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THE MOSES LAKE WATER ENVIRONMENT

A Report Prepared for the

MOSES LAKE IRRIGATION AND REHABILITATION DISTRICT

MOSES LAKE, WASHINGTON

BY

UNIVERSITY OF WASHINGTON

COLLEGE OF ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

MAY, 1964

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A Report Prepared for

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Moses Lake Irrigation and Rehabilitation District
Moses Lake Washington

by

Robert O. Sylvester
Professor of Sanitary Engineering

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University of Washington
Department of Civil Engineering
May 1964

UNIVERSITY OF WASHINGTON
Department of Civil Engineering

May 21, 1964

Members of the Board
Moses Lake Irrigation and Reclamation
District
Moses Lake, Washington

Attention: Mr. Karl Goodrich, Chairman

Gentlemen:

In compliance with our contract of April 26, 1963 regarding an "Engineering and Ecological Study for the Rehabilitation of Moses Lake", we are herewith submitting the findings of our study and evaluation entitled "The Moses Lake Water Environment". You will recall that the procedures and objectives of this study were discussed at a meeting in Moses Lake on June 10, 1963, attended by representatives of the District, the City of Moses Lake, U. S. Bureau of Reclamation, State Department of Game, Pollution Control Commission, and the Grant County Health Department. A prepublication review of this report was made in Moses Lake on May 19, 1964, attended by a representative of the State Department of Health and the Moses Lake Citizen's Advisory Committee, in addition to those represented at the earlier review meeting.

As a guide to the recommendations contained in the report, it is suggested that an early action leading toward possible Lake rehabilitation would be the engaging of a biologist to locate the carp spawning areas in Moses Lake and the period of spawning. It is further suggested that the economics of Lake rehabilitation (benefit-cost analysis) be studied as an additional guide on the decisions that must be made. Social implications would be inherent to the study as would be the proposed lock and canal connecting Moses Lake with the Potholes Reservoir.

It has been a pleasure to have worked with the District and citizens of the Moses Lake Community and we sincerely hope that our study will encourage the trials for Lake water quality improvement and that it will not discourage you because of the magnitude of the problems.

Very truly yours,

Robert O. Sylvester
Professor of Sanitary Engineering

Ray T. Oglesby
Research Assistant Professor of Sanitary Biology

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INTRODUCTION

On April 26, 1963, the Moses Lake Irrigation and Rehabilitation District signed a contract with the University of Washington for an "Engineering and Ecological Study for the Rehabilitation of Moses Lake". The purpose of this study was to define the water quality problems in Moses Lake through field observations; relate these problems to the water environment and the drainage area characteristics; and prepare, if feasible, recommendations for Lake rehabilitation.

Moses Lake is located in Central Washington (see Figure 1) in an area that was surrounded largely by desert until after World War II. The Columbia Basin Irrigation Project then brought water and diversified farming to the area. The City of Moses Lake thenceforth grew very rapidly, from a population of 326 in 1940, to 2679 in 1950 and 11,299 in 1960. Growth in the metropolitan area was further enhanced by construction of the nearby Larson Air Force Base. The present population of the Moses Lake Metropolitan area is estimated to be around 20,000 persons.

Moses Lake has a large recreation and aesthetic potential in its naturally arid setting. This recreation potential for fishing, swimming, boating, and water skiing and the potential for shoreline home development has not been realized because of adverse water quality in the Lake and other interfering factors. These adverse conditions were reported to be heavy seasonal algal blooms; turbidity, a large population of carp, shallowness, possible fecal pollution, emergent vegetation, and mosquito breeding. Factors believed to be contributing to these conditions were; the carp population, feed lots along the lake shore, discharge of the Moses Lake City sewage treatment plant, Crab Creek drainage, discharge from irrigated lands, and the causeways across Pelican Horn, Parker Horn, and the lower lake.

Pot Holes Reservoir immediately south of Moses Lake is widely used for recreation and the Irrigation and Rehabilitation District has been desirous of connecting the reservoir with Moses Lake through a dredged channel and boat locks. Potholes Reservoir is a sump for collection of irrigation return or drainage water and canal wastage and is used by the U. S. Bureau of Reclamation to feed the Potholes East Canal.

The Moses Lake Irrigation District has, in recent years, has become more in-

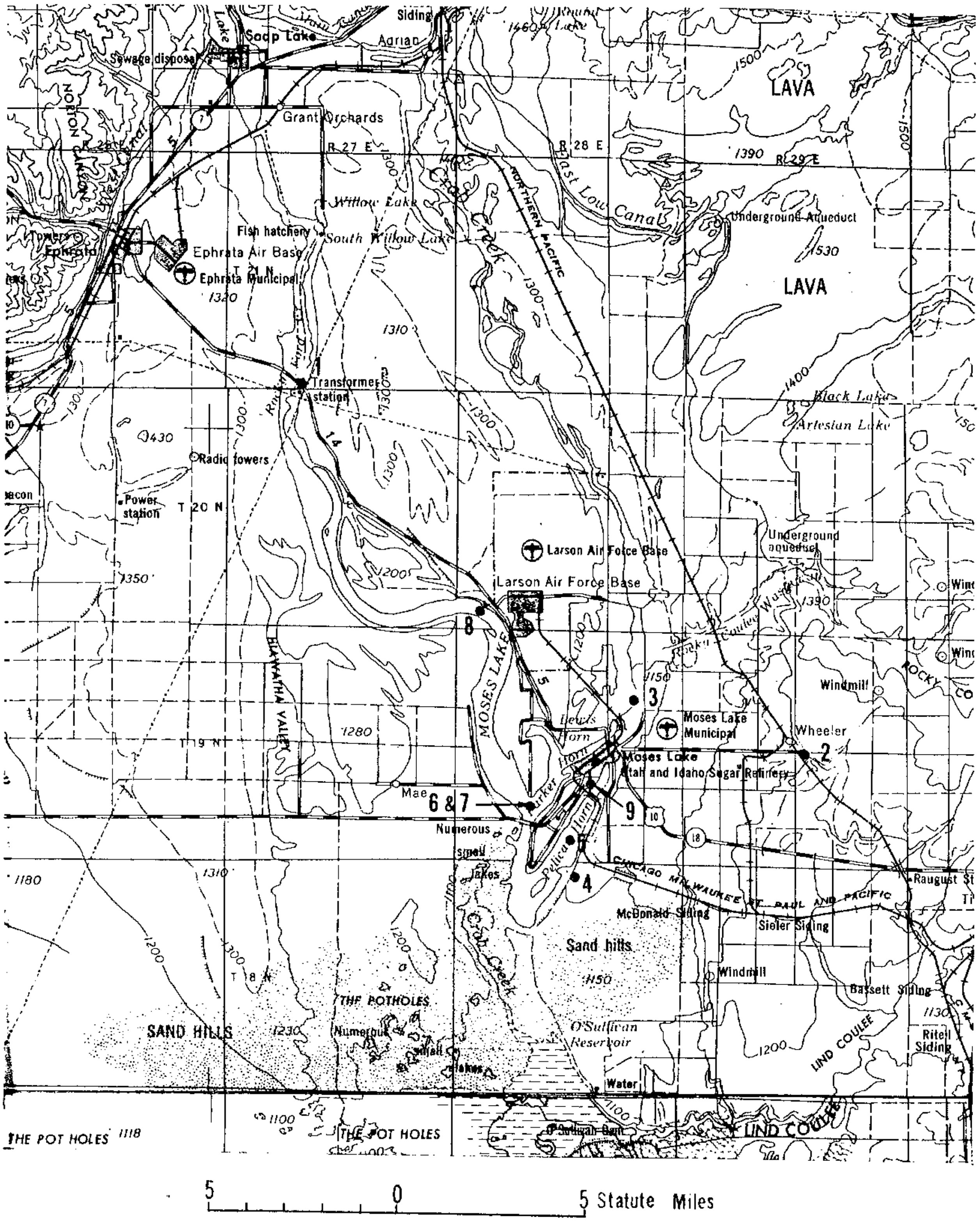


Fig. 1. Map Of Moses Lake And Vincinity

terested in Lake rehabilitation for purposes other than, or in addition to, irrigation and they have changed their name to include rehabilitation. The Washington State Legislature, in addition to giving them the authority to add rehabilitation to their name, has given them control over several Lake and shoreline uses. District boundaries are limited to the southern portion of the Lake.

DESCRIPTION OF MOSES LAKE

History

The community adjacent to the Lake was platted in 1911 under the name of "Neppel". In 1938, Neppel changed its name to that of the adjacent lake which years earlier had been named after Chief Moses, a chief of the Wenatchee tribe.

Moses Lake was formed many years ago by drifting sand damming the Crab Creek Valley. Prior to 1904 (1) there was not a surface outlet, just subsurface seepage through the sand dunes. In 1904 flood waters cut a channel through the sand and lowered the lake level some eight to ten feet. Through construction of a dam with outlet gates the then newly formed Moses Lake Irrigation District restored the lake level to its pre-breakout elevation of 1046 feet, the present normal lake water surface elevation. The State of Washington bed and shoreline rights extended up to elevation 1048.0 feet. These rights have been acquired by the Bureau of Reclamation (2) which, through its new outlet works, can control the lake water surface between elevations about 1040 and 1048.

Irrigation water is pumped directly from the Lake or it is taken from wells whose water table is maintained from lake seepage. Because of urbanization and the recent availability of Columbia River water, the land irrigated by pumpage from the Lake has been, according to Mr. Karl Goodrich, Chairman of the District, reduced from about 10,000 acres to a present total of 3000-3500 acres. Four to five acre-ft. per acre per year are applied for irrigation. Inflow to the Lake has increased in recent years due to the presence of irrigation return flow. A surplus of water exists during all seasons of the year.

Physical Features

The lake area was measured from U.S.G.S. Quadrangles, having a scale of 1:24,000, using a planimeter. Lake depths were approximated by running cross-sectional traverses about every 2000-5000 feet, depending upon the section of

Lake, using a recording fathometer loaned by the Washington Department of Game.

Overall lake characteristics are as shown in Table 1 below. Table 2 gives the characteristics of various segments of the Lake.

Table 1 - Physical Characteristics of Moses Lake[1]

Shoreline length;		58.5 miles
Surface area at lake elevation 1046	10.6 sq. mi. or	6800 acres
" " " " " 1041	10.3 " " "	6600 "
" " " " " 1048	10.7 " " "	6850 "
Water volume at elevation 1046;		126,000 acre-ft.
" " " " 1041;		92,000 " "
" " " " 1048;		138,500 " "
Mean depth (Volume divided by surface area, elevation 1046)		18.5 ft.
Maximum depth;		38 "
Maximum width;		4,900 "
Length, north end to east end Pelican Horn;		20.5 miles

1. Approximate values using measurement methods described.

Table 2 - Segment Characteristics of Moses Lake[1]

Segment	Surface Area Acres	Volume Acre-ft.
Entire lake	6800	126,000
Pelican Horn including S. end lake	1600	25,000
Parker and Lewis Horn	975	11,700
Lewis Horn	217	2,180
South of Highway 10 Bridge	2030	33,300
Lake above Parker Horn to Air Force Beach	2150	60,200
Air Force Beach to Head of Lake	1640	20,800

1. Approximate values at elevation 1046.

Relatively deep water extends to near the shoreline in most areas of the Lake with the exception of the upper end of the horns and the north end of the Lake. Most of the shoreline and bottom are rocky (see Figure 2) with mud bottoms in the lake extremities and a sandy shoreline along the southwestern portion of the Lake.

Because of carp activity (presumably), there is essentially no emergent vegetation in Moses Lake away from the shoreline. Cattails are found along the shoreline where the water is shallow and particularly around the islands. The upper end of Pelican and Parker Horns and the north end of the Lake are marshy.

Normal operating lake elevation is 1046 feet, which is now controlled by the District in cooperation with the U. S. Bureau of Reclamation. Lake level

Fig. 1. Rocky Ford Creek, Station 1

Fig. 2. East Low Canal Sampling, Station 2

Fig. 3. Crab Creek, Station 3

Fig. 4. Subsurface Seepage, Station 4

PLATE A

Fig. 1. Pelican Horn near Station 5

Fig. 2. State Park, near Station 6 and 7

Fig. 3. Airmans' Beach near Station 8

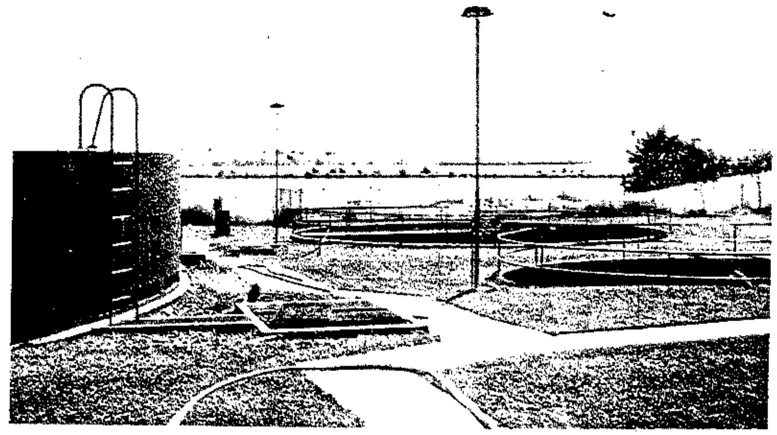


Fig. 4. Sewage Treatment Plant, Station 9

PLATE B

can be lowered to about elevation 1041 and raised to 1048. During the winter, the lake level is lowered to permit working on shoreline structures, to reduce possible ice damage and to provide storage for late winter runoff. Table 4 shows average monthly lake elevations during the period of this report. When irrigation demands in the lower Columbia Basin Project increase as more land is brought under irrigation, it may be necessary to raise Potholes Reservoir above its average 1036 foot elevation to elevation 1047.5 which will back water into Moses Lake above its usual operating elevation.

Lake Uses

Moses Lake is used for boating, water skiing, swimming, fishing and as a source of irrigation water as mentioned previously. A portion of the shoreline along Pelican, Parker and Lewis Horns and the central portion of the Lake is used for homesites. Additional homesites are being platted and homes are being built, but as with the recreation, this has been hampered by poor water quality. A state park is located on the main Lake opposite the entrance to Parker Horn; the Air Force has a park located near Larson Air Force Base in the central portion of the Lake; there is one marina on Parker Horn and another on the main Lake near Highway 10.

From 500-1000 tons of carp are seined from the Lake annually and used for food at the trout farm on Rocky Ford Creek or processed into fish meal at a by-products plant in the nearby town of Wilson Creek. Because of the good fishing in nearby Potholes Reservoir and adjacent lakes, the fishing pressure in Moses Lake is lessened. Fish caught consist of trout, perch, crappie, bluegill, bass, carp and catfish.

During the autumn, according to the Department of Game, as many as 50,000 ducks at one time will use Moses Lake as a resting place and refuge during the hunting season.

OBJECTIVES OF THE STUDY

The objectives of the University in making the study of Moses Lake were as follows:

1. To obtain data over a period of about one year commencing in March of 1963.

2. To define the physical characteristics of the Lake and its relation to inflows and outflows.

3. To locate and identify all factors that would relate to the Lake water quality.

4. To relate Lake water quality to the above factors and evaluate their significance.

5. To develop a monograph on carp and specifically relate carp to water quality.

6. To obtain physical, chemical and biological water quality data from representative portions of the Lake and from the significant inflows.

7. To collect data and opinions from others who have an interest in the Lake.

8. To assess the Lake's existing condition in respect to its present and proposed uses.

9. To discuss and recommend, if practicable, methods of Lake rehabilitation.

DATA COLLECTION

Sampling Program

The principal objectives were to (1) determine the extent and variability of algae, algal nutrients, bacterial pollution and turbidity in Moses Lake and (2) evaluate the sources and potential sources of waters which flow or may be diverted into Moses Lake as agents affecting the overall quality of water in the Lake including algal nutrients, turbidity, and bacteria potentially of human origin.

The following sampling stations were established (see Figure 1 and Plates A and B):

No. 1. Rocky Ford Creek at the highway bridge on State Highway 11-G between Moses Lake and Ephrata, approximately 2.5 mi. from the north end of the Lake.

No. 2. East Low Canal from the highway bridge at Wheeler. This station is located a short distance south of Rocky Coulee Wasteway.

No. 3. Crab Creek approximately 0.6 mi. upstream from Moses Lake.

No. 4. Ground water seepage at the lower portion of Karl Goodrich's property on the south side of Pelican Horn about midway between Galleys Is. and Goat Is. The springs were located approximately 15 ft. above the elevation of the Lake and about 500 ft. from the lake shoreline.

No. 5. Pelican Horn at the center of the Horn midway between Marsh Is. and Goat Is. Samples were taken by boat from near the surface except those of December and February which were taken from under the nearby highway bridge where the

Lake was free of ice.

No. 6 and 7. 300-500 yds. offshore from the State Park. Station 6 samples were taken near the surface whereas those for Station 7 were taken immediately above the bottom. December and February samples were collected from the nearby highway bridge where the lake was free of ice because of warmer bottom water upwelling as it moved through this constricted area to the lake outlet.

No. 8. Midlake off Airman's Beach. Samples were collected from just below the surface. December and February samples were collected by chopping a hole through the ice near shore.

No. 9. Sewage treatment plant for the City of Moses Lake. Samples were taken in the effluent as it was discharged from the chlorine contact chamber. The treated plant effluent is subsequently discharged into Pelican Horn below the railroad causeway.

During the summer and early fall, routine samples were collected every two weeks. Additional collections were made in April, May, October, December and February. On several occasions samples were gathered and analyzed at short time intervals over a twenty-four hour period in order to determine diurnal variations in water quality; phytoplankton populations and their distribution and chemical activity. Sampling was usually begun between 8:00 and 9:00 AM and completed by 2:00 - 3:00 PM. Stations were visited in the numbered sequence shown above so that those from the Lake were taken between late morning and early afternoon.

Water was collected at Stations 1, 3, 4, and 9 by hand immersion of sampling bottles. At the other stations samples were taken with a Kemmerer-type plastic, 2-liter bottle lowered, with both ends open, on a calibrated line. At the desired depth the bottle was completely closed by a triggering device actuated by jerking the line. Due to the tubular configuration and length of the sampler, a column of water about 18 in. in height was taken, so that samples described as surface actually represent the water layer to a depth of 18 to 24 inches.

Analytical Procedures

1. Chemical

All chemical procedures used were taken from Standard Methods, 11th Edition (8) and are summarized below.

Determination	Sample Treatment*	Method Used	Page Reference
Dissolved oxygen	--	Alsterberg Modification of Winkler Method	309
Orthophosphate	Filtration	Stannous Chloride	202
Total Phosphate	Acid digestion	Stannous Chloride	204
Nitrate Nitrogen	Filtration, acid preservation	Phenoldisulfonic Acid	177
Nitrite Nitrogen	Filtration, acid preservation	Diazotization	180
Organic Nitrogen	Acid preservation	Kjeldahl	182
Ammonia Nitrogen	Acid preservation	Kjeldahl	167
Chloride	--	Mohr Method	78
Alkalinity Total Bicarbonate Carbonate	--	Acid titration to phenolphthalein and methyl orange and points	44
Sulfate	--	Turbidimetric	241
Calcium	--	EDTA titration	67
Magnesium	--	Calculated by difference	--
Sodium	Filtration	Flame photometric	231
Potassium	Filtration	Flame photometric	207
Iron	--	Phenanthroline	140
Hardness	--	EDTA titration	133

*Chemical procedures for removing interferences other than turbidity and for pH adjustments are not listed although such steps were included when preliminary tests indicated their desirability.

Other than the addition of acid to water subsequently analyzed for the various forms of nitrogen, samples were not preserved. Phosphate and alkalinity, both of which may be altered by biological growth, were determined at the Moses Lake Sewage Treatment Plant laboratory whenever possible with a resultant delay of one to three hours between sample collection and analysis. When samples were returned to Seattle for determination of these parameters, a delay of six to ten hours resulted.

2. Physical

Parameters Determined	Instrument Used
Temperature	For surface samples hand thermometers calibrated at ± 0.1°C were used. Subsurface readings were taken with thermistors lowered on calibrated lines and having an electronic readout.
pH	Beckman Model N (laboratory) or Model G (field) pH meters.
Turbidity	Jackson candle and Hellige turbidimeters. Device used depended on degree of turbidity.
Conductivity	Industrial Instruments conductivity meter.

Temperature, and, often pH were measured in situ. Turbidity and conductivity were determined in the laboratory on the day upon which the samples were taken.

3. Biological

a. Tests for bacteriological quality

Multi-tube fermentation tests (three tubes in each dilution) for members of the coliform group of bacteria were performed according to the procedures outlined in Standard Methods, 11th Edition (8). Presumptive tests only were routinely done. On several occasions culturing with brilliant green bile lactose broth indicated 90-95 percent confirmation of the presumptive tests. Results were expressed in terms of the most probable number (MPN) of coliforms present per 100 ml of water. Samples were collected in sterile, screw capped bottles which were only partially filled. Fermentation tubes were inoculated and incubation begun within a maximum of ten hours after collection of the samples. Chlorine residuals in the sewage treatment plant effluent samples were neutralized by the addition of sodium thiosulfate.

b. Collection and examination of plankton samples.

The greatest problem in quantitatively evaluating the phytoplankton population was the collection of samples. The species of blue-green blooms formed dense agglomerations in the upper few inches of water with very great variations in numbers occurring within a few feet. Due to the large and unavoidable sampling errors, a semi-quantitative approach was used in estimating concentrations. Samples were 250 ml in volume, were preserved in 4 percent formalin, and were kept in the dark until ready for examination. When necessary, samples were concentrated in a Sedgewick-Rafter filtration apparatus. A portion of the concentrate was then used to fill a Sedgewick Rafter counting cell which held a volume of exactly 1 ml of sample. The contents of the counting cell were quickly scanned at a magnification of 100X (10X ocular and 10X objective calibrated by use of an ocular and a stage micrometer) to determine whether or not the proper degree of concentration had been obtained. The phytoplankton in 10 fields, selected at random, were then identified and counted. Identifications were aided by alternate use of 21X and 42X objectives. Counts were coverted into volumetric standard units per milliliter of original unconcentrated sample volume as follows:

$$\text{factor} = \frac{\dfrac{\text{no. fields in 1 ml counting cell}}{\text{1 mm deep}}}{\text{no. fields counted}} \times \frac{\text{ml concentrate}}{\text{ml water in original sample}}$$

$$= \frac{1000}{10} \times \frac{\text{ml concentrate}}{250} = (0.4)(\text{ml concentrate})$$

multiplication of the count per 10 fields times this factor gave the number of cells per milliliter. Smith (10) was used in making identifications, some of which were subsequently checked by algologists at the University.

Obviously cell counts, even if very accurately performed on samples which are representative of the population, may not correlate with the nuisance aspects of the problem in Moses Lake. For example, in the main body of the Lake two species of algae were responsible for the objectionable green scums of summer and autumn. Rather than occurring as a mixture, one of these species was predominantly a summer form and the other dominated during the autumn. Cell counts indicated that populations of the former generally contained larger numbers of organisms. However, cells of the autumn form (a colonial alga) occupied a much larger volume than did the filaments which dominated during the summer. Visual observations of the Lake indicated little change in appearance to correspond with the change in speciation.

Climatological Data

Table 3 presents climatological data for the Moses Lake station. It indicates that the study period, March, 1963 through February, 1964 was warmer and dryer than a normal year. The low precipitation in January and February resulted in a below average runoff into Moses Lake. Another period affecting

Table 3 - Climatological Data, Mean Monthly[1]

(March, 1963 - February, 1964)

Month	Average Temp. °F		Precipitation, Inches		Avg. Wind Speed MPH	Pan Evap. Inches	Prevailing Wind Direction[4]	Mean Wind Speed, MPH[4]
	Study Period	Departure From Normal	Study Period	Departure From Normal				
March	43.2	+3.0	0.62	-0.01	--	--	SW	10.3
April	46.9	-1.8	1.85	+1.37	3.18	3.84	N	9.7
May	56.6	-0.9	0.54	-0.35	2.79	8.33	SW	9.3
June	63.8	+0.1	0.03	-0.69	2.48	9.40	SW	9.1
July	66.8	-3.2	0.36	+0.03	2.46	10.21	SW	8.7
August	69.3	+1.8	0.05	-0.30	2.14	9.65	SW	7.8
September	65.9	+4.8	0.09	-0.36	1.85	6.62	N	8.9
October	52.4	+3.4	0.08	-0.69	2.51	3.86	N	8.5
November	39.9	+2.9	0.96	+0.01	--	--	N	7.0
December	27.9	-1.9	1.32	+0.55	--	--	N	7.7
January	32.0	+7.9	0.60	-0.49	--	--	N	9.2
February	34.9	+3.2	0.10	-0.55	--	--	N	8.7
Summation	(2)	+19.3	6.60	(3)		51.91		

[1]Data from U. S. Weather Bureau records.

[2]Average yearly temperature is 48.4 °F. In study period it was 49.8 °F.

[3]Mean annual rainfall = 8.17 inches.

[4]Larson AFB data.

the Moses Lake water quality was in July when air temperatures were below normal. July air temperatures would normally be the maximum found during the year.

Moses Lake is frozen over during most of the period of November through March and in this period, evaporation pans freeze and evaporation data are not recorded. Since evaporation is related to wind speed, wind velocities are not recorded in the months when evaporation data are not obtained. Using an evaporation pan correction factor of 0.7 (5), the approximate evaporation from the surface of Moses Lake in the study period was 0.7 x 51.9 = 36.4" or a total water volume of approximately 22,500 acre-feet. Total rainfall in this period was 6.6 inches.

The prevaling wind direction in the area is from the north with the exception of March, May, June, July, and August, when it is from the southwest.

Lake Inflows and Outflows

Inflows to Moses Lake consist of Rocky Ford Creek, Crab Creek, subsurface seepage, the Rocky Coulee Wasteway leading from the East Low Canal, the Moses Lake sewage treatment plant, and precipitation. The Larson Air Force Base sewage treatment plant discharges into a subsurface drainage field a mile or so from the Lake and is not considered to have any significant influence on the Lake other than the contribution of some nutrients through subsurface flow. Outflows are the lake outlet into the Potholes reservoir, and evaporation. Subsurface seepage outflow, according to Mr. George Neff, U. S. Bureau of Reclamation Drainage Engineer, is insignificant. All inflows but the subsurface seepage are monitored and the outlet flow is monitored. Subsurface seepage is obtained by calculation and evaporation is obtained by calculation and/or pan data. Table 4 gives the monitored inflows and outflows as well as the lake elevation.

Rocky Ford Creek:

This creek originates in a series of large springs about six miles from its mouth in Moses Lake and about five miles east of Ephrata. These springs are located in a small cirque and provide a fairly uniform average discharge throughout the year which has about doubled since 1949. This may be associated with storage behind Grand Coulee Dam as the West and East Columbia Basin Canals were not filled until 1952 and the first water was pumped into the equalizing reservoir (Banks Lake) in 1951 (3). The mean annual flow is 82.4 cfs (4) and the drainage area is but 11.7 sq. mi.

Table 4 - Moses Lake Measured Inflows and Outflows, C.F.S.

(Monthly mean values)

Month 1963-64	Rocky Ford Creek	Crab Creek	Rocky Coulee Wasteway	Moses Lake Sewage Treatment Plant	Lake Outlet	Lake Water Surface Elevation	
						Mean Ft.	Change Ft.
March	73.5	48.0	0	1.8	128	1046.0	+0.23
April	81.5	34.9	1	1.9	135	1046.2	+0.09
May	80.3	22.8	0.5	2.0	120	1046.1	-0.29
June	81.0	19.6	0.5	1.9	43.7	1046.0	+0.25
July	82.4	33.4	0.5	2.0	17.2	1046.4	+0.46
August	85.2	41.5	0.5	2.1	96.0	1046.7	-0.10
September	85.4	43.7	5.3	2.0	192	1046.4	-0.15
October	83.7	40.5	69.0	1.9	377	1046.4	+0.12
November	78.1	32.1	6.9	1.7	622	1044.4	-2.75
December	76.2	23.0	0	1.7	249	1043.3	-0.29
January	70.3	16.0	0	1.7	220	1043.1	-0.22
February	62.7	10.1	0	1.8	119	1042.9	+0.10
Mean	78.3	30.5	7.0	1.9	193	1045.3	-2.50

Data furnished by the U. S. Bureau of Reclamation and the City of Moses Lake, U.S.G.S. and U.S.B.R. records.

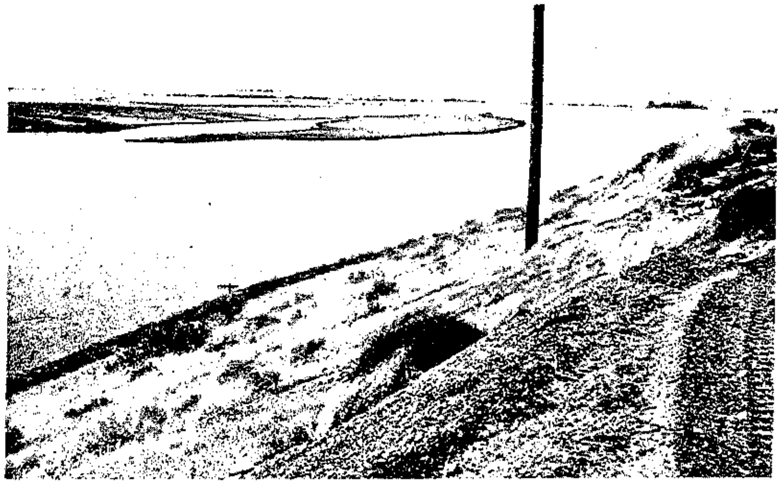


Fig. 1. Central Moses Lake Looking North

Fig. 2. Fish Hatchery on Rocky Ford Creek

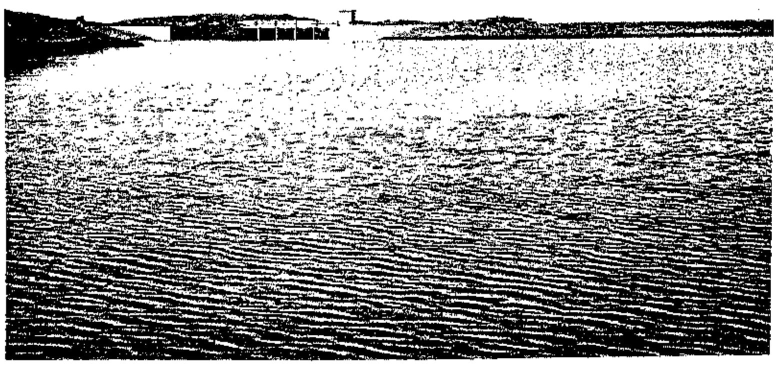


Fig. 3. Moses Lake Outlet Structure, U.S.B.R.

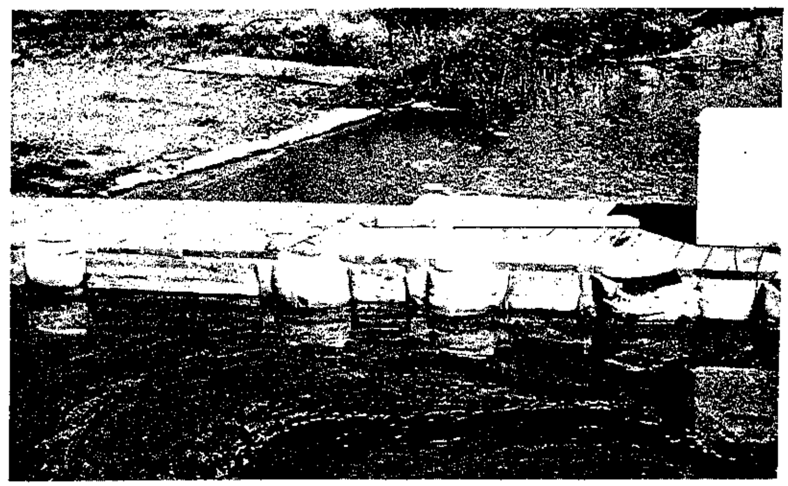


Fig. 4. Typical Algae Mat Along Shore

PLATE C

A very large trout farm (McCreery's Trout Hatchery) utilizes the spring water for the rearing of trout eggs and mature trout. The trout are fed ground carp obtained from Moses Lake and elsewhere and ground fish viscera obtained from the coast. During feeding, a considerable portion of this food passes through the ponds and downstream to Moses Lake. Approximately one and one-half million trout were being held in the ponds in August, 1963. Very little else in the drainage basin, other than perhaps some grazing sheep, affects the creek as it flows through the old coulee.

Crab Creek:

This creek drains a very large area extending nearly to Spokane, comprising some 2,040 sq. mi. (4). Most of the flow is underground and, prior to the advent of irrigation return flow in 1952, the creek flow was negligible except during infrequent periods of heavy runoff. Since 1952, the mean annual flow has been 79 cfs through 1960, most of this occurring in January through March. Flow is gaged about two miles upstream from the water quality sampling station and does not measure approximately 10 cfs of subsurface inflow present at the sampling station.

Crab Creek receives the drainage from several feed lots and a number of pastures. It is frequented by many ducks.

Rocky Coulee Wasteway:

This wasteway permits the discharge of water from the Columbia Basin East Low Irrigation Canal into Crab Creek just above its confluence with Moses Lake. It has a capacity of about 4500 cfs (6) and a length of some five miles. There normally is no appreciable discharge through the wasteway other than seepage. Water wasted through this wasteway would have about the same quality when discharged into Crab Creek as it has in the East Low Canal. As shown in Table 4, flow from this wasteway during the period of the study was negligible.

Sewage Treatment Plant:

The Moses Lake sewage treatment plant is located on upper Pelican Horn but pipes its effluent for discharge further down the Horn to a point just past the railroad causeway. This plant is of the "secondary" type employing biological treatment through trickling filters with effluent chlorination. The facility is well supervised, well operated, and produces an effluent commensurate with the plants' design capabilities.

Subsurface Seepage:

The single major source of inflow to Moses Lake is from subsurface seepage. Geologic profiles of the Moses Lake area (3) indicate a subsurface water movement from east to west and a water table rise of up to 60 feet just east of the lake, this since advent of the Columbia Basin Project.

Most of this inflow occurs below the water surface; however seepage springs are abundant on the east side of Pelican Horn. The principal location of subsurface inflow would appear to be along the east shoreline of the main lake opposite the Larson Air Force Base as this was the only significant section of the lake free of ice. The City Engineer, Mr. Garth Anderson, stated that the City drains up to 1300 gpm of ground water into the upper end of Pelican Horn. Inflow quantities cannot be measured directly and must be calculated indirectly as shown in a subsequent section on the water budget.

Outflow:

Because very little seepage was noted in the Potholes area prior to the reservoir impoundment and because of water table elevations, the outflow from Moses Lake is essentially all via the control works maintained by the U. S. Bureau of Reclamation and the District. Water pumped for irrigation is not monitored and must be calculated from the approximate area irrigated times a normal water application rate for irrigation, say 5 acre-ft. per acre per year, varying monthly with crop requirements, over 3500 acres. A portion of the water pumped for irrigation (that not lost to evapo-transpiration - about 50 percent) will return to the lake via subsurface water. There has been a surplus of water in the lake even during July when evaporation is high and irrigation demands are at a maximum.

The outlet works built by the District in 1929 (to raise the lake level from its prior elevation of 1038 feet to 1046 feet) consists of six tubes, each 6 ft. in diameter and set at elevation about 1040 according to Mr. Goodrich.

The new outlet works, completed by the Bureau of Reclamation in 1963, consists of five spillway channels, each 10 feet wide with 12" x 12" stoplogs set at about elevation 1040. A combined discharge capacity of about 2700 cfs (5) at lake elevation 1046 is provided by both outlet works. At lake elevation 1041, the outflow capacity is very limited.

Evaporation as an outflow is shown in the water budget calculations.

DISCUSSION AND ANALYSIS OF DATA

Water Budget

Table 5 gives the water budget for Moses Lake by the month for the period of March, 1963 through February, 1964. The water budget for Moses Lake can be written as follows:

Creek inflows + rainfall + subsurface inflow + Rocky Coulee Wasteway + sewage treatment plant - evaporation - outlet discharge - irrigation pumpage = change in lake content.

Evaporation was obtained by using a pan coefficient of 0.7 which agrees reasonably well with calculated methods according to Graham (2). Since the lake was not entirely frozen over throughout the winter, since some evaporation did occur from the ice surface, and since the lake itself was largely open in the months of March and November (although pan evaporation data are not obtained in these months as shown in Table 3), the pan evaporation data for April is also used in March and the pan evaporation data for October is also used for November.

All inflow and outflow values can be measured with some degree of accuracy with the exception of subsurface inflows which are calculated by difference between inflow and outflow. An irrigation pumpage of five acre-feet per acre was used over 3500 acres prorated in accordance with data obtained from the Yakima Valley Project (7). The lake water surface elevation on March 1, 1963 was 1045.83 feet and on February 29, 1964 it was 1043.06 feet. Surface runoff from the land area surrounding Moses Lake is considered to be negligible because of the low amount of rainfall and the high porosity of the soil.

The water budget in Table 5 indicates the following:

1. That Rocky Ford Creek and subsurface inflows are the principal water supplies for Moses Lake.

2. That on a yearly basis, Rocky Ford Creek contributes approximately 35 percent of the inflow, Crab Creek 14 percent, the Moses Lake City sewage treatment plant 0.8 percent, precipitation 2 percent, subsurface inflow 45 percent and Rocky Coulee Wasteway 3 percent. The contribution by Rocky Coulee Wasteway was almost negligible in the study period except at the end of the irrigation season when surplus flows were released and when the canal was drained.

3. That irrigation pumpage constitutes only about ten percent of the lake outflow and that perhaps 50 percent of this returns to the lake by subsurface inflow, representing the difference between water applied to the land and evapo-

Table 5 - Water Budget for Moses Lake - March 1963 - February 1964

(Values in acre-feet)

Month	Inflow							Outflow				Change in Lake Content[1]
	Rocky Ford Creek	Crab Creek Plant	Sewage Treatment Plant	Rocky Coulee Wasteway	Precipitation	Sub-surface	Total	Lake Outlet	Evaporation	Irrigation Pumpage	Total	
March	4,530	2,950	111	0	352	3,287	11,230	7,640	1,520	170	9,330	+ 1,900
April	4,850	2,080	112	60	1,050	3,618	11,770	8,070	1,520	1,570	11,160	+ 610
May	4,930	1.400	119	32	306	4,673	11,460	7,160	3,290	2,980	13,430	- 1,970
June	4,820	1,160	113	30	17	5,040	11,180	2,600	3,730	3,150	9,480	+ 1,700
July	5,070	2,050	122	32	204	4,042	11,520	1,020	4,050	3,330	8,400	+ 3,120
August	5,240	2,550	128	32	29	4,011	11,990	5,700	3,820	3,150	12,670	- 680
September	5,080	2,600	117	317	51	7,295	15,460	11,410	2,620	2,450	16,480	- 1,020
October	4,970	2,410	116	4,100	45	13,809	25,450	22,400	1,530	700	24,630	+ 820
November	4,640	1,910	101	409	544	12,486	20,090	37,000	1,530	--	38,530	-18,440
December	4,530	1,370	104	0	750	6,106	12,860	14,800	--	--	14,800	- 1,940
January	4,180	950	104	0	340	6,066	11,640	13,100	--	--	13,100	- 1,460
February	3,730	600	98	0	57	3,275	7,760	7,100	--	--	7,100	+ 660
Total	56,570	22,030	1,345	5,012	3,745	73,708	162,410	138,000	23,610	17,500	179,110	-16,700

[1] (+) is an increase; (-) is a decrease in lake storage.

transpiration.

4. That evaporation losses are about equal to the Crab Creek inflow.

5. That subsurface inflow augmented by recent irrigation subsurface seepage did not reach Moses Lake until September and that relaxation of the ground water table build-up during the irrigation season continued throughout the winter. Maximum subsurface inflow occurred in October at the end of the irrigation season.

6. That the overall theoretical period of water exchange in Moses Lake at elevation 1046, using the study period inflow data, is once very 0.78 years.

7. That the data in the study period are representative of a normal year.

Phosphorus Budget

The prolific algal blooms in Moses Lake are sustained by a number of nutritional elements, some required in relatively large amounts such as carbon, hydrogen, oxygen and nitrogen and others in less amount, such as phosphorus, iron, colbalt, calcium, etc. If one necessary element is present in minimal amounts, it will control the growth rates. It is unlikely that carbon, hydrogen or oxygen could be limiting and very little is known about the nutritional levels of iron, cobalt etc. required in the water environment. Investigators have found on a number of occasions that phosphorus is limiting to growth and that in some instances, nitrogen has been limiting. Because blue-green algae, such as are found in Moses Lake, may be capable of fixing nitrogen from the atmosphere, it is not feasible to attempt the calculation of a nitrogen budget. This leaves phosphorus as the nutritional element whose concentration might be calculated in an input-output budget and whose concentration might be manipulated for algal control.

Table 6 gives the approximate mean monthly concentrations of soluble phosphorus as phosphate in Moses Lake and its tributaries, prepared by interpolation from Figure 3. Values for Moses Lake are the mean of the four lake sampling stations. These values would vary widely, depending upon the phosphate uptake by plankton in the particular area sampled or upon the recycling present from bottom sediments. Because of this wide variability and the infrequency of sampling, one must look at the mean of all the values for a particular station, rather than individual values, to obtain a concept of the phosphorus magnitude for that station.

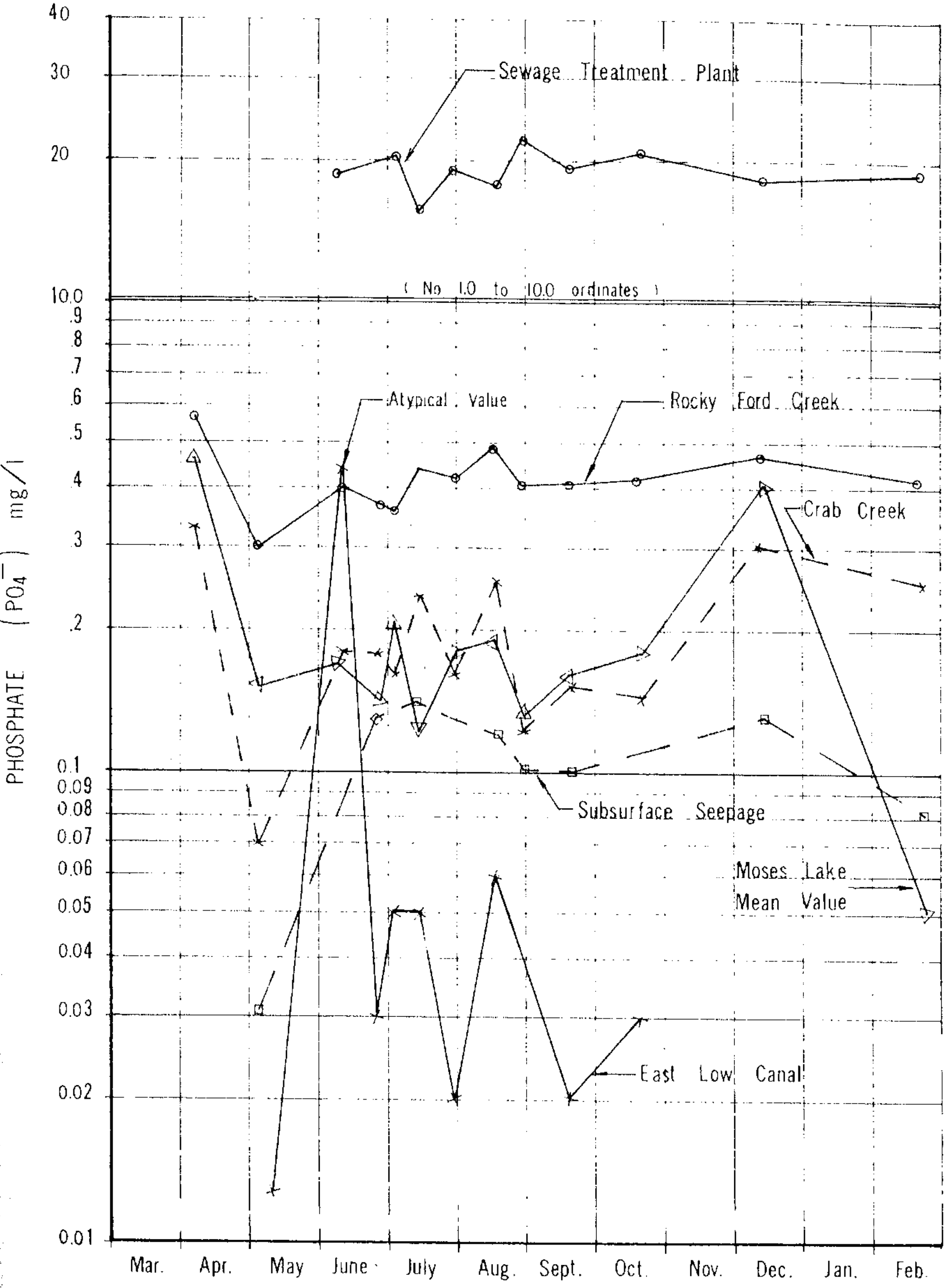
Crab Creek flow is gaged about two miles above the point of water quality

Table 6 - Mean Monthly Phosphate Concentrations, mg/l $PO_4^{\equiv}$, 1963-64

(Extrapolated by straight line interpolation from Fig. 3)

Station	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
#1 - Rocky Ford Creek	0.50	0.44	0.34	0.38	0.41	0.44	0.41	0.42	0.45	0.46	0.44	0.43
#2 - East Low Canal	--	--	0.02	0.05	0.04	0.04	0.02	0.03	--	--	--	--
#3 - Crab Creek	0.27	0.16	0.10	0.17	0.19	0.18	0.14	0.15	0.23	0.29	0.27	0.26
#4 - Subsurface Seepage	0.06	0.05	0.04	0.09	0.13	0.12	0.10	0.11	0.12	0.12	0.10	0.08
#9 - Sewage Treatment Plant[1]	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Mean for Lake	0.09	0.28	0.16	0.16	0.16	0.17	0.15	0.18	0.27	0.35	0.15	0.07

[1] Mean of monthly values.



PHOSPHATE CONCENTRATIONS IN LAKE INPUT

Fig. 3

sampling, between which inflows an estimated 7500 acre-feet per year of ground water, which has been prorated in proportion to the ground water inflow shown in the water budget, Table 5, Rocky Coulee Wasteway also inflows in this section of Crab Creek. In preparing the phosphorus budget, these inflows were added to the Crab Creek measured flow and the same ground water inflow was reduced from the subsurface seepage shown in Table 5 in computing the phosphorus addition from subsurface sources.

Subsurface seepage phosphate values show a slight increase in the irrigation season representing some phosphate loss by the farmers; Crab Creek shows a reduction in phosphate during the irrigation season when return flow dilutes the normally more saline waters of Crab Creek; and Rocky Ford Creek shows a fairly constant phosphate value the year around.

Table 7 is an input-output phosphorus budget calculation for Moses Lake in which the difference between inflow and outflow phosphorus is due to one of or a combination of the following: phosphorus contained in the plankton; gain or loss with change in lake level; phosphorus which has been concentrated by evaporation; and that which becomes permanently locked in the lake sediments. The actual phosphorus content in the lake water at any instant is a function of the input to the lake, the uptake by living plant matter and its decomposition to elemental substances by bacteria, and the amount or rate of return of these decomposed products to the overlying or surrounding water.

The phosphorus budget indicates that the sewage treatment plant contributes 41 percent of the input, Rocky Ford Creek 39 percent, subsurface inflow 11 percent, and Crab Creek 9 percent.

Nitrogen Input

As previously discussed, it is not practicable to prepare a nitrogen budget since it is possible for blue-green algae to fix nitrogen from the atmosphere. It is of value however to account for the principal sources of nitrogen since they will most certainly have a bearing on the extent of algal growth in Moses Lake. Table 8 gives the total nitrogen (organic, ammonia and nitrate nitrogen) in the input water as prepared from Appendix A. Missing values were assumed to be the same as the average of the remaining values. Nitrites are not included as they are usually very small although they may reach significant values in the sewage treatment plant effluent as can be seen in Appendix A.

Table 8 shows an increase in the input nitrogen concentrations starting

Table 7 - Phosphorus Budget for Moses Lake

(Pounds per month as total phosphate, $PO_4^{\equiv}$)

Month 1963-64	Inflow					Outflow		
	Rocky Ford Creek	Crab Creek[1]	Sub-surface Inflow[2]	Sewage Treatment Plant	Total	Lake Outlet[3]	Irrigation Pumpage[3]	Total
March	6,200	2,400	480	5,730	14,810	1,860	40	1,900
April	5,800	1,060	450	5,790	13,100	6,150	1,190	7,340
May	4,600	510	460	6,150	11,720	3,120	1,300	4,420
June	5,000	760	1,110	5,830	12,700	1,140	1,370	2,510
July	5,500	1,270	1,290	6,300	14,360	450	1,450	1,900
August	6,300	1,440	1,150	6,610	15,500	2,640	1,460	4,100
September	5,600	1,280	1,790	6,050	14,720	4,660	1,000	5,660
October	5,700	1,870	3,730	6,000	17,300	11,000	340	11,340
November	5,700	1,990	3,680	5,220	16,590	27,100	--	27,100
December	5,700	1,550	1,790	5,380	14,420	14,100	--	14,100
January	5,000	1,130	1,490	5,380	13,000	5,350	--	5,350
February	4,400	650	640	5,070	10,760	1,350	--	1,350
Total	65,500	15,910	18,060	69,510	168,980	78,920	8,150	87,070

[1]Includes some subsurface seepage and Rocky Coulee Wasteway discharge (see discussion).
[2]A portion included in Crab Creek discharge (see discussion).
[3]Using mean phosphate content of lake water.

in May that reach a peak during the late summer. Individual values are not necessarily representative of the month shown because of the variability in sampling times and the variability in monthly sampling frequency. They do illustrate relative concentration values however.

Table 9 gives the relative total nitrogen inputs to Moses Lake in pounds per month. Values are maximum in the summer and early autumn indicating a large loss of farm fertilizer. Subsurface seepage samples were not collected in October. If they had been, the October value would have been about the same as the September value. Table 9 indicates that the principal source of nitrogen to Moses Lake is from subsurface seepage followed by Rocky Ford Creek. Crab Creeks' and the sewage treatment plants' contribution are about equal and considerably less than the other two sources.

Summary of Water Quality Data

In this section, a general summary of water quality is presented for each of the sampling stations with special emphasis on the salts of nitrogen and phosphorus. Certain items, such as dissolved oxygen and pH, which have special significance in terms of phytoplankton activity are reserved for subsequent discussions. Complete tabular summaries of all water quality data are included in Appendix A. A number of the determinations are reported to an accuracy greater than that inherent in the test procedure. This was done in an attempt to detect possible differences in values where the concentrations were small and where rounding off would make them of little use in some instances, such as with nitrates. A check on laboratory techniques used in determinations for sulfates, sodium and potassium indicate that the sulfate values are generally below the true values and sodium and potassium are generally above. These values have only a very minor significance in the study.

Rocky Ford Creek - Station 1:

The relatively large sustained flow rate of this tributary causes considerable significance to be attached to materials suspended or dissolved in its waters. Also the introduction of this flow into the uppermost portion of the Lake means that such materials have a relatively long rentention time, and hence an extended period for reaction, in the Lake.

A most important feature of Rocky Ford Creek is the large amount of phosphate which it contributes to Moses Lake. Average soluble and total phosphate were both about 0.4 mg/l (see Figure 3). The major source of this nutrient is

Table 8 - Total Nitrogen Input to Moses Lake, <u>mg/l</u>

Source	May	June	July	Aug.	Sept.	Oct.	Dec.
Rocky Ford Creek[1]	0.14	0.25	0.55	0.74	1.63	1.14	0.30
Crab Creek[1]	0.32	0.22	0.38	0.91	1.10	0.65	0.40
Subsurface Seepage[1]	0.15	0.50	0.39	6.18	5.15	--	0.42
Sewage Treatment Plant	11.64	6.83	9.46	13.87	13.31	20.06	17.04
East Low Canal[*,2]	0.13	0.05	0.07	0.24	0.09	0.13	--

[*]This is not now a significant input but is included for comparative purposes.

[1]Nitrates most significant.

[2]Organic nitrogen most significant.

Table 9 - Total Nitrogen Input to Moses Lake, lbs/month

Month	Rocky Ford Creek	Crab Creek	Subsurface Seepage	Sewage Treatment Plant
May	1,870	1,220	1,900	3,770
June	3,280	690	6,870	2,110
July	7,600	2,130	4,290	3,150
August	24,800	6,330	67,400	4,830
September	22,600	7,770	102,000	4,250
October	15,400	4,260	--	6,320
December	3,700	1,490	7,000	4,830

unknown but is presumed to be leaching from phosphate bearing rocks and other materials since little seasonal variation exists. Orthophosphate in the major springs from which the creek arises was measured in late August at a concentration of 0.48 mg/l. The concentration at the regular sampling station a few hours later was 0.54 mg/l. Measurements in the holding ponds of the trout hatchery before and immediately after feeding indicated that temporary increases in phosphate concentrations may be brought about by feeding. Additionally, uneaten food plus metabolic waste products from a large trout population in the holding ponds would be expected to yield further nutrients upon its eventual decomposition in the Lake.

Nitrogen, primarily in the form of nitrates, is also contributed to the Lake in large amounts by Rocky Ford Creek. The seasonal variations in this nutrient indicate the probable influence of runoff from fertilized land. Peak values of more than 1.5 mg/l occurred in mid-August and again during mid-February.

Other inorganic ions measured were present in about the following concentrations: chloride, 10 mg/l; sulfate, 20 mg/l; calcium, 30 mg/l; magnesium, 15 mg/l; sodium, 40 mg/l; potassium, 10 mg/l; and iron, 0.3 mg/l. Rocky Ford Creek water would be classified as moderately hard. No carbonate alkalinity was ever detected and bicarbonate alkalinities averaged about 150 mg/l as $CaCO_3$. Fecal bacteria contribution to Moses Lake are not significant and turbidities were low except in the spring when carp were noticed in the stream.

East Low Canal - Station 2:

Canal water was of a high and uniform quality during most of the summer and fall but showed some undesirable characteristics in a single sample taken June 11 when phosphates and phytoplankton reached comparatively high values. Nutrient concentrations in May and again from late June thru mid-October were generally low. Orthophosphate values ranged from 0.01-0.05 mg/l and those for total phosphate from 0.01-0.30 mg/l. (On June 11 corresponding concentrations were 0.44 and 0.69 mg/l respectively.) Nitrate nitrogen was negligible, being undetectable in several samples. Organic and ammonia nitrogen concentrations were likewise insignificant.

Inorganic elements other than the nutrients were present in lower concentrations than in any other waters examined in the study. Total alkalinity averaged about 65 mg/l as $CaCO_3$ and the hardness about 75 mg/l as $CaCO_3$. Coliform bacteria and turbidities were low.

Crab Creek - Station 3:

The quality of the water contributed by Crab Creek is generally more variable than that from the other tributary sources examined. This is probably due to its relatively large drainage area, the farming and livestock habitation along its banks, and the presence of irrigation return flow in varying quantities.

Orthophosphate concentrations were generally about half those of Rocky Ford Creek, ranging from 0.07-0.33 mg/l. Total phosphate values were often considerably higher (0.16-0.57 mg/l) than those for the soluble phosphate. Nitrate nitrogen was on the order of 0.1 mg/l until late July, when a progressive increase ensued culminating in concentrations of about 0.9 mg/l in mid-September. This was followed by a decline through December and a second increase to 1.78 mg/l was found on February 20. Concentrations of ammonia nitrogen (0.00-0.15 mg/l) and total organic nitrogen (0.00-0.23) were presumed to indicate little of significance.

Inorganic constituents in addition to phosphate and nitrates were more variable than for other stations but the following figures are indicative of normal values: chlorides, 13 mg/l; sulfates, 35 mg/l; calcium, 40 mg/l; magnesium, 20 mg/l; sodium, 55 mg/l; potassium, 14 mg/l and iron, 0.3 mg/l. Carbonate alkalinity was occasionally present and total alkalinity values varied from 180 mg/l to 242 mg/l as $CaCO_3$. In terms of hardness, the water is classified as being hard. The fecal bacteria concentration in Crab Creek water was typical of a stream in a farming area. Turbidities varied, depending upon the rate of runoff and disturbance to the stream bed by livestock and carp.

Seepage - Station 4:

The quality of this water is good with the exception that very large quantities of nitrate nitrogen were present, largely from irrigation return flow, during a considerable part of the year. In the critical phytoplankton growth season it is estimated that over half of this plant nutrient entering the Lake did so via seepage.

The pattern of nitrate nitrogen fluctuation was almost identical to that obtained for Rocky Ford Creek. Thru July concentrations were comparatively low (0.00-0.78 mg/l). However, on August 16 a value of 7.6 mg/l was obtained. Nitrate nitrogen then decreased to about 4.5 mg/l thru the middle of September and was down to 0.27 mg/l by early December. A high concentration (4.52 mg/l) was again present in the February 20 sample, the reason for which is not readily apparent. Nitrogen in forms other than nitrate was insignificant. Phosphates were uniformly low compared with all other stations except the East Low Canal. Orthophosphates ranged from 0.03-0.15 mg/l and total phosphates ranged from 0.11-0.40 mg/l. Coliform bacteria and turbidity were not found in samples collected as the water percolated from the soil.

The following figures indicate average concentrations of inorganic materials other than plant nutrients: chlorides, 20 mg/l; sulfates, 50 mg/l; calcium, 50 mg/l; magnesium, 25 mg/l; sodium, 55 mg/l; potassium, 10 mg/l; and iron, 0.1 mg/l. The seepage is a hard water (about 200 mg/l as $CaCO_3$) and alkalinities ranged from 200-300 mg/l as $CaCO_3$.

Sewage Treatment Plant Effluent - Station 9:

Effluent from the Moses Lake sewage treatment plant, though small in volume, may be quite significant from the standpoint of algal productivity because of the large amounts of phosphorous which it contributes to the water of Pelican Horn. These high phosphate concentrations in the effluent are normal for treatment plants and in the case of Moses Lake, they ranged from 17.4-22.1 mg/l. The forms of nitrogen present depended largely upon the sewage temperature, the amount of plant recirculation, and the quality of digester supernatant return. Of the various forms of nitrogen, particularly high concentrations (up to 17.8 mg/l) of ammonia nitrogen were observed during the autumn and winter. Organic nitrogen averaged around 0.5 mg/l during most of the year with a maximum value of 1.64 mg/l being obtained on July 29. Nitrate nitrogen values were generally low except during the autumn and winter. A maximum of 6.0 mg/l was present in the February sample. A single measurement of nitrite nitrogen indicated a concentration of 0.50 mg/l on October 19. Other inorganic elements are of little significance because of the low volume of discharge. In general alkalinities averaged about 200 mg/l and the water was moderately hard. The dominant ion species in terms of concentration were sodium and sulfate.

An examination of the sewage treatment plant operating records, in regard to effluent quality control, indicated that the plant is well operated and that the effluent quality is normal for a plant employing biological treatment through use of trickling filters. The effluent is very well disinfected and the concentration of coliform bacteria (fecal bacteria) discharged to Moses Lake has little sanitary significance.

Pelican Horn - Station 5:

The principal source of input water to Pelican Horn is from subsurface seepage. Other sources include the sewage treatment plant and drainage water from the City of Moses Lake's drainage system. Undoubtedly other water is added thru exchange with the main basin of the Lake, particularly in the summer, when prevailing southwesterly winds would tend to push surface water from the lower lake into the Horn. However, based on a comparison of algal populations and chemical data, it was demonstrated that water quality in the upper portion of Pelican Horn remained somewhat different from that in the rest of the Lake, having a slightly higher concentration of most dissolved substances.

Plant nutrients are contributed in significant amounts to the Horn as noted in the above sections. Orthophosphate and total phosphate were almost always present in appreciable quantities so that these were not the limiting factors in phytoplankton production. Values for the former ranged from 0.04 mg/l to 0.85 mg/l and for total phosphate from 0.19 to 1.80 mg/l. On the other hand, nitrate nitrogen was either absent or present in quantities of less than 0.03 mg/l during eight of the twelve sampling periods. Organic and ammonia nitrogen were generally present in larger quantities but the availability of these forms as nutrients for the phytoplankton types dominant is Pelican Horn is questionable. Neither organic (0.00-0.40 mg/l) nor ammonia nitrogen (0.00-0.47 mg/l) showed any correlation with algal density.

Certain ionic constituents, other than those serving as major plant nutrients, demonstrate a difference between the surface water in Pelican Horn and that in the main body of Moses Lake, as shown below. Most other inorganic ions were of the same order of magnitude in all areas of the Lake. These were:

Station	Chlorides*	Sulfates*	Sodium*	Mean Conductivity**
Pelican Horn	19, 16, 26	31, 31	63, 80	387
State Park (Surface)	14, 12, 14	24, 26	52, 63	357
Airman's Beach	14, 12, 12	23, 25	45, 63	330

*Concentration in mg/l; **umhos/cm @ 25°C.

calcium, 25 mg/l; magnesium, 17 mg/l; potassium, 14 mg/l and iron, 1 mg/l. Carbonate alkalinity was present during periods of high phytoplankton activity. A maximum of 88 mg/l as $CaCO_3$ was measured in Pelican Horn. The water throughout the Lake was moderately hard. Turbidity and coliform bacteria in the Lake are discussed in a following section of this report.

State Park, Surface - Station 6:

The location of this station might be described as being the recreational center of Moses Lake and therefore the parameters of its water quality assume particular significance. An insufficient source of available nitrogen appeared to be the limiting algal growth factor. Concentrations of nitrate nitrogen varied from 0.00-0.16 mg/l, averaging about 0.05 mg/l during the season when the Lake was plagued by algal blooms. However, two factors make an evaluation of the limiting nature of this particular nutrient difficult to determine. First, in an actively growing ecosystem, nutrients are being continually circulated so that concentrations in solution at any specific time may not be indicative of their true potential for promoting or maintaining a high population density; and second, many species of blue-green algae (the type that produced all of the nuisance blooms in the main body of the Lake) have the ability to fix atmospheric nitrogen. That is, they are capable of acting like the terrestrial legumes in using the air as a direct source of nitrogen for their metabolic processes. Phosphate is almost certainly not a limiting growth factor. The minimum concentration of orthophosphate observed during the warmer months was 0.07 mg/l. Concentrations ranges of other ionic constituents are discussed in the preceding section.

State Park, Bottom - Station 7:

Vertical cross-sections of temperature were routinely taken at all lake stations but only off the State Park were water samples consistantly collected from near the bottom for chemical and biological analysis. Figure 4 indicates that from the June thru the September sampling dates, the Lake was thermally stratified. Such stratification means that warmer, and hence less dense, water overlies a cooler and denser layer. A body of water in this condition offers considerable resistance to the mixing action of wind so that dissolved oxygen in the bottom waters is either not replenished or is replaced at a slow rate. Continual respiration by organisms in this lower layer of water results in the gradual depletion of the oxygen and generally a lowering of the pH. Conditions may thereby be made slightly more favorable for solution of mineral material including nutrients. Of course the depletion of dissolved oxygen itself may have profound effects on the biota. This will be discussed in more detail in a subsequent section.

Indications were that some mixing between the upper and lower layers of water must have occurred during most of the summer. There was a gradual decrease in the dissolved oxygen thru the end of August but neither inorganic nor organic materials followed this trend so that no summer storage of nutrients in the deeper water was evident. Orthophosphates ranged from 0.13-0.44 mg/l and total phosphates from 0.22-0.85 mg/l. During the summer, concentrations were higher than at the surface due to phytoplankton activity in the latter layer of water. Both ammonia (0.00-0.69 mg/l) and organic (0.00-0.27 mg/l) nitrogen values showed marked but erratic variations. Nitrate nitrogen averaged only about 0.05 mg/l during the summer months. Other ion species corresponded well with comparable surface concentrations.

Airman's Beach - Station 8:

As in the case of the State Park sampling station, this represents an area of the Lake receiving extensive recreational usage. Observations during the winter showed an ice-free area immediately south of the beach that would indicate extensive subsurface seepage water additions in this area. Drainage from Rocky Ford Creek would be expected to exert considerable influence on the water quality of the upper lake; and in addition, surface drift occasioned by the prevailing southwesterly summer winds, may be a factor.

As found near the State Park, phosphate always appeared to be present in excess (0.06-1.00 mg/l from June thru September) whereas nitrate nitrogen was undetectable in four of the summer samples. Since blue-green algae were almost the sole forms at this station, the significance of ammonia and organic nitrogen is again difficult to determine. Usually larger amounts of ammonia and organic nitrogen were present compared to the other Lake stations. On December 12 ammonia nitrogen (sample collected through hole in ice) reached the astoundingly high value of 19.5 mg/l. Organic nitrogen also reached its peak value of 0.51 mg/l on this date. It is hypothesized that the ice which covered the Lake at this time might have acted to trap the ammonia which may otherwise have volatilized or possibly been utilized by algae. Inorganic ions other than nutrients were about the same as those found at other lake stations.

ASSESSMENT OF PRESENT LAKE CONDITION

The present condition of Moses Lake (an obvious situation to local water users) may be summarized as follows:

1. The Lake is not bacterially contaminated and in fact enjoys a surprisingly low fecal bacterial population.

2. Algal populations in extreme nuisance numbers occur in the summer

and early autumn. Nutrients for sustaining these algal blooms originate in all the inflows and from within the Lake itself.

3. Turbidity (from bottom silt) in the water is apparant throughout the year but is less evident during the cold season when the carp are not active and during the periods of heavy algal growth when the algae remove colloidal particulates with their subsidence.

4. Carp are present in large numbers and have the undesirable characteristics of competing with game fish for food and of stirring up the bottom in their feeding, thus creating a turbidity problem. Carp have the desirable characteristic of limiting the growth of aquatic vascular plants and thus reducing the potential mosquito problem and making the Lake more amenable for recreation. Rooted vegetation in the Lake is desirable for fish and waterfowl harborage.

5. The present condition of lake water quality renders it less attractive for homesites, boating, swimming, fishing and aquatic sports.

In the following pages these conditions, as summarized above, are discussed in some detail.

Phytoplankton (Algae), Distribution, Quality and Quantity

Phytoplankton (algal) densities according to general types are summarized by station and date in Appendix B. Specific identifications, where important nuisance species were involved, are mentioned in the following discussion.

Crab and Rocky Ford Creeks:

The phytoplankton populations of Crab and Rocky Ford Creeks consisted almost entirely of relatively small numbers of diatoms. Algae were absent from the subsurface seepage, and so these three water sources are not considered to be of any importance as direct carriers of phytoplankton into the Lake. East Low Canal water was likewise comparatively free of algae except on one occasion. On June 11 a blue-green algae, Anabaena spp. occurred in large enough numbers, approximately 800/ml, to visually color the water.

Pelican Horn:

The phytoplankton population in Pelican Horn was dense enough to produce a visible bloom from early July throughout the remainder of the summer. However, during August, September and October the dominant species of algae in this Horn were different from those in the remainder of the Lake (Table

10). In May, June and early July the only algae present were small numbers

Table 10 - Percentage of Major Phytoplankton Groups at Stations 5, 6 and 8 by Sampling Dates

Month	Station		
	Pelican Horn	Off State Park	Off Airman's Beach
5-4-63	85% diatom	53% green*	43% green*
6-11-63	87% "	74% diatom*	75% diatom
6-26-63	58% blue-green	84% "	84% blue-green
7-2-63	95% diatom	100% blue-green	98% " "
7-13-63	92% blue-green	97% " "	67% diatom*
7-29-63	79% " "	92% " "	98% blue-green
8-16-63	95% green	56% " "	63% " "
8-27-63	77% "	71% " "	89% " "
8-28-63	75% "	78% " "	94% " "
9-18-63	61% "	88% " "	100% " "
10-19-63	100% "	78% " "	95% " "
12-12-63	100% diatom	100% diatom	--
2-20-64	100% "	98% "	--

*So few organisms that relative percentages are of little significance.

of diatoms with the exception of the June 26 sample when considerable numbers of blue-green algae were present for the first time. Samples taken July 13 contained over 10,000 filaments of blue-greens per milliliter, the dominant form being Aphanizomenon flos-aquae. By the middle of August green algae, consisting of two forms tentatively identified as being Hormidium spp. and and Mougeotia spp., had become dominant. This was in contrast to the remainder of the Lake where green algae never reached significant numbers. Green algae continued to be the major forms in the Pelican Horn population thru the October 19 sampling date, and at all times during this period were abundant enough to cause the water to be visibly green. The December and February samples contained almost exclusively diatoms which reached a concentration of 3,350 per milliliter on the latter date. Fluctuations in pH, carbonate alkalinity, and dissolved oxygen would all indicate that phytoplankton chemical activity was generally about the same here as in other portions of the Lake sampled. Samples were taken on August 27 to demonstrate the diurnal variability of these parameters (Table 11). Numbers of organisms remained relatively constant and chemical activity evidently reached a peak during the afternoon. Vertical cross-sections of temperature in-

Table 11 - Variations With Time and Depth of Phytoplankton and Associated Variables During the Period August 27-28

Determination	Depth	August 27				August 28
		0720	1110	1820	2230	1215
Carbonate alkalinity as mg/l $CaCO_3$	Surface	72	64	84	72	80
	Bottom	80	60	48	44	--
Percent saturation of dissolved oxygen	Surface	111	132	172	152	110
	Bottom	109	109	95	75	--
pH	Surface	9.2	9.25	9.3	9.05	9.1
	Bottom	9.25	9.2	9.0	8.85	--
Total phytoplankton per milliliter	Surface	--	3960	3540	3760	2240
Secchi disc readings in feet	--	--	2	2.2	--	1.8

dicated stratification occurred from June thru October. Table 11 would indicate that some mixing probably occurs at night. Secchi disc readings indicate the depth range of visibility by the human eye. This may also be considered a rough approximation of light penetration and would indicate that, due to the density of the organisms themselves, active growth is probably restricted to the upper few feet of water.

State Park:

Phytoplankton were present in numbers sufficient to give a strong green color to the surface water from the July 2 sampling data through at least the 19th of October (a sampling date). Patches of relatively clear water, sometimes equaling in size the areas of algal bloom, were generally present. These nuisance blooms were composed almost entirely of blue-green algae. The July 2 sample contained an estimated 17,600 organisms per milliliter and consisted of a single species, the filamentous Aphanizomenon flos-aquae. Subsequent summer and autumn samples generally contained some filamentous and occasionally colonial green algae. The freshwater dinoflagellate Ceratium hirundinella was common during the remainder of July. By mid-July a second blue-green alga, Anabaena spp. appeared in the samples but was always present in lower numbers than A. flos-aquae. On August 27 a third blue-green alga, Microcystis spp., had appeared in the Lake. This form became the dominant species in September and remained so thru the October sampling date. The change in blue-green speciation did not result in any visible changes of water quality in the Lake. Green it was in July and green it remained in September and October. During the winter, centric diatoms were the dominant phytoplankters and reached a concentration of 4,340 in the February 20 sample causing supersaturation (119%) of the water with oxygen and a pH of 8.9.

Phytoplankton numbers in the bottom samples were generally low as would be expected since conditions were not such that growth could occur there. Some idea of vertical and diurnal distribution can be gained from Table 4.

Table 12 - Variation of Phytoplankton Numbers with Time and Depth at the State Park Station

	July 13		July 14
Time / Depth	0100	0430	1200
Surface	160	1570	12,400
15 Feet	760	260	--
Bottom	208	76	--

	August 27				August 28
Time / Depth	0700	1055	1740	2205	1115
Surface	220	960	340	420	1520

	September 17		September 18
Time / Depth	1440	2040	1200
Surface	40	27,500	340
2 Feet	100	270	--
10 Feet	220	90	--
20 Feet	200	340	--

The samples of September 17 indicate the extreme variability in numbers at the surface. The very large increase between afternoon and evening is probably a reflection of the patchy distribution described above as well as growth. The diurnal variations in the chemical and physical properties of water affected by phytoplankton growth are summarized for two sampling periods in Tables 13 and 14.

Some vertical mixing took place in the early morning hours as indicated by a temperature profile taken at 0430 which showed a difference of only 0.7°C between the surface and bottom compared with a difference of 3.7°C at noon on the following day (Figure 4). Diurnal changes during both of the sampling periods are not very marked reflecting the relatively small numbers of phytoplankton (Table 12) present at these times. Despite these relatively low concentrations, the population was still of such a density as to constitute a visual nuisance.

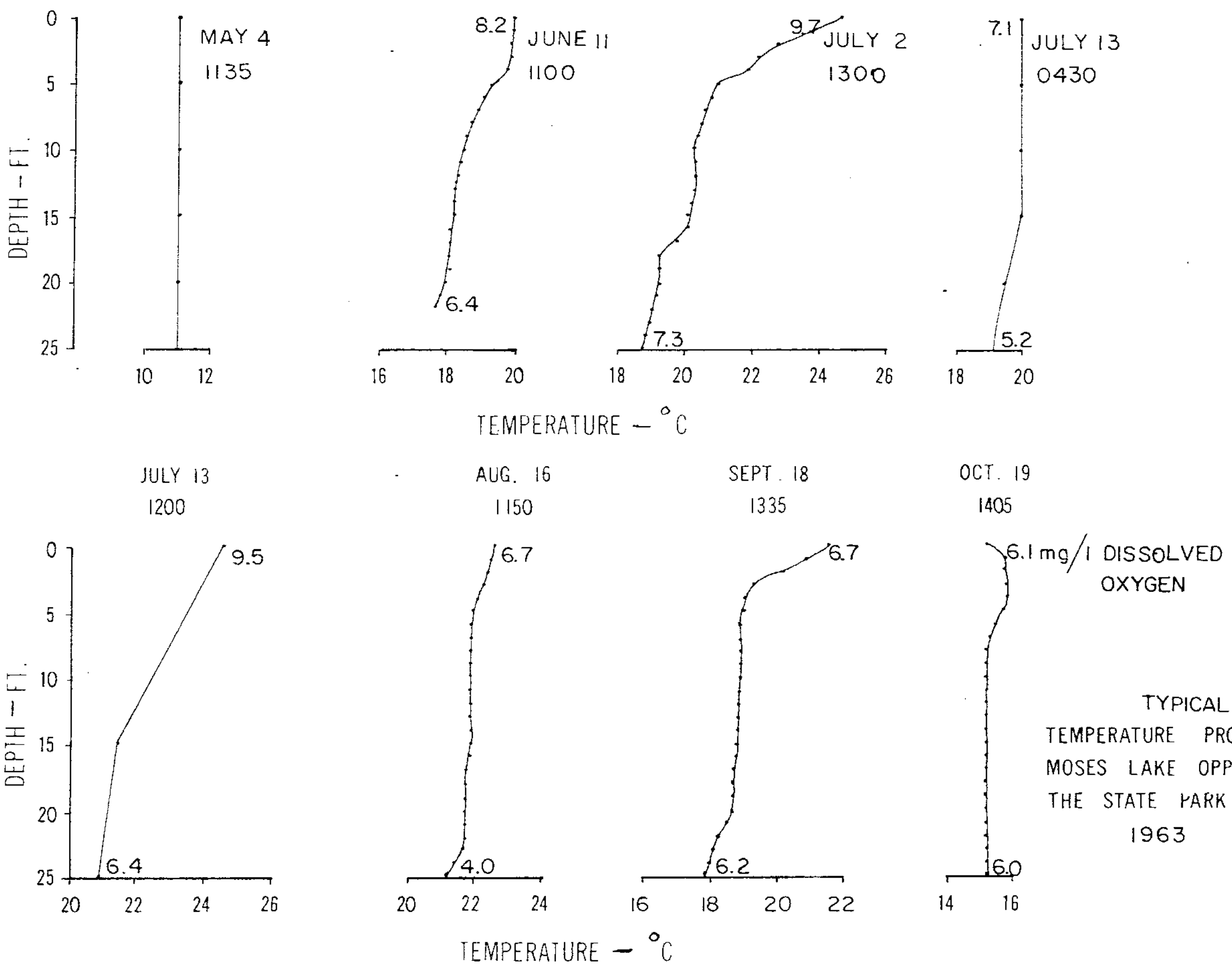
Airman's Beach:

Speciation of phytoplankton and succession of species were essentially the same as at the State Park station. Visual observations seemed to indicate that maximum surface concentrations of algae in Moses Lake occurred in the vicinity of Airman's Beach. Due to the semiquantitative aspects of sampling noted above, this conclusion was not always verified by counts of organisms, the second highest single count (25,150 filaments per milliliter) during the study was obtained at this station. The prevailing wind direction in the summer and the morphometry of the lake basin in the vicinity of Airman's Beach, might lead one to hypothesize an accumulation of phytoplankton in this area. Although currents were not studied in the investigation, there is also evidence of a potential counterforce to drift accumulation of algae. On almost all occasions during the summer, the surface water temperature at the Airman's Beach station was higher than that at the State Park at all times of day and night. This phenomenon should produce a surface drift down the lake towards the State Park.

Diurnal variations in phytoplankton and in water quality characteristics influenced by phytoplankton metabolic activity were measured at this station on July 12-13 and again on August 27-28. The results are summarized in Tables 15 and 16. The first table shows some diurnal variation in all of the items measured but is most marked in the percent saturation of dissolved oxygen which reached the amazing value of 224% at 1755 on July 13. Unfortunately, comparable plankton counts were not made for these samples, but the observation of an extremely dense surface population at that time was noted. Phytoplankton numbers showed a marked periodicity during the August 27-28 sampling and this is vividly reflected by the accompanying chemical and physical measurements, particularly the carbonate alkalinity and the percent saturation of dissolved oxygen. Note also the gradually increasing phosphate concentration in the bottom water.

Phytoplankton Significance

To the people using Moses Lake for recreational purposes, the extensive



TYPICAL
TEMPERATURE PROFILES,
MOSES LAKE OPPOSITE
THE STATE PARK.
1963

Fig. 4

Table 13 - Diurnal Variations in Water Quality Parameters Associated with Phytoplankton Activity Off the State Park, July 12-13, 1963

Determination	Depth	July 12	July 13					
		2145	0115	0420	0800	1140	1400	1800
Carbonate alkalinity as mg/1 $CaCO_3$	Surface	20	24	20	20	12	6	18
	15 Feet	8	8	20	16	10	12	10
	Bottom	0	4	6	8	8	0	0
Percent saturation of dissolved oxygen	Surface	85	77	77	78	112	84	80
	15 Feet	74	74	76	74	78	69	76
	Bottom	65	47	56	50	71	56	53
pH	Surface	8.7	8.8	8.5	8.6	8.8	8.3	8.6
	15 Feet	8.5	8.6	8.5	8.5	8.6	8.4	8.5
	Bottom	8.3	8.4	8.2	8.3	8.6	8.2	8.3
Orthophosphate in mg/1	Surface	0.15	0.13	0.15	0.17	0.09	0.16	0.20
	15 Feet	0.11	0.16	0.15	0.17	0.15	0.24	0.22
	Bottom	0.14	0.30	0.21	0.19	0.13	0.24	0.23

Table 14 - Diurnal Variations in Water Quality Parameters Associated with Phytoplankton Activity Off the State Park, August 27, 1963

Determination	Depth	August 27			
		0700	1100	1740	2200
Carbonate alkalinity as mg/1 $CaCO_3$	Surface	32	32	48	45
	Bottom	28	24	23	16
Percent saturation of dissolved oxygen	Surface	60	70	84	83
	Bottom	60	60	53	55
pH	Surface	8.8	8.8	8.8	8.6
	Bottom	8.8	8.7	8.6	8.4
Orthophosphate in mg/1	Surface	0.14	0.13	0.18	0.20
	Bottom	0.16	0.15	0.20	0.20
Secchi disc reading in feet	--	--	1.8	2.0	--

algal blooms which occur during the warm months are considered a nuisance. This reaction is based on aesthetic considerations occasioned by the intense green color and the actual change in physical texture produced by the extremely dense phytoplankton populations in the surface waters. It is also based on the disagreeable coating given anything immersed in the water and also on occasional odors of decaying algae on shore.

Algae are an intrinsic part of the biota in a fertile lake and exert an influence on other forms of life, including fish, which may be present. For example, phytoplankton produce oxygen during the daytime, (see Table 14) but must use this vital gas in order to remain alive in the hours of darkness. Many cases have been documented where this property of algal metabolism has

Table 15 - Diurnal Variations in Surface Water Quality Parameters Associated with Phytoplankton Off the Airman's Beach, July 12-13, 1963

Determination	July 12	July 13					
	2120	0040	0400	0730	1120	1328	1755
Carbonate alkalinity as mg/l-$CaCO_3$	36	28	20	20	20	32	48
Percent saturation of dissolved oxygen	118	101	105	108	136	119	224
pH	9.0	8.8	8.8	8.8	9.0	9.0	8.9
Orthophosphate	0.03	0.02	0.05	0.03	0.05	0.04	0.09

Table 16 - Diurnal Variations of Phytoplankton and Associated Water Quality Parameters Off the Airman's Beach, August 27-28, 1963

Determination	Depth		August 27			August 28
		0635	1030	1715	2145	1215
Carbonate alkalinity as mg/l $CaCO_3$	Surface Bottom	52 64	72 48	92 48	80 36	48 --
Percent saturation of dissolved oxygen	Surface Bottom	82 62	110 61	169 52	172 55	108 --
pH	Surface Bottom	9.2 9.2	9.2 8.8	9.2 8.9	9.0 8.6	9.0 --

(continued on next page)

Table 16 (cont)

Orthophosphate	Surface Bottom	0.13 0.15	0.12 0.16	0.12 0.18	0.13 0.25	0.12 --
Secchi disc reading in feet	--	--	1.1	1.3	--	1.8
Total phytoplanktors per ml	Surface	1,150	1,900	4,300	4,600	1.800

resulted in very wide diurnal fluctuations in the amount of dissolved oxygen. These fluctuations, if extreme, may be harmful and even fatal to fish. In the case of Moses Lake this does not seem to be a problem. Another relationship between algae and fish is the latter's food supply. None of the species observed in Moses Lake feed directly upon algae, but they do depend upon crustaceans and other lower forms of animals which in turn depend either directly or indirectly upon these minute plants as a source of food. It is evident that Moses Lake has an overabundance of algae which serves as an indirect fish food.

The phytoplankton in Moses Lake may play an important role in suppressing the growth of rooted aquatic vegetation. All plants must have light in order to grow. Secchi disc readings would indicate that the algal population utilize this energy source to such an extent that significant amounts are confined to the upper few feet. Thus, during much of the growing season of plants, light may not be sufficient to support the development of rooted aquatic vegetation over much of the Lake's surface where they might otherwise be abundant. A counteraction to this is the possible coagulating effect which algal cells may exert on silt particles (see section on turbidity below).

A final consideration is the possible significance to water quality in the Potholes Reservoir if algal blooms are artificially curtailed in Moses Lake by chemical means. By tying up nutrients in cell material, phytoplankton may substantially increase the nutrient retention time in a lake and may also cause a certain portion of the nutrients to be "permanently" removed from solution by deposition in the bottom sediments. Removal of these mechanisms would inevitably result in an increased nutrient flow, and hence possible increased phytoplankton activity, in the Potholes Reservoir.

Bacteriological Quality

Moses Lake is used for bathing, boating, water skiing, and fish caught from its waters are subsequently eaten by humans. The bacteriological quality of the water is therefore of considerable significance. Tests for bacteria originating in the feces of warm blooded animals (coliform group) were conducted routinely according to Standard Methods (8) and are reported in Appendix A. These are indicator bacteria and are not harmful in themselves.

Rocky Ford Creek:

The most probable number (MPN) of coliform bacteria ranged from 91 to 1,100 and averaged 390 per 100 milliliters of water. No seasonal variation was apparent. Livestock watering in the Creek and grazing along its periphery were considered to be the most logical source of the contamination since there is little human habitation between the fish hatchery and the sampling station. Herds of sheep and occasional horses and cattle were seen in the coulee through which Rocky Ford Creek flows. Ducks were also observed nesting along the banks. These bacteriological values are considered to have no sanitary significance.

East Low Canal:

Coliform determinations indicated an average MPN of only 20 and a maximum of 43 organisms per 100 milliliters. As in Rocky Ford Creek, these organisms originate with animal life and have no particular sanitary significance. East Low Canal water can be considered as having a high quality from the bacteriological standpoint.

Crab Creek:

Coliform bacterial counts were higher in Crab than in Rocky Ford Creek, averaging 890 per 100 milliliters of sample. They exhibited no seasonal variations but several relatively high values were obtained, as for example on July 14 when the MPN was 4,600 organisms per 100 milliliters. A number of homes are located near the creek which may directly or indirectly contribute sewage to the creek. Cattle graze along the banks and several livestock holding areas are located in the creek basin and are the most likely source of the great majority of fecal bacteria detected. Large numbers of waterfowl were present in and around the creek during the autumn and winter months, and these may also have been contributors.

Seepage:

Coliforms were absent in samples collected directly as the water percolated from the soil. They were found in samples collected after the water had flowed over the surface for a short distance because of the presence of cattle feces.

Sewage Treatment Plant Effluent:

Coliform bacteria concentrations were variable from one sampling date to another but agreed fairly well between duplicate samples collected at the same time. Concentrations ranged from a low of 150 to a high of 11,000 coliforms per 100 milliliters, the average being 3080 per 100 milliliters. This difference is to be expected as the effluent is not homogenous and humus from filter sloughing causes a variation in the coliform bacteria kill from the applied chlorine.

Pelican Horn:

Coliform bacteria were of particular interest in Pelican Horn because of the discharge of treated sewage into its upper end. On July 2 samples indicated a count of 2,900 organisms per 100 milliliters of water. On all other occasions tests indicated that coliforms were either absent (three of the eleven samples) or present in insignificant numbers. The average MPN of all samples was 270 per 100 milliliters. The north shore and part of the south shore of Pelican Horn contain residences. Cattle graze along the southwestern shore but probably exert little influence on water quality at the sampling stations. Waterfowl are common in Pelican Horn and may be a source of coliforms. The most obvious potential source of these indicator bacteria is the sewage treatment plant effluent, but the generally low numbers would indicate that it has had no appreciable effect on the bacterial population of Pelican Horn. Effluent coliform concentrations would actually be less than those shown herein as there is an additional contact time of effluent and chlorine below the point of sampling. (Samples were neutralized with sodium thiosulfate to destroy the chlorine at the point of sample collection.)

State Park:

Indicators of human bacterial pollution are especially significant in the proximity of a bathing beach. Bacteriological quality of the lake at this station was generally excellent and in all cases MPN's indicated an acceptable quality of water for recreational usage. During the period of June through September the maximum surface MPN was only 75 coliforms per 100 milliliters and the average for the entire year was 27. A slightly higher but still insignificant concentration of coliforms was obtained in the bottom samples. The probable origin of fecal bacteria in this area of the lake is not known but could conceivably have been from any of the sources previously noted, or from the bathers themselves.

Airman's Beach:

Due to considerable recreational usage, the importance of water quality at this station is comparable to that of the State Park. Bacteriological tests indicated an excellent quality of water in the midportion of this area of the lake. A maximum MPN of 75 coliforms per 100 milliliters was obtained on July 2 and 50% of the samples exhibited an MPN of 0. The average MPN over the entire period of study was only 9 organisms per 100 milliliters of water. As with the State Park station, the possible source of these few fecal bacteria is not known, but because of the low numbers involved, is not important.

Bacterial Significance - Summary:

Data collected in this study indicate that the bacteriological quality of Moses Lake was excellent. According to the bacterial evidence, there is no reason why full recreational usage cannot be made of the lake waters. Bacteriological data collected by the Grant County Health Department (9) corroborate these data. The occasional high concentrations of coliform bacteria are typical of a natural environment and can be attributed essentially to waterfowl and the bathers themselves when samples are collected from a bathing area.

Turbidity

During the periods when the surface of Moses Lake is not covered by either ice or algal blooms, the water appears to be quite turbid. Routine measurements of turbidity were performed in the laboratory and results are summarized in Table 17. The East Low Canal generally contained negligible amounts of suspended matter. Rocky Ford Creek visually appears to be quite turbid at all times of the year; but, in view of the relatively low readings obtained in actual determinations, this is thought to be caused by a heavy contribution of coarse debris from the dense vegetation along the creek banks and from the upstream hatchery. (This coarse debris does not register as turbidity on a turbidimeter, like silt for example) Actual turbidities are higher in spring and early summer, probably due to work at the upstream hatchery. Crab Creek contains considerably more suspended material during most of the year and values tend to fluctuate more in response to meteorological conditions. The State Fish Hatchery on a Crab Creek tributary would be expected to have little effect on Crab Creek water quality.

The lake itself is generally more turbid than its tributaries, indicating the existence of some internal mechanism for maintaining particles in suspension. However, the lake does appear to respond directly to meteorological conditions as evidenced by the relatively high turbidities present at Airman's Beach and on the bottom at the State Park on July 2. During the preceding night a series of brief but violent thunderstorms occurred on the west side of the lake, and on the following day high turbidities were a reflection of direct runoff into the lake.

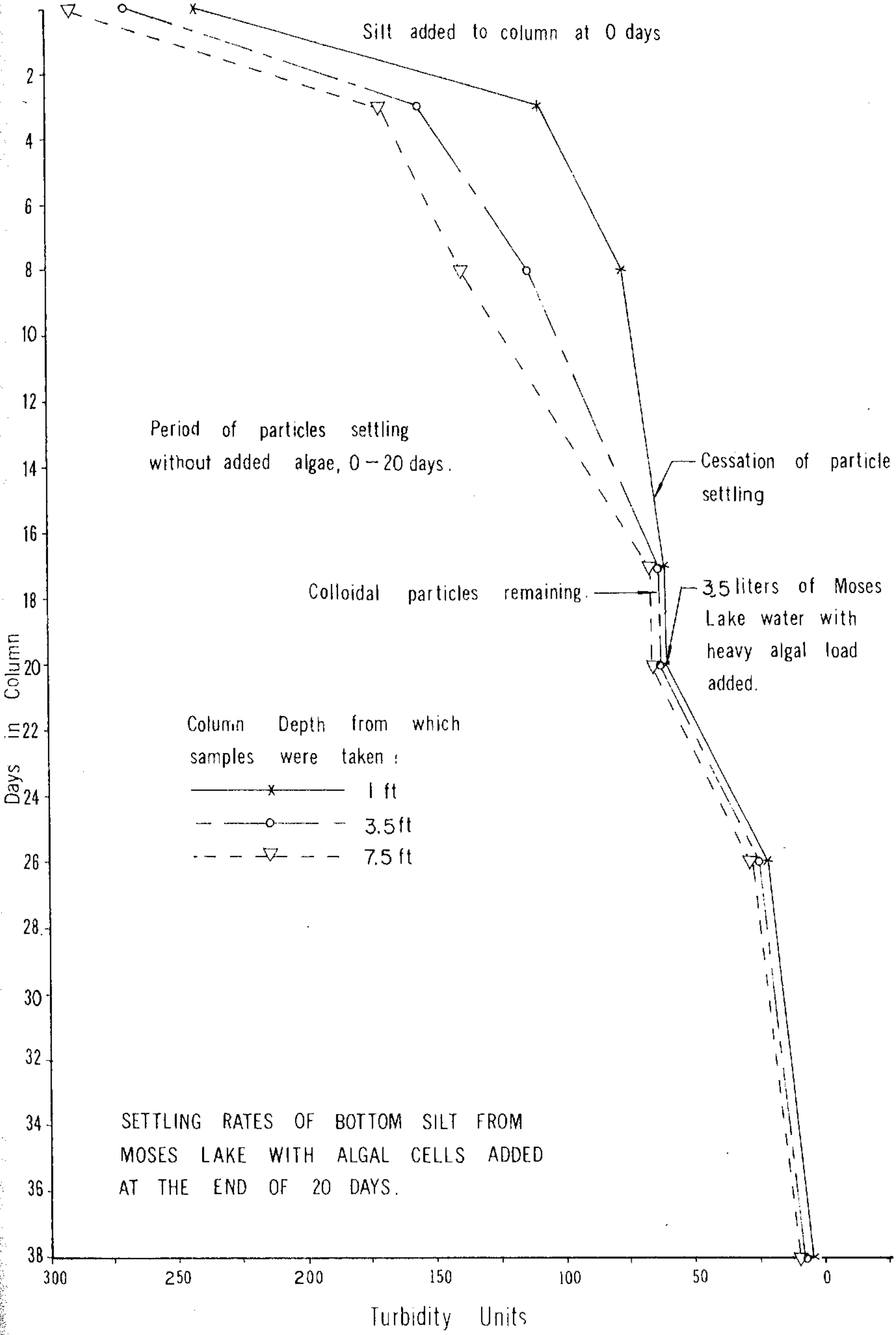
Laboratory experiments with lake mud which had been allowed to settle on the bottom of a large plexiglass tank indicated that bottom materials consolidated quite well and that a relatively high degree of turbulence was necessary to introduce turbidity in the overlying water. Observations, especially during spring spawning, and general knowledge of the feeding habits of carp

Table 17 - Moses Lake and Tributary Turbidities - Turbidity Units

	1963												1964
Station	4-6	5-4	6-4	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-2	2-2
1	24	33	19	8	9	6	10	7	7	6	2	5	9
2	--	1	10	8	18	4	6	3	2	3	1	--	--
3	121	24	26	20	4	16	13	11	9	5	4	13	31
5	--	36	14	31	22	22	17	22	23	12	6	10	10
6	88	110	14	23	32	22	19	19	22	14	22	8	21
7	91	95	23	35	57	21	18	15	36	3	21	13	--
8	73	36	17	27	125	--	16	18	17	7	16	9	16

strongly suggests these fish as the agents responsible for maintaining a relatively large amount of silt in suspension during the warmer months. The higher turbidities in the spring are probably more a reflection of carp feeding than they are of runoff from the creeks.

Once in suspension, much of the material composing the bottom sediments resettles very slowly as illustrated in Figure 5. Figure 5 data are based on a laboratory experiment in which silt taken from Moses Lake was mixed in a nine-foot high column of water. Subsequent reductions in turbidity were followed by determinations on samples from the 1, 3.5, and 7.5 foot depths. After approximately 20 days, three liters of Moses Lake water containing



Silt added to column at 0 days
Period of particles settling without added algae, 0 – 20 days.
Cessation of particle settling
Colloidal particles remaining.
3.5 liters of Moses Lake water with heavy algal load added.
Column Depth from which samples were taken :
1 ft
3.5 ft
7.5 ft
SETTLING RATES OF BOTTOM SILT FROM MOSES LAKE WITH ALGAL CELLS ADDED AT THE END OF 20 DAYS.
Days in Column
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
300
250
200
150
100
50
0
Turbidity Units

Fig. 5

blue-green algae was added at the top of the column. The subsequent rate of decrease in turbidity was marked as shown in Figure 5. These algal cells appear to act as adsorbing agents in removing fine suspended materials from the water. This laboratory experiment then tends to explain the reduction in water turbidities observed during periods of heavy algal productivity in Moses Lake.

Samples of bottom sediment were collected at the three lake sampling stations and analyzed for their organic content and their bulk density. Mean sample values were as shown below:

	Percent Organic by Dry Weight	Bulk Density $lbs/ft.^3$
Pelican Horn, Station 5	8.3	49
State Park, Station 7	10.8	49
Airman's Beach, Station 8	15.5	38

The above values indicate that the bottom sediments are rather light and fluffy when dried and that their organic content is surprisingly low, considering the algal productivity in the lake. This suggests that bacterial decomposition returns most of the deposited algal cells to their original inorganic constituents. Since a large portion of the organic debris on the lake bottom is composed of sedimented plankton, the organic percentages above indicate that Pelican Horn has the least, and the lake opposite the Airman's Beach, the greatest algal blooms.

As with the algal blooms the primary significance of turbidity lies in the response of the observer to a visual impression. People simply prefer a clear water for recreational purposes and for aesthetic enjoyment. This is particularly true in the Northwest which abounds in water resources having this property. However, in the case of Moses Lake, suspended silt may very well have significant effects on other water quality parameters. By filtering out the incident sunlight, turbidity undoubtedly helps to limit the growth of plants, both planktonic and rooted, in the lake. It is also possible that heavy, local production of suspended material by carp spawning and feeding may cause increased mortalities in the eggs of game fish. The buildup of bottom sediments is likewise lessened as material is carried through the outlet that otherwise would reside on the lake bottom.

Fish Populations

The present study of Moses Lake did not include direct sampling in order to define the fish populations. However, conversations with local residents and Department of Game biologists have provided a general knowledge of the species present and their relative importance to game and commercial fishermen. Considerable numbers of rainbow trout, largemouth black bass, white crappie and yellow perch appear to be present. Several local residents have reported good catches of large rainbow trout and a number of people fishing from the banks were observed with large numbers of pan fish. The dominant fish species in the lake is without doubt the European carp, Cyprinus carpio. A commercial haul seine operation in the upper lake resulted in catches totaling about 800,000 pounds in 1962. This fish is viewed with repugnancy by almost all users of the lake and it would seem that its eradication would be met with almost universal enthusiasm.

It is probable that removal of all fish and subsequent restocking with trout (spiny ray fish take too long to develop and would have to compete with carp regrowth and subsequent destruction) would result in a very fine lake for trout fishing, at least for several years. Additionally, destruction of the carp would probably result in a decrease in turbidity during the warmer months. On the other hand, carp are known to feed on both insect larvae and on the seeds of higher plants so that their removal might well result in an increase in both insects and emergent vegetation along the shore. Also the turbidity which they are expected to cause, at least in part, acts to decrease the light needed for plant growth. Finally, at least one person receives an income from the carp fishery in Moses Lake which would be terminated upon removal of the fish.

The Carp

Some general data on the European carp, Cyprinus carpio, are given below as extracted from references (11) and (12) and from general observation and deduction. Some contradictions are to be found in the literature regarding carp characteristics. Carp are believed to have been introduced into Moses Lake shortly after the coming of the railroads to the area.

A. General Data:

1. Introduced to Europe from eastern Asia, and to United States about 100 years ago.

2. Originally intended as food source to be raised on fish farms.
3. Found in all U. S. states except Alaska and occurs in southern Canada.
4. It has become a major nuisance in most places.
5. Its value as a source of protein in the United States is declining as immigration has lessened and people's previous food habits are changing in the new world.
6. The principal value of carp in the United States is as a fish and animal food and as a fertilizer.
7. The market for carp is small and usually centered in the large cities and the prices are low.
8. Difficult to catch with hook and line and they will not fight.

B. Effect of Feeding and Spawning on Other Fish:

1. Unacceptable to some species of fish.
2. Roiled water:
   a. Interferes with sight feeding by other fish.
   b. Inhibits growth of aquatic plants.
   c. Smothers eggs and young fry.
3. Destruction of aquatic plants (this may not be a disadvantage in some instances):
   a. Interference with habitat.
   b. Loss of cover.
   c. Loss of spawning area.
   d. Loss of nursery areas.
   e. Loss of plant food.
   f. Loss of cover for fish food organisms.
   g. Destruction of eggs and fry of other fish.

C. Feeding:

1. Compete with other fishes for food.
2. Feed by sucking in mouthfuls of mud and spitting out all but the food organisms which roils the water (makes it turbid).
3. Feed on small animals and plant material. Mosquito larvae are a favorite with the fry.
4. Carp will lie dormant when the water is very cold.
5. The record North American carp weighed 55 pounds.
6. Generally in shallow water after dark and in deep water during the day.

D. Spawning and Growth:

1. Thrive in warm water.
2. Spawn when temperature of water is above 60°F. (15.5 C.), usually May through July and sometimes into August.
3. Spawn in shallow water (one to three feet in depth) and they prefer area with heavy vegetation.
4. Female ovary contains usually several hundred thousand eggs of which several hundred are spawned at a time. This requires a considerable time period to complete spawning.
5. Spawning is accomplished with a very large amount of splashing which is done to spread the eggs about. The eggs have an adhesive coating for adhering to bottom vegetation or debris. Those eggs not adhering are lost. This violetn agitation accompanying spawning, over an area about six feet in diameter for each fish, is responsible for much of the destruction to other fish and their spawn.
6. Carp eggs will hatch in 4-14 days, depending upon the water temperature.

7. Fry are approximately 3 millimeters long at hatching and assume adult form at 9 millimeters.
8. About 20 days after hatching, the fry are approximately an inch long and move into somewhat deeper water where they remain for most of the summer.
9. Carp keep growing indefinitely and live to a fairly old age in the absence of predators and the presence of adequate food.

E. Possible Control Measures:

1. Fencing or draining of spawning areas.
2. Filling spawning areas.
3. Poisoning of spawning areas with rotenone or toxaphene.
4. Poisoning of lake itself with rotenone or toxaphene.
5. Fluctuation of lake level during spawning season.
6. Destruction of eggs by some physical force.
7. Establishment of a heavy commercial fishing pressure.
8. Introduction of predators.
9. Introduction of lethal diseases or parasites specific to carp.

SUMMARY AND RECOMMENDATIONS

In the period of April 1963 through February 1964, personnel of the Civil Engineering Department at the University of Washington conducted a study of Moses Lake and tributary water quality and environmental factors, for the purpose of defining the water quality problems in the Lake, the probable origin of these problems, and to make recommendations on possible methods of lake rehabilitation. Water quality samples were collected from nine sampling stations on 13 sampling trips during the study period and analyzed for their physical, chemical, and biological quality. Local, state, and federal officials were contacted for their views and information on the Lake and its uses.

Moses Lake has large recreation and homesite potential that is not now being realized essentially because of the water turbidity, heavy summer algal blooms, and a very large carp population. The following paragraphs discuss these problems and make recommendations for corrective action.

To make Moses Lake attractive for the building of homes along its shores for fishing, bathing, boating, wildlife propagation, and for general aquatic sports, it is necessary that there be a reduction in turbidity, the carp population (to be replaced with game fish) and algae; that shoreline vegetation be maintained in most areas and that the shallow-marshy areas of the shoreline be filled. Some of these objectives are incompatible or will give rise to other objectionable features as discussed below.

Economic Study

The improvement of Moses Lake water quality and general appearance will cost varying amounts of money, depending upon what is done and the degree of improvement that is sought. Moses Lake has a potentially great recreational and aesthetic value to the entire community and surrounding area. This value is both social and monetary. Before any steps are taken on lake rehabilitation, it would be appropriate to assess probable social and monetary values that would be achieved through this or that rehabilitation measure. This assessment should greatly aid in the decision making necessary for the advancement of any particular project.

Filling of Shallow Areas

Shallow areas in the Lake should be filled (or deepened) to reduce emergent littoral vegetation, carp spawning, and mosquito breeding. This will of course reduce wildlife refuge and fish (other than carp) refuge. It is particularly desirable that the extreme upper ends of both Pelican and Parker Horns be filled as they are also unsightly.

Carp Control

The creation of a good sport fishery in Moses Lake and the reduction of turbidity is dependent upon the killing of hundreds of thousands of carp together with the repeated destruction of carp eggs. A greatly reduced carp population may give rise to aquatic vegetation growths that will be bothersome to boaters, that will encourage mosquito breeding and that will reduce shoreline usage; but which would improve harborage for wildlife and game fish. Reduction of the carp population will also reduce the regeneration of nutrients from the bottom into the overlying water, thus aiding in algal control. However, the reduced turbidity would tend to encourage algal growth by increased light penetration. Whatever method of carp control might be used, it would not completely eradicate the carp for a number of reasons and so the control measures adopted must be repeated at intervals to maintain as low a population level as practicable.

It is considered impractical to attempt the control of carp in Moses Lake by the introduction of predators or carp diseasea. A successful commercial fishery for carp would be dependent upon maintaining a large carp population in Moses Lake to optimize the fishing effort and return. This is contrary to the rehabilitation objectives. The desirability of filling (or deepening) shallow areas has already been discussed.

Fencing of several lake areas where boat traffic is not a consideration would be valuable in denying the adult carp an area in which to spawn and also in reducing the area where other control methods might be used. Areas where fencing could be of considerable value include the north end of the Lake, upper Parker and Pelican Horns, and the inlets off the southwest lake shoreline Carp frequent Rocky Ford and Crab Creeks. Fences should be installed well before the spawning season; they should be constructed with ice pressures in mind; and they should have openings that will exclude small adult carp.

If the entire Lake were to be sprayed with one percent rotenone at a concentration of 1.0 mg/l with rotenone costing $0.17 per pound, the cost for rotenone alone would be $60,500; or for 0.05 mg/l of toxaphene at $0.40 per pound, the cost would be about $7,120 for the toxaphene. If the Lake level were reduced to elevation 1041 feet, say about the end of the irrigation season in early October and before the carp have gone into the deeper water for winter hibernation, the cost would be about $45,300 for rotenone and $5,350 for toxaphene. The required dosage of rotenone or toxaphene may be considerably less or slightly more than indicated above which would affect the toxicant cost in direct proportion to the dosage rate. Toxicant dosage rates to be used would come from the Department of Game after they had made an assessment of the various factors involved, such as percent kill desired, water temperature, method of application, water depth etc. If a temporary channel was blasted or dug through the sand dunes at the south end of the Lake in early October (also a time when the Potholes Reservoir could be drawn down); and the Moses Lake level was drawn down to about elevation 1030, the cost of poisoning would be reduced by over 65 percent.

Another control method that would at first seem very simple and desirable is the fluctuation of lake level. This would involve dropping the lake level about two feet, after the carp have spawned, to kill the eggs. Disadvantages of this method are that; the carp spawn repeatedly over a considerable period of time, necessitating frequent lake draining and filling; dropping the lake level two feet would expose a number of irrigation pump intakes that would have to be relocated; dropping the lake level two feet would take about three days from elevation 1046 and, at the normal rate of June or July inflow, 38 days would be required to bring the lake elevation back to elevation 1046, unless water is diverted into Moses Lake from the East Low Canal through Rocky Coulee Wasteway. These periods are calculated without consideration of irrigation withdrawals which would lengthen the time of filling. Another disadvantage of water level fluctuation would be the occurrence of lower lake levels at a time of near maximum water and shoreline usage. Water level fluctuation is thus impractical unless large volumes of East Low Canal water would be available for discharge into Moses Lake at about two week intervals over a period of about two months. These times would have to be determined by careful biological observation during the spawning season.

Destruction of carp eggs during the spawning season by periodic passes over the spawning areas with a shallow draft boat jetting water into the egg harborage areas through means of a pump might offer an easy and inexpensive means of carp population control after a large portion of the adults had been removed by other means. The pump could also be used as a jet drive for the boat. A disadvantage of this method might be the concurrent destruction of game fish spawn and wildlife nests. This would be a consideration for resolution by the Department of Game.

Recommendation:

Since Moses Lake is a large body of water where carp control measures over the entire Lake would be very expensive at this time and since little local experience has been had with carp control, it is recommended that a trial program of carp control be conducted in a portion of the Lake that is widely used and one that can be isolated from the remainder of the Lake. This can be done in Pelican Horn together with the south portion of the Lake below the highway causeway. If this program is successful and practicable, it might be extended to other portions of the Lake at a later date. It should be indicated herein that carp killed by any process will accumulate along the shoreline, decay, and perhaps produce obnoxious odors unless removed. Carp removal may be nearly impossible and the populace should to told of the impending odor nuisance. Recommendations are as follows:

1. With the cooperation of the Department of Game, or through a biologist engaged for this purpose, determine the spawning areas and periods of spawning in Pelican Horn and southwest Moses Lake below the highway.

2. Construct a heavy wire mesh carp fence across the open water under the highway bridge, extending from elevation 1050 to the lake bottom, with a ten-foot opening for boat passage. To keep appreciable numbers of carp from passing through this opening, a spring-loaded wire mesh gate should be installed that will automatically return to position after a boat passes through. Other methods of carp passage control, such as electrodes, sound, agitation, etc., are not sufficiently developed, foolproof, or economical at this time for use in Moses Lake.

3. Consult the Department of Game as to the desirability of fencing off or filling some carp spawning areas where this would not interfere with boating and future game fish spawning.

4. With the advice and cooperation of the Department of Game, using the toxicant selected, poison Pelican Horn and lower Moses Lake below the highway causeway immediately following the irrigation season. Using application rates and unit prices previously discussed, the cost of this would be about \$12,000 for rotenone and \$1,400 for toxaphene at lake elevation 1046. (This does not include the cost of application) If the lake elevation were reduced

to 1041, the toxicant costs would be reduced by approximately 30 percent.

The advantages of poisoning the Lake in early October would be that:

a. The prevailing wind is from the north which should carry some of the decaying carp odors away from the City.

b. Farmers are not irrigating from the Lake.

c. Recreational use of the Lake is low.

d. Dead carp decay rates will be lower than in summer when air and water temperatures are greater. This should reduce the odor intensity and provide a longer period of time for carp collection if this is desired. A disadvantage is that odors would be present for a longer period of time and with a cool autumn and winter, they might persist after the ice is gone in the spring.

5. Assess the poisoning results and if good, then stock this area of the Lake with game fish.

6. Again after consultation with the Department of Game, consider the desirability of maintaining carp control by egg destruction during the spawning season through use of a boat filled with an agitator as described above. The boat would have to make passes over the spawning beds about once every five days during the spawning season. It is possible that mature carp populations may be kept down by use of the "electro-toxis" fish guidance system in which the fish is guided to an electrode by electric impulses. It is shocked at the electrode and then removed from the water.

7. If the trial program above is not too costly; is successful in greatly reducing the carp population; produces a large reduction in turbidity; enables the establishment of a good sport fishery; and emergent vegetation does not become a nuisance; then consideration should be given to the desirability of extending this program to other portions of Moses Lake.

Algae Control

Algal growth can be limited through temperature control, light reduction, food removal, or by placing toxicants in the environment. Temperature or light manipulation in Moses Lake is not practicable, leaving food and toxicants as the possible agents for algal control.

As discussed in a previous section, the primary sources of algal food in Moses Lake are Rocky Ford Creek, subsurface seepage, the Moses Lake City sewage treatment plant, and regeneration from the bottom sediments. Little if anything of a practical nature can be done to limit the nutrient input from Rocky Ford Creek and from subsurface seepage. Regeneration from the bottom sediments should be greatly lessened by a large reduction in the carp population, as previously discussed. (The concommitment reduction in turbidity along with the carp reduction would of course have the opposite effect of permiting more light penetration and thus more algal growth. This is considered to be of less significance however than nutrient inputs from the sediments).

Removal of the sewage treatment plant effluent from the Moses Lake drainage basin could be done by piping it to the sand dune area south of the City. Or phosphorus, the chief nutrient in the effluent, could be largely removed by a tertiary treatment process. Both of these would be expensive and would really achieve little in the way of significant algal control since phosphorus is now present in Moses Lake in excessive amounts for algal needs. Nitrogen appears to be the limiting principal nutrient and the contribution of nitrogen to Moses Lake from the sewage treatment plant is minor in comparison with other sources.

Another possible method of algae population diminution is to reduce the food supply through large scale dilution using a low-nutrient content diluting water. This is the method now being started in Seattle's Green Lake (14). The U. S. Bureau of Reclamations' East Low Canal water, available essentially April through September, is the only local water meeting this requirement. For effective algal reduction over the entire Lake, low-nutrient content dilutting water would have to be introduced at the north end of the Lake and at the head of Parker and Pelican Horns. At this time, the only location where East Low Canal water might be added would be through the Rocky Coulee Wasteway and into Crab Creek for discharge into Parker Horn. The specific levels of nutrient requirements to trigger a nuisance bloom of algae in Moses Lake are not known; in fact they are not known in any natural body of water with any degree of accuracy. However, East Low Canal water (Tables 6 and 8) contains only a small fraction of the nutrients found in the other input water to Moses Lake, or in the Lake itself. Any appreciable dilution would be beneficial. For example, to theoretically flush Parker Horn once monthly with East Low Canal water would require a continuous discharge through Rocky Coulee Wasteway of about 200 c.f.s.[1]

[1] 200 c.f.s. is taken only as an example. It does however, represent a reasonable value and one that should provide much improvement to Parker Horn and the lower Lake. Trial may indicate this value to be somewhat excessive for the needs of Moses Lake or it may indicate an insufficiency,

This would represent five times the present flow in Crab Creek during the month of August.

200 c.f.s. of water is equivalent to 400 acre-feet per day and at the very low price of $0.85 per acre-foot, the cost of this daily addition of water would be $340. Clearly, it is necessary that this East Low Canal water be available at a greatly reduced rate if nutrient dilution by flushing is to be practicalbe in Moses Lake. The addition of East Low Canal water to upper Parker Horn would have some beneficial effect on the lower Lake and on lower Pelican Horn because of the direction of natural outflow and because of wind mixing.

Algal destruction or control through the use of an algicide is a common control method in municipal water reservoirs, small lakes and swimming pools. The usual agent is copper sulfate applied by broadcasting crystals or by spraying a solution over the water. Copper sulfate is effective in controlling or preventing algae growth if it is applied in adequate quantities at the onset of an algal bloom. The quantity required is dependent upon the species of algae to be destroyed and water quality characteristics such as pH, temperature, and alkalinity. Copper sulfate has the following disadvantages:

1. It is very expensive to use in a large lake.
2. It does not degrade biologically (as the carbonate) and will accumulate on the lake bottom.
3. The best and most lasting control will result, according to Mackenthun (15), if the lake water alkalinity is 50 mg/l or less. Moses Lake water alkalinity is over three times this amount.
4. It must be added several times in a season if nuisance blooms are to be prevented.
5. Unless added very carefully, it will kill game fish and fish food. It may affect the crops being irrigated with Moses Lake water.
6. Correct dosages must be determined as too little will result in no appreciable benefit while too much represents a waste of money and perhaps added fish destruction.

It is suggested that the application of an algicide such as copper sulfate to Moses Lake would be practicable only in semi-isolated portions of the Lake where wind mixing would not exchange the water with general lake water every few days. (Mackenthun (15) states that it would probably be a waste of money to use an algicide along the shoreline areas only of a large, fertile lake which is long and narrow and subject to considerable wind and wave action). For example, the application of 1.0 mg/l of copper sulfate to Lewis Horn with the chemical @ $0.20 per pound would cost $237 per application for the chemical alone. Three applications per year would represent a chemical cost of about $700 each year. To this must be added the cost of equipment and skilled labor, say at the rate of about one dollar per acre. The approximate cost of a single application to the upper two feet of water in Parker and Lewis Horns would be $1050 for chemicals and $975 for application.

Senate Bill 2493 of the present 88th Congress would authorize the Secretary of the Interior to determine that certain costs of operating and maintaining Banks Lake and Potholes Reservoir on the Columbia Basin project for recreational purposes are nonreimbursable. This would mean maintaining fairly constant water surface elevations in these reservoirs necessitating more pumping from the Columbia River and more water release into the Potholes Reservoir. It seems certain that this bill will be enacted into law as the benefit-cost ratio was reported to be 2.42 (13). Much benefit to Parker Horn and lower Moses Lake in the form of clearer water and perhaps reduced algal blooms would result if this water to maintain Potholes Reservoir levels could be routed thereto via Rocky Coulee Wasteway, Crab Creek, Parker Horn, and lower Moses Lake.

Mr. W. E. Rawlings, Project Manager, Columbia Basin Project, U.S. Bureau of Reclamation stated at the agency pre-publication review of this report in Moses Lake on May 19 that the Bureau does not usually have surplus water in the East Low Canal during June through August and that feeder systems to the canals are now operated at capacity. Water would be available however in the period of March to June and in September and October. The flushing of Parker Horn and lower Moses Lake in May would have some benefit lasting into the early summer.

Recommendation:

With the assumption that the District will be successful in working out an arrangement with the Bureau in the near future for release of 200 or more cubic feet per second of East Low Canal water routed through Moses Lake, it is recommended that:

1. No other algal control measures be instigated at this time.

2. That sewage treatment plant or local school personnel be engaged to collect bi-weekly samples of Moses Lake water from off the Airman's Beach and

from the middle of Parker and Pelican Horns. These samples would be analyzed during the period of May through September for soluble phosphate, nitrate, turbidity, and total algal mass.

3. No. 2 above would be done only if carp eradication procedures are carried out in Pelican Horn and if East Low Canal water is diverted through Moses Lake. This sampling-surveillance procedure should show the effectiveness of carp control on algal populations and the amount of dilution required in Moses Lake to lessen algal blooms. The surveillance should be done over a period of several years until fairly definite data are obtained that may be extrapolated to other portions of the Lake.

4. Any other method of widespread algal control at this time appears to be impracticable. Perhaps one of these days an inexpensive, specific, biodegradable algicide will be developed that can be used throughout Moses Lake. The upper portion of Moses Lake would appear to be committed to its present state at this time unless large amounts of diluting water can be added at the north end.

5. If large amounts of diluting water are added to Crab Creek, the feasibility of conducting some of this flow to the upper end of Pelican Horn should be investigated.

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Grant County Health Department for assistance in sampling and providing data.

State Department of Health for background data.

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APPENDIX A

WATER QUALITY DATA

Moses Lake and Tributaries

WATER QUALITY DATA

Station 1--Rocky Ford Creek at Ephrata Highway

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	9.9	12.0	15.6	14.0	16.3	-	14.5	14.3	14.2	11.9	10.6	5.2	6.9
pH	7.8	7.2	8.7	8.2	8.1	8.1	8.0	-	7.8	6.7	8.0	7.6	7.8
Diss. Oxy., mg/l	-	-	9.1	-	-	-	-	-	-	-	-	-	-
Diss. Oxy., % satur.	-	-	90	-	-	-	-	-	-	-	-	-	-
Turbidity units	24	33	19	8	9	6	10	7	7	6	2	5	9
Cond., µmhos/cm, 25°C	213	330	-	473	291	317	368	370	388	339	238	193	-
Orthophosphate, mg/l[1]	0.57	0.30	0.40	0.37	0.36	0.44	0.42	0.48	0.41	0.41	0.42	0.47	0.42
Total phosphate, mg/l	-	0.32	0.52	0.39	0.24	0.47	-	0.30	0.42	-	-	0.52	-
Ammonia N, mg/l[2]	-	0.10	0.02	0.11	0.00	0.00	0.20	0.13	0.07	0.12	0.04	0.08	-
Organic N, mg/l	-	0.00	0.08	0.00	0.14	0.01	0.02	0.16	0.13	0.21	0.00	0.07	-
Nitrate N, mg/l	0.22	0.04	0.02	0.28	0.47	0.67	0.13	1.61	1.38	1.30	1.10	0.15	1.77
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	-	0.03	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$

[2] Nitrogens are reported as N

WATER QUALITY DATA

Station 1--Rocky Ford Creek at Ephrata Highway

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	750	93	93	1,100	460	200	-	91	430	430	-	430	240
Chloride, mg/l	8	-	-	-	11	-	-	-	-	6	-	6	-
Carbonate alk., mg/l[1]	0	0	-	-	0	0	0	0	0	0	0	0	0
Total alk., mg/l[1]	144	158	150	-	160	160	152	158	148	166	158	158	160
Calcium, mg/l	25	20	39	-	28	30	30	-	31	32	31	30	-
Magnesium, mg/l	18	22	16	-	18	20	16	-	18	12	14	16	-
Sodium, mg/l[2]	35	32	-	-	50	-	-	-	-	-	-	-	-
Potassium, mg/l[2]	13	12	-	-	15	-	-	-	-	-	-	-	-
Sulfate, mg/l[3]	-	-	-	-	26	-	-	-	-	21	-	-	-
Total hardness, mg/l[1]	137	142	138	136	144	155	138	-	150	129	137	141	-
Total algae/ml	382	514	938	186	488	1,110	-	940	490	126	340	-	-
Iron, mg/l	-	-	-	-	0.35	-	-	-	-	0.22	-	-	-

[1] Reported as equivalent calcium carbonate

[2] Values believed to be high.

[3] Values believed to be low.

WATER QUALITY DATA

Station 2--East Low Canal at Wheeler

Determination	1963									
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19
Temp., °C	8.5	18.0	16.0	16.8	18.6	19.0	21.9	19.5	18.4	15.0
pH	7.2	8.3	8.3	7.9	8.1	8.2	-	8.1	7.2	7.0
Diss. Oxy., mg/l	-	-	-	-	-	-	-	-	-	-
Diss. Oxy., % satur.	-	-	-	-	-	-	-	-	-	-
Turbidity Units	1	10	8	18	4	6	3	2	3	1
Cond., µmhos/cm, 25°C	171	-	167	127	121	148	153	153	132	95
Orthophosphate, mg/l[1]	0.00	0.44	0.03	0.05	0.05	0.02	0.06	0.01	0.02	0.03
Total phosphate, mg/l	0.12	0.69	0.13	0.08	0.06	0.04	0.39	0.00	-	-
Ammonia N, mg/l[2]	-	0.00	0.01	0.00	0.02	0.08	-	0.09	0.02	0.12
Organic N, mg/l	-	0.00	0.00	0.08	0.00	0.03	0.15	0.15	0.07	0.00
Nitrate N, mg/l	0.04	0.06	0.02	0.00	0.02	0.00	0.03	0.02	0.00	0.01
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	0.00

[1] Phosphate is reported as $PO_4^{\equiv}$

[2] Nitrogens are reported as N

WATER QUALITY DATA

Station 2--East Low Canal at Wheeler

Determination	1963										1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	
MPN Coliform/100ml	0	23	3.6	7.3	43	23	39	43	0	-	
Chloride, mg/1	-	-	-	2	-	-	-	-	6	-	
Carbonate alk., mg/1[1]	0	0	-	0	0	0	0	0	0	0	
Total alk, mg/1[1]	64	68	-	70	74	64	64	60	68	65	
Calcium, mg/1	13	21	-	20	22	22	-	21	21	20	
Magnesium, mg/1	11	5	-	6	6	4	-	5	5	6	
Sodium, mg/1[2]	9	-	-	14	-	-	-	-	-	-	
Potassium, mg/1[2]	4	-	-	7	-	-	-	-	-	-	
Sulfate, mg/1[3]	-	-	-	58	-	-	-	-	12	-	
Total hardness, mg/1[1]	77	76	76	76	79	73	-	73	71	77	
Total algae/ml.	106	858	630	240	260	-	12	158	-	366	
Iron, mg/1	-	-	-	0.03	-	-	-	-	0.05	-	

[1] Reported as equivalent calcium carbonate.

[2] Values believed to be high.

[3] Values believed to be low.

WATER QUALITY DATA

Station 3--Crab Creek Just North of Lake

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	10.6	10.0	21.3	21.0	22.0	-	18.0	17.2	18.3	13.4	12.0	2.8	5.7
pH	8.2	8.3	8.6	8.5	8.2	8.5	8.1	-	8.3	8.2	8.1	8.2	8.5
Diss. Oxy., mg/1	-	-	-	-	-	-	-	-	-	-	-	-	-
Diss. Oxy., % satur.	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity Units	121	24	26	20	4	16	13	11	9	5	4	13	31
Cond., µmhos/cm, 25°C	234	670	-	433	362	381	480	494	582	476	339	280	-
Orthophosphate, mg/1[1]	0.33	0.07	0.18	0.18	0.16	0.24	0.16	0.26	0.12	0.15	0.14	0.30	0.25
Total phosphate, mg/1	-	-	0.40	0.30	0.22	6.24	0.26	0.57	0.16	-	-	0.34	-
Ammonia N, mg/1[2]	-	0.00	0.03	0.06	0.00	0.04	0.07	0.15	0.07	-	0.00	0.04	-
Organic N, mg/1	-	0.20	0.13	0.00	0.16	0.15	0.07	0.23	0.20	0.17	0.00	0.04	-
Nitrate N, mg/1	0.18	0.12	0.04	0.19	0.24	0.08	0.34	0.48	0.70	0.88	0.65	0.32	1.78
Nitrite N, mg/1	-	-	-	-	-	-	-	-	-	-	0.01	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$

[2] Nitrogens are reported as N.

WATER QUALITY DATA

Station 3--Crab Creek Just North of Lake

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	2,900	150	1,500	29	75	4,600	230	430	72	430	-	230	36
Chloride, mg/l	14	-	-	-	13	-	-	-	-	10	-	14	-
Carbonate alk., mg/l[1]	0	0	8	-	0	12	0	0	20	0	10	0	-
Total alk., mg/l[1]	180	224	183	-	216	203	193	208	200	230	228	242	235
Calcium, mg/l	31	37	38	-	42	43	42	-	48	47	49	52	-
Magnesium, mg/l	24	37	18	-	18	18	19	-	20	21	21	23	-
Sodium, mg/l[2]	42	65	-	-	57	-	-	-	-	-	-	-	-
Potassium, mg/l[2]	14	14	-	-	14	-	-	-	-	-	-	-	-
Sulfate, mg/l[3]	-	-	-	-	34	-	-	-	-	36	-	-	-
Total hardness, mg/l[1]	173	244	169	175	179	182	186	-	202	206	210	224	-
Total algae/ml.	364	738	1,154	1,310	846	260	-	544	380	292	190	-	-
Iron, mg/l	-	-	-	-	0.28	-	-	-	-	0.25	-	-	-

[1] Reported as equivalent calcium carbonate.

[2] Values believed to be high.

[3] Values believed to be low.

WATER QUALITY DATA

Station 4--Seepage on Karl Goodrich's Farm

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	13.0	14.2	14.2	14.3	15.2	14.5	14.8	14.4	14.4	-	13.8	14.0
pH	8.2	7.3	7.4	7.7	7.7	7.8	-	7.7	7.6	-	7.7	8.0
Diss. Oxy., mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Diss. Oxy., % satur.	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity units*	-	-	-	-	-	-	-	-	-	-	-	-
Cond., µmhos/cm, 25°C	505	-	364	439	500	604	726	675	624	-	372	-
Orthophosphate, mg/l[1]	0.03	-	0.13	0.15	0.14	0.13	0.12	0.10	0.10	-	0.13	0.08
Total phosphate, mg/l	0.40	0.12	0.14	0.11	0.14	0.21	0.37	0.12	-	-	0.16	-
Ammonia N, mg/l[2]	-	0.00	0.01	0.05	0.02	0.04	0.03	0.04	0.16	-	0.00	-
Organic N, mg/l	-	0.02	0.00	0.09	0.08	0.03	0.23	0.13	0.09	-	0.15	-
Nitrate N, mg/l	0.02	0.26	0.70	0.78	0.09	0.00	≈7.60	4.34	4.90	-	0.27	4.52
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	-	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$

[2] Nitrogens are reported as N

* These values are essentially zero.

WATER QUALITY DATA

Station 4--Seepage on Karl Goodrich's Farm

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml*	-	-	-	-	-	-	-	-	-	-	-	-
Chloride, mg/1	-	-	-	22	-	-	-	-	20	-	22	-
Carbonate alk., mg/1[1]	0	0	-	0	0	0	0	0	0	-	0	0
Total alk., mg/1[1]	204	208	-	234	219	200	231	224	262	-	302	221
Calcium, mg/1	32	46	-	52	-	54	-	60	62	-	67	-
Magnesium, mg/1	34	25	-	24	-	26	-	24	13	-	32	-
Sodium, mg/1[2]	48	-	-	65	-	-	-	-	-	-	-	-
Potassium, mg/1[2]	10	-	-	11	-	-	-	-	-	-	-	-
Sulfate, mg/1[3]	-	-	-	45	-	-	-	-	52	-	-	-
Total hardness, mg/1[1]	217	217	214	232	238	244	-	251	210	-	300	-
Total algae/ml*	-	-	-	-	-	-	-	-	-	-	-	-
Iron, mg/1	-	-	-	0.01	-	-	-	-	0.12	-	-	-

[1] Reported as equivalent calcium carbonate.

[2] Values believed to be high.

[3] Values believed to be low.

* These values are essentially zero.

WATER QUALITY DATA

Station 5--Moses Lake, Pelican Horn Below Causeway

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	11.0	19.9	20.5	23.2	25.0	24.0	23.0	21.8	19.7	15.8	-	3.9
pH	8.6	8.5	8.4	8.6	9.4	9.2	-	9.1	9.0	9.0	8.4	9.2
Diss. Oxy., mg/l	-	8.7	-	8.1	12.2	13.1	9.3	9.7	8.6	10.8	10.2	19.8
Diss. Oxy., % satur.	-	94	-	93	145	154	107	110	94	108	70	150
Turbidity units	36	14	31	22	22	17	22	23	12	6	10	10
Cond., µmhos/cm, 25° C	380	-	410	336	342	421	440	479	396	293	376	-
Orthophosphate, mg/l[1]	0.22	0.06	0.20	0.38	0.15	0.13	0.10	0.04	0.07	0.06	0.85	0.06
Total phosphate, mg/l	0.30	0.19	0.37	0.35	0.21	0.36	0.57	0.22	-	-	1.80	-
Ammonia N, mg/l[2]	0.70	0.07	0.07	0.47	0.01	0.10	0.36	0.11	0.06	0.00	0.27	-
Organic N, mg/l	0.30	0.13	0.00	0.07	0.17	0.26	0.40	0.27	0.29	0.20	0.16	-
Nitrate N, mg/l	0.20	0.00	0.01	0.00	0.08	0.00	0.00	0.02	0.02	0.02	0.46	0.05
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	0.00	-	-

1 Phosphate is reported as $PO_4^{\equiv}$

2 Nitrogens are reported as N

WATER Q' LITY DATA

Station 5--Moses Lake, Pelican Horn Below Causeway

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	43	9	0	2,900	0	3.6	23	3.6	9.1	-	0	3.6
Chloride, mg/l	-	-	-	19	-	-	-	-	16	-	26	-
Carbonate alk., mg/l[1]	-	36	-	18	42	88	-	80	24	20	0	22
Total alk., mg/l[1]	174	144	-	174	165	170	168	164	184	184	240	208
Calcium, mg/l	19	19	-	22	22	24	-	22	23	27	32	-
Magnesium, mg/l	25	17	-	17	18	18	-	18	18	16	22	-
Sodium, mg/l[2]	63	-	-	80	-	-	-	-	-	-	-	-
Potassium, mg/l[2]	13	-	-	15	-	-	-	-	-	-	-	-
Sulfate, mg/l[3]	-	-	-	31	-	-	-	-	31.4	-	-	-
Total hardness, mg/l[1]	152	117	127	126	127	134	-	134	133	133	170	-
Total algae/ml	124	336	6,500	2,590	10,600	12,700	3,000	2,240	1,640	1,560	42	3,500
Iron, mg/l	-	-	-	1.1	-	-	-	-	0.35	-	-	-

1 Reported as equivalent calcium carbonate.

2 Values believed to be high.

3 Values believed to be low.

WATER QUALITY DATA

Station 6--Moses Lake, Off State Park-Surface

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	8.4	11.0	19.9	19.5	24.6	24.6	23.5	22.5	21.6	21.5	16.3	0.0	3.8
pH	8.1	8.0	8.5	8.2	8.6	8.7	8.7	-	8.7	8.8	8.6	7.9	8.9
Diss. Oxy., mg/l	-	-	8.2	7.0	9.7	11.1	9.7	6.7	8.2	6.7	6.1	12.4	15.5
Diss. Oxy., % satur.	-	-	89	75	115	131	101	77	108	75	62	85	119
Turbidity Units	88	110	14	23	32	22	19	19	22	14	22	8	21
Cond., µmhos/cm, 25°C	202	352	-	576	302	304	368	430	468	356	288	273	-
Orthophosphate, mg/l[1]	0.41	0.15	1.64	0.14	0.12	0.07	0.15	0.08	0.15	0.28	0.28	0.31	0.04
Total phosphate, mg/l	-	0.22	1.52	0.24	0.28	0.13	0.30	0.49	0.30	-	-	0.34	-
Ammonia N, mg/l[2]	-	-	0.04	0.11	0.03	0.00	0.13	0.04	-	0.08	0.24	0.27	-
Organic N, mg/l	-	-	0.16	0.00	0.05	0.15	0.15	0.38	0.12	0.15	0.18	0.11	-
Nitrate N, mg/l	0.09	0.30	0	0.04	0.04	0.16	0.00	0.02	0.02	0.02	0.11	0.46	0.31
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	-	0.02	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$.

[2] Nitrogens are reported as N.

WATER QUALITY DATA

Station 6--Moses Lake, Off State Park - Surface

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	150	23	15	3.6	75	0	21	23	0	9.1	-	7.3	0
Chloride, mg/l	12	-	-	-	14	-	-	-	-	12	-	14	-
Carbonate alk., mg/l[1]	0	0	10	-	30	20	32	-	40	20	7	0	-
Total alk., mg/l[1]	155	164	142	-	166	160	158	164	140	180	184	196	196
Calcium, mg/l	31	20	23	-	25	24	26	-	25	25	32	33	-
Magnesium, mg/l	13	24	15	-	16	15	16	-	17	17	16	17	-
Sodium, mg/l[2]	39	52	-	-	63	-	-	-	-	-	-	-	-
Potassium, mg/l[2]	14	14	-	-	14	-	-	-	-	-	-	-	-
Sulfate, mg/l[3]	-	-	-	-	24	-	-	-	-	26	-	-	-
Total hardness, mg/l[1]	128	150	120	138	127	120	131	-	134	133	146	152	-
Total algae/ml.	34	22	38	625	17,600	12,400	4,650	1,640	1,520	340	1,150	190	4,344
Iron, mg/l	-	-	-	-	1.22	-	-	-	-	0.5	-	-	-

[1] Reported as equivalent calcium carbonate.

[2] Values believed to be high.

[3] Values believed to be low.

WATER QUALITY DATA

Station 7--Moses Lake Off State Park - Bottom

Determination	1963											1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-14	12-12
Temp., °C	8.2	10.9	17.6	19.0	18.0	21.4	20.0	19.7	20.3	17.7	15.1	0.5
pH	8.1	8.2	8.6	8.1	8.4	8.4	8.1	-	8.4	8.8	8.4	7.6
Diss. Oxy., mg/l	-	-	6.4	6.3	7.3	7.3	4.4	4.0	2.7	6.2	6.0	12.4
Diss. Oxy., % satur.	-	-	67	67	77	82	48	43	30	64	59	86
Turbidity Units	91	95	23	35	57	21	18	15	36	3	21	13
Cond., µmhos/cm, 25°C	206	354	-	283	310-	315	400	396	492	371	284	266-
Orthophosphate, mg/l[1]	0.39	0.15	0.13	0.14	0.21	0.13	0.31	0.44	0.23	0.15	0.25	0.31
Total phosphate, mg/l	-	0.22	0.34	0.27	0.20	0.22	0.49	0.85	0.41	-	-	0.34
Ammonia N, mg/l[2]	-	-	0.32	0.28	0.00	0.69	0.15	0.16	0.24	0.11	0.09	0.18
Organic N, mg/l	-	-	0.02	0.00	0.06	0.27	0.12	0.20	0.19	-	0.05	0.22
Nitrate N, mg/l	0.24	0.12	0.00	0.06	0.06	0.08	0.00	0.02	0.07	0.03	0.11	0.43
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	-	0.02	-

[1] Phosphate is reported as $PO_4^{\equiv}$.

[2] Nitrogens are reported as N.

Station 7--Moses Lake Off State Park-Bottom

Determination	1963											1964	
	4-6	5-4	6-11	6-26	7-2	7-14	7-24	8-16	8-28	9-18	10-14	12-12	2-20
MPN Coliform/100ml	750	-	3.6	3	15	7.3	3	9.1	9.1	14	-	-	
Chloride, mg/l	10	-	-	-	16	-	-	-	-	12	-	14	
Carbonate alk., mg/l[1]	0	0	4	-	0	4	0	-	12	16	3	0	
Total alk, mg/l[1]	157	164	151	-	178	158	166	177	168	184	183	194	
Calcium, mg/l	32	20	22	-	24	18	28	-	28	27	30	33	
Magnesium, mg/l	16	24	16	-	16	21	16	-	18	16	17	18	
Sodium, mg/l[2]	39	45	-	-	68	-	-	-	-	-	-	-	
Potassium, mg/l[2]	13	14	-	-	14	-	-	-	-	-	-	-	
Sulfate, mg/l[3]	-	-	-	-	24	-	-	-	-	45	-	-	
Total hardness, mg/l[1]	147	150	124	127	129	131	134	-	146	133	146	157	
Total algae/ml	54	36	216	840	590	5,450	580	840	222	220	170	-	
Iron, mg/l	-	-	-	-	1.74	-	-	-	-	0.73	-	-	

[1] Reported as equivalent calcium carbonate.

[2] Values believed to be high.

[3] Values believed to be low.

Station 8--Moses Lake, Larson A.F.B. - Midlake ($\approx$ 1 ft.)

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	9.05	12.0	20.5	21.0	24.7	21.3	24.0	23.5	21.8	20.1	16.5	0.0	0.0
pH	8.1	8.0	8.1	8.5	8.6	8.6	8.8	-	9.05	7.6	8.6	8.4	8.7
Diss. Oxy., mg/l	-	-	7.2	-	8.4	5.7	9.4	6.8	9.5	7.4	6.8	-	23
Diss. Oxy., % satur.	-	-	79	-	100	64	111	79	108	80	69	-	169
Turbidity Units	73	36	17	27	125	-	16	18	17	7	16	9	16
Cond., µmhos/cm, 25°C	198	352	-	364	309	331	384	414	420	345	249	256	
Orthophosphate, mg/l[1]	0.40	0.10	1.00	0.06	0.13	0.13	0.12	0.16	0.12	0.14	0.22	0.17	0.04
Total phosphate, mg/l	-	0.11	0.34	0.24	0.11	0.31	0.29	0.51	0.30	-	-	0.25	-
Ammonia N, mg/l[2]	-	-	0.00	0.09	0.00	0.21	0.25	0.05	0.34	0.53	0.16	19.5	-
Organic N, mg/l	-	-	0.09	0.00	0.06	0.11	0.29	0.21	0.16	0.26	-	0.51	0.15
Nitrate N, mg/l	0.07	0.12	0.00	0.00	0.06	0.08	0.00	0.00	0.01	0.02	0.06	0.32	-
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	-	0.01	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$.

[2] Nitrogens are reported as N.

WATER QUALITY DATA

Station 8--Moses Lake, Larson A.F.B. - Midlake ($\approx$1 ft.)

Determination	1963												1964
	4-6	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	0	-	9	0	75	3.6	0	3.6	0	7.2	-	6	0
Chloride, mg/1	10	-	-	-	14	-	-	-	-	12	-	12	-
Carbonate alk., mg/1[1]	0	0	4	-	20	-	40	-	48	0	11	0	-
Total alk., mg/1[1]	154	164	151	-	166	160	152	158	152	262	176	190	192
Calcium, mg/1	31	20	22	-	24	24	24	-	25	23	27	32	-
Magnesium, mg/1	15	24	16	-	16	16	20	-	16	15	16	18	-
Sodium, mg/1[2]	39	45	-	-	63	-	-	-	-	-	-	-	-
Potassium, mg/1[2]	14	13	-	-	14	-	-	-	-	-	-	-	-
Sulfate, mg/1[3]	-	-	-	-	23	-	-	-	-	25	-	-	-
Total hardness, mg/1[1]	136	150	120	122	126	127	141	-	129	121	133	154	-
Total algae/ml	14	20	158	25,150	1,700	150	11,900	800	1,800	250	1,100	-	-
Iron, mg/1	-	-	-	-	0.47	-	-	-	-	0.48	-	-	-

[1] Reported as equivalent calcium carbonate

[2] Values believed to be high.

[3] Values believed to be low.

WATER QUALITY DATA

Station 9--Sewage Treatment Plant Effluent

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
Temp., °C	15.5	21.7	22.0	-	-	22.0	-	-	20.4	-	-	-
pH	7.2	7.4	7.5	8.0	7.6	7.7	-	7.6	9.3	7.5	7.6	7.9
Diss. Oxy., mg/l	-	-	-	-	-	-	-	-	-	-	-	-
Diss. Oxy., % satur.	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity units	33	-	20	21	-	13	15	21	4	22	-	26
Cond., µmhos/cm, 25° C	923	-	800	611	806	1,200	-	1,012	1,116	586	512	-
Orthophosphate, mg/l[1]	-	-	19.8	20.4	-	19.0	17.4	22.1	19.2	20.8	18.0	19.0
Total phosphate, mg/l	-	18.8	23.4	22.6	15.6	18.0	20.2	17.8	-	-	23.2	-
Ammonia N, mg/l[2]	-	-	1.30	-	-	4.49	12.8	12.4	-	17.8	10.36	-
Organic N, mg/l	-	0.66	0.74	0.53	0.29	1.64	0.41	0.71	0.45	0.59	0.68	-
Nitrate N, mg/l	0.28	0.24	0.85	0.10	0.23	-	-	0.04	3.00	1.67	6.00	3.30
Nitrite N, mg/l	-	-	-	-	-	-	-	-	-	0.50	-	-

[1] Phosphate is reported as $PO_4^{\equiv}$

[2] Nitrogens are reported as N

WATER QUALITY DATA

Station 9--Sewage Treatment Plant Effluent

Determination	1963											1964
	5-4	6-11	6-26	7-2	7-14	7-29	8-16	8-28	9-18	10-19	12-12	2-20
MPN Coliform/100ml	460	4,600 2,100	460	150	230 750	11,000 11,000	4,600 2,400	2,400 1,500	2,400 930	-	11,000 4,600	930 930
Chloride, mg/1	-	-	-	64	-	-	-	-	79	-	78	-
Carbonate alk., mg/1[1]	0	0	-	0	0	0	0	0	18	0	0	0
Total alk., mg/1[1]	236	216	-	224	176	204	224	232	168	264	248	230
Calcium, mg/1	15	20	-	18	20	22	-	22	26	28	24	-
Magnesium, mg/1	23	14	-	16	17	18	-	18	18	15	18	-
Sodium, mg/1[2]	130	-	-	60	-	-	-	-	-	-	-	-
Potassium, mg/1[2]	19	-	-	19	-	-	-	-	-	-	-	-
Sulfate, mg/1[3]	-	-	-	48	-	-	-	-	59	-	-	-
Total hardness, mg/1[1]	141	110	127	110	120	131	-	134	138	133	134	-
Total algae/ml	-	-	-	-	-	-	-	-	-	-	-	-
Iron, mg/1	-	-	-	0.32	-	-	-	-	0.32	-	-	-

1 Reported as equivalent calcium carbonate.

2 Values believed to be high.

3 Values believed to be low.

APPENDIX B

PLANKTON DATA

Moses Lake and Tributaries

MOSER LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms			Other	Total All Forms
				Filament	Other	Total	Pennate	Centric	Total		
4/6/62		1	54	-	-	-	328	-	328	-	382
		3	-	42	20	62	320	-	320	-	364
		6	8	-	18	18	8	-	8	-	34
		7	14	-	20	20	20	-	20	-	54
		8	4	-	6	6	4	-	4	-	14
5/4/63		1	20	-	-	-	494	-	494	-	514
		2	-	16	2	18	88	-	88	-	106
		3	8	30	-	30	700	-	700	-	738
		4	-	-	-	-	22	-	22	-	22
		5	-	6	12	18	96	10	106	-	124
		6	-	12	2	14	8	-	8	-	22
		7	2	6	-	6	26	2	28	-	36
		8	-	2	14	16	4	-	4	-	20

* See text for station locations.

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms			Other	Total All Forms
				Filament	Other	Total	Pennate	Centric	Total		
6/11/63		1	6	-	-	-	932	-	932	-	938
		2	788	16	2	18	40	12	52	-	858
		3	56	-	10	10	1,088	-	1,088	-	1,154
		4 No sample									
		5	2	-	40	40	82	212	294		336
		6	-	-	8	8	-	28	-	2	38
		7	-	8	12	20	104	92	196	-	216
		8	-	12	18	30	14	114	128	-	158
6/26/63		1	-	-	-	-	186	-	186	-	186
		2	10	12	16	28	588	4	592		630
		3	105	45	5	50	1,140	15	1,155		1,310
		4 Bad sample									
		5	3,800	-	200	200	2,300	200	2,500	-	6,500
		6	75	-	25	25	500	-	500	25	625
		7	10	4	-	4	1,288	30	1,318		1,332
		8	21,100	200	-	200	3,850	-	3,850		25,150

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms			Other	Total All Forms
				Filament	Other	Total	Pennate	Centric	Total		
7/2/63		1	-	-	-	-	488	-	488	-	488
		2	-	16	8	24	188	28	216	-	240
		3	-	6	24	30	816	-	816	-	846
		4	-	-	-	-	-	-	-	-	0
		5	60	40	40	80	2,440	10	2,450	-	2,590
		6	17,600	-	-	-	-	-	-	-	17,600
		7	90	10	10	20	470	10	480	-	590
		8	1,660	-	40	40	-	-	-	-	1,700
7/13/63	0100	6	80	20	20	40	20	20	40	-	160
		6a(15ft)	700	60	-	60	-	-	-	-	760
		7	6	30	-	30	66	106	172	-	208
7/13/63	0430	6	1,550	10	10	20	-	-	-	-	1,570
		6a	240	-	10	10	-	10	10	-	260
		7	-	10	-	10	32	34	66	-	76

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green Filament	Green Other	Green Total	Diatcms Pennate	Diatcms Centric	Diatcms Total	Other	Total All Forms
7/14/63		1	-	-	-	-	1,110	-	1,110	-	1,110
		2	-	-	10	10	70	170	240	10	260
		3	10	16	74	90	1,090	2	1,092	-	1,192
		4	-	-	-	-	-	-	-	-	0
		5	10,250	50	50	100	-	250	250	-	10,600
		6	12,200	50	50	100	50	50	100	-	12,400
		7	5,400	50	-	50	-	-	-	-	5,450
		8	-	50	-	50	100	-	100	-	150
7/29/63		5	10,000	2,500	200	2,700	-	-	-	-	12,700
		6	4,300	200	-	200	-	-	-	150	4,650
		7	10	430	-	430	140	-	140	-	580
		8	11,700	100	-	100	-	-	-	100	11,900

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green: Filament	Green: Other	Green: Total	Diatoms: Pennate	Diatoms: Centric	Diatoms: Total	Other	Total All Forms
8/16/63		1	10	-	-	-	940	10	950	-	960
		2	-	-	-	-	10	2	12	-	12
		3	-	4	4	8	510	26	536	-	544
		4 No sample									
		5	150	2,750	100	2,850	-	-	-	-	3,000
		6	920	600	100	700	-	-	-	20	1,640
		7	220	460	-	460	120	40	160	-	840
		8	500	240	20	260	-	-	-	40	800
8/27/63	0635	8	950	200	-	200	-	-	-	-	1,150
	0700	6	90	130	-	130	-	-	-	-	220
8/27/63	1030	8	1,700	100	-	100	-	-	-	100	1,900
	1055	6	680	240	40	280	-	-	-	-	960
	1110	5	720	3,000	40	3,040	-	-	-	200	3,960
8/27/63	1715	8	4,200	100	-	100	-	-	-	-	4,300
	1740	6	280	40	20	60	-	-	-	-	340
	1820	5	900	2,520	60	2,580	-	-	-	60	3,540
8/27/63	2145	8	4,500	-	100	100	-	-	-	-	4,600
	2205	6	360	60	-	60	-	-	-	-	420
	[illegible]	5	[illegible]	[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	[illegible]

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms				
				Filament	Other	Total	Pennate	Centric	Total	Other	Total All Forms
8/28/63	0930	1	-	-	10	10	480	-	480	-	490
	1000	2	-	26	12	38	120	-	120	-	158
	1030	3	-	20	-	20	330	30	360	-	380
		4 No sample									
	1055	5	540	1,640	40	1,680	-	-	-	20	2,240
	1115	6	1,180	240	-	240	-	100	100		1,520
	1130	7	24	122	8	130	34	34	68	-	222
	1215	8	1,700	-	-	-	-	-	-	100	1,800
9/17/63	1440	6 (5fc)	-	30	-	30	10	-	10	-	40
		(2 ft)	-	100	-	100	-	-	-	-	100
		(10 ft)	100	120	-	120	-	-	-	-	220
		(20 ft)	140	60	-	60	-	-	-	-	200
	2040	6 (5 fc)	27,500	-	-	-	-	-	-	-	27,500
		(2 ft)	200	70	-	70	-	-	-	-	270
		(15 ft)	30	50	-	50	-	-	-	10	90
		(20 ft)	260	80	-	80	-	-	-	-	340

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms			Other	Total All Forms
				Filament	Other	Total	Pennate	Centric	Total		
9/18/63	0850	1	-	-	-	-	126	-	126	-	126
		2 No sample									
		3	2	2	2	4	286	-	-	-	292
		4 No sample									
		5	640	1,000	-	1,000	-	-	-	-	1,640
		6	300	40	-	40	-	-	-	-	340
		7	50	170	-	170	-	-	-	-	220
	1300	8	250	-	-	-	-	-	-	-	250
10/19/63		1	-	10	-	10	330	-	330	-	340
		2	-	22	-	22	340	4	344	-	366
		3	-	-	-	-	190	-	190	-	190
		4 No sample									
		5	-	1,540	20	1,560	-	-	-	-	1,560
		6	900	250	-	250	-	-	-	-	1,150
		7	10	120	-	120	40	-	40	-	170
		8	1,050	50	-	50	-	-	-	-	1,100

MOSES LAKE AND TRIBUTARIES

Phytoplankton (No./ml.)

Sample Date	Time	Sample Station No.*	Blue-green	Green			Diatoms			Other	Total All Forms
				Filament	Other	Total	Pennate	Centric	Total		
12/12/63		5	-	-	-	-	28	10	38	-	38
		6	-	-	-	-	12	178	190	-	190
		8									
2/20/64		5	-	-	-	-	50	3,500	3,500	-	3,500
		6	40	80	-	120	-	4,224	4,224	-	4,344