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THE RELATION OF IRRIGATION RETURN-FLOWS TO WATER CHEMISTRY AND PERIPHYTON IN THE LEMHI RIVER, IDAHO

by

Mr. Thomas Halbach

and

Dr. C. Michael Falter
College of Forestry, Wildlife & Range Sciences

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ABSTRACT

Irrigation development in the Lemhi Valley is related to both the chemical quality of the river water and the in-stream algal populations. Nitrate concentrations in the river peaked shortly after onset of irrigation in the spring, then decreased through the summer. Nitrates also decreased downriver due to high algal demand and possible dentrification within the soil. Phosphate concentrations increased more slowly than did nitrates after onset of irrigation but increased consistently downriver. In late August, soluble phosphates were seven to eight times more abundant at the mouth of the river than in the headwaters. Nitrate concentrations ranged from <.10 in August to >2.8 mg/l in November, while phosphates ranged from .008 mg/l in August to .098 mg/l in July. Total dissolved solids increased downriver, and ranged from 140 mg/l in May to 385 mg/l in August.

Comparison of two adjacent stream drainages in the Lemhi basin showed a conductivity profile which increased 900% from source to mouth in the irrigated drainage but only 25% in the nonirrigated drainage.

Algal communities in the river were composed almost entirely of epilithic diatoms (Class Bacillariophyceae), except in the extreme lower river during late July and August. A bloom of the green alga, Cladophora sp., completely dominated the flora of the lower river at that time. Cladophora did not colonize on the glass slides used as artificial substrates, giving an

underestimate of the actual algal production in the lower river. Algal density on the slides generally increased slowly for the first 2 weeks and then increased at a much faster rate. Periphyton cell density after 28 days colonization on bare slides ranged from 256 to 16,106 cells per mm^2. Density on natural substrate was similar to or slightly greater than on glass slides after periods of 28-42 days in the river. Turbidity, temperature and altitude accounted for more of the variability in cell numbers than did nutrient concentrations.

Primary production of periphyton collected on glass slides in the river and tested in bioassays showed few significant differences between various parts of the river. Production was lowest upriver and at RK 17.6. We concluded that low temperature limited production upriver and low nitrate limited production at RK 26.7. Oxygen production ranged from 0.44 to 1.72 mg/l/hr per slide after a 4-8 hour bioassay.

INTRODUCTION

The amount of irrigated land in Idaho is expected to increase substantially in the future. In 1972, approximately 1.5 million ha were being irrigated, with a potential for almost 3.2 million additional ha to be brought under irrigation (Interim State Water Plan, 1972).

Studies on the impact of irrigation development have focused mainly on the effect of increasing salinity levels on crop production and water reuse potential, while neglecting changes in the rivers and streams receiving runoff and sub-surface drainage.

Nutrient accumulation in ground water, especially nitrates and phosphates, following application of water to agricultural land has been well-documented (Sylvester and Seabloom, 1962: Johnson, et. al, 1965; and Bolton et. al, 1970). The entrance of these nutrients into surface waters can lead to noxious algal blooms and other water quality problems.

This study was funded by the Idaho Water Resources Institute with the following objectives.

1. To determine whether there is a change in the concentration of dissolved nutrients in the Lemhi River as it drains irrigated agricultural land;
2. To determine whether there is a change in periphyton standing crop along the stream length;
3. To compare productivity rates of periphyton along the stream length, and;
4. To compare nutrient levels in two similar, tributary drainages with differing irrigation histories.

DESCRIPTION OF AREA

The Lemhi River flows for 90 km through a high mountain valley in east central Idaho adjacent to the Idaho-Montana border (Figure 1). It flows northwestward through a flat flood plain ranging from .8 to 1.6 kilometers in width before discharging into the Salmon River near Salmon, Idaho at an altitude of 1189 meters. The Lemhi River falls 632m in its 90 km length, an average drop of 7m per km. The valley floor is bordered on both sides by terraces 15-60m in height, which slope up to broad alluvial fans emerging from the mountains.

Six percent (202.3 km^2) of the Lemhi River drainage area was irrigated cropland in 1972-1973. Rainfall on the valley floor averages only 22.3 cm annually at Salmon so that irrigation is necessary for intensive crop production. Livestock ranching and forage crops are the principal agricultural activity in the valley.[1] Alfalfa was grown mostly on the drier "upland bar soils" while native grasses were grown on the wet meadows along the river bottom. Fertilizer use was extensive; nitrate was applied in the Lemhi Valley at the rate of 45-68 kg/ha along the river bottom while phosphate was applied more extensively on the bar lands.

Most irrigating in the early 1970's was done by blockage of gravity canals running from the river, thus, flood-irrigating the fields. The irrigation season generally ran from mid-April to mid-October, with a consumptive use requirement of 3719 m^3/ha.

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[1] The above agricultural information about the Lemhi Valley was provided by Robert Loucks, County Extension Agent for Lemhi County, Salmon, Idaho.

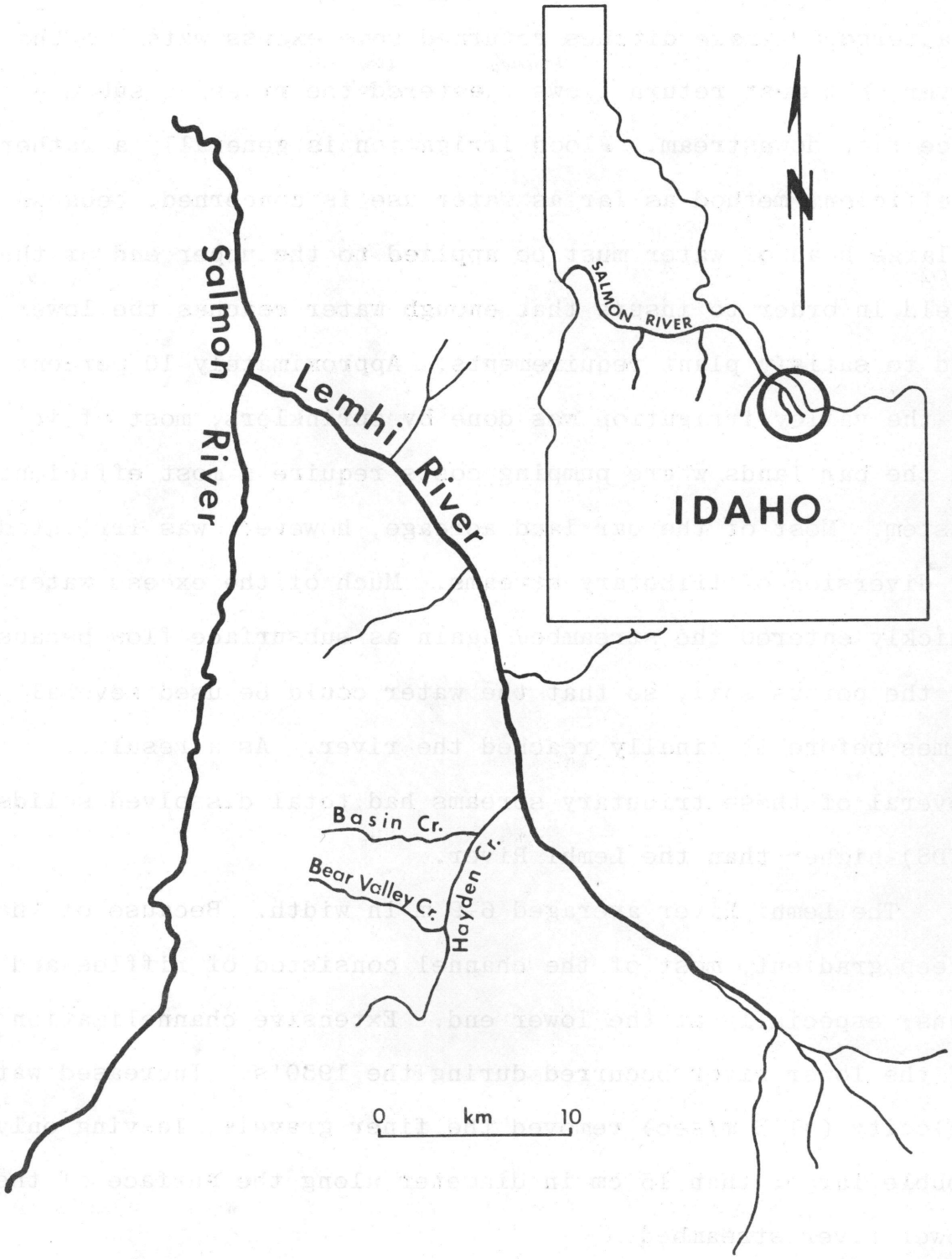


Figure 1. Lemhi River Study Area and Major Tributaries

Scattered drainage ditches returned some excess water to the river, but most return flows reentered the river as subsurface flow downstream. Flood irrigation is generally a rather inefficient method as far as water use is concerned, because a large head of water must be applied to the upper end of the field in order to insure that enough water reaches the lower end to satisfy plant requirements. Approximately 10 percent of the valley irrigation was done by sprinklers, most of it on the bar lands where pumping costs require a most efficient system. Most of the bar land acreage, however, was irrigated by diversion of tributary streams. Much of the excess water quickly entered the streambed again as subsurface flow because of the porous soil, so that the water could be used several times before it finally reached the river. As a result, several of these tributary streams had total dissolved solids (TDS) higher than the Lemhi River.

The Lemhi River averaged 6-9 m in width. Because of the steep gradient, most of the channel consisted of riffles and runs, especially at the lower end. Extensive channelization of the lower river occurred during the 1950's. Increased water velocity (>1.6 m/sec) removed the finer gravels, leaving only cobble larger than 15 cm in diameter along the surface of the lower river streambed.

Average daily discharge (1955-1963, 1967-1972) measured at the RK 46.3 gauging station was 7.7 m^3/sec in August 1967 (U.S.D.I., 1972).

Daily temperature fluctuations in the river were high and ranged as much as 12 C along the lower reaches. Daily fluctuations of 4-8 C were common along the middle stretch of river, while at the upper end temperatures ranged from 2-4 C in early summer to 6-8 C during July and August.

The aquatic vascular plants, Zanichellia palustris (horned pondweed) and Ranunculus aquatilis (buttercup) formed dense mats of vegetation in riffle areas of the upper river. During late summer these mats obstructed the current and deepened the flow in the upper river. Marl accumulated on the substrate surrounding these plants.

Goodnight and Bjornn (1970) estimated annual fish production in the upper Lemhi River at 13.6 gm/m^2/year. Mountain whitefish (Prosopium williamsoni) comprised 60-80 percent of the fish biomass in the river. Steelhead and rainbow trout (Salmo gairdneri) and chinook salmon (Onchorynchus tshawytscha) made up most of the remainder of the fishery resource.

METHODS

The following six stations were sampled from July 3, 1972 to September, 1973 in the Lemhi River (Figure 2).

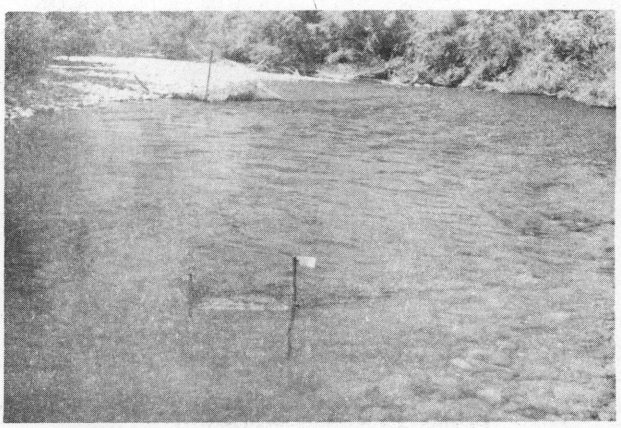
Station 1 - RK 7.6, 4.8 km upstream from the city of Salmon.

Station 2 - RK 26.7.

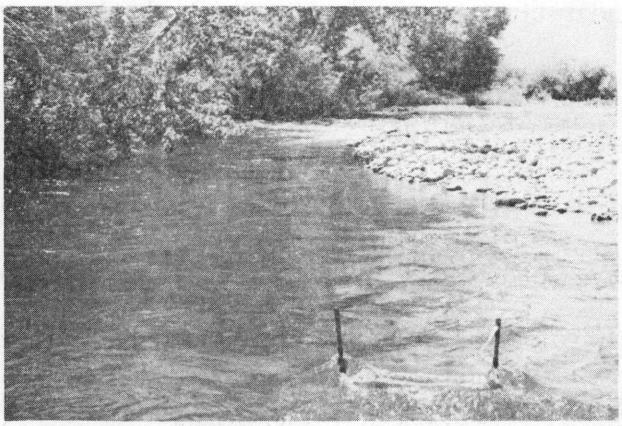
Station 3 - RK 45.2, 3.5 km downstream from the mouth of Hayden Creek.

Station 4 - RK 51.0

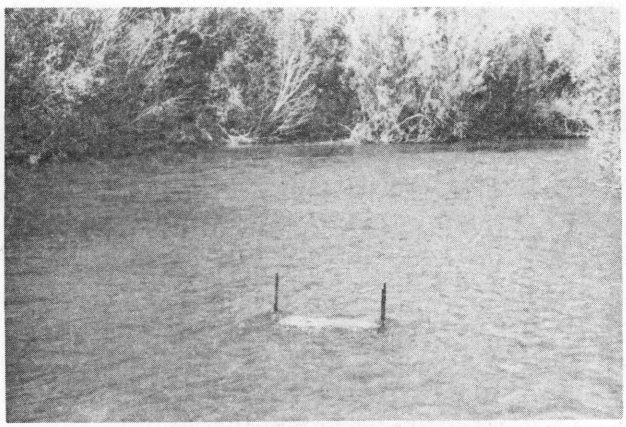
Station 5 - RK 76.7, 13.3 km downstream from the town of Leadore.



Station 1
(RK 7.6)

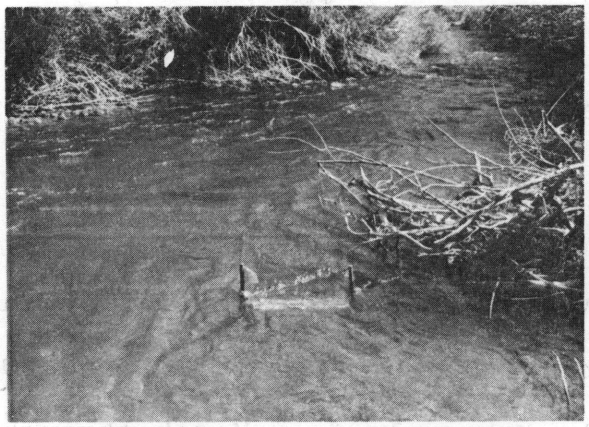


Station 2
(RK 26.7)

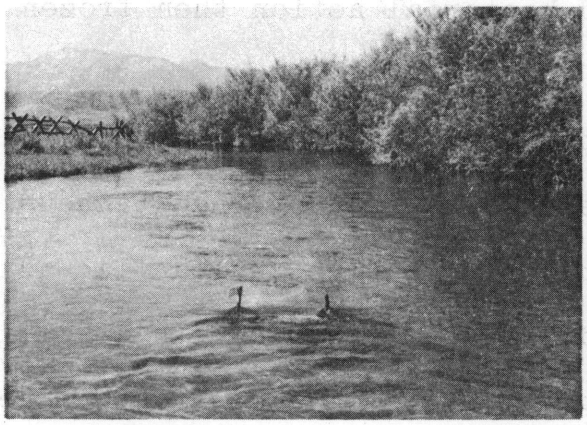


Station 3
(RK 45.2)

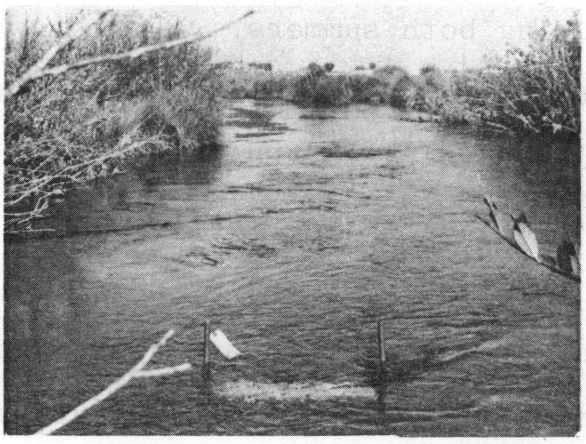
Figure 2. Lemhi River sampling sites -
Periphyton Samplers Visible at Each Station



Station 4
(RK 51.0)



Station 5
(RK 76.7)



Station 6
(RK 90.0)

Figure 2. Lemhi River Sampling Sites -
Periphyton Samplers Visible at Each Station

Station 6 - RK 90.0, near Leadore just downstream from the junction of Texas and Eighteenmile Creeks.

Water Chemistry

Water samples were taken from each station in the river at 2-week intervals during the summers of 1972 and 1973, and at approximately monthly intervals from March through May, then September through November of 1973. The samples were fixed with $HgCl_2$ to retard bacterial action then frozen at -20 C until analysis.

Inorganic phosphorus (orthophosphate) concentrations of the water samples were determined by the stannous chloride method and nitrate-nitrogen by the brucine sulfanilic-acid method (APHA, 1971). Turbidity was measured with a Hellige Turbidimeter. A Solu-Bridge conductivity meter determined conductivity expressed as mg/l NaCl (TDS). TDS measurements were also taken on the water samples from many of the tributary streams and irrigation drains during both summers. Alkalinity in the Lemhi River was measured twice monthly during July and August of both years and determined according to APHA (1971).

No part of the Lemhi River was unaffected by irrigation return-flows, so we selected Bear Valley Creek, a second-order tributary of the Lemhi as a control to measure nutrient trends in the area during the irrigation season. Bear Valley Creek was in an essentially undisturbed condition, except for some cattle grazing along the stream banks. Bear Valley Creek was compared with a similar stream, Basin Creek, in an adjacent parallel

valley. Both streams begin in alpine lakes 2500 meters mean sea level and empty into Hayden Creek, a major tributary of the Lemhi River. Basin Creek drains approximately 445 hectares of irrigated land. A comparison of the two streams should give a measure of the influence of irrigation return-flows on the water chamistry in a small drainage. Conductivity, turbidity, NO_3, and PO_4 measurements were taken on both streams during 1973.

Periphyton

We collected periphyton samples at each station by submerging 2.5 x 7.6 cm glass microscope slides in the river for a period of 28 days as described by Walker (1972). The slides were held in a wooden frame staked to the river bed so that the current flowed parallel to their surface. Each frame held 20 slides placed 1.9 cm apart and 15-20 cm below the surface. Glass slides have been used as a collecting substrate for periphyton by many investigators including Sladecek and Sladeckova (1964), Patrick (1968), and Cooper and Wilhm (1970). This procedure is generally believed to collect a representative sample of the natural algal community.

We removed slides at 7-day intervals in 1972 and at 4-day intervals in 1973 for identification of algae and measurement of cell density. Each slide was stored in 4 percent formaldehyde for a week, then scraped clean with a razor blade and camel's hair brush. After quantitative subsampling, 60 to 240 microscope fields were counted in a Palmer Counting Cell, then

extrapolated to total number of individual cells per mm^2 of slide surface.

We checked validity of glass slides as collecting substrate for periphyton by using a small sampler constructed of a short length of plastic pipe with one end coated with a thin layer of "Silicon-Seal" providing a watertight seal when pressed against the surface of a rock. Preservative was poured into the sampler, the enclosed algal growth scraped off with a brush, then pipeted out the suspension of algal cells. The area sampled was 571 mm^2.

We compiled monthly averages of eight variables at each station (temperature, turbidity, TDS, NO_3, PO_4, altitude, alkalinity, and current velocity) then ran a stepwise multiple correlation analysis correlating these parameters with the dependent variable, cell number per mm^2 of slide surface.

Productivity

Slides were removed after 28 days in the river and transported in river water back to the University of Idaho in Moscow for bioassays to determine productivity by oxygen production at each station. Each slide was placed inside a stoppered 250 ml glass bottle with river water from the same site, then incubated for 4-8 hours in a constant temperature water bath. Temperatures in 1972 were controlled 21.0-22.5 C for the July run and 17.0-19.0 C for the August run. Temperature in 1973 was maintained at 17.5 C for all runs. An overhead light source provided 9,470 lux in 1972 and 10,870 lux in 1973. We chose a light source

of this magnitude because that is approximately the level above which other factors such as temperature and CO_2 availability become more limiting than light (Phinney and McIntire, 1965). After incubation, the oxygen content was determined in each bottle by titration (APHA, 1971).

A defect of the bioassay apparatus was the missing effect of current on the slides inside the glass bottles. The algal communities on the slides probably showed a decreased response to the absence of current, since the phenomenon of physiological enrichment was lacking in the closed system. As a result, the productivity estimates were probably an underestimate of the actual potential productivity. All slides experienced the same bias, though, so comparisons between stations should be valid.

RESULTS AND DISCUSSION

Water Chemistry in the Lemhi River

Nitrate

Nitrate levels in the Lemhi River were distinctively different between the upriver and downriver stations. The correlation coefficient between nitrate concentration and altitude was .89 indicating an essentially linear decline in nitrates downriver (Figure 3). Nitrate concentrations began to increase at the lower four stations about the end of April, just after irrigation began. Nitrate concentrations at that time ranged from 0.60 mg/l at RK 26.7 to 1.41 mg/l at RK 51.0, but did not increase at RK 90.0 until the end of May when they reached 2.73 mg/l. The later appearance of increased nitrates upriver was probably due to the fact that irrigation began later in the upper valley. RK 76.7 had continuously high nitrate levels throughout the spring and summer. The source of the high nitrate levels could be the large amounts of underground water which enter the Lemhi River in this area.

The highest nitrate concentrations in the Lemhi River during the irrigation season occurred during mid-June . . . . 1.30 mg/l at RK 26.7 to 2.67 mg/l at RK 76.7 (Figure 4). This was immediately after the period of maximum snow melt in the mountains and during a time of heavy rains. Nitrate levels then decreased to a low in July for the upper three stations

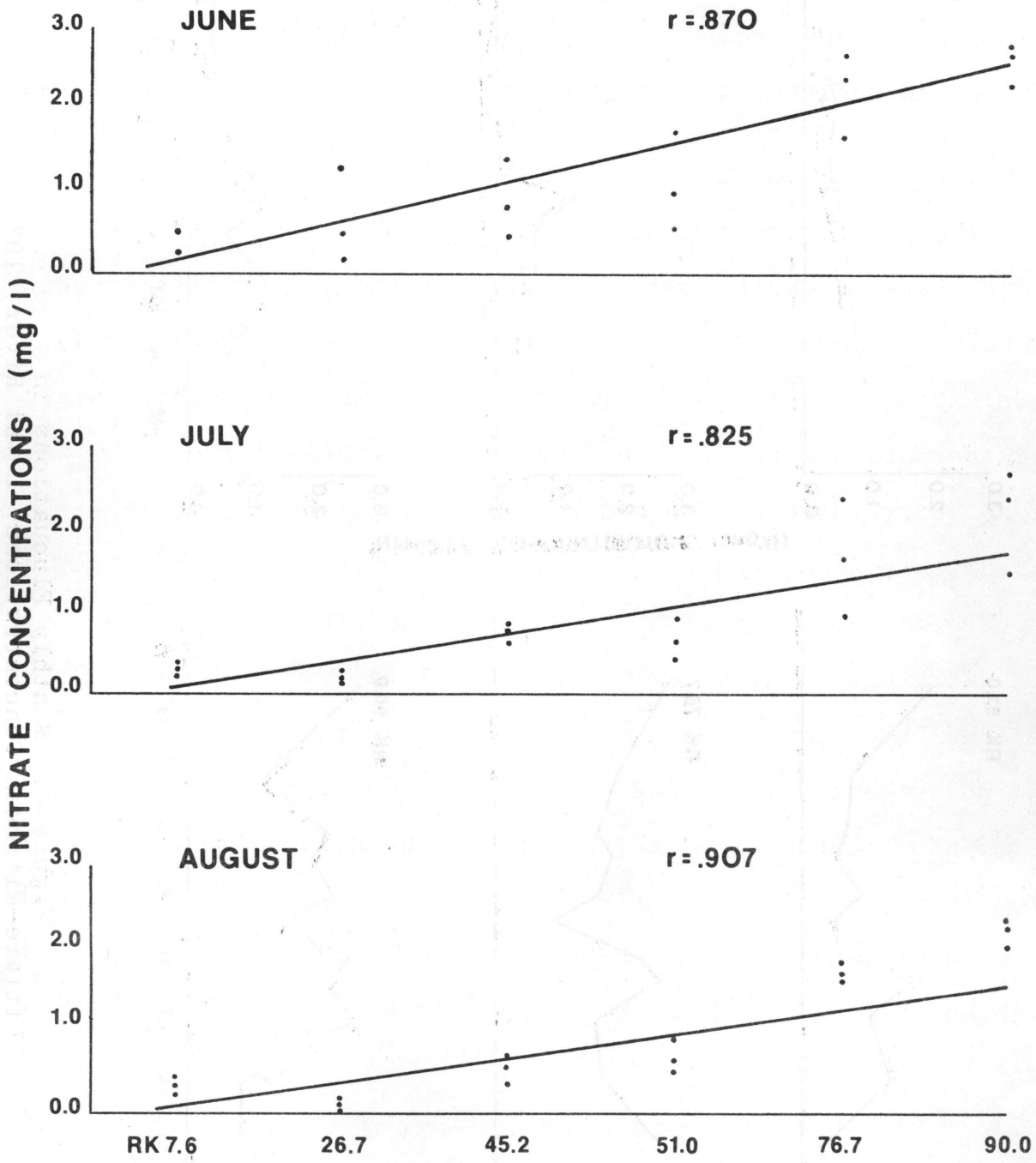


Figure 3. Linear Decrease Downstream in Nitrate-Nitrogen Concentrations, Lemhi River, 1973.

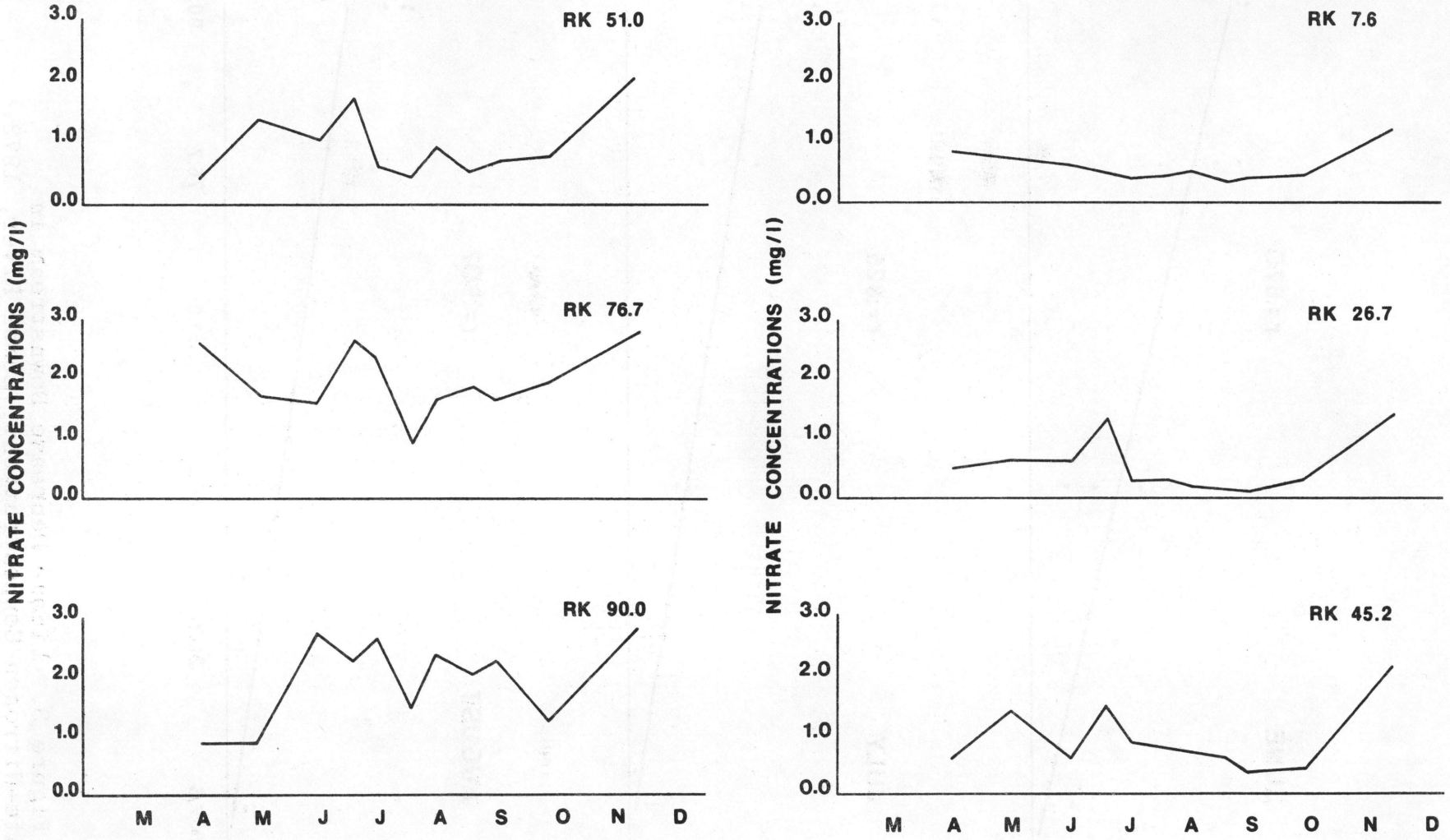


Figure 4. Monthly Flucuations in
Nitrate-Nitrogen Concentrations, Lemhi River, 1973.

and a low in August for the lower three. The highest nitrate concentrations during the year occurred at all stations in November (1.14 to >2.80 mg/l).

The decline in nitrate concentrations downriver can be attributed to two possible causes, high nitrate demand by algal communities in the river, and possible denitrification within the soil. The decline in nitrate levels throughout the summer appears to be a natural phenomenon, even with no irrigation. Concentrations in the "control" stream, Bear Valley Creek, exhibited this same trend, with a low of 0.17 mg/l occurring at the end of August.

The fact that the Lemhi irrigation projects depend on the relatively inefficient technique of flood irrigation, and the lack of a network of surface drains, implies that large amounts of water will enter the soil and return to the river as sub-surface flow. Since nitrate fertilizer application in the valley is heavy, the excess water could be expected to carry large amounts of the very soluble nitrate back into the river. High nitrate discharge evidently occurred at the upriver stations where concentrations are the highest in the river. There is no reason to suppose that this would not occur along the lower river, yet nitrate concentrations continually declined downstream.

Bower et al. (1969) reported that heavy nitrate fertilizer use along the Rio Grande did not increase nitrate concentration in the river downstream. They believed denitrification was occurring in the water-saturated soil. Since the land along

the Lemhi River is wet and has a shallow watertable, denitrification could be a possible explanation for the decline in nitrates downstream. Since some diversions divert more than half of the total river flow by late summer, water flowing in the river may be applied to the surrounding fields several times before leaving the valley. High nitrate levels in the upper river could be continually reduced by denitrification every time the water is diverted and allowed to pass through the soil as subsurface return-flow. Other researchers, however, have found either little change in nitrate level of subsurface runoff after passage through the ground or gross increases in nitrate concentrations (Bondurant, 1971; Busch, et al., 1972; Carter, 1971; and Fitzsimmons et al., 1972). Furthermore, soil denitrification should be at a maximum along the upper Lemhi because of wetter soils, but nitrates are near maximal here.

Lowest nitrate concentrations in the Lemhi River (<.10 mg/l at RK 26.7) corresponded with the period of highest productivity (August) as measured by the bioassay test and cell density on both glass slides and natural substrate. The low concentrations may have been due to high algal demand removing most of the nitrates from the water. The fact that nitrate concentrations at RK 26.7 were below whose in the control stream, Bear Valley Creek, at that time further indicates that algal demand may have been responsible. Chu (1943) found that nitrate concentrations below .10 mg/l were generally below limiting levels for algal growth.

Nitrate decline downriver during the summer was quite consistent, averaging about .03 mg/l per kilometer. The nitrate removal by the stream bottom was -0.04 mg/l NO_3/hectare of river bottom in June and -0.04 mg/l NO_3/ hectare in July.

Buscemi (1969) reported a different pattern of nitrate fluctuations in the Palouse River in northern Idaho. Highest concentrations occurred prior to spring rains and again after snowmelt. Speth et al. (1970) reported that nitrate concentrations in the main Salmon River below the mouth of the Lemhi River did not peak until July, about a month after the irrigation peak in the Lemhi. This lag was attributed to runoff from agricultural lands upstream.

Phosphate

Phosphate concentrations were at their lowest level at the end of March before the beginning of runoff and the start of the irrigation season, ranging from .034 to .012 mg/l at that time. Little change was seen in April, but concentrations were highest at the upper three stations in late May (range of .023-.065 mg/l) and at the lower two stations in July (range of .075-.098 mg/l) (Figures 5 & 6).

Phosphate concentrations in the Lemhi River showed a trend exactly opposite to that of nitrates (Figure 5). A correlation of -.96 between altitude and phosphate concentrations in the river indicated an essentially linear build-up of phosphates downstream. The continuous increase in phosphates downstream reflected the continued addition over and above that removed

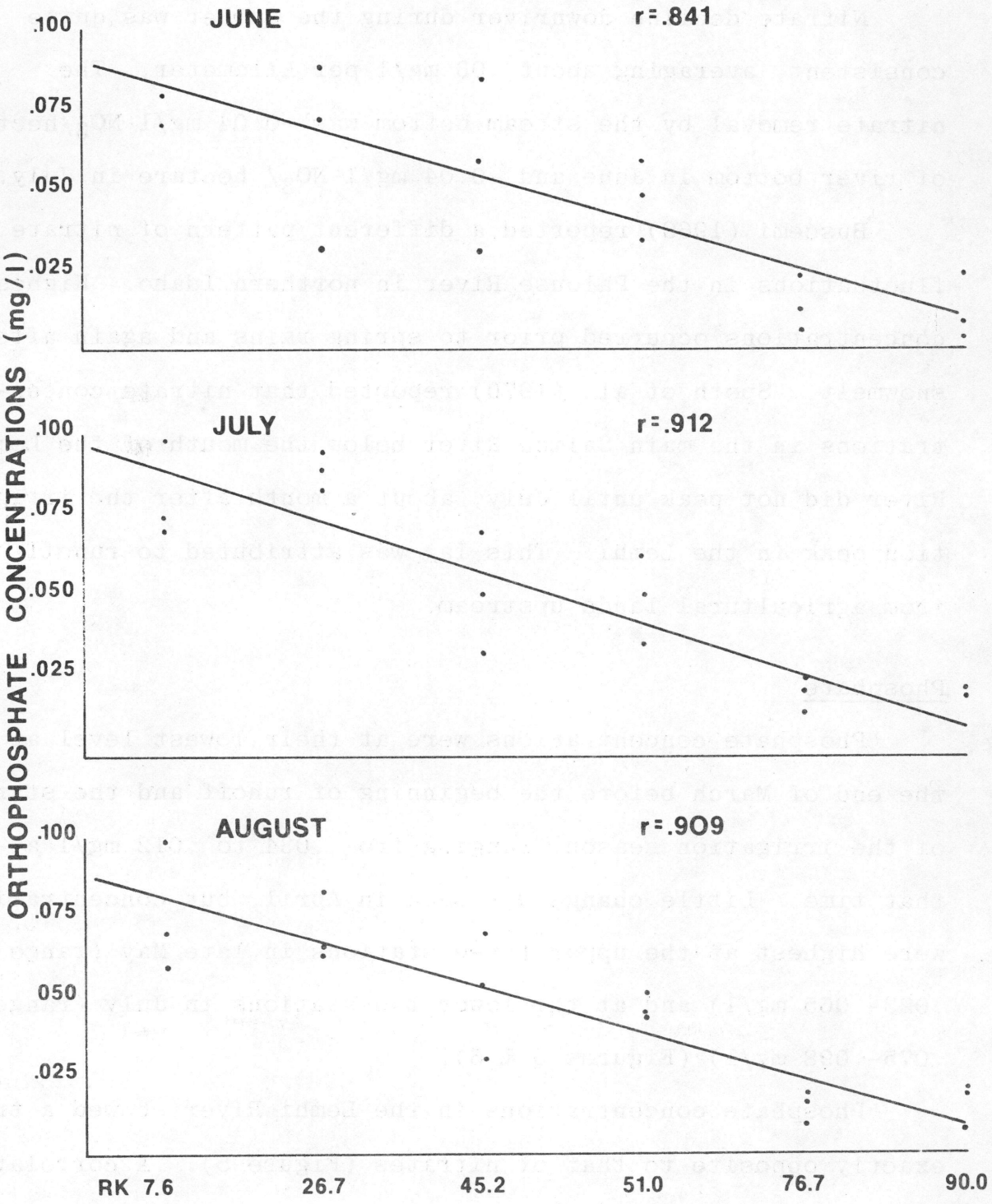


Figure 5. Linear Increase Downstream in Orthophosphate Concentrations, Lemhi River, 1973.

by algal demand. Downstream build-up averaged +.0018 mg/l per km in early June and fell to +.0006 mg/l per km by August.

Carter et. al. (1971) reported that 70 percent of the phosphate in applied irrigation water from the Snake River remained in the soil or was removed by plants. They believed that because of this, the application of irrigation water to farmland would decrease the phosphate concentration of the water if initial levels were above 0.01 to 0.02 mg/l. This soil retention of phosphates obviously was not occurring on the Lemhi River where phosphate concentrations continously increased downstream. The upriver stations had peak concentrations in May because of the slow transport of the phosphates by ground water, peak concentrations did not appear at RK 45.2 until June and at RK 26.7 until July.

The simple correlation coefficient between phosphates and turbidity was -.05. This low value was evidence that phosphates did not enter primarily through surface runoff, the main souce of turbidity. Between turbidity and TDS, however, the correlation coefficient was .79, indicating that the two parameters could have similar modes of entry into the river. This was supported by the fact that TDS levels in a surface irrigation drain checked periodically were consistently 65-75 percent higher than in the river at that point. This relation of soluble salts to surface runoff was surprising, becuase Bondurant (1971) reported no increases in conductivity between applied irrigation water and the resulting surface runoff.

TDS levels generally increased downriver from RK 90.0,

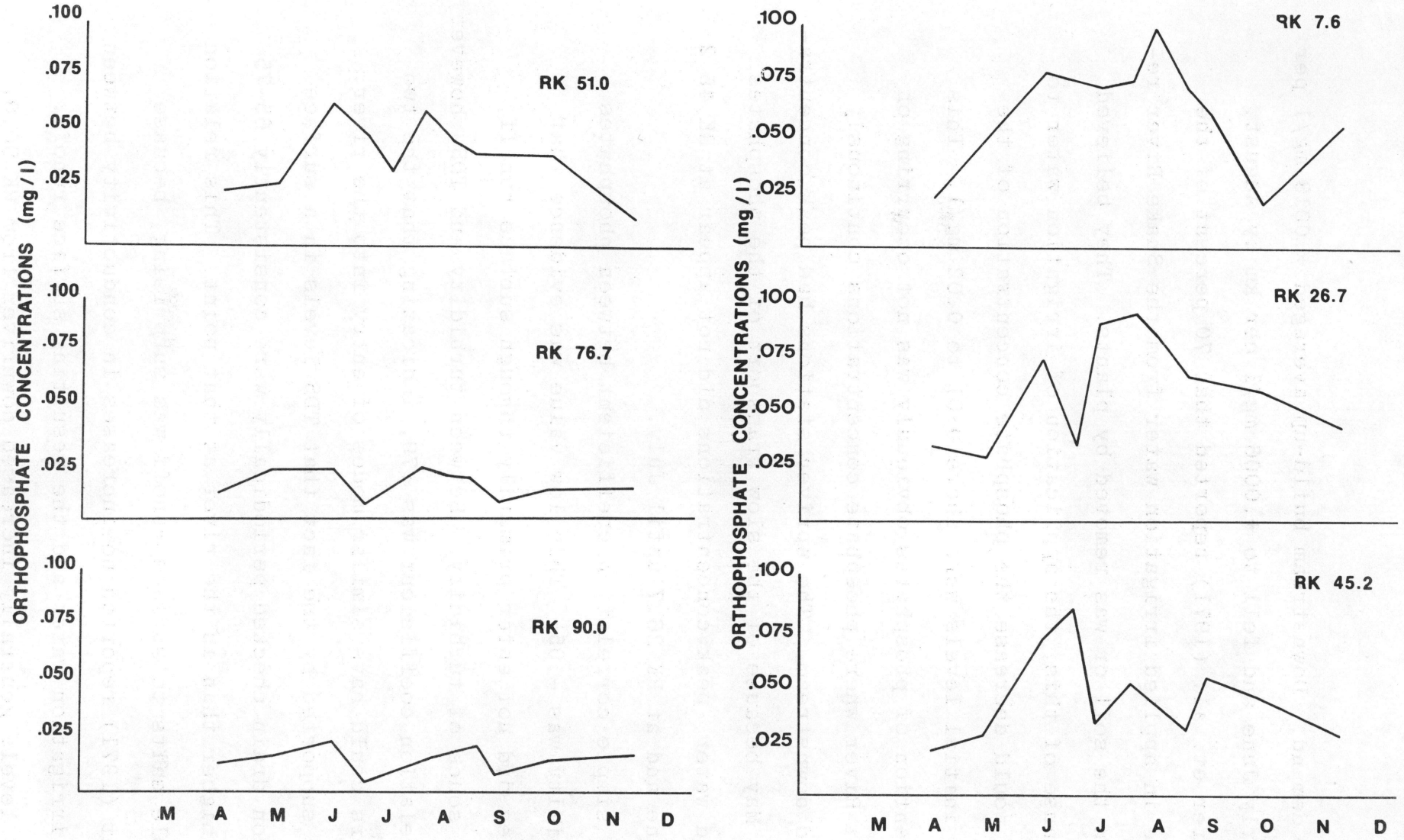


Figure 6. Monthly Fluctuations in Orthophosphate Concentrations, Lemhi River, 1973.

with the exception of a slight decrease downstream from the upper two stations (Figure 7). The decline resulted from the diluting effect of Hayden Creek entering the river. That average increase in TDS concentrations downriver was +2.25 mg/l per km in June, +2.35 in July and +2.90 in August. Correlation between TDS and altitude was poor because of lower TDS concentrations in middle reaches of the stream. The high levels at RK 90.0 (195-285 mg/l) reflected extensive irrigation development along the upstream tributaries of the Lemhi River, Texas, and Eighteenmile Creeks.

TDS concentrations, both in the river and in the tributary streams, increased continously throughout the summer (Figure 7). Levels were lowest in March and April, 200 mg/l at all stations. From the end of May to the end of August there was an essentially continuous increase from one sampling period to the next. Highest concentrations were reached on August 30 (385 mg/l at RK 7.6 to 235 mg/l at RK 76).

Dissolved solids concentrations in the small tributary streams flowing off the alluvial fans and terraces were high throughout the summer if the tributary stream was being utilized for irrigation. Streams such as Timber Creek and Big 8-Mile Creek had TDS levels ranging from about 40 to 70 mg/l NaCl, supporting the fact that they received little drainage off irrigated land. Bohannon, Sandy, and Pattee Creeks received extensive irrigation drainage and had TDS levels ranging from 200 to 500 mg/l.

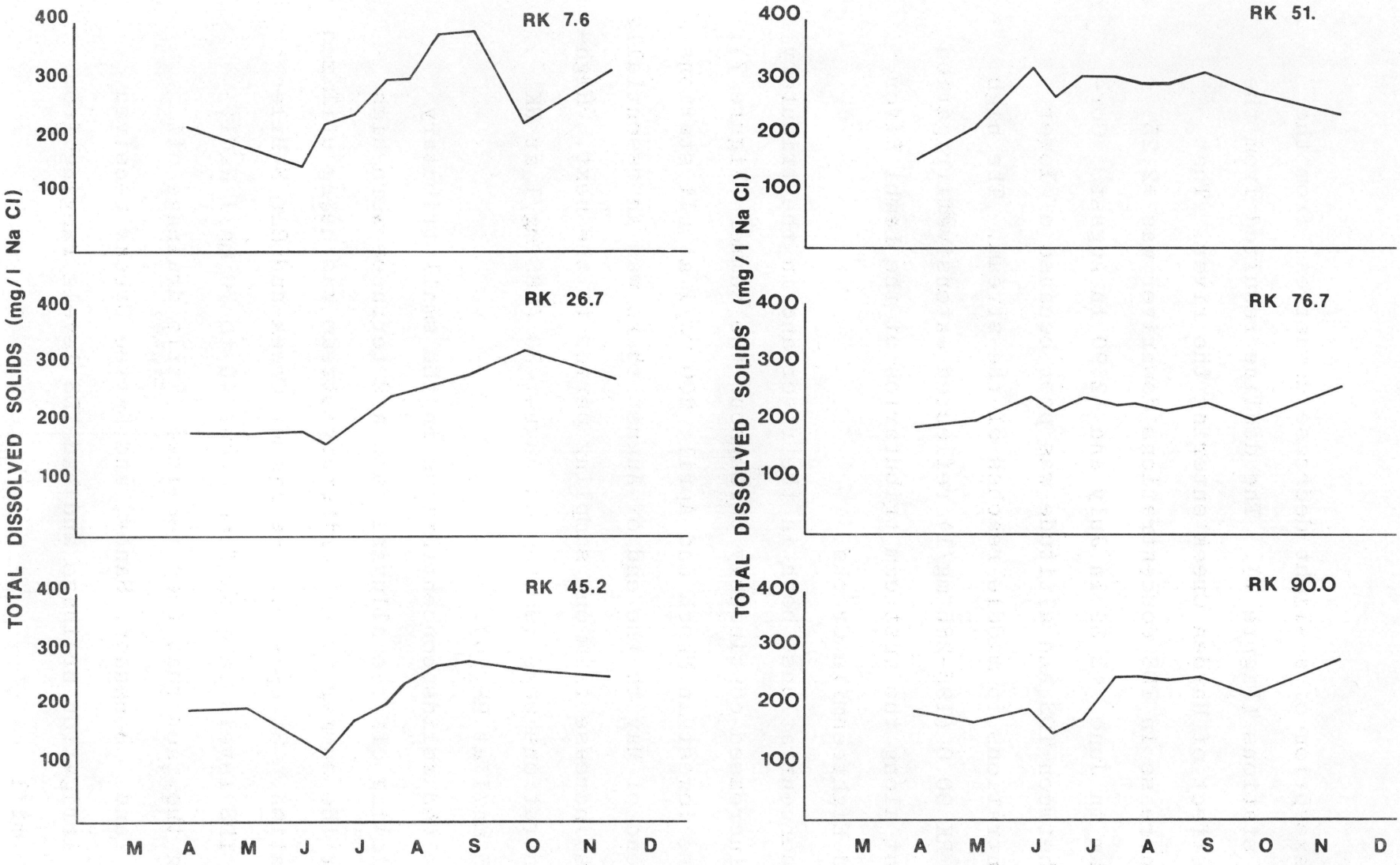


Figure 7. Monthly Fluctuations in
Total Dissolved Solids, Lemhi River, 1973.

The water in heavily utilized streams like Sandy Creek was used three or four times before it finally reaches the river, because it quickly percolates through the porous soil after being applied on the fields and reenters the stream again as ground water. Bohannon Creek had the highest TDS levels found, at times exceeding 500 mg/l NaCl. A conductivity profile of this stream was run in August of 1972. TDS levels were found to remain below 100 mg/l until near the mouth of the creek, where they jumped to 500 mg/l in a short time. Concentrations increased almost 100 times from source to mouth for Bohannon Creek and 32 times for Wimpey Creek, another heavily utilized stream nearby.

Alkalinity concentrations in the Lemhi River were high throughout the summer and always exceeded 150 mg/l (Table 1). Alkalinity levels paralleled TDS concentrations and also showed high correlation with turbidity. Large $CaCO_3$ deposits occurred on the bar soils and are probably the main source for the bicarbonate ion.

Table 1

Methyl-orange Alkalinity Levels (mg/l), Lemhi River, 1972-1973.

	1972		1973			
Station	Aug. 2	Aug. 14	July 10	July 24	Aug. 12	Aug. 30
1	208 mg/l	234	190	206	254	258
2	181	214	168	184	215	228
3	180	192	149	176	209	222
4	220	222	217	209	239	242
5	192	206	179	186	187	200
6	232	216	200	203	225	216

Water Chemistry of Basin and Bear Valley Creeks

Bear Valley Creek (nonirrigated) and Basin Creek (irrigated) had distinctively different chemical characteristics during the summer months. Spring runoff tended to wash plant and animal wastes into the stream and would account for the high nutrient levels found at that time in Bear Valley Creek (1.47 mg/l NO_3 and .116 mg/l PO_4 on April 28).

Nutrient levels in Basin Creek were high throughout the summer. By May 31, phosphates were greater than three times the concentration found in the Lemhi River. July phosphate concentrations in Basin Creek were almost nine times those in Bear Valley Creek. By the end of June, nitrate concentrations in Basin Creek were almost 4½ times those in Bear Valley Creek. Annual low nitrate concentrations of .38 mg/l occurred in late August, the same time as in Bear Valley Creek and in the Lemhi River.

TDS concentrations in Basin Creek increased continuously throughout the summer and reached a peak of 300 mg/l at the end of August, a level 32 times greater than in Bear Valley Creek. A conductivity profile of both streams in August 1972 showed a 900% increase in TDS from source to mouth in Basin Creek but only a 25% increase in Bear Valley Creek.

Periphyton

There were no pronounced trends in cell numbers from upstream to downstream stations in the Lemhi River (Table 2). There was a slight trend for algae numbers to peak in central sections of the stream with lower algae density both upstream and downstream.

Table 2

Periphyton Densities on Artificial Substrate in the Lemhi River, 1972-1973 (Cell Number Per mm^2 of Slide Surface)

River Kilometers	Date and Cell Counts			
1972	July 10	July 17	July 24	August 1
7.6	2144	8571	----	----
26.7	1324	3806	2131	6436
45.2	6041	9522	6246	----
51.0	5053	6344	2544	7783
76.7	3209	20,252	25,125	----
90.0	276	2988	4865	6626
	August 8	August 15	August 22	August 28
7.6	212	1937	2874	3385
26.7	437	1023	3349	2612
45.2	251	4126	5850	5525
51.0	333	1161	2320	4732
76.7	1031	2141	4991	4268
90.0	248	2109	2376	3599

1973	June	6	9	13	17	21	25	28
7.6		16	10	126	144	3872	3250	6439
26.7		13	6	139	2.5	124	3059	2494
45.2		45	45	28	138	162	661	1243
51.0		42	94	205	---	928	13,203	--
76.7		78	1046	6993	6731	3979	4628	8417
90.0		29	2.5	28	131	552	1132	256
	July	3	6	10	14	18	22	26
7.6		33	171	156	289	4224	3718	8837
26.7		225	572	222	881	2064	2555	4450
45.2		16.5	197	2194	4606	--	2954	8022
51.0		524	1599	1052	1096	2675	1636	6125
76.7		106	1471	9429	6801	4357	6899	8327
90.0		10	135	1388	663	414	704	1094
	August	30	3	7	11	15	19	23
7.6		3	71	455	1614	3709	2967	5900
26.7		14	90	343	988	3735	2503	2875
45.2		76	254	488	12862	16213	16106	10648
51.0		38	135	1075	5515	7814	2494	8234
76.7		71	783	2893	3212	5593	4953	3212
90.0		1.7	179	1348	7283	7515	10343	7533

Cell numbers increased slowly for the first 14 days on the glass slides placed in the Lemhi River as a collecting substrate, and then began to build up rapidly (Table 2). Cell densities were unstable, fluctuating from one sampling period to the next. This was especially noticeable in 1972 when high water between July 17 and 24 scoured the slides in the river. The slow accumulation of cells at downstream stations in June, 1973 was due to high spring runoff scouring the slides. Upstream stations were above the mouth of Hayden Creek, the principle source of high water.

Butcher (1946) in a study of algal communities of rivers in Britain compared algal cell densities on glass slides with the overall nutrient condition of the river, and devised the following guide to interpret his results of stabilized algal communities:

< 2000 algal cells per mm^2 - oligotrophic conditions

2500-10,000 cells per mm^2 - eutrophic conditions

10,000-100,000 cells per mm^2 - mesosaprobic conditions

By these criteria, the Lemhi River in summer would be classified as a eutrophic river.

Algal communities in the Lemhi River were composed almost entirely of epilithic diatoms (Class Bacillariophyceae). We identified 19 algal genera in the 1972 samples taken from the river (Table 3). During early July, Navicula was the most common genus at the lower four stations and Synedra and Diatoma at the upper two. Cocconeis became dominant at all stations beginning in late July while Navicula, Gomphonema, and Achnanthes were sub-dominants.

Table 3

Algal Genera Found in the Lemhi River, 1972

Achnanthes	Diatoma	Navicula
Cladophora	Eunotia	Nitzschia
Closterium	Fragillaria	Pinnularia
Cocconeis	Gomphonema	Rhoicosphenia
Cyclotella	Gyrosigma	Surirella
Cymatopleura	Melosira	Synedra
Cymbella		

During late July and all of August, the filamentous green alga, Cladophora sp., formed extensive mats on the river bottom at RK 7.6. This growth did not extend upriver to RK 26.7 indicating some change in the river between those two points preventing the upstream spread of the algae. High temperatures, low flow, and high nutrient levels were the three most probable reasons for the appearance of Cladophora in this area. The biggest difference between the lower two stations was the higher flow (81 vs 44 cm/sec), and the low level of nitrates below limiting levels ($< .10$ mg/l) at RK 26.7. One or both of these factors probably limited the upstream spread of the algae.

The glass microscope slides used as a collecting substrate did not adequately sample Cladophora because the long filaments would not attach to their surface. The oxygen production and cell counts did not show any great difference between the river at RK 7.6 and the other stations, probably because productivity was greatly underestimated here due to the selectivity of the slides against the filamentous algae.

The diatom Cocconeis formed a dense uni-algal epiphytic growth on the Cladophora strands growing on the river bottom. This growth made productivity measurements at RK 7.6 even more of an underestimate.

Correlation Analysis

The parameters, turbidity, temperature, TDS, altitude and nitrate accounted for 47 percent of the variability in cell numbers found on glass slides over the entire river (Table 4). By dividing the river in half and running the lower three stations together and the upper three together, the analysis demonstrated higher correlations. Turbidity, altitude, temperature, TDS and nitrate accounted for 90 percent of the variability in cell numbers in the lower river, while altitude, TDS, phosphate, and nitrate accounted for 78 percent of the variability in cell numbers in the upper river. Dividing the Lemhi River in two between RK 45.2 and 51.0 for the correlation analysis eliminated much of the variability in the data which resulted from treating the entire river as one unit. The upper and lower halves of the Lemhi River are distinctively different, both in physical and chemical aspects; the data within each half are much more similar.

Weiss (1970) used a similar regression analysis when studying algal response in bioassay tests to water from the New Hope River in North Carolina. He found that the total biomass produced was directly related to the magnitude of the nitrate and phosphate levels in the river water. His variables, however, consisted only of the various chemical forms of nitrogen and

Table 4

Stepwise and Simple Multiple Correlation Values From Eight Variables Run Against Cell Density On Glass Slides, Lemhi River, 1973

	Multiple Correlation of Y on Cumulative X	Simple Correlation of Y on a Single X
Cell number (Y) vs. all X values		
Turbidity	$R^2 = .207$	.455
Temperature	$R^2 = .276$	.296
TDS	$R^2 = .326$	.344
Altitude	$R^2 = .357$	-.095
Nitrate	$R^2 = .474$	-.196
Velocity	$R^2 = .482$	.191
Alkalinity	$R^2 = .490$	.289
Phosphate	$R^2 = .490$	.081
Cell Number (Y) vs. 1-2-3 X* values		
Turbidity	$R^2 = .430$	.656
Altitude	$R^2 = .550$	.009
Temperature	$R^2 = .610$	.447
TDS	$R^2 = .675$	.475
Nitrate	$R^2 = .904$	-.162
Phosphate	$R^2 = .904$	-.202
Cell Number (Y) vs. 4-5-6 X values**		
Altitude	$R^2 = .360$	-.560
TDS	$R^2 = .531$	.210
Phosphate	$R^2 = .671$	.577
Nitrate	$R^2 = .776$	-.505
Temperature	$R^2 = .777$	.297
Turbidity	$R^2 = .777$	.259

*X variables from Stations 1, 2, and 3.
**X variables from Stations 4, 5, and 6.

phosphorus and did not include physical factors. He found nitrogen levels to be more critical to algal growth in rivers and phosphorus levels to algal growth in lakes.

The positive relation of turbidity to cell density on the glass slides was difficult to explain. There could be some form of organic enrichment that entered the river by the same pathway as turbidity and had a stimulatory effect on the algal growth. Patrick (1966) in a study of the effects of nitrate and phosphate concentrations on diatom growth, verified the action of other factors such as organic nutrients or trace elements acting in combination with nitrate and phosphate to stimulate growth.

The importance of temperature to algal cell density was easier to understand. The upper reaches of the Lemhi River were much colder than the lower especially at RK 90.0 where temperatures never exceeded 15.0 C. Patrick (1966) found that temperature and day-length were better correlated with algal growth than were nitrate and phosphate levels. She showed that optimum temperatures for diatoms were usually between 20.0 and 30.0 C. Since temperatures continually increase downstream, each descending station had more optimum temperature conditions for algal growth. At RK 7.6, mid-summer temperatures commonly exceeded 20.0 C.

Periphyton Productivity

Productivity as measured by net oxygen production in bio-assays increased throughout the summer, peaking at 1.72 mg O_2/l/hr

per slide at RK 7.6 in late August (Table 5). There was no predictable pattern as to which station would be the most productive but stations from the lowermost station or from middle reaches of the river were usually the three most productive.

Water and periphyton from the Lemhi River at RK 90.0 were consistently the least productive of all stations. Temperatures in this area ranged from a low of 2.0 C in June to a high of 15.0 C in July, consistently the coldest in the river. Average monthly high temperatures were 9.3 C in June and 12.2 C in July and August. Phinney and McIntire (1965) found that when light and CO_2 were not limiting, an increase in temperature would increase algal photosynthesis. Kobayasi (1961) found the photosynthetic rate of periphyton to be affected by both light and temperature and that production was higher in the warmer less-shaded lower reaches of the River Arakawa than in its cooler upper reaches.

During August of both 1972 and 1973, water and periphyton from Lemhi River at RK 26.7 ranked very low in productivity despite the higher temperatures prevailing downriver. Nitrate concentrations were below 0.10 mg/l during August of both years in this part of the river. Visual observation of the river bed around RK 26.7 consistently showed it to be the area in the river most lacking in algal growth. Ranking of the stations in order of productivity showed a straight downriver increase except that RK 26.7 was lowest instead of second highest. The only factors significantly different between the downstream 2 stations during August were the lower nitrate concentrations at RK 26.7 and

Table 5

Net Oxygen Production in Bioassay Tests (mg/l O_2/hr/slide) Ranked and Separated by Duncan's Multiple Range Test, 1972-1973. Means Not Underlined by a Common Line are Significantly Different.

July, 1972

RK	90.0	7.6	51.0
O_2	.77	.99	1.12

August, 1972

RK	90.0	26.7	51.0	76.7	7.6	45.2
O_2	.64	1.09	1.17	1.23	1.45	1.49

June, 1973

RK	90.0	26.7	45.2	7.6	76.7
O_2	.44	.52	.52	.89	1.27

July, 1973

RK	90.0	7.6	26.7	51.0	76.7	45.2
O_2	.52	1.23	1.26	1.31	1.37	1.61

August, 1973

RK	26.7	90.0	76.7	51.0	45.2	7.6
O_2	.88	1.05	1.14	1.40	1.57	1.72

September, 1973

RK	90.0	90.0+P[1]	76.7	45.2	26.7	26.7+N[2]	51.0
O_2	.80	.86	.92	.96	1.23	1.37	1.59

[1] 90.0+P = RK 90.0 water + .05 mg/l PO_4
[2] 26.7+N = RK 26.7 water + .20 mg/l NO_3

higher current velocity and greater flow at RK 26.7 than at RK 7.6. The data indicated that nitrate deficiency was limiting to algal growth in the river at that time.

In the September, 1973 bioassay, 0.20 mg/l NO_3 N was added to RK 26.7 water. Oxygen production increased from 1.23 to 1.37 mg/l O_2/hr/slide but this increase was not significant (Table 5). At the time of this September run, however, the nitrate concentration of RK 26.7 water had already increased to 0.25 mg/l NO_3 from the August low of 0.10 mg/l NO_3.

Water from RK 90.0 was spiked with 0.05 mg/l PO_4·P in the September bioassay to test whether the August low phosphate concentrations at RK 90.0 were limiting periphyton production. Production increased from 0.80 to 0.86 mg/l O_2/hr/slide but the increase was not significant. Phosphate concentrations in the river meanwhile, had increased from 0.008 mg/l in August to 0.015 mg/l in September.

There was some tendency for algal communities in the river to become adapted to water from the site where they were collected. Although differences were not significant, whenever slides were tested in water from another part of the river, oxygen production was always lower than when run in water to which they were accustomed. This trend consistently indicated adaption of the algal communities to nutrient conditions in their native reach of the river.

The chemical parameters in the water, TDS, nitrate, phosphate, alkalinity, and turbidity accounted for only 36 percent of the variability in oxygen production between water from different

stations in the bioassays (Table 6). Physical factors such as temperature, altitude, and current velocity were not included in the variables run against oxygen production because they were held constant during bioassays.

Algal productivity correlated poorly (r=.20) with cell density on glass slides. In July 1972, cell densities at RK 76.7 were as high as 25,000 per mm^2 due to the bloom of a very small diatom, Synedra sp., yet total primary production at RK 76.7 was not significantly higher than elsewhere in the river. In July 1973, cell density at RK 7.6 was almost twice that at RK 26.7 after 28 days (8835 vs 4450 cells per mm^2) yet oxygen production at that time was almost identical between the two stations (1.23 mg O_2/l hr vs 1.26 mg/l, respectively).

Table 6

Stepwise Simple and Multiple Correlation Values From Five Variables Run Against Net Oxygen Production From Lemhi River Bioassays, 1973

	Multiple correlation of Y on Cumulative X	Simple correlation of Y on a Single X
Net oxygen production vs. all X		
TDS	R^2 = .286	.535
Nitrate	R^2 = .338	-.347
Phosphate	R^2 = .351	.213
Alkalinity	R^2 = .358	.464
Turbidity	R^2 = .358	.425

CONCLUSIONS

Irrigation development along the Lemhi River appears to have had significant effects on chemical parameters and algal growth in 1972 and 1973. Primary production was high and the river was in a eutrophic condition as measured by nutrient levels and the quantity of algal growth.

Water Chemistry

1. Nitrate concentrations increased in the lower Lemhi River immediately after start of irrigation in the spring, indicating a quick response to nutrients entering the river from subsurface return-flows.

2. Nitrate concentrations declined throughout the summer in the Lemhi River and drastically declined downstream. Algal demand for nitrates in the river, denitrification within the soil, and reduced input after extensive leaching through the irrigation season were possible causes for the decreased concentrations. Because nitrate concentrations in the river were highest in the upper valley where nitrate loss by denitrification would be expected to be at a maximum in the wet soils, high algal demand was considered to be a more probable reason for the decrease downstream.

3. Phosphate concentrations in the Lemhi River increased more slowly than nitrates after start of irrigation in the spring because of their lower solubility in the returning subsurface flow. Their main mode of entry into the river appeared to be

the same as that of nitrates, subsurface flow, and not surface runoff as had been reported in other drainages.

4. Phosphate concentrations in the Lemhi River increased throughout the river length indicating that they were continually entering the river at a faster rate than the algal demand was removing them. Concentrations peaked in July, then declined throughout the summer and fall.

5. Comparison of two adjacent stream drainages in the Lemhi basin showed a conductivity profile which increased 900% from source to mouth in the irrigated drainage but only 25% in the un-irrigated drainage.

Periphyton

1. Algal communities in the Lemhi River were dominated by the diatoms Cocconeis, Diatoma, Navicula, and Synedra. The more productive river reaches were dominated by the green alga Cladophora in late summer.

2. Glass microscope slides were an effective means of collecting a sample of the diatom community in the Lemhi River. Cell density on natural substrate was similar to or slightly greater than on glass slides after periods of 28-42 days in the river.

3. Turbidity, temperature, and altitude accounted for more of the variability in cell numbers on glass slides than did nutrient concentrations in the water.

Productivity

1. Primary productivity in the Lemhi River as measured by

the oxygen production bioassay increased throughout the summer, reaching a maximum in August. Peaks of productivity shifted up and down the river.

2. Productivity was lowest in the Lemhi River at RK 26.7 in August, 1973. This low productivity was likely due to the low concentration of nitrates ($<.10$ mg/l). An "in situ" bioassay in August with spiked and unspiked water from the Lemhi River at RK 26.7 would confirm whether nitrates actually were limiting production at that time.

3. Algal cell density was not a good measure of primary productivity due to variations in cell size and growth forms. Correlation between cell density and oxygen production from the bioassay tests were poor ($r = .20$).

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