1971

Effects of the Cle Elum Reservoir on the Ephemeroptera (Mayflies) of the Cle Elum River

David Bruce Ainsworth

Central Washington University

72

EFFECTS OF THE CLE ELUM RESERVOIR ON THE EPHEMEROPTERA (MAYFLIES) OF THE CLE ELUM RIVER

A Thesis

Presented to

the Graduate Faculty

Central Washington State College

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

David Bruce Ainsworth

August, 1971

APPROVED FOR THE GRADUATE FACULTY

____

Stamford D. Smith, COMMITTEE CHAIRMAN

____

Robert E. Pacha

____

Jack A. Peary

EFFECTS OF THE CLE ELUM RESERVOIR

ON THE EPHEMEROPTERA (MAYFLIES)

OF THE CLE ELUM RIVER

by

David Bruce Ainsworth

August, 1971

This paper presents the results of a study on the physical and chemical effects of the Cle Elum Reservoir on the Cle Elum River and an evaluation of these effects on Ephemeroptera populations in the Cle Elum River. The study was designed to compare riffles (controls) above the reservoir with similar riffles below and to evaluate qualitatively and quantitatively mayfly populations as affected by reservoir operation.

Recommendations included additional field and laboratory research.

ACKNOWLEDGMENTS

I would like to express appreciation to my major professor Dr. Stamford Smith for his inspiration and guidance throughout my research. I would also like to thank Dr. Jack Perry and Dr. Robert Pacha for their guidance and critical reading of my manuscript.

I would like to express my gratitude to Mr. Steven L. Jensen, University of Utah, for confirming mayfly species identification.

I am grateful for the careful sorting of samples to Mrs. Loretta Franks and my wife Katherine. Another word of thanks to my wife for her help in the field.

A special word of thanks to Mr. Don Peck for his extra hours of work as my resident assistant, without which I would not have completed my writing on schedule.

To all the professors and stockroom people at Central Washington State College, thanks for all your help and support.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

ABSTRACT

Four permanent study sites in the Cle Elum River in Washington were sampled at approximately one-week intervals from May, 1970 to April, 1971 except during the winter when samples were taken monthly. All four sites were riffles, two above (controls) and two below the Cle Elum Reservoir. The four riffles were chosen on the basis of their estimated similarities in substrate size.

Mayflies were collected with a Surber square-foot bottom sampler and their average number/ft^2 was determined at each riffle. Physical measurements were obtained at each riffle for water velocity, volume of flow, temperature, and turbidity. Chemical analyses were made at each riffle for alkalinity, total hardness, nitrogen, phosphate, dissolved oxygen, and pH.

Below the impoundment water velocity and volume of flow were almost diametrically opposite normal conditions due to regulation of the reservoir. The reservoir effected the water temperature below by lowering the summer temperatures and delaying the time of temperature decrease in the fall. In the winter the impoundment appeared to increase the alkalinity and total hardness below the reservoir over "natural" winter increases.

The reservoir did not alter the mayfly species composition in the Cle Elum River. There was an increase in the density

of mayflies below the impoundment possibly due to altered environmental conditions brought about by operation of the reservoir.

INTRODUCTION

Water is an essential natural resource that is continually increasing in demand. Our water supply is limited and does not grow with increasing needs. One means of increasing the available water supply is by retaining it in storage reservoirs when runoff is high. Therefore, it is inevitable that storage reservoirs will become more numerous. With the increasing need for more storage reservoirs there is a need for a better understanding of their effects on the ecology of receiving streams. This knowledge is necessary for intelligent planning of future water conservation and water resource development in order to keep such practices in accord with our environment.

The purpose of this study was to determine the physical and chemical effects of the Cle Elum Reservoir on the Cle Elum River and to evaluate these effects in respect to the Ephemeroptera of the Cle Elum River. Specific objectives were: (1) To determine the effects of the reservoir on current velocity, volume of flow, turbidity, and temperature. (2) To determine the effects of the reservoir on alkalinity, hardness, dissolved oxygen, and pH. (3) To evaluate the effects of the reservoir on the Ephemeroptera of the Cle Elum River.

The reservoir selected for this specific investigation was the Cle Elum Reservoir which is located on the Cle Elum

River on the east side of the Cascade Mountains in Washington. The dam is regulated to maintain flow in the Yakima River for agricultural purposes. The dam was constructed during 1931 and 1932.

The Cle Elum Reservoir was chosen because the reservoir and the Cle Elum River are nearly pristine. They are affected very little by human populations. Therefore, environmental data obtained is relatively indicative of the reservoir and not of other added pollutants. Also a steam operated electric power producing plant is proposed for the region and the Cle Elum Reservoir is to receive the hot water effluents of this plant. Therefore, an analysis of current ecological conditions would serve as baseline information from which to gauge the effects of dumping heated effluents into the reservoir in respect to the receiving stream. Another reason for choosing this reservoir is that it is over 38 years old and has had time for major physical and chemical adjustments. Therefore, the results of this study show the relatively long term effects of a storage reservoir.

Study sites above and below the reservoir were riffles and were chosen because of their similar estimated substrate size which is evidently the most reliable of environmental parameters in such situations. The riffles above were used as controls since no pre-impoundment data were available.

LITERATURE REVIEW

Reservoirs

"Strictly speaking, a reservoir results when any watercourse, no matter how small, is dammed; however, distinctions are usually drawn between ponds and artificial lakes after rather indefinite surface areas are exceeded" (Neel, 1963). Dams may be constructed for a variety of purposes which include power for small industries, public water supply, irrigation reservoirs, hydroelectric power, flood control, navigation, fish and wildlife protection and propagation, recreation, silt trap, and water releases for various ancillary purposes such as dilution of sewage and improvement of water quality.

The function assigned to a reservoir dictates the type of dam it must have and the manner in which water is released. This can have varying affects on the characteristics of the reservoir and the stream below. Kittrell (1959) describes storage reservoirs as typically being located on tributary streams with steep slopes. The dams are usually 100 to 125 feet high and the stored water spreads beyond the former river channel to form a large surface area with negligible flow. Mackenthun and Ingram (1967) state that the storage reservoir is used to impound water when surface runoff is high for release when runoff is low. Since the surface water level varies over a wide range this necessitates having the discharge outlet located deep in the reservoir below the minimum level of water to be used.

Neel (1963) has identified several phenomena occurring in reservoirs that can have an effect on water quality. He states that "Reservoir modifications of water chemistry vary with age of impoundment, extent and duration of thermal stratification, frequency of density currents, ..."

In comparing a natural lake with a reservoir, Mackenthum and Ingram (1967) and Neel (1963) explain that a glaciated lake begins as an oligotrophic lake and proceeds to become eutrophic. A reservoir, in contrast, is formed over rich bottom land with fertile topsoils and begins life with a high productive potential. As nutrients and organic material are leached from the soil, productivity tends to decline and the reservoir never regains its initial productivity.

Kittrel (1959) states that water may be retained for several months in a reservoir and significant amounts may remain for nearly a year. Neel (1963) has assumed that for the estimate of water quality effects and other purposes that reservoir releases will be chemically representative of the mixture of seasonal inflows stored. This means that the major effect of a reservoir on seasonal river discharge is the extended duration of chemically distinct seasonal flows downstream. So the time required for the appearance of any seasonal segment is increased and flows that were developed in summer runoff will not emerge until winter. This phenomena was observed in the Missouri River, where the "normal" winter range occurred in July for hardness and low summer concentrations were delayed until winter.

According to Churchill and Asce (1958) reservoirs can result in an improvement of water quality in regards to turbidity, as pools are settling basins where suspended matter may settle out. Neel (1963) states that probably the most common reservoir effect on turbidity is complete or near-complete removal of carried-in silt and other suspended materials.

Raphael's (1961; 1962) work on the Columbia River showed that the effect of slowing down a river and spreading it out over wider areas by river dams increases the temperature of the water over its natural change in the unconfined river gorge. During the cooler month of September, Raphael reported a reverse effect, temperatures were reduced and icing became a problem. Mackenthun and Ingram (1967) report that there is a gradual expansion in depth of upper temperature zones as a result of removing water from a deep penstock in irrigation reservoirs. As the water is removed, the water level drops and warmer surface water moves downward into the reservoir increasing the depth of the epilimnion.

Pfitzer (1954), Kittrell (1959), Neel (1963) and others have reported that reservoirs exhibit seasonal stratification similar to lakes. Kittrell (1959) and Pfitzer (1954) state that thermal stratification of reservoirs causes resistance to water circulation which reduces or prevents the transport of oxygen from the surface to the depths. Therefore reservoirs reduce reaeration rates greatly in comparison to free flowing streams. In the epilimnion wind induces currents which circulate the epilimnion increasing the uptake of atmospheric oxygen and also algae in the quiet lake waters produce oxygen via photosynthesis (Reid, 1961). At the same time Reid indicated that dissolved oxygen may be quite low in the hypolimnion as it is shut off from contact with the atmosphere by the overlying thermocline and epilimnion and what oxygen is present is removed by decomposition and not replaced. Therefore retention of water for several months in the hypolimnion can result in very reduced or even total oxygen depletion, even in reservoirs with inflow waters of good quality (Pfitzer, 1954; Kittrell, 1959; Love, 1961; Mackenthun and Ingram, 1967).

Mackenthun and Ingram (1967) reported four well-defined horizontal zones with respect to dissolved oxygen during thermal stratification in the Norris Reservoir, Tennessee. They reported a well-aerated surface stratum, a zone of stagnant water within the thermocline, an area rich in dissolved oxygen below the thermocline, and a bottom layer of stagnant water.

Various other changes in water also occur especially in the region of the hypolimnion. Lake marl, essentially calcium carbonate, is precipitated from the photosynthetic zone by certain bacteria and algae and will often be converted into bicarbonate in the hypolimnion, which increases the alkalinity. Elevation in concentration of carbon dioxide, nitrogen and phosphorus compounds, iron and manganese may also be expected in the hypolimnion (Neel, 1963; Reid, 1961; Love, 1961).

Another characteristic of reservoirs is the occurrence of density currents. Love (1961) describes density currents as the result of the differences in density of both inflowing and stored water. The difference in density of inflowing water is due to a variance in temperature, salinity and suspended matter.

Pfitzer (1954) has observed that the dissolved oxygen profile of a reservoir depends on the presence or absence of density currents. Neel (1963) states that density currents are responsible for "bottomset", the siltation of large areas of reservoir bottoms.

Receiving Streams

Several workers have indicated that streams receiving effluent from a reservoir are subject to alterations in flow rates, temperatures, dissolved oxygen content, and various radical alterations of water chemistry (Pearson *et al.*, 1968; Sylvester, 1963; Pfitzer, 1954; Neel, 1963; Love, 1961).

Pearson *et al.*, (1968) in their study of the Green

River below The Flaming Gorge Dam which is used primarily for power supply, recorded a general increase in volume of flow during summer, fall, and winter, and a decrease in spring flow in comparison to normal flow conditions. They recorded extreme diurnal fluctuations in flow due to power demands. This phenomenon has also been reported by Pfitzer (1954) and Neel (1963). Neel (1963) reports that flow in irrigation reservoirs may be stopped abruptly by closing the gates or increased to several thousand cubic feet per second in a very short time by the reverse action. He also indicates that a reduction in winter flow below normal unregulated levels usually occurs in irrigation reservoirs.

Due to the removal of suspended matter by reservoirs, previously turbid or periodically turbid streams can be clear the year round for varying distances below a reservoir, as was recorded below the Flaming Gorge Dam in Utah (Pearson et al., 1968). It is also possible to maintain a turbid effluent the year around when discharge is taken from near the bottom (Neel, 1963). Hilsenhoff (1971) reported increased siltation as a result of an impoundment with a hypolimnion drain.

Reservoirs can have definite effects on downstream water temperatures. Several workers have indicated that in reservoirs where water is withdrawn from the hypolimnion there is a delay in river temperature rise in the summer and a delay in river temperature decrease in the fall (Dendy and Stroud, 1949;

Dodds and Hisaw, 1925; Neel, 1963; Pearson et al., 1968; Eschmeyer and Smith, 1943; Sylvester, 1963; Churchill and Asce, 1958).

In general, dissolved oxygen is not a limiting factor in mountain streams (Armitage, 1958), but reservoir effluents have been reported to alter the dissolved oxygen content in receiving streams (Reid, 1961; Kittrell, 1959; Love, 1961; Pfitzer, 1954). Kittrell (1959) and Reid (1961) state that thermal stratification causes resistance to circulation and mixing of water, which reduces or prevents transport of oxygen from the epilimnion to the hypolimnion. Further reduction of oxygen content in the hypolimnion can occur due to oxidation of organic substances. Discharges from the hypolimnion, therefore, can result in a low dissolved oxygen content downstream. The opposite effect has been observed by Reid (1961) where water discharge from the oxygen rich epilimnion increased the dissolved oxygen content of the downstream water.

Other changes in water chemistry on streams receiving water from an impoundment have been recorded (Neel, 1963; Reid, 1961). Neel (1963) states that density currents may increase or decrease dissolved mineral discharge into receiving streams. If inflow water originates in cold rain or snow and drops its silt load near the convergence line the outflow may have a relatively low mineral content. If inflow water contains fine suspended sediment, it may add to the discharge mineral load.

Several workers have indicated that if releases are from near the bottom of the reservoir an increase in alkalinity and carbon dioxide will occur. Also slight increases in nitrogen and phosphorus compounds, iron, and manganese may be expected (Neel, 1963; Love, 1961; Reid, 1961). Large increases in phosphorus and nitrogen concentrations were recorded soon after impoundment of Mill Creek in Wisconsin (Hilsenhoff, 1971).

Biological

The biological composition of a river depends on such factors as speed of current, bottom type, temperature, width and depth, volume of flow, flora, fauna, and chemical characteristics of the water (Cummins, 1962; Gilpin and Brusven, 1970; Ricker, 1934). Alteration of these conditions by an impoundment can effect plant and animal life below an impoundment.

Pfitzer (1954) states that obstruction of rivers is not drastic nor overly important to aquatic life in the river below depending upon one important factor, that is the type and location of the water discharge outlet of the dam. A discharge outlet from the epilimnion or thermocline generally has little or no effect on the river below.

An outlet located deep in the hypolimnion has a great effect on the temperature and dissolved oxygen below the reservoir which can alter plant and animal life. Water discharged from deep in the hypolimnion, as is the case in irrigation reservoirs, often differ widely in character from that held at the reservoir surface. This can produce unnatural river discharge patterns, especially during the irrigation season (Neel, 1963; Love, 1961; Mackenthun and Ingram, 1967; Pearson et al., 1968, Pfitzer, 1954; Sylvester, 1963).

Streams receiving effluent from an irrigation reservoir are subject to daily fluctuations of water flow due to irrigation demands. Rapids and riffles are generally the most productive habitats for benthic organisms and can dry up or be greatly reduced in size when irrigation demands are low (Cummins, 1962; Neel, 1963). Neel (1963) reports that complete stopage or extremely reduced flow can imprison fish in isolated pools of low dissolved oxygen and limited food, and make them more susceptible to predation. Fluctuation in water flow such as a marked decrease in volume might expose sedentary forms of insects, clams and fixed oligochaetes making survival difficult (Taft and Shapovalor, 1935). In contrast, a sudden increase in volume might carry off bottom organisms (Maciolek and Needham, 1951; Thorup, 1970). The effect of reduction in volume of flow on animals depends upon time of occurrence in relation to the animals life-cycle (Hynes, 1958). Reduction of winter flow rates below normal unregulated levels downstream from an irrigation reservoir is common and often reduces the streams carrying capacity for many forms of life (Neel, 1963). Pennak and Van Gerpen (1947) determined that Ephemeroptera, Elmidae, and several families of Diptera are adapted to a wide range of current speed and exposure in stream habitats. This could be significant in streams subject to fluctuation in flow.

Pearson et al. (1968) observed a near failure of Baetis sp.I (Ephemeroptera: Baetidae) summer generations due in part to high flows (low temperatures were also recorded during this time). As a result of extreme diurnal fluctuations in flow due to power demands it was indicated that the invertebrate community, particularly in the first 20 kilometers below the dam, may never stabilize and will continually be in stages of succession as varying conditions favor some groups, then others. A transition zone was observed with a recovery zone downstream where the river benthic community was similar to preimpoundment.

Amount of discharge is one of the chief factors which determine the number of animals drifting past a sampling point and if the volume of water flowing through a drift sampler increases, the size of the catch increases (Elliott, 1967). Other factors reported to influence the magnitude of drift are water temperature, current velocity, stage of life cycle, population density, and growth rate (Dimond, 1967; Elliott, 1967; Waters, 1962). Elliott (1967) indicated that variations in water velocity appeared to have little effect on numbers of benthic organisms present in drift, but Minshall and Winger

(1968) state that a decrease in stream flow increases drift. It is possible that reduction of current velocity alters the water-substrate interface and diffusion gradient, creating a respiratory stress. Reduction of volume results in a reduction in living space, as a result there is an increase in activity which could be responsible for an increase in drift. Minshall and Winger (1968) state that "Irrigation and reservoir management practices tend to cause periodic fluctuations in local stream levels, particularly during the summer months, when stream flows already are minimal. These reductions and failure to maintain certain low-flow standards probably result in removal of large numbers of benthic invertebrates."

Anderson and Lehmkuhl (1968) reported that catastrophic drift from a sudden increase of flow displaced large numbers of benthic organisms but they indicated that the removal of allochthonous food could be more detrimental to benthos than the direct mortality caused by catastrophic drift. Chapman and Demory (1963) and Gilpin and Brusven (1970) have indicated that mayfly nymphs feed mainly on algae and detritus. Therefore, a reduction in available food increases the searching behavior causing more individuals to be passively caught in the current (Dimond, 1967).

Reservoirs can have definite effects on stream temperature. Numerous workers have indicated the effects that temperature has on aquatic organisms. Dodds and Hisaw (1925) indicate that temperature is the prime factor in determining altitudinal zonation. Ide (1935) also states that water temperature of a stream limits the distribution of mayflies, within which are other limiting factors such as the rate of flow, bottom type and vegetation.

Ide (1935) found an increase in the number of Ephemeroptera species downstream from the source of the stream where greater temperature fluctuations occurred. Vincent (1967) reported observations by Sprules that as the average summer temperature increased, the number of Ephemeroptera and Trichoptera species increased while the Plecoptera decreased. Ide indicates the absence of certain species at the upper stations seemed to be due to the failure of the water to rise to a temperature sufficiently high to allow the individuals of those species to grow and complete their development. Increase in the number of species downstream is due to higher temperatures in the lower parts of the stream. He further indicates that the increase in numbers results from the addition of species to those already found. Only two species found near the source were not collected below.

In the Green River an increase in the number of taxa and a decrease in the density of bottom fauna was noted downstream from the dam (Pearson _et al._, 1968). They stated that a reduction in standing crop of Simulidae at 11.7 km below the dam may have been due to low water temperatures. They observed a near failure of Baetis sp. I summer generations due in part to low water temperatures induced by reservoir effluent.

A pre-impoundment survey recorded 43 and 32 species of aquatic insects before impoundment in different forks of a river. Only 17 and 13 species respectively were recorded after impoundment. They indicated temperature as being significantly different after impoundment (Pfitzer, 1954).

Cold water from low levels in Fontana Reservoir have been reported by Dendy and Stroud (1949) to have drastically altered the fish environments in Cheoah and Calderwood Reservoirs and in the Little Tennessee River below. Once productive warm-water fisheries existing in these waters were largely eliminated by impoundment. An observation very similar to this was reported by Eschmeyer and Smith (1943) below Norris Dam. Due to cold water effluent from Norris Reservoir they found that most warm-water species of fish in the tailwaters had a condition of the ovaries in which the eggs are held long beyond spawning time and new eggs are formed around the old egg mass. Therefore, normal spawning did not take place and many minnow species disappeared.

Needham *et al*. (1935) reported that low water temperature delayed the hatching of Baetis eggs, but they did not determine minimum hatching or lethal temperatures. Pearson reported that below the Flaming Gorge dam, Baetis sp. I did not have a summer generation in the first 11.7 kilometers below the dam due to high flows and low water temperatures. Hatching was delayed until temperatures began to rise during fall overturn.

Flattum (1963) recorded that a definite relationship exists between the rate of embryonic development of eggs and temperature in Hexagenia limbata (Serville) (Ephemeroptera: Ephemeridae). The cooler the temperature (to a critical point) the slower the rate of embryonic development and vice versa. Richard's (1959) defined temperature threshold as the temperature below which the processes of developing, hatching, etc., does not occur. He determined that there is not just one threshold but many thresholds. For example the threshold for actual embryonic development is considerably lower than the threshold for hatching.

Nebeker's (1971a) study of Pteronarcys dorsata Newman (Pteronarcidae: Plecoptera) indicated that at temperatures below five degrees centigrade food consumption was greatly decreased and there was no emergence, even though nymphs appeared healthy. Nebeker (1971b) stated that water temperature has a direct effect on the emergence time of aquatic insects, even though photoperiod may be the initial stimulus. Emergence of stoneflies occurred four to six months earlier in lower warmer waters than in colder waters at higher elevations. Nebeker (1971b) reported observations by Jackson confirming the fact that insects which normally emerge only in spring and summer will emerge the year around below artificially heated outflows.

Lennon (1941) reported that increased drift occurs upon a rise in water temperature. Neither absolute temperature nor rate of temperature change appeared to effect the time of increase, but temperature may affect the magnitude of the nocturnal drift (Waters, 1962).

Temperature is an extremely important factor influencing seasonal life histories (Hartland-Rowe, 1964). Hynes (1961) has divided species which have a seasonal life cycle (i.e. those in which there is a seasonally changing size distribution) into two categories, slow and fast. The slow category is that in which the eggs hatch soon after being laid and in which larval growth is slow and steady over a long period. The fast category is that in which there is rapid growth after a long egg-diapause or an intermediate generation.

Probably the most common reservoir effect on turbidity is complete or near-complete removal of carried in silt resulting in clear streams below a reservoir (Neel, 1963). This can produce excellent conditions for growth of periphyton and phytoplankton due to increased light penetration. Sedimentation and high turbidity reduces light penetration that can adversely affect agal growth (Reid, 1961; Ulfstrand, 1967). This can have a direct affect on the available food supply for fish, insects and other aquatic organisms (Armitage, 1958; Vincent, 1967).

Various changes in water chemistry, on streams receiving water from an impoundment, have been recorded. During summer stratification in the Kerr Reservoir on the Roanoke River in Virginia greatly reduced dissolved oxygen concentrations were recorded in the lower depths. This resulted in low dissolved oxygen in the tailwaters due to the hypolimnion drain. The low dissolved oxygen was indicated to be detrimental to certain species of fish spawning nearby (Love, 1961). Pearson et al., (1968) recorded six ppm dissolved oxygen or higher at all stations below the Flaming Gorge Dam, with the highest levels at the sampling station closest to the dam where summer water temperatures were low, water clear, and algae growth extensive. Low dissolved oxygen has been reported to occur in isolated pools as a result of stoppage or reduction in flow from irrigation reservoirs, and can be detrimental to fish and other aquatic organisms trapped in the pool.

The bicarbonate ion which is measured in terms of alkalinity is utilizable by plants for use in photosynthesis and is an apparent measure of water fertility (Armitage, 1958; Smith, 1968). It has been reported that releases from the hypolimnion generally have elevations in concentrations of bicarbonate, free carbon dioxide, and nitrogen and phosphorus compounds. Due to the high nutrient content, hypolimnion releases generally stimulate phytoplankton or other algal growth (Armitage, 1958; Neel, 1963; Vincent, 1967). Vincent observed an increase in biomass and numbers in lower riffles of the Gibbon River and indicated that the increase was probably due to greater ion concentration and alkalinity.

DESCRIPTION OF STUDY AREA

The Cle Elum River and associated reservoir are located on the east side of the Cascade Mountains, east of Snoqualmie Pass in Washington. The Cle Elum River originates at an elevation above 4,000 feet and flows approximately 35 miles in a southeasterly direction to join the Yakima River at an elevation of 1,900 feet. The Cle Elum River drains about 202 square miles and discharges over 635,000 acre-feet annually. The general topography of the drainage basin is one of deep, steep sided valleys. The mountains to a large extent are comprised of ancient sedimentary rocks, most are folded and at least partially metamorphosed. Intrusions of large granitic batholiths are also common (Franklyn and Dyrness, 1965).

The Cle Elum River is dammed about six miles above its confluence with the Yakima River at an elevation of about 2,100 feet (Fig. 1). The dam is regulated to maintain flow in the Yakima River for agricultural purposes. The dam was constructed during 1931 and 1933, the closure was complete on February 2, 1932. Before 1931 there was a timber crib dam with a height of about ten feet at the same site. It was built about 1906 and provided about 26,000 acre-feet of storage. The original lake had a surface area of about 2,000 acres (Newell, 1931).

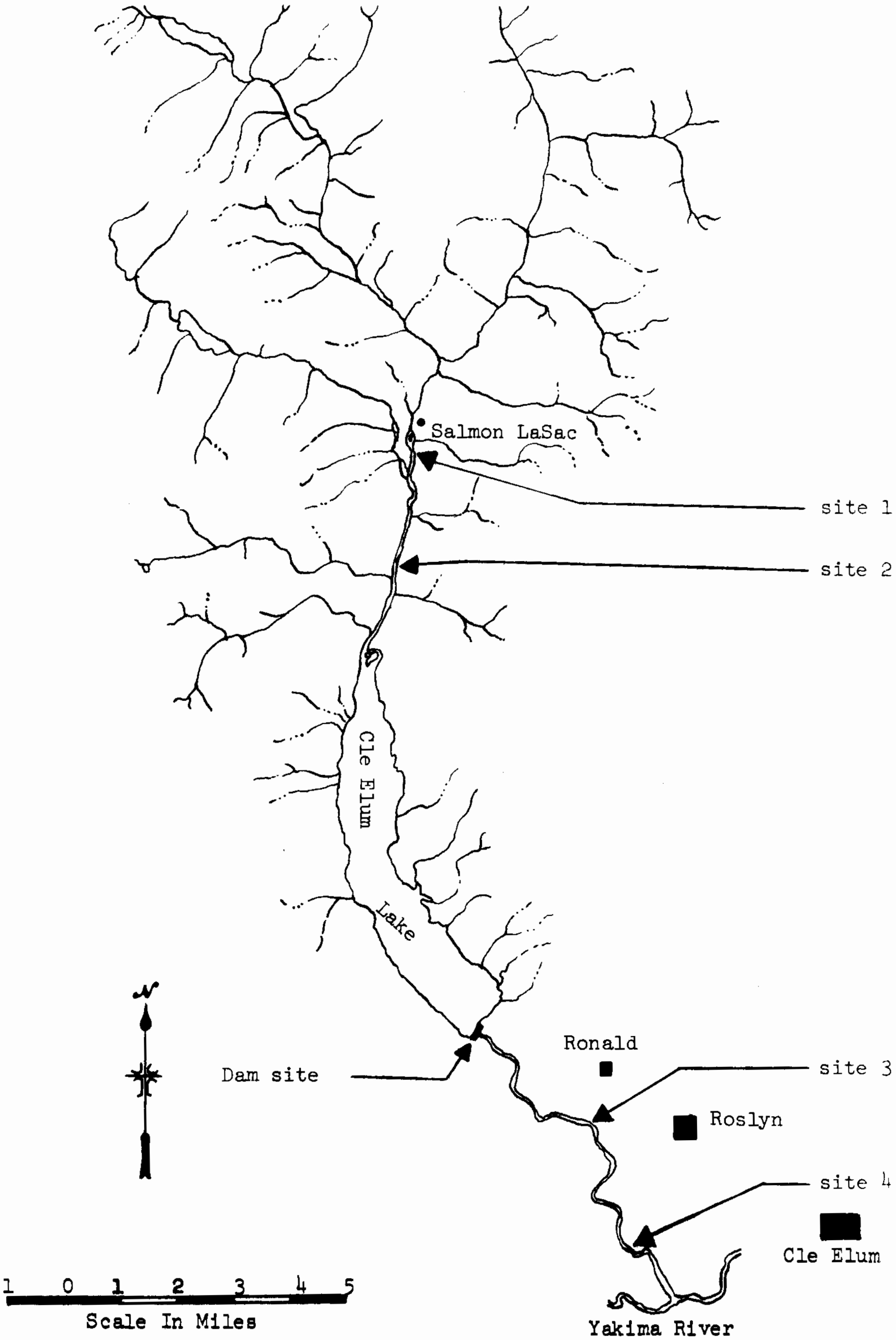

Fig. 1. Map of Cle Elum River drainage with study sites labeled.

The present reservoir is approximately seven miles long with a maximum pool elevation of 2,240 feet. The storage capacity is about 436,900 acre-feet, of which 93,000 acre-feet are located below the draw down point and unavailable for irrigation and river flow. This means that the discharge outlet tunnel, which is located at an elevation of 2,110 feet, is deep in the reservoir but above the bottom as is shown in Fig. 2.

There are numerous papers on the terrestrial vegetation of Washington. The paper by Franklin and Dyrness (1969) on the _Vegetation of Oregon and Washington_ was found to be the most adequate and is used here in discussing forest zonation.

The confluence of the Cle Elum River with the Yakima River is at an altitude of about 1,900 feet which is the upper limits of the "_Pinus ponderosa_ Zone". In this zone there are a few seral stands of Quaking aspen (_Populus tremuloides_ Michx.), Western larch (_Larix occidentalis_ Nutt.), and an apparent grading in of Grand fir (_Abies grandis_ (Dougl.) Lindl.), and Douglas-fir (_Pseudotsuga menziesii_ (Mirb.) Franco). Streamside vegetation includes stands of willow (_Salix_ spp.) and alder (_Alnus_ spp.).

There is a definite new zonal succession appearing between the Yakima River and the Cle Elum dam within a distance of approximately six miles with a rise in elevation of about 200 feet. This is the "_Pseudotsuga menziesii_ Zone" or Douglas-fir

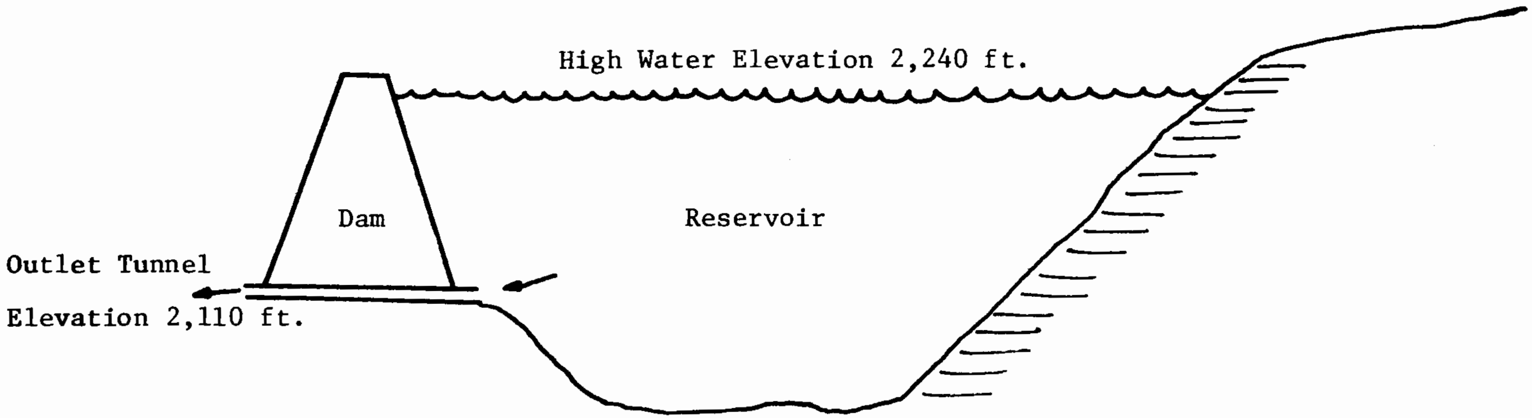

Fig. 2. Schematic cross section of the Cle Elum Reservoir (Rogers Engineering Co., Inc., 1969).

zone. In this zone there are many seral stands of Douglas-fir, Ponderosa pine (*Pinus ponderosa* Laws), and Western Larch.

The area surrounding the reservoir is very disturbed and contains many seral communities. Probably an "*Abies grandis* Zone" or Grand fir zone does exist, but it is weakly developed. In this zone there are many seral stands of Grand fir, Ponderosa pine, Western larch, and Douglas-fir.

Above the reservoir about one mile, at an elevation of about 2,200 feet, there is a grading in of the "*Tsuga heterophylla* Zone" or Western hemlock zone. This zone continues up through the highest study site which is approximately three miles above the reservoir at an elevation of 2,360 feet. The most common forest tree species found within this zone are Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Grand fir, and Western red cedar (*Thuja plicata* Donn).

Two study sites were established above and below the reservoir, respectively. All four sites are riffles and were chosen because they had similar substrate size. The sampling sites are plotted by number in Fig. 1 and the physical and chemical characteristics of the riffles are shown in Table 1.

Site I (Fig. 3) is located 16 miles above the confluence with the Yakima River and three miles above the reservoir. Samples were taken from approximately 200 feet of the riffle. The riffles average width varied between 30 and 110 feet and the average depth varied between 0.6 and 3.0 feet. The bottom

TABLE 1

PHYSICAL AND CHEMICAL FACTORS AT EACH RIFFLE

ENVIRONMENTAL FACTORS		Site I	Site II	Site III	Site IV
Physical					
elevation (ft)		2360	2280	2080	2000
length (ft)		200	150	200	150
ave. width (ft)					
range		30-110	60-130	30-120	30-150
ave. depth (ft)					
range		0.6-2.7	1.0-3.0	0.7-2.8	0.5-3.0
current speed					
(ft/sec) ave.		3.1	2.4	2.9	3.3
range		2.2-5.3	1.1-5.0	0.9-6.1	0.9-6.1
volume (ft^3/sec)					
range			137-1872		15-2693
turbidity (JTU)		0.0	0.0	0.0	0.0
temperature (C)					
ave.		7.4	8.1	9.3	9.2
range		0.0-15	1.0-15	1.0-17	1.0-17
Chemical					
pH	ave.	7.27	7.28	7.30	7.42
	range	6.92-7.90	6.90-7.90	7.00-7.65	7.04-8.10
D.O. (ppm)	ave.	11	11	11	11
	range	10-15	9-15	9-15	9-15
CO_2 (ppm)	ave.	5	5	5	5
	range	5-5	5-5	5-5	5-5
alkalinity (ppm)	ave.	25	25	34	36
	range	15-50	15-50	21-60	21-80
hardness (ppm)	ave.	22	21	25	28
	range	14-35	15-35	15-43	21-50
nitrogen (ppm)	ave.	3.9	3.9	3.8	3.7
	range	1.0-5.1	1.5-8.3	1.5-6.0	1.6-5.5
phosphate (ppm)	ave.	0.06	0.05	0.05	0.04
	range	0.02-0.13	0.03-0.12	0.03-0.11	0.03-0.15

Fig. 3. Site I, upstream view (March, 1971).

Fig. 4. Site II, upstream view (March, 1971).

is composed primarily of small cobble, coarse pebbles and some large cobble (Table 2) with little or no silt.

Site II (Fig. 4) is located one mile above the reservoir at an elevation of about 2,280 feet. Samples were taken from approximately 150 feet of the riffle. The riffle varied between 60 and 130 feet wide and the average depth varied between 0.6 and 3.0 feet deep. The bottom is composed primarily of small cobble, coarse pebbles and some large cobble. A little silt accumulates during low flow periods.

Site III (Fig. 5) is located two and one-half miles below the Cle Elum River Dam at an elevation of about 2,080 feet. Samples were taken from approximately 200 feet of the riffle. The riffle varied between 30 and 120 feet wide and the average depth varied between 0.7 and 2.8 feet deep. The bottom is composed primarily of small cobble, coarse pebbles and some large cobble. A little silt accumulates during low flow periods.

Site IV (Fig. 6) is located five miles below the dam at an elevation of about 2,000 feet. Samples were taken from approximately 150 feet of the riffle. The riffle varied between 30 and 150 feet wide and the average depth varied between 0.5 and 3.0 feet deep. The bottom is composed primarily of small cobble, coarse pebbles and some large cobble with little or no silt.

TABLE 2

MODIFIED WENTWORTH'S SEDIMENT CLASSIFICATION*

1. Boulder: (more than 256 mm) more than 10"
2. Large Cobble: (126-256 mm) 5 - 10"
3. Small Cobble: (64-26 mm) 2-1/2 - 5"
4. Coarse Pebble: (6-64 mm) 1/4 - 2-1/2"
5. Fine Pebble: (1-6 mm)
6. Sand: (0.062-1 mm)
7. Silt: (0.004-0.062 mm)
8. Clay: (less than 0.004 mm)
9. Ooze: (particulate organic and inorganic material)

*Gilpin and Brusven (1970).

Fig. 5. Site III, upstream view (March, 1971).

Fig. 6. Site IV, upstream view (March, 1971).

METHODS AND MATERIALS

The method of analysis was based on a comparison of four morphologically similar riffles, two above and two below the reservoir. Study sites were chosen on similarities of substrate size which was visually estimated using a modification (Gilpin and Brusven, 1970) of Wentworth's sediment classification (Welch, 1948) (Table 2). The two riffles above were used as controls to compare the two riffles below as no pre-impoundment information is available. Sites I and II are above the reservoir and sites III and IV are below (Fig. 1).

Physical

Turbidity was measured in Jackson Turbidity Units - Formazin Standard with a Hach Portable Engineer's Laboratory (Hach Chemical Company, Ames, Iowa). The float technique was used to measure current velocity in feet per second (Welch, 1948). Volume of flow was calculated at sites II and IV in cubic feet per second using the average width, depth, and velocity (Welch, 1948). Temperature was recorded at the time each collection was made.

Chemical

Water chemistry analyses were made at each site for alkalinity, total hardness, nitrogen (nitrate and nitrite), phosphate (ortho and meta), carbon dioxide, dissolved oxygen, and pH with a Hach Portable Engineer's Laboratory.

Biological

Quantitative samples of benthic organisms were taken with a Surber square-foot bottom sampler. Three samples were taken at each site on as close to a weekly basis as possible except during the winter when samples were taken once a month. Mayflies were identified to species whenever possible. The Mayflies of Idaho, by Steven L. Jensen (1966), was used in classifying specimens.

RESULTS

Physical

Temperature. The results of taking periodic temperature readings are recorded in Table 3. The average temperatures above and below are compared in Fig. 7 and indicate that during peak irrigation demands in the summer there was an inversion in the temperature profile. From the middle of July, 1970 through August, 1970 the river water was colder below the reservoir than above. In the fall the reservoir slowed the rate of water temperature decrease below the impoundment in comparison to the decrease in temperature above.

The average temperature for the year and the yearly range for each site is given in Table 1. The average temperature at site I was 7.4° C and ranged from a minimum of 0.0 to a maximum of 15.0° C. The average temperature at site II was 8.1° C and ranged from 1.8 to 15.0° C. The average temperature at site III was 9.3° C and ranged from 1.0 to 17.0° C. The average temperature at site IV was 9.2° C and ranged from 1.0 to 17.0° C.

Velocity. The results of measuring current velocity in feet per second is listed in Table 3 and the average above is compared to below in Fig. 8. There is a greater current velocity below the reservoir in the summer due to irrigation

TABLE 3

RESULTS OF TEMPERATURE, CURRENT VELOCITY, AND VOLUME OF FLOW

	Temperature (° C)				Current Velocity (ft/sec)				Volume (ft^3/sec)	
Date	I	II	III	IV	I	II	III	IV	II	IV
1970										
5/2	5.0	5.0	6.5	7.0	2.6	2.2	0.9	0.9	500	15
5/8	4.0	5.0	7.5	7.0	2.7	2.5	1.0	1.0	610	20
5/21	3.0	4.9	10.0	10.0	3.4	3.3	1.2	1.1	860	30
5/30	6.0	7.0	11.0	10.1	3.0	2.9	1.4	1.4	720	47
6/6	7.0	7.0	9.0	9.0	3.8	3.7	2.5	2.8	900	560
6/18	9.0	10.0	14.3	14.5	3.5	3.3	3.5	3.7	860	977
7/2	12.8	8.1	10.1	10.0	4.1	2.7	4.4	4.0	635	1158
7/9	11.5	13.0	17.0	17.0	3.3	3.7	5.3	5.4	968	1658
7/16	15.0	15.0	12.0	13.0	4.4	2.9	5.1	5.7	718	2693
7/23	13.0	13.0	9.0	9.0	3.4	2.3	6.1	6.1	584	2685
7/30	14.0	14.0	10.0	10.0	3.4	2.2	5.0	5.2	537	1960
8/6	13.0	13.5	11.0	10.0	2.8	2.1	5.4	5.6	448	2293
8/19	12.0	14.0	14.0	14.2	2.2	1.7	4.8	5.6	137	2387
9/5	10.0	11.0	15.0	15.0	2.5	2.4	4.2	4.9	364	1933
9/12	9.5	11.0	14.0	13.5	2.5	1.5	3.6	4.8	200	1652
9/26	9.0	10.0	12.0	12.0	2.9	1.7	2.4	4.8	373	1352

TABLE 3 (Continued)

Date	Temperature (° C) I	II	III	IV	Current Velocity (ft/sec) I	II	III	IV	Volume (ft^3/sec) II	IV
1970										
10/4	8.5	10.2	12.0	12.0	2.5	1.1	1.2	2.5	170	422
10/11	8.3	9.0	10.0	10.0	2.7	2.1	1.2	4.4	431	498
10/18	6.8	7.2	9.0	8.5	2.2	1.3	1.1	1.4	191	46
11/1	3.2	5.0	8.0	6.0	2.6	1.3	1.0	1.1	189	28
11/14	3.0	3.5	7.0	7.5	2.6	1.9	1.0	1.1	271	29
12/29	0.0	1.0	1.0	1.0	2.7	1.6	2.5	1.4	352	32
1971										
1/31	1.0	4.0	4.0	4.0	5.3	5.0	4.0	3.0	1872	48
2/27	1.0	1.0	1.0	1.0	2.8	2.5	2.0	1.7	578	60
3/30	2.0	3.5	4.0	4.0	2.6	2.2	2.1	2.3	373	81
4/30	3.8	4.0	4.5	4.5	5.6	5.4	6.0	5.9	714	2610

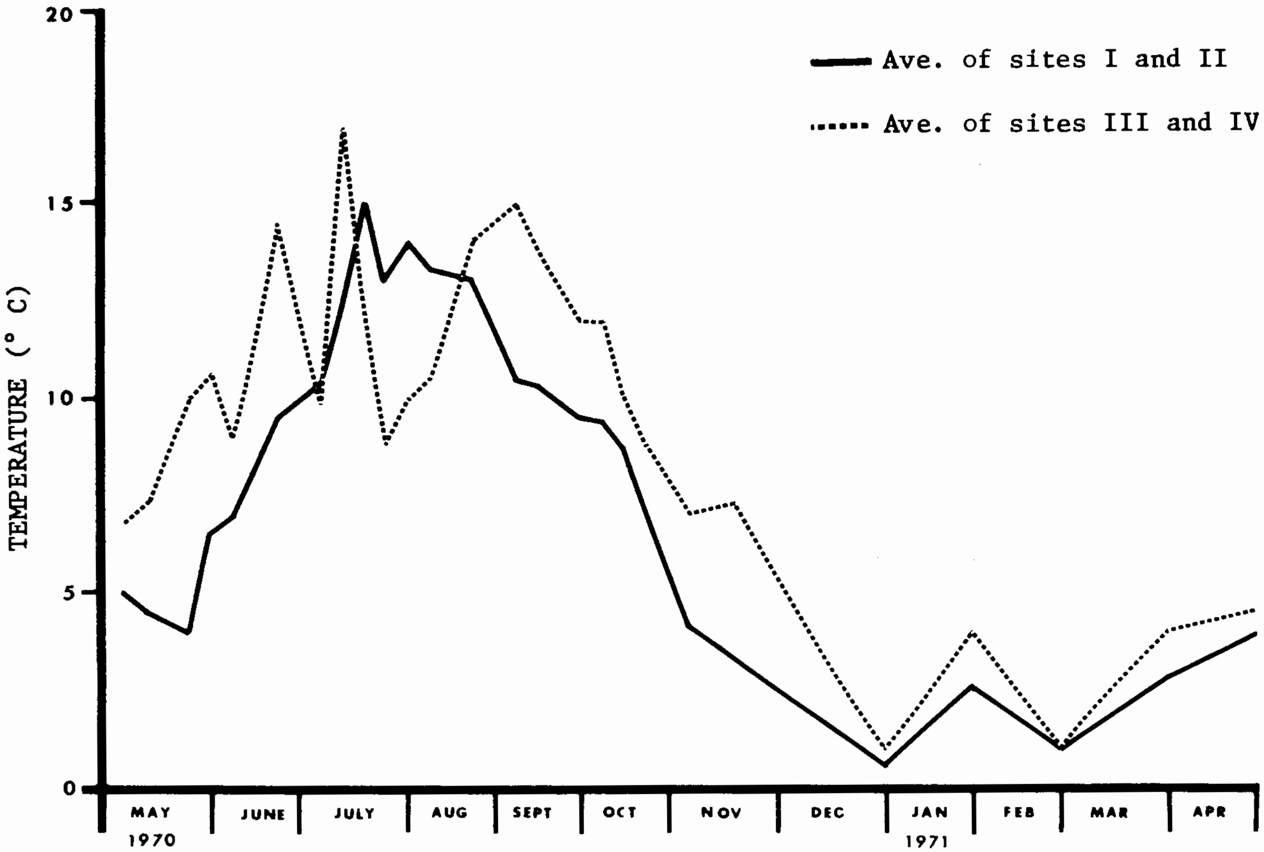

Fig. 7. A comparison of water temperature above and below the reservoir.

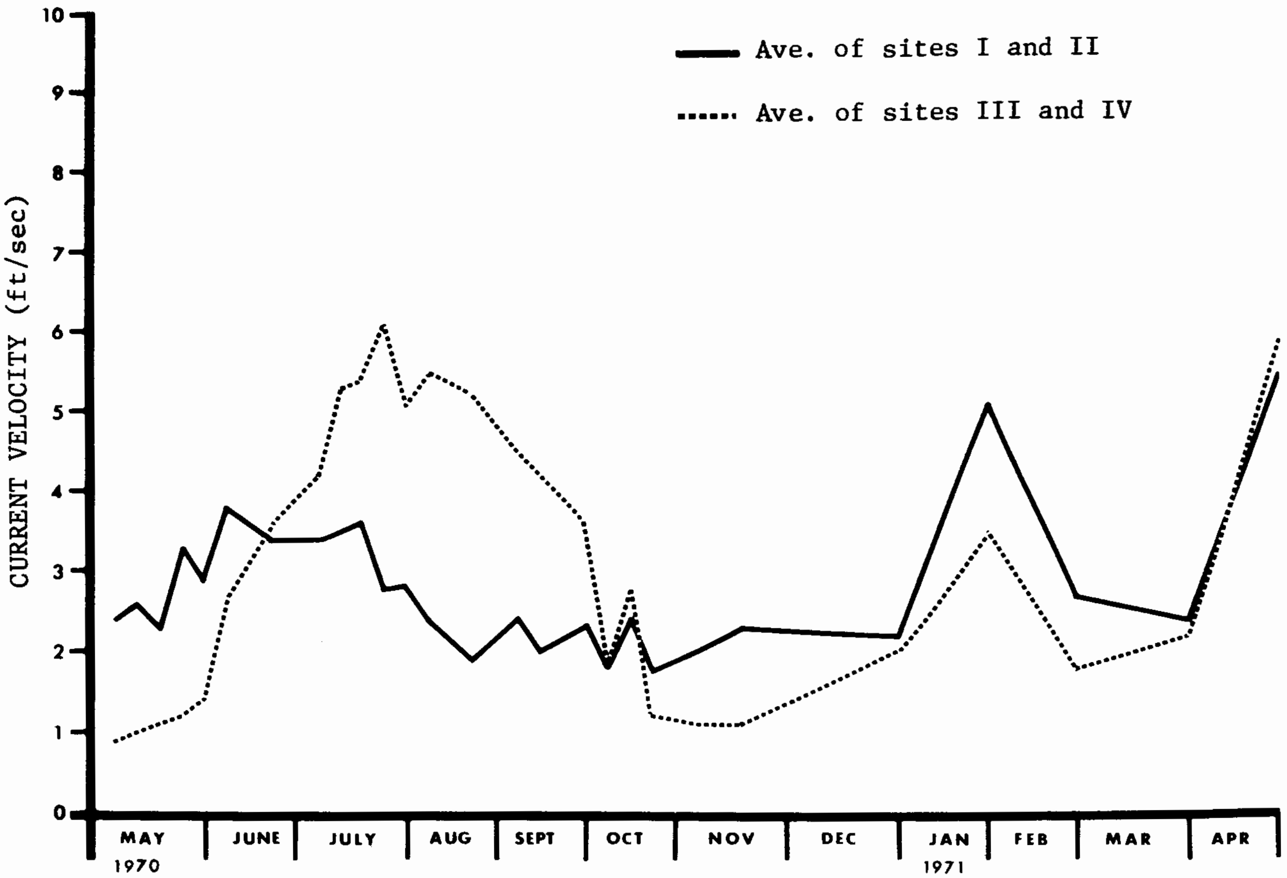

Fig. 8. A comparison of water velocity above and below the reservoir.

demands at that time. During the non-irrigating seasons the reverse is true, current velocity is greater above than below the reservoir. The results of applying a T-test (Table 4) indicates no significant difference between any sites. Therefore, the net effect of current velocity throughout the year was similar at each site although seasonally different.

The average current velocity for the year and the yearly range for each site is presented in Table 1. At site I the average velocity was 3.2 feet per second (ft/sec) and ranged from 2.2 ft/sec to 5.6 ft/sec. The average velocity at site II was 2.5 ft/sec and ranged from 1.1 to 5.4 ft/sec. The average velocity at site III was 3.0 ft/sec and ranged from 0.9 to 6.1 ft/sec. At site IV the average for the year was 3.4 ft/sec and ranged from 0.9 to 6.1 ft/sec.

Volume of Flow. The results of monitoring the volume of flow in cubic feet per second (CFS) is presented in Fig. 9 and recorded in Table 3. Volume of flow was measured only at site II above the reservoir and at site IV below the reservoir. It is apparent that there is a great variation in the volume of flow. The results of applying a T-test indicates a significant difference in volume of flow between sites II and IV. During the non-irrigating season there was a reduction in flow below the impoundment in comparison to "normal" flow above. During the summer which is the peak irrigating season there was a tremendous increase in volume of flow below the impoundment

TABLE 4

RESULTS OF T-TEST COMPARING MAYFLY POPULATIONS, CHEMICAL AND PHYSICAL FACTORS BETWEEN SITES[1]

	Above I/II	I/III	I/IV	II/III	II/IV	Below III/IV	Average I&II/III&IV
Biological							
Total mayflies	1.60	6.05*	6.39*	7.54*	6.53*	0.44	9.52*
Baetis spp.	0.07	4.51*	4.68*	4.51*	4.65*	0.13	7.41*
Cinygmula spp.	0.16	0.44	2.88*	0.32	2.77*	2.49*	3.21*
Ephemerella flavilinea	1.86	3.70*	5.63*	3.05*	5.07*	2.10*	6.57*
Ephemerella doddsi	6.76*	1.86	0.13	5.52*	5.60*	1.89	5.29*
Ephemerella inermis	2.82	7.31*	2.03*	5.60*	0.23	5.35*	7.42*
Pseudocloeon spp.	0.19	3.80*	5.06*	3.68*	4.99*	2.86*	7.34*
Rhithrogena hageni	0.37	3.68*	6.35*	3.60*	6.22*	0.91	7.29*
Chemical							
Alkalinity	0.21	5.06*	4.54*	5.10*	4.61*	1.01	
Physical							
Current velocity	0.11	0.02	0.03	0.09	0.13	0.05	
Volume of flow							2.76*

[1]Significant difference was figured at the 5% level.

*Indicates a significant difference.

Fig. 9. A comparison of the volume of flow above and below the reservoir.

in comparison to "normal" flow above.

The minimum and maximum flow rates are listed in Table 1. Above the reservoir the minimum volume of flow recorded was 137 CFS on August 19, 1970. The maximum volume of flow recorded was 1,872 CFS on January 31, 1971. Below the reservoir the minimum volume of flow recorded was 15 CFS on May 2, 1970. The maximum volume of flow recorded was 2,693 CFS on July 16, 1970.

Turbidity. Turbidity remained zero JTU throughout the entire sampling period both above and below the reservoir (Table 1).

Chemical

Alkalinity. The results of measuring alkalinity are recorded in Table 5. Alkalinity exhibited similar seasonal cycles both above and below the reservoir (Fig. 10). During the spring of 1970 the alkalinity was slightly higher below the reservoir than above. It was approximately equal during the summer. Beginning in October, 1970 there was an increase in alkalinity both above and below the reservoir. It can be seen that there was a much greater increase in alkalinity below the reservoir than above.

The average alkalinity for the year and the yearly range is presented in Table 1. The average alkalinity at site I and site II was 25 ppm and ranged from 15 to 50 ppm. At site III the average alkalinity was 34 ppm and ranged from 21 to 60 ppm.

TABLE 5

RESULTS OF ALKALINITY, TOTAL HARDNESS AND pH

Date	Alkalinity (ppm)				Total Hardness (ppm)				pH			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1970												
5/2	30	22	30	25	25	25	25	25	7.15	7.06	7.50	7.50
5/8	26	25	32	31	25	21	30	25	7.16	7.51	7.25	7.30
5/21	21	21	35	35	21	20	30	30	7.10	7.10	7.30	7.20
5/30	25	21	44	30	20	20	30	25	7.20	7.10	7.20	7.30
6/6	20	16	40	30	14	16	30	37	7.05	7.10	7.29	7.41
6/18	20	16	30	30	20	16	25	21	7.10	7.30	7.30	7.40
7/2	20	20	24	25	20	16	20	20	7.10	7.10	7.00	7.15
7/9	17	15	25	24	15	15	22	20	7.28	7.10	7.10	7.25
7/16	15	15	25	25	15	15	20	20	7.02	6.90	7.06	7.04
7/23	21	21	21	21	15	15	20	20	7.30	7.27	7.25	7.25
7/30	25	25	29	29	20	19	20	20	7.30	7.38	7.40	7.50
8/6	27	28	25	25	20	20	24	25	7.03	7.21	7.21	7.25
8/19	25	28	25	25	20	24	20	20	7.35	7.45	7.20	7.35
9/5	20	25	25	25	22	22	21	21	7.50	7.20	7.15	7.50
9/12	20	25	25	25	20	20	20	23	7.00	7.20	7.30	7.30
9/26	20	20	30	25	20	20	15	25	6.92	7.20	7.00	7.13

TABLE 5 (Continued)

Date	Alkalinity (ppm)				Total Hardness(ppm)				pH			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1970												
10/4	25	27	35	30	20	23	30	25	7.39	7.35	7.48	7.25
10/11	20	20	35	35	21	21	25	24	7.60	7.25	7.40	7.50
10/18	25	26	60	58	20	40	40	39	7.45	7.40	7.25	7.65
11/1	15	15	55	60	25	20	40	45	7.25	7.21	7.40	7.70
11/14	25	25	50	65	25	20	43	50	7.40	7.35	7.52	7.85
12/29	50	50	34	34	35	35	30	30	7.90	7.90	7.40	7.40
1971												
1/31	30	30	39	80	20	20	30	40	7.20	7.30	7.30	8.10
2/27	35	35	35	65	25	30	30	35	7.40	7.40	7.40	7.50
3/30	40	40	35	55	30	30	30	35	7.40	7.40	7.50	7.60
4/30	30	30	30	30	30	20	30	30	7.45	7.50	7.65	7.60

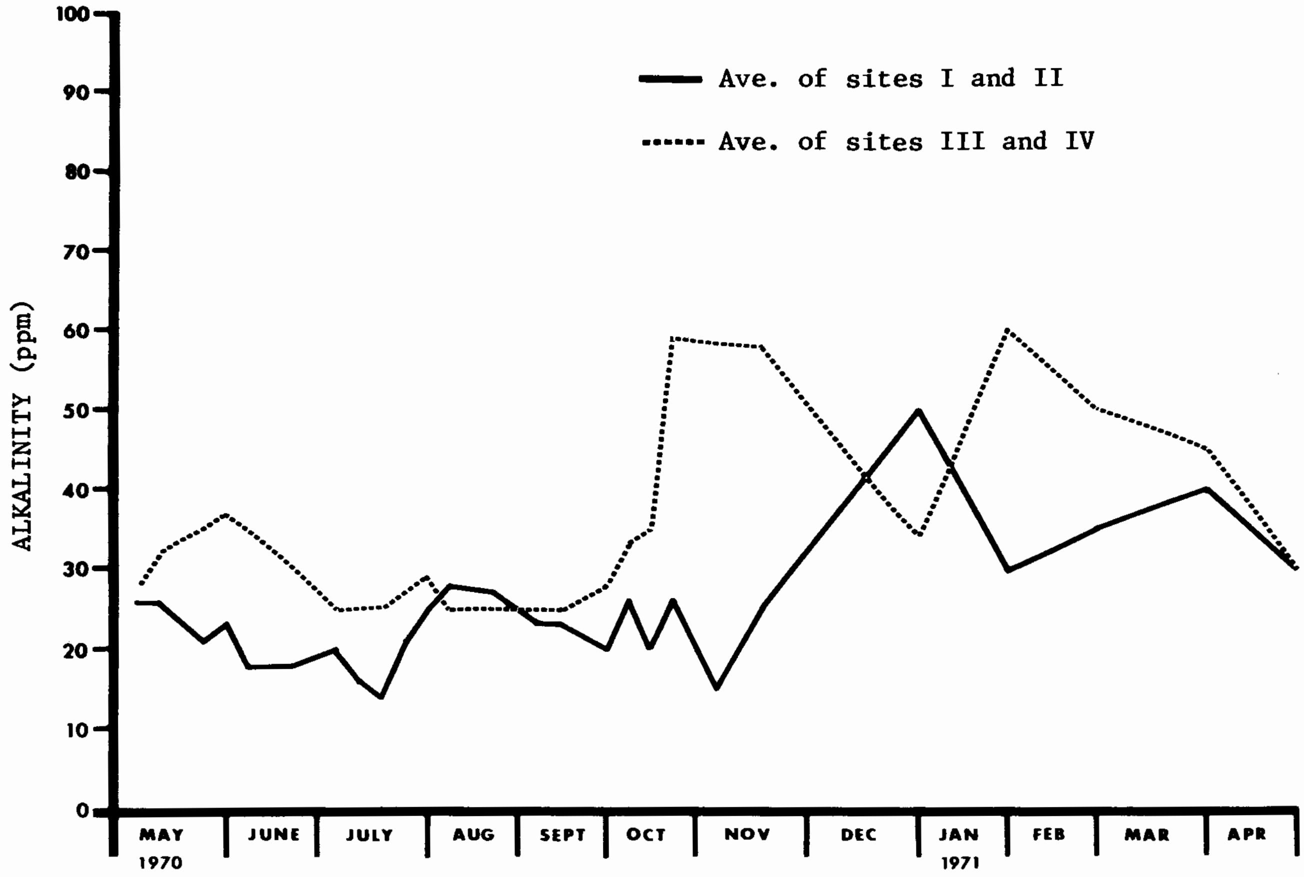

Fig. 10. A comparison of alkalinity above and below the reservoir.

The average alkalinity at site IV was 36 ppm and ranged from 21 to 80 ppm. A T-test (Table 4) indicates that there was no significant difference between sites I and II above the reservoir and no significant difference between sites III and IV below the reservoir. But any time a site above the reservoir was compared with a site below the reservoir there was a significant difference.

Total Hardness. The results of measuring total hardness are listed in Table 5. Hardness exhibited seasonal trends above and below the reservoir (Fig. 11). It was at its lowest during the summer months and at its highest during the winter. Total hardness was slightly higher below the reservoir during the spring and approximately equal at all four sites during the summer. In mid October, 1970 there was an increase in hardness below the reservoir. An increase in hardness above the reservoir did not occur until mid November, 1970, one month later. The magnitude of increase was greater below the reservoir than above throughout the winter.

The average hardness for the year and the yearly range is presented in Table 1. The yearly average for hardness at site I was 22 ppm and ranged from 15 to 35 ppm. At site II the yearly average was 21 ppm and ranged from 15 to 35 ppm. The yearly average at site III was 25 ppm and ranged from 15 to 43 ppm. At site IV the yearly average was 28 ppm and ranged from 20 to 50 ppm.

Oxygen. Dissolved oxygen concentrations were 9 ppm or

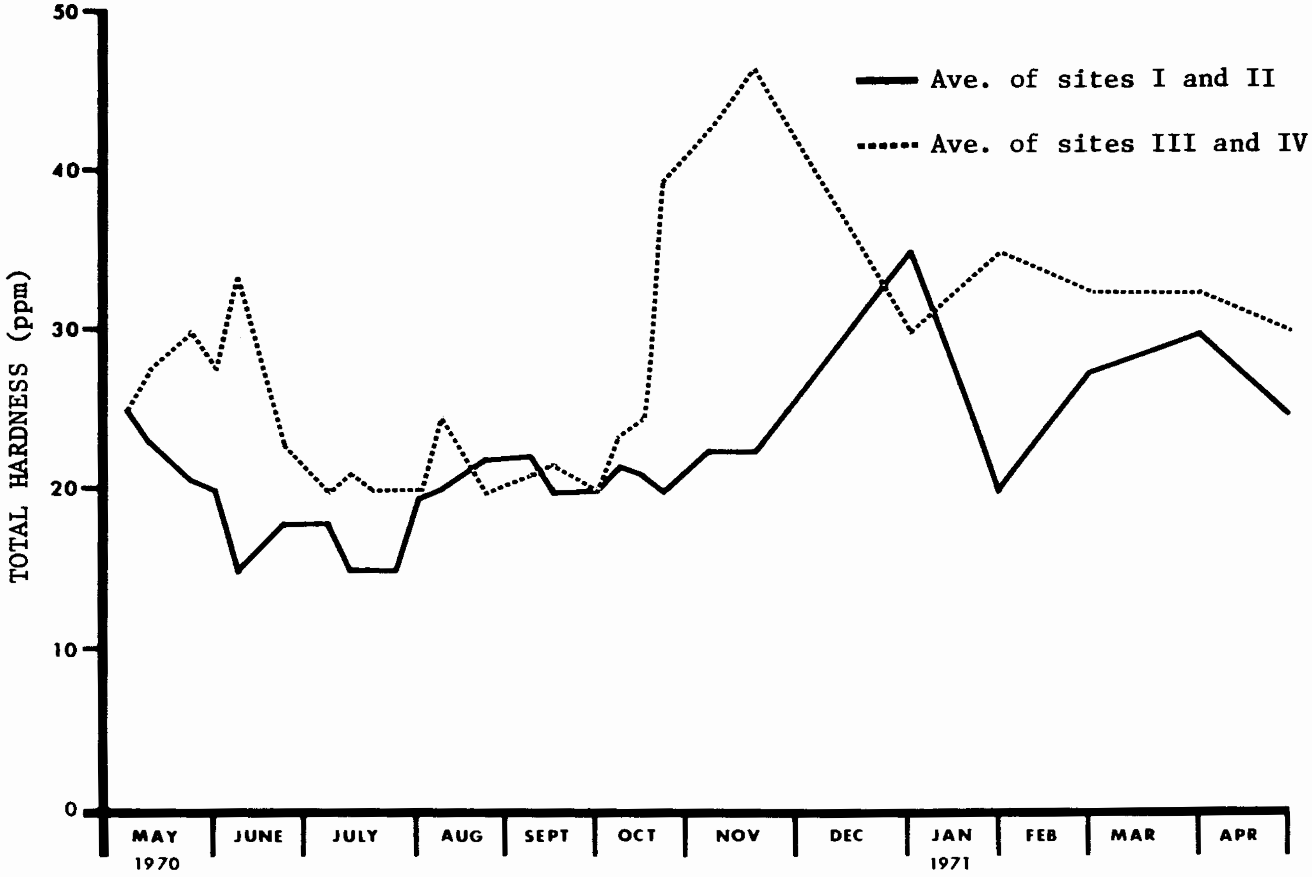

Fig. 11. A comparison of total hardness above and below the reservoir.

higher at all sites throughout the study (Table 6). All sites had a yearly average of 11 ppm dissolved oxygen. Site I ranged from 10 to 15 ppm and sites II, III, and IV ranged from 9 to 15 ppm (Table 1). Most of the measurements indicated about 100 per cent saturation.

Other Chemicals. Carbon dioxide remained at 5.00 ppm throughout the year. Nitrogen (nitrate and nitrite) concentrations averaged between 3.7 and 3.9 ppm at all sites and ranged from 1.5 to 8.3 ppm. Actual nitrogen concentrations are listed in Table 6 and the yearly averages and ranges are recorded in Table 1. Phosphate (ortho and meta) concentrations averaged between 0.04 and 0.06 ppm at all sites and ranged from 0.02 to 0.15 ppm throughout the year. Phosphate concentrations are recorded in Table 6 and the yearly averages and ranges are recorded in Table 1. The pH at all sites averaged between 7.27 and 7.42 and ranged from 6.90 to 8.10 throughout the year. No seasonal trends were apparent. The results of measuring pH are recorded in Table 5 and the yearly averages and ranges are in Table 1.

Biological

Mayflies. A total of 22 species of mayflies were collected (Table 7). There were 20 species collected above and 20 species collected below the reservoir. Two species occurred above the reservoir but not below and two species occurred below the

TABLE 6

RESULTS OF DISSOLVED OXYGEN, NITROGEN (NITRATE AND NITRITE), AND PHOSPHATE (ORTHO AND META) IN PPM

Date	Dissolved Oxygen				Nitrogen				Phosphate			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1970												
5/2	12	12	11	12	5.0	5.5	6.0	5.5	0.06	0.05	0.05	0.05
5/8	11	11	10	12	5.0	5.4	5.5	5.5	0.08	0.07	0.05	0.04
5/21	11	11	10	9	3.8	3.9	3.4	3.3	0.04	0.03	0.05	0.05
5/30	11	11	10	9	4.3	4.9	4.5	4.0	0.13	0.12	0.11	0.10
6/6	12	12	10	11	5.1	4.9	4.5	4.5	0.13	0.04	0.07	0.07
6/18	11	10	9	9	3.1	3.5	4.0	4.5	0.05	0.03	0.04	0.03
7/2	10	10	10	10	3.8	3.0	2.9	3.9	0.04	0.04	0.05	0.05
7/9	10	10	10	10	2.0	2.0	3.5	2.0	0.04	0.04	0.06	0.05
7/16	10	10	10	11	4.5	3.0	3.5	3.5	0.03	0.03	0.04	0.04
7/23	10	10	10	10	4.0	4.0	3.5	3.5	0.04	0.04	0.04	0.04
7/30	10	9	11	11	1.0	1.5	1.5	1.6	0.02	0.03	0.03	0.03
8/6	10	10	10	11	5.0	3.5	3.9	3.8	0.05	0.05	0.06	0.05
8/19	10	10	10	10	1.5	2.0	1.8	1.9	0.07	0.03	0.06	0.03
9/5	10	10	10	10	5.0	5.0	5.5	5.0	0.06	0.06	0.06	0.06
9/12	10	10	10	10	2.5	2.2	2.5	2.0	0.05	0.03	0.03	0.05
9/26	10	11	11	11	2.9	2.7	3.5	3.5	0.05	0.05	0.06	0.06

TABLE 6 (Continued)

Date	Dissolved Oxygen I	II	III	IV	Nitrogen I	II	III	IV	Phosphate I	II	III	IV
1970												
10/4	11	11	10	11	4.5	4.0	4.5	3.9	0.05	0.05	0.05	0.05
10/11	10	10	10	10	4.0	4.0	3.9	3.7	0.04	0.03	0.05	0.05
10/18	11	11	10	10	4.5	5.1	4.2	5.1	0.12	0.08	0.08	0.08
11/1	11	11	11	11	5.0	4.0	4.9	4.5	0.07	0.07	0.06	0.06
11/14	11	11	11	12	4.0	4.0	3.0	3.0	0.04	0.04	0.04	0.06
12/29	13	13	13	13	4.1	4.1	4.1	4.1	0.08	0.08	0.07	0.07
1971												
1/31	13	14	14	14	4.1	8.3	4.8	5.4	0.05	0.05	0.09	0.15
2/27	15	15	15	15	4.5	4.5	3.4	3.2	0.06	0.06	0.07	0.09
3/30	15	15	14	14	3.2	2.5	1.9	1.9	0.06	0.06	0.06	0.08
4/30	15	14	15	16	4.0	3.5	3.0	4.0	0.08	0.06	0.09	0.08

TABLE 7

LIST OF EPHEMEROPTERA COLLECTED IN THE CLE ELUM RIVER

Organism	Sites in Which They Occurred
Ephemerellidae	
Ephemerella inermis	I, II, III, IV
Ephemerella flavilinea	I, II, III, IV
Ephemerella tibialis	I, II, III, IV
Ephemerella doddsi	I, II, III, IV
Ephemerella heterocaudata	I, IV
Ephemerella spinifera	I, II, III, IV
Ephemerella margarita	I, II, III, IV
Ephemerella edmundsi	III, IV
Ephemerella aurivillii	IV
Heptageniidae	
Cinygmula spp.	I, II, III, IV
Rhithrogena sp. I	I, II, III
Rhithrogena hageni	I, II, III, IV
Epeorus longimanus	I, II, III, IV
Epeorus albertae	I, II, III, IV
Epeorus sp. I	I, II
Heptagenia criddlei	I, II
Baetidae	
Baetis spp.	I, II, III, IV
Pseudocloeon spp.	I, II, III, IV
Leptophlebiidae	
Paraleptophlebia heteronea	I, II, III, IV
Paraleptophlebia sp. I	II, IV
Siphlonuridae	
Siphlonurus occidentalis	I, IV
Ameletus spp.	I, II, III, IV

reservoir but not above. *Epeorus* sp. I and *Heptagenia criddlei* McDunnough were found to be present above the reservoir and absent below. *Ephemerella edmundsi* Allen and *Ephemerella aurivillii* (Bengtsson) were absent above and present below the impoundment.

The number of Mayfly species collected per site is presented in Fig. 12. Above the reservoir there were 19 species collected at site I and 18 at site II. Below the reservoir there was a drop in the total number of species collected to 16 at site III and then an increase to 19 species at site IV.

The results of calculating the years average total number of individual mayflies per square foot at each site is presented in Fig. 13. At site I there was an average of 22 mayflies/ft^2 and at site II an average of 19 mayflies/ft^2 for an average of 21 mayflies/ft^2 above the reservoir. Below the reservoir there was an increase in the number of mayflies per square foot. At sites III and IV the average was 51 mayflies/ft^2. The species primarily responsible for the increase in numbers below the reservoir are listed in Table 8. Table 8 gives a comparison of the relative numbers per square foot above and below the reservoir. Sites I and II are averaged together as are III and IV for ease of comparing.

In regards to the total mayflies per square foot there was no significant difference between sites I and II. There was also no significant difference between sites III and IV. A significant difference was found when any site above the reservoir was compared to any site below.

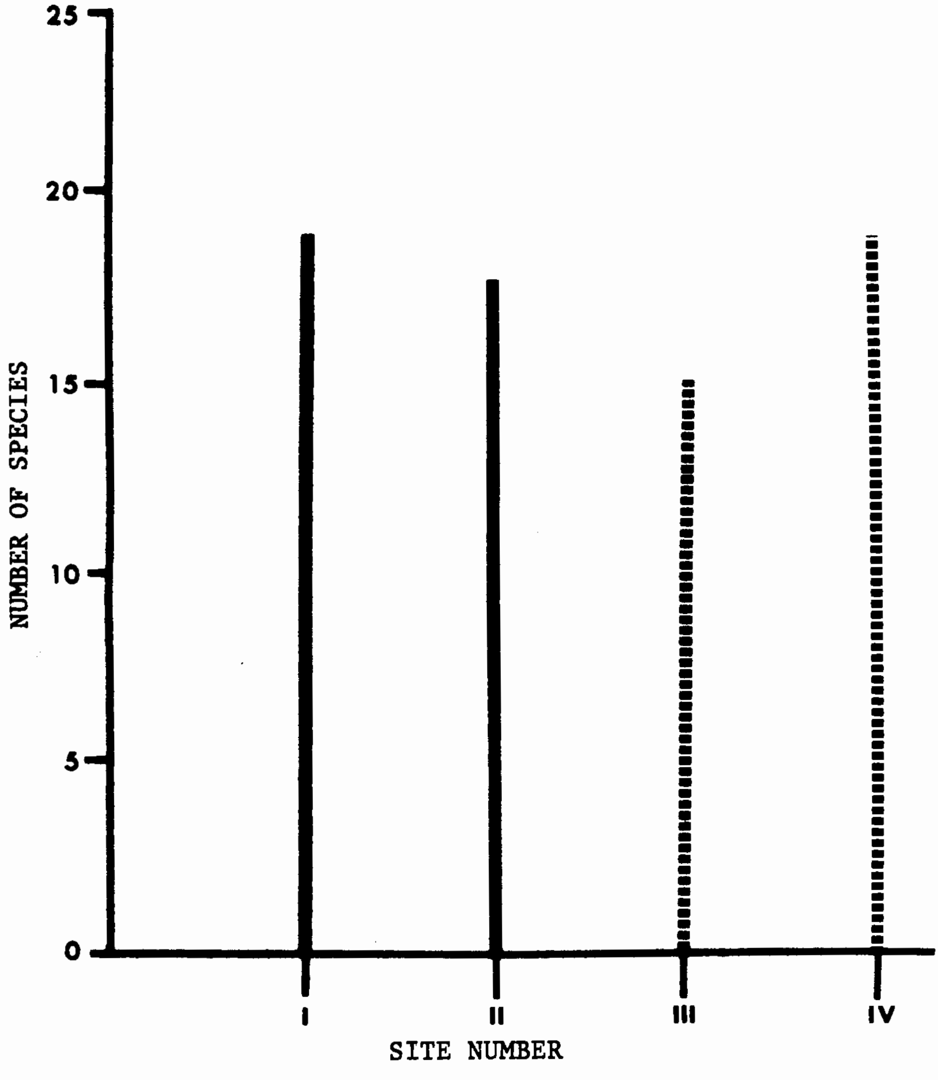

Fig. 12. A comparison of the number of species collected at each study site.

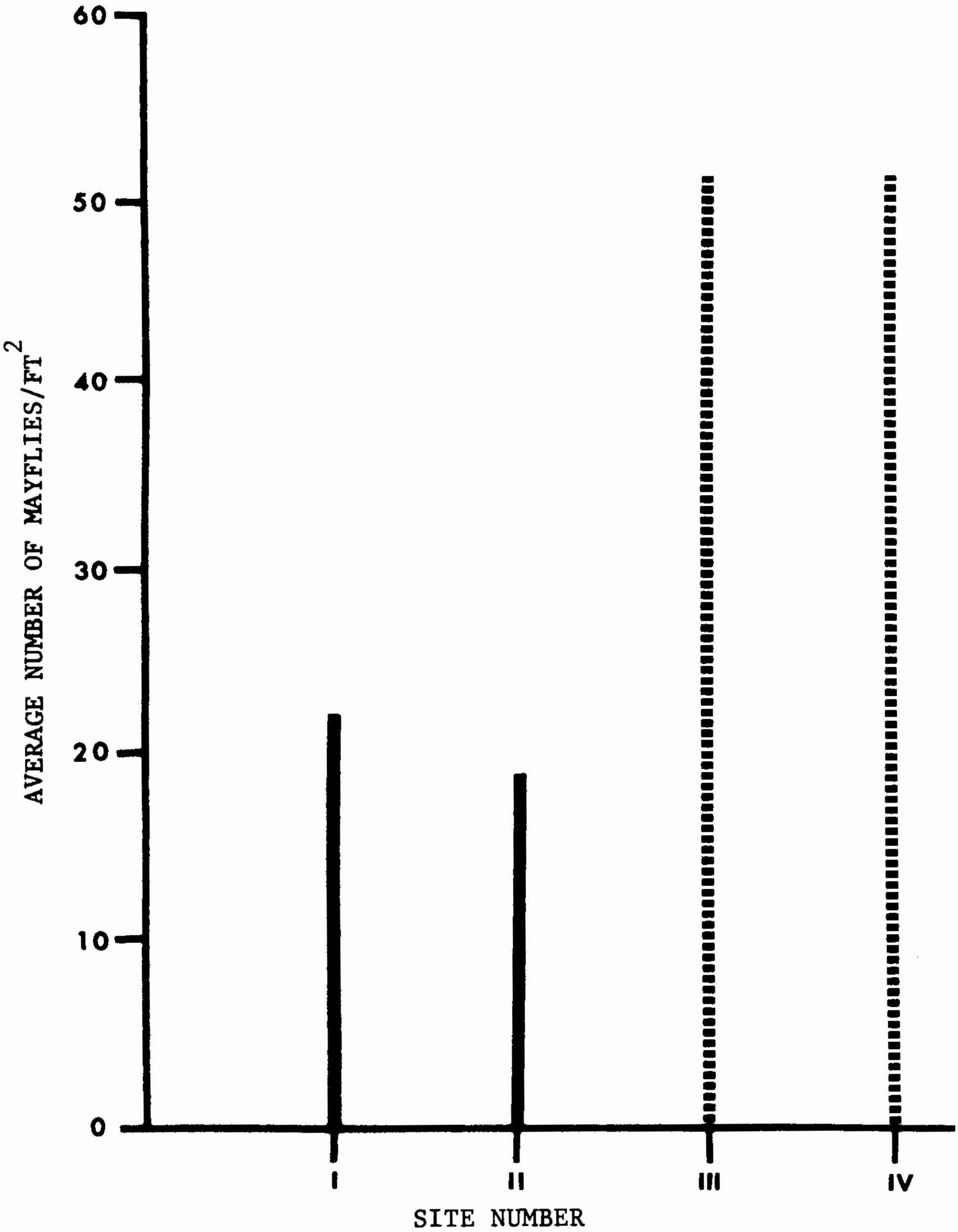

Fig. 13. A comparison of the average total number of mayflies per square-foot collected at each study site.

TABLE 8

A COMPARISON OF THE NUMBER OF INDIVIDUAL MAYFLY SPECIES/FT^2 PRIMARILY RESPONSIBLE FOR INCREASED NUMBERS BELOW THE RESERVOIR

Organism	Sites I & II	Sites III & IV
Ephemerella inermis	3.03	6.67
Ephemerella flavilinea	1.56	7.60
Ephemerella doddsi	0.94	2.10
Cinygmula spp.	5.33	8.68
Rhithrogena hageni	0.46	6.02
Baetis spp.	2.10	7.65
Pseudocloeon spp.	1.22	4.42
Paraleptophlebia heteronea	0.12	1.93

The seasonal variance in average total mayflies per square foot above and below the reservoir are presented in comparison to volume of flow, temperature, and alkalinity in Figures 14, 15 and 16.

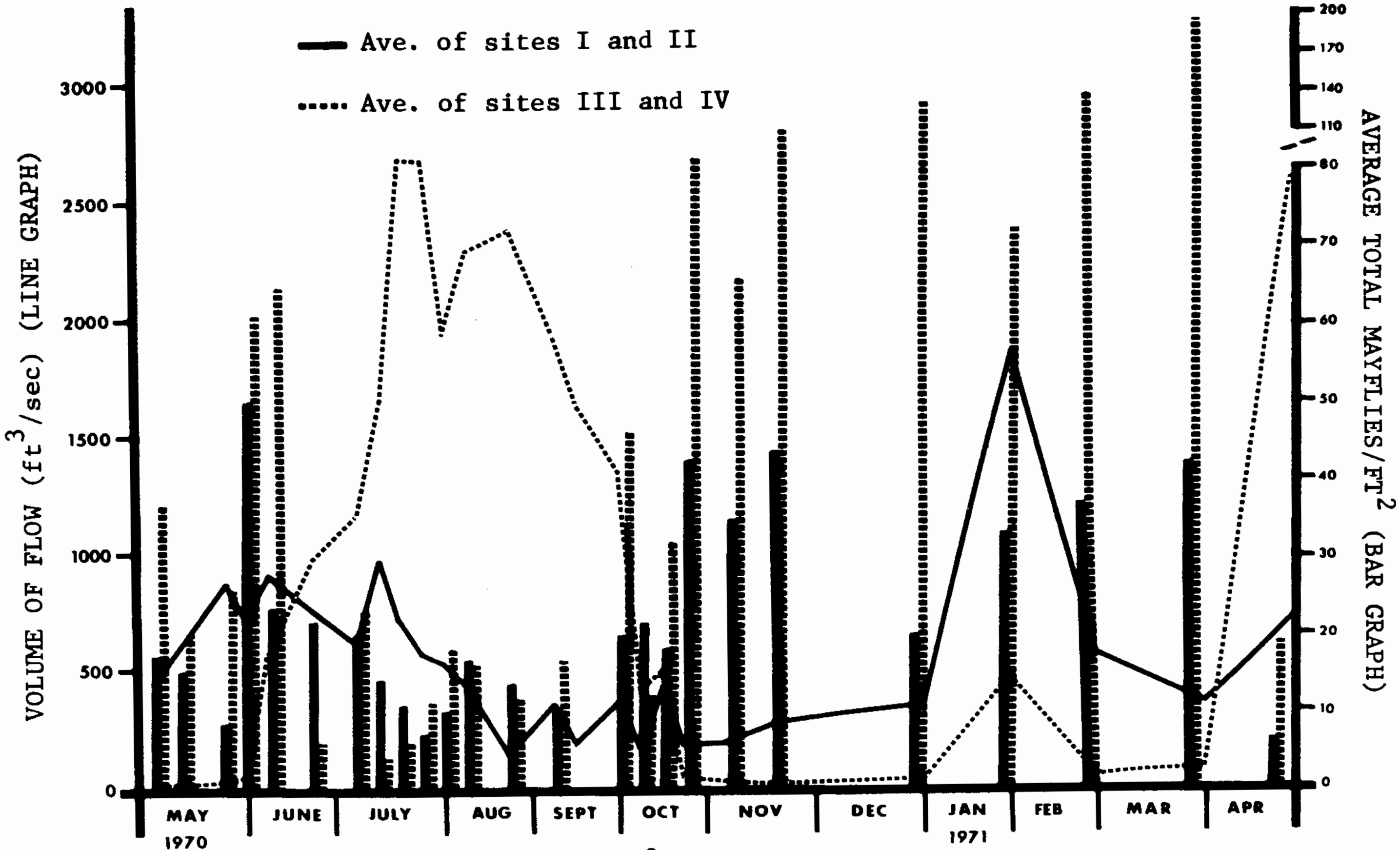

Fig. 14. The seasonal variance of mayflies/ft^2 above (ave. of sites I and II) and below (ave. of sites III and IV) the reservoir compared with the volume of flow.

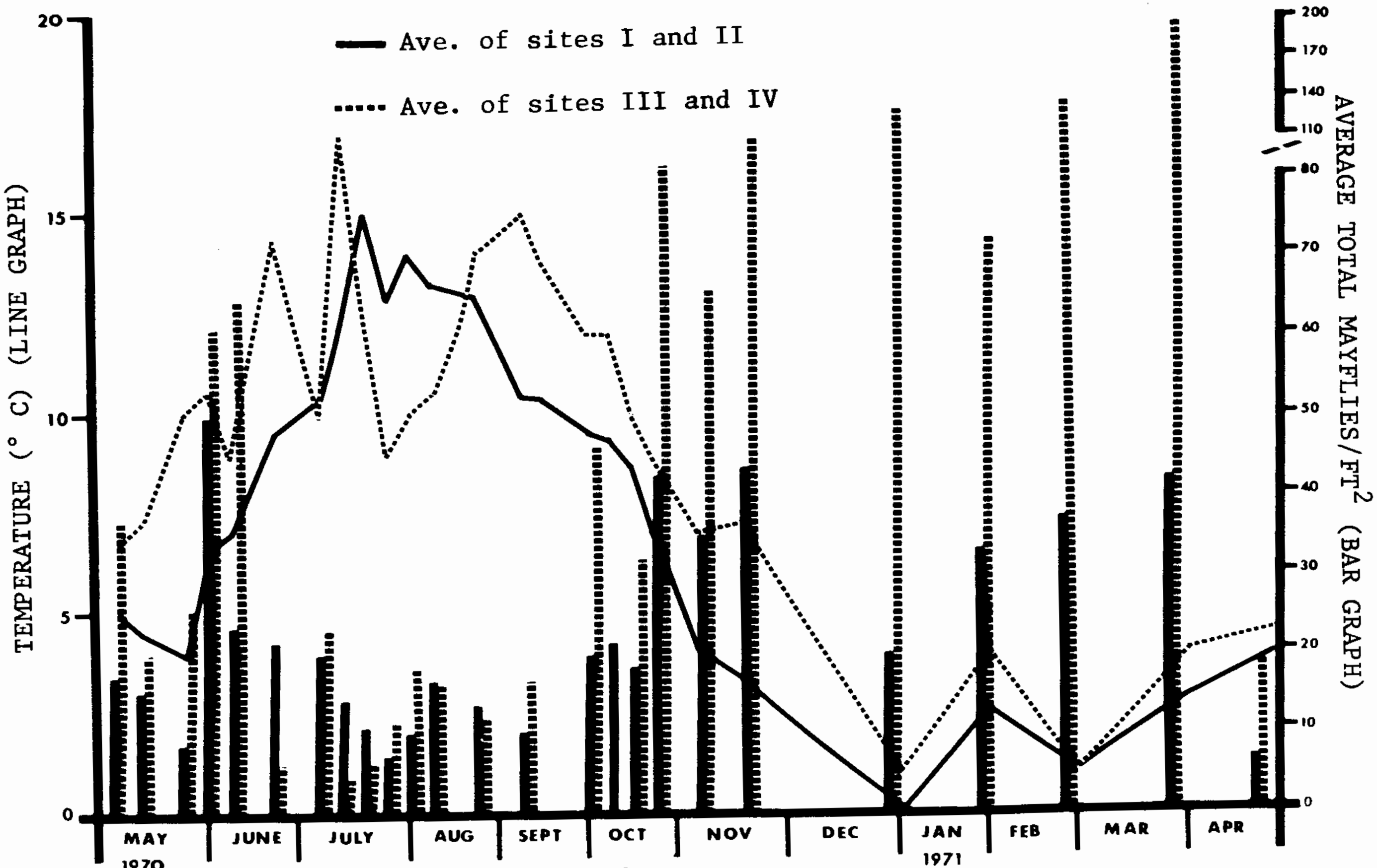

Fig. 15. The seasonal variance of mayflies/ft^2 above (ave. of sites I and II) and below (ave. of sites III and IV) the reservoir compared with the average water temperatures.

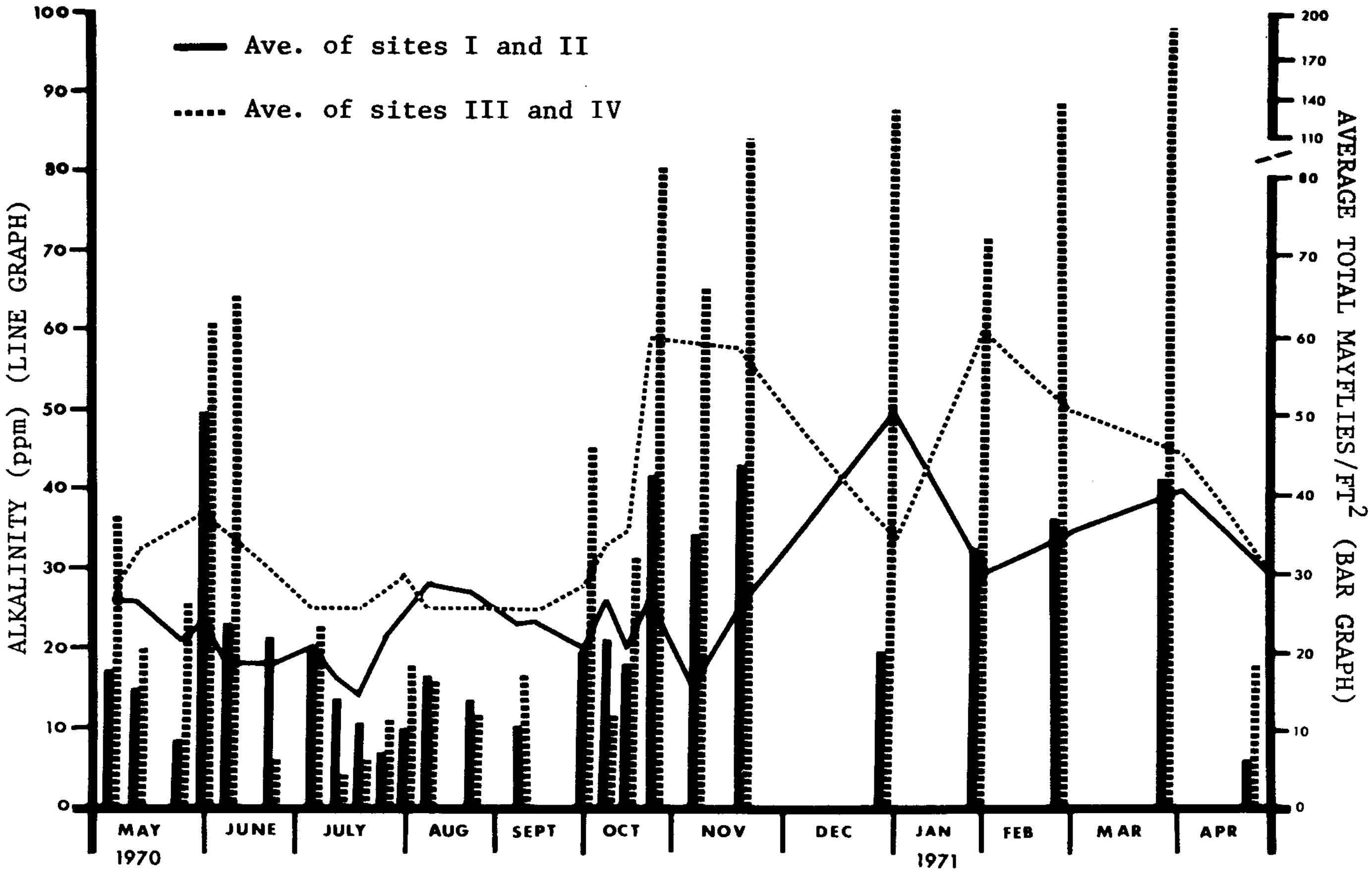

Fig. 16. The seasonal variance of mayflies/ft^2 above (ave. of sites I and II) and below (ave. of sites III and IV) the reservoir compared with the average alkalinity.

DISCUSSION

I would like to reiterate some of the material presented in the literature review regarding the environmental variables that have been used by other researchers to evaluate benthic communities. Substrate, current velocity, food material, and temperature seem to be of primary importance in determining the distribution of benthic organisms. Other factors such as width and depth, volume of flow, flora, fauna, and chemical characteristics of the water are also important. The importance of their interrelations remains to be completely delineated. According to Cummins (1962) it may be that all physical and chemical factors must be evaluated to achieve reasonable accuracy in the prediction of distribution. He states that in some cases the most important is the physical nature of the substrate. Distribution of food is directly dependent upon substrate therefore, food has an indirect relationship upon distribution. The results obtained by a number of investigators quite clearly supports the general concept that substrate size can serve as a common denominator in benthic ecology. This is why for this study, substrate size was approximated and used in determining study sites above and below the reservoir.

One other aspect is that since the impoundment was completed in 1932 the reservoir has had over 38 years for general adjustment before the present study was begun. Therefore, the data and discussion presented here covers the effects of an impoundment in which the major physical and chemical adjustments have been made.

Effects of Reservoir

Physical. The result of taking periodic temperature readings indicates that during peak irrigation demands in the summer there was an inversion in the "normal" temperature profile of the river (Fig. 7). This inversion was probably due to removing cold water from the reservoir. From the middle of July through August the river water was colder below the reservoir than above. In the fall the reservoir tended to delay and slow the rate of temperature decrease below the reservoir in comparison to the decrease in temperature above. In other words the impoundment effected the seasonal temperature cycle in the river below by lowering the average summer temperature and delaying the occurrence of temperature decrease in the fall. Findings similar to these have been reported by other investigators as mentioned in the literature review.

Since velocity and volume of flow seem to be interrelated and follow the same seasonal cycle they will be discussed together. The regulation of the reservoir drastically altered the seasonal cycles of current velocity (Fig. 8) and volume of flow (Fig. 9). In the summer during the peak irrigation season the volume of flow and corresponding current velocity were increased tremendously below the impoundment in comparison to the seasonally "normal" flow and velocity above the reservoir. For example, stream flow in July above the reservoir was approximately 700 CFS and below the impoundment due to irrigation needs the volume of flow was 2700 CFS. Information obtained from the Bureau of Reclamation in Yakima, Washington for the same time period indicates that release from the dam sometimes reaches slightly over 3000 CFS. The actual maximum outlet capacity for the dam is 4,000 CFS but was never reached during the time of this study. At the end of the irrigation season the current velocity and volume of flow below the impoundment were reduced to a minimum. The overall result of the impoundment on volume of flow is a lowering of winter flow and a raising of summer flow in comparison to the normal unaltered flow rates above the reservoir. This alteration of flow is almost diametrically opposite of natural conditions.

The unusual sudden increase in volume of flow above and below the reservoir in the last week of January was due to a period of exceptionally warm weather causing large amounts of surface runoff from snow melt and therefore is "natural". The drastic increase in volume below the reservoir at the end of April was probably due to the necessity of releasing large quantities of water for flood control. Because of the greater than usual quantity of available water in the form of snow the reservoir had to be kept low in anticipation of the large quantities of water expected.

Since there was a great seasonal variation in velocity a T-test was applied to determine if there was a significant difference between study sites. The results of the T-test (Table 4) indicate that there were no significant differences in velocity between any of the sites. The net effect of velocity, although seasonally different, is probably the reason that the substrate size was similar in all riffles. Hopefully then, the microhabitats are somewhat similar in all study sites.

Chemical

Alkalinity exhibited similar seasonal cycles above and below the reservoir (Fig. 10). During the springs of 1970 and 1971 alkalinity was slightly higher below the reservoir than above. It was approximately equal during the summer. Beginning in October, 1970 there was an increase in alkalinity both above and below the reservoir. There was a much greater increase in alkalinity below the reservoir than above during the fall and winter. Table 4 presents the results of applying the T-test to alkalinity. There was no significant difference between sites I and II and no significant difference between sites III and IV. But when any site above was compared with any site below there was a significant difference. Therefore, during the winter, the reservoir appears to have the effect of increasing the alkalinity in the river below. Reports indicate that the bottom water of stratified reservoirs sometimes contain water high in alkalinity. If the bottom region in the Cle Elum Reservoir was high in alkalinity, it is possible that as a result of the mixing caused by Fall overturn that bottom waters high in alkalinity, mixed with water above lower in alkalinity. The reservoir was also very low at this time so the mixing process plus alkalinity increases from surface runoff and ground water could have resulted in water of higher alkalinity throughout the reservoir than present while stratified. This could possibly account for the increased alkalinity in the river below the reservoir.

Total hardness exhibited seasonal trends (Fig. 11) similar to alkalinity and winter increases could possibly have been due to overturn in the reservoir. Hardness was at its lowest during the summer months and at its highest during the winter. It was slightly higher below the reservoir during the spring and approximately equal during the summer. In mid October, 1970 there was an increase in hardness below the reservoir. An increase in hardness above the reservoir did not occur until mid November, 1970. The magnitude of increase was greater below the reservoir than above throughout the winter. The time of increase in hardness above the reservoir is possibly the normal time of winter increases for the Cle Elum River. Hardness rising one month sooner below the reservoir tends to support the hypothesis that the reservoir is affecting the alkalinity and hardness content in the river below.

Dissolved oxygen concentrations were nine ppm or higher at all sites throughout the study. All sites had a yearly average of 11 ppm and varied from 9 to 16 ppm throughout the year. Most of the results showed about 100 per cent saturation. Dissolved oxygen was probably not a limiting factor in regards to mayfly or other benthos and was apparently not altered by impoundment.

Carbon dioxide, nitrogen, phosphate, and pH were each similar above and below the reservoir indicating that the impoundment probably had little effect on these factors in the receiving stream.

Biological Implications

Fig. 12 illustrates the relationship between the number of species collected per site. Above the reservoir at sites I and II there were 19 and 18 species recorded respectively. Below the reservoir at sites III and IV there were 16 and 19 species collected respectively. The number of species recorded decreased at site III below the dam but increased at site IV to the same number of species at site IV as was recorded at site I.

With this information in mind it is interesting to compare the average number of individual mayflies per square foot at each site (Fig. 13). Above the reservoir at sites I and II there were 22 and 19 mayflies/ft^2 respectively for an average of 21 mayflies/ft^2 above the reservoir. Below the reservoir at sites III and IV there was an average of 51 mayflies/ft^2 at both sites. Ide (1935) reported that there is a tendency in Ephemeroptera to increase in numbers down from the headwaters of a river due to an increase in the number of species. If this is typical for mayflies, then there has been a change in this trend, probably caused by the impoundment.

A T-test was used to determine if significant differences occurred between study sites. The results of the T-test in regards to the total mayfly population can be seen in Table 4. Sites I and II were not significantly different from each other and neither were sites III and IV. But whenever any site above the reservoir was compared with any site below there was a significant difference when comparing the total mayfly population. This difference was due to the numbers of individuals and not to the number of species per site as there were only two species present above and not below and only two species present below and not above and these were present in very small numbers.

Since the two sites above and the two sites below respectively were not significantly different in regards to their total mayfly populations I have averaged them together in the following discussion.

The seasonal variance in total mayflies per square foot above and below the reservoir is presented in comparison to the volume of flow in Fig. 14. It can be readily observed in the summer that when the volume of flow is very high below the reservoir the average number of mayflies per square foot is low in comparison to the rest of the year. This could be due to several factors. Increased volume and at the same time increased velocity (Fig. 8) could have direct effects on mayflies and other benthic organisms by removing them from the substrate. Probably a more important effect than removal of mayflies would be the removal of allochthonous food material. It has been previously reported that the removal of food from the substrate probably increases the searching behavior for food and probably results in more individuals being passively caught in the current. Increased volume in the summer could also have effects on mayflies and other aquatic insects that emerge during the summer. For insects such as mayflies that do not have a quiescent pupae it would probably not have as great an effect as it would on those that pupate. Mayflies can move over the substrate or move into the drift until they make their way to the shallow outer margins of the stream where they could emerge with little difficulty. For those insects that pupate and are fixed to the substrate such as Trichoptera, emergence into a large, swiftly moving stream could be hazardous. Therefore, an increase in summer flow rates below the reservoir could affect the benthos in various ways.

Another possible reason for the smaller number of individuals during high flow is sampling error. Cummins (1966) reported that the standing crop of insects increased from the margin of a riffle and was maximized at the center. During extremely high flow it was impossible to sample in the middle of the river. The possibility of sampling error is reduced somewhat when comparing the mayflies per square foot above and below the reservoir. The number per square foot above the reservoir were also low during the summer when flow was relatively low above in comparison to the flow below. It was possible to sample all areas of the river above the reservoir at that time. This indicates that the benthic population of mayflies during the summer in the Cle Elum River may be "normally" fewer in numbers than at other times. There was probably some sampling error below the reservoir as the magnitude of greater numbers below does not correlate with the differences between population numbers above and below during the rest of the year. The reason for the evident summer decrease was probably emergence. This indicates that below the reservoir the increased summer volume of flow probably had little effect on mayfly emergence.

Drift rates were not measured but due to the presence of organisms in the outer margins of riffles during high flow it can be assumed that drift, since it is apparently the main means of dispersal within a stream, was responsible for their presence. It would be interesting to know the drift rates in the river as it might give a better indication of population dynamics as affected by regulation (fluctuation) of stream flow. Another unknown aspect of interest is the effect of fluctuating water flow on the hyporheic populations in the outer margins of the stream.

Since volume is directly related to stream width, fluctuations in volume of flow, therefore, have a direct effect on the living space available to mayflies. This could have a direct effect on the number of organisms per square foot. When flow is high, the benthos are distributed over a large area reducing the average number of organisms per square foot. When flow is low the benthos occupy a smaller living area resulting in higher densities. The increase in the number of mayflies per square foot in the fall could then be due to decreased living space. Also at this time many small instars were present.

It has been reported that the effect of reduction in living space also increases drift rates due to more activity in response to competition for living space. Therefore, fluctuations of stream flow created by an impoundment probably does have an effect on the measureable number of benthic organisms present at any one time in a stream. Although it does not sppear to have any measurable effects on the actual species composition of mayflies present in the river.

The seasonal variance in total mayflies per square foot above and below the reservoir in comparison to water temperature is shown in Fig. 15. It is apparent that the number of mayflies per square foot are lower during the summer than at any other time of the year. In general, the mayflies present during late spring and early summer were mature forms. Therefore, the reduction in numbers both above and below during the summer is probably due to emergence. The increase in numbers during the fall is probably due to the hatching of eggs as most of the mayflies present appeared to be very small instars. The lower temperatures recorded below the reservoir during the summer were apparently not low enough to have any adverse effect on mayfly emergence. According to Hynes (communication) it is doubtful if temperature is the main factor controlling emergence. He reported that in unusual years various species have emerged at the right time even when the temperature was exceptionally cold (Hartland-Rowe, 1964).

Alkalinity has been used as an apparent measure of water fertility by many researchers. Moyle (1949) classified fish and plant productivity of natural lakes on the basis of total alkalinity. Direct correlations between alkalinity and mayfly numbers were not readily apparent (Fig. 16). However, I feel that these interrelationships warrant further investigations.

Increase in the number of mayflies per square-foot below the reservoir was due primarily to eight species: Ephemerella inermis, E. flavilinea, E. doddsi, Cinygmula spp., Rhithrogena hageni, Baetis spp., Pseudocloeon spp. and Paraleptophlebia heteronea (Table 8). The increases were seasonal and followed the same trend as the total number of mayflies (Fig. 14).

This increase occurred at the same time that several environmental conditions began to change with the onset of fall weather conditions in September: (1) a decrease in the volume of flow below the reservoir; (2) a decrease in current velocity; (3) the end of the summer temperature inversion resulting in warmer water below the reservoir than above and also at this time the temperature of the water above the reservoir was declining more rapidly than the water below; and (4) an increase in alkalinity and hardness which was proportionally higher below the reservoir than above.

Since there is not a great difference in the species composition above and below the reservoir it appears that the reservoir is causing some environmental change that enables a greater proliferation of individuals. Further, it is possible that the environmental conditions below the reservoir are affecting the early part of the instar survival curve allowing more early instars to survive in the fall. This could be due to several environmental factors: (1) greater primary production (autochthonous) over an extended period of time; (2) greater amounts of allochthonous material; (3) increased living space below the reservoir. More living space may have increased the number of individuals that could exist together. Also the results of the population being more dispersed may have reduced predation rates.

It is interesting to note but difficult to explain the distribution of four species present in sites III and IV. *Ephemerella inermis* was more abundant at site III than at site IV. *Ephemerella flavilinea*, *Cinygmula* spp., and *Pseudocloeon* spp. were more abundant at site IV than at site III. The various physical and chemical parameters measured did not differ significantly (Table 4). Therefore, it is possible that interspecific relationships are of more significance than abiotic parameters.

In conclusion these results indicate the need for further studies on the effects of storage reservoirs. Limnological data are needed on the reservoir and constant monitoring of physical parameters are needed on the river. All benthic organisms need to be studied and detailed life history information is needed. Finally, selected species need to be brought into the laboratory and studied under controlled conditions in regard to environmental parameters associated with reservoirs.

LITERATURE CITED

Anderson, N. A. and D. M. Lehmkuhl. 1968. Catastrophic drift of insects in woodland streams. Ecology, 49 (2):198-206.

Armitage, K. B. 1958. Ecology of the riffle insects of the Firehole River, Wyoming. Ecology, 39:571-580.

Chapman, Donald W. and Robert L. Demory. 1963. Seasonal changes in the food ingested by aquatic insect larvae and nymphs in two Oregon streams. Ecology, 44 (1):140-146.

Churchill, Milo A. and A. M. Asce. 1958. Effects of storage impoundments on water quality. Trans. Amer. Soc. of Civil Engineers, 123:419-464.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. The Amer. Midland Natur., 67 (2):477-504.

Cummins, K. W., W. P. Coffman and P. A. Roff. 1966. V. Running waters, trophic relationships in a small woodland stream. Verh. Internat. Verein. Limnol., 16:627-639.

Dendy, J. S. and R. H. Stroud. 1949. The dominating influence of Fontana Reservoir on temperature and dissolved oxygen in the Little Tennessee River and its impoundments. J. Tennessee Acad. of Sci., 24 (1):41-51.

Dimond, John B. 1967. Evidence that drift of stream benthos is density related. Ecology, 48 (5):855-857.

Dodds, G. S. and F. L. Hisaw. 1925. Ecological studies on aquatic insects. IV. Altitudinal range and zonation of mayflies, stoneflies, and caddisflies in the Colorado Rockies. Ecology, VI (4):380-390.

Elliott, J. M. 1967. The life histories and drifting of the Plecoptera and Ephemeroptera in a Dartmoor Stream. J. Animal Ecol., 36:343-362.

Eschmeyer, R. W. and C. G. Smith. 1943. Fish spawning below Norris Dam. J. Tennessee Acad. of Sci., XVII (1):4-5.

Flattum, Roger. 1963. Apparent effects of refrigeration on the rate of embryonic development of mayfly (Hexagenia limbata) eggs. Zoology, 31 (1):82-83.

Franklin, Jerry F. and C. T. Dyrness. 1969. Vegetation of Oregon and Washington. U.S.D.A. Forest Service Research Paper PNW-80:216 p.

Gilpin, B. R. and M. A. Brusven. 1970. Food habits and ecology of mayflies of the St. Maries River in Idaho. Melanderia, 4:19-40.

Hartland-Rowe, R. 1964. Factors influencing the life-history of some stream insects in Alberta. Verh. Internat. Verein. Limnol, XV:917-925.

Hilsenhoff, William L. 1971. Changes in the downstream insect and amphipod fauna caused by an impoundment with a hypolimnion drain. Ann. of the Entomol. Soc. of Amer., 64 (3):743-746.

Hynes, H. B. N. 1958. The effect of drought on the fauna of a small mountain stream in Wales. Verh. Int. Verein. Theor. Angew. Limnol, 13.

__________. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol., 57 (3):344-388.

Ide, F. P. 1935. The effect of temperature on the distribution of the mayfly fauna of a stream. Publ. of the Ontario Fish. Res. Lab., 50:6-82.

Jensen, Steven L. 1966. The Mayflies of Idaho (Ephemeroptera). Unpublished M.S. thesis, Univ. of Utah, 365 p.

Kittrell, F. W. 1959. Effects of impoundments on dissolved oxygen resources. Sewage and Industrial Wastes, 31 (9): 1065-1078.

Lennon, R. E. 1941. Drift-borne organisms in Pond Brook, Passaconaway, N. H. Univ. New Hampshire Ext. Serv., Contr. No. 2, Biol. Inst.

Love, S. K. 1961. Relationship of impoundment to water quality. J. Amer. Water Works Assoc., 53 (5):559-568.

Maciolek, J. A. and P. R. Needham. 1951. Ecological effects of winter conditions and trout foods in Convict Creek, California. Trans. Amer. Fish. Soc., 81:202-217.

Mackenthun, K. M. and W. M. Ingram. 1967. Biological Associated Problems in freshwater environments their identification, investigation and control. U.S. Department of the Interior, Federal Water Pollution Control Administration, 287 p.

Minshall, G. W. and P. V. Winger. 1968. The effect of reduction in stream flow on Invertebrate drift. Ecology, 49 (3): 580-582.

Minshall, G. W. and Robert A. Kuehne. 1969. An ecological study of invertebrates of the Duddon, an English Mountain Stream. Arch. Hydrobiol., 66 (2):169-191.

Moyle, J. B. 1949. Some indices of lake productivity. Trans. Amer. Fish. Soc., 76:322-334.

Nebeker, Alan V. 1971a. Effect of water temperature on nymphal feeding rate, emergence, and adult longevity of the stonefly Pteronarcys dorsata. J. Kansas Entomol. Soc., 44 (1):21-26.

__________. 1971b. Effect of temperature at different altitudes on the emergence of aquatic insects from a single stream. J. Kansas Entomol. Soc., 44 (1):26-35.

Needham, J. G., J. R. Traver, Yin-chi-Hsu. 1935. The biology of mayflies. Comstock Publ. Co., Ithaca, New York, 759 p.

Neel, Joe Kendell. 1963. Limnology in North America, ed. by David G. Frey, The University of Wisconsin Press, pp. 575-593.

Newell, R. J. 1931. Construction, Lake Cle Elum Storage Reservoir. Annual Project History, Department of the Interior, Bureau of Reclamation, Yakima Project, Washington, pp. 93-103.

Pearson, W. D., R. H. Kramer and D. R. Franklin. 1968. Macro-invertebrates in the Green River below Flaming Gorge Dam, 1964-65 and 1967. Proc. Utah Acad. Sci. 45 (1): 148-167.

Pennak, R. W. and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology, 28 (1):42-48.

Pfitzer, Donald W. 1954. Investigations of waters below storage reservoirs in Tennessee. 19th North American Wildlife Conference, pp. 271-282.

Raphael, J. M. 1961. The effects of Wanapum and Priest Rapids Dams on the temperature of the Columbia River. Grant Co. P.U.D. No. 2, Ephrata, Washington.

__________. 1962. The effect of Wells and Rocky Reach Dams on the temperature of the Columbia River. Grant Co. P.U.D. No. 2, Ephrata, Washington.

Reid, George K. 1961. Ecology of inland waters and estuaries, Reinhold Publishing Corp., New York, 375 pp.

Richards, Von A. Glen. 1959. Studies on temperature thresholds in insect development. Biol. Zent., 2:308-314.

Ricker, W. E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud., 37:1-114.

Rogers Engineering Co., Inc. 1969. Proposed Cle Elum Steam Power Plant summary. 16 Beale Street, San Francisco, California.

Smith, Stamford D. 1968. The Rhyacophila of the Salmon River drainage of Idaho with special reference to larvae. Ann. Entom. Soc. Amer., 61 (3):655-674.

Sylvester, Robert O. 1963. Effects of water uses and impoundments on water temperature. Water temperature influences, effects, and control. U.S. Dept. of Health, Education and Welfare, Public Health Service, Pacific Northwest Water Laboratory, Corvallis, Oregon, pp. 6-28.

Taft, A. C. and L. Shapovalov. 1935. A biological survey of streams and lakes in Klamath and Shasta National Forests of California. U.S. Bureau of Fisheries (mimeographed).

Thorup, Jens. 1970. Frequency analysis in running waters and its application on a springbrook community. Arch. Hydrobiol., 68 (1):126-142.

Ulfstrand, S. 1967. Microdistribution of benthic species (Ephemeroptera, Plecoptera, Trichoptera, Diptera: Simulidae) in Lapland streams. Oikos, 18 (2):293-309.

Vincent, Ernest R. 1967. A comparison of riffle insect populations in the Gibbon River above and below the Geyser Basins, Yellowstone National Park. Limnol. and Oceanogr., 12 (1): 18-26.

Waters, T. F. 1962. Diurnal periodicity in the drift of stream invertebrates. Ecology, 43 (2):316-320.

__________. 1968. Diurnal periodicity in the drift of a day-active stream invertebrate. Ecology, 49 (1):152-53.

Welch, Paul S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc., New York, 381 p.