Brine Contamination in the Muskingum River

Revealed from data assembled by . . . .

OHIO STATE DEPARTMENT OF HEALTH
OHIO DEPARTMENT OF NATURAL RESOURCES
U. S. CORPS OF ENGINEERS
U. S. GEOLOGICAL SURVEY
COLUMBIA CHEMICALS DIVISION
Pittsburgh Plate Glass Company
MORTON SALT COMPANY

. . . and interpreted by the

OHIO RIVER VALLEY
WATER SANITATION COMMISSION

OHIO RIVER VALLEY WATER SANITATION COMMISSION

An interstate agency representing Illinois, Indiana, Kentucky, New York, Ohio, Pennsylvania, Virginia and West Virginia

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OHIO RIVER VALLEY
WATER SANITATION COMMISSION

414 WALNUT STREET CINCINNATI 2, OHIO

To the Chairman and
Members of the Commission:

Water-quality contamination from brine wastes commands special attention in the Ohio River valley. These wastes originate from the processing of salt. And salt deposits represent one of the major natural resources of the valley on which is founded a vast chemical industry that promises to become even greater. However, if this economic destiny is to be achieved some method for brine-waste disposal other than indiscriminate discharge into streams must be developed.

Some of the harsh realities of water-quality degradation from brine contamination are revealed in this report. These include the loss of potability in local sources of supply; increase in hardness, the effects of which impinge on consumers far beyond the origin of waste discharge; and certain physiological implications, the significance of which is now under scrutiny by medical authorities. This investigation of conditions in the Muskingum River should be considered, therefore, as a case history of what can happen in other parts of the Ohio Basin.

Findings from this report, coupled with other studies, are providing the basis on which future policy decisions regarding chloride limits may be evaluated by the Commission. The report also addresses itself to questions regarding disposal methods that may prove helpful to the chemical industries that face this problem.

As indicated elsewhere, data for this report were compiled with the aid of five public agencies and two industries. But your staff assumes complete responsibility for the interpretation on which the findings and recommendations are based. These reflect in large part the earnest endeavors of William R. Taylor, chemical engineer, and Harold W. Streeter, consultant. Important initial planning of the survey was done by Robert K. Horton, sanitary engineer.

Edward J. Cleary

Edward J. Cleary

Executive Director
and Chief Engineer

August 15, 1951

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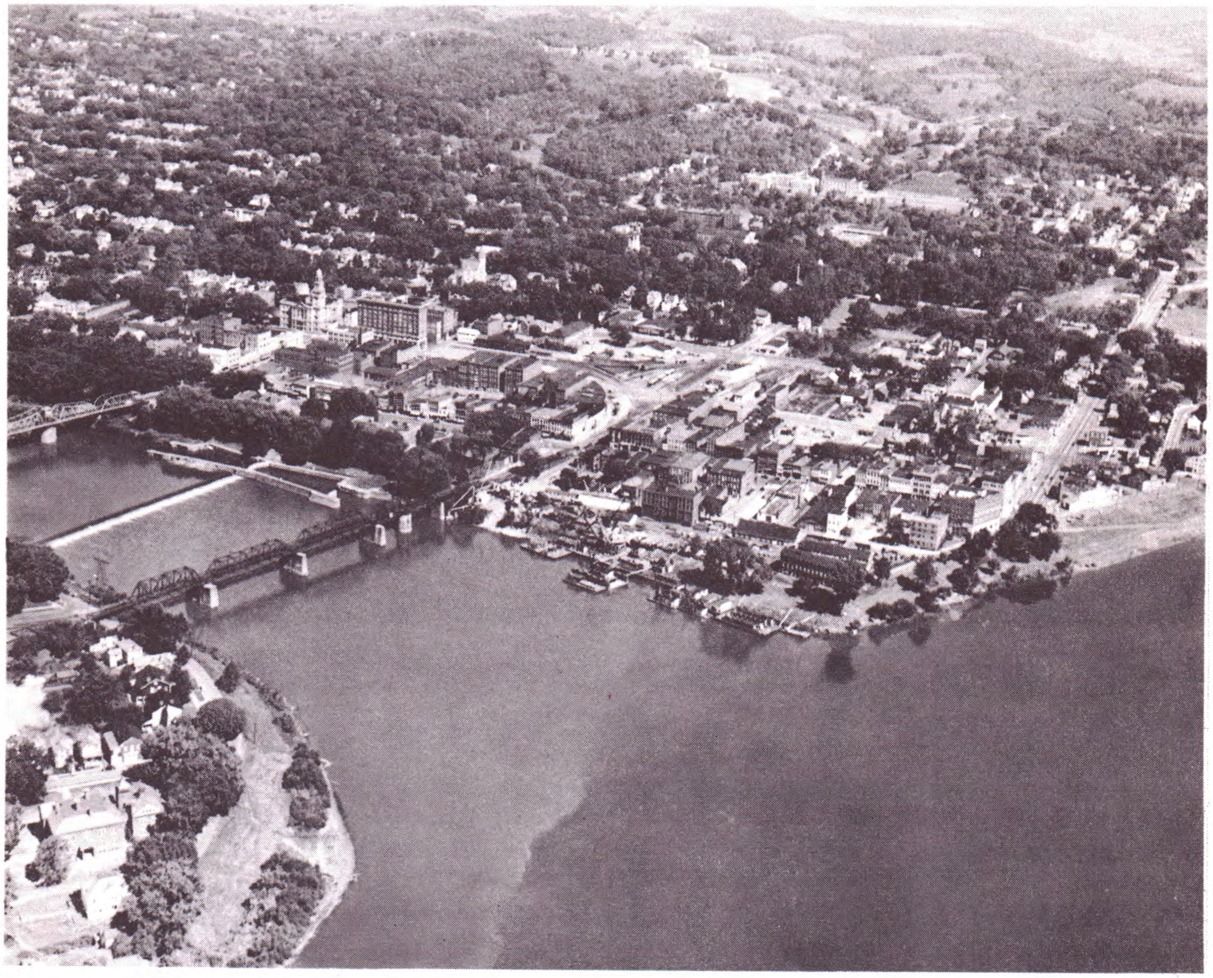


Photo by S. Durward Hoag

The Muskingum River -- that drains the eastern part of Ohio -- empties into the Ohio River (right) at Marietta.

FINDINGS AND RECOMMENDATIONS

The Muskingum River chloride investigation was pointed toward an appraisal of pollution from brine-processing wastes. It was intended to:

> Determine the nature and magnitude of brine-waste discharges and their effect on water quality,
>
> Determine the effects of resulting salinity on the Ohio River and,
>
> Provide an economic evaluation of brine pollution in degradation of water supplies and damage to river structures.

Data presented in this report should aid in eventual formulation of policy with regard to control of brine pollution in the Ohio River valley.

Summary of findings -- Brine pollution of the Muskingum River arises from wastes discharged into the headwaters by two industries processing salt brine. Effects of chloride contamination extend throughout the entire length of the river. High concentrations of inorganic ions (notably chloride, calcium and sodium) were found at all sampling stations on the main stem (Fig 1). Tributaries other than the Tuscarawas River and Chippewa Creek, the streams initially receiving the brine wastes, had relatively low chloride concentrations.

Chloride concentration of the Ohio River was increased 21 ppm -- from 26 to 47 -- by the Muskingum River (survey averages). The Muskingum contributed a daily average of about 1,000 tons of chloride ion to the Ohio River during the survey period. The chloride contribution from the Muskingum was of the same order of magnitude as the total chloride content of the Ohio River above the Muskingum mouth.

Total hardness concentrations (mostly noncarbonate) were high for the entire length of the Muskingum and decreased progressively downriver because of dilution. The Muskingum contribution, arising largely from industrial waste discharges, increased the total hardness of the Ohio River 32 ppm -- from 132 to 164 (survey averages).

Average total hardness of the Muskingum was well above that of the unaffected tributaries. If uncontaminated by brine wastes, the Muskingum could be used as a source of water supply by some 125,000 people residing along the river. The cost of removing the excess hardness from such a supply during the survey period was estimated at $14,600.

Chloride concentrations during the second and third weeks of the survey were in excess of 200 ppm at all sampling stations on the main stem. Maximum chloride concentration found was 15,200 ppm, a concentration near that of sea water.

For comparative purposes it should be recalled that the chloride limit established in the U. S. Public Health Service Drinking Water Standards is 250 ppm.

Measurements of specific conductance and chloride concentration of daily samples showed a close correlation between these two variables throughout a wide range of concentrations. Because of this relationship it should be possible to make rapid chloride-concentration determinations using specific conductance measurements; the convenience of this test commends it for surveys and other field work.

Waste-brine discharges were not constant, but fluctuated widely. Reported plant discharges were lower than net loads measured in the river. Seepage from waste lagoons is thought to be partly responsible for these differences, but it was not possible to measure the amount of seepage directly.

Chloride content of the river in tons of chloride ion per day was calculated for each sampling station. These daily loads varied because of irregularities in the brine-waste discharges. Waves of brine pollution were traceable from their sources to the mouth of the river and permitted rough estimates of their time of passage from point-to-point at the prevailing rates of stream flow. From these estimates, an approximate time-of-flow curve for the length of the river was developed.

Stream flows prevailing in the Muskingum during the survey were equivalent to those normally exceeded 80 to 85% of the time, based on flow records of the past twenty-six years. The inverse relationship between volume of flow and river chloride concentration would indicate that chloride concentrations measured during this survey will be exceeded 15 to 20% of the time, assuming no change in waste loads.

Recommendations -- Processing of brine from salt deposits, which represent one of Ohio's greatest natural resources, creates chloride wastes. In the Muskingum River the discharge of such wastes has an adverse effect on water quality.

Although companies processing brines report that much research has been undertaken to find a method of treatment of brine wastes, no practical and feasible method has yet been discovered. Further intensified research is necessary if salt deposits are to be developed without the discharge of highly concentrated chloride wastes detrimental to stream quality.

Research might be pointed to major process changes. Development of a modified Solvay process -- which would recover ammonia by a "springing" agent other than lime -- might make possible recovery of chlorides as chlorine or a saleable chlorinated by-product.

Removal of sulfates and other impurities from concentrated brines in salt manufacture would permit further evaporation of these brines with consequent reduction in waste volume and increase in product recovery. The possibility of manufacture of electrolytic caustic soda and chlorine from concentrated salt brines should not be overlooked. "Good housekeeping" within the processing plant and minor process changes might also reduce waste loads.

The possibility of underground disposal of chloride wastes should be investigated. Underground disposal of oil-field brines and certain chemical wastes has been practiced with success, particularly in Texas and Oklahoma. Local geological conditions are a primary factor in determining the feasibility of underground disposal. The stratum selected must be pervious, large enough to provide sufficient storage volume, located below the source of fresh water in the area and be free from fault zones that might permit flow of wastes to fresh-water sources. Furthermore, underground disposal is said to be successful only when the waste is chemically stable, clear and free from suspended solids. Obviously, the waste must be of a nature that will not cause an unfavorable reaction with the rock of the stratum selected. Legal questions of responsibility may arise if, after a period of years, the waste should reappear.

Future surveys of the Muskingum should include determination of hardness to provide information of special significance to waterworks operators. Hardness was not determined in daily samples from the present investigation.

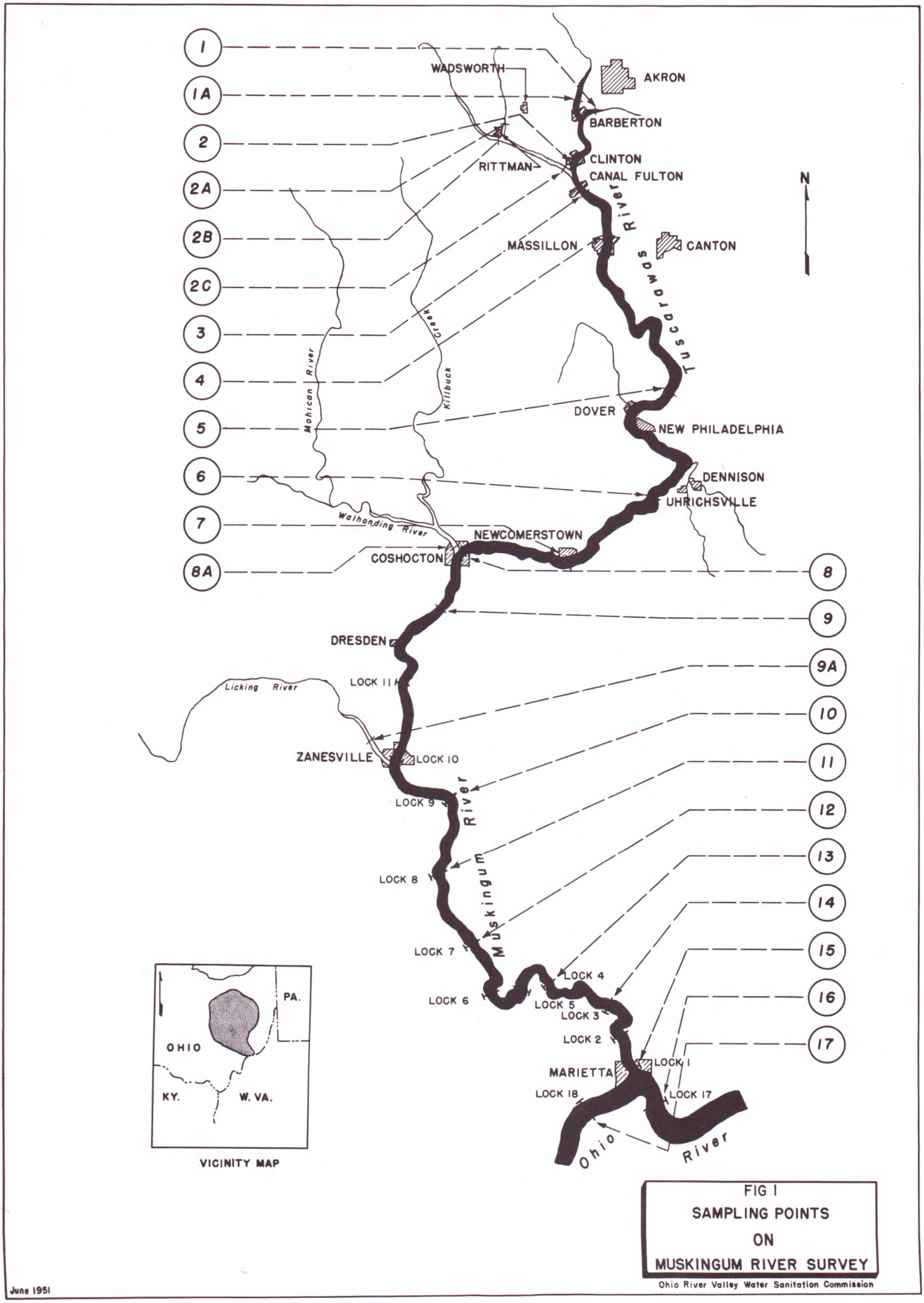


FIG I
SAMPLING POINTS
ON
MUSKINGUM RIVER SURVEY

Ohio River Valley Water Sanitation Commission

WHY THE SURVEY WAS UNDERTAKEN

Brine-waste discharges represent a major pollutant in the Muskingum River and its tributaries. Chlorides, once added to water, are not reduced by natural purification nor can they be economically removed by other means. Water heavily contaminated with chlorides is lost for many uses; its overall quality is degraded and its value as a basic resource for industrial processing is impaired.

The problem -- Waste produced in the manufacture of chemicals from salt brine in Summit and Wayne counties of Ohio is responsible for brine pollution of the Muskingum River. The raw brine is obtained by introducing water into underground deposits of rock salt and pumping out saturated artificial brine for processing.

Summit and Wayne counties have rock salt deposits estimated at 81.5 billion tons compared to a total for the state of Ohio of 1,957 billion tons. Salt deposits at Barberton, Summit County, are about 2,800 feet below ground level and at Rittman, Wayne County, about 2,600 feet underground. Salt from these deposits is well adapted to chemical manufacture, due to its high concentration of sodium chloride and low concentrations of undesirable impurities (Ohio State University Engineering Experiment Station Circular 49, Sept 1946).

Two industries are concerned in the Muskingum problem: The Columbia Chemical Division of the Pittsburgh Plate Glass Company manufactures soda ash (Solvay process), caustic soda, chlorine and allied chemicals. This plant started production at Barberton, Ohio, in 1899 and is one of the state's largest salt consumers. The plant discharges a waste that contains a mixture of calcium and sodium chlorides. About one and a half tons of calcium chloride are discharged as waste for every ton of soda ash produced. A small part of the waste calcium chloride is recovered and sold; it is reported that there is no market for all the calcium chloride that could be recovered.

About the turn of the century the Ohio Salt Company was organized and started production at Rittman, Wayne County. This plant is now operated by the Morton Salt Company. It produces various grades of sodium chloride by evaporation of artificial salt brine. As evaporation of the brine and removal of crystallized sodium chloride progresses, impurities (principally sulfates) build up in the solution. Eventually this impurity build-up lowers the sodium chloride quality below that acceptable in the market. At that point, the concentrated impure brine solution is dumped and the process continued with fresh brine. Part of the raw brine is treated before evaporating; processing of the treated brine is responsible for most of the waste discharged.

Calcium and sodium chloride wastes from Columbia Chemical are discharged to the Tuscarawas River just above Clinton, Ohio (Fig 1). Sodium chloride wastes from Morton Salt are discharged to Chippewa Creek at Rittman, Ohio.

These waste discharges flow to the Ohio River by the following route: Chippewa Creek flows into the Tuscarawas River between Clinton and Canal Fulton, Ohio. At Coshocton, Ohio, the Muskingum River is formed by the confluence of the Tuscarawas and Walhonding Rivers. The Muskingum joins the Ohio River at Marietta, Ohio, some 220 river miles from the sources of waste discharge.

The survey -- To evaluate the present status of brine pollution in the Muskingum and its effect on the Ohio River, a three-week study was organized by the Commission at the request of the Ohio Department of Health.

The survey was carried out during October 2 to 27. Field work was suspended for one week (October 8 to 15) to provide an opportunity to appraise the first week's results.

The agencies and individuals actively participating in the survey are listed at the beginning of this report.

Average total hardness at Marietta was 425 ppm during the survey. This is an increase of 203 ppm over what might be expected if the Muskingum did not receive brine-waste discharges. About 56,000 people residing between Marietta and Coshocton could use the Muskingum as a source of supply. Softening this water during the three-week survey period would have cost $3,900 to remove the excess hardness of 203 ppm, based on an average cost of $21.00 per million gallons per 100 ppm of hardness removed and assuming a water consumption of 75 gallons per capita per day. L. R. Howson (Journal American Water Works Association, 43 253-259, 1951) quotes cost of softening that range from $31 to $20.50 per million gallons per 100 parts hardness removed, hence $21.00 is a conservative figure.

At Coshocton, the average hardness was 894 ppm, or 672 ppm above the average hardness of the tributaries. It would have cost the 68,000 people living along the Muskingum between Coshocton and Massillon about $10,700 to remove this additional hardness, using the same cost figures.

The total operating cost of removing the excess hardness from Marietta to Massillon during the survey would have been $14,600. This cost cannot be extrapolated to give an annual charge because the flows experienced during the survey are equaled or exceeded about 85% of the time. Lower hardness concentrations can be expected during higher flows. A sound estimate of an annual softening cost would necessitate a hardness survey lasting a year or more.

Corrosion effects -- Corrosion of industrial equipment and other installations is another type of damage that may be attributed to chloride wastes under certain conditions. But corrosivity of water cannot be calculated from chemical analyses alone. It must be determined directly.

In an attempt to estimate corrosion damage, ten industrial and municipal installations on the Muskingum River were visited to explore their individual experiences with Muskingum River water.

Only two companies were found that used the Muskingum water directly. Neither company reported any corrosion difficulties beyond that ordinarily experienced with more "normal" water. Therefore no specific examples of corrosion directly attributed to chlorides in the Muskingum can be reported in connection with this investigation.

Physiological effects on health -- Some years ago the U. S. Public Health Service conducted taste studies of chlorides in connection with the establishment of drinking water standards. These studies were never published, but persons in the Service familiar with the work recall that waters containing 250 ppm chloride could be tasted by most of the workers. Only a few could taste lower concentrations. On that basis, it is said, 250 ppm was recommended as the chloride limit in drinking waters. This recommended limit was exceeded at almost all sampling stations on the Muskingum during the survey.

The medical profession in recent years has compiled evidence to indicate that sodium intake is an important factor in the treatment of cardiac and hypertension patients. One authority recommends 200-400 milligrams of sodium per day as the permissible limit of intake in such cases (Principles of Internal Medicine, T. R. Harrison, editor, Blakiston Company, Philadelphia, 1950, page 1323).

As an example of the sodium contribution of the Muskingum, one might consider the case of a cardiac patient drinking the water at Sta 8, which is about halfway downriver. The survey-average sodium concentration at this point was 253 ppm. With a water intake of two quarts daily, that patient would ingest about 480 milligrams of sodium per day from water alone. This would be above the recommended upper limit.

It should be noted that sodium is not held responsible for a cardiac condition. Sodium is said to be of physiological significance only after serious cardiac difficulties have developed.

High-saline waters have other physiological effects. It has been recognized that men and animals can acquire a tolerance for water with excessive salinity, but in general such waters cause gastric disturbances and catharsis (E. W. Moore, Water Works Engineering, Feb 1951, p 135).

A great deal more information is necessary to permit a complete appraisal of the physiological effects of chlorides in drinking water. One important factor yet to be fully investigated -- is the effect of different types of chlorides on man. For example, potassium, sodium and calcium chloride -- or any mixture of these -- have widely varying physiological effects. The Commission is sponsoring research on these matters at the Kettering Laboratory of Applied Physiology in Cincinnati.

Raw materials are lost -- In the manufacture of soda ash from sodium chloride brine by the Solvay process, only the sodium is used. Little of the chloride ion available is recovered. Of each pound of sodium chloride introduced as raw material, 35.5/58.5 or 60% is wasted. This waste is a loss of natural resources and a loss in profit. When a method of manufacture is developed that will utilize raw brine fully, the loss of a natural resource from waste will be largely eliminated.

Waste in the manufacture of sodium chloride by evaporation of salt brine arises when sulfate impurities in the brine become sufficiently concentrated to lower the purity of salt produced. At that point, the brine solution is dumped. If sulfates (and other impurities) could be removed, the solution could be evaporated further. This would not only result in savings in raw material and operating costs but would also reduce stream pollution from brine wastes.

HOW THE DATA WERE GATHERED

The Muskingum River survey -- a cooperative fact-finding chloride investigation -- was undertaken at the request of the Ohio State Department of Health.

Prior records of chloride analyses on samples taken from various points on the river were studied in preparation for the survey. But these samples were taken under isolated conditions and at irregular intervals. Although these data were probably adequate for local studies and situations, they failed to provide sufficient information for a comprehensive understanding of the effects of chloride-waste discharges.

To secure the requisite information on the extent of chloride contamination in the Muskingum River, the Commission enlisted the aid of:

Ohio Department of Health engineers, who collected samples at seven stations and were responsible for the transportation of all samples to the laboratory.

U. S. Geological Survey Laboratory in Columbus, which analyzed all samples and furnished sampling equipment.

Ohio Department of Natural Resources and the U. S. Geological Survey, who together contributed flow data.

U. S. Corps of Engineer personnel, who collected water samples from 18 sampling stations on the Muskingum and Ohio Rivers.

Two industries -- Morton Salt Company and the Columbia Chemicals Division of the Pittsburgh Plate Glass Company -- who collected samples in their plants from which individual plant loads were determined.

Drainage areas -- Drainage areas above each sampling point were determined by planimeter from U. S. Geological Survey quadrangle maps (Table 1). Reference points for which drainage areas have been accurately determined were taken from "Ohio Stream Drainage Areas and Flow Duration Tables," C. H. Wall and C. V. Youngquist, Bull. 111, Ohio State University Engineering Experiment Station, May, 1942.

The drainage area between reference and sampling points was determined by planimeter. This area was added to or subtracted from the reference-point area to give the area above the sampling point. Error was minimized by this procedure.

River mileage -- River miles from the mouth for each sampling point were determined by a mileage measurer from U. S. Geological Survey quadrangles (Table 1).

Discharge -- Flow data are important in any stream survey, since total quantities of any stream constituent are computed from flow and concentration. Flow figures were taken from gaging stations which were in operation during the survey. In addition, a gage was installed at Canal Fulton, Ohio, especially for this survey.

Where sampling stations did not coincide with a gage, the flows at the nearest gage were proportioned on the basis of drainage area to give a calculated flow at the sampling station (Table 2).

The source of flow data for each sampling station is given below:

Sampling Station	Flow Data Source
15	Calculated from McConnelsville gage
14	Calculated from McConnelsville gage
13	Calculated from McConnelsville gage
12	McConnelsville gage
11	Calculated from McConnelsville gage
10	Calculated from McConnelsville gage
9	Calculated from gage south of Coshocton
9A	Dillon gage
8	Coshocton gage
8A	Coshocton gage
7	Newcomerstown gage
6	Calculated from Newcomerstown gage
5	Gage near Dover Dam
4	Calculated from Massillon gage
3	Canal Fulton gage
2	Clinton gage

Local geology near Barberton materially affects the discharge of the Tuscarawas River in that area. The headwaters run over buried glacial valleys containing large amounts of gravel. This gravel provides excellent storage for water and recharges the stream during periods of low flow.

Runoff for the Tuscarawas headwaters, therefore, was in excess of that expected from drainage area considerations. Little Chippewa Creek and River Styx runoffs were lower than drainage area indicated.

Apportionment of flow by drainage area ratios was not considered valid for sampling stations in the headwaters area. Spot measurements made during the survey were utilized to provide daily flow data for stations in these headwaters (Table 3).

The flow in Chippewa Creek and small tributaries was obtained by subtraction of Clinton flows from the flows at Canal Fulton. On the basis of spot measurements, the flow at Clinton plus 3 cfs was subtracted from the flow at Canal Fulton and the difference recorded as the flow at the mouth of the Chippewa, Sta 2C. Flows at Sta 2A and 2B were adjusted from flows at Sta 2C, utilizing drainage areas. Ratios of flows at Sta 1 and 1A based on spot measurements were used to determine flows at these two stations.

All flow data are subject to error because of inability to measure stream discharge with complete accuracy. This error, estimated at 10%, influences stream load measurement and should be kept in mind in evaluating stream loads.

Chemical analyses -- All daily water samples were analyzed for chlorides (Table 4) and specific conductance (Table 5). The daily samples from each sampling station were composited on a weekly basis and given a complete mineral analysis (Table 6). Where chloride concentration and specific conductance were high, a small number of daily samples was taken for the composite. In all, 973 daily and 150 composite samples were analyzed.

Sampling was suspended after one week to permit evaluation of preliminary results. This check on sampling point results indicated that all critical areas were being adequately sampled.

The complete mineral analysis included tests for calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, total hardness, non-carbonate hardness, specific conductance, pH, and alkalinity. Specific gravity was also determined for samples where chloride concentrations were unusually high.

Daily chloride analyses were reported in milligrams per liter; chlorides in composite samples were reported as ppm. In this report, milligrams per liter have been considered equal to ppm. The maximum error due to this assumption is about 1.5%, an insignificant item compared to sampling errors. For complete accuracy, milligrams per liter above 5,000 should be converted to ppm by means of specific gravity.

Industrial loads -- Industrial loads were determined by the Ohio Department of Health with the cooperation of the Morton Salt Co. at Rittman, Ohio, and the Columbia Chemical Division of the Pittsburgh Plate Glass Company at Barberton, Ohio.

The waste lagoons of Columbia Chemical are located just below the confluence of Wolf Creek and the Tuscarawas River. The Morton Salt plant is located at the confluence of Chippewa Creek and River Styx.

Sampling and flow measurement at the two plants were carried out by plant personnel. The sampling program was designed by G. A. Hall of the Ohio Department of Health to fit individual plant processing procedures.

The industrial survey covered one week of plant operation, Oct 16 to 22 inclusive. Total loads reported were:

Date Oct 1950	Morton Salt By Sampling	Morton Salt Company's estimate	Columbia Chemical By Sampling
	Tons chloride ion per day		Tons chloride ion per day
16	42.5	70.5	1,857
17	25.1	26.7	1,529
18	11.0	27.3	306
19	16.9	26.1	355
20	24.9	6.1	482
21	7.0	1.2	391
22	19.0	1.2	-
Avg	20.9	22.7	820

Because of the nature of Morton Salt Company process, waste discharges are irregular and highly concentrated. Accurate representative sampling is almost impossible. To aid in establishing industrial loads, the company cooperated by furnishing their estimate of the waste load. This estimate is based on production figures and a salt balance of the plant. A salt balance is the accounting of all salt entering and leaving the plant.

WHAT THE DATA MEAN

Interpretation of the data collected is presented in the following pages. Significant items discussed are: the effect of the Muskingum on the Ohio River; discharge data; chloride, sodium and calcium profiles of the river; and industrial loads. Chloride concentration as related to flow and specific conductance is also discussed.

Effect on the Ohio River -- A graphic analysis of daily chloride contributions of the Muskingum to the Ohio River is shown in Fig 2. The Muskingum chloride quantity input was approximately equal to the chloride load already carried by the Ohio above the Muskingum mouth. The sum of these loads very closely approximated the load found at Sta 17 below the Muskingum mouth, thus:

The Muskingum contributed a daily average of 954 tons of chloride ion to the Ohio River during the survey. The increase in chloride content of the Ohio following entrance of flow from the Muskingum was 1,030 tons of chloride ion per day (survey averages).

The chloride concentration of the Ohio River was increased 21 ppm -- from 26 to 47 -- by the Muskingum (survey averages). Maximum concentration in the Ohio below the Muskingum mouth was 58 ppm.

The average total hardness of the Ohio during the survey increased 32 ppm, from 132 to 164, and was primarily noncarbonate. Alkalinity increased 11 ppm, from 16 to 27.

Discharge -- Flow records of Ohio streams are available in Bulletin 10, Ohio Department of Natural Resources (Sept 1949). These records are summaries which show the percent of time various discharges have been equaled or exceeded (the basis of "duration" curves). They cover a period of about 30 years, although records at any one gaging station may not have been continuous. Comparison of survey-average flows with the longest recent period of these stream flow records showed:

Gage	Period of record	% of time survey-average flow is equalled or exceeded
Clinton, O.	1926-45	48
Dover Dam	1936-45	75
Newcomerstown	1938-45	83
Coshocton (South)	1936-45	84
McConnelsville	1938-45	85

From this comparison, it is evident that the survey was conducted during a period of reasonably low flow. With the exception of the headwaters, the survey deals with flows normally exceeded 80 to 85 percent of the time.

The relation between volume of flow and chloride concentration (survey averages) is shown in Fig 3. Theoretically, this relationship should be a perfect straight-line function if chloride loads were constant at the point of waste discharge and no addition to or reduction in chloride loads occurred down-river. That is, chloride concentration would be inversely proportional to flow and plotted points would fall on a straight line of a 45 degree slope.

The line of best fit in this plot does not have a 45 degree slope, and the points do not fall on a perfect straight line, due to variable chloride loads. This variation in chloride loads is caused by irregular waste discharge in the headwaters. The actual chloride concentration in the stream at any time cannot be obtained from a given flow measurement using this graph. The graph is intended to show that approximate average chloride concentrations can be predicted from flow data.

On this basis, the chemical concentrations found during the survey will be exceeded 15 to 20 percent of the time, assuming that waste loads do not change.

Conductance as a function of chloride concentration -- Electrical conductance of a solution depends on the amount and kind of mineral salts present. The number of ions available determines the electric current-carrying property of a solution. Conductance is measured as the reciprocal of resistance, in reciprocal ohms or "mhos."

Specific conductance is defined as the conductance of a specimen between opposite faces of a one centimeter cube. A one centimeter cube means a specimen one centimeter in length and one square centimeter in cross section.

Good correlation between chloride concentration and specific conductance was obtained (Fig 4). The curve was eye-fitted. Most chloride concentrations given by this curve for a particular conductance reading will be within 5% of the true value; a few values may vary by as much as 12.5%. This range is probably due to differences in chemical composition of the water and the effect of dissociation.

Application of this curve would permit a very rapid chloride survey of the river. One man with a portable conductivity meter could check sufficient points on the river to give a complete picture of chlorides in about two days. Little expense would be involved and a significant saving in time could be achieved. This curve could be used either for policing purposes or to determine the effect of any unusual occurrence in plant-waste discharge.

A similar curve has been published in "Salinity of the Lower Savannah River in Relation to Stream Flow and Tidal Action" by W. L. Lamar, U. S. Geological Survey. The values and general trend of his curve agree very closely with those found on the Muskingum, in spite of the differences in water composition.

Time-of-flow -- One of the methods of determining time-of-flow is the measurement of concentration peaks produced downstream when a large amount of salt is put into the river and its passage followed by analyses. As this was a chloride survey involving variable industrial loads, slugs of chloride were passing down the river.

By plotting tons of chloride load per day against date, similarities in chloride content at adjacent stations can be observed. The time in days between any two peaks or depressions in these curves is the time of passage between the two points. From knowledge of this time and the mileage points, a time-of-flow curve can be constructed (Fig 5).

Knowing the mile points of two locations, the accumulated time of flow can be read from the graph. The curve shows a relatively constant river velocity until about Mi 90, with an increase in velocity to Mi 70. At that point the velocity decreases and is again relatively constant to the mouth of the river.

It should be emphasized that this curve is approximate and is valid only for the range of flow encountered during this survey. This range of flow might best be defined as 1,000 to 1,500 cfs measured at McConnelsville, Ohio. Any other range of flow would probably not give the same time of passage.

Chloride profile of the river -- An overall picture of the Muskingum River -- as to chloride content (tons of chloride ion per day), flow (cfs), and chloride concentration (ppm) -- is shown in Fig 6. The chloride content curve is actually a salt balance for the entire river. If brine waste discharge had been constant, a plot of chloride content (tons per day) would have yielded a straight horizontal line. Daily values of chloride content for each sampling station are given in Table 7.

Chloride content in tons per day was computed thus:

$$\text{cfs} \times \text{ppm} \times 5.38/2{,}000.$$

The chloride-content curve for the week of October 2 to 7 shows values approximating 1,500 tons of chloride ion per day in the upper reaches, down to Mi 170. Further down the river the chloride content drops off and at Mi 50 decreases greatly.

A somewhat similar pattern for the week of October 16 to 22 was obtained for the upper reaches of the river. At about Mi 100 the similarity disappeared, however, and higher values of chloride content were noted at Mi 50.

An entirely different picture of chloride content was obtained for the week of October 23 to 27. The higher values occurred about Mi 140 and a relatively constant value for chloride content was found for the remainder of the river.

These curves indicate brine waste discharge is not constant, but intermittent. If it could be shown that the peaks encountered during the first two weeks of the survey were reflected downriver in the last two weeks of the survey, then the fluctuations of the chloride content curve could be explained.

Time-of-flow studies were made, therefore, in an attempt to explain the chloride load fluctuations (Fig 5). Information obtained from them substantiated the entire pattern of the survey. The high points on the upper reaches reappeared down river at approximately the time indicated by the time-of-flow studies. That is, the high point of 1,500 tons during the first week at Mi 190 was reflected during the second week, Oct 16 to 22, at Mi 60. If the two peaks were caused by the same chloride slug, then about fourteen days would have been required for the slug to travel from Mi 190 to Mi 60. Time-of-flow studies showed that thirteen days were required for the river to flow between these two points.

Likewise, the peak load which occurred during the second week at Mi 190 was the same peak which occurred during the third week at Mi 140. An average of time according to weeks showed that six days should have elapsed between these peak loads. From time-of-flow studies, five and one-half days was necessary for the river to travel between these two points.

The low chloride content of 600 tons at Mi 30 during the first week of the survey was discharged about twenty-two days before the survey, or about Sept 10. This low value could have been caused by a change of waste lakes at Barberton. The amount of waste discharged is decidedly decreased by changing waste lakes. No waste is discharged until the new lake is filled, which may take two or three days.

Somewhat lower chloride content downstream may be due to two factors:

1. Lower plant loads preceding the survey.
2. Loss of high-chloride water by seepage, with some recharge of the stream from low-chloride aquafers during periods of low flow.

Of these factors, the first is probably more significant. But no records of plant discharge are available that show load variations before the survey.

The flow and concentration variations on these three curves were very normal and showed no discrepancies. At Mi 110 the Walhonding River joins the Muskingum; flow and concentrations varied accordingly. The chloride-content curve was unaffected.

Calcium profile of the river -- Weekly averages of calcium loads in tons per day (Fig 7) showed a pattern very similar to that of chlorides. Maximum and minimum loads occurred at about the same river points as did those for chlorides. Calcium concentrations were determined by composite sample analyses and are presented in Table 6. Concentrations on the main stem of the river were much higher than "normal" stream water.

Sodium profile of the river -- Stream loads and concentrations of sodium ion are shown in Fig 8. Values were plotted from analyses of composite samples taken from sampling stations on the main stem. A pattern very similar to that of the calcium profile was found. Sodium is important because of physiological effects on cardiac and hypertension patients.

Hardness -- Future surveys of the Muskingum -- either chemical or sanitary -- should include daily determination of hardness to provide information of special significance to waterworks operators. Hardness was not determined on daily samples from the present investigation.

Hardness from composite sample analyses was high and primarily noncarbonate (Table 6). Calcium contributed most of the noncarbonate hardness. The economic effect of high hardness has been discussed in the section on economic losses. Obviously, the high hardness values will increase the costs of any water-softening plant installed.

pH -- No significant variations in pH were noted. The samples were all slightly alkaline. Minimum pH was 7.3, maximum was 8.4.

Sulfates -- The Chippewa Creek area was high in sulfate with a maximum concentration of 545 ppm. The U. S. Treasury Drinking Water Standards recommend 250 ppm. Except for Chippewa Creek, the sulfate content of tributaries in the Muskingum basin was below 250 ppm.

Industrial loads -- Columbia Chemical - Loads found in the streams were much larger than the industrial loads reported. A comparison of tons of chloride ion per day in the vicinity of Columbia Chemical showed:

Date	Sta 1 Tuscarawas	Sta 1A Wolf Creek	Columbia Chemical	Sta 2 Tuscarawas
Oct 16	0.1	0.7	1,857	2,225
17	0.1	0.9	1,529	2,600
18	0.1	0.7	306	1,550
19	0.1	0.6	355	1,220
20	0.1	0.8	482	1,320
21	0.1	0.8	391	1,435
22	0.1	0.9	-	1,740
Avg	0.1	0.8	820	1,724

Wastes from Columbia Chemical are lagooned before release to the stream. Total lagoon area is about 150 acres; depths range to 30 feet.

Seepage from this lagoon probably contributes a considerable portion of the chloride load found in the stream. Although this factor was included in the plant discharge, evidently the seepage was greater than had been estimated. It could not be measured directly.

The chloride loads found at Sta 2 were substantiated by those found at downriver stations and are considered accurate within the limits of error usually encountered on a survey of this type. No salt wells were being brought in during the survey and no appreciable sources of chloride waste in the vicinity other than this plant have been reported.

Allowing one day's lapse in time, the variation in the stream loads at Sta 2 followed the trend of Columbia Chemical's discharge very closely. The chloride input above the plant is negligible, averaging about one ton per day.

Morton Salt Co. - Lack of accurate stream flow data in the vicinity of the Morton Salt Company makes a load comparison difficult. Flows in Chippewa Creek were computed, using spot measurements made during the period of the survey as a basis. Tons of chloride per day calculated from these flows showed:

Date	Sta 2A River Styx	Sta 2B Chippewa Cr.	Morton Salt Company By Sampling	Morton Salt Company Company Estimate	Sta 2C Chippewa Cr.
Oct 16	0.4	4.7	42.5	70.5	77
17	0.4	12.0	25.1	26.7	210
18	0.6	17.3	11.0	27.3	160
19	0.6	9.3	16.9	26.1	91
20	0.4	11.0	24.9	6.1	107
21	0.5	11.2	7.0	1.2	86
22	0.4	6.3	19.0	1.2	46
Avg	0.47	10.2	20.9	22.7	111

The loads found at Sta 2C were greatly in excess of the reported plant loads. No other significant sources of chloride waste in this vicinity have been reported.

Tons of chloride ion per day above and below the confluence of Chippewa Creek and the Tuscarawas were:

Date	Sta 2C Mouth Chippewa Cr.	Sta 2 Tuscarawas, Clinton	Sta 3 Tuscarawas, Canal Fulton
Oct 16	77	2,225	1,840
17	210	2,600	2,655
18	160	1,550	1,820
19	91	1,220	1,250
20	107	1,320	1,340
21	86	1,435	1,400
22	46	1,740	1,140
Avg	111	1,724	1,635

Chloride loads at Sta 2 and 3 showed fairly good agreement. Chloride loads will reflect errors in flow measurements -- possibly 10%.

Inability to get truly representative samples of a highly concentrated water probably accounts for a large part of the discrepancy. Within the limit of error, the total tonnage at Sta 2 and 2C approximate that found at Sta 3.

****

In conclusion -- This report has presented the basic data obtained in a chloride investigation of the Muskingum River. It has defined the effect of Muskingum waters on the Ohio River and established the nature and magnitude of the effects of brine-waste contamination on the Muskingum itself.

The economic picture of damages caused by brine wastes is extremely complex and merits further study. Enough information has been assembled, however, to serve as a basis for a more comprehensive evaluation of all forms of damage.

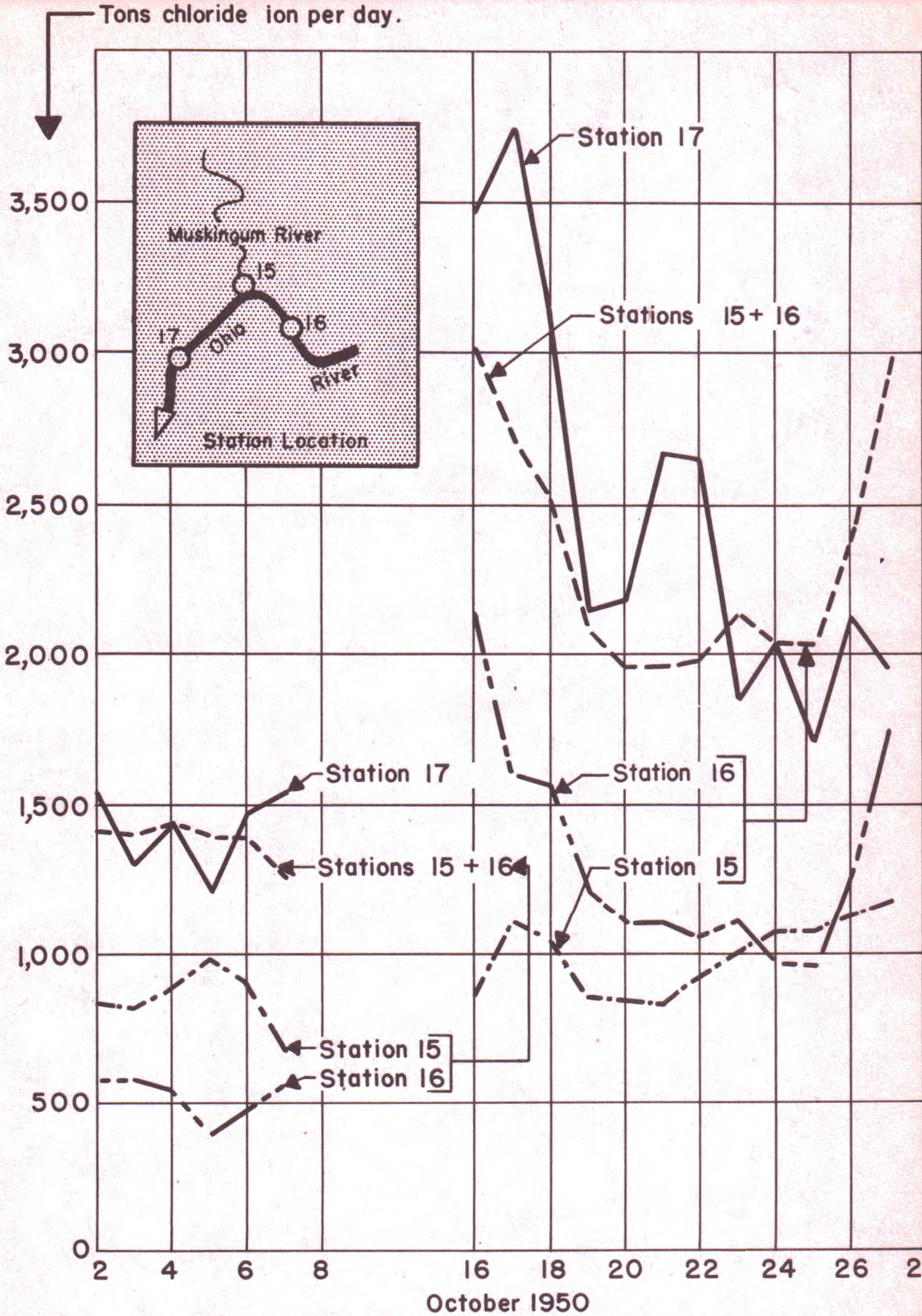


Fig 2—Effect of Muskingum River on Chloride Content of the Ohio River. The sum of chloride loads at stations 15 and 16 agrees well with stream loads at station 17. Chloride contribution of the Muskingum is almost equal to the chloride load already present in the Ohio River.

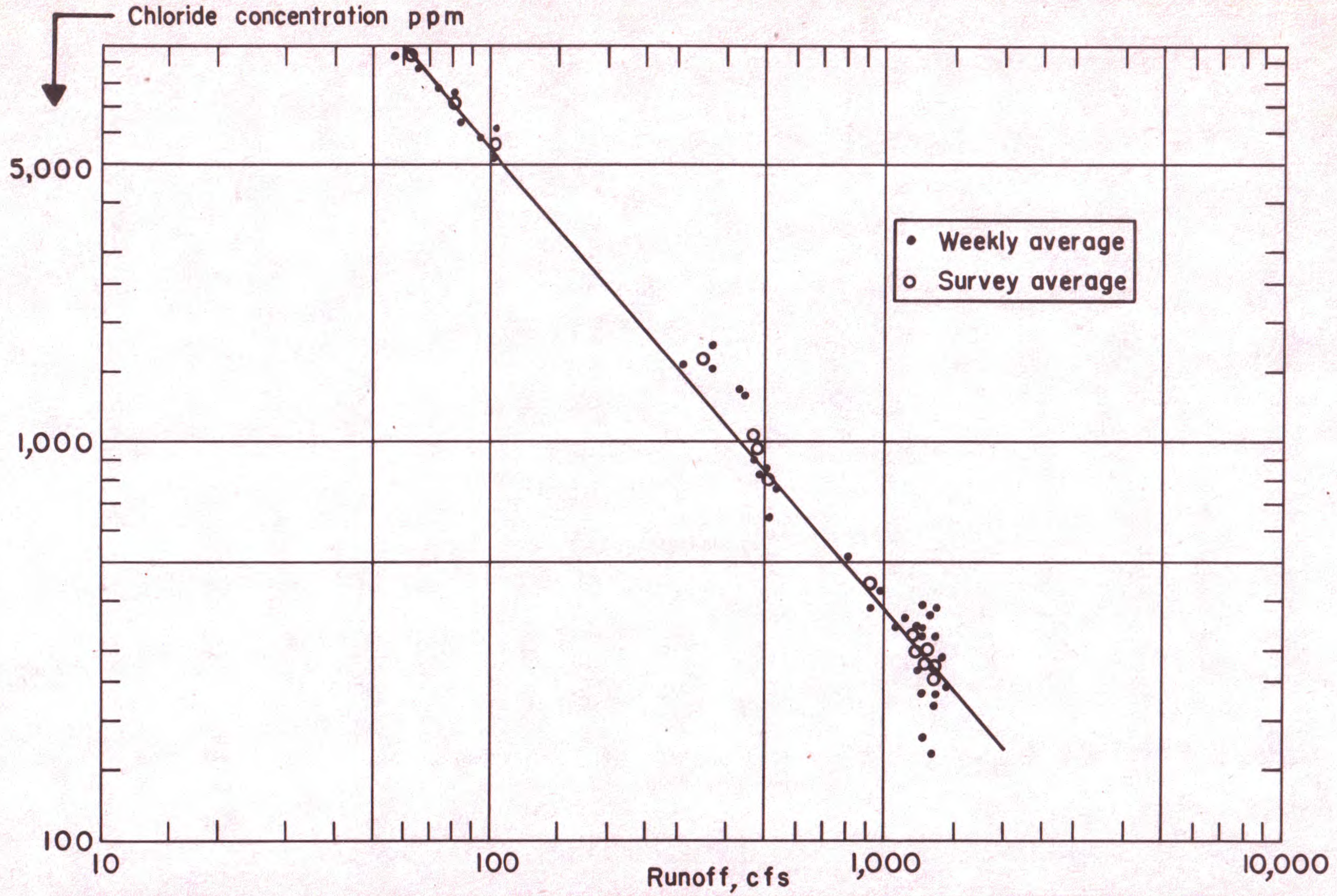


Fig 3 - Relation of chloride concentration to flow. The effect of short-time averaging can be seen by the greater range of weekly averages, compared to survey averages. Fluctuation in chloride loads is responsible for these variations. The line was eye-fitted to survey averages.

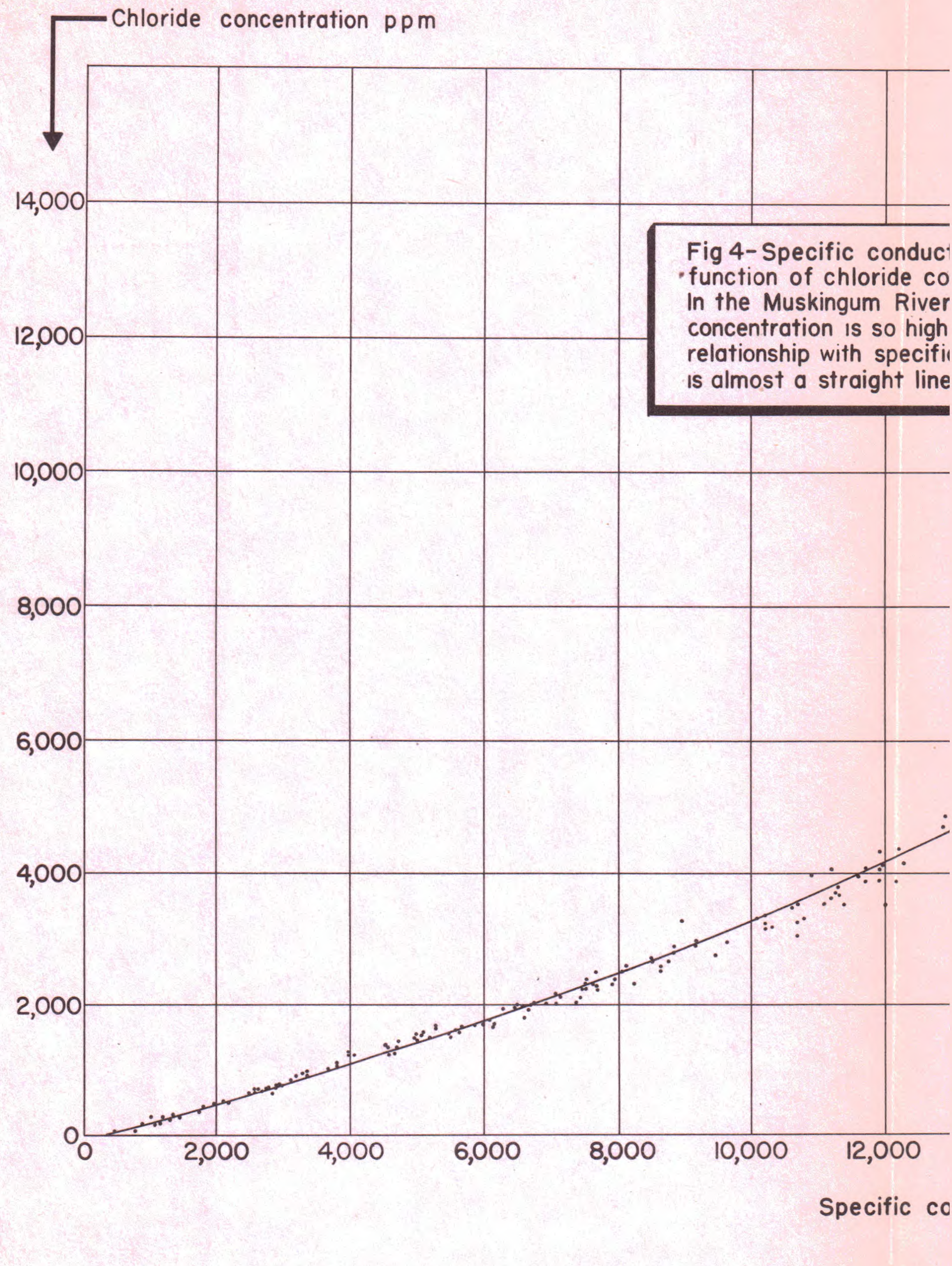
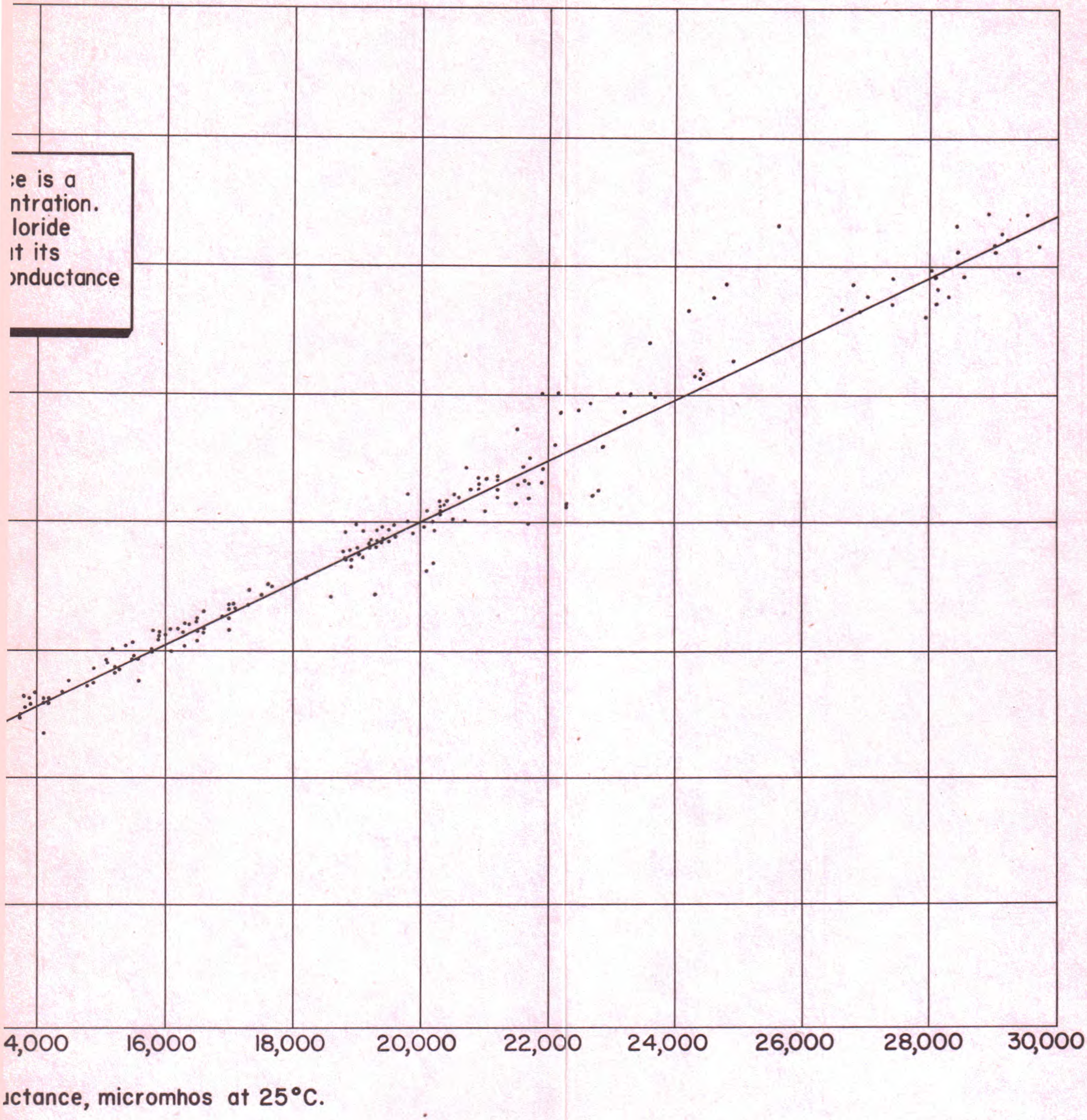


Fig 4- Specific conduct
function of chloride co
In the Muskingum River
concentration is so high
relationship with specifi
is almost a straight line

June 1951



Ohio River Valley Water Sanitation Commission

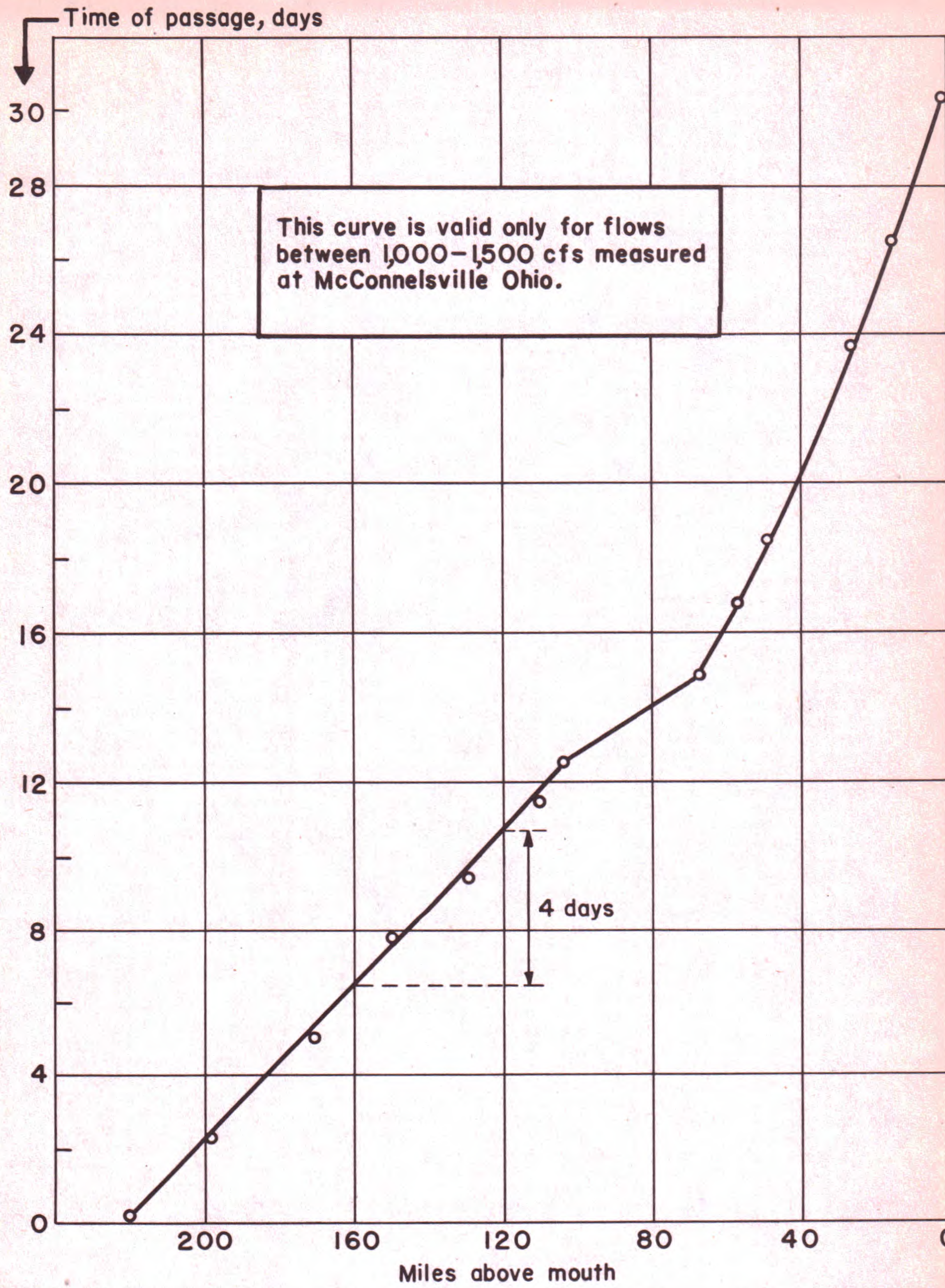


Fig 5— Time of flow for Muskingum River. The time necessary for the river to pass any two points is given by the vertical intercept between them. In the example shown four days are required for the river to flow from mile point 160 to 120.

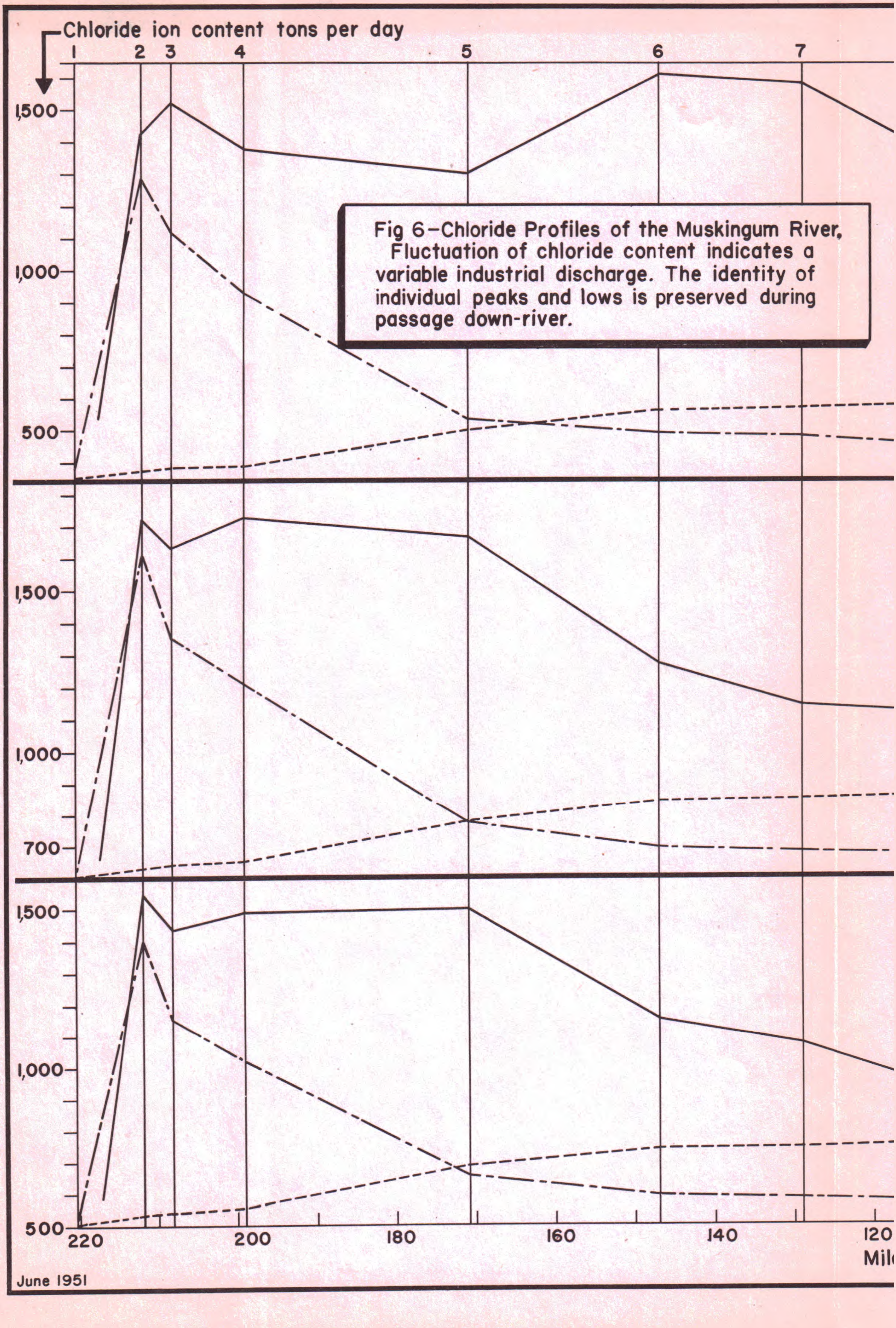
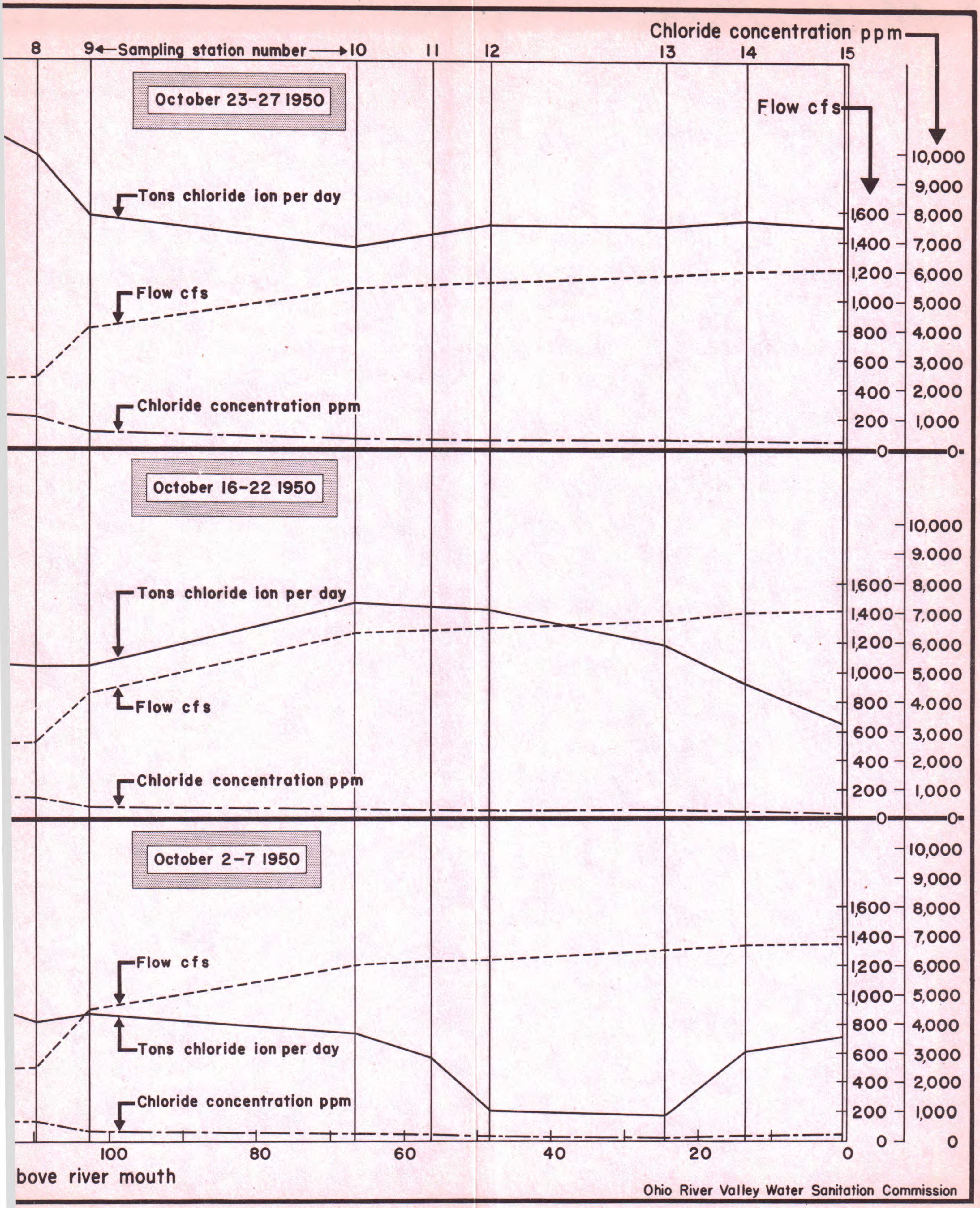
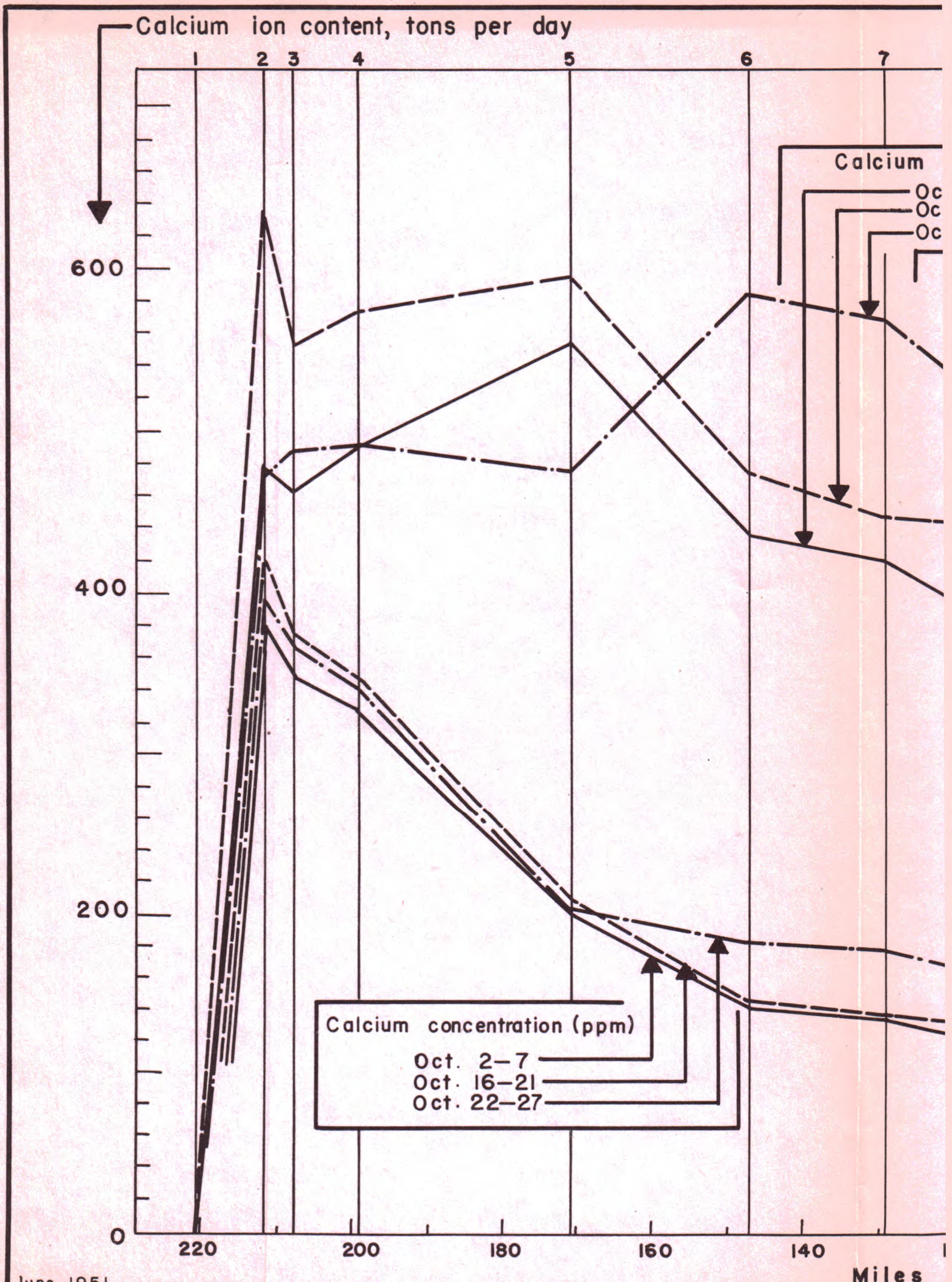


Fig 6–Chloride Profiles of the Muskingum River, Fluctuation of chloride content indicates a variable industrial discharge. The identity of individual peaks and lows is preserved during passage down-river.



Ohio River Valley Water Sanitation Commission


Calcium ion content, tons per day
1
2
3
4
5
6
7
600
400
200
0
220
200
180
160
140
Miles
Calcium
Oc
Oc
Oc
Calcium concentration (ppm)
Oct. 2-7
Oct. 16-21
Oct. 22-27
June 1951

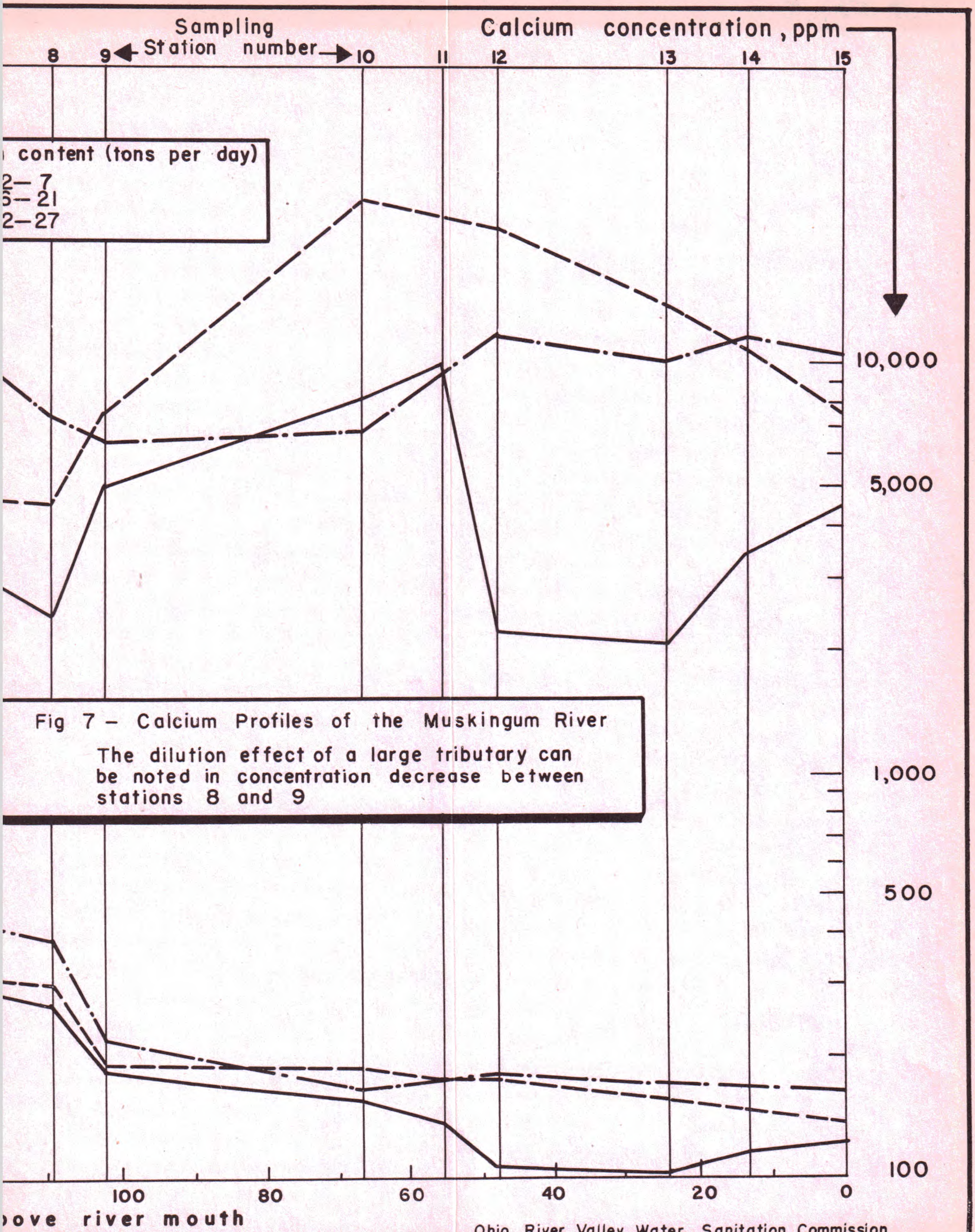
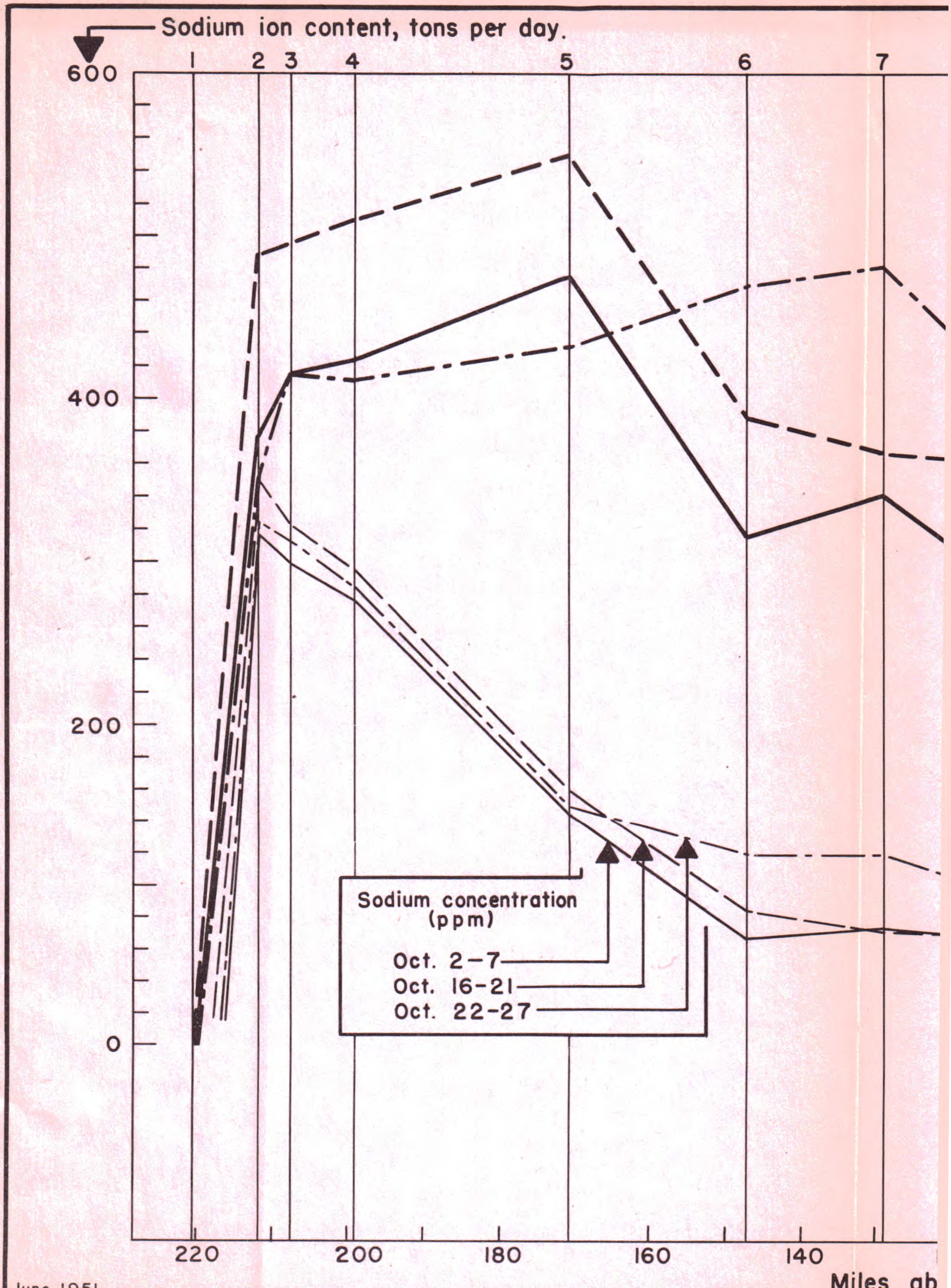


Fig 7 – Calcium Profiles of the Muskingum River

The dilution effect of a large tributary can be noted in concentration decrease between stations 8 and 9


Sodium ion content, tons per day.
600
400
200
0
1
2
3
4
5
6
7
Sodium concentration (ppm)
Oct. 2-7
Oct. 16-21
Oct. 22-27
220
200
180
160
140
Miles ab
June 1951

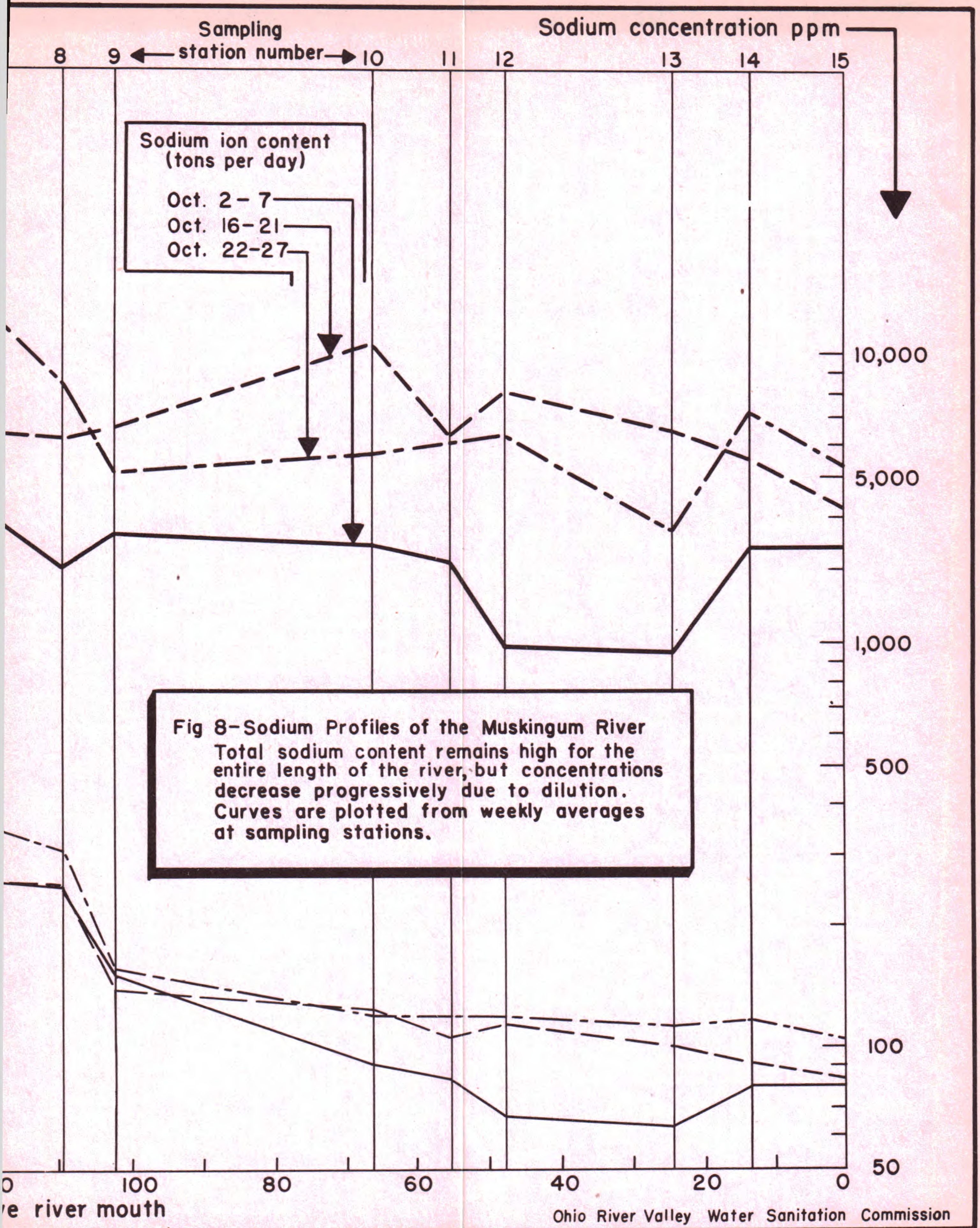


Fig 8–Sodium Profiles of the Muskingum River
Total sodium content remains high for the entire length of the river, but concentrations decrease progressively due to dilution. Curves are plotted from weekly averages at sampling stations.

Ohio River Valley Water Sanitation Commission

Fig 9

Conversion Chart for Determining Permissible Plant Load

$$\text{Tons per day} = \text{cfs} \times \text{ppm} \frac{5.38}{2{,}000}$$

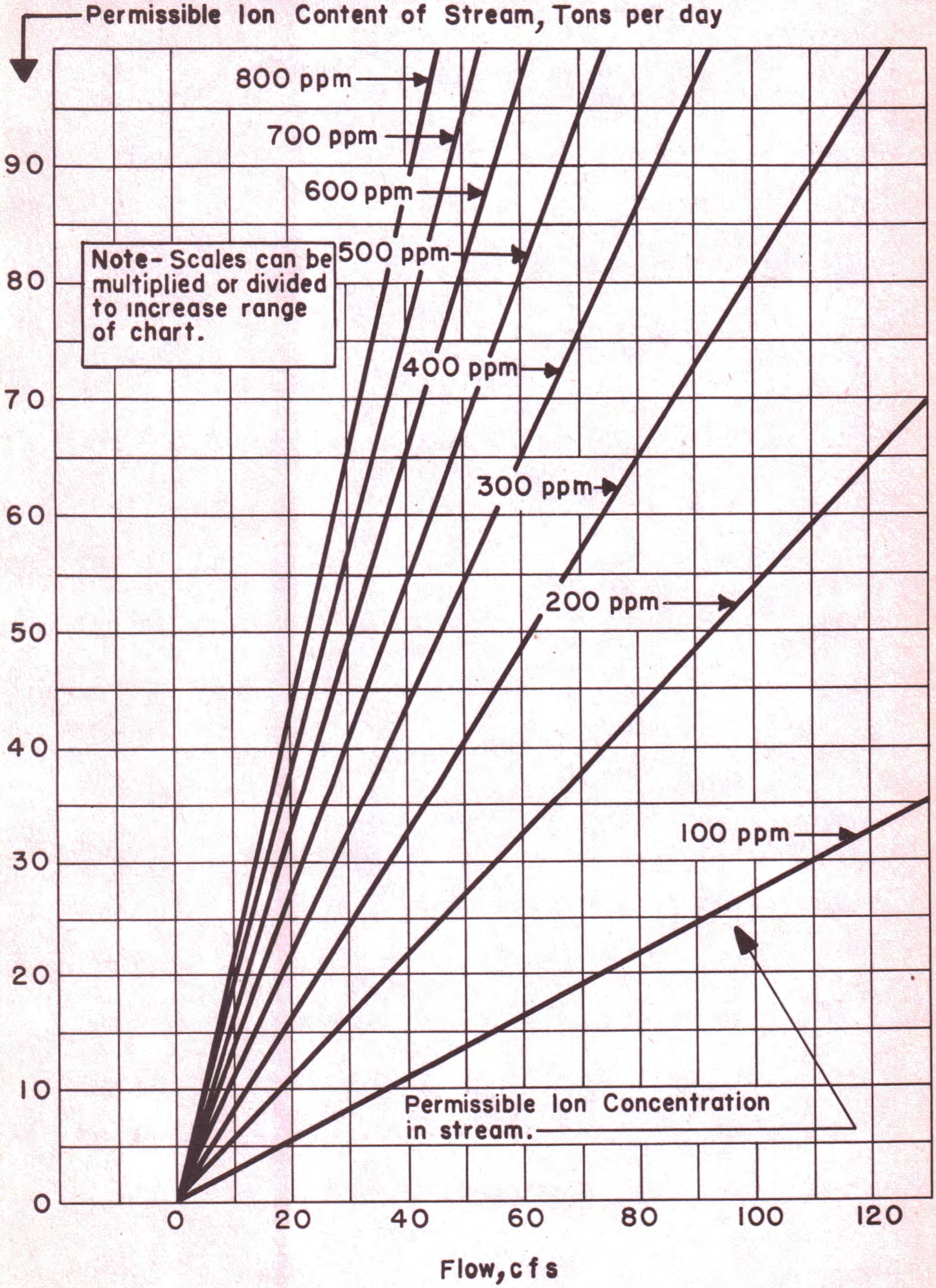


TABLE 1 -- LOCATION OF SAMPLI

Sampling Station Number	Stream	Location
1	Tuscarawas River	Bridge, Ohio route 619, Barberton
1A	Wolf Creek	Bridge, U. S. route 224, Barberton
2	Tuscarawas River	Bridge, U. S. route 21, Clinton
2A	River Styx	Bridge, Ohio route 94, ½ mile east of R
2B	Chippewa Creek	Morton Salt Co. pump station, Ohio rout east of Rittman
2C	Chippewa Creek	Highway bridge intersection of North La Road and Canal Fulton Road near Clint
3	Tuscarawas River	Upstream Bridge, Market St., Canal Fult
4	Tuscarawas River	Bridge, intersection Lake Ave. (N.W.) a (N.W.)
5	Tuscarawas River	Dover Dam
6	Tuscarawas River	Bridge, U. S. route 36, ½ mile west of
7	Tuscarawas River	Bridge, South River St., Newcomerstown
8	Tuscarawas River	Bridge, Ohio route 76, Northwest side C
8A	Walhonding River	Bridge, U. S. route 36, Roscoe
9	Muskingum River	Bridge, ½ mile northeast of Conesville
9A	Licking River	Bridge, Dillon Reservoir Project, Dillo
10	Muskingum River	Bridge at Muskingum Lock & Dam No. 9, D
11	Muskingum River	Pool at Lock & Dam No. 8, Rokeby Lock
12	Muskingum River	Pool at Lock & Dam No. 7, McConnelsvill
13	Muskingum River	Pool at Lock & Dam No. 4, Beverly
14	Muskingum River	Bridge downstream from Lock No. 3, Lowe
15	Muskingum River	Bridge, Putnam Street, Marietta
16	Ohio River	Ohio Lock No. 17, Reno
17	Ohio River	Ohio Lock No. 18, Constitution

POINTS

	Drainage Area Square Miles	Miles Above Muskingum Mouth	Sampling Personnel
	64	220.4	Ohio Dept. of Health
	61	220.4	Ohio Dept. of Health
	165	211.9	Ohio Dept. of Health
tman	29.5	219.3	Ohio Dept. of Health
94,			
	115	219.4	Ohio Dept. of Health
ence			
	188	211.2	Ohio Dept. of Health
	405	208.1	Ohio Dept. of Health
3rd St.			
	476	199.1	Corps of Engineers, Massillon
	1,397	179.9	Corps of Engineers, Dover Dam
denhutten	2,376	147.0	Corps of Engineers, New Philadelphia
	2,436	129.0	Corps of Engineers, New Philadelphia
hocton	2,590	109.9	Corps of Engineers, New Philadelphia
	2,252	109.9	Corps of Engineers, New Philadelphia
	4,869	102.7	Corps of Engineers, New Philadelphia
	753	79.3	Corps of Engineers, Dillon
can Falls	7,186	66.7	Corps of Engineers, Lock No. 9
	7,374	56.2	Corps of Engineers, Lock No. 8
	7,411	48.1	Corps of Engineers, Lock No. 7
	7,701	24.6	Corps of Engineers, Lock No. 4
	7,986	13.8	Corps of Engineers, Lock No. 3
	8,038	0.2	Corps of Engineers, Lock No. 1
	26,950	--	Corps of Engineers, Lock No. 17
	35,600	--	Corps of Engineers, Lock No. 18
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TABLE 2 -- DAILY DISCHARGE OF MUSKINGUM R

Sampling Station Number	October 1950 2	3	4	5	6	7	Avg 2-7	Oc 16	17	18
1*	3.1	3.4	3.4	3.2	3.0	3.0	3.1	3.3	3.2	3.2
1A*	8.4	9.3	9.2	8.6	8.2	8.0	8.6	8.9	8.6	8.6
2	63	69	68	64	61	59	64	66	64	64
2A*	3.0	2.8	1.3	2.4	2.4	2.5	2.4	2.5	2.4	2.4
2B*	11.5	11.0	4.9	9.2	9.2	9.8	9.2	9.8	9.2	9.2
2C*	19	18	8	15	15	16	14	16	15	15
3*	85	90	79	78	78	89	83	85	82	82
4*	102	108	112	108	100	98	104	119	116	104
5	367	367	409	374	354	334	367	445	416	374
6*	490	475	485	490	460	429	471	546	530	507
7	504	488	496	504	472	440	484	560	544	520
8	536	519	527	536	502	468	514	595	578	553
8A	451	420	417	411	401	390	415	600	565	541
9*	970	919	902	919	902	851	910	1,110	1,070	1,030
9A*	100	95	93	90	90	88	93	140	134	120
10*	1,350	1,260	1,190	1,170	1,170	1,090	1,205	1,380	1,360	1,310
11*	1,380	1,290	1,220	1,200	1,200	1,160	1,241	1,420	1,400	1,340
12	1,390	1,300	1,230	1,210	1,210	1,170	1,251	1,430	1,410	1,350
13*	1,440	1,350	1,280	1,260	1,260	1,220	1,301	1,490	1,470	1,400
14*	1,500	1,400	1,320	1,300	1,300	1,260	1,346	1,540	1,520	1,450
15*	1,510	1,410	1,330	1,310	1,310	1,270	1,356	1,550	1,530	1,460
16	13,500	13,300	12,800	9,250	10,100	11,700	11,775	38,000	27,300	24,900
17	12,600	13,100	13,100	11,700	9,580	12,800	12,146	41,600	30,300	27,400

*Flows calculated from nearest gaging station.

ER AT SAMPLING STATIONS (cfs)

er 1950 19	20	21	22	Avg 16-22	October 1950 23	24	25	26	27	Avg 23-27	3-Week Avg
3.0	3.1	3.1	3.0	3.1	2.9	2.8	2.7	2.8	2.8	2.8	3.0
8.1	8.4	8.5	8.2	8.4	8.0	7.6	7.3	7.6	7.6	7.6	8.2
60	62	63	61	62	59	56	54	56	56	56	61
2.5	2.2	2.5	1.7	2.3	2.0	2.0	2.2	2.4	2.4	2.2	2.3
9.8	8.5	9.8	6.7	9.0	8.0	8.0	8.6	9.2	9.2	8.6	8.9
16	14	16	11	14	13	13	14	15	15	14	14
79	79	82	75	80	75	72	71	74	74	73	79
102	96	100	95	104	95	98	89	91	95	93	101
347	327	321	321	364	314	314	321	302	295	309	350
510	475	413	452	490	452	437	437	429	429	436	469
512	488	424	464	501	464	448	448	440	440	448	480
544	519	451	493	533	493	476	476	468	468	476	511
509	488	462	450	516	436	420	415	408	408	417	449
970	901	892	851	974	836	820	796	787	796	807	906
112	110	105	100	117	105	105	100	95	93	100	103
,260	1,220	1,150	1,170	1,264	1,120	1,120	1,090	1,050	1,060	1,088	1,195
,290	1,250	1,180	1,160	1,291	1,150	1,150	1,120	1,070	1,080	1,114	1,215
,300	1,260	1,190	1,170	1,301	1,160	1,160	1,130	1,080	1,090	1,124	1,235
,350	1,310	1,240	1,220	1,354	1,210	1,210	1,180	1,120	1,130	1,170	1,285
,400	1,360	1,280	1,260	1,401	1,250	1,250	1,220	1,160	1,170	1,210	1,319
,410	1,370	1,290	1,270	1.411	1,260	1,260	1,230	1,170	1,180	1,220	1,329
,600	19,600	19,000	16,500	23,700	13,900	12,100	11,800	13,700	13,100	12,900	16,125
,700	20,400	18,700	17,400	25,000	13,800	13,600	11,800	13,600	12,600	13,000	16,715

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TABLE 3 -- MISCELLANEOUS DISCHARGE MEASUREMENTS

Station	Date	Discharge, cfs
1	October 23, 1950	2.98
1	27	2.69
1A	23	7.55
1A	27	7.92
2A	23	1.62
2A	27	2.66
2C	23	14.2
2C	27	13.0
3	4	81.8
3	18	75.9

TABLE 4 -- CHLORIDE CONCENTRATIONS IN M

Sampling Station No.	October 1950 2	3	4	5	6	7	Avg. 2-7	16	17	18
1	10	12	15	18	30	18	17	10	14	16
1A	50	30	30	24	24	31	31	32	38	32
2*	6,283	11,266	11,733	9,698	6,921	7,576	8,912	12,533	15,200	9,033
2A*	90	114	56	88	75	135	93	60	68	98
2B*	760	1,500	142	177	209	46	472	182	498	702
2C*	2,033	3,695	2,346	2,108	2,091	3,088	2,560	1,795	5,200	3,755
3*	5,420	8,698	7,693	6,356	5,068	5,648	6,480	8,161	11,983	8,241
4	4,320	4,050	7,260	6,270	5,190	4,090	5,196	5,450	6,500	9,150
5	1,500	1,580	1,540	1,180	1,360	2,000	1,526	1,420	1,380	1,550
6	738	795	1,000	993	1,020	905	908	850	850	925
7	660	688	788	888	988	990	833	800	725	775
8	512	547	639	688	734	848	661	775	750	775
8A	9	9	11	11	13	12	10	11	10	10
9	298	333	377	398	443	481	388	440	436	415
9A	14	16	12	13	14	16	14	8	11	10
10	218	294	340	276	230	252	268	345	490	480
11	115	167	200	242	342	330	239	358	290	312
12	145	157	156	177	205	256	182	385	390	315
13	177	179	183	167	152	147	167	260	322	290
14	288	270	212	181	189	181	220	245	238	245
15	204	216	248	283	258	204	235	210	271	268
16	16	16	16	16	18	18	16	21	22	22
17	45	37	41	39	57	45	44	31	46	42

*Averages of hourly samples

KINGUM RIVER (Milligrams per liter)

tober 1950					October 1950						
19	20	21	22	Avg. 16-22	23	24	25	26	27	Avg. 23-27	3-Week Avg.
14	12	12	13	13	11	16	20	15	14	15	15
28	36	34	39	34	39	40	34	36	30	35	33
,583	7,905	8,493	10,598	10,192	12,466	8,053	11,916	7,300	7,608	9,462	9,564
80	70	75	75	75	72	86	76	74	95	80	83
356	485	430	352	429	648	125	178	199	125	255	385
,120	2,831	1,993	1,453	2,735	3,496	7,990	3,248	2,593	2,630	3,991	3,095
,880	6,313	6,325	5,660	7,509	8,066	6,146	9,933	8,013	6,566	7,744	7,231
,500	4,920	5,300	5,200	6,145	4,350	6,480	4,700	7,550	6,300	5,876	5,754
,400	1,950	2,500	1,980	1,740	1,450	1,550	1,620	1,390	1,890	1,580	1,624
,000	975	1,050	1,200	978	1,480	1,780	1,450	1,050	1,100	1,372	1,064
850	975	850	1,000	853	975	1,200	1,580	1,650	1,200	1,321	976
750	790	790	860	784	800	925	910	1,160	1,460	1,051	817
10	10	10	9	10	10	11	11	10	11	10	10
404	410	445	455	429	455	451	500	521	690	523	441
11	13	12	14	11	14	12	12	14	14	13	13
398	358	341	330	391	340	351	344	350	358	348	338
412	466	421	--	376	--	--	--	--	--	--	308
295	348	450	465	378	420	376	352	344	330	364	308
329	368	378	375	331	328	295	310	382	440	351	282
285	310	330	352	286	380	382	362	310	290	344	280
228	232	252	275	248	299	321	345	365	375	341	269
22	21	22	24	22	30	30	30	34	50	34	26
42	40	53	57	44	50	56	54	58	58	55	47

ORSANCO

TABLE 5 -- SPECIFIC CONDUCTANCE OF ALL DAILY SAM

Sampling Station Number							October 1950		
	2	3	4	5	6	7	16	17	18
1	358	372	414	407	443	409	414	422	461
1A	927	965	948	801	738	887	1,290	1,030	894
2 *	15,600	24,100	27,000	23,250	17,820	19,130	30,000	35,200	22,000
2A	901	1,000	724	852	812	1,030	774	787	900
2B	2,980	5,170	1,040	1,110	1,260	740	1,140	2,140	2,600
2C *	6,608	11,070	7,990	6,940	6,800	9,910	6,060	14,940	11,750
3 *	13,970	20,330	19,400	16,530	13,750	15,280	21,180	29,200	20,950
4	11,900	11,200	18,900	16,600	14,200	11,700	14,600	17,100	22,900
5	4,940	5,090	5,050	4,240	4,650	6,480	4,700	4,550	5,090
6	2,790	2,970	3,470	3,530	3,570	3,260	3,130	3,100	3,330
7	2,560	2,670	2,910	3,200	3,470	3,530	3,000	2,900	2,900
8	2,080	2,190	2,470	2,560	2,710	3,070	2,910	2,760	2,870
8A	453	450	447	434	435	435	447	437	432
9 *	1,420	1,328	1,650	1,692	1,820	1,932	1,820	1,840	1,770
9A	483	485	496	486	483	471	455	499	497
10	1,280	1,350	1,540	1,310	1,160	1,240	1,540	1,980	1,930
11	925	995	1,080	1,190	1,490	1,480	1,600	1,410	1,460
12	880	916	934	990	1,080	1,230	1,720	1,680	1,480
13	982	974	990	911	858	847	1,270	1,450	1,360
14	1,300	1,280	1,090	939	967	939	1,250	1,170	1,240
15	1,080	1,100	1,190	1,300	1,220	1,040	1,080	1,280	1,290
16	340	340	336	348	352	371	459	475	478
17	459	428	436	412	477	451	491	546	541

* Average of hourly samples

LES (Micromhos at 25°C)

19	20	21	22	23	24	25	26	27
417	402	394	397	382	406	405	429	407
950	920	1,070	1,290	1,220	1,080	1,160	1,080	855
19,200	19,500	20,700	25,400	29,000	20,400	28,100	18,600	19,200
836	800	840	820	838	852	825	833	890
1,710	2,130	1,950	1,740	2,810	984	1,170	1,260	1,010
7,200	9,640	6,750	5,140	10,490	21,730	9,770	8,220	8,470
16,000	16,100	16,200	14,970	19,800	16,100	23,700	19,630	16,650
17,000	13,400	14,200	14,100	12,200	16,500	12,900	18,800	16,200
4,610	6,160	7,650	6,210	4,840	4,960	5,210	4,550	5,880
3,420	3,330	3,620	3,970	4,760	5,600	4,740	3,790	3,790
3,050	3,300	3,100	3,490	3,390	4,050	5,070	5,250	4,050
2,770	2,850	2,880	3,040	2,900	3,280	3,190	3,960	4,760
433	434	428	430	430	447	453	457	456
1,720	1,730	1,820	1,860	1,850	1,840	2,000	2,070	2,550
510	507	499	514	518	531	535	531	532
1,730	1,600	1,550	1,530	1,550	1,550	1,560	1,590	1,620
1,760	1,920	1,780	--	--	--	--	--	--
1,400	1,540	1,860	1,910	1,770	1,630	1,580	1,560	1,530
1,480	1,630	1,660	1,630	1,490	1,380	1,430	1,660	1,820
1,350	1,410	1,470	1,560	1,660	1,660	1,580	1,450	1,380
1,170	1,170	1,250	1,330	1,400	1,490	1,570	1,640	1,650
471	433	432	402	407	407	403	409	451
532	543	573	550	498	520	501	506	502

ORSANCO

TABLE 6 -- MINERAL ANALYSES OF COMP

	SiO_2	Fe	Ca	Mg	Na	K	CO_3	HCO_3	SO_4
Station 1									
Oct. 2-7	11		52	13	11	3.0	0	165	52
16-21			58	12	9.8	2.8	11	151	49
22-27			59	12	12	3.0	5	170	48
Station 1A									
Oct. 2-7			115	18	60	4.0	0	230	243
16-21			105	22	92	3.8	0	188	325
22-27			107	22	108	4.4	0	201	373
Station 2									
Oct. 2			2,150	19	1,650	17	0	217	143
3-5	16	0.07	3,700	44	2,970	27	0	170	192
6-7			2,480	19	1,920	18	0	196	165
16-17			4,780	19	3,600	33	0	107	268
18-21			2,840	27	2,250	23	0	180	174
22-24			3,770	34	2,770	28	0	158	212
25-27			3,110	19	2,380	24	0	217	205
Station 2A									
Oct. 2-7			85	20	80	17	0	217	115
16-21			77	21	53	16	6	182	114
22-27			77	25	56	15	9	204	118
Station 2B									
Oct. 2			88	29	436	7.2	5	251	133
3			102	30	1,000	8.2	0	265	154
4-7			81	26	116	7.6	0	254	127
16-21			99	27	292	7.4	6	232	125
22-27			89	29	188	7.2	10	272	116
Station 2C									
Oct. 2			154	29	1,400	11	0	222	312
3-4	17	0.55	253	39	1,850	16	0	250	539
5-7			170	34	1,600	13	0	287	335
17-18			337	54	2,870	23	0	286	545
16-19-21			204	31	1,400	13	0	256	439
22			168	41	916	12	6	240	314
23			192	39	2,190	16	0	239	361
24			354	41	4,970	21	0	272	510
25-27			171	28	1,800	12	0	262	295

ITE SAMPLES (parts per million)

Cl	F	NO_3	Dissolved Solids	Total Hardness as $CaCO_3$	Noncarbonate Hardness	pH	Specific Gravity	Alkalinity as $CaCO_3$	Specific conductance micromhos at 25°C
21			264	184	49	8.1		135	454
16			259	194	52	8.0		142	426
23			264	196	48	8.1		148	425
57			695	362	174	7.8		188	995
46			770	352	198	7.7		154	1,050
35			841	360	195	7.4		165	1,060
6,220			11,000	5,430	5,250	7.7	1.005	178	16,800
0,700			18,600	9,420	9,280	7.4	1.010	139	27,300
7,070			12,500	6,280	6,120	7.3	1.004	161	19,000
3,600			23,400	12,000	11,900	7.6	1.014	88	32,600
8,200			14,270	7,200	7,050	7.6	1.006	147	21,000
0,600			18,600	9,540	9,410	7.4	1.010	129	26,200
8,810			15,500	7,840	7,660	7.5	1.010	178	22,300
118			579	293	115	7.9		178	974
70			517	280	120	7.9		160	818
80			506	294	112	8.1		182	802
750			1,740	340	126	8.2		214	3,060
1,500			3,060	376	159	8.3		217	5,320
195			738	311	103	8.0		208	1,320
465			1,210	358	158	8.2		200	2,170
280			878	340	100	8.2		240	1,460
2,000			3,960	502	320	7.6		182	6,670
3,100	0.4		6,150	790	585	7.8		205	10,100
2,410			4,790	562	327	7.8		235	8,110
4,420			8,570	1,060	826	7.8		234	13,300
2,180			4,540	636	426	7.6		210	7,330
1,510			3,140	590	383	8.0		207	5,060
3,400			6,470	640	444	7.8		196	10,200
7,950			14,500	1,050	831	7.6	1.006	223	21,800
2,850			5,400	540	325	7.6		215	8,960

(Continued on Next Page)

TABLE 6 -- MINERAL ANALYSES OF COMPOSITE

	SiO_2	Fe	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	
Station 3										
Oct. 2-4			2,380	19	1,990	20	0	196	209	7
5-7	15	0.25	1,800	22	1,720	7.8	0	233	209	5
16-18			3,090	24	2,780	25	0	182	259	9
19-21			2,030	58	1,820	19	0	235	207	6
22-24			2,220	24	1,920	20	0	233	214	6
25-27			2,700	19	2,320	23	0	210	217	7
Station 4										
Oct. 2-7			1,740	15	1,520	15	0	231	164	5
16-21			2,050	39	1,820	19	0	204	193	6
22-27			1,960	34	1,650	17	0	240	188	5
Station 5										
Oct. 2-7			565	19	484	8.4	0	150	186	1
16-21			609	29	564	8.8	8	124	190	1
22-27			573	27	520	8.8	0	163	193	1
Station 6										
Oct. 2-7			344	21	248	9.4	0	113	198	
16-21			359	18	296	8.8	0	120	210	
22-27			497	16	400	11	0	132	221	1
Station 7										
Oct. 2-7			322	21	264	8.2	0	112	193	
16-21			331	19	272	8.8	6	107	201	
22-27			473	27	400	9.8	5	117	207	1
Station 8										
Oct. 2-7			268	18	200	6.2	0	109	176	
16-21			307	23	252	8.0	9	105	195	
22-27			387	27	308	9.0	5	114	193	1
Station 8A										
Oct. 2-7	4.9	0.04	57	17	8.6	2.4	6	189	57	
16-21			58	17	24	2.4	10	182	56	
22-27			57	18	12	2.6	8	186	59	
Station 9										
Oct. 2-4	6.2	0.04	168	18	120	5.2	0	143	134	
5-7			196	18	124	6.4	0	149	133	
16-21			190	20	140	5.4	10	137	134	
22-27			222	21	156	5.6	7	148	135	

SAMPLES (parts per million) (Continued)

l	F	NO_3	Dissolved Solids	Total Hardness as $CaCO_3$	Noncarbonate Hardness	pH	Specific Gravity	Alkalinity as $CaCO_3$	Specific conductance micromhos at 25°C
20			10,800	6,020	5,860	7.5	1.004	161	19,000
50			10,300	4,590	4,440	7.6		191	15,700
20			16,200	7,810	7,660	7.5	1.009	149	23,200
20			11,200	5,290	5,100	7.5	1.005	193	16,300
60			11,800	5,650	5,460	7.5	1.006	191	17,100
90			14,200	6,820	6,650	7.3	1.008	172	20,300
00			9,560	4,400	4,210	7.7		189	14,500
00			10,900	5,280	5,110	7.8	1.008	167	16,500
70			10,400	5,040	4,840	7.7	1.005	197	15,100
00			3,220	1,490	1,370	7.8		123	5,260
60			3,310	1,640	1,530	8.0		115	5,480
00			3,430	1,540	1,400	7.9		134	5,080
00			2,160	944	851	7.8		93	3,360
25			2,540	970	872	7.9		98	3,410
50			2,840	1,310	1,200	7.9		108	4,430
35			2,100	892	800	8.0		92	3,120
50			2,290	905	807	8.0		98	3,120
50			2,910	1,290	1,190	8.0		104	4,120
75			1,720	744	655	8.0		89	2,580
75			2,280	860	759	8.0		101	2,920
10			2,460	1,080	980	8.0		102	3,420
10	0.2	1.5	268	210	45	8.3		165	460
14			289	214	48	8.3		166	466
11			276	216	50	8.3		166	442
48	0.8	3.0	971	490	373	8.0		117	1,600
48			1,190	562	440	8.1		122	1,870
18			1,400	556	427	8.2		129	1,810
05			1,250	640	507	8.1		133	1,960

(Continued on Next Page)

TABLE 6 -- MINERAL ANALYSES OF COMPOSITI

	SiO_2	Fe	Ca	Mg	Na	K	CO_3	HCO_3	SO_4
Station 9A									
Oct. 2-7	1.6	0.04	59	21	10	2.6	8	196	73
16-21			66	20	13	3.2	10	211	67
22-27			70	22	16	2.8	14	218	73
Station 10									
Oct. 2-7	5.9	0.04	155	7.3	90	4.4	0	136	127
16-21			187	18	124	5.4	8	132	137
22-27			167	20	120	5.2	6	144	142
Station 11									
Oct. 2-7			138	21	84	4.4	6	124	135
16-21			177	17	104	5.0	6	127	126
Station 12									
Oct. 2-7			105	17	67	4.6	0	121	120
16-21			176	21	112	5.2	5	131	144
22-27			181	20	120	5.0	7	138	142
Station 13									
Oct. 2-7			101	12	63	4.0	0	104	116
16-21			157	18	100	5.4	0	134	147
22-27			170	20	112	4.8	6	133	133
Station 14									
Oct. 2-7			113	15	80	5.0	0	105	123
16-21			143	17	92	4.6	0	145	132
22-27			169	19	116	4.8	6	130	148
Station 15									
Oct. 2-7	2.1	0.05	120	17	80	4.4	0	112	128
16-21			133	19	83	4.2	0	142	123
22-27			165	20	104	4.6	6	128	149
Station 16									
Oct. 2-7	6.6	0.04	32	8.0	20	2.8	0	21	119
16-21			44	9.7	26	4.0	0	16	166
22-27			38	10	27	2.6	0	22	118
Station 17									
Oct. 2-7	5.8	0.04	43	9.0	26	3.0	0	37	112
16-21			51	13	32	3.4	0	23	167
22-27			49	11	32	3.0	0	38	125

SAMPLES (parts per million) (Continued)

l	F	NO_3	Dissolved Solids	Total Hardness as $CaCO_3$	Noncarbonate Hardness	pH	Specific Gravity	Alkalinity as $CaCO_3$	Specific conductance micromhos at 25°C
.2	0.3	1.0	295	234	60	8.4		174	498
.3			330	248	58	8.3		190	521
0			338	264	62	8.3		202	536
0	0.6	2.0	852	416	305	8.1		111	1,330
8			1,130	542	420	8.2		122	1,760
.0			928	498	370	8.1		128	1,500
0			800	430	318	8.1		112	1,270
1			1,050	512	398	8.2		114	1,640
8			636	330	231	8.2		99	1,020
9			1,040	524	408	8.1		116	1 640
1			1,040	536	411	8.1		125	1,610
0			613	302	217	8.2		85	942
1			966	468	358	8.1		110	1,480
8			926	508	389	8.2		119	1,520
4			739	344	258	8.2		86	1,090
5			848	428	309	8.1		119	1,330
5			996	502	386	8.1		116	1,500
1	0.4	2.0	783	368	276	8.1		92	1,180
2			874	412	296	8.2		116	1,230
5			938	496	381	8.2		115	1,470
5	0.3	2.0	222	113	96	8.1		17	353
2			304	149	136	7.9		13	471
3			258	136	118	7.9		18	406
1	0.4	1.9	281	145	115	8.0		30	455
3			361	182	163	7.8		19	547
4			320	167	136	8.0		31	497

TABLE 7 -- TONS OF CHLORIDE ION PER DA

Sampling Station Number	October 1950						Avg	October 1950				
	2	3	4	5	6	7	2-7	16	17	18	19	
1	0.1	0.1	0.1	0.1	0.2	0.1	0.14	0.1	0.1	0.1	0.1	
1A	1.1	0.8	0.7	0.6	0.5	0.7	0.73	0.7	0.9	0.7	0.6	
2	1,060	2,080	2,140	1,667	1,145	1,195	1,547	2,225	2,600	1,550	1,220	1,
2A	0.7	0.9	0.2	0.6	0.5	0.9	0.63	0.4	0.4	0.6	0.6	
2B	23.5	44.5	1.4	4.4	5.2	1.2	13.7	4.7	12.0	17.3	9.3	
2C	104	180	50	85	84	125	104	77	210	160	91	
3	1,240	2,005	1,630	1,340	1,070	1,350	1,439	1,840	2,655	1,820	1,250	1,
4	1,180	1,180	2,200	1,820	1,475	1,080	1,489	1,745	2,025	2,550	1,780	1,
5	1,490	1,560	1,690	1,180	1,290	1,795	1,500	1,700	1,545	1,560	1,310	1,
6	975	1,015	1,305	1,305	1,260	1,040	1,150	1,260	1,210	1,260	1,340	1,
7	895	900	1,055	1,155	1,255	1,270	1,071	1,205	1,065	1,085	1,170	1,
8	740	765	910	990	995	1,070	911	1,245	1,170	1,155	1,100	1,
8A	12.2	11.3	13.9	13.6	15.6	14.1	13.4	19.9	17.0	16.2	15.2	
9	775	825	915	985	1,075	1,105	946	1,315	1,255	1,160	1,050	
9A	3.8	4.1	3.0	3.1	3.4	3.5	3.5	3.0	4.0	3.2	3.3	
10	795	995	1,090	870	725	720	874	1,285	1,790	1,690	1,355	1,
11	575	575	660	780	1,105	1,030	787	1,370	1,090	1,130	1,440	1,
12	545	550	515	575	665	805	609	1,480	1,475	1,140	1,040	1,
13	690	645	630	565	515	480	587	1,040	1,270	1,090	1,190	1,
14	1,160	1,015	750	635	665	615	806	1,015	970	950	1,070	1,
15	830	820	885	995	910	695	855	875	1,115	1,050	865	
16	580	580	555	397	485	565	527	2,140	1,615	1,470	1,220	1,
17	1,530	1,300	1,440	1,230	1,480	1,550	1,421	3,475	3,750	3,100	2,150	2,

AT SAMPLING STATIONS

0	21	22	Avg 16-21	October 1950 23	24	25	26	27	Avg 23-27	3-Week Avg
.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
.8	0.8	0.9	0.78	0.8	0.8	0.7	0.7	0.6	0.72	0.74
	1,435	1,740	1,724	1,970	1,210	1,730	1,095	1,145	1,430	1,585
.4	0.5	0.4	0.47	0.4	0.5	0.5	0.5	0.6	0.47	0.52
.0	11.2	6.3	10.2	14.0	2.7	4.1	4.9	3.1	5.8	10.5
	86	46	111	122	280	123	104	106	147	121
	1,400	1,140	1,635	1,625	1,190	1,890	1,595	1,310	1,522	1,588
	1,420	1,335	1,732	1,115	1,210	1,125	1,845	1,615	1,382	1,544
	2,160	1,715	1,670	1,225	1,305	1,400	1,125	1,495	1,310	1,514
	1,170	1,460	1,278	1,805	2,090	1,700	1,210	1,270	1,615	1,271
	970	1,255	1,147	1,220	1,450	1,900	1,950	1,425	1,589	1,244
	960	1,140	1,124	1,060	1,185	1,170	1,465	1,840	1,344	1,114
.7	13.8	12.2	15.1	13.1	14.0	13.7	12.2	13.5	13.3	14.2
	1,070	1,040	1,126	1,020	1,000	1,075	1,110	1,485	1,138	1,069
.8	3.4	3.7	3.5	3.9	3.4	3.2	3.6	3.5	3.5	3.5
	1,060	1,005	1,337	1,030	1,065	1,015	990	1,065	1,033	1,098
	1,345	--	1,324	--	--	--	--	--	--	1,055
	1,445	1,465	1,317	1,315	1,180	1,075	1,000	965	1,107	1,023
	1,260	1,225	1,196	1,065	960	980	1,150	1,340	1,100	966
	1,140	1,190	1,067	1,280	1,285	1,190	965	910	1,126	996
	840	935	932	1,010	1,085	1,080	1,150	1,190	1,103	954
	1,120	1,065	1,390	1,120	975	965	1,255	1,765	1,208	1,042
	2,670	2,650	2,855	1,850	2,045	1,710	2,120	1,960	1,937	2,071

ORSANCO

OHIO RIVER VALLEY
WATER SANITATION COMMISSION

AN INTERSTATE AGENCY

ESTABLISHED JUNE 30, 1948