 50 miles from the dam than would the Cross Mountain impact on the Yampa at the same distance.

It will be important to learn what WPRS plans to do regarding future operation at Flaming Gorge Dam and their degree of willingness to modify the operation of the dam in relation to endangered species. An adequate assessment and prediction of the impact of the Juniper-Cross Mountain Project on endangered species requires assessment of Flaming Gorge impact (Flaming Gorge Dam releases average about twice the annual flow that originates from the Yampa -- therefore Flaming Gorge flows are twice as significant in relation to creating more favorable conditions for endangered species in the Green River).

Holden and Crist (1979, 1980) reported capturing 16 young-of-the-year squawfish from the Green River at Jensen, Utah, in 1978 and 8 in 1979 (where daily fluctuation is 16 inches). Comparison with the abundance of young squawfish found in Vanicek's early postimpoundment study where daily fluctuations at Jensen were only about 4 inches, would indicate that the 16 inch fluctuation inhibits but does not block successful reproduction. What are the exact habitat conditions at Jensen that allow successful reproduction and survival of young with a 16 inch daily fluctuation? Can these conditions be created in other areas subjected to large fluctuations to increase squawfish reproductive success? What range between 4 and 16 inches is least inhibiting to reproduction? These are the basic, essential questions on which information is needed to allow endangered species to be maintained and with increased abundance in coexistence with water development. A cooperative agreement concerning the operations of Flaming Gorge Dam and the Juniper-Cross Mountain Project has the potential to create optimum spawning and rearing conditions for endangered species in the Green River below the mouth of the Yampa if these conditions can be quantified, attention focused on the truly significant issues, and agreement to cooperate obtained from WPRS. The Juniper-Cross Mountain Project flows can not do the job alone.

WE Q. 49. Describe the agricultural lands that would be inundated by the project, their combined area, present use, and crop value.

WE Q. 50. Assess the impact of fencing on the current use of the river as a water source by livestock and wildlife.

C-U Q. 51. Assess the impacts and potential mitigation measures associated with wildlife and livestock drowning in the unstable winter ice on the project reservoirs.

C-U Q. 52. How would mitigation for loss of big-game winter range inter[illegible] with grazing? Would wildlife mitigation require displacement of present livestock activities?

BROWN Q. 53. What is the present contribution of recreation activities (hunting, rafting, etc.) to the local economy on the project area?

EDAW Q. 54. Revise the recreation demand projections for the project based upon the 1981 Colorado State Comprehensive Outdoor Recreation Plan (SCORP).

IFCO, C-U Q. 55. Provide a specific schedule of reservoir drawdown and downstream flows on a diurnal and monthly basis, considering biotic and recreational requirements.

KB, RD Q. 56. How would compensation for lands required for the project be determined. Would it be based on agricultural or developed land values? Would only inundated acres be purchased?

KP, C-U, RD Q. 57. What measures would be taken to mitigate the loss of tax revenues from private lands that would be incorporated in the project? Would the Applicants make payment in lieu of taxes?

WE, Brown, RD Q. 58. How would agricultural land values be affected by the project? What is the economic contribution of these lands to the local economy?

RD Q. 59. Where would construction workers come from if the construction schedule is delayed so that the Juniper-Cross Mountain Project could not draw workers from other projects in the area, as planned?

RD Q. 60. What would a delayed construction schedule mean in terms of labor force, immigration, impacts on housing, services and infrastructure, employment, local economy, and local government revenues and expenditures?

RD Q. 61. Indicate the number, type, origin/destination, and routes to be used by construction worker vehicles and trucks used to deliver materials. Define hours/day and days/week when construction activities would occur.

WE Q. 62. Provide copies of the following maps at a large scale: (a) land ownership (with property lines) of inundated lands, and (b) specific reservoir levels (highest, lowest, normal).

Jennings Q. 63. Provide: (1) the final report that has been completed on archeological investigations conducted for the project in 1980, and (2) the comments of the Colorado State Historic Preservation Officer (SHPO) and Interagency Archeological Services (Denver office) (IAS), U.S. Department of the Interior, on the content of the report.

Jennings Q. 64. Provide a report on 1981 archeological investigations for completing identification of eligible properties for the National Register of Historic Places, and an assessment of impacts to these sites. The report should contain the following:

(a) information about how archeological surveys, subsurface testing, and other procedures, if any, were conducted to inventory sites;

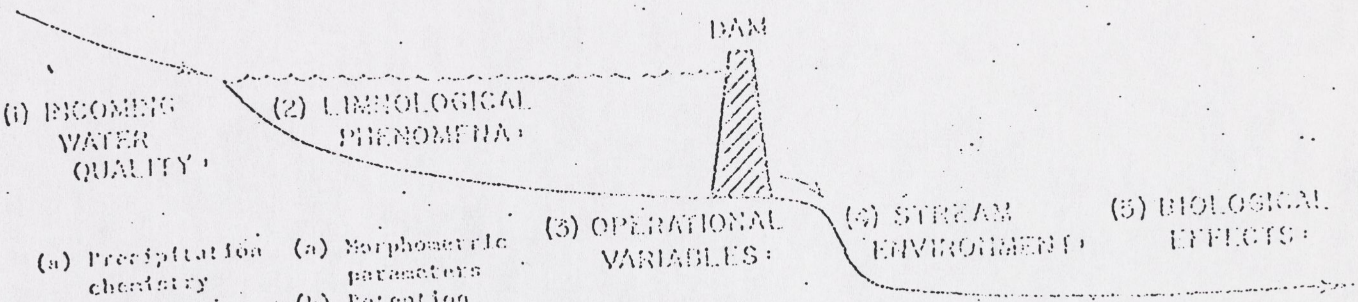
(b) data to support recommendations concerning eligibilty of sites for the National Register, including site survey forms;

(c) an assessment of the nature of impacts on inventoried sites;

(d) a detailed management plan for avoiding or mitigating impacts to eligible properties for the National Register;

(e) an overview of known archeological and historic resources in the vicinity of the major alternative development sites, and the potential for discovering and affecting eligible properties at these locations; and

(f) evidence of consultation with the SHPO and the IAS about the scope and design of these investigations and the format of the report; the report should also be filed with the SHPO and the IAS with a request to forward comments to the Commission.



(a) Precipitation chemistry
(b) Basin geochemistry
(c) Terrestrial vegetation
(d) Climatic conditions
(e) Anthropogenic impacts

(a) Morphometric parameters
(b) Retention time
(c) Impoundment age
(d) Turbidity currents
(e) Drawdown extent
(f) Thermal stratification
(g) Chemical stratification
(h) Edaphic factors
(i) Biological activities

(a) Discharge pattern
(b) Release depth

(a) Thermal regime
(b) Flow regime
(c) Nutrient levels
(d) Substrate type
(e) Water clarity
(f) Lentic plankton
(g) Dissolved salts
(h) Dissolved gases
(i) Organic detritus

(a) Riparian vegetation
(b) Aquatic vegetation
(c) Ecological diversity
(d) Biotic productivity
(e) Migratory movements
(f) Species composition
(g) Life-cycle phenomena
(h) Trophic structure

Figure 1. Major factors and phenomena influencing the stream environment below dams and resultant effects on stream biota.

Appendix A. From Zimmerman, H. (C.S.U. grad. student, conducting research on invertebrate production above and below 36 Colorado reservoirs).

Table 4. Frequency of occurrence (number of sites present/number of sites sampled) and abundance (+ = 1-10/m², ++ = 11-100/m², +++ = 101-1000/m², ++++ = >1000/m²) of each taxon, for all drainage basins combined.

Taxon	Upstream		Downstream	
	Frequency	Abundance	Frequency	Abundance
Plecoptera				
Alloperla (s.l.) spp.	.92	++	.31	+++
Claassenia sabulosa	.25	++	.00	--
Isogenoides elongatus	.25	+	.08	++
Isoperla quinquepunctata	.17	++	.15	++
Perlesta placida	.25	+	.00	--
Pteronarcella badia	.42	++	.00	--
Zapada oregonensis	.08	++	.00	--
Ephemeroptera				
Baetis bicaudatus	.74	+++	.62	+++
Baetis insignificans	.17	++	.00	--
Baetis tricaudatus	.58	+++	.23	+++
Cinygmula sp.	.50	++	.00	--
Drunella doddsi	.25	+	.00	--
Drunella grandis	.08	++	.00	--
Drunella coloradensis	.08	++	.00	--
Epeorus alberta	.08	+	.00	--
Epeorus deceptivus	.50	++	.08	+
Epeorus longimanus	.33	++	.00	--
Ephemerella inermis	.25	++	.31	++
Ephemerella infrequens	.08	+++	.08	++
Ephemerella tibialis	.17	++	.00	--
Heptagenia sp.	.17	++	.00	--
Paraleptophlebia packi	.00	--	.08	++
Paraleptophlebia sp. A	.42	++	.23	++
Rhithrogena hageni	.75	++	.00	--
Timpanoga hecuba	.08	+	.08	+
Tricorythodes minutus	.17	++	.15	+++
Odonata				
Ophiogomphus sp.	.00	--	.08	++
Trichoptera				
Agapetus sp.	.17	++	.08	++
Agraylea sp.	.08	++	.00	--
Anagapetus sp.	.08	+	.00	--
Arctopsyche grandis	.50	++	.08	+
Brachycentrus sp.	.75	++	.08	++
Cheumatopsyche sp.	.17	++	.15	+
Glossosoma sp.	.25	+	.00	--
Hesperophylax sp.	.17	++	.00	--
Hydropsyche sp.	.33	++	.31	+++
Hydroptila sp.	.08	++	.08	+++
Lepidostoma sp.	.08	+++	.00	--
Rhyacophila sp.	.50	++	.00	--
Wormaldia sp.	.25	++	.00	--

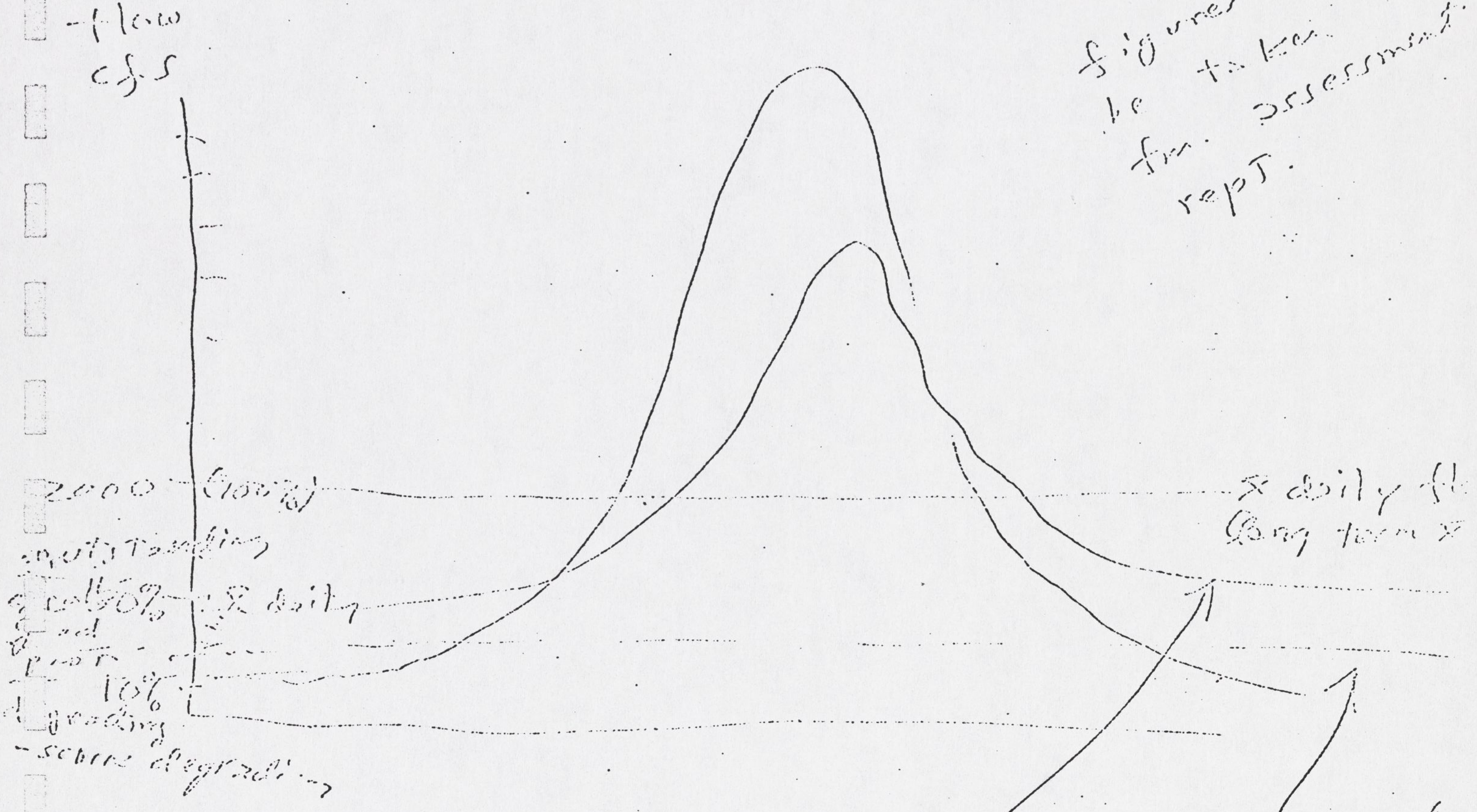
Taxon	Upstream Frequency	Upstream Abundance	Downstream Frequency	Downstream Abundance
Coleoptera				
Agabus sp.	.08	++	.08	++
Heterlimnius corpulentus	.75	++	.31	+++
Optioservus sp.	.17	++	.23	++
Zaitzevia parvula	.25	++	.15	++
Diptera				
Atherix pachypus	.17	++	.31	++
Chelifera sp.	.08	+	.00	--
Dicranota sp.	.17	+	.08	++
Euparyphus sp.	.00	--	.08	++
Hemerodromia sp.	.17	+	.00	--
Hexatoma sp.	.75	++	.15	++
Hydrella sp.	.08	+	.00	--
Limnophora sp.	.08	+	.08	+
Pericoma sp.	.08	+	.00	--
Probezzia sp.	.17	+	.00	--
Psychoda sp.	.00	--	.08	+
Simulium sp.	.83	+++	.69	++++
Tipula sp.	.17	+	.00	--
Cardiocladius sp.	.17	+++	.23	++
Cricotopus sp.	.67	+++	.85	+++
Diamesia sp.	.25	+++	.31	+++
Eukiefferiella sp.	1.00	+++	.85	+++
Heterotrissocladius sp.	.00	--	.08	+
Orthocladius sp.	.67	+++	.70	+++
Polypedilum fallax	.08	+++	.31	++
Procladius sp.	.42	++	.38	+++
Pseudodiamesa sp.	.17	+++	.15	++
Rheotanytarsus sp.	.50	++	.23	++
Thienemanniella sp.	.08	++	.00	--
Amphipoda				
Crangonyx sp.	.00	--	.08	+
Gammarus lacustris	.00	--	.15	+++
Hyallela azteca	.00	--	.15	++
Miscellaneous				
Polycelis coronata	.25	++	.15	++
Eiseniella tetraedra	.08	+	.15	++
Limnodrilus hoffmeisteri	.00	--	.15	++
Nais sp.	.00	--	.15	++++
Tubifex tubifex	.08	+++	.08	+++
Helobdella stagnalis	.00	--	.08	++
Lymnaea sp.	.00	--	.08	++
Sperchon sp.	.08	+	.00	--

APPENDIX B

fig.
pg. 31

— what we want to show is that by USFWS own standards — Juniper-Crane post impoundment flows are better than pre impoundment — re. aquatic life, fishes, etc.

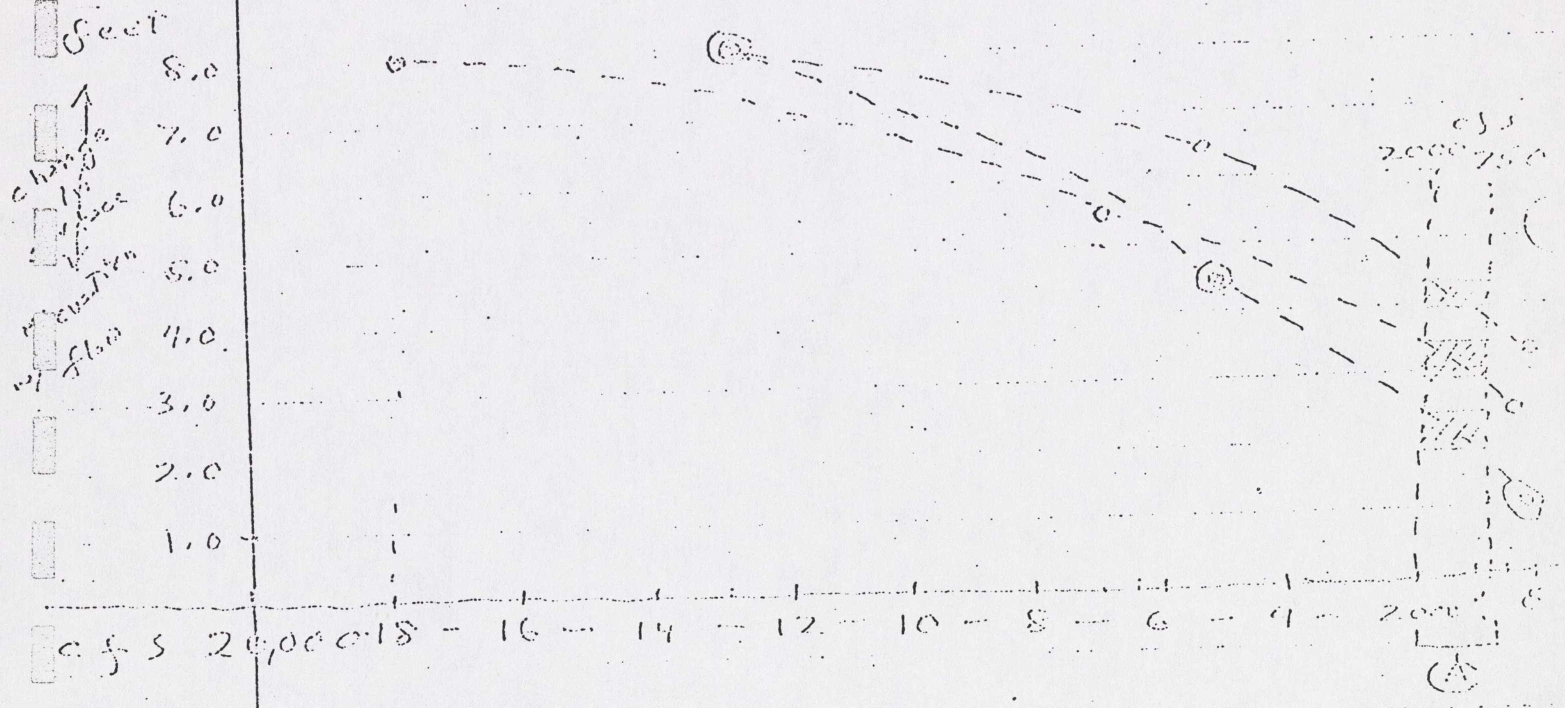
— data & figures can be taken fr. assessment rept.



pre impoundm. most of year in poor — degraded range

post impoundment — : moves flows up into good — excellent, —

[illegible]



Three stage flow relationships, Yampa R. below Cross Mtn. Canyon. (From table 2.2.-8 of Assessment Rep.).

(A) Daily fluctuations of 750-2000 cfs over 12 hr. period at mouth of Yampa due lowest flow periods when Cross Mtn. Da. releases change from 500 cfs to 2000 cfs on

For your review
It contains your changes
that I received 4/23/83

Draft
4/25/83

hydrographic data
are taken
Sects 3 [illegible]
[illegible] 19 [illegible]
[illegible] [illegible] [illegible]
1982 [illegible] [illegible] sampling
— new [illegible] [illegible]
most [illegible] [illegible]
— [illegible] [illegible] [illegible]
14-15 [illegible]

ASSESSMENT OF THE IMPACT OF THE GCC DIVERSION/INTAKE SYSTEM ON THE AQUATIC ENVIRONMENT OF THE COLORADO RIVER

Prepared for
GCC JOINT VENTURE

By
NUS CORPORTION

Denver, Colorado

April 25, 1983

Project 4724

Richard S. Nugent
Project Manager

Behnke
EXHIBIT
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1.0 INTRODUCTION

This report contains an assessment of the potential impact of the proposed GCC diversion/intake system on the aquatic environments of the Colorado River in the vicinity of the site. Particular emphasis has been placed on examination of the possible effects on threatened and endangered species. The impacts on other biota and on certain physical and chemical parameters are also discussed.

The aspects of the proposed project that could affect the aquatic environment may be divided into those resulting from construction activities and those resulting from the operation of the intake. The construction impacts are generally short-term and, except for the small area of river bottom upon which the structures will be built, will cease after construction on the facility is completed. For this assessment, the area of impact for potential construction effects is defined as extending from the site itself downstream about one mile. This determination is based on the assumption that the only impact of construction outside the site might be some short-term increases in turbidity during construction and removal of the cofferdam needed to build certain facility structures in the river. These impacts are discussed in detail below.

The operational effects produced by the intake will be present for the life of the facility. The area of impact in this case may extend from the intake itself downstream to about State Line, a distance of approximately 75 river miles. The potential for downstream effects are related primarily to the reduction in river flow resulting from water withdrawal by the facility. These potential effects are also assessed in the following sections.

2.0 PHYSICAL-CHEMICAL ASPECTS

The construction of the GCC diversion/intake system will result in some short-term increases in turbidity due primarily to the emplacement and removal of the cofferdam. These effects are not expected to have serious impact on river water quality. All construction activities will be carried out using appropriate precautions to prevent suspended solids from entering the river from surface runoff from disturbed areas or from other sources. Proper engineering practice and appropriate precautions will be used to prevent any spills and/or leakage of solvents and petroleum products from reaching the river. Solid waste materials will also be disposed of in an acceptable manner.

442.25

The operation of the intake will affect the abiotic component of the river principally through flow reduction. The maximum diversion possible by GCC under their water rights will range from 380 cfs (23,365 acre-ft) in August to 442 cfs (27,190 acre-ft) in May. The percentage of the flow at DeBeque that will be theoretically withdrawn ranges from about 5% in June to a maximum of about 32% in February. The maximum average total annual diversion ~~will~~ would be 303,988 acre-ft or about 14.5% of the flow at DeBeque. This level of flow reduction will affect the 40-mile reach of the river downstream of the site to the point where the Gunnison River discharges into the Colorado at about RM 171. ① The flow of the Gunnison approximates that of the Colorado during most months. On an annual basis, the Gunnison contributes about 44% of the flow of the Colorado River as measured at State Line. Consequently, the percentage depletion caused by the GCC withdrawals is reduced by about half below this confluence and, accordingly, potential effects are reduced. Between the Gunnison and State Line (considered the lower limit of the area of potential impact) there are no major tributaries to the Colorado and water flow and quality are influenced primarily by the numerous irrigation laterals that withdraw and return substantial volumes of water in this reach of the river. At State Line, the effects of the GCC withdrawals are largely masked by the influence of the Gunnison and the irrigation diversion and return flows (Table 2-1). The percentages that the flow at State Line will be reduced by the GCC withdrawals range from about 2.4% in June to about 11.5% in August.

Insert ① However, the GCC joint venture's expected total net annual depletion is anticipated to be 73,000 acre-ft (Getty 27,000; ~~Chevron 24,000~~; Cities 26,000) for all three companys' needs.
Chevron (D.O. [illegible]) 17,000 [illegible]

Any possible effect of the GCC diversion on levels of total dissolved solids (TDS) in downstream areas is expected to be minimal. Typically, the flow into the Colorado River from the Gunnison River is higher in TDS than the Colorado at that point. In effect, the Colorado dilutes the dissolved solids content of the water entering from the Gunnison. Therefore, theoretically, the GCC withdrawals would reduce this dilution flow resulting in higher TDS concentrations downstream from the confluence of the two rivers. However, the impacts on TDS levels of the numerous irrigation diversions and return flows in Grand Valley are so great that any effect caused by the GCC project would be masked by the overall changes in dissolved solids that occurs in this reach of the Colorado. ~~Moreover, the fish species of special interest in this area (eg. squawfish and humpback chub) have both been shown to tolerate a wide range of TDS concentrations (Bureau of Reclamation, 1982).~~

The withdrawal of water by GCC will theoretically result in small increases in the concentration of dissolved solids (TDS) in downstream areas. Using equations developed by the Bureau of Reclamation and assuming the average annual TDS concentration at DeBeque is in the order of 300 parts per million (ppm), it can be estimated that the annual withdrawal of 110,000 acre-ft by GCC will result in increases in TDS at Imperial Dam (near the Arizona-Mexico border) of about 10.4 ppm in 1990, 8.2 ppm in 2000 and 8.9 ppm in 2010. As the fish species of special concern in the areas ~~immediately~~ downstream of the proposed intake site (i.e., squawfish and humpback chub) have both been shown to tolerate a wide range of TDS concentrations (Bureau of Reclamation 1982), it is anticipated that the GCC withdrawals will not adversely impact these fishes due to increases in dissolved solids.

3.0 THREATENED AND ENDANGERED SPECIES

There are four fish species that have been given special status by the federal and/or Colorado governments:

- Colorado squawfish (endangered: federal and state)
- Humpback chub (endangered: federal and state)
- Bonytail chub (endangered: federal and state)
- Razorback sucker (endangered: state)

The potential impact of the proposed project on each of them is assessed below.

3.1 Colorado Squawfish, Ptychocheilus lucius.

3.1.1 Area of Impact.

The effects of the proposed GCC diversion on squawfish are evaluated for the reach of the Colorado River from the Grand Valley diversion dam at Palisades (RM 185) to State Line (RM 132). These limits were chosen because Squawfish do not occur above the diversion dam and effects of the flow reductions are not expected to (1) extend below State Line because of the flow inputs by the Gunnison River (RM 171) and the impacts of the agricultural diversions and return flows in Grand Valley.

This reach of the Colorado River (RM 185 to RM 132) may be ~~is~~ significant for squawfish because successful reproduction has occurred every year from 1979 through 1982, as verified by the finding of young-of-the-year (YOY) specimens in this river section (Bureau of Reclamation 1982). Accordingly, spawning, incubation, and early larval development will be of primary concern with respect to potential impacts on squawfish. Valdez et al. (1982) identify the 22-mile reach of the river from Loma (RM 154) to State Line (RM 132) as being critical to squawfish during these life stages.

3.1.2 Critical Periods.

The period June 15 to August 30 appears to be critical to spawning and incubation ~~of~~ for squawfish. The most sensitive time for development in nursery areas is from about July 1 through August 30 (Valdez et al. 1982). The exact timing and length of these critical periods each year is determined primarily by water temperature.

Miller et al. (1983a, 1983b) reported on squawfish spawning and squawfish larvae collections in the Colorado River in 1982. Congregations of sexually mature squawfish indicated spawning sites in two areas of the Colorado River in Colorado, one site near C ~~F~~lifton, the other near Black Rocks. Sampling for larval fish in August found 24 squawfish larvae along the Colorado River below these suspected spawning sites and above ~~the~~ State Line. September and October samplings found YOY squawfish only in Utah, below RM 110. Evidently, there is a downstream movement of YOY squawfish spawned in Colorado. The 1982 sampling indicates that the most critical period for the maintenance of habitat quality of squawfish nursery sites in the impact area would be from time of spawning until late August-early September.

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3.1.3 Critical Environmental Factors.

The two environmental factors that are generally regarded as the most critical in determining the success of the squawfish in the Upper Colorado River are: river flow and the presence of non-native fishes. With respect to potential impacts of the GCC project, it is the river flow that will be of principal concern.

River flow effects squawfish success in several ways:

- controlling water temperatues critical to spawning and larval development
- determining availability of nursery areas along the river
- flushing spawning areas at peak flows

Water temperatures are critical to the maintenance of squawfish populations in this reach of the Colorado River because the fish is a warmwater species living near the upstream limits of its distribution in the mainstem river. Preferred temperatures for squawfish spawning and early development are maintained in this section of the river for only a relatively brief period in most years. Indeed, there is no historical evidence that the species was ever common in the Colorado River in Colorado. (3) Laboratory studies to determine the preferred temperatures of the various life stages of the species have shown that juvenile and adult squawfish most typically selected water temperature from about 22°C to 28°C, with a final preferred temperature estimated at about 25.5°C (Bulkley et al. 1982). Thus, an appropriate temperature regime for nursery habitat, where YOY squawfish can develop after hatching, is about 22°C to 28°C, with an optimum of about 25°C to 26°C, especially during the first few weeks after hatching when the larvae are most vulnerable. In the Colorado River during the late spring and summer, the river water is warmed primarily due to the influence of higher ambient air temperatures. The rate of warming is inversely proportional to the volume of river flow (e.g. water temperature increases more rapidly during low flows). Accordingly, the squawfish optimum temperatures of 24°C or more are generally reached in the Upper Colorado in July and August at river flows of about 2,000 to 4,000 cfs. When flows exceed 5,000 cfs, water temperatures tend to remain below 24°C.

The extent to which water temperature is important to successful squawfish reproduction can be seen from the recent history of flow management in the Green River. (4) Between 1966 and 1978, few YOY squawfish were found in the Green between about Ouray, Utah and the Yampa River (Holden 1973; Holden and Crist 1978, 1980; Holden and Selby 1978; Seethaler et al. 1979). A change was made in the outlet works of the Flaming Gorge dam in 1979. This resulted in warmer water being released into the Green River: the average July water temperature at Jensen, Utah increased from 18°C - 19°C to 21°C - 23°C. Shortly thereafter, many YOY squawfish were again found in this reach of the river as evidenced by the collection of more than two thousand~~s~~ YOY in this section of the Green River (Tyus~~,~~ et al. 1982, Holden and Selby 1979) ~~collected there~~ between 1979 and 1982.

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The physical habitat within nursery areas is also critical for the survival of newly hatched squawfish. When the larval squawfish absorbs its yolk and becomes free-living it is only 6 to 7 mm and is essentially planktonic. It must get into quiet backwaters and side channels where more typical lentic-type food organisms, such as rotifers and minute crustaceans, are more abundant. There are a variety of such potential nursery habitats along the Colorado River. Some maintain more optimum conditions at higher flows (e.g. 3500 -5000 cfs) and some are more optimum for YOY survival at lower flows. Thus, spawning success should occur over a range of flows if flows remained relatively stable during the early life history stages (typically late July and August), especially if warm water temperatures are maintained. However, fluctuations in flow which result in rises and declines of the river surface level during the larval development period may have negative impacts on YOY squawfish survival in small, shallow backwaters. For example, extrapolating from stage-flow data from the USGS Colorado River guage at State Line, the river surface level changes about one inch for every 100 cfs change in flow. Thus, YOY squawfish taking up residence in a side channel habitat at a flow of 3000 to 3500 cfs may be flushed out if the river rises 18 to 20 inches with an increase in flow to 5000 to 6000 cfs. On the other hand, YOY entering shallow backwaters created at flows of 5,000-6,000 cfs could be left stranded or forced out when flows drop to 2500-3000 cfs. ⑤
Thus, an optimum flow regime would be one that would maintain the most nursery habitat in a relatively stable condition for the first few weeks of life (typically late July and the month of August) and also maintain warm water temperatures (e.g. 24° or more).

It is important to note at this point the role that non-native fishes have in the reduced success of squawfish reproduction in the Upper Colorado. The most optimum backwater habitat, the large off-channel ponded areas along the river, ⑥
which maintain good habitat conditions under a wide range of river flows, are probably a negative influence on YOY squawfish survival because these habitats harbor high densities of non-native fishes that prey on small squawfish. On October 5, 1981, about 30,000 YOY squawfish (35 to 85 mm) raised at the Dexter, New Mexico National Fish Hatchery, were stocked into six sites along the Colorado River

from Clifton to above Black Rocks (Miller et al. 1983a). These hatchery-reared squawfish all had minute magnetic tags implanted in their snouts. Subsequent fish collections made in the habitats containing largemouth bass and green sunfish revealed a high incidence of predation on the newly-stocked tagged squawfish. It is doubtful that this section of the Colorado River can become an important nursery area for squawfish, regardless of flows and temperatures, unless non-native predators can be controlled.

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The third important role that river flow plays in squawfish reproduction is in flushing loose debris and sediment out of the spawning locations. Although no squawfish spawning has actually been observed in the Upper Colorado River, based on information from other locations, it is assumed that squawfish in this area prefer to spawn over a cobble substrate. The presence of excessive sediment in the spawning locations can smother the developing eggs or young larvae. Accordingly, the high river flows that occur during snowmelt are important in maintaining these areas by removing the sediment from the gravel bottom.

Miller et al. (1982) presented USGS flow data for the Colorado River recorded at the State Line. They divided the periods of analysis into pre-impoundment (1951-1965) and post-impoundment (1969-1981). The present (post-impoundment) period maintains more stable and higher flows during July and August, the most critical period for squawfish:

JULY

	Pre-Impoundment	Post-Impoundment
Median flow	3,800-4,000 cfs	5,600 - 5,800 cfs
Most frequent low flow	2,200 - 2,400 cfs	3,200 - 3,400 cfs
50% average daily exceedance flow	4,100 cfs	5,800 cfs
75% average daily exceedence flow	2,200 cfs	3,500 cfs

A similar trend can be seen in the August flows. These differences are due to the controlled release from upstream reservoir storage in the post-impoundment period.

The information in Table 3-1 also illustrates this point. RJB new

The comparisons of flows under present (post-impoundment) and pre-impoundment conditions demonstrate that a much more stable flow, characterized by a higher median flow, much higher minimum flow, and considerably less fluctuation around the median flow now exist during periods of squawfish spawning and rearing of young in comparison to historical flow regimes. Comparisons of the relative success of squawfish spawning in the two periods cannot be made because no information exists for the pre-impoundment conditions. However, based on our present understanding of squawfish requirements during the critical life stages, it is likely that present flow regimes are more conducive to successful squawfish spawning and rearing than those of the pre-impoundment period, but that the predominance of non-native predators in the most optimum nursery habitats severely limits squawfish spawning success irregardless of flows.

3.1.4 Estimates of Flow Requirements.

In order to properly assess any potential impact of the GCC water withdrawal on squawfish, it is first necessary to estimate the flow requirements of the species in the Upper Colorado River within the reach extending from about Cameo to State Line. Some flow estimates have already been made (Bureau of Reclamation 1982). These were first approximations based primarily on the data generated during the 1979-1981 Colorado River Fishery Project. For the analysis in this report, a somewhat different approach was taken using both the CRFP information and some results of the Colorado Division of Wildlife collections during the same period. An examination of these data reveals that the numbers of squawfish YOY collected during both studies varied from year to year indicating that in certain years more YOY were produced and survived than in other years. By relating these levels of success to the flow and water temperature regimes that occurred during the years sampled, an indication can be obtained of the environmental requirements of these early life stages in the reach of the river under consideration. It is recognized that the results of the YOY sampling during the two studies are not directly comparable from year to year or one study to the other, due to variability in sampling technique, timing and expertise of the collectors. However, even though the results of the sampling cannot be considered strictly quantitative and could not be validly subjected to statistical analysis, they can be viewed as indicative of general trends in squawfish spawning success during the years samples were collected. As such, the 1980 collections indicated a much greater abundance of YOY squawfish than did the 1979 or the 1981 collections. The FWS investigators working in the Colorado River from Lake Powell to about Grand Junction captured about 10 times more YOY squawfish per effort of sampling in 1980 than in 1979. They found none in 1981 and 148 in 1982 (Miller et al. 1983b). RJB ref The most quantitative data for YOY squawfish collections in the Colorado River from the State Line (RM 132) to Grand Junction (RM 170) were obtained by the Colorado DOW monitoring studies for 1979-1982. In 1979, 155 collections yielded eight YOY squawfish; in 1980, 114 collections yielded 77 YOY; in 1981, 319 collections found only a single YOY; in 1982, 16 YOY were collected in approximately 300 samples (Haynes et al. 1982, Haynes and Muth 1983). RJB updat All YOY were taken by CDOW between RM 135 and RM 153. The hydrographic data are is taken from the published USGS records at this gauging station which was chosen as being most representative of the conditions in the reach of the river where potential effects of the proposed project could be manifested. The results of these analyses are discussed for each year of sampling in the following paragraphs.

<u>1979 and 1980</u>. It is evident from both the FWS and CDOW catch statistics that, in 1980, many more squawfish YOY were produced than in 1979. An examination of the river flow and temperature data for these two years (Figures 3-1 and 3-2) reveals that there were major differences in these regimes during the months that are critical to squawfish spawning, incubation and rearing (i.e., June-August). Although total annual flow volumes at State Line were above normal for both years, the flows for July and August of 1980 were close to the long-term average, while those for 1979 were considerably above normal:

	July	August
1979	11,580 cfs	4,338 cfs
1980	7,183 cfs	3,073 cfs
1969-1981 average	6,900 cfs	3,110 cfs

Also, the flows in August (when YOY are most vulnerable) were relatively more stable in 1980 than in 1979. However, it is the temperature regime (as influenced indirectly by flow) that appears to be the major environmental factor responsible for the far greater success of squawfish reproduction in 1980 than in 1979. Natural spawning of squawfish was observed at the Willow Beach Hatchery in water of 20-21°C (Hamman 1982). The mean daily temperature of the Colorado River at State Line is, ⑨ on the average, about 1°C less than the maximum daily temperature during the summer. The calculation of spawning time derived from the size of YOY squawfish (Haynes and Muth 1983a) and the time of congregations of sexually mature squawfish, assumed ready to spawn, reported by Miller et al. (1983a), indicate that spawning of squawfish in the Colorado River in Colorado is initiated after a daily maximum water temperature of 22°C is recorded at State Line. Young squawfish prefer temperatures of 24°C to 28°C. In 1980, spawning temperatures were reached earlier (than in 1979) and a considerable part of the critical early life-history stage had optimum growing temperatures (Figure 3-2). ⑪ In 1979, in comparison, spawning temperatures were delayed by two or three weeks, and maximum water temperatures during July and August barely attained levels sufficient for optimum growth and then only for a very brief period (Figure 3-1).

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The water temperature regimes for 1979 and 1980 can also be compared in relation to cumulative warming. In 1979, a maximum of 20°C was first attained on July 12. From that date through August 31, water temperatures of 20°C were attained or exceeded on 47 days. Accordingly, total accumulation of "degree days" in excess of 20°C during this period was 108. In 1980, water temperatures first reached 20°C on June 26 and from then through August 31, every day reached or exceeded 20°C for a total accumulation of 291 degree days. In 1979, July and August water temperatures reached or exceeded 22°C on a total of 23 days and the cumulative degree days in excess of 22°C was 36. In 1980, river temperatures reached or exceeded

22°C on 58 days during July and August, for an accumulation of 165 degree days in excess of 22°C. The inference drawn from this analysis is that the higher summer flows of 1979 maintained water temperatures too cool for successful squawfish spawning and larval survival. The lower summer flows of 1980 provided more optimum temperatures and this was reflected in the ten-fold increase in YOY squawfish sampled in 1980.

1981. Figure 3-3 illustrates conditions in 1981, which was an extremely low flow year. A peak river flow was reached on June 9 (11,200 cfs) and rapidly declined to less than 4000 cfs by June 17 and then to less than 3000 cfs on June 27. Thereafter, until the end of August, flows fluctuated greatly, increasing or decreasing by 1,000 to 1,500 cfs at one or two week intervals. Because of the low flow, the river water warmed rapidly in 1981, reaching 24°C on June 22, and remaining above 22°C for July and August. Thus, the temperature regime appears to have been favorable for squawfish spawning success in 1981. If the 1981 sampling was indeed indicative of spawning success, then the reason for failure is more likely related to the flow pattern. Squawfish probably spawned early in 1981 (late June to early July) based on the temperature regime information. The young, during their first few weeks of life in the nursery habitats, would have been subjected to highly erratic flow fluctuations from 1600 cfs to 3800 cfs; that is, on a week by week basis river levels would rise or fall about 10 to 20 inches. This could have resulted in YOY either being stranded or flushed out of their nursery areas.

Another characteristic of the 1981 flow regime that bears scrutiny in relation to squawfish spawning success is the magnitude and duration of the peak flow. The maximum flow of 11,200 cfs occurred on June 9. This flow was approximately 200 percent of the long-term average daily flow and such a percentage flow is generally considered a "flushing" flow for mitigation purposes in regards to regulation of fish habitat (i.e., the flow expected to flush out silt and fine material from gravel, rock areas). However, only six days of 1981 had flows of 10,000 cfs or greater. In most years, peak flows between 15,000 to 30,000 cfs occur in the Colorado River at the State Line. It is possible that in 1981 the peak flows were insufficient to properly clear out squawfish spawning areas and that successful incubation was limited.

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1982. The 1982 data on squawfish spawning success is based on more intensive sampling by the USFWS. The timing of sampling was geared to information obtained from radio-tagged spawners so that the sites and times of spawning could be much better estimated than in previous years (Miller et al. 1983a, 1983b). Thus, the 1982 YOY collections have a high positive bias for success in comparison with the 1979-1981 collections. From July 27 to August 27, 1982, 195 collections have been made by USFWS biologists in the Colorado River from Lake Powell to the Grand Valley diversion dam (about RM 185). Of these, 23 samples contained 124 YOY squawfish from 9 to 25 mm in length. In the section of the Colorado River under consideration for impact analysis (RM 135 to RM 185), seven samples contained 24 YOY squawfish. Two YOY taken at RM 175.3 and one taken at RM 175.9 extend the occurrence of YOY squawfish about 33 miles upstream from previous records and are the first records above the confluence with the Gunnison (RM 171). Radio-tagged spawning squawfish had been tracked to a site in the Colorado River near Clifton, Colorado, (about RM 180) one of these spawners had migrated from Lake Powell, about 200 miles for spawning. The remaining 21 YOY were found in five collections from RM 135.3 to RM 151.5. | The September and October sampling by USFWS personnel found YOY squawfish only below RM 110 in Utah. Evidently, downstream movement of the young spawned in Colorado occurs about 4 to 6 weeks after hatching.

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For a comparative indication of squawfish spawning success in the Colorado River in Colorado, the results of the CDOW squawfish YOY sampling programs from 1979 through 1982 provides the best source of information because the timing, sites sampled, gear, and expertise are comparable from year to year. Approximately 300 collections were made in 1982 which yielded 16 YOY squawfish between RM 135 to RM 151 (Haynes and Muth 1983b). These results indicate that the 1982 spawning success was similiar to 1979 when 155 collections yielded 8 YOY squawfish. The July-August flow and temperature regimes followed similiar patterns in 1979 and 1982. In both years flows were well above average and a surge in flows occurred during mid-late August.

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indicated to be low and highly variable. Even in the best years, YOY survival is only a small fraction of what is produced along comparable sections of the Green River. A major factor limiting survival of YOY may be predation by non-native fishes that dominate the largest backwater nursery habitat, thus restricting YOY survival to small habitats such as shallow side channels and shoreline "pockets" that are susceptible to the loss of critical habitat characteristics during periods of fluctuating river flows.

The most successful spawning, as indicated by numbers of YOY found, occurred in 1980. Figure 3-2 illustrates the relative stability of the flow from late July to late August in 1980 which was necessary to maintain optimum squawfish nursery habitat during the first few weeks of life. The higher flows of 1979 probably resulted in spawning at much higher flows (5,000 - 8,000 cfs versus 4,000 - 6,000 cfs in 1980) and more limited opportunity for the YOY to find suitable nursery habitat. A sharp rise in flow in mid-August 1979 (from 3,500 cfs to 5,200 cfs in a six day period) was probably detrimental due to a flushing out of YOY from nursery sites. All eight YOY found in 1979 were from shoreline sites in the large pool environment at Black Rocks, whereas the 77 YOY found in 1980 were taken from numerous backwater habitats along 20 miles of river. In 1981, the low, but erratic flow was probably a negative influence due to relatively rapid fluctuations after spawning from highs in excess of 3,000 cfs to lows of about 1,500 cfs which would have resulted in highly unstable nursery habitats. Only a single YOY was found in 1981. Success in that year would most likely have been better if post-spawning flows stabilized around 2,000 cfs.

The 1982 spawning success was approximately similar to that of 1979 according to CDOW collections, and the 1979 and 1982 flow and temperature regimes were generally similar (Figures 3-1 and 3-4).

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Idealized Flow Regime - Based on the foregoing analysis, an idealized flow regime for successful reproduction can be developed for State Line. Figure 3-5 shows this regime for a normal flow year. To provide for adequate flushing flows, the generally accepted USFWS recommendation for other rivers of a peak flow of 200 percent of the average daily flow can be suggested for a period of two weeks. This would mean a flow of 11,600 cfs should be maintained at State Line for two weeks during the peak run-off period in May and June. At this time, the magnitude and duration of a flushing flow designed to maintain habitat quality of squawfish spawning and nursery sites and the deepwater area in Black Rocks can only be roughly estimated. The USFWS research on endangered Colorado River fishes and their environment is now in its fifth year (1983). It may be assumed that quantification of habitat relationships to flow regimes has received careful consideration and that USFWS flow recommendations based opn concrete data will be soon available. Until then, various options may be available for arriving at a flushing flow recommendation in relation to flow peaks and duration. The virgin, undepleted flow of the Colorado River at State Line probably averaged about 7,000 cfs or slightly greater (Joseph et al. 1977). Examination of flow duration curves for the Colorado River at State Line reveals that during the 1951-1965 (pre-impoundment) period, flows during May exceeded 12,000 cfs 50% of the time, and exceeded 15,000 cfs 40% of the time. The June flows for this period exceeded 15,000 cfs 55% of the time. The flow duration curve for the 1969-1981 (post-impoundment) period is comparable: 12,000 cfs exceeded 50% of the time and 15,000 cfs exceeded 35% of the time in May and these same levels were exceeded 65% and 55% of the time, respectively, during June. Thus, until hard data are available on sediment transport capacity and hydrology for this section of the Colorado River, an interim recommendation for flushing flows might include a peak of 14,000 - 15,000 cfs for one or two days and an 11,000 - 12,000 cfs flow for 10 days to two weeks (for background information see Simons et al. 1981).

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From about mid June, the flow should steadily decline to 5000 cfs or less by early July. This would warm the water to maximum temperatures of 23°C - 24°C or more (mean daily water temperature is about 1.[illegible]°C less than maximum during July and August) and stimulate early spawning of squawfish. About one week after the time of peak spawning when the YOY squawfish are taking up residence in nursery sites, the flow should be stable, at least for the next 4 to 6 weeks (mid July to late August). For normal flow years, this is about 3,000 cfs during August (note that the 50% August exceedance flow is 2,600 cfs for pre-impoundment period and 2,900 cfs

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for post-impoundment period). In reality, however, because there is no major impoundment that can regulate the flow comparable to Lake Powell's capabilities to regulate Colorado River flows in the lower basin, the average July flows during spawning can be expected to be about twice as high as the average August flows that are assumed to be needed for maintaining nursery habitat. Also, there is limited regulation between years (the total storage capacity of present upstream impoundments is less than the annual average flow volume), thus any recommended flows must consider what flows are available during high, normal, and low flow years. For a normal flow year, after squawfish spawning, the aim would be to maintain nursery habitat from late July through August at about 3,000 -3,500 cfs with a goal of avoiding rapid fluctuations in flow. Actually, the mid to late July flow would be expected to be 4,000 - 5,000 cfs and August flows of 2,800 -3,000 cfs in normal years. Once the base flow is reached, fluctuations ideally should not increase or decrease by more than 1,000 cfs during August, especially the first half of the month. A reasonable minimum flow within these fluctuations for August in normal years is 2,300 cfs, the present (post-impoundment) 75% exceedance flow (the 75% preimpoundment exceedance flow was 1,900 cfs). Future depletions, under this recommendation, would be regulated to maintain an August flow of at least 2,300 cfs in the Colorado River at State Line. The basis for flow recommendations for higher than normal and lower than normal flow years would take into account the base flow present about one week after peak spawning and attempt to maintain a relatively stable level around the base flow and avoid rapid fluctuations. For example, a high flow year may have a base flow of 4,000 cfs, the goal would be to maintain a range from 3,000 to 5,000 cfs. A low flow year may have a base flow of 2,000 cfs. A range from 1,700 to 2,300 fcs should maintain nursery habitat in which YOY squawfish established residence at 2,000 cfs.

If future studies verify that all, or virtually all, YOY squawfish move downstream into Utah by September from the area under consideration, then some thought could be given to upstream river regulation aimed at depleting the autumn flow to a very low level (ca. 1000 cfs). Such a low flow would desiccate many of the backwater and side channel connections that harbor non-native fishes. The goal would be to reduce potential predator abundance in these sites, making them more favorable as squawfish nursery areas the following summer.

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3.1.5 Potential Impact.

The construction activities and the operation of the intake itself will not effect any of the life stages of squawfish because the fish does not occur in the Colorado River above the Grand Valley diversion dam, about 25 miles below the site. The water withdrawal (442 cfs) is not expected to have a negative influence on squawfish spawning success if it does not cause depletion of August flow at State Line to fall below 2,300 cfs during average flow years. As discussed above, this is a conservative estimation of the lower range of optimal-to-good flows for maintaining nursery habitat. It is the most frequent low at State Line during August under present (post-impoundment) conditions (but is 1000 cfs more than the most frequent pre-impoundment low flow for that month). It is also about 40 percent of the long-term average daily flow. Also, GCC diversions during May and June will not adversely effect peak flushing flows if they do not reduce flow below 11,600 cfs for a two week period during these months.

3.2 Humpback Chub, Gila cypha

3.2.1 Area of Impact.

This species occurs in the Black Rocks area of the Colorado River (RM 135-137) and in Westwater Canyon (RM116-124) below State Line. Black Rocks is within the potential area of impact assumed for the proposed intake. Westwater Canyon is (14)
somewhat below the area of concern. Humpback chub populations are believed to be self-sustaining in these areas; i.e., no movement to other river areas is required to complete its life cycle. Accordingly, all life history stages of this species can be found in Black Rocks and Westwater Canyon.

Some specimens of an unusual chub have been collected in DeBeque Canyon (RM (15)
195) about 5 to 6 miles below the proposed intake location (Valdez et al. 1982). This chub has been called a "humpback chub-like" fish and there was initial speculation as to its genotype. The taxonomic characters of the fish are predominantly characteristic of the roundtail chub (G. robusta). Specimens were examined by Dr. R. R. Miller of the University of Michigan to clarify the taxonomy of this chub. It was Dr.

Miller's conclusion that the DeBeque chub should be classified as G. robusta because it overwhelmingly possess the roundtail chub genotype (personal communication to R. J. Behnke). Based on this information, the population in DeBeque Canyon has not been considered a special status species for this report and this area is therefore not dealt with in this section.

3.2.2 Critical Environmental Factors.

The two principal concentrations of the humpback chub are found in relatively deep, swift reaches of the Colorado that differ markedly from most other areas of the upper mainstem river. Investigations indicate that adults and juveniles prefer habitats with bedrock, boulder and sand substrates. They are rarely found in the swift water areas, but rather prefer the slower pools and eddies.

Bioassay and toxicity tests with humpback chub carried out as part of the Colorado River Fisheries Project demonstrate the hardiness of the species to potential environmental stresses (Bureau of Reclamation 1982). No avoidance was found to water with the highest levels of total dissolved solids (TDS) of 11,600 parts per million. The humpback chub is more resistant to acute toxicity from organic and inorganic toxicants than non-native fishes such as channel catfish, fathead minnows and bluegill. The studies on humpback chub in the Little Colorado River (Kaeding and Zimmerman 1982) demonstrate that the greatest concentration of humpback chub known in the Colorado River basin thrives in an extremely harsh environment tolerated by very few other fish species.

There is conflicting evidence regarding the critical water temperatures for the important life stages of the humpback chub. Laboratory and hatchery investigations indicate optimum temperatures of $16^{o}C$ - $18^{o}C$ are for spawning; $20^{o}C$ - $26^{o}C$ for egg incubation and larval development and $24^{o}C$ - $26^{o}C$ for growth (Bureau of Reclamation 1982). However, the report by Valdez et al. (1982) indicates that spawning of this chub occurred in the Colorado River at Black Rocks during peak runoff periods of 1980 and 1981 at temperatures much below the indicated optimum for spawning, incubation and YOY growth.

There has been some speculation as to the need to maintain certain water temperatures during spawning periods in order to prevent hybridization between the humpback and roundtail chubs (Bureau of Reclamation 1982). However, hybridization between these two species has yet to be verified in the wild (Valdez et al. 1982) and there are no data in the published literature indicating that the two species have different preferred spawning temperatures, or any other specific preferences that act to enforce reproductive isolation by temporal or spatial separation during spawning.

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3.2.3 Flow Requirements.

A major concern of flows for maintenance of humpback chub habitat relates to the magnitude of the peak flushing flows and their significance in maintaining the peculiar habitats in Black Rocks and Westwater Canyon. Since no factual data exist on this question, it would be reasonable to recommend the same flushing flow for humpback chub as for squawfish -- a minimum of 11,600 cfs for 14 days during peak runoff periods in normal flow years.

There is little factual information upon which to base recommendations for required flows for any life stage of this species. The Final Report on the Colorado River Fishery Project (Bureau of Reclamation 1982) suggests that flows of 10,000 to 13,000 cfs are necessary from May 1 to June 30 during the spawning period for humpbacks. Presumably, this is the minimum range to be reached during the annual May-June runoff period. At these flows, although water temperatures will be appropriate for spawning, they will not reach the levels that have been found in the laboratory to be optimal for humpback chub egg incubation and larval rearing. Prewitt et al. (1982) present information derived from a flow-temperature model for the Colorado River at Black Rocks that illustrates that water temperatures would not rise above 16°C in the May to mid-June period if water flows exceed about 10,000 cfs. A more practical approach for correlating flow-temperature relationships is to simply observe the U.S.G.S. records for the Colorado River at the State Line for a period of years. The records do support the assumption that 16°C water temperatures are rare during the May - mid-June period when flows exceed 10,000

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cfs. For example, from June 1 to June 15, 1982, during high flows (15,000 - 18,000 cfs), maximum water temperatures at State Line ranged from 13.9°C to 15.6°C, whereas, this temperature range was achieved during the first week of April, 1981, with flows of about 2000 cfs.| There is not sufficient data on YOY humpback chubs to determine flow requirements for this life stage. Valdez et al. (1982) do suggest that any dramatic changes in flow during nursery periods could reduce the area of shallow water habitat available. However, there is little information on whether the availability of such habitat would, in fact, change under lower flow conditions, except that Prewit et al. (1982) state that the instream flow model for adult humpback chub habitat at Black Rocks indicates a general trend for increased habitat at lower flows due to lower velocities, but little overall change was predicted over a wide range of flows. Valdez et al. (1982) also suggest that median flows during at least 2 out of 3 consecutive years will protect juvenile and adult humpbacks. This would require flows of about 5,600-5,800 cfs in July and about 2,800 -3,000 cfs in August under post-impoundment conditions during two of three years.

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3.2.4 Potential Impact.

The construction activities and the operation of the intake will not have any effect on the humpback chub because the nearest population is at Black Rocks, about 73 river miles below the site. The water withdrawals by GCC may effect the humpback only if flows at State Line fall below 10,000 to 13,000 cfs in May and June and below about 5,600 cfs in July and 2,800 cfs in August. Projections show that depletions to these levels will not occur in normal flow years (Table 2-1).

3.3 Bonytail Chub, Gila elegans

3.3.1 Area of Impact.

None, the bonytail is extirpated from the upper mainstem Colorado River and probably from the entire upper basin as well. During the past four years, a single specimen of a Gila chub was tentatively identified as G. elegans (from the Green River) (Tyus et al. 1982). It is highly unlikely that a viable population could have been overlooked during the intensive and widespread fish sampling by state and federal agencies and by others during the past several years. Apparently, the remnants of the G. elegans genotype has been absorbed into G. robusta and G. cypha through hybridization.

The latest official position of the U.S. Fish and Wildlife Service regarding Gila elegans under Section 7 Consultation of the Endangered Species Act was given in the Biological Opinion for the White River, Utah dam project (February 24, 1982 from Regional Director USFWS Denver, to BLM State Director, Salt Lake City), which states:

> "the only recognized pure population of bonytail chub occurs in Lake Mohave, Arizona. The bonytail chub is probably extirpated from the entire upper Colorado River basin."

3.3.2 Potential Impact.

The proposed plant will have no impact on the bonytail chub, because no individuals of this species are believed to be in the area of potential impact.

3.4 Razorback Sucker, Xyrauchen texanus

3.4.1 Area of Impact.

The razorback sucker has been found above the site at RM 221 and RM 224 between DeBeque and Rifle and at several locations downstream within the potential area of impact. The species was found most frequently in abandoned gravel pits adjacent to the river near Grand Junction. Only adult specimens have been collected.

3.4.2 Environmental Requirements.

The razorback sucker prefers water of low velocity. Aggregations of the species occur in the Walter Walker pond and the Clifton gravel pond, especially in the spring. It is likely that lentic type environments are favored for spawning and important nursery habitats. Razorback sucker larvae lack the ability to swim for about two weeks after hatching (Inslee 1982) and thus, they are extremely vulnerable to predation and to suffocation by silt. It is believed that the lack of reproductive success of this fish is due largely to predation by the non-native species that occur in high numbers in the remaining habitats suitable for razorback spawning (Bureau of Reclamation 1982). ⑰

Razorback suckers have been reported to spawn over a wide range of temperatures, 10°C to 20°C. This wide range is probably an evolutionary adaptation to correlate spawning with the peak runoff flows when the maximum amount of backwater, lentic type habitat would be available for rearing of young.

3.4.3 Estimates of Flow Recommendations.

Due to the lack of information on the various life history aspects of the species, no soundly based recommendations for an optimum or minimum flow regime can be made. The species occurs in greatest abundance in impoundments and off-channel ponds (lentic environments). Originally, the high runoff-flows forming the backwater habitats were probably an important aspect of the life history of the species by creating the necessary nursery environment. These habitats are now dominated by non-native fishes which probably preclude any survival from spawning by preying on eggs and larvae in these confined areas.

3.4.4 Potential Impact.

The construction of the GCC intake is not expected to impact the razorback sucker because of the limited time such activities will be in effect and the few individuals of this species that are present in this reach of the river. The operation of the intake will not result in the entrapment of any razorbacks because the individuals present in the vicinity of the site are adults large enough (55 cm) to escape the 2 fps approach velocity should they get past the fish-protection facilities in the intake. The water withdrawals will not impact the species because the flow reduction downstream will not significantly effect the preferred artificial off-channel habitats near Grand Junction.

4.0 OTHER AQUATIC ORGANISMS

There are several aspects of the construction and operation of the proposed diversion/intake system that will have some impact on the other aquatic biota in the Colorado River near the site.

4.1 Construction Effects

The emplacement of the cofferdam and associated temporary structures in the river will destroy the benthic organisms in about one acre of river bottom at the site. This impact is considered temporary because the benthic forms present are adapted to the ephemeral conditions in the river and will repopulate effected areas after the cofferdam is removed.

The impacts of turbidity produced during construction will be minimal. Turbidity caused by the construction and removal of the cofferdam will not be serious because these activities will be carried out during low-flow periods and their duration will be short. Also, aquatic organisms are tolerant to turbid conditions due to the high natural suspended solid load carried by the river at this point. Turbid water generated during construction within the cofferdam will be pumped to a settling pond prior to release to the river or will not be returned to the river. Construction on river bank areas will be planned so that any runoff from exposed surface areas will not carry suspended material into the river.

4.2 Operation Effects

The emplacement of the weir, King's Vanes and intake structure itself will permanently occupy about 0.5 acres of river bottom. However, the loss of this small area of benthic habitat is not considered serious because of the large uneffected areas in this reach of the river. It is anticipated that the presence of the weir at this point in the river will result in an increased deposition of smaller sized sediment in the upstream areas behind this structure. This is not considered to be an adverse impact since other areas of low velocity flow and sediment accumulation occur along this reach of the Colorado.

The King's Vanes will direct bed-load sediment away from the intake structure and through the slot in the weir to downstream areas. Benthic organisms, demersal spawning products and food materials in the sediment will also be directed past the intake, thereby minimizing the losses that would otherwise result if these materials were removed from the river with the water drawn into the intake.

One unavoidable impact of the operation of the intake will be the loss of fish larvae, YOY and small juveniles that will be removed from the river with the water, i.e., will be entrained by the intake. There are no data available to quantify these losses; however, the numbers of ichthyoplankton and small fish in the water column is believed to be small based on the life histories of the fishes in this reach of the river. It is also believed that there are no critical spawning areas in the vicinity that would be effected nor are the eggs or early life stages of any special status species believed to occur at the intake site, or in immediate areas upstream. Accordingly, these unavoidable losses of fish due to entrainment are not expected to be significantly adverse.

The movement of fish up-or downstream past the site should not be impaired by the weir because the open area in the structure will allow passage in both directions. The water impounded behind the weir may provide a resting, feeding and/or spawning habitat for some fish species where there was none before. This potential effect is not expected to adversely impact the fish populations in the river.

5.0 LITERATURE CITED

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JOHN MINGC

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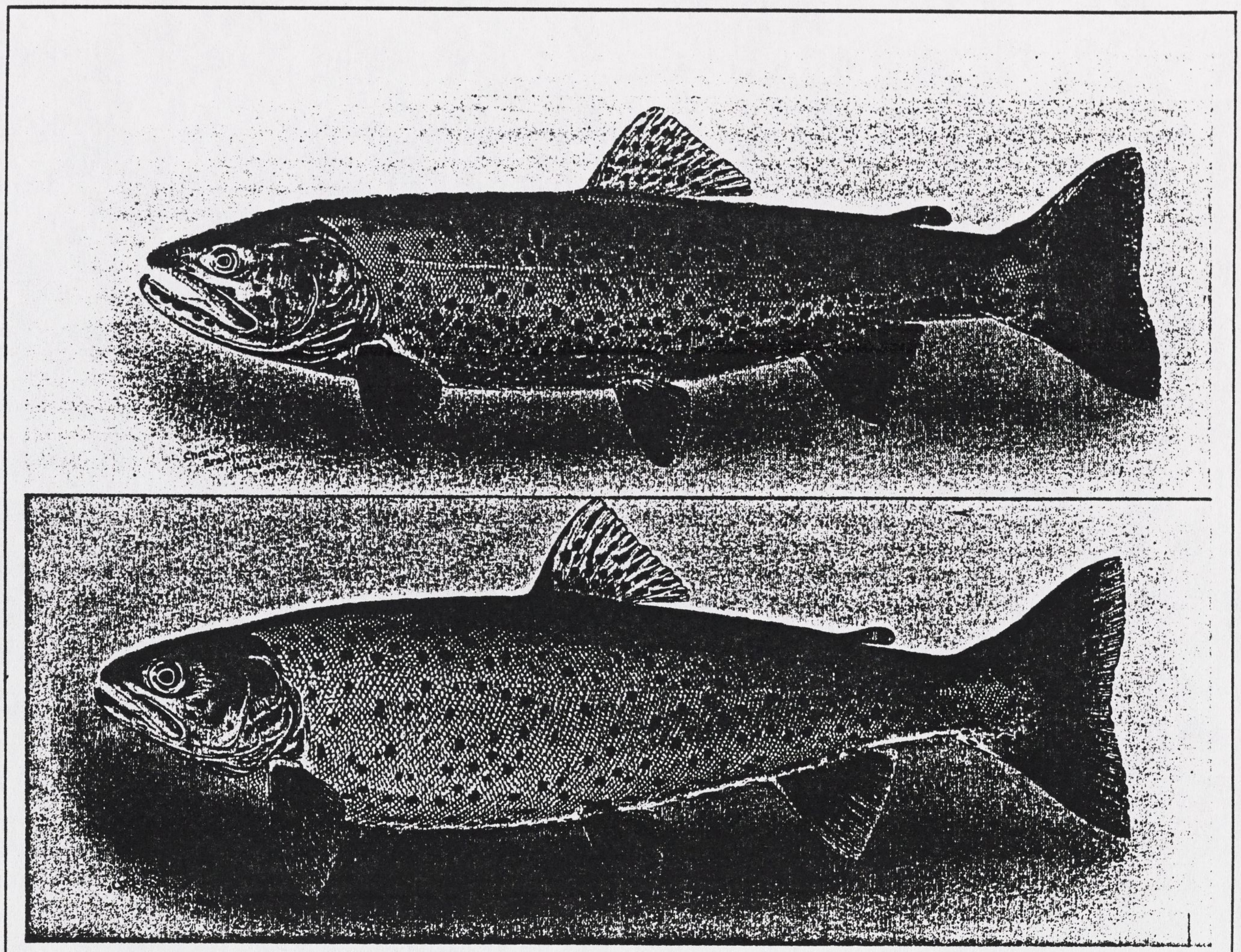
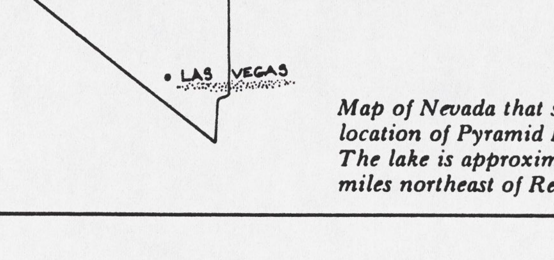


Watercolor renderings of a male (top) and female (bottom) Lahontan cutthroat trout, Salmo clarki henshawi, *painted by Charles Bradford Hudson in 1904. Hudson (1865 to 1939) was employed as an illustrator for many years by the Smithsonian Institution and the Bureau of Fisheries. David Starr Jordon once referred to him as the world's greatest painter of fish. Hudson was also well known as a landscape painter, an etcher, an author, and an illustrator for some popular magazines. The trout specimens he used for these paintings were taken from Lake Tahoe. The paintings are currently in the collection of the Smithsonian Institution.*

AL HASSALL



Map of Nevada that shows the location of Pyramid Lake. The lake is approximately forty miles northeast of Reno.

Pyramid Lake and its Cutthroat Trout

by Robert J. Behnke

Pyramid Lake and its giant cutthroat trout have been the subject of numerous magazine articles. Many of these articles are characterized by misinformation and hyperbole. The true story of Pyramid Lake, its enormous cutthroat trout, and their fate is indeed fascinating, but requires no fanciful embellishments. It is the intent of this endeavor to right some obvious wrongs and clear up any misconceptions concerning this extraordinary fishery.

The Great Basin of the western United States encompasses a large region south of the Columbia River drainage in Oregon, west and north of the Colorado River basin of Utah and Nevada, and east of the Sierra Nevada of California. Within this region, streams run from the mountains out onto the desert or into sumps, such as Great Salt Lake, Utah, and Pyramid Lake, Nevada. No running water escapes to the ocean. During the last glacial epoch (from about ten thousand to seventy thousand years ago), there were periods when the climate was cooler and wetter than it is now, and large lakes formed in numerous separate basins. For example, a lake formed in the Lahontan basin that was slightly larger than Lake Erie. The Lahontan basin of Nevada, as well as northeastern California, was invaded by an ancestral cutthroat trout at an unknown time. It is commonly assumed that this cutthroat-trout ancestor gained access to the Lahontan basin from the Columbia basin at the beginning of the last glacial period or about seventy thousand years ago, but it may have been much earlier. Fossil trout bones, several million years old, have been uncovered in the Lahontan basin, and they are similar to the bones of the Lahontan cutthroat trout, *Salmo clarki henshawi.*

In any event, this ancestral trout was the only large predatory fish among numerous species of minnows and suckers that established themselves. It evolved into an efficient predator and may have attained a large size in order to make use of the large stocks of forage fishes. The most common Lahontan minnow, the tui chub, commonly attains a maximum size of fifteen to eighteen inches, certainly more than a mouthful for a pan-sized trout, but a mere appetizer to a subspecies of trout whose weight averages twenty pounds.

Approximately ten thousand years ago, when the climate became warmer and drier, Lake Lahontan rapidly declined in size. About a thousand years later, it desiccated considerably and left two sump lakes, Walker Lake and Pyramid Lake. But, only Pyramid Lake maintained continuity and retained a full complement of Lahontan fishes. This allowed the Lahontan cutthroat trout to continue without interruption its evolutionary specialization as a large, predatory trout. In addition to the populations in Walker and Pyramid lakes, the Lahontan cutthroat trout survived in mountain rivers and lakes, such as Lake Tahoe, but these environments and their associated fish faunas were vastly different from Pyramid Lake, and these populations were subjected to evolutionary pressures distinctly different from those affecting the cutthroat of Pyramid Lake; other Lahontan cutthroat trout introduced into Pyramid Lake never approached the maximum size of the native trout. Although all Lahontan cutthroat trout populations that have been isolated from each other for about nine thousand years (since the desiccation of Lake Lahontan) exhibit little morphological differentiation and are all classified as the same subspecies, *henshawi*, they have all evolved different life-history specializations, and none were so finely adapted to make such efficient use of the Pyramid Lake environment as was the native Pyramid Lake trout—thus their enormous size.

What happened to the original Pyramid Lake cutthroat trout is an interesting case history of a conflict of values between settlers in the area and native Americans, particularly as this conflict relates to values associated with water. While the dating of artifacts indicates that the first native Americans appeared on the shores of Lake Lahontan about twelve thousand years ago, the present Paiute Indian culture at Pyramid Lake began only about six hundred years ago. The Pyramid Lake Paiutes developed great skills as fishermen and established a relatively stable, advanced society. The first nonnative Americans to visit Pyramid Lake were John C. Fremont, his scout Kit Carson, and their exploration party. Fremont had traveled south from Oregon to explore the Great Basin and to search for the mythical Buenaventura River that ancient maps depicted as draining the Great Basin to the Pacific Ocean. On January 10, 1844, Fremont and his party crested a ridge north of Pyramid Lake and were astonished at the sight of a vast sea existing in the midst of a great expanse of desert. Fremont's party camped near the mouth of the Truckee River where it entered Pyramid Lake and soon came in contact with the Paiute Indians. The initial contact was friendly. In fact, the Paiutes brought freshly caught trout to Fremont and his party. Fremont remarked, "Their flavor was excellent—superior, in fact, to that of any fish I have ever known. They were of extraordinary size—about as large as the Columbia River salmon—generally from two to four feet in length." Unfortunately, in less than a hundred years from the time Fremont first saw these giant cutthroat trout, this magnificent fish was actually exterminated from the waters of Pyramid Lake.

The California gold rush of 1849 and the Nevada mining boom of the 1850s brought many settlers to the Pyramid

Lake area. There were conflicts with the Paiute Indians, but during the 1860s a peace treaty was negotiated. The treaty established the Pyramid Lake Indian Reservation and gave ownership of Pyramid Lake and its fishes to the Paiutes. However, the Indians were given no control over the Truckee River, the only stream flowing into the lake that is suitable for the spawning of the cutthroat trout, and the major water supply for the lake.

The rapidly increasing population centers of western Nevada and eastern California created a great demand for lumber. Numerous lumber mills were set up on the Truckee River in California in the 1860s. As the stumpage in the watershed was lumbered, massive amounts of sawdust were dumped into the river, and in 1869 a Reno newspaper reported that "millions" of spawning trout were killed in the Truckee River as a result of sawdust pollution. During spring runoff, the sawdust deposits were transported to the mouth of the Truckee River, sometimes in such quantity that the spawning runs of trout from the lake were completely blocked. By 1875, dams blocked the river near Reno, effectively reducing potential spawning habitat by about seventy-five percent. From 1899 to 1930, a paper mill at Floriston, California, dumped up to a hundred fifty thousand gallons per day of highly toxic wastes into the Truckee River, eliminating all fish life for a considerable distance downstream. In addition, numerous unscreened irrigation ditches must have led to the destruction of millions of young cutthroat trout in the river as they migrated downstream to Pyramid Lake.

In 1868, the railroad was extended to Wadsworth, Nevada, a short distance from Pyramid Lake; this provided the opportunity to ship trout to distant markets and resulted in a tremendous increase in commercial exploitation of the resource. During their spawning runs, the trout were netted, snagged, speared, clubbed, and dynamited. It is incredible that even with all these adversities the Pyramid Lake cutthroat trout lasted as long as they did. They must have been a superbly adapted fish because they not only persisted but managed to remain abundant until the 1920s when successful spawning became rare.

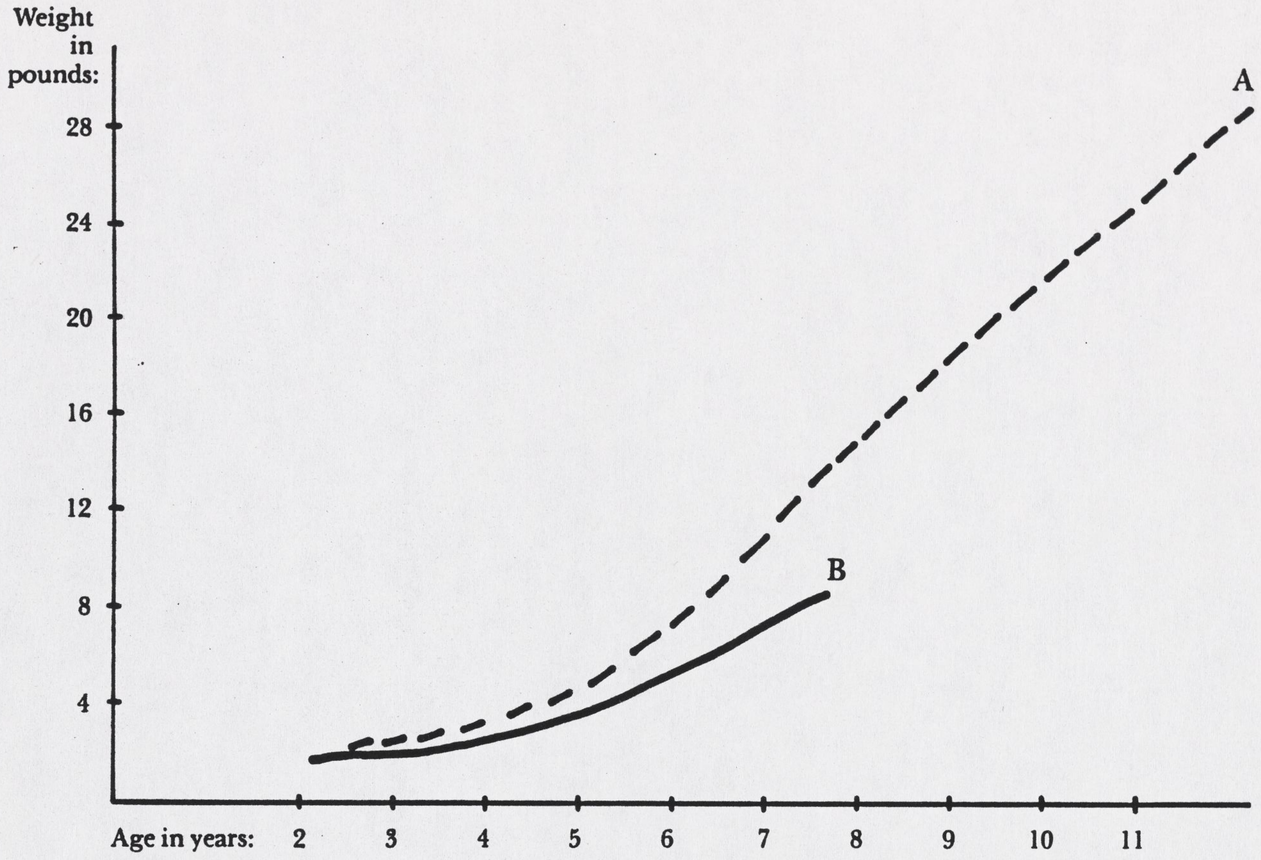
The ultimate demise of the Pyramid Lake cutthroat trout began in 1903 when a new government agency, the Reclamation Service (now the Bureau of Reclamation) annouced plans for its first project: the Newlands Project. It would divert water from the Truckee River to the Carson River in order to irrigate desert lands and make them bloom. The early history of the Newlands Project is one I am sure the present Bureau of Reclamation would prefer to forget, as it was an incredibly unwise use of a natural resource. The first Commissioner of Reclamation, Frederick Newell, drummed up support for the Newlands Project with speeches to Nevada audiences in which he frequently emphasized the philosophy of the department: "Fish have no rights in water law." This is still a popular cliche among western water-users.

The gates on Derby Dam, about thirty miles above Pyramid Lake, were closed June 7, 1905, in a grand ceremony highlighted by the dewatering of the Truckee River below the dam and resulting in the stranding of numerous, large cutthroat trout.[1] Derby Dam was constructed with a fish ladder, but the ladder was poorly designed and cheaply constructed. It was essentially a failure as a fish-passage device. Between 1905 and the early 1920s, there was a sufficient surplus flow in the Truckee River so that trout could spawn below the dam and even get over the fish ladder in some years. The trout population in Pyramid Lake remained relatively high, and their enormous size attracted presidents, supreme-court justices, and movie stars who had an interest in the gentle art. In the 1920s, the Bureau of Reclamation added an electrical generating facility to its Newlands Project, as it seemed utterly foolish to let surplus water flow out into a desert lake (only to evaporate) when it could be diverted through turbines that gererated electricity and additional income. Thus additional water was diverted out of the Truckee River to the Carson basin, and cutthroat trout spawning became more infrequent. The last major, successful spawning run occurred in 1927, with some reproduction reported in 1928 or 1929. Some artificial propagation and stocking occurred in 1930. A high flow in 1928 allowed some trout to get above Derby Dam all the way to Reno. The people of Reno had not seen the Pyramid Lake trout that far up the river for so long they forgot its correct classification and the mayor of Reno mistakenly declared Rainbow Day in honor of the cutthroat trout. In 1938 the offspring from this spawning run made the last attempt to spawn in the Truckee River, but the flow was shut off and the fish and their spawn perished. Thus ended the era of the world's largest cutthroat trout and probably the largest trout native to western North America. Stories relating that the native cutthroat trout did not completely perish from Pyramid Lake but were able to reproduce in springs on the lake bottom have persisted. But all known springs in Pyramid Lake have temperatures or chemistry lethal to trout eggs. I know of no evidence suggesting that the native trout did not become extinct in Pyramid Lake.

The data gathered on the 1938 spawning run is truly amazing. The Indians harvested 1,069 trout in their commercial fishery. When a United States Fish and Wildlife Service biologist weighed a sample of 195 fish from the run, the average weight was twenty pounds! He measured 321 trout taken from the 1938 spawning run; about ninety percent of these ranged from thirty-two to thirty-eight inches, with a few fish of forty inches. No maximum weights were given in this report, but extrapolation from a length-weight curve suggests that a forty-inch trout would weigh between thirty and thirty-five pounds.

How abundant was the original Pyramid Lake cutthroat trout, and what was its maximum size? These questions can never be known with any degree of certainty. In the 1880s, long after most of the upstream spawning and nursery areas were blocked or polluted in the Truckee River, commercial shipments of trout from Wadsworth ranged from two hundred to two hundred fifty thousand pounds per year. Records for another commercial fishery point at Verdi are not available. An unknown quantity of trout were transported by wagon to towns in Nevada and were consumed on the Indian reservation as well. I would estimate that even under the conditions of a declining fishery of the 1880s, the annual catch then was probably about five hundred thousand pounds, and the actual biomass of trout in Pyramid and Winnemucca lakes was in excess of two million pounds. The official world record cutthroat trout of forty-one pounds was caught in 1925 by a Paiute Indian, John Skimmerhorn, but there were reports of larger specimens taken by the Indian commercial fishery. Mr. Fred Crosby, the agent for the tribal fishery, claimed to have seen a cutthroat trout of sixty-two pounds in 1916!

The Nevada Fish and Game Department began to plant trout in Pyramid Lake in 1950 on an experimental basis. Rainbow trout were stocked at first, but it was soon found that the Lahontan cutthroat trout from available stocks in Heenan Lake, California, and Summit Lake, Nevada, grew faster and survived better than the rainbow trout. The advantage of Lahontan cutthroat trout over all other species and subspecies of salmonid fishes stocked into Pyramid Lake was most likely due to their tolerance to high alkalinity, or more specifically, to the concentration of carbonate and bicarbonate ions in the water. As salts and various ions are transported into Pyramid Lake each year via the Truckee River, evaporation and the lack of any outflow concentrates salts. Pyramid Lake water, in recent years, has exhibited an average salinity of about 5,400 parts per million or about fifteen percent of the salinity of ocean water (35,000 ppm.). Of the total (5,400 ppm. total salts) carbonate and bicarbonate ions average more than 1,100 ppm. Most



A. Estimated age and growth of the original native cutthroat trout in Pyramid Lake. Admittedly, there are little data available to construct such a curve, and considerable error may be involved. Spawning probably first occurred at age four at a size of three to four pounds. Thereafter, growth was rapid. The 1938 spawning run consisted of fish thirty to forty inches in length and averaging twenty pounds in weight. It is assumed that this run originated from reproduction from 1927 through 1930 or of fish aged eight to eleven in the 1938 run.

B. Known age and weight of 604 non-native cutthroat trout sampled in Pyramid Lake in 1975 and 1976. Of 604 fish age two or more, only six (1 percent) attained age seven and none were age eight. Typically, in large populations, the maximum weight of an individual in any age class is about twice that of the average weight of its cohorts; thus, the maximum weight expected from the original native cutthroat trout would have been at least forty pounds and perhaps sixty pounds. The maximum weight expected of the present non-native cutthroat throut stocked into Pyramid Lake would be about sixteen pounds. There is a hereditary basis governing maximum growth and maximum age. This fact must be recognized and used before the Pyramid Lake fishery can regain even a semblance of its former greatness.

fish species are physiologically stressed at carbonate-bicarbonate levels greater than 1,000 ppm. The pH of Pyramid Lake averages 9.2.

The stocking of Lahontan cutthroat trout from Heenan Lake or Summit Lake into Pyramid Lake, first by the Nevada Fish and Game Department, then by the United States Fish and Wildlife Service and by the Paiute Indian Tribe, can be considered successful in that a popular fishery for large cutthroat trout has been reestablished. Many more pounds of hatchery trout have been stocked, however, than have been caught in this fishery during the past thirty years. On the average, it takes fifteen to twenty hours of angling to catch a legal-sized trout. But a small group of Pyramid Lake "experts," fishing during winter months, have had considerably better angling success—and the exploits of these anglers have been the subject matter of several magazine articles. The present fishery pales in comparison to the fishery that was established when the trout were able to spawn in the Truckee River. Valid creel-census data are lacking for the Pyramid Lake fishery. Various estimates during the past ten years indicate an annual catch of legal-size fish of four thousand to twenty thousand, averaging about twenty inches in size, or an annual harvest of about ten thousand to forty-five thousand pounds. Minimum legal lengths have ranged from fifteen to nineteen inches, and the present minimum is set at eighteen inches, with only flies and lures allowed. The annual catch of cutthroat from Pyramid Lake during the past ten years is probably less than five percent of the catch of a hundred years ago. In comparison, the maximum size and maximum life span of the nonnative cutthroat trout falls considerably short of the native Pyramid Lake trout. The graph compares the age and growth of the nonnative cutthroat trout stocked into Pyramid Lake with that of the native trout (the latter data is estimated from historical records). The maximum life span of the original strain was probably eleven years in Pyramid Lake. Adequate reconstruction of an age-growth curve of the original Pyramid Lake trout is hampered by lack of precise data. All that is known is that a run of trout from thirty to forty inches in length occurred in 1938 averaging twenty pounds, with a maximum weight of about thirty to thirty-five pounds. It is assumed that all of these trout resulted from spawning from 1928 through 1930. That is, they were eight to eleven years old. Nonnative cutthroat from Heenan Lake and Summit Lake origins have a maximum life span of seven years when they average eight pounds in weight. A hereditary-based difference between the native Pyramid Lake cutthroat trout and the stocks of Heenan and Summit lakes resulted in different life histories, influencing maximum size and age, which is predicted from evolutionary theory. The nonnative stocks of Lahontan cutthroat trout evolved in isolation from the past ten thousand years or more without large stocks of relatively large forage fishes in their environment. Thus, they did not obtain the size of the cutthroat trout in ancient Lake Lahontan.

It is interesting to note that from 1976 to 1978, several trout weighing more than twenty pounds were caught in Pyramid Lake. Twenty-pound trout were not caught before or since that time. What differentiated these large trout from the other nonnative cutthroat trout in Pyramid Lake? They could be the result of the size of the trout stocked, the time of year they were stocked, a particular stocking site (environmental factors), or a different origin of the planted fish (hereditary factor). I examined records of all of the trout stocked into Pyramid Lake from 1950 to 1977. In 1970, the Nevada Fish and Game Department stocked forty-eight hundred two-year-old Lahontan cutthroat trout of Walker Lake origin. Since 1948 the Walker Lake cutthroat trout have been maintained in a hatchery, but of all Lahontan cutthroat trout, the Walker Lake stock continued to evolve (until 1948 at least) as a predator on tui chub in an environment most comparable to Pyramid Lake. I suspect that the exceptionally large trout caught in the 1976 to 1978 period were eight- to ten-year-old Walker Lake cutthroat trout. I suggest that the hereditary factor be given more recognition if the Pyramid Lake fishery is to regain a semblance of its original glory.

I bring this matter up because in 1979 I published a paper with Terry Hickman that reported the discovery of what we believe to be the original Pyramid Lake cutthroat trout—still existing in a small stream on the Nevada-Utah border.[2] Mr. Hickman was attempting to locate populations of the rare Bonneville basin cutthroat trout at the time, when he found an unusual trout in a tiny stream draining Pilot Peak on the Nevada-Utah border. The characteristics of the newly found cutthroat trout unmistakenly identified it as the Lahontan basin subspecies *henshawi*. The small stream on Pilot Peak is in the Bonneville basin, so the trout had to be introduced by man. Cutthroat trout were known from the stream prior to 1950 (when Lahontan cutthroat trout from Heenan Lake were first available for stocking). We determined that Pyramid Lake cutthroat trout were the only source of Lahontan cutthroat trout propagated in Nevada (beginning in 1883) before the propagation of trout from Heenan and Summit lakes, thus the Lahontan cutthroat trout on Pilot Peak probably had its origin from the original stock native to Pyramid Lake. The existence for many generations of a small population in a tiny stream, in such a completely different environment from Pyramid Lake, has undoubtedly altered the genetics (heredity) of the only known living descendents of the native cutthroat trout of Pyramid Lake. However, I believe that the Pilot Peak population and the Walker Lake stock of Lahontan cutthroat trout might offer genetic diversity for larger maximum size and longer life span than is presently found in the Heenan Lake and Summit Lake stocks. By stocking large numbers of genetically diverse Lahontan cutthroat trout into Pyramid Lake, then continually selecting the oldest and largest spawners that survive in Pyramid Lake to reproduce the next generation (no significant natural reproduction is likely to occur in the Truckee River in the foreseeable future), a trout approximating the maximum size and age of the native trout might be obtained. By experimenting to determine the best rearing techniques, the most opportune size, time, and locations for stocking, and by producing sterile fish with no gonad development (which will increase growth and life span), it is probable that the annual catch of Pyramid Lake trout could be increased by fourfold to fivefold over current levels, and a new world-record cutthroat trout might be in the offing. This is all predicated, however, on a sufficient flow of water (about four hundred thousand acre feet per year) in the Truckee River to maintain the Lake at its current level. In 1983, after a long legal battle, the Supreme Court of the United States ruled that the Pyramid Lake Indian Tribe is legally entitled to only thirty thousand acre feet of water each year from the Truckee River for irrigation and that they have no legal claim to the water for Pyramid Lake or its fishes. I can only hope that there are public officials with an innate sense of justice and decency who will attempt to work out a compromise on water use in the Truckee River basin so that flow adequate to maintain the present lake level can be achieved. I also hope that some of the ideas and theories discussed herein will be applied in an effort to restore the greatness of the Pyramid Lake trout fishery. §

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1. Water diverted from the Truckee River lowered the lake level by eighty-five feet, most of the decline coming after 1920. Evaporation rates are high in this desert region—about four feet per year. If no inflowing water were to enter Pyramid Lake from the Truckee River for one year, the lake level would drop by four feet minus the relatively few inches of precipitation falling directly on the lake and the very minor input of a few springs and ephemeral dry washes. The surface area of Pyramid Lake and connecting Winnemucca Lake was about two hundred thousand acres until around 1910. Since then the lake has shrunk to little more than one thousand surface acres.

2. T. J. Hickman and R. J. Behnke, *The Progressive Fish-Culturist* (1979), *41*, 135.

Robert Behnke is a professor of fisheries biology in the department of Fishery and Wildlife Biology at Colorado State University, Fort Collins, Colorado. In addition to numerous professional articles, he writes a regular column for Trout *magaine. He has also written the section on salmoniformes for the* Encyclopedia Britannica. *We would like to add a note of thanks to Bob Berls, John Mingo, and Chip Clark, who were instrumental in obtaining the color photographs of Hudson's paintings of the cutthroat trout that illustrate this piece.*

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210 Clayton Street Suite 3 Denver, CO 80206
(303) 329-8618

January 12, 1987

Dr. Robert Behnke
3429 East Prospect Road
Fort Collins, CO 80525

Re: U.S. District Court, No. CIV-82-1540M
The Pueblo of Acoma, et al., v. City of Grants, et al.

Dear Dr. Behnke:

The transcript of your deposition is now ready for you to read and sign. I believe that Mr. Johnson will be in touch with you to make arrangements for you to read and sign his copy of the transcript.

However, if you so wish, you may come to our offices to read and sign the original transcript, you may do so. Please be sure to make an appointment, to ensure there will be someone here to assist you.

The Federal Rules of Civil Procedure allow a witness thirty days to read and sign his transcript. If we have not heard from you within the next thirty days, we will file the transcript without signature, pursuant to the Rules.

If you have any questions, please do not hesitate to call.

Sincerely,

Becky S. Jackson

Becky S. Jackson

cc: Ms. Watson
Mr. Johnson