A STUDY OF THE SOURCES OF PHOSPHORUS IN THE SEWAGE OF A SMALL RESIDENTIAL COMMUNITY

SANITARY ENGINEERING RESEARCH LABORATORY
COLLEGE OF ENGINEERING
AND
SCHOOL OF PUBLIC HEALTH
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31 July 1965

Mr. Theodore E. Brenner
Assistant Technical Director
The Soap and Detergent Association
295 Madison Avenue
New York 17, New York

Dear Mr. Brenner:

In compliance with the terms of the Research Grant presented to The Regents of the University of California by the Soap and Detergent Association we are transmitting a report entitled A Study of the Sources of Phosphorus in the Sewage of a Small Residential Community.

It has truly been a stimulating experience working with you on this investigation and we look forward eagerly to further close cooperation with you in the future.

Sincerely yours,

David Jenkins

P. H. McGauhey
Co-Faculty Investigators

DJ:en
Enclosure

A STUDY OF THE SOURCES OF PHOSPHORUS IN THE SEWAGE OF A SMALL RESIDENTIAL COMMUNITY

By

David Jenkins

Prepared for

The Soap and Detergent Association in Fulfillment of a Research Grant Presented to the Regents of the University of California

August 1965

Sanitary Engineering Research Laboratory
College of Engineering
and
School of Public Health
University of California
Berkeley

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I. INTRODUCTION

THE CHANGING NATURE OF POLLUTION

Pollution of natural waters has accompanied mankind ever since his formation of an organized society. In early times, and until the industrial revolution, the burden of pollution borne by receiving waters was solely of human and domestic origin. Because of its "natural" origin this organic type of polluting material could be rendered innocuous by treatment which consisted merely of intensifying the natural environment and confining it within a sewage treatment plant to produce higher rates of reaction. With the advent of the Industrial Revolution, which was to bring about the development of a society based on an urban-industrial complex, pollution's scope broadened to include the wastes of industry. As industry diversified and population expanded in numbers yet concentrated in density, the protection and provision of a water supply, safe and adequate from both a quality and quantity standpoint, was made more critical and difficult.

Man's technology demanded the provision of more and better water yet also helped to produce further and intractable waste products that contributed to the downgrading of water quality.

The point has now been reached where the supply of water is limited, yet the numbers and inventiveness of man continue to expand at an alarming rate. We must nowadays turn to sources of water that, because of past bountifulness, could previously be discarded as unsuitable. We must also protect bodies of water, for aesthetic and recreational reasons, which previously did not require protection because the limited load of pollution that they were required to bear could be dispensed with under natural conditions without severely detracting from the beneficial qualities of the water. These facts often mean that materials not previously regarded as pollutants now assume that status.

Classically we were concerned with gross pollution by organic matter that rendered streams and lakes devoid of life-giving oxygen. Later we had our attention turned to the waste products of industry--often materials untouched by biological treatment processes and toxic to aquatic life. Now we find ourselves, as it were, turning full circle as our concern comes to rest on the very materials that are essential for biological growth, the major inorganic nutrients--nitrogen and phosphorus.

EUTROPHICATION

The natural process of eutrophication in bodies of water can be likened to aging, with time measured on a geologic scale. The presence of man can speed up eutrophication by supplying the nitrogen and phosphorus required for the growth of autotrophic organisms.

In situations where the supply of one or more nutrients is limited the provision of these nutrients can produce a drastic change in the regime of the water. What was once a clear lake can lose its transparency because of the growth of planktonic algae which in severe cases of eutrophication appear as blooms.

Large populations of surface growing algae can form scums which later decompose with the production of unsightly and malodorous conditions. The growth of higher aquatic plants can reach such proportions that they spread over the surface of the body of water leading to the eventual blocking of a stream or filling in of a lake. Although all these are natural processes in the evolution of a lake or stream they are encouraged and hastened by the provision of inorganic nutrients.

The discharge of nutrients in a sewage effluent into a stream or body of water can be likened to the spreading of fertilizer on arable land. The fertilizer will supply the land with a potential to yield crops; the discharge of nitrogen and phosphorus into a stream will enrich the water with nutrients essential for plant or algal growth.

Concern over the increasing problem of eutrophication has been expressed by many writers and in some instances has prompted restrictions on the discharge of nutrient materials into receiving waters. For example, interim standards to protect the beneficial uses of the waters of San Francisco Bay and the Delta Region in California have been suggested that include restriction of the phosphate concentration of the water to 0.5 mg as PO_4/l. While admitting that this is a "ballpark figure" Fisher [1] states that some restriction on nutrient concentration must be made if the waters of the bay are to remain suitable for recreational, aesthetic, and export purposes. It is against this background of growing concern and impending action that the study reported herein was conducted. The study was designed to employ a materials balance technique to determine quantitatively the sources of phosphorus in the domestic sewage from a residential community with special reference to the contribution made by synthetic detergents.

SOURCES OF PHOSPHORUS IN SEWAGE

Various estimates have been made of the daily per capita dietary phosphorus requirements, the daily per capita phosphorus excretion, and the daily per capita phosphorus contribution to sewage.

The dietary requirements for phosphorus are exceedingly variable. Von Wazer [2] states figures from 150 U.S. dietaries as follows:

maximum – 18.9×10^{-3} lb PO_4/capita/day

minimum – 4.0×10^{-3} lb PO_4/capita/day

mean – 10.7×10^{-3} lb PO_4/capita/day

Hawk, Osser, and Summerson [3] in their text on practical physiological chemistry state that the daily per capita excretion of phosphorus in feces and urine amounts to about 11.5×10^{-3} lb as PO_4/capita/day. This figure is in agreement with the average dietary requirement stated by Von Wazer [2] with the assumptions that there is little, if any, accumulation of phosphorus in the mature human body and that the feces and urine are the major paths of phosphorus excretion.

When one examines sewage to determine the per capita sewage phosphorus contribution, several sources besides dietary contribution must be considered. The carriage water may contain phosphorus (though usually in small amounts); industrial wastes may contribute; waste food discharge to the sewer through garbage disposal may add further phosphorus (though this source has only of recent years obtained great significance); water infiltrating sewers from arable land may contain considerable amounts of phosphorus; and since the advent of synthetic detergents in about 1940 a further source of phosphorus has been added to sewage.

Pre-detergent estimates of per capita daily sewage phosphorus loadings have been made. In 1872 Letheby [4] reporting on "The Sewage Question" gave the per capita phosphorus content of London raw sewage as 12.1×10^{-3} lb as PO_4/capita/day.

Veatch, 1938, [5] reported between $6.4–9.9 \times 10^{-3}$ (mean 7.25×10^{-3}) lb as PO_4/capita/day in U.S. raw sewages while in 1947 Rudolfs [6] found for United Kingdom, U.S., and German raw sewages per capita loadings of between $6.6–9.9 \times 10^{-3}$ lb as PO_4/capita/day. These estimates are all of the same order as the expected amount of phosphorus excreted by a person in a day indicating that excretion of dietary phosphorus was the major contributor to sewage phosphorus. Folwell, 1936, [7] however, makes a higher estimate of 22.4×10^{-3} lb as PO_4/capita/day for U.S. raw sewage.

The per capita sewage phosphorus loadings have, in general, increased as can be judged by comparing measurements made prior to 1950 with those made more recently. It was about that time that synthetic detergents gained wide acceptance and popularity. This is not, of course, tantamount to saying that the whole increase in sewage phosphorus content is due solely to synthetic detergents; other changes, e.g., the greater use of household garbage disposal units and the increased standard of living could also contribute to this increase.

In 1958 Deitz and Harmeson [8] calculated from data collected by analysis of Illinois streams that the phosphorus contribution from domestic sewage could range from $9.5–117 \times 10^{-3}$ lb as PO_4/capita/day. Other work on the domestic sewage phosphorus contribution has given much narrower ranges of figures because the direct analysis of sewage was employed rather than computations based on stream analysis. Engelbrecht and Morgan [9] determined that between $14–35 \times 10^{-3}$ lb as PO_4/capita/day was present in Illinois sewage effluents. Harkness and Jenkins [10] determined the per capita phosphorus contribution in a purely domestic sewage in England to be between $23.2–34.6 \times 10^{-3}$ lb as PO_4/capita/day.

Of the estimates of the phosphorus contribution of synthetic detergents to domestic sewage, none have been performed using a materials balance technique so that the detergent input and output from the community could be checked for agreement.

Sawyer [11] in 1950 estimated that the detergent industry contribution was about 13.4×10^{-3} lb as PO_4/capita/day while an estimate of 16.1×10^{-3} lb as PO_4/capita/day was made in 1955 by the American Association of Soap and Glycerine Producers [12]. Harkness and Jenkins [10] used an average ABS/PO_4 input ratio found by analysis of several packaged detergent products to determine the percentage phosphorus contribution to sewage attributable to synthetic detergents. They estimated that 21 per cent of sewage phosphorus was from this source. However, their results were not checked by an ABS input-output balance. Voss [13] in an estimate derived from the detergent usage and the average detergent composition in the Lake Constance area of Switzerland found the detergents' contribution to sewage was about 4.1×10^{-3} lb as PO_4/capita/day which gave a figure of 36 per cent for the fraction of sewage phosphorus derived from detergents.

Huber [14], though giving no background data on his method of computation, arrived at a detergent phosphorus contribution to domestic sewage on the order of 20–25 per cent of the total sewage phosphorus.

THE INVESTIGATION

It was a major objective of this study to place on a quantitative basis the amount of sewage-borne phosphorus in a purely residential community which was directly attributable to synthetic detergents, through the use of a materials balance technique.

ACKNOWLEDGMENTS

The investigation was supported by a research grant to The Regents of the University of California from the Soap and Detergent Association.

This study was carried out under the co-faculty investigatorship of Professors David Jenkins and P. H. McGauhey. Professor Jenkins served as project director.

In the field phase of the investigation Mr. Larry W. Esvelt served as Project Engineer. Mr. Lloyd L. Medsker was Project Chemist in the latter part of the study and carried out the work on methodology and sample preservation. Messrs. Earl S. Flowers, Takashi Asano, and Paul Graham analyzed the seemingly endless succession of samples of water and sewage taken during the earlier phases of the Project.

The entire staff of the Valley Community Services District are to be heartily thanked. Without their cooperation this study would have truly been impossible. Special thanks are due to Mr. Jack Wright (formerly Manager and Engineer to the District and now City Engineer of Emeryville, California). Mr. Jack Muir, Superintendent of the District's Water Pollution Control Plant, is thanked for his enthusiastic cooperation in the sewage sampling program, for supplying sewage flow and composition data, and for furnishing plant operating records and details of the village sewerage system. He and his operating staff assisted in the sewage sampling program.

The VCSD Recreation Department and their band of young helpers made the survey of San Ramon Village a resounding success.

Mr. Ben Harry, the Editor of the "Village Pioneer," deserves our praise for the very effective publicity given to the Investigation through his organization.

Safeway Stores, Inc. gave the Investigation a high degree of cooperation. Mr. Fred Trummer, manager of Store 648 in San Ramon Village, made available his sales records on detergents. Mr. F. S. Szymanski, Account Manager, allowed the project to use records of detergent deliveries to the San Ramon Village Store.

Messrs. Bill Deleuchi and Emmett Spencer of the FMC Corporation are thanked for their technical assistance.

The members of the Soap and Detergent Association's Phosphate Committee, especially Messrs. Theodore E. Brenner, P. J. Weaver, M. V. Trexler, and Clayton Callis, are thanked for their constructive criticism and invaluable information on detergent brand composition.

II. ORGANIZATION OF THE INVESTIGATION

DESCRIPTION OF STUDY AREA

In making the choice of a community on which a study of the sources of sewage phosphorus could be made it was decided that the ideal community should:

1. Be close to SERL.
2. Be a typical community.
3. Be a domestic community (no industry).
4. Be tightly sewered (no infiltration water).
5. Be fairly isolated (inter-community marketing limited).
6. Have accurate population records available.
7. Have good sewage treatment plant records available.
8. Have a good relationship with the University.
9. Have a major identifiable source of detergents.

San Ramon Village fitted most of these criteria. Perhaps the most serious deviation from ideal was the fact that one could hardly call the community a typical one. Factors which contributed to its atypical nature were:

1. Its very hard domestic water supply.
2. An extremely rapid rate of population growth.
3. The unestablished nature of the community.

However, the disadvantages were far outweighed by the advantages of this site for the study. San Ramon Village is located in Livermore Valley approximately 40 miles southeast of Berkeley, California. The development is entirely residential and since 1960 has been constructed by two or three developers who offer single-family dwellings in the price range from $15,000 to $30,000. There are a few multiple-dwelling units.

At the time of the study about 700 acres of the area were developed but construction was still proceeding at a rapid rate. (Cf. Figure 1.)

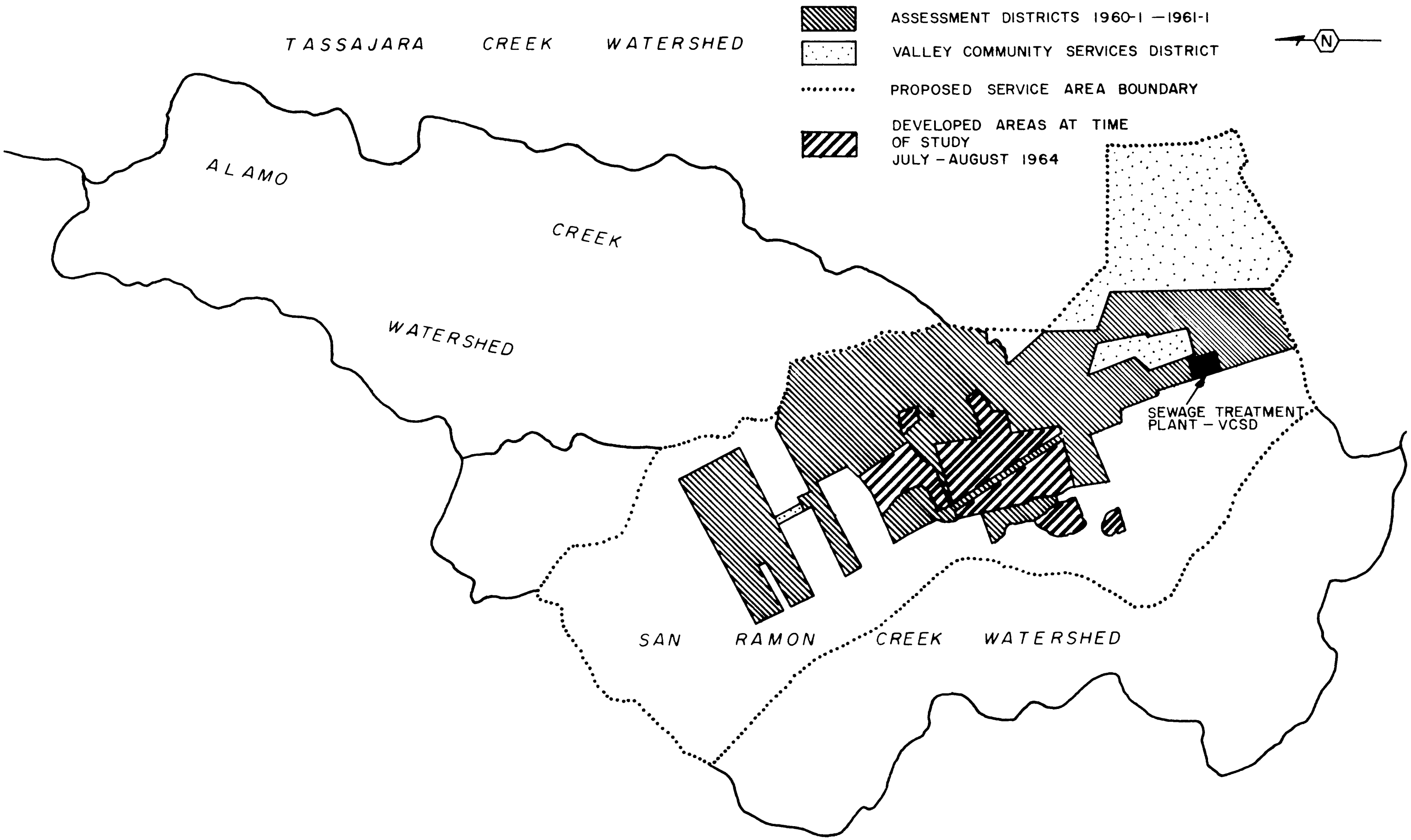

FIGURE 1. SAN RAMON VILLAGE AND SURROUNDING AREA SHOWING BOUNDARIES OF VALLEY COMMUNITY SERVICES DISTRICT

The area's needs for water, fire protection, recreational facilities, and sewage disposal are met by a Community Services District named Valley Community Services District (VCSD). Such Services Districts are public agencies organized and governed in accordance with the provisions of the government code of the State of California. They can only be formed in unincorporated territory but their boundaries may cross county lines.

The VCSD water supply originates from two general sources--a system of 3 wells within the confines of the District and South San Francisco Bay aqueduct water purchased from Zone 7 of the Alameda County Water Conservation and Flood Control District. During the study period the water supplied to San Ramon Village consisted of about 64 per cent well water and 36 per cent Zone 7 purchased water. Average water quality characteristics presented in Table I demonstrate that the water supply can be classified as very hard.

TABLE I

DOMESTIC WATER QUALITY CHARACTERISTICS
DURING THE STUDY PERIOD

Characteristic	Well Water	Zone 7 Water
Total Solids, mg/l	558	496
Conductivity, μ mhos	890	630
Total Hardness, mg as $CaCO_3$/l	184	250
Chloride, mg/l	120	26
pH	7.7	7.7

The sewerage system serving the area consists of round concrete pipe sewers with sealed joints to prevent ground water infiltration. The system is extremely tight as evidenced by the treatment plant flow records which show no increase in flow during periods of heavy rainfall. The sewerage system carries the completely domestic sewage of the area to a treatment plant located approximately 2 miles from San Ramon Village. The VCSD has a policy of mandatory hookup to the sewerage system. This proved to be of considerable help to the project since it was possible to obtain accurate population estimates from the VCSD records on numbers of sewer connections.

The sewage treatment plant, designed by Brown and Caldwell Engineers, was completed only recently, in September 1961. The plant, designed for an initial capacity of 2 mgd, treats the sewage by the activated sludge process. The excellent plant records maintained by VCSD greatly assisted the execution of the study.

The only store in the village in which soaps, detergents, and cleansers could be purchased was a supermarket operated by Safeway Stores, Inc. The next market was about six miles away. It was therefore surmised that a large proportion of the San Ramon Village residents would carry out their marketing at the Village Safeway Store and this would fill the criterion for an easily identifiable source of detergent materials.

APPROACH RATIONALE

In order to derive a quantitative estimate of the amount and sources of phosphorus in the domestic sewage of a community, it was decided that a materials balance approach would be the most suitable. This type of approach would first identify the major contributors of phosphorus to a sewage and then determine the magnitude of each contribution. Concurrently, the magnitude of the phosphorus content of the sewage from the community would be determined by analysis. Using this approach a balance between input (to the sewage) and the sewage phosphorus content found by analysis could be made.

The following input sources of phosphorus were identified:

1. Domestic wastes--including feces, urine, and waste food disposed of by garbage grinders.

2. Industrial wastes--this source was eliminated because of the absence of any industry in the system.

3. Infiltration water--this source was also eliminated by the extremely tight sewerage system.

4. Carriage water--the phosphorus content of the domestic water supplied to the Village was measured.

5. Detergents and other cleansing products--this source could be quantitated by a determination of detergent sales (or consumption) followed by an analysis of the detergent products to determine their phosphorus content. In order to make a measurement of the detergent phosphorus contribution a reliable estimate of detergent sales to the Village community was necessary. To accomplish this the Village population was surveyed using a questionnaire designed mainly to determine their detergent, soap, and cleanser purchasing habits. The details of this survey and the results it yielded are discussed later in the report.

The phosphorus (and ABS) content of the detergent brands constituting the major part of the product sales to the village was determined first by analysis of products taken from the shelves of the Village Safeway Store. When it was demonstrated that a large analytical error was introduced into the results by the procedures followed in this analysis, it was decided to use the figures for phosphorus and ABS provided by the manufacturers of the various detergent products, through the Soap and Detergent Association.

The analysis of the raw sewage for phosphorus was performed on 24-hour composite raw sewage samples taken after the screens at the VCSD sewage treatment plant.

III. METHOD OF PROCEDURE

THE SURVEY

The primary purpose of the survey of the San Ramon Village population was to gather information on the detergent, soap, and cleanser purchasing habits of the community. Questions regarding brand, size of package, and frequency and place of purchase were asked. Other information essential to the study for characterization of the community was gathered, viz.:

1. The number of persons in each residence. Using an average figure in combination with the VCSD sewer connection record it was possible to establish the population tributary to the sewerage system.

2. The amount of time spent outside the Village by the residents.

3. The number of adult residents.

4. The number of residences containing garbage disposals, washing machines, and automatic dishwashers.

5. The amount of laundry done outside San Ramon Village.

The survey was preceded by an information campaign designed to alert the residents to the purposes of the study in their community. The preliminary information was also intended to place the residents in a cooperative and receptive frame of mind since it was learned that the presence of large numbers of door-to-door salesmen who were circulating in the community had produced a feeling of frigidity and even open resentment toward strange callers at the front door.

A letter explaining the nature and purpose of the project (Appendix A, Figure A-1) was sent to all the telephone listings for San Ramon Village in the Southern Alameda County telephone directory (some 1300). Together with this letter was enclosed a sample questionnaire identical to the one used later in the survey (Figure A-2). In addition, a one-fourth page advertisement was run in the local (free home delivery) weekly newspaper "The Village Pioneer" to apprise the residents of the noncommercial nature of the survey that was to be conducted (Figure A-3).

The survey was conducted on a house-to-house basis by 17 teenagers in the summer employ of the Recreation Department of VCSD. The use of these youngsters identified by their distinctive red jackets, and known locally by the village residents, greatly expedited the conduct of the survey. "The Village Pioneer" also publicized the use of VCSD Recreation Department personnel by running a front page photograph of some of the participating persons.

The survey was conducted mainly in the evening hours between 1730 and 2030. Each house was approached only once. If the householder had filled out the sample questionnaire mailed to him previously it was accepted. If not, the surveyor either had the householder fill out the questionnaire or he asked the questions and recorded the answers himself. The survey was started on 20 July 1964 and was completed by 31 August 1964.

DETERGENT SALES

Estimating the detergent input to the San Ramon Village proved to be one of the more difficult aspects of the study. The first method used was based on the results of the survey that showed 71.5 per cent of the surveyed population purchased their detergents from the Village Safeway Store. Consequently the sales records of the Safeway Store were examined for the 12-week period just prior to the commencement of the study. The sales figures for the brands of household detergents, liquid detergents, and dishwasher detergents which constituted the great majority of detergent products sold by the store were recorded. On converting these sales figures into "lb ABS input week" and "lb phosphorus input week" using product mix analyses produced by the Soap and Detergent Association, it was found that the weekly input of ABS to the Village far exceeded the amount of ABS found by analysis in the sewage. The sales figures of the Village Safeway Store were suspected as the source of error.

Since the package detergent "Tide" was by far the sales leader at the Village Safeway Store it was decided to check the Safeway Store's sales figure for "Tide" against the results obtained from the questionnaire, i.e., what the population said they had bought. This method gave "Tide" consumption figures even higher than the "Tide" sales figures from the Village Safeway Store.

It was then learned that the Village Safeway Store very often offers a sales promotion on "Tide." It so happened that such a sales promotion was taking place during the period covered by the Store's sales figures which were given to the study. It was also suspected that the "Tide" purchasing figures derived from the survey questionnaire would reflect the higher "Tide" input to the system during such sales promotions. Thus both these methods of detergent sales estimation were suspected of being very sensitive to short term fluctuations in sales. When the store offers a reduced price on an item it could be expected to sell more than the average amount of that item; when a housewife can obtain an item cheaper one would expect that she would buy more than usual (and more than she would use immediately).

Since the estimation of detergent output from sewage analyses reflected the real demand for detergents, a true input figure for ABS could only be obtained from sales figures if these were known over an extended period of time when fluctuations caused by sales promotions would be evened out.

Through the courtesy of the Safeway Stores, Inc. it was possible to obtain such an estimate. The delivery records from the Safeway Central

Wholesaling Warehouse to the San Ramon Village Safeway Store were obtained for the period March through September 1964 for the detergent products constituting the majority of detergent materials sold. Average weekly sales were computed from the figures for this extended period and converted to ABS and phosphorus using information supplied by the Soap and Detergent Association.

SEWAGE SAMPLING AND SAMPLE PRESERVATION

Raw sewage was sampled at the VCSD sewage treatment plant for three one-week periods, 13-19 July, 27 July—2 August, and 10-17 August. Hourly grab samples were taken of the sewage after it had passed through the "Barminutor" screens. Each sampling day began at 0800 and ended at 0700 on the following day. One set of the duplicate grab samples was preserved with about 40 mg/l mercuric chloride, then stored at room temperature while the second aliquot was refrigerated at 4°C. The hourly grab samples were composited in ratio to the flow to the plant at the time of sampling, using 100 ml of sample per 1 mgd flow.

The composite of preserved samples was used for analysis of COD, ABS, and phosphorus forms while the unpreserved sample was used for BOD, suspended solids, ammonia nitrogen, and total unoxidized nitrogen determinations.

ANALYSIS OF SEWAGE AND CARRIAGE WATER

Common Sanitary Chemical Analyses

Biochemical Oxygen Demand. BOD was determined by the method given in Standard Methods, 11th Edition, p. 318 [15].

Chemical Oxygen Demand. COD was determined by a method similar to that given in Standard Methods, 11th Edition [15] except that silver sulfate was used as a catalyst and mercuric sulfate was added to complex chloride ion as $HgCl_2$ to prevent its oxidation during the test (Cripps and Jenkins [16]).

Suspended Solids. Suspended solids were determined by the membrane (Millipore) filter technique of Winneberger *et al.* [17]. This technique eliminates the common gravimetric errors associated with the handling of membrane filters; i.e., hygroscopicity, loss of soluble filter components, and electrostatic effects.

Ammonia Nitrogen. Ammonia nitrogen was determined by the distillation and nesslerization technique outlined in Standard Methods, 11th Edition, p. 168 [15].

Total Nitrogen. Total nitrogen was determined by the distillation and titration method given in Standard Methods, 11th Edition, p. 305 [15], except that a methyl red/alphazurine (Patent Blue A) indicator was used for end point determination [18].

pH. pH measurements were performed using a Radiometer 22 pH meter.

Methylene Blue Active Substances (MBAS). ABS was measured in water and sewage samples as methylene blue active substances by the technique given in Recommended Methods for the Analysis of Trade Effluents [19]. The technique gave satisfactory results when applied to water and sewage samples but not when used for the analysis of dilute solutions of marketed detergent products.

Differentiation and Analysis of Phosphorus Forms

Differentiation. An initial classification of the forms of phosphorus that might exist in a domestic sewage was made on the basis of the following assumptions:

1. There was an insignificant amount of insoluble orthophosphate.

2. There was an insignificant amount of insoluble polyphosphate.

3. The insoluble phosphorus in sewage was all organic in nature.

4. There was an insignificant amount of soluble organic phosphorus in sewage (in comparison with the amounts of other forms of phosphorus).

The analytical scheme based on these assumptions is illustrated in Figure 2. This scheme of analysis was used throughout the study.

On further examination (after the analytical survey of the sewage had been completed), it was found that this scheme of analysis was in error because of the significant amounts of insoluble ortho- and polyphosphate present in the sewage. These quantities were significant because of the very hard carriage water in the area and were probably due to precipitation of poly- and to a lesser extent orthophosphates as calcium or magnesium salts. The effect that the analytical error had was to give low results for ortho- and polyphosphate. Since the only significant source of polyphosphate in the raw sewage was from synthetic detergent and cleansing products it was important to obtain an accurate figure for this entity so that it could be used as a check on the results for the detergent phosphorus contribution obtained from an input-output phosphorus balance. In order to correct the original values for the error in ortho- and polyphosphate, a revised scheme of analytical differentiation of phosphorus forms (Figure 3) was used to analyze samples of VCSD raw sewage in parallel with analyses made by the scheme used during the raw sewage survey. On the basis of the results obtained from this comparative study a correction factor was developed which could be applied to the original polyphosphate results. The correction factor, which varied with the polyphosphate concentration (see Figure 4 and Table II), was as follows:

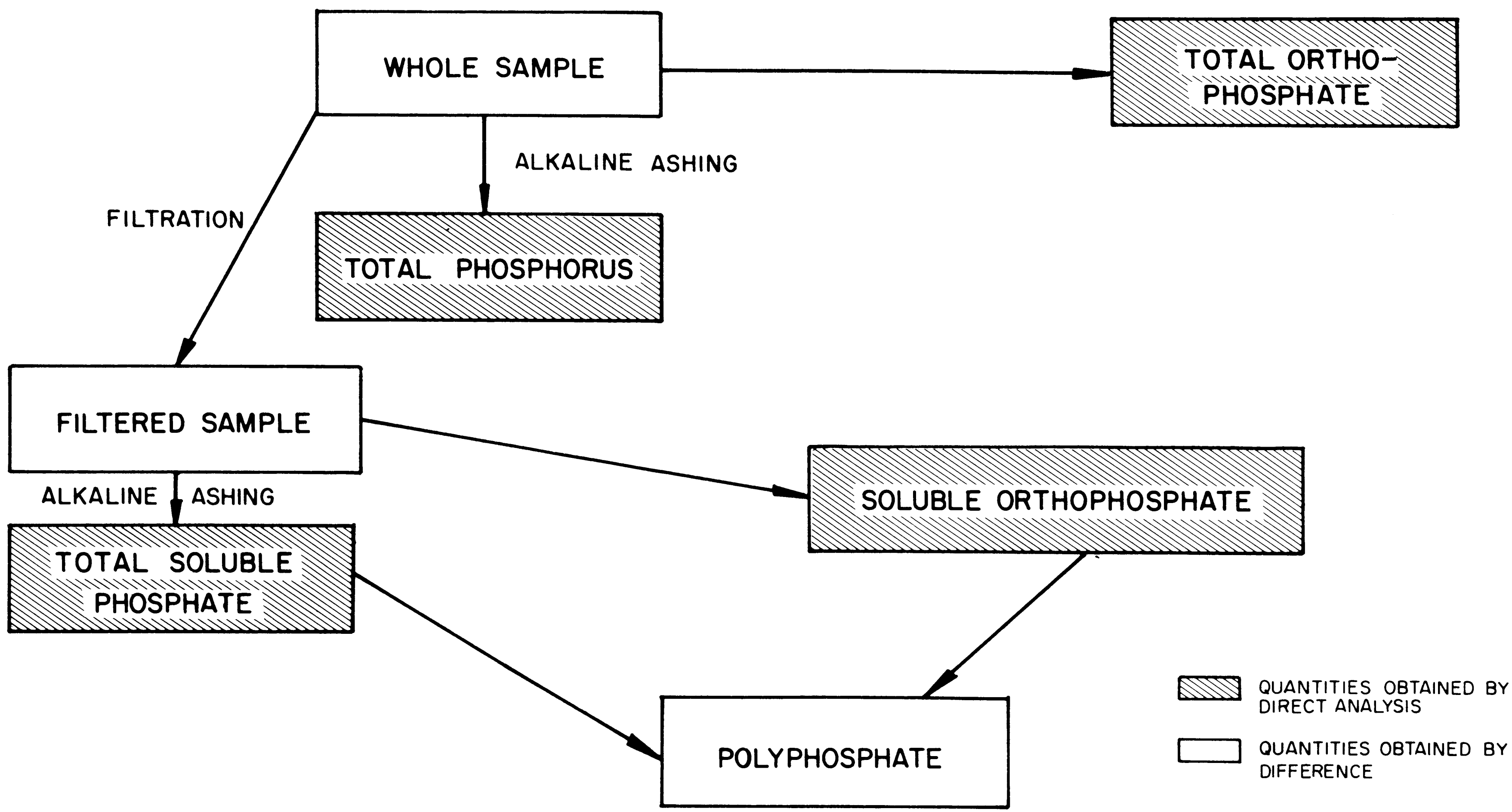

FIGURE 2. ORIGINAL ANALYTICAL SCHEME FOR DIFFERENTIATION OF PHOSPHORUS FORMS IN SEWAGE

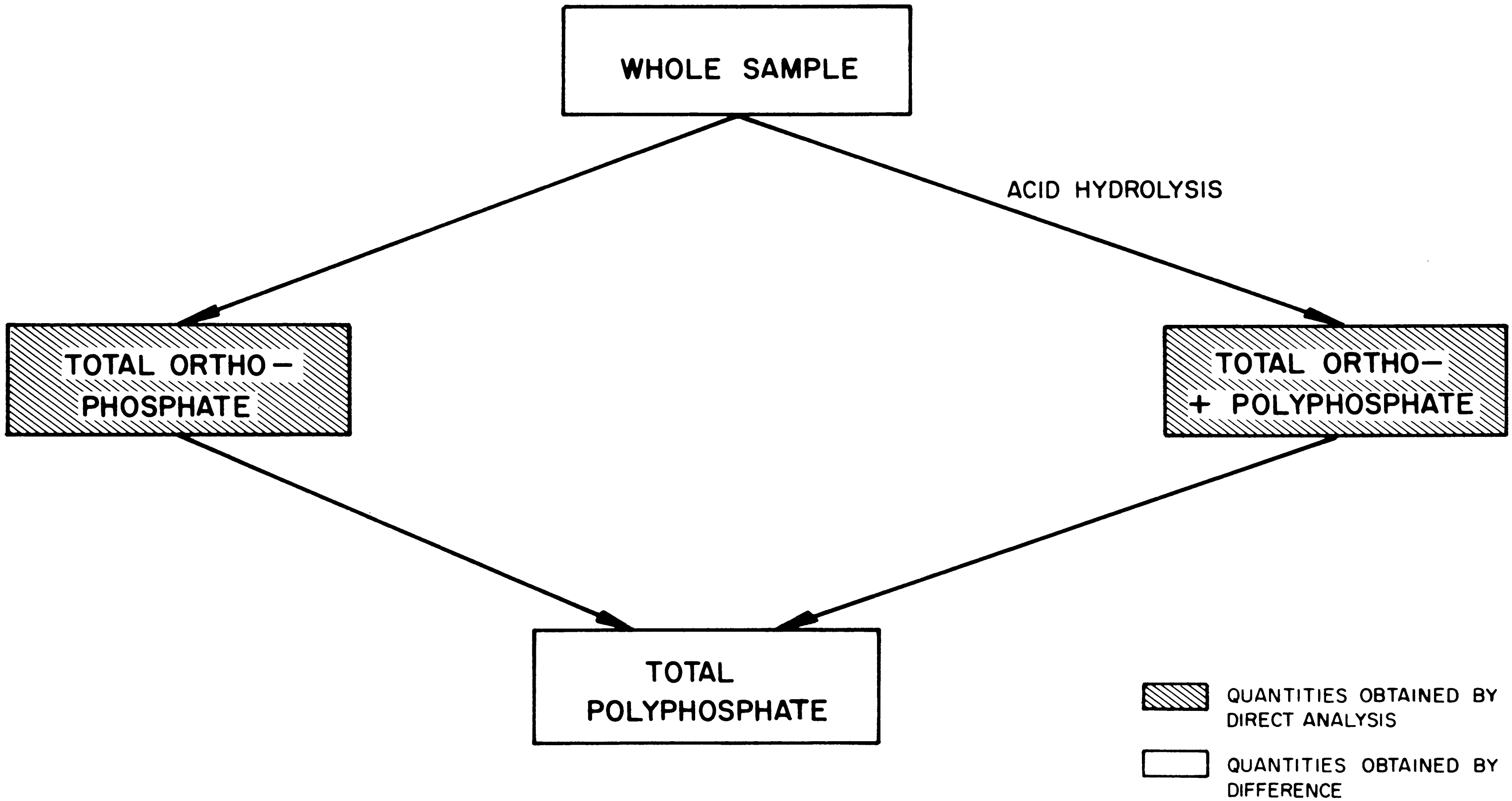

FIGURE 3 . ANALYTICAL SCHEME USED FOR CORRECTION OF ORIGINAL ORTHO- AND POLYPHOSPHATE DATA

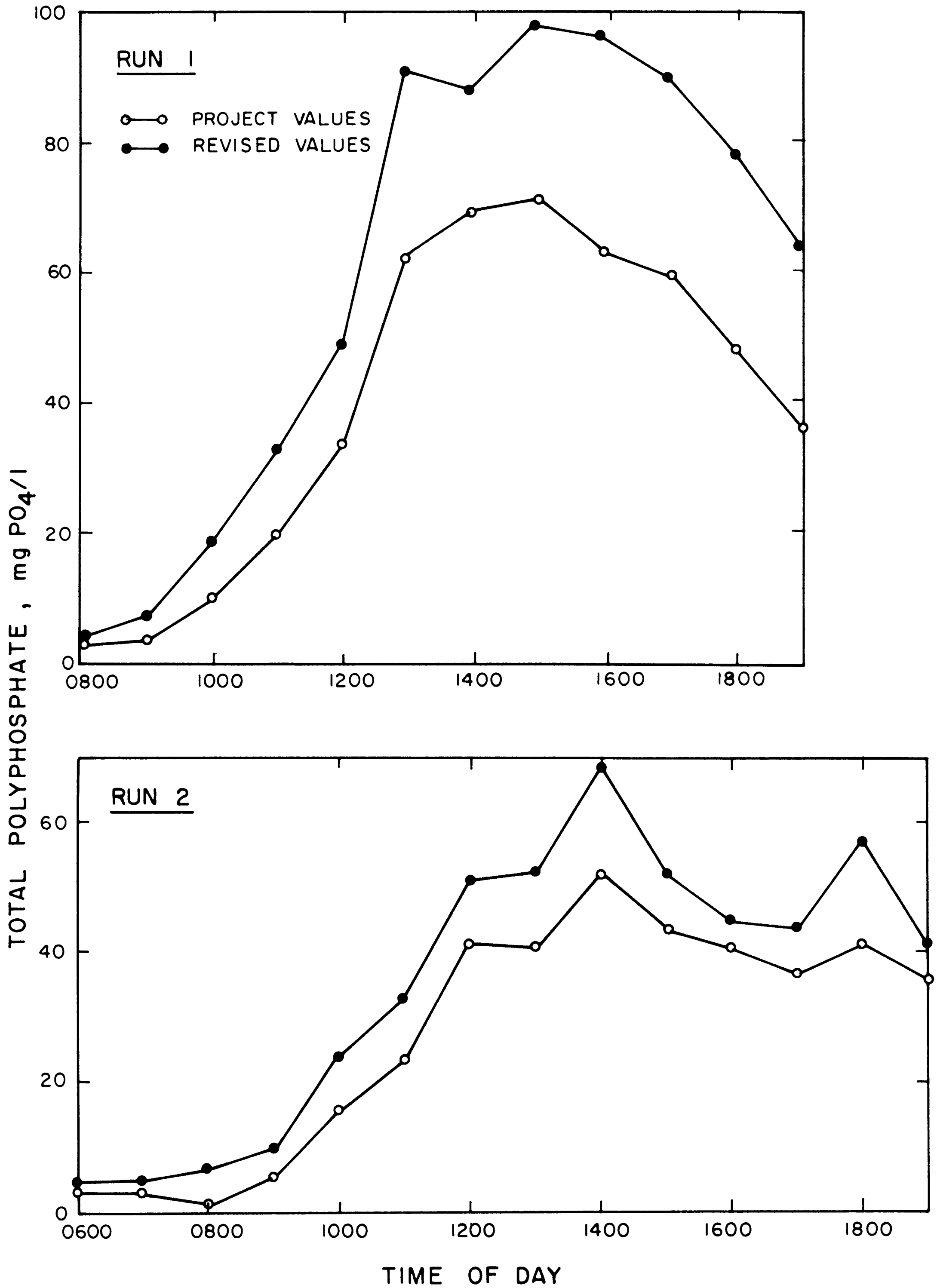

FIGURE 4. COMPARISON OF PROJECT AND REVISED POLYPHOSPHATE VALUES

TABLE II

CORRECTION OF PROJECT POLYPHOSPHATE VALUES

Polyphosphate, mg as PO_4/l			Ratio of True Value to Revised Value
Project Value	True Value	Revised Value[a]	
1.6	6.6	--	--
2.7	4.3	4.3	1.00
3.2	5.1	5.1	1.00
3.3	7.5	--	--
3.3	4.5	5.3	.85
5.4	9.6	8.6	1.12
9.7	18.4	15.5	1.19
15.6	24.2	25.0	.97
19.9	32.7	31.9	1.02
23.2	37.9	37.1	1.02
33.6	48.7	53.8	.90
35.1	62.8	56.2	1.12
35.4	41.1	46.0	.90
36.9	43.6	48.0	.91
40.5	52.3	52.7	.99
40.6	44.9	52.8	.85
40.9	56.7	53.2	1.07
41.5	51.1	54.0	.95
43.6	52.0	56.7	.92
47.5	77.0	61.8	1.24
52.1	68.8	67.7	1.02
58.2	89.2	75.7	1.18
60.8	90.9	79.2	1.15
62.6	95.8	81.5	1.18
68.3	87.9	88.8	.99
70.3	97.5	91.4	1.07

[a]Correction Factors:
Polyphosphate $\leq$ 35 mg/l x 1.60.
Polyphosphate $>$ 35 mg/l x 1.30.

For polyphosphate ≦ 35 mg as PO_4/l, multiply original project value by 1.60.

For polyphosphate > 35 mg as PO_4/l, multiply original project value by 1.30.

During the first week of sewage sampling, orthophosphate analyses were performed on the filtered samples. In order to correct this first week's orthophosphate results to take account of the insoluble orthophosphate, a correction factor was developed (cf. Figure 5 and Table III) which was as follows:

For orthophosphate ≦ 20 mg as PO_4/l, multiply original project value by 1.09.

For orthophosphate > 20 mg as PO_4/l, multiply original project value by 1.23.

Based on the experience obtained during this project the scheme of analytical differentiation for the various forms of phosphorus in a sewage illustrated in Figure 6 is recommended. This scheme not only separates the various species of phosphorus (ortho, poly, and organic) but also enables the separation of each of these species into soluble or suspended fractions.

Methods of Analysis.

Total phosphate: Total phosphate was determined on a sample after alkaline ashing. A suitable sample volume was treated with 1 ml of 5% $MgCl_2 \cdot 6H_2O$ solution and evaporated to dryness on a steam table. The dried sample was ashed at 800°C for 1 hour. The residue was taken up in 10-ml acid molybdate solution and then treated as in the determination of orthophosphate.

Orthophosphate: The amino naphthol sulfonic acid (ANS) method outlined in Standard Methods, 10th Edition, was used with the following modifications:

1. Absorbance was read at 630 mμ instead of the recommended 690 mμ.

2. A smaller volume of strong-acid molybdate solution (3 ml instead of 4 ml) was used.

3. A shorter reaction time (6 min instead of 10 min) was used.

The two latter modifications were made to reduce the possibility of polyphosphate hydrolysis during the orthophosphate analysis.

Polyphosphate: In the original project analyses polyphosphate was measured by difference between total soluble and total orthophosphate.

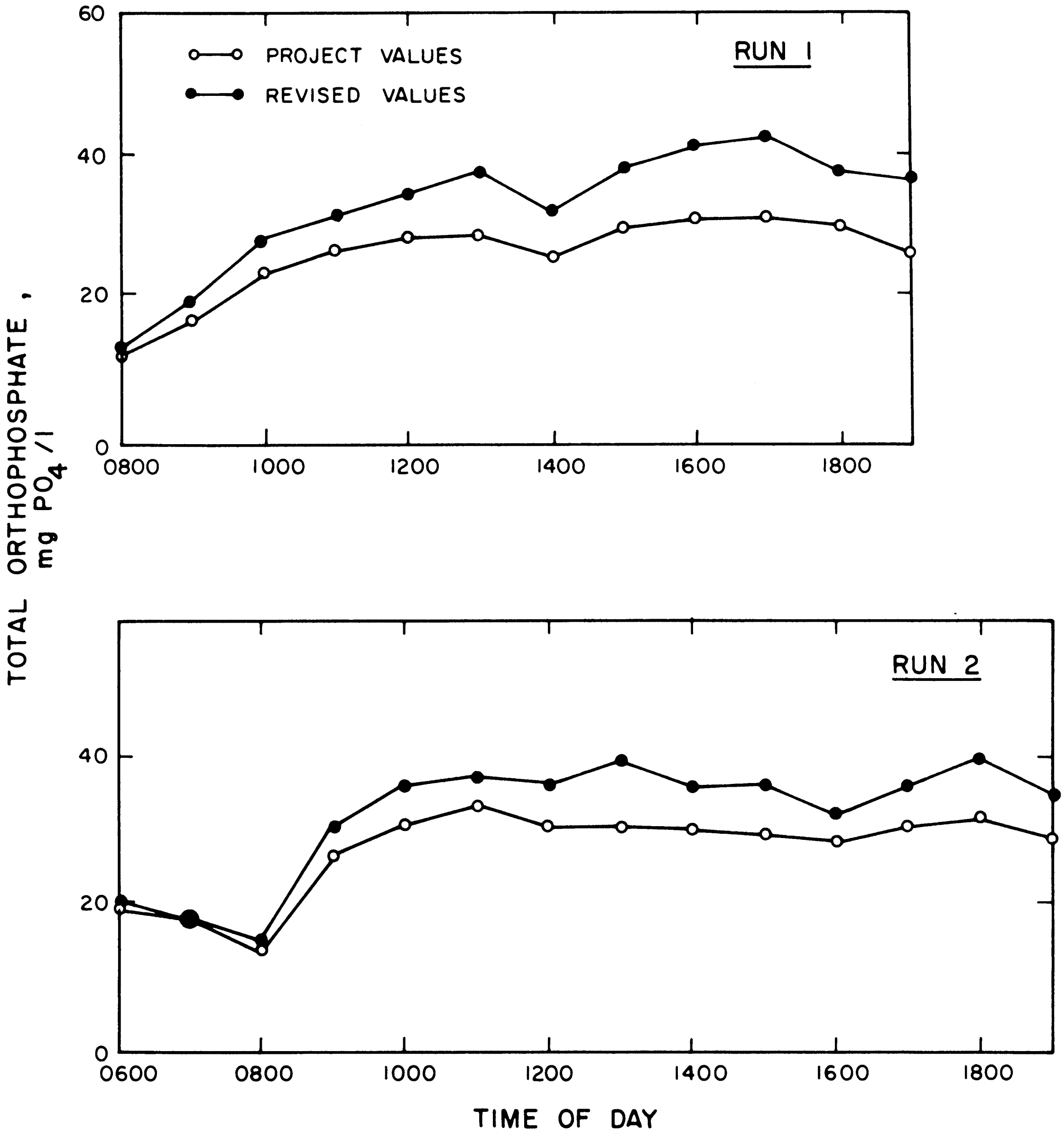

FIGURE 5. COMPARISON OF PROJECT AND REVISED ORTHOPHOSPHATE VALUES

TABLE III

CORRECTION OF PROJECT ORTHOPHOSPHATE VALUES

Orthophosphate, mg as PO_4/l			Ratio of True Value to Revised Value
Project Value	True Value	Revised Value[a]	
12.1	13.2	13.2	1.00
14.0	15.8	15.2	1.04
17.3	19.8	18.8	1.05
18.4	18.9	20.0	.95
19.7	20.5	21.4	.96
23.6	28.4	27.8	1.02
25.7	36.0	31.6	1.14
25.7	31.5	31.6	1.00
26.8	32.1	33.0	.97
27.4	31.1	33.7	.92
28.4	34.5	34.9	.99
28.4	37.4	34.9	1.07
29.2	33.3	35.9	.93
29.7	37.6	36.6	1.03
29.7	37.6	36.6	1.03
29.8	35.9	36.7	.98
30.4	37.5	37.4	1.00
30.8	40.3	37.9	1.06
31.0	42.0	38.2	1.10
31.1	37.0	38.3	.97
31.1	37.2	38.3	.97
31.4	37.2	38.6	.96
31.7	37.2	39.0	.95
31.7	40.4	39.0	1.03
32.5	41.0	40.0	1.02
34.4	38.1	42.3	.90

[a]Correction Factors:
Orthophosphate $\leq$ 20 mg/l x 1.09.
Orthophosphate $>$ 20 mg/l x 1.23.

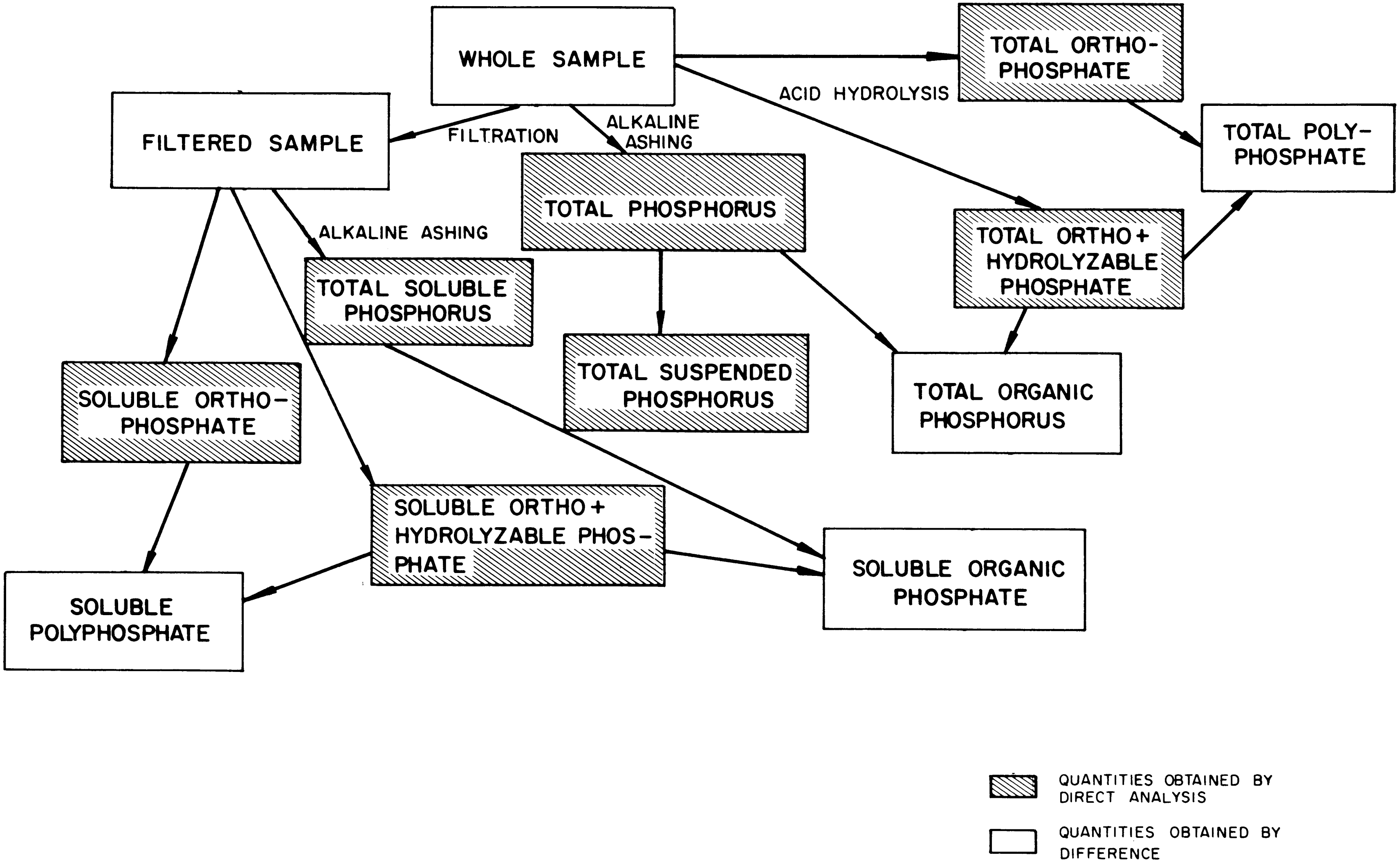

FIGURE 6. RECOMMENDED SCHEME FOR DIFFERENTIATION OF VARIOUS FORMS OF PHOSPHORUS IN RAW SEWAGE

In later work polyphosphate was determined by difference between total ortho + hydrolyzable phosphate and total orthophosphate.

Comparison of Methodology with American Soap and Glycerine Producers Methods. The foregoing methodology was compared with a reference procedure published by the American Association of Soap and Glycerine Producers (AASGP) [20] which employs a nitric/sulfuric acid digestion for total phosphorus determination. The colorimetric determination of phosphate is made using stannous chloride as a reducing agent for the molybdo-phosphate complex. In order to prevent hydrolysis of polyphosphate during the analysis, the technique calls for the immediate extraction of the molybdo-phosphate complex into a benzene-isobutanol solvent mixture.

The results of the comparative studies of the SERL and AASGP methods for the analysis of raw sewage from VCSD and from Richmond, California are presented in Table IV. The results of replicate analyses from which the means in Table IV are derived are presented in Appendix B. There is no significant difference in the precision of the SERL and AASGP methods as evidenced by the data on standard deviations and coefficients of variation presented in Table V. Both series of methods have extremely good precision.

There is no significant difference in the orthophosphate values found by the two methods which indicates that the SERL method does not cause polyphosphate reversion to orthophosphate. This conclusion was further verified by using the SERL orthophosphate method to analyze solutions of pure sodium tripolyphosphate supplied by the California Research Corporation. In these experiments no reaction attributable to orthophosphate was detected.

A significant difference was found to exist between the values obtained for total phosphate by the two methods. The AASGP method gave results which were consistently lower than the SERL method.

On further investigation it was noted that the AASGP method stated that the same standard curve should be used in the ortho-, ortho + hydrolyzable, and total phosphate analyses. However, the conditions in the ortho- and ortho + hydrolyzable phosphate analyses differ from those in the total phosphate determination. In the ortho- and ortho + hydrolyzable method 40 ml aqueous phase and 50 ml of an organic phase consisting of a 1:1 mixture of benzene:isobutanol is used, while in the total phosphate analysis 225 ml aqueous phase and 67 ml of an organic phase composed of 50 ml 1:1 benzene:isobutanol and 17 ml isobutanol is employed. Thus, not only is there a difference in solvent to aqueous phase ratio but also in solvent composition.

Using separate standard curves, one for ortho- and ortho + hydrolyzable phosphate and another for total phosphate, employing the same conditions of solvent to aqueous phase ratio and solvent composition used in the actual tests, it was demonstrated that the SERL and AASGP methods for total phosphate gave identical results.

It is therefore recommended that the foregoing modifications be introduced into the AASGP method for total phosphate.

TABLE IV

COMPARISON OF AASGP AND SERL METHODS FOR PHOSPHATE DETERMINATIONS IN RAW SEWAGE

Method	Ortho mg as PO_4/l	Ortho + Hydrolyzable mg as PO_4/l	Total, mg as PO_4/l	
			AASGP Standard	SERL Standard

A. VCSD Raw Sewage (mean of 5 analyses)

Method	Ortho mg as PO_4/l	Ortho + Hydrolyzable mg as PO_4/l	Total, AASGP Standard	Total, SERL Standard
Unfiltered Sample				
AASGP	30.6	57.8	57.1	63.7
SERL	31.9	--	--	64.3
Filtered Sample				
AASGP	27.0	47.2	43.4	48.5
SERL	25.8	--	--	47.9

B. Richmond Raw Sewage (mean of 3 analyses)

Method	Ortho mg as PO_4/l	Ortho + Hydrolyzable mg as PO_4/l	Total, AASGP Standard	Total, SERL Standard
Unfiltered Sample				
Reference	14.5	23.9	23.9	26.7
AASGP	13.9	--	--	26.6
Filtered Sample				
Reference	13.5	21.8	20.0	22.3
AASGP	13.8	--	--	22.1

Changes in Phosphorus Forms Taking Place Prior to Analysis

The changes that forms of phosphorus might undergo between their discharge to the sewer and time of analysis can be divided into two categories: first, those before sampling and after discharge to the sewer; and secondly, those after sample collection and preservation and before analysis.

The changes in the sewer system before sample collection could be biochemical, chemical, or physical while those occurring in a preserved sample (where the purpose of preservative is to halt biochemical changes) should only be chemical and physical.

TABLE V

PRECISION OF SERL AND AASGP ANALYTICAL METHODS FOR VARIOUS FORMS OF PHOSPHATE

Analysis	Standard Deviation mg/l		Coefficient of Variation %	
	SERL	AASGP	SERL	AASGP
A. VCSD Raw Sewage				
Filtered ortho	0	0.30	0	1.1
Unfiltered ortho	0.54	0.66	1.7	2.2
Filtered ortho + hydrolyzable	---	0.08	---	0.2
Unfiltered ortho + hydrolyzable	---	0.95	---	1.7
Filtered total	0.11	0.33	0.2	0.7
Unfiltered total	0.12	0.33	0.2	0.5
B. Richmond Raw Sewage				
Filtered ortho	0.12	0.12	0.8	0.9
Unfiltered ortho	0.25	0.26	1.8	1.8
Filtered ortho + hydrolyzable	---	0.36	---	1.7
Unfiltered ortho + hydrolyzable	---	0.56	---	2.3
Filtered total	0.3	0.21	1.4	0.9
Unfiltered total	0.35	0.21	1.4	0.8

Changes in Phosphorus Forms Prior to Sampling. Samples of VCSD raw sewage were taken, put on ice, and immediately transported back to the laboratory. An aliquot was taken and analyzed for phosphorus forms; the remainder of the sample was stirred gently on a magnetic mixer at room temperature. Aliquots were withdrawn for analysis at various time intervals. The results in Table VI and Figure 7 show that after 21 hours almost all of the soluble polyphosphate (approximately 30 mg as PO_4/l) had disappeared. Its disappearance was accompanied by an increase in soluble orthophosphate of equivalent magnitude. Changes in the other forms of phosphorus were minor in comparison.

TABLE VI

CHANGES OF PHOSPHORUS FORMS IN UNPRESERVED VCSD RAW SEWAGE UNDER STIRRED CONDITIONS AT ROOM TEMPERATURE

Time of Stirring, hr	Phosphorus Forms as mg PO_4/l							
	Total Phosphorus		Orthophosphate		Polyphosphate		Organic Phosphate	
	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble
A. Sewage Sampled 12 February 1965								
0	30.9	59.1	8.0	24.9	8.7	31.6	14.2	2.6
1	31.3	58.7	5.8	25.8	10.9	30.7	14.6	2.2
2	31.2	58.8	7.1	27.1	6.4	30.5	17.7	1.2
3	31.2	58.8	4.9	29.0	10.3	28.0	16.0	1.8
21	29.7	60.3	5.9	55.2	8.7	1.3	15.1	3.8
B. Sewage Sampled 17 February 1965								
0	16.0	56.8	3.9	26.3	8.1	27.4	4.0	3.1
3	17.2	55.6	5.0	28.4	8.1	24.2	4.1	3.0
19	19.3	52.6	5.0	50.8	7.5	2.4	6.8	0.3
21	21.0	51.8	7.9	49.2	6.8	1.8	6.3	0.8

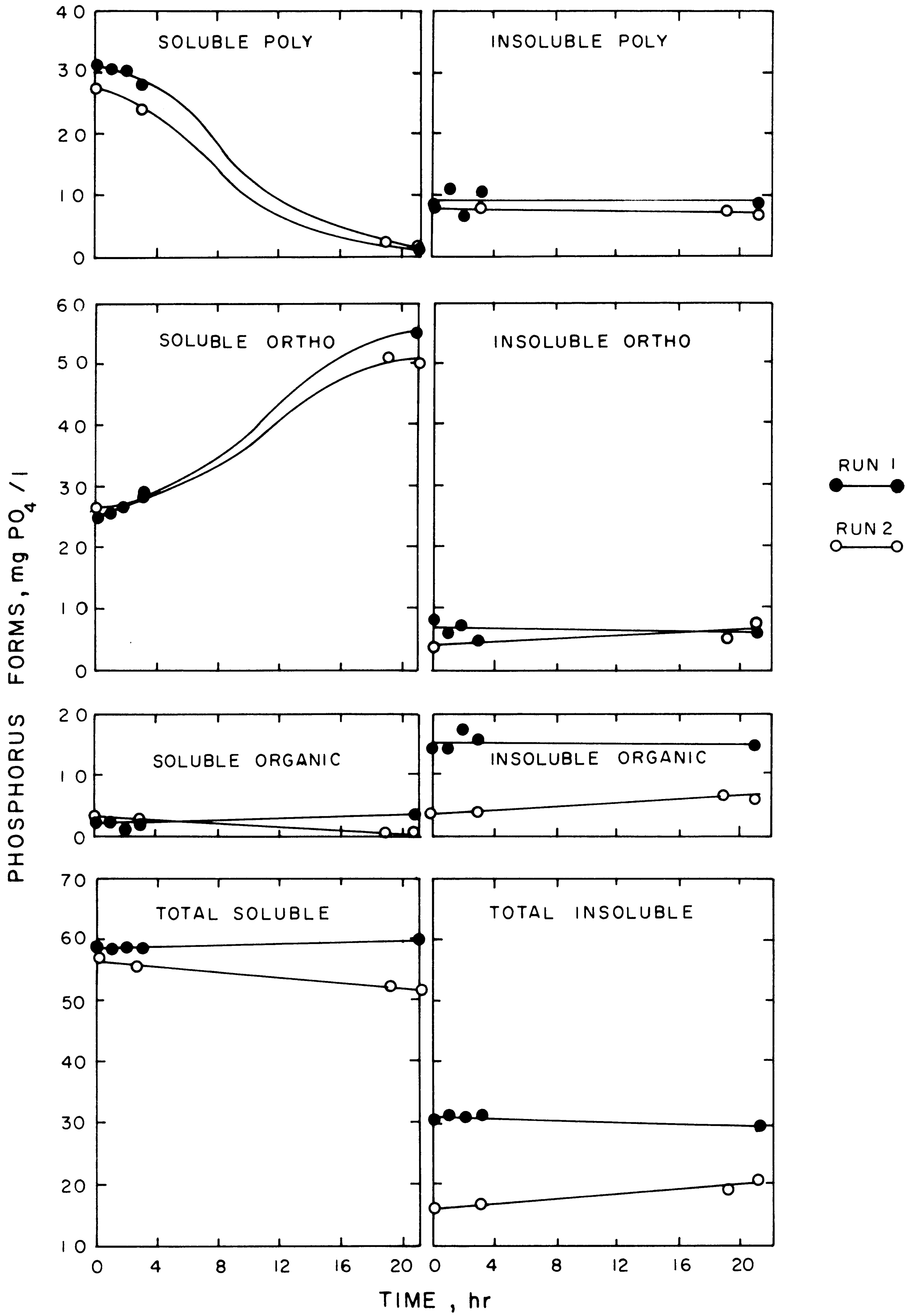

FIGURE 7. CHANGES IN PHOSPHORUS FORMS IN VCSD RAW SEWAGE UNDER STIRRED CONDITIONS AT ROOM TEMPERATURE

Changes in Phosphorus Forms between Preservation and Analysis. The first indication that changes in the forms of phosphorus may occur in a preserved sample was seen in the results of an experiment in which varying amounts of sodium tripolyphosphate were added to a Millipore-filtered VCSD raw sewage which had been depleted of its original polyphosphate content by natural hydrolysis. The sample had an initial orthophosphate concentration of 50 mg as PO_4/l. After standing for several hours the clear filtrate became increasingly turbid and analyses of a filtered aliquot of the turbid solution showed a decrease of both soluble poly- and orthophosphates. Orthophosphate precipitation, which occurred in the absence of any polyphosphate, was increased by the presence of polyphosphate indicating co-precipitation of ortho- and polyphosphate. Precipitation of polyphosphate became more pronounced as the concentration of polyphosphate was increased from 6 to 48 mg as PO_4/l (cf. Figure 8 and Tables VII and VIII). Since Millipore filtration is, for all practical purposes, a sterilization technique these changes could not be attributed to bacterial action. They therefore might be expected to occur in an unfiltered raw sewage sample which had been sterilized by chemical means such as those employed during the project's sewage sampling program.

Employing the same technique as that mentioned previously, a preserved VCSD raw sewage sample was stirred at room temperature and analyzed over a 21-hr period for various phosphorus forms. A decrease in soluble polyphosphate from about 30 mg as PO_4/l to between 7 and 8 mg as PO_4/l was noted. This decrease in soluble polyphosphate was accompanied by an increase of insoluble polyphosphate from about 5–6 mg as PO_4/l to approximately 24–25 mg/l. During this time the insoluble orthophosphate concentration doubled, changing from about 5–7 mg/l to about 12–13 mg/l. The increase in insoluble orthophosphate was not accompanied by an equivalent decrease in soluble orthophosphate indicating that some small amount of orthophosphate (either soluble or insoluble) on the order of 3–8 mg as PO_4/l was being formed. The most probable source was the hydrolysis of polyphosphate since it was shown that very little change in the organic phosphorus (either soluble or insoluble) took place (Table IX and Figure 9).

Another experiment was performed to determine the effectiveness of mercury as a preservative under normal quiescent storage conditions both at room temperature and in a refrigerator at 4°C. The results, shown in Table X and Figure 10, indicate that refrigeration is necessary as well as preservation with mercury if samples are to be stored for more than a day before analysis. Even in the presence of mercury at room temperature, significant decreases of both soluble and insoluble polyphosphate took place in 2 days with increases in soluble and insoluble orthophosphate. While these changes in phosphorus forms were not completely inhibited by refrigeration of the preserved samples, a very significant decrease in the rates of change was produced.

It is recommended that if preservation with mercury is to be used then the samples should be refrigerated and the analysis carried out within a period of 48 hours. In view of this conclusion it is further recommended that a more effective preservative than mercury be sought for sewage samples to be analyzed for various forms of phosphorus.

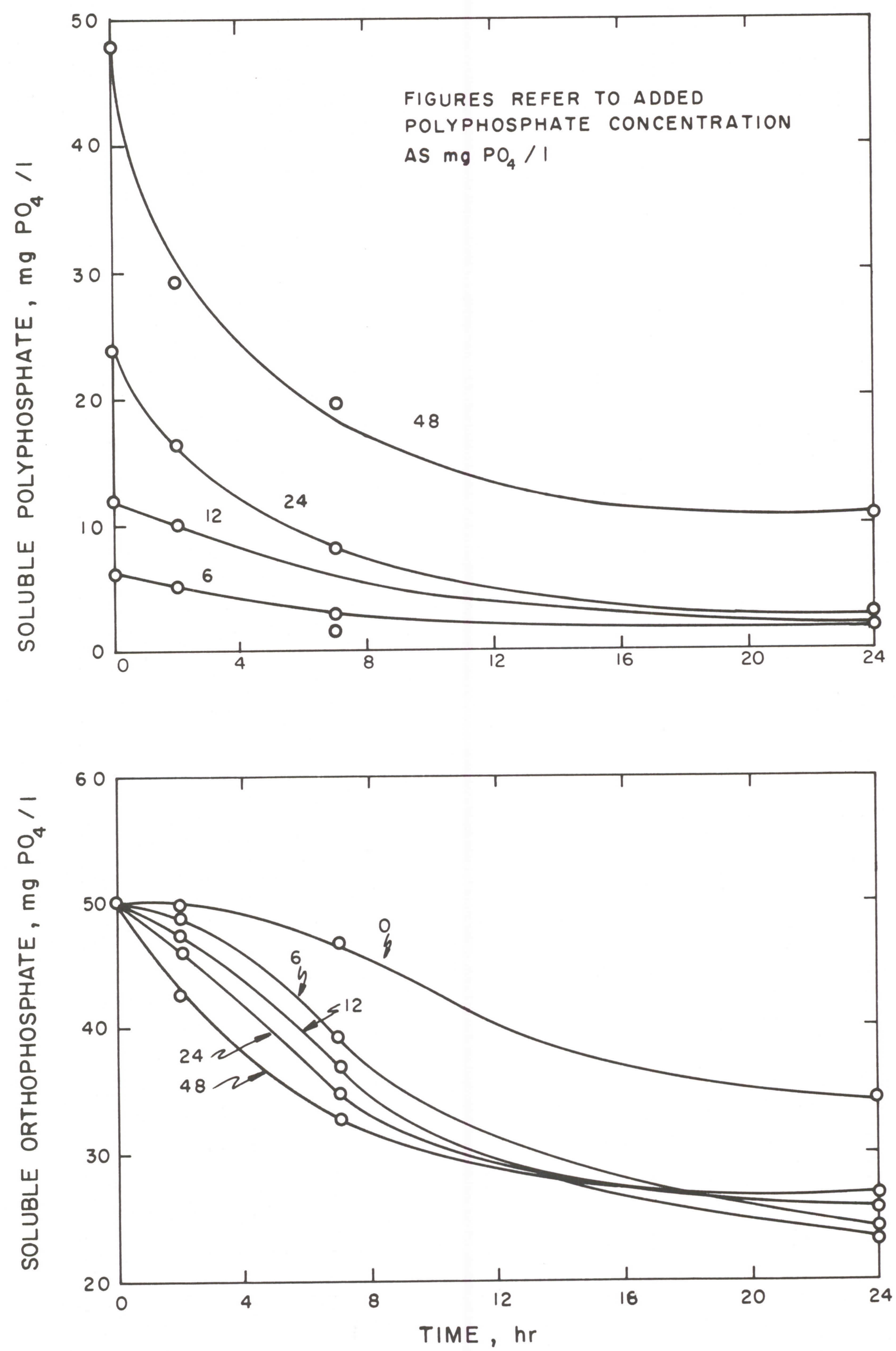

FIGURE 8 . CHANGES IN SOLUBLE ORTHO- AND POLYPHOSPHATE CONCENTRATION IN MILLIPORE FILTERED VCSD RAW SEWAGE UNDER QUIESCENT CONDITIONS AT ROOM TEMPERATURE

TABLE VII

PRECIPITATION OF POLYPHOSPHATE IN MILLIPORE-FILTERED VCSD SEWAGE UNDER QUIESCENT CONDITIONS AT ROOM TEMPERATURE

Time, hr	Tripolyphosphate Added as mg PO_4/l														
	0			6			12			24			48		
	Relative Turbidity	Soluble Polyphosphate Remaining		Relative Turbidity	Soluble Polyphosphate Remaining		Relative Turbidity	Soluble Polyphosphate Remaining		Relative Turbidity	Soluble Polyphosphate Remaining		Relative Turbidity	Soluble Polyphosphate Remaining	
		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%
0	0	--	--	0	6.0	100	0	12.0	100	0	24	100	0	48	100
2	0	--	--	10	5.0	83	21	10.0	83	51	16.2	67	135	29.4	61
7	7	--	--	122	2.8	47	182	1.6	13	252	8.2	34	317	19.6	41
24	257	--	--	> 500	1.8	30	> 500	1.6	13	> 500	2.6	11	> 500	11.2	23

TABLE VIII

PRECIPITATION OF ORTHOPHOSPHATE IN MILLIPORE-FILTERED VCSD RAW SEWAGE IN THE PRESENCE OF VARYING AMOUNTS OF POLYPHOSPHATE

Time, hr	Tripolyphosphate Added as mg PO_4/l														
	0			6			12			24			48		
	Relative Turbidity	Soluble Orthophosphate Remaining		Relative Turbidity	Soluble Orthophosphate Remaining		Relative Turbidity	Soluble Orthophosphate Remaining		Relative Turbidity	Soluble Orthophosphate Remaining		Relative Turbidity	Soluble Orthophosphate Remaining	
		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%		mg PO_4/l	%
0	0	50	100	0	50	100	0	50	100	0	50	100	0	50	100
2	0	50	100	10	48.8	98	21	47.4	95	51	46.0	92	135	42.8	86
7	7	46.8	94	122	39.4	79	182	36.8	74	252	34.8	70	317	32.8	66
24	257	34.2	68	> 500	24.2	48	> 500	23.2	46	> 500	25.8	52	> 500	26.8	54

TABLE IX

CHANGES IN PHOSPHORUS FORMS IN PRESERVED VCSD RAW SEWAGE UNDER STIRRED CONDITIONS AT ROOM TEMPERATURE

Time of Stirring, hr	Phosphorus Forms as mg PO_4/l							
	Total Phosphorus		Orthophosphate		Polyphosphate		Organic Phosphate	
	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble
A. Sewage Sampled 12 February 1965								
0	21.2	61.1	5.3	25.5	6.0	32.7	9.9	2.9
1	22.0	60.3	5.0	25.5	6.8	32.2	10.2	2.6
2	21.5	60.8	6.3	25.8	5.5	31.9	9.7	3.1
3	22.7	59.6	7.1	25.8	5.9	30.2	9.7	3.6
21	45.8	36.5	12.4	26.3	24.5	7.4	8.9	2.8
B. Sewage Sampled 17 February 1965								
0	16.3	59.4	6.5	25.8	5.0	31.2	4.8	2.4
3	18.2	57.5	6.3	25.8	8.0	29.0	3.9	2.7
19	43.4	31.9	11.6	22.4	25.6	8.9	6.6	0.6
21	43.8	31.9	13.4	21.8	23.9	8.7	6.5	1.4

TABLE X

CHANGES IN PHOSPHORUS FORMS IN PRESERVED VCSD RAW SEWAGE UNDER QUIESCENT CONDITIONS

Time of Storage, days	Phosphorus Forms as mg PO_4/l							
	Total Phosphorus		Orthophosphate		Polyphosphate		Organic Phosphate	
	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble	Insoluble	Soluble
A. At Room Temperature								
0	27.2	75.2	6.3	26.8	12.7	44.2	8.2	4.2
1	26.0	76.4	6.8	31.6	10.6	42.7	8.6	2.1
2	25.2	77.2	10.4	38.2	4.6	37.3	10.2	1.7
B. At 4°C								
0	24.6	77.8	6.1	26.8	14.8	46.8	3.7	4.2
1	23.6	78.8	5.3	28.4	11.4	46.6	6.9	3.8
2	23.2	79.2	6.9	30.2	9.4	46.8	6.9	2.2
6	22.0	80.4	5.3	33.9	7.7	45.8	9.0	0.7

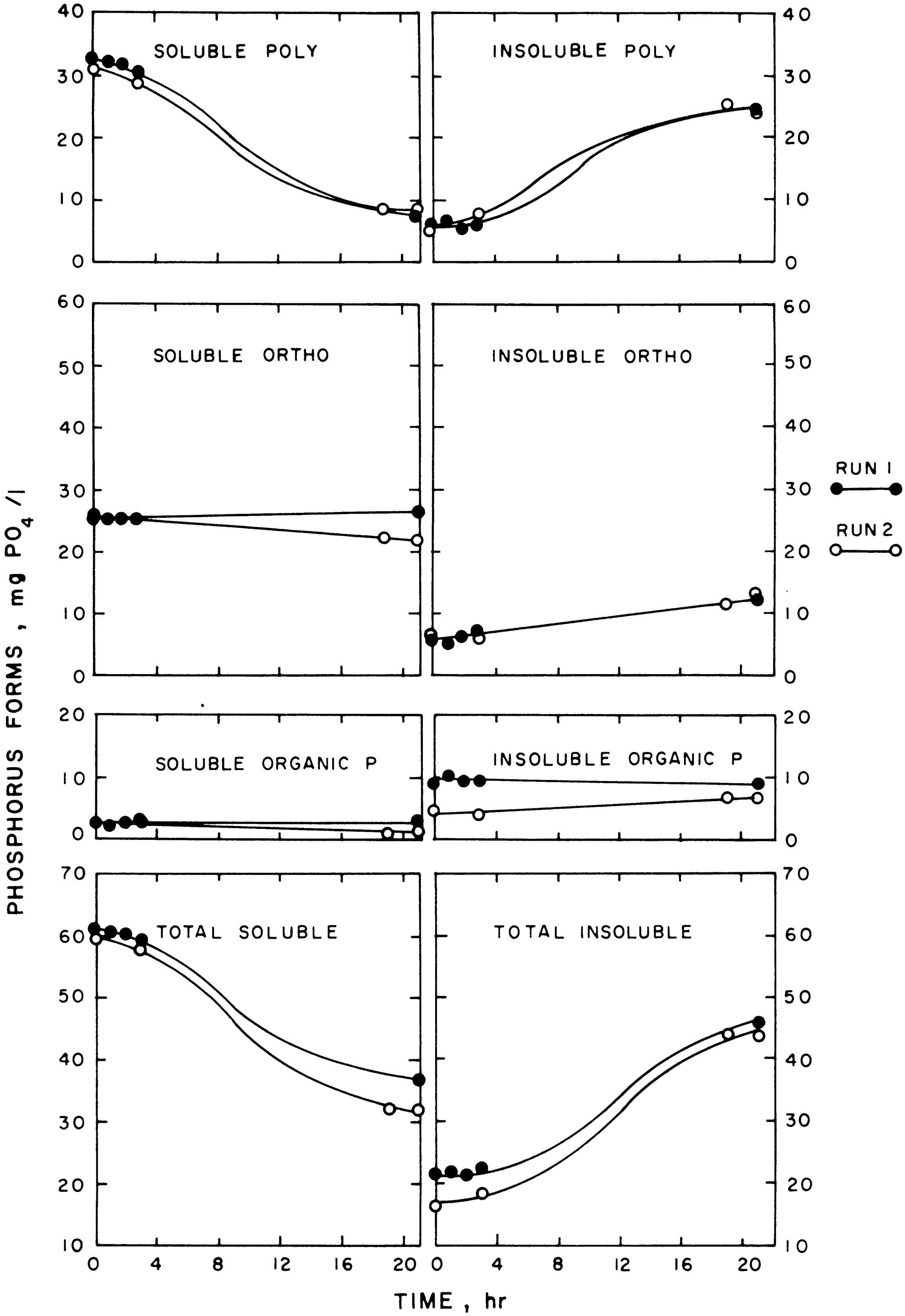

FIGURE 9. CHANGES IN PHOSPHORUS FORMS IN PRESERVED VCSD RAW SEWAGE UNDER STIRRED CONDITIONS AT ROOM TEMPERATURE

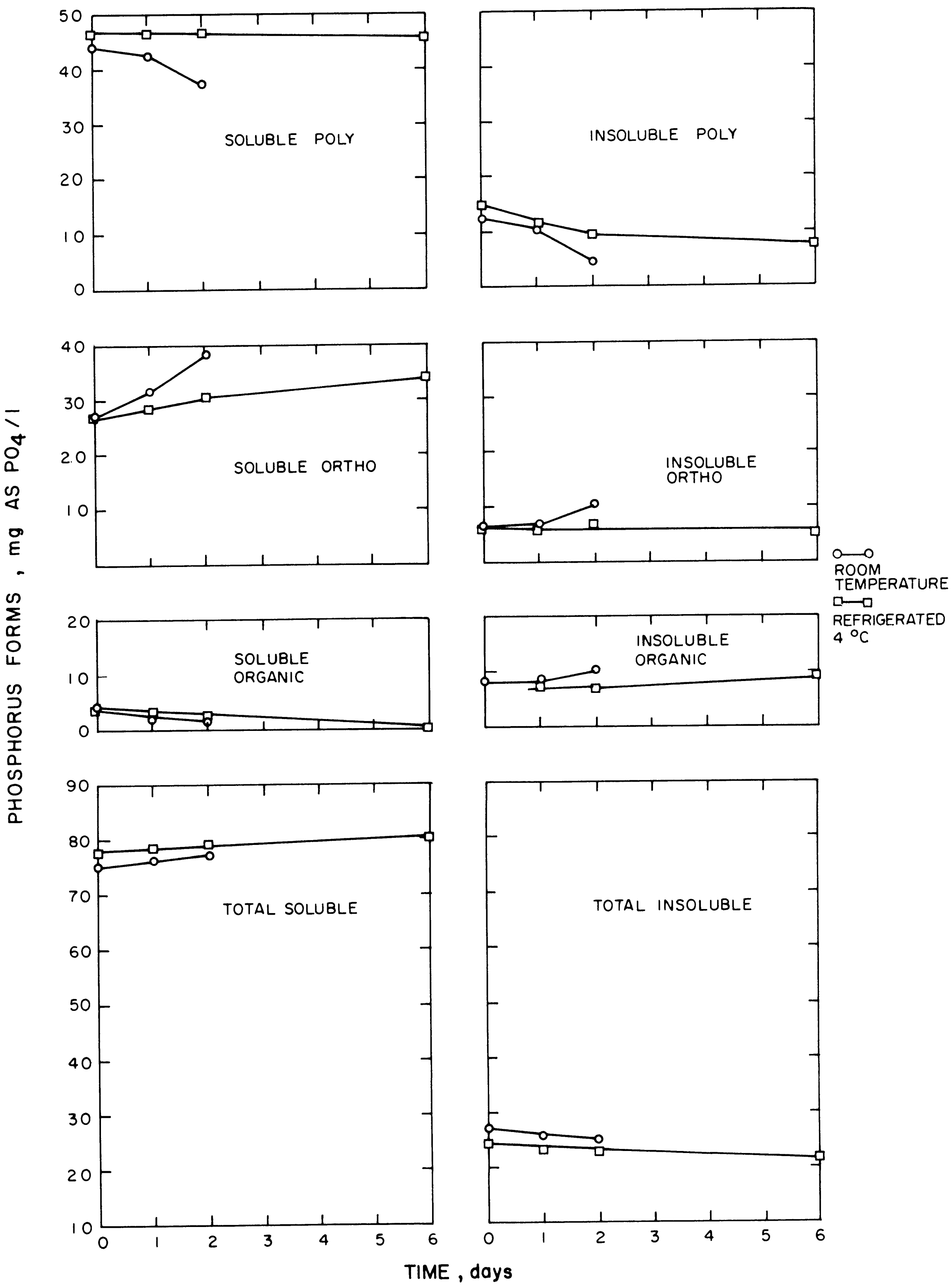

FIGURE 10. CHANGES IN PHOSPHORUS FORMS IN PRESERVED VCSD RAW SEWAGE UNDER QUIESCENT CONDITIONS AT ROOM TEMPERATURE AND AT 4 °C

IV. RESULTS

THE SURVEY

In all, a total of 1256 questionnaires were completed giving a 56.5 per cent coverage of the 2220 homes occupied at the time. An average of about 11.5 minutes was used in completing the questionnaire by the survey personnel.

The data derived from the questionnaires are summarized in Table XI while a summary of results by tracts as they were individually covered is presented in Appendix C.

TABLE XI

AVERAGE DATA DERIVED FROM QUESTIONNAIRE

Coverage of San Ramon Village population . .	56.5	per cent
Residents per household	4.39	persons
Total estimated population	9750	persons
Population over 12 years old	60.4	per cent
Human waste expended outside village by village residents	8.6	per cent
Households with garbage disposal	96.0	per cent
Households with washing machines	95.0	per cent
Households with automatic dishwashers	29.0	per cent
Laundry done outside San Ramon Village . . .	3.7	per cent
Detergent purchasing at Village Safeway Store	71.5	per cent

The coverage of 56.5 per cent was an extremely high one. It is reasonable to assume that a representative sample of the population was surveyed and that the unsurveyed (43.5 per cent) population does not have habits which differ significantly from the surveyed population.

The estimation of 4.39 persons per household combined with the monthly sewer connection figures of the VCSD made the total population estimate of 9750 persons at the midpoint of the sewage sampling period (Figure 11). The estimation of the per cent human waste expended outside the VCSD sewerage system by Village residents was made by assuming that for every resident-day spent outside San Ramon Village, one-half of the human-waste contribution was expended outside the village.

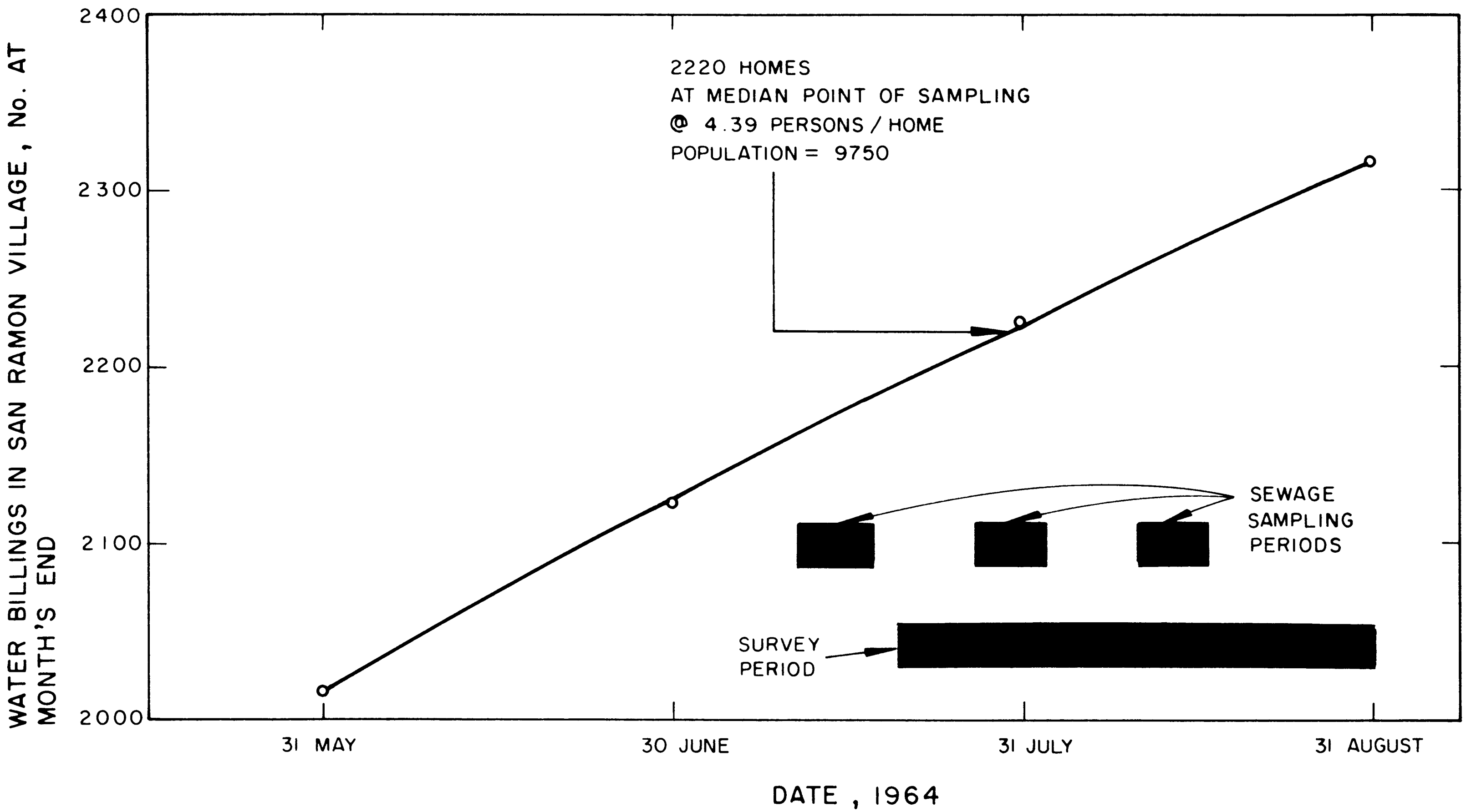

FIGURE 11. POPULATION OF SAN RAMON VILLAGE DURING SURVEY AND SAMPLING PERIODS ESTIMATED FROM WATER BILLINGS

The finding that 71.5 per cent of the Village residents' detergent marketing was performed at the Village Safeway Store was an extremely significant one. This meant that there was an identifiable source for the majority of detergents bought by the Village residents and it could be reasonably assumed that the residents who did not shop for detergents at the Village Safeway Store did not have detergent marketing habits (as far as quantity and brand purchased was concerned) which differed significantly from the Safeway shoppers.

Using these figures and assumptions it was possible to examine the Safeway sales records to obtain an input figure for detergents into San Ramon Village.

As has been described previously, this method was subject to error because of the uneven sales of detergents from the Village Safeway Store caused by sales promotions on several brands. More reliable figures for detergent input to San Ramon Village sewage were obtained by a search of delivery records for detergents from the Safeway Central Wholesale Warehouse over a seven-month period (Table XII). Very large fluctuations were noted in the weekly delivery figures which confirmed the suspicion that gross inaccuracies could have been introduced by the use of short term sales records from the store itself. In order to relate these sales figures to the sales that would be taking place in the Village during the sewage sampling period, the population trend for the period over which the detergent sales were estimated was obtained and a mean population for this period was calculated. This showed a mean population of 9500 as compared with 9750 at the midpoint of sewage sampling.

The weekly average deliveries by brand are summarized in Table XIII. Also presented in Table XIII are the average weekly ABS and phosphorus inputs to San Ramon Village due to detergents. It should be noted that the powder detergent brands listed comprise 89 per cent of the total powder detergents sold by the Village Safeway Store. The remaining 11 per cent powder detergents differed significantly in their ABS and phosphorus content from the mean ABS and phosphorus content of products comprising 89 per cent of the sales but the Soap and Detergent Association was able to supply ABS and phosphorus contents for this group of minor brands. Similarly, the computations for dishwasher, liquid, and water conditioning products were made and a total ABS and phosphorus output from the Safeway Store was calculated. This figure was then corrected to account for the fact that only 71.5 per cent of the San Ramon Village residents did their detergent shopping at the Village Safeway Store and that the Safeway Store sells only 95 per cent of its products to San Ramon Village residents. Further correction was made to account for the change in Village population from the mean period of sampling (9750) to the mean period over which sales figures were measured (9500). Using this combination of correction factors, a final correction factor of 1.36 was arrived at thus:

$$\frac{\text{Population mean of sampling period}}{\text{Population mean of sales period}} \times \frac{\text{Sales by Safeway to Village residents}}{\text{Fraction of Village residents shopping at Safeway Store}} = \frac{9750}{9500} \times \frac{0.95}{0.715} = \underline{\underline{1.36}} \,.$$

TABLE XII

WAREHOUSE DELIVERIES OF SYNTHETIC DETERGENTS TO SAN RAMON VILLAGE SAFEWAY STORE

Brand	Number of Pounds Delivered from Warehouse by Week																												
	12 Mar	19 Mar	26 Mar	2 Apr	9 Apr	16 Apr	23 Apr	30 Apr	7 May	14 May	21 May	28 May	4 Jun	11 Jun	18 Jun	25 Jun	2 Jul	9 Jul	16 Jul	23 Jul	30 Jul	6 Aug	13 Aug	20 Aug	27 Aug	2 Sep	9 Sep	17 Sep	24 Sep
	Powder Detergents																												
Ajax	61.6	61.6	92.4	123	92.4	154	123	123	61.6	RECORDS MISSING	RECORDS MISSING	123	0	RECORDS MISSING	123	0	61.6	0	RECORDS MISSING	RECORDS MISSING	RECORDS MISSING	123	92.4	61.6	0	61.6	RECORDS MISSING	123	123
Parade	308	0	0	246	308	185	154	154	308			0	154		0	246	92.9	0				154	308	185	0	0		60	0
Tide	62.1	432.5	432.5	215	462.5	589.3	1384.5	1726.6	2498.1			586.5	800		125.1	1974.5	30	93				188.1	156	1292.1	1632.1	1694.5		220.2	1048.5
Superb	300	300	0	120	150	300	300	300	150			15	315		15	315	180	0				150	330	120	315	0		0	255
All	230.7	36.8	0	76.1	227.7	191.7	191.7	231.7	267.7			302	0		118	231.7	118	0				228.5	265.5	79.3	154.8	429.8		307	152.3
Dash	232	351	193.8	193.8	307.7	350.5	190	346.7	468.8			388	0		154.7	183.8	426.5	581.7				390.5	348.7	270	427.7	583		393	0
Salvo	172.5	69.0	0	103.5	172.5	138	138	173.5	172.5			172.5	0		103.5	103.5	103.5	241.5				138	138	103.5	138	138		172.5	207
Vim	57	0	0	28.5	91.5	0	67.5	87.5	87.5			28.5	0		28.5	59	28.5	106				146.5	146.5	205.5	57	0		57	57
Diaper Sweet	0	0	0	0	0	0	0	0	60			18	0		42	80	42	60				42	38	0	60	18		60	42
	Liquid Detergents																												
Brocade	127.5	51.0	75	69	93.0	225	60	66	117			111	18		109.5	109.5	109.5	18				108.8	42	36	126	102		76.5	76.5
Lux	52.5	16.5	52.5	34.5	34.5	18	34.5	34.5	36			51	100.5		36	34.5	88.5	34.5				52.5	52.5	34.5	82.5	36		52.5	87
Trend (Pink)	0	0	0	0	0	0	0	0	0			0	0		0	16.5	16.5	16.5				49.5	49.5	0	0	0		16.5	16.5
Joy	51	16.5	34.5	0	51	16.5	34.5	34.5	33			34.5	34.5		34.5	34.5	16.5	18				34.5	34.5	68.5	51.5	85		51	51
Trend	49	50.5	50.5	50.5	67	48.5	32.5	51	83			67	33		32.5	50.5	32.5	50.5				83	67	65.5	184	48.5		83	99
Ivory	118.5	52.5	52.5	18.0	36	54	52.5	87	87			103.5	103.5		67.5	85.5	100.5	52.5				70.5	52.5	123	16.5	69		34.5	105
	Dishwasher Detergents																												
Thrill	33	34.5	49.5	0	34.5	16.5	34.5	18	34.5			34.5	16.5		16.5	18	0	34.5				51	16.5	16.5	18	0		34.5	34.5
Wisk	0	25	25	0	75	0	75	50	175			25	0		0	25	25	25				50	50	50	50	50		75	75
All	45	30	15	15	15	30	15	30	15			30	30		30	45	45	15				60	45	30	0	0		45	45
Cascade	60	60	60	60	60	60	60	60	150			30	30		30	60	60	60				90	60	60	30	180		120	120
Finish	15	15	15	0	15	0	0	15	15			0	0		15	30	15	15				45	75	30	45	45		15	30
Electrasol	30	45	45	0	0	15	15	30	30			30	30		75	45	45	45				41.3	41.3	0	41.3	124		0	41.3
Calgonite	30	75	45	60	0	15	0	30	30			15	15		15	30	15	30				60	60	60	0	45		150	0

TABLE XIII

DETERGENT SHIPMENTS FROM SAFEWAY WAREHOUSE TO SAN RAMON VILLAGE STORE FOR PERIOD 12 MARCH–24 SEPTEMBER 1964

Detergent Brand	Total Amount Shipped lb	Average Amount Shipped per Week lb	ABS lb/wk	Phosphorus as lb PO_4/wk
Powders				
Ajax	1784.8	81.1		
Parade	2862.9	130.1		
Tide	17368.4	789.5		
Superb	3930.0	178.6		
All	3840.0	174.5		
Dash	6832.1	310.6		
Salvo	2691.0	122.3		
Vim	1135.5	51.6		
Diaper Sweet	522.0	23.7		
These comprise ~ 89% of sales of powdered detergents			233.3	696.3
The remaining ~ 11% contribute		230	34.5	57.6
Liquids				
Brocade	1926.8	87.6		
Lux	1020.0	46.4		
Trend (pink)	453.0	20.6		
Joy	682.5	31.0		
Trend	1011.5	46.0		
Ivory	1471.5	66.9		
Thrill	513.0	23.3		
Wisk	925.0	42.0		
These comprise ~ 94% of sales of liquid detergents			80.0	6.7
The remaining ~ 6% contribute		23.0	3.6	1.3
Dishwashing				
Dishwasher All	630.0	28.6		
Cascade	1560.0	70.9		
Finish	450.0	20.5		
Electrasol	769.2	35.0		
Calgonite	780.0	35.5		
These comprise ~ 100% of sales of dishwashing detergents			---	59.8
Water Conditioners				
Total sales		184.0	1.7	14.5
Total ABS and PO_4 input from Safeway Store			353.1	836.2

The corrected values of ABS and phosphorus attributable to detergents were 68.6 lb/day and 162.4 lb/day, respectively (cf. Table XIV).

TABLE XIV

CALCULATION OF TOTAL PHOSPHORUS AND ABS INPUT TO VCSD SEWAGE TREATMENT PLANT

Type of Product	Recorded %	Unrecorded %	Safeway Sales, lb/wk		
			Product	Total PO_4	ABS
Laundry Powders	89		1862	696.3	233.3
		11[a]	230	57.6	34.5
Liquids	94		364	6.7	80.0
		6	23	1.3	3.6
Dishwasher Powders	100		190	59.8	---
Water Conditioners	100[a]		184	14.5	1.7
Total			2869	836.2	353.1
Actual Consumption[b]			3902	1137	480
Actual Consumption, lb/day			557	162.4	68.6

[a]Average PO_4 content of the minor laundry brands is 25% vs. 37% for the major. Although less significant, differences in average PO_4 and ABS exist in other categories. Therefore, assuming that the minor brands have the same compositions as the major brands will lead to error.

[b]Based on factor of 1.36:

$$\frac{9750}{9500}\ \frac{\text{population mean of sampling period}}{\text{population mean of sales period}} \times \frac{0.95}{0.715}\ \frac{\text{fraction sold by Safeway to SRV}}{\text{fraction of SRV buying at Safeway}} = 1.36.$$

SEWAGE AND WATER SUPPLY ANALYSIS

General

During the sewage sampling periods the VCSD was contracting with a local highway construction firm to supply secondary sewage effluent. Because of the fluctuation of sewage flow throughout the day, there was insufficient flow during two or three hours in the morning (usually between 0700 and 0900) to meet the demands of this contract. Consequently, during times of peak flow, secondary effluent was bypassed to an emergency holding basin and subsequently recycled through the plant at periods of low flow. Since the point of effluent return was above the raw sewage sampling point this recycle caused some dilution of several early morning samples. These samples were composited on the basis of "the total raw sewage plus recycled flow" and a correction factor applied to the composite sample to account for its dilution. Since the recycled secondary effluent had a negligible BOD, COD, suspended solids, ammonia, and total unoxidized nitrogen contents in comparison to the raw sewage, only a volumetric correction was required for these quantities. These correction factors are given in Table XV. However, since the recycled effluent contained significant quantities of phosphate and ABS, it was necessary to include both a volumetric and a concentration correction for these quantities.

Thus:

$$\begin{array}{c}\text{corrected}\\ \text{concentration}\\ \text{(mg/l)}\end{array} = \left[\begin{array}{c}\text{observed}\\ \text{concentration}\\ \text{(mg/l)}\end{array} \times \begin{array}{c}\text{volumetric}\\ \text{correction}\\ \text{factor}\end{array}\right] - \left[\begin{array}{c}\text{concentration}\\ \text{in recycled}\\ \text{effluent}\\ \text{(mg/l)}\end{array} \times \left(1 - \begin{array}{c}\text{volumetric}\\ \text{correction}\\ \text{factor}\end{array}\right)\right].$$

The concentration of phosphorus forms and ABS are given in Table XVI.

All data given in the following sections have been corrected by the aforementioned factors. Uncorrected raw data appear in Appendix D.

Sanitary Chemical Analyses

The analyses of daily composite samples for BOD, COD, suspended solids, ammonia, and total unoxidized nitrogen are given in Table XVII on both a loading (lb/day) and a concentration (mg/l) basis. From Figure 12, which shows the daily loadings of these parameters, it can be seen that the ammonia and total unoxidized nitrogen and suspended solids loadings do not vary in any significant pattern throughout the week.

TABLE XV

VOLUMETRIC CORRECTION FACTORS FOR DAILY COMPOSITE SAMPLES

Date	Dilution Factor	Date	Dilution Factor	Date	Dilution Factor
13 Jul	1.025	28 Jul	1.071	11 Aug	1.095
14 Jul	1.042	29 Jul	1.052	12 Aug	1.094
15 Jul	1.042	30 Jul	1.092	13 Aug	1.051
16 Jul	1.033	31 Jul	1.074	14 Aug	1.071
17 Jul	1.032	1 Aug	1.0	15 Aug	1.0
18 Jul	1.0	2 Aug	1.0	16 Aug	1.0
19 Jul	1.0	10 Aug	1.110	17 Aug	1.045
27 Jul	1.049				

TABLE XVI

CONCENTRATION OF PHOSPHATE AND ABS IN RECYCLED SECONDARY EFFLUENT

Date	Unfiltered Samples		Filtered Samples		ABS mg/l
	Total Phosphate mg as PO_4/l	Ortho-phosphate mg as PO_4/l	Total Phosphate mg as PO_4/l	Ortho-phosphate mg as PO_4/l	
14 Jul	4.8	--	3.8	2.3	0.8
15 Jul	7.3	--	2.8	2.2	0.8
16 Jul	11.2	--	10.4	10.3	0.8
17 Jul	17.3	--	16.3	16.3	0.8
27 Jul	14.8	13.5	13.5	10.3	1.0
28 Jul	7.3	6.28	5.7	5.2	0.9
29 Jul	17.0	16.9	15.2	14.8	1.1
30 Jul	11.0	10.2	10.0	10.0	1.3
31 Jul	23.0	22.4	22.0	22.0	1.3
11 Aug	26.9	26.4	24.4	27.6	1.5
12 Aug	41.4	41.0	42.9	36.8	1.9
13 Aug	30.1	26.4	29.2	27.7	1.7
14 Aug	26.6	25.2	27.4	25.6	1.6
17 Aug	45.4	43.2	43.5	42.5	1.7

TABLE XVII

DAILY COMPOSITE CONCENTRATION AND LOADING OF COD, BOD, SUSPENDED SOLIDS, AMMONIA, AND TOTAL UNOXIDIZED NITROGEN AT VCSD TREATMENT PLANT

Date	Flow	COD		BOD		SS		NH_3-N		Total N	
	mgd	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day
A. Week No. 1											
Mon 13 Jul	.702	571	3300	286	1700	340	2000	20.3	120	37.6	220
Tue 14 Jul	.707	463	2700	171	1000	278	1600	18.4	110	38.8	230
Wed 15 Jul	.700	403	2400	176	1000	154	900	17.5	100	31.2	180
Thu 16 Jul	.599	395	2000	220	1100	145	720	17.4	87	32.8	160
Fri 17 Jul	.663	443	2500	199	1100	225	1200	16.6	92	36.2	200
Sat 18 Jul	.633	422	2200	182	960	202	1100	17.9	94	33.7	180
Sun 19 Jul	.621	476	2500	---	---	188	970	20.2	100	35.3	180
B. Week No. 2											
Mon 27 Jul	.551	579	2700	256	1200	220	1000	22.6	104	34.6	160
Tue 28 Jul	.445	580	2200	244	900	217	800	23.7	88	42.0	160
Wed 29 Jul	.507	493	2100	239	1000	336	1400	35.5	150	39.6	170
Thu 30 Jul	.462	551	2100	267	1000	224	860	25.4	97	44.5	170
Fri 31 Jul	.492	581	2400	250	1000	346	1400	25.4	104	53.0	220
Sat 1 Aug	.421	820	-	349	1200	536	1900	27.7	97	54.0	190
Sun 2 Aug	.417	672	2300	277	970	312	1100	24.0	84	55.8	190
C. Week No. 3											
Mon 10 Aug	.508	563	2400	244	1030	262	1100	24.0	100	44.0	190
Tue 11 Aug	.440	550	2000	274	1000	228	840	26.0	95	42.3	160
Wed 12 Aug	.494	524	2200	273	1120	241	1000	23.0	95	42.1	170
Thu 13 Aug	.460	558	2100	264	1010	274	1060	25.4	98	50.6	190
Fri 14 Aug	.494	505	2100	216	890	260	1070	24.0	99	41.1	170
Sat 15 Aug	.432	541	2000	242	870	232	840	24.1	87	40.0	140
Sun 16 Aug	.404	440	1500	216	730	166	560	25.4	86	40.4	140
D. Mean Loadings By Day Of Week											
Mon			2800		1300		1370		110		190
Tue			2300		1000		1080		98		180
Wed			2200		1000		1100		115		170
Thu			2100		1000		880		110		170
Fri			2300		1000		1220		98		200
Sat			2100		1000		1280		92		170
Sun			2100		850		877		90		170
E. Overall Mean Daily Loading											
			2320		1040		1115		102		179

However, BOD and COD loadings show a high value on Mondays ("washday") and very little difference between other days of the week.

The per capita BOD contribution was found to be 0.12 lb/day or 53 g/day. This is very close to the "domestic sewage population equivalent" given by Imhoff and Fair [21] as 54 g/capita/day. The total unoxidized nitrogen value of 9.16 g/capita/day is also in good agreement with the value of 10 g/capita/day quoted by Imhoff and Fair [21].

Analysis of Phosphorus Forms

Carriage Water. Water is supplied to San Ramon Village by three wells (Nos. 1, 3, and 4) and by importation from the South Bay Aqueduct (Zone 7). The phosphate concentrations in each of these supplies during the sampling periods is shown in Table XVIII together with phosphate concentrations in water from a well (No. 2) that was being developed and was pumping approximately 0.2 mgd directly into a sewer during the first week of sampling. Table XIX shows the average percentage of the total water supply contributed by each source, the overall mean phosphate concentration, and average per cent daily contribution based on average sewage flow of 0.46 mgd. Also shown in Table XIX is the daily contribution of phosphate by the developing well during the first week of sampling. Using the average sewage flow during the sampling period (0.46 mgd) and the overall mean phosphorus content of the water supplies (0.356 mg as PO_4/l), it is found that the average daily phosphorus contribution to the sewage attributable to the carriage water is 1.4 lb as PO_4/day. The developing well (No. 2) added an additional 0.5 lb as PO_4/day during the first week's sampling giving an average of 1.9 lb as PO_4/day for that week. It will be seen that this amount of phosphorus is negligible in comparison with that contributed from other sources.

Sewage. The various forms of phosphorus were analyzed on 24-hr composite samples for each day of the three sampling periods. In addition, during the three sampling weeks hourly samples were analyzed at least once for every day of the week. The results of the analyses which appear in Tables XX through XXIII and Figures 12 and 13 have been corrected for dilution by recycled effluent. Also the polyphosphate values for all three weeks and the orthophosphate values for the first sampling week have been adjusted using the correction factors developed during the study after it became evident that a significant amount of polyphosphate was present in an insoluble form.

From Table XXII and Figures 13 and 14 it can be seen that the total phosphorus load averages 243 lb as PO_4/day. Of this, 87 lb as PO_4/day is recorded as polyphosphate, 148 lb as PO_4/day is orthophosphate, and the remainder is presumably organic phosphorus (8 lb as PO_4/day).

The total phosphorus load shows its highest value on Monday. This can be attributed to higher polyphosphate and organic phosphate loadings since the orthophosphate load changes very little during the week. Polyphosphate, however, shows a dramatic decrease as the week progresses, averaging 150 lb as PO_4/day on Monday and only 58 lb as PO_4/day on Sunday. These figures again lead one to the conclusion that the conventional Monday washday is not yet dead!

TABLE XVIII

CARRIAGE WATER PHOSPHORUS CONTENT

Date	Total P as PO_4, mg/l				
	Well 1	Well 3	Well 4	Zone 7	Developing Well 2
13 Jul					0.12
14 Jul	0.31	0.24	0.30	0.22	0.20
15 Jul	0.38	0.31	0.39		0.19
16 Jul	0.28	0.19	0.35	0.44	0.14
17 Jul	0.65	0.46	0.62	0.70	0.69
18 Jul	0.57	0.47	0.64	0.44	0.51
19 Jul	0.54	0.34	0.42		0.21
20 Jul	0.57	0.46	0.52		0.33
27 Jul	0.52	0.43	0.42	0.26	
29 Jul	0.64	0.42	0.77	0.39	
30 Jul	0.28	0.19	0.31		
1 Aug	0.59	0.24	0.39		
3 Aug				0.11	
10 Aug	0.20	0.10	0.16	0.05	
13 Aug	0.50	0.38	0.25	0.19	
17 Aug	0.26	0.16	0.22	0.26	
Mean	0.45	0.31	0.41	0.31	0.30

TABLE XIX

CARRIAGE WATER FLOWS AND PHOSPHORUS CONTENTS

Source of Supply	Per Cent Contribution to Supply[a]				Mean Phosphorus Content mg as PO_4/l	Overall Mean Phosphorus Content mg as PO_4/l
	Week of Sampling			Mean		
	1	2	3			
Well 1	13.6	14.2	13.5	13.8	0.45	0.356
Well 3	24.4	23.2	24.5	24.0	0.31	
Well 4	26.6	26.2	26.6	26.5	0.41	
Zone 7	35.4	36.4	35.4	35.7	0.31	

[a]Based on an average sewage flow of 0.46 mgd.

TABLE XX

CORRECTED CONCENTRATION OF PHOSPHORUS FORMS IN DAILY COMPOSITE SAMPLES OF VCSD RAW SEWAGE

Date	Flow mgd	Total mg as PO_4/l	Ortho mg as PO_4/l	Poly mg as PO_4/l
Week No. 1. 13-19 July 1964				
13 Jul	0.702	61.7	32.2	28
14 Jul	0.707	43.7	28.3	21.4
15 Jul	0.700	43.5	24.7	19.5
16 Jul	0.599	40.2	21.2	17.3
17 Jul	0.663	44.1	25.6	16.9
18 Jul	0.633	44.9	27.8	12.3
19 Jul	0.621	42.6	28	14.2
Week No. 2. 27 July—2 August 1964				
27 Jul	0.551	74.5	36.2	36.8
28 Jul	0.445	62.5	34.3	33.4
29 Jul	0.507	57.4	44	27.2
30 Jul	0.462	58	33	~ 24
31 Jul	0.492	59.8	35	7.7
1 Aug	0.421	67.3	47.9	8
2 Aug	0.417	57.2	36.4	19.8
Week No. 3. 10-17 August 1964				
10 Aug	0.508	72.5	43.8	23.4
11 Aug	0.440	49.8	37.5	15.2
12 Aug	0.494	57.6	35.2	19.4
13 Aug	0.460	60	36.8	15.3
14 Aug	0.494	60.1	33.4	18.9
15 Aug	0.432	59.9	32.4	17.4
16 Aug	0.404	53	35.7	9.8

TABLE XXI

CORRECTED WEIGHTS OF PHOSPHORUS FORMS IN DAILY COMPOSITE SAMPLES OF VCSD RAW SEWAGE

Date	Flow mgd	Total mg as PO_4/l	Ortho mg as PO_4/l	Poly mg as PO_4/l
Week No. 1. 13-19 July 1964				
13 Jul	0.702	360	190	160
14 Jul	0.707	260	170	130
15 Jul	0.700	250	140	110
16 Jul	0.599	200	110	86
17 Jul	0.663	240	140	94
18 Jul	0.633	240	150	66
19 Jul	0.621	220	150	74
Week No. 2. 27 July—2 August 1964				
27 Jul	0.551	340	170	180
28 Jul	0.445	230	130	120
29 Jul	0.507	240	190	110
30 Jul	0.462	220	130	93
31 Jul	0.492	250	140	32
1 Aug	0.421	240	170	29
2 Aug	0.417	200	130	69
Week No. 3. 10-16 August 1964				
10 Aug	0.508	310	190	99
11 Aug	0.440	180	140	56
12 Aug	0.494	240	150	80
13 Aug	0.460	230	140	59
14 Aug	0.494	250	130	78
15 Aug	0.432	220	120	62
16 Aug	0.404	180	120	32

TABLE XXII

AVERAGE DAILY WEIGHTS OF PHOSPHORUS FORMS IN VCSD RAW SEWAGE

Form of Phosphorus lb as PO_4/day	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Overall Daily Average
Total	340	220	240	220	250	230	200	243
Ortho	180	150	160	130	140	150	140	148
Poly	150	100	100	79	68	52	58	87

ABS Analysis of Sewage

ABS analyses were made on daily composite samples for each day of the three weeks of sampling. In addition, hourly ABS analyses were made once for each day of the week. The results of these analyses, expressed as an ABS loading are shown in Tables XXIV and XXV and Figures 15 and 16. ABS concentration data are given in Appendix D.

The overall average daily ABS load was 61.2 lb/day. In common with other parameters the ABS load was greatest on Monday (averaging about 81 lb/day) and declined as the week progressed to a low value of about 50 lb/day on Sunday.

TABLE XXIII

HOURLY LOADINGS OF PHOSPHORUS FORMS IN VCSD RAW SEWAGE EXPRESSED AS LB PO_4/DAY

Time of Day	Total	Ortho	Poly	Time of Day	Total	Ortho	Poly	Time of Day	Total	Ortho	Poly
Monday 27 July											
0800	10	6	-	1600	760	240	240	2400	250	150	72
0900	100	64	-	1700	560	200	192	0100	210	130	64
1000	190	150	-	1800	450	180	184	0200	120	81	24
1100	120	270	70	1900	470	190	224	0300	48	42	6
1200	770	310	88	2000	310	160	97	0400	37	28	6
1300	940	300	288	2100	320	170	86	0500	13	8	2
1400	940	260	336	2200	320	180	53	0600	10	7	-
1500	700	250	240	2300	330	170	114	0700	10	7	-
Tuesday 11 August											
0800	7	5	0.4	1600	270	140	83	2400	240	160	37
0900	67	58	3	1700	220	150	56	0100	140	99	5
1000	130	95	-	1800	270	150	85	0200	110	81	18
1100	210	150	21	1900	230	130	53	0300	66	46	7
1200	300	220	53	2000	250	140	72	0400	26	23	12
1300	280	180	46	2100	280	180	51	0500	13	11	3
1400	310	190	106	2200	300	180	34	0600	8	7	1
1500	280	150	141	2300	270	160	64	0700	7	7	0.2
Wednesday 15 July											
0800	25	20	6	1600	410	197	240	2400	280	185	80
0900	87	63	40	1700	360	209	160	0100	140	93	40
1000	230	172	88	1800	360	160	192	0200	120	84	32
1100	310	142	42	1900	370	153	150	0300	80	58	11
1200	410	295	78	2000	190	109	83	0400	49	36	8
1300	490	221	304	2100	200	135	58	0500	32	27	3
1400	450	246	256	2200	260	148	98	0600	22	19	5
1500	400	197	272	2300	240	160	72	0700	22	17	5
Thursday 13 August											
0800	8	7	1	1600	370	210	176	2400	260	170	77
0900	71	58	9	1700	300	180	85	0100	130	100	19
1000	150	120	10	1800	260	150	59	0200	95	72	18
1100	210	160	34	1900	240	140	75	0300	48	38	0.5
1200	300	220	45	2000	220	130	46	0400	23	19	3
1300	370	260	35	2100	180	130	38	0500	11	9	0.5
1400	400	240	67	2200	220	160	0.8	0600	8	7	0.6
1500	390	170	240	2300	250	160	70	0700	4	4	0.4
Friday 14 August											
0800	7	6	-	1600	430	240	40	2400	250	150	50
0900	82	45	-	1700	330	180	86	0100	130	97	16
1000	180	110	7	1800	330	180	38	0200	100	69	10
1100	240	170	24	1900	290	170	58	0300	100	67	2
1200	410	240	102	2000	360	170	72	0400	33	23	0.8
1300	500	310	110	2100	260	160	61	0500	22	15	0.5
1400	460	290	153	2200	250	160	69	0600	11	8	0.8
1500	400	230	192	2300	280	170	78	0700	8	6	-
Saturday 15 August											
0800	6	5	-	1600	430	220	30	2400	220	160	-
0900	9	7	-	1700	310	190	-	0100	150	100	-
1000	50	37	4	1800	260	160	27	0200	88	72	2
1100	290	220	-	1900	210	170	77	0300	70	55	-
1200	410	290	64	2000	230	180	-	0400	45	33	-
1300	550	270	288	2100	210	140	0.6	0500	26	20	3
1400	640	300	73	2200	230	140	0.5	0600	12	9	-
1500	490	280	72	2300	270	180	38	0700	8	7	-
Sunday 2 August											
0800	7	6	-	1600	430	260	208	2400	230	160	72
0900	7	5	-	1700	320	200	101	0100	180	120	72
1000	41	33	-	1800	270	170	82	0200	120	89	32
1100	220	110	10	1900	270	170	139	0300	62	48	3
1200	270	140	-	2000	270	160	118	0400	29	23	8
1300	390	250	99	2100	260	170	148	0500	12	9	2
1400	420	260	93	2200	290	150	90	0600	8	7	1
1500	390	240	137	2300	270	180	110	0700	2	2	2

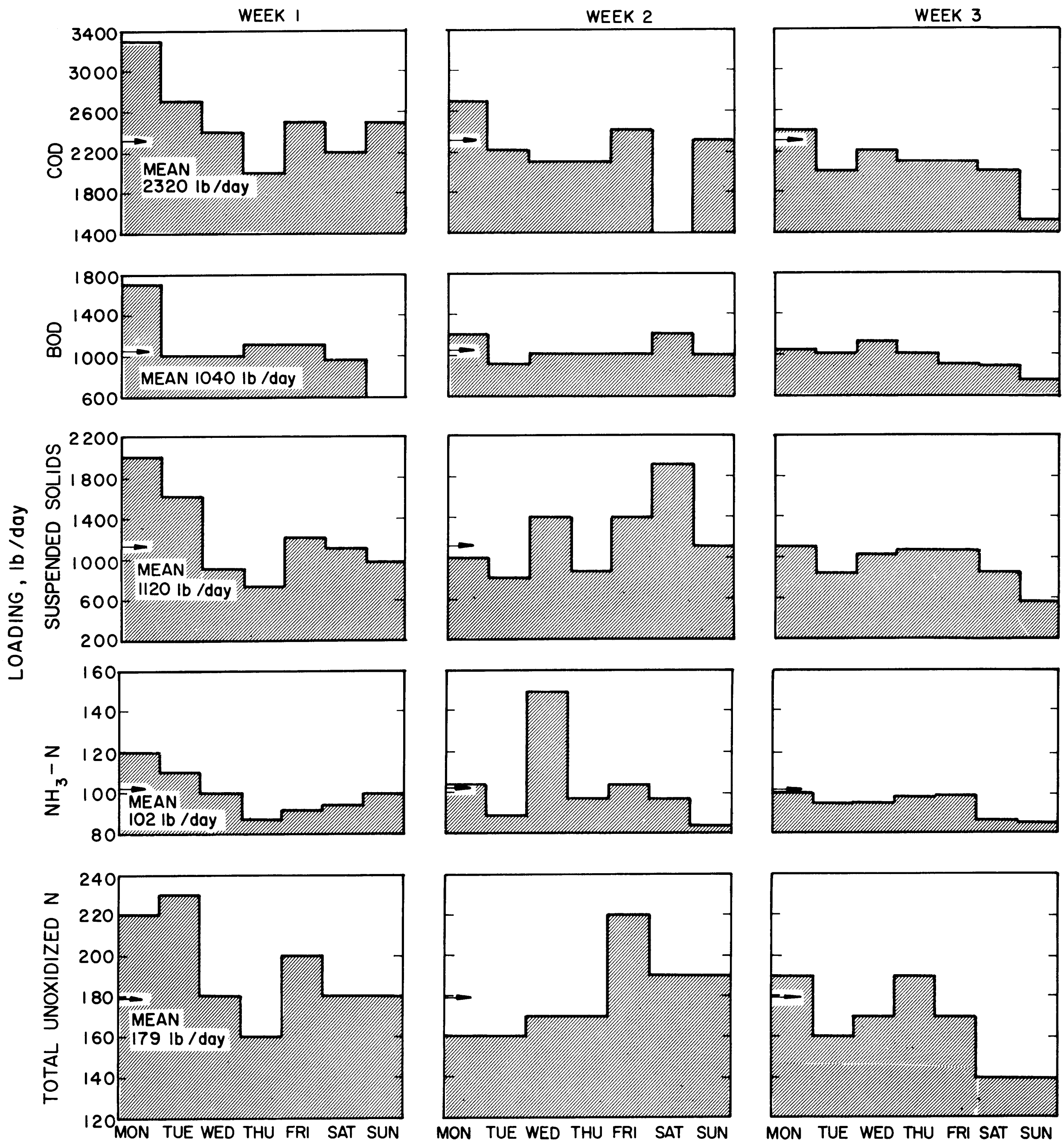

FIGURE 12 . DAILY LOADING OF COD, BOD, SS, NH_3-N, AND TOTAL UNOXIDIZED NITROGEN AT VCSD TREATMENT PLANT

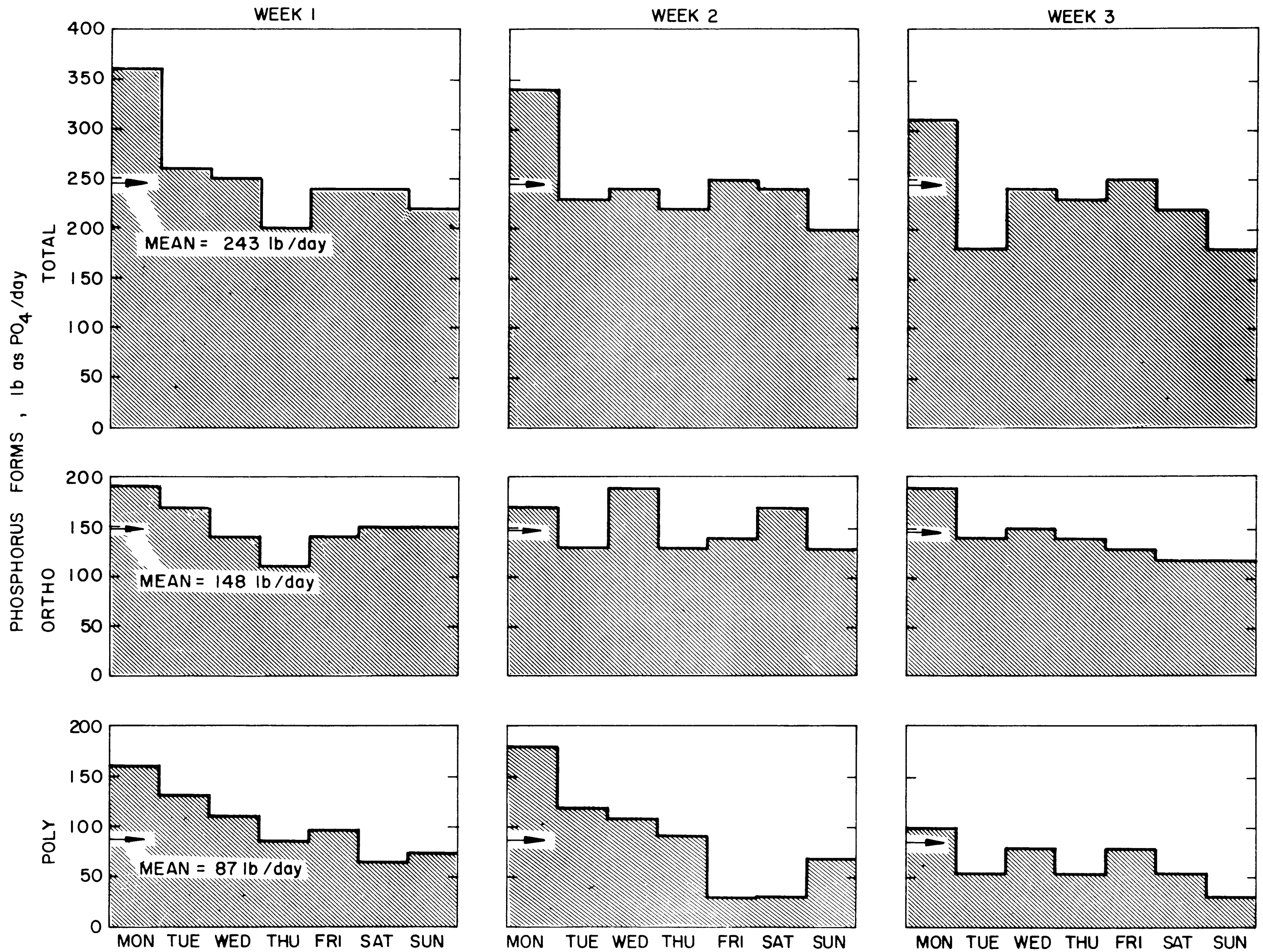

FIGURE 13. DAILY LOADING OF PHOSPHORUS FORMS IN VCSD RAW SEWAGE

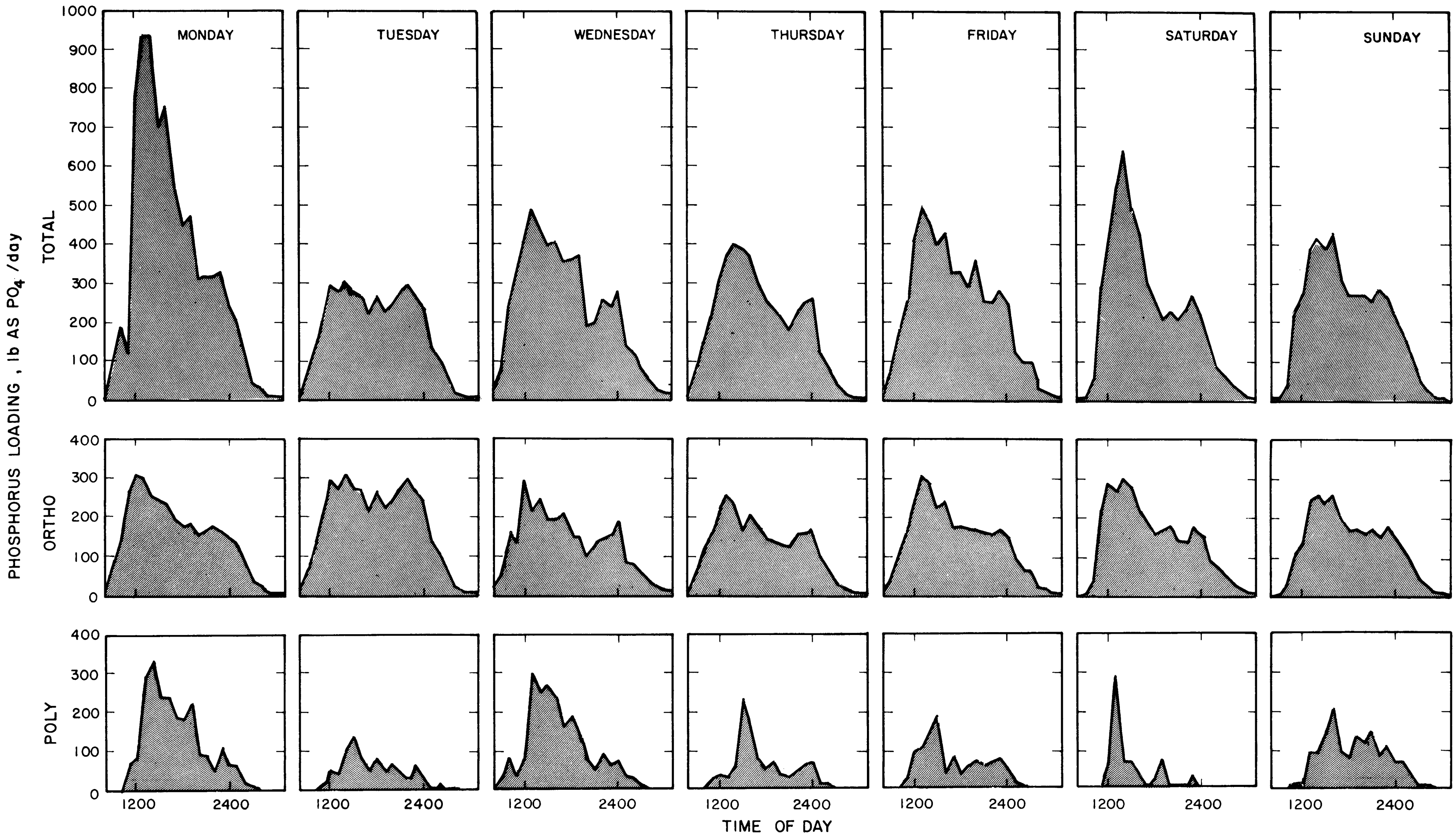

FIGURE 14. HOURLY LOADING OF VARIOUS PHOSPHORUS FORMS IN VCSD RAW SEWAGE FOR EACH DAY OF THE WEEK

TABLE XXIV

LOADING AND CONCENTRATION OF ABS IN VCSD RAW SEWAGE

Week No. 1				Week No. 2				Week No. 3				Average ABS lb/day
Date	Flow mgd	ABS		Date	Flow mgd	ABS		Date	Flow mgd	ABS		
		mg/l	lb/day			mg/l	lb/day			mg/l	lb/day	
13 Jul	0.702	14.9	87.4	27 Jul	0.551	16.3	75.2	10 Aug	0.508	19.4	82.0	80.9
14 Jul	0.707	12.3	72.8	28 Jul	0.445	15.0	56.1	11 Aug	0.440	12.7	46.3	57.0
15 Jul	0.700	11.5	67.1	29 Jul	0.507	15.3	64.9	12 Aug	0.494	14.8	61.0	63.8
16 Jul	0.599	10.6	53.0	30 Jul	0.462	14.6	56.2	13 Aug	0.460	14.6	55.9	54.7
17 Jul	0.663	11.1	61.1	31 Jul	0.492	14.4	58.9	14 Aug	0.494	15.3	63.0	60.4
18 Jul	0.633	11.7	62.0	1 Aug	0.421	13.0	45.6	15 Aug	0.432	15.3	55.1	54.7
19 Jul	0.621	10.6	54.8	2 Aug	0.417	15.3	53.1	16 Aug	0.404	12.8	43.1	50.1
Overall Daily Average ABS												61.2

TABLE XXV

HOURLY ABS LOADING FOR EACH DAY OF THE WEEK

Time of Day	ABS Loading, lb/day						
	Mon 27 Jul	Tue 11 Aug	Wed 15 Jul	Thu 13 Aug	Fri 14 Aug	Sat 15 Aug	Sun 2 Aug
0800	2.3	0.8	4.8	0.6	0.5	1.0	1.1
0900	19	8.6	11	9.1	9.7	1.7	1.0
1000	25	19	32	21	21	7.8	8.3
1100	67	38	43	24	36	49	32
1200	130	62	88	34	78	86	41
1300	168	48	108	79	117	125	93
1400	168	71	132	72	120	137	99
1500	213	68	106	75	120	125	106
1600	141	63	109	83	96	108	103
1700	116	54	93	57	76	80	82
1800	92	58	88	49	81	68	65
1900	90	56	78	65	80	64	58
2000	76	55	55	56	73	62	62
2100	82	74	59	51	75	55	67
2200	84	99	70	57	79	52	65
2300	89	57	82	58	63	75	82
2400	80	67	91	59	54	62	88
0100	56	38	44	39	34	40	55
0200	31	23	29	24	24	16	30
0300	11	12	20	11	14	16	16
0400	8.2	5.8	12	5.6	6.2	10	5.8
0500	2.4	2.2	8.2	1.8	2.5	3.6	2.3
0600	1.6	1.0	5.5	1.5	1.7	1.4	1.5
0700	1.6	1.1	4.6	0.8	1.3	1.4	0.3

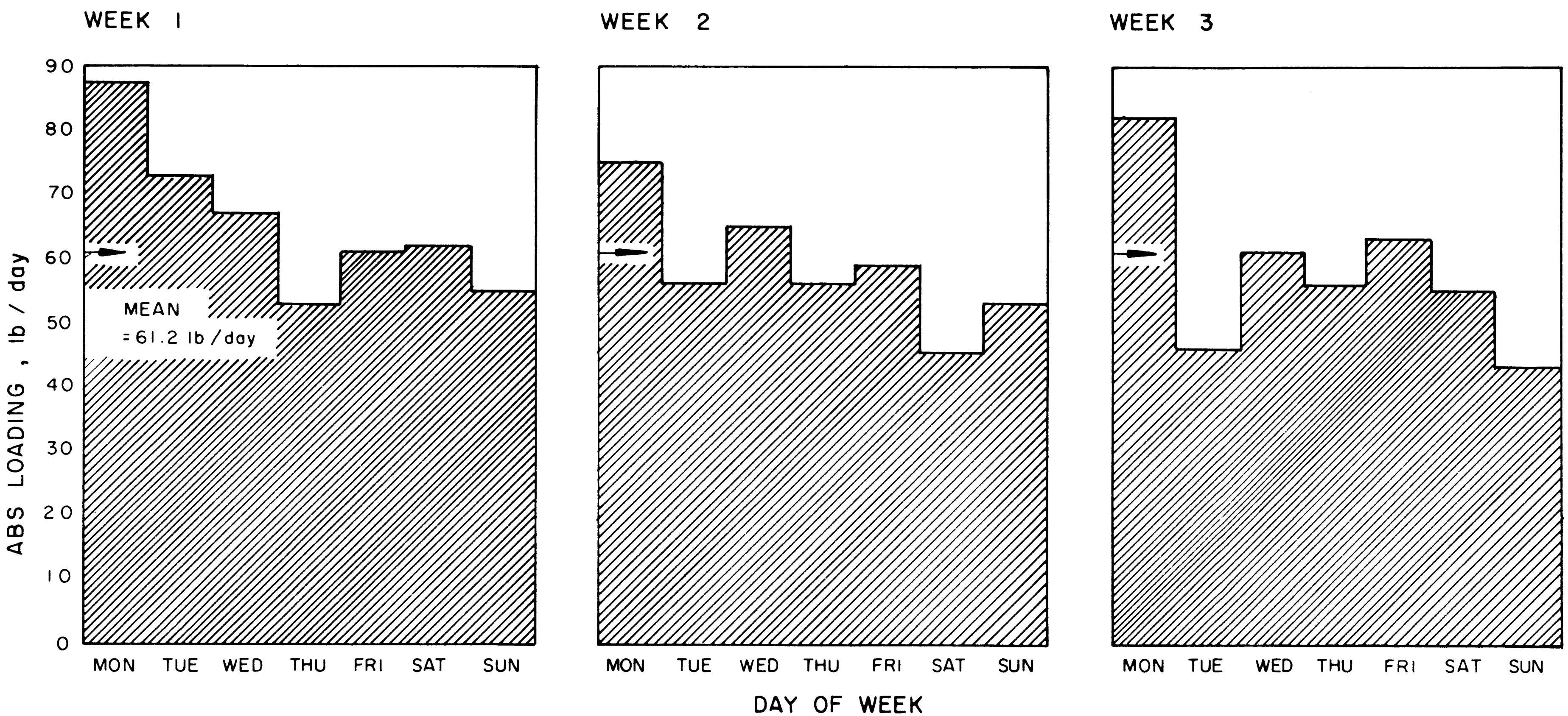

FIGURE 15 . ABS LOADING IN VCSD RAW SEWAGE

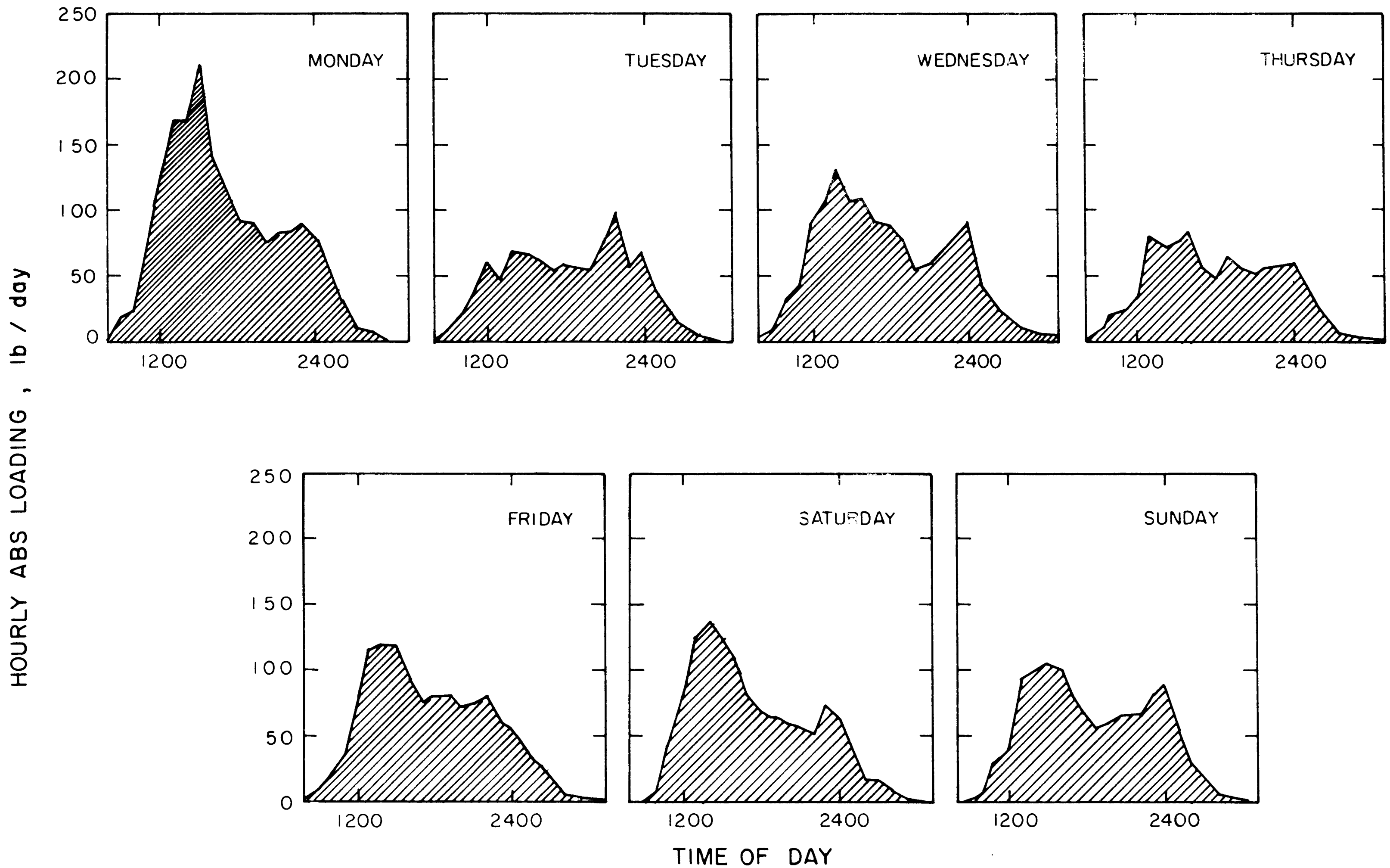

FIGURE 16 . HOURLY ABS LOADING IN VCSD RAW SEWAGE FOR EACH DAY OF THE WEEK

V. DISCUSSION

The major objective of this study--to determine the contribution of synthetic detergents to the phosphorus content of a domestic sewage--can be approached from two different starting points, both of which employ the materials balance concept. Before proceeding to a discussion of these two methods of calculation and the results which they yield, it would be prudent to obtain an estimate of the validity of some of the assumptions that were made during the course of the study. This can be accomplished by a comparison of the ABS input to the Village by sales, and its output to the sewer as measured during the sewage sampling program. Inspection of Table XIV reveals that the sales input to the Village community was 68.6 lb ABS/day. By analysis of VCSD raw sewage an average daily content of 61.2 lb ABS/day was found. These figures are in extremely good agreement. The raw sewage ABS content can be expected to be lower because of degradation of biologically labile ABS isomers in the sewer. The figure may also tend to be lowered by uses of ABS that do not always return the material to the sewer--e.g., car washing.

The good agreement of ABS input/output figures lends support to the assumptions made and allows one to proceed with confidence to the calculation of a phosphate balance.

The first method of determining the phosphorus contribution of synthetic detergents involves the use of the ABS and phosphate figures for input from synthetic detergents and the total phosphate content of the raw sewage determined by analysis.

From Table XIV the daily input of total phosphorus attributable to synthetic detergents is seen to be 162.4 lb as PO_4/day. By analysis of VCSD raw sewage the average daily total phosphorus load was found to be 243 lb as PO_4/day. Thus by this method of calculation synthetic detergents contribute 162.4/243 x 100 = 67 per cent of the phosphorus in the sewage. The second method of calculation involves the use of the average normal dietary per capita phosphorus contribution to sewage. If the figure of 10.7×10^{-3} lb as PO_4/capita/day given by Von Wazer [2] is used, then the human phosphorus contribution is:

$$10.7 \times 10^{-3} \frac{\text{lb as } PO_4}{\text{persons-day}} \times 9750 \text{ persons} = \underline{104 \text{ lb as } PO_4/\text{day}} \ .$$

Since the survey of the Village population showed that a considerable number of the residents spent eight hours or more per day outside the Village, the dietary phosphorus contribution should be reduced to account for the waste expended away from the VCSD sewerage system. Realizing that any correction made for such a factor must necessarily be an arbitrary one, the assumption was made that one-half of the human waste of an individual was expended for each resident-day spent outside the Village. Using this "rationale" the figure of 8.6 per cent for "human waste expended outside the Village by Village residents" was obtained from the survey data (Table XI). Thus, of the 104 lb as PO_4/day expended by the Village residents, only 104 x (1.00 − 0.086) = 95 lb as PO_4/day is contributed to the VCSD sewers. Subtracting this contribution and the carriage water contribution of about 1.5 lb as PO_4/day from the total phosphorus loading in the VCSD raw sewage gives a detergent contribution of 243 − (95 + 1.5) = 146.5 lb as PO_4/day. Thus, by this method of calculation synthetic detergents contribute 146.5/243 x 100 = 60 per cent of the phosphorus in the sewage. Because the only significant source of polyphosphate (condensed phosphates) in sewage is from synthetic detergent products, this material should be an excellent method of determining the phosphorus contribution of detergents to a sewage. However, the precipitation and especially the hydrolysis of polyphosphates in the sewer prior to the sampling point at the plant precluded any accurate use of the polyphosphate figures for accurate detergent contribution calculations.

Assuming a minimum design velocity of 2 ft/sec in the VCSD sewerage system, the time of travel of sewage from various parts of the community was calculated from a map of the Village sewerage system to be between 2-3 hours. Since the sewage flow at the time of the study was only about 25 per cent of the design flow of 2 mgd, it might be assumed that the 2 ft/sec velocity would be close to the average velocity during the time of the study. From Figure 7 it can be seen that the maximum rate of polyphosphate reversion is about 3 mg/l/hr, or with the starting concentration used in these experiments about 10 per cent of the initial amount per hour. Thus, on this basis one might expect a reversion of between 20—30 per cent of the polyphosphate during its 2-3 hours travel in the sewer. The actual average amount of reversion found in the study amounted to about 60 per cent if one assumes that 90 per cent of the phosphorus attributed to detergents was polyphosphate.

It should by no means be construed that these figures for per cent contribution by detergents to the phosphorus in sewage are universally applicable, or even representative. All factors point to the conclusion that these figures for detergent contribution are indeed high. The hardness of the water, the unestablished nature of the community, and the large number of young children in each family would all tend to boost the usage of detergent products. This study showed an ABS consumption of 7.04×10^{-3} lb/capita/day.

VI. SUMMARY AND CONCLUSIONS

A materials balance approach has been used successfully to study and quantitate the sources of phosphorus in a domestic sewage. A fairly isolated residential community of about 10,000 persons with no industry and an identifiable source of detergents was used for the study. This community was served by a tight sewerage system and a treatment plant that kept excellent operating data.

Hourly composite and separate samples of raw sewage were taken at the community sewage treatment plant for three one-week periods. Samples were analyzed for the common sanitary chemical parameters, for ABS, and for the various forms of phosphorus--total, soluble, insoluble, polyphosphate, and orthophosphate. As a result of this detailed analysis of sewage for the various forms of phosphorus, an improved and more accurate analytical scheme was developed. The behavior of polyphosphate in preserved and unpreserved samples of sewage stored at room temperature and 4°C was studied and it was found that only by preservation and low temperature quiescent storage could reversion or precipitation of polyphosphate be prevented.

The estimation of ABS and phosphorus input to the community was made by the combination of a door-to-door survey (to determine detergent marketing habits of the community) and a search of the sales records of the local source of detergents--a Safeway Supermarket. Sales records over a period of seven months had to be used in order to average out the effects of sales promotions on various brands of detergent products. The sales figures were combined with the detergent marketing habits of the community and a figure supplied by the Soap and Detergent Association for the ABS and phosphorus contents of the detergents sold in the area, to arrive at the ABS and phosphorus input to the system attributable to synthetic detergents.

Using these figures it was estimated that about 67 per cent of the phosphorus in the sewage was of detergent origin. A further estimate was made by subtracting from the total sewage phosphorus content the reported normal average dietary phosphorus (corrected for that expended away from the community) and the phosphorus content of the carriage water. The remainder, which was assumed to be the detergent contribution, was about 60 per cent of the total.

Although attempted, it was not possible to use the condensed or polyphosphate content of the sewage (found by analysis) as an accurate means of measuring detergent phosphorus contribution, even though the only significant source of this species in sewage is from synthetic detergents. This was due to the complicated and poorly defined reversion and precipitation undergone by this material in its passage through the sewer prior to sampling at the treatment plant.

The sewage characteristics of this community, apart from the high hardness (about 275 mg as $CaCO_3$/l) and total dissolved solids (about 900—1000 mg/l), were close to classical estimates. Thus the daily per capita BOD and nitrogen contributions were 0.12 lb and 9.16 g, respectively.

The daily fluctuations of ABS and the various forms of phosphate followed the typical diurnal variation encountered in sewage flow and load. It was established that, at least in this community, the Monday washday is not dead.

Organic load was highest on Monday while ABS and polyphosphate loads on this day in the sewage were greatly in excess of any other day of the week.

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COLLEGE OF ENGINEERING
SANITARY ENGINEERING
RESEARCH LABORATORY
RICHMOND FIELD STATION

1301 SOUTH 46TH STREET
RICHMOND, CALIFORNIA 94804

July 10, 1964

Dear Resident of San Ramon Village:

We greatly need your help in a study being conducted by the University of California in its continued program of research on ways for protecting the quality of the streams and lakes of California, and of the Nation.

We are interested in the nutrients which are present in waste waters, because they stimulate growth of plants in water. These water plants take many forms, from large weeds to tiny algae, which sometimes form green scums. Their effect on water is to produce tastes and odors and spoil it for recreation and other use.

For this study we are particularly interested in determining the household contribution of these nutrients. To do this, we need to know something of the products which you use in your home. We can accomplish our task by finding out how much of what types of products are being used in a community and by making chemical analyses of both these agents and the waste water. Our own laboratories can make the analyses, but we need the help of householders in estimating the amounts of products used.

San Ramon Village has been selected as the community to assist us because it has a new well-operated sewerage system; because the entire community is served by a single modern, efficient waste treatment plant which keeps excellent records; because the Valley Community Services District is willing to cooperate in this important study; and because we believe that its citizens have an interest in California's water problems.

What you can do to help us is to answer a few questions when one of your young neighbors calls at your home during the week beginning July 20. In providing our interviewer with this information you will help us to contribute in a small way to the summer employment of boys of San Ramon Village, and in a large way to the solving of important problems of water quality. Needless to say, all information you provide will be confidential and anonymous.

Please do not hesitate to write us at the above address or call us at 235-6000, Ext. 225, if you have any questions or comments.

D Jenkins
David Jenkins
Assistant Research Chemist

P H McGauhey
P. H. McGauhey
Director

FIGURE A-1. LETTER SENT TO HOMEOWNERS PRIOR TO SURVEY OF SAN RAMON VILLAGE

(Sample Copy)

UNIVERSITY OF CALIFORNIA PHOSPHATE STUDY QUESTIONNAIRE FORM

1. How many persons reside in your household? ______________

2. How many are over 12 years old? ______________

3. Does anybody in your household work or normally spend any full days outside of San Ramon Village?

   Yes ☐ No ☐

   If Yes, how many days per week? ______________

4. Do you have the following appliances in your home?

Dishwasher	Yes ☐	No ☐
Washing Machine	Yes ☐	No ☐
Garbage Disposal	Yes ☐	No ☐

5. Is any of your laundry done outside San Ramon Village? Yes ☐ No ☐

   If Yes, how much? 100% ☐ 75% ☐ 50% ☐ 25% ☐

6. How many quarts of milk are used in your house per week? ______________

7. Please furnish the indicated information on the following products:

   A. Liquid detergents

Brand	Size	How often purchased
______	______	______
______	______	______
______	______	______

   B. Powdered or dry detergents and soaps

______	______	______
______	______	______
______	______	______

   C. Package water softeners (conditioners)

______	______	______
______	______	______

8. How much of each of the items listed in Question 7 do you buy in San Ramon Village?

	All	Nearly All	75%	50%	25%	None
Liquid	☐	☐	☐	☐	☐	☐
Powdered or Dry	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

FIGURE A-2. QUESTIONNAIRE FORM USED IN SAN RAMON VILLAGE SURVEY

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THE SANITARY ENGINEERING RESEARCH LABORATORY OF

THE UNIVERSITY of CALIFORNIA HAS SELECTED YOU

AND YOUR NEIGHBORS IN SAN RAMON VILLAGE FOR A SURVEY BEGINNING NEXT MONDAY

- **Local Teenagers have been hired to ask you a few questions about some of the household products you use.**
- **They will NOT be selling anything.**
- **Each teen interviewer will wear an easy-to-identify VCSD red, recreation jacket.**

U. C. asks for 10 minutes of your time in order to complete this survey. The information gathered will not be used commercially, and you will remain anonymous.

THANK YOU FOR YOUR CO-OPERATION

UNIVERSITY OF CALIFORNIA, BERKELEY
SERL

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FIGURE A-3. ADVERTISEMENT PLACED IN "VILLAGE PIONEER" PRIOR TO SAN RAMON VILLAGE SURVEY

APPENDIX B

COMPARISON OF SERL AND AASGP ANALYTICAL METHODS FOR VARIOUS FORMS OF PHOSPHORUS IN RAW SEWAGE

TABLE B-1

COMPARISON OF SERL AND AASGP ANALYTICAL METHODS
FOR VARIOUS FORMS OF PHOSPHATE

Method	Ortho mg as PO_4/l	Ortho + Hydrolyzable mg as PO_4/l	Total, mg as PO_4/l AASGP Standard	Total, mg as PO_4/l SERL Standard
A. VCSD Raw Sewage				
Unfiltered Sample				
AASGP	29.5 30.4 31.2 30.6 31.0	56.4 57.6 58.0 58.8 58.0	56.8 56.8 57.2 57.2 56.8	63.4 63.4 64.0 64.0 63.4
SERL	32.4 32.4 31.8 31.8 31.0	-- -- -- -- --	64.8 63.5 62.7 65.7 64.8	
Filtered Sample				
AASGP	27.4 26.6 27.2 26.9 27.0	47.2 47.2 47.6 46.8 47.2	43.6 43.6 42.8 43.2 43.2	48.8 48.8 48.0 48.4 48.4
SERL	25.8 25.8 25.8 25.8 25.8	-- -- -- -- --	48.0 48.0 47.8 47.8 47.8	
B. Richmond Raw Sewage				
Unfiltered Sample				
AASGP	14.2 14.7 14.6	23.3 24.4 24.0	24.0 23.7 24.1	26.8 26.5 26.9
SERL	14.2 13.7 13.9	-- -- --	26.4 27.0 26.4	
Filtered Sample				
AASGP	13.4 13.6 13.6	21.7 22.2 21.5	20.1 19.8 20.2	22.4 22.1 22.5
SERL	13.7 13.9 13.7	-- -- --	22.2 22.4 21.8	

TABLE C-1

SUMMARY OF SURVEY RESULTS BY TRACT

Tract No.	No. of Houses If Tract Complete	Questionnaires Returned	Per Cent Coverage	No. of People per House	People Over 12 Years Old %	Time Spent Outside San Ramon Village %	Laundry Done Outside San Ramon Village %	Milk Consumption qt/person/wk	Detergent Purchased at San Ramon Village %
2163	191	115	60.3	4.35	60.4	8.46	0.96	2.83	79.2
2394 2405 2466 2467 2985	309[a]	130		4.39	58.3	9.89	8.6	2.83	66.8
2250	82	43	52.5	4.70	59.4	7.5	1.2	3.53	65.8
3024 3170	149[a]	26		1.92	100	9.42	10.6	1.28	83.1
2164	198	105	53	4.64	52.6	7.34	2.1	3.00	81.1
2910	84[a]	24		4.58	73.6	7.91	2.1	2.42	63.5
2162		8		3.12	60.0	7.43	0	3.00	75.0
2286 2472		193		4.49	61.9	7.83	4.15	2.46	66.3
3030		9		4.67	47.6	6.80	1.2	3.24	65.6
Part of 2485	147[a]	102		4.19	60.7	10.30	2.2	3.09	68.4
2249 2287 Part of 2483	291	140		4.66	59.7	7.21	6.25	2.59	75.1
3023 3029	76[a]	37		4.35	59.6	10.24	4.0	2.46	71.1
2245	230	170	73.9	4.50	59.0	8.58	1.47	2.95	77.1
2289		154		4.23	60.6	9.60	3.4	2.61	63.2

[a]Not all houses completed or occupied.

TABLE D-1

UNCORRECTED CONCENTRATIONS OF PHOSPHATE AND ABS IN DAILY COMPOSITE SAMPLES

Date	Unfiltered Sample		Filtered Sample		ABS mg/l
	Total mg as PO_4/l	Ortho mg as PO_4/l	Total mg as PO_4/l	Ortho mg as PO_4/l	
13 Jul	60.4	--	42.7	25.6	14.6
14 Jul	42.0	--	35.1	22.1	11.9
15 Jul	42.0	--	31.0	19.4	11.1
16 Jul	39.2	--	29.6	19.2	10.2
17 Jul	43.1	--	30.9	20.6	10.7
18 Jul	44.9	--	30.3	22.6	11.7
19 Jul	42.6	--	31.6	22.7	10.6
27 Jul	71.8	35.1	57.4	35.1	15.6
28 Jul	58.7	32.3	49.9	30.4	14.1
29 Jul	55.1	42.3	48.7	32.5	14.6
30 Jul	54.0	31.3	45.0	31.6	13.5
31 Jul	56.9	33.9	38.1	34.8	13.5
1 Aug	67.3	47.9	44.4	39.4	13.0
2 Aug	57.2	36.4	46.8	34.4	15.3
10 Aug	67.5	41.7	54.4	41.4	17.6
11 Aug	47.8	35.6	41.5	32.8	11.6
12 Aug	56.2	35.7	39.0	27.3	13.7
13 Aug	58.4	36.2	42.9	33.6	13.9
14 Aug	57.9	31.8	47.2	36.2	14.4
15 Aug	59.9	32.4	43.1	32.2	15.3
16 Aug	53.0	35.7	37.7	31.6	12.8

TABLE D-2

UNCORRECTED CONCENTRATIONS OF COD, BOD, SS, NH_3-N, AND TOTAL N IN DAILY COMPOSITE SAMPLES, mg/l

Date	COD	BOD	SS	NH_3-N	Total N
13 Jul	556	279	332	19.8	36.6
14 Jul	444	164	268	17.8	37.2
15 Jul	386	169	148	16.8	30.0
16 Jul	382	213	140	16.8	31.7
17 Jul	428	193	218	16.0	35.0
18 Jul	422	182	202	17.9	33.7
19 Jul	476	---	188	20.2	35.3
27 Jul	552	244	210	21.5	33.0
28 Jul	541	227	202	22.1	39.2
29 Jul	461	227	224	33.7	37.6
30 Jul	504	244	205	23.2	40.6
31 Jul	540	233	322	23.6	49.2
1 Aug	820	349	536	27.7	54.0
2 Aug	672	277	312	24.0	55.8
10 Aug	506	220	236	21.6	39.6
11 Aug	501	250	206	23.7	38.6
12 Aug	478	249	220	21.0	38.4
13 Aug	530	251	260	24.1	48.0
14 Aug	471	201	242	22.4	38.4
15 Aug	541	242	232	24.1	40.0
16 Aug	440	216	166	25.4	40.4

TABLE D-3

HOURLY CONCENTRATION OF ABS AND PHOSPHORUS FORMS IN VCSD RAW SEWAGE

Time of Day	Flow mgd	Total mg as PO_4/l	Ortho mg as PO_4/l	Poly[a] mg as PO_4/l	ABS mg/l	Time of Day	Flow mgd	Total mg as PO_4/l	Ortho mg as PO_4/l	Poly[a] mg as PO_4/l	ABS mg/l
Monday, 27 July											
0800	0.650(0.050)	19.8(25)	13.6(14)	--	2.4(4.8)	2000	0.610	60.3	32.0	19.2	15.0
0900	0.510(0.480)	25.3(25)	16.1(16)	--	3.3(4.8)	2100	0.640	59.7	32.0	16.3	15.5
1000	0.580	38.4	30.2	--	5.2	2200	0.680	56.2	32.1	9.3	14.8
1100	0.720	70.2	44.6	11.7	11.3	2300	0.660	60.0	30.2	20.6	16.4
1200	0.760	121	49.2	13.9	20.5	2400	0.610	49.8	29.9	14.1	15.7
1300	0.840	135	42.2	40.2	23.9	0100	0.500	50.5	31.3	15.2	13.3
1400	0.740	153	41.6	53.4	27.1	0200	0.330	43.4	29.3	8.8	11.1
1500	0.710	118.8	43.1	40.3	36.0	0300	0.180	31.9	28.2	4.0	7.4
1600	0.620	147	45.5	47.0	27.4	0400	0.130	34.6	26.3	5.3	7.6
1700	0.560	121.1	42.7	42.8	24.9	0500	0.050	29.9	19.1	5.1	5.8
1800	0.530	102.7	39.8	41.7	21.0	0600	0.040	28.1	19.8	--	4.8
1900	0.530	106.5	43.5	48.9	20.3	0700	0.040	29.6	19.8	--	4.8
Tuesday, 11 August											
0800	0.600(0.030)	27.2(27)	20.6	1.6	3.2(3.4)	2000	0.570	55.7	32.2	16.6	12.5
0900	0.570(0.300)	26.9	23.1	1.1	3.4(3.6)	2100	0.580	58.0	37.4	10.5	15.3
1000	0.390	39.1	29.4	--	5.8	2200	0.640	55.3	33.1	6.4	18.6
1100	0.450	55.5	39.2	5.6	10.1	2300	0.630	51.0	30.1	12.2	10.8
1200	0.580	61.2	44.6	10.9	12.7	2400	0.620	46.9	31.4	7.0	13.0
1300	0.530	62.7	40.5	10.4	10.8	0100	0.430	38.1	27.7	1.3	10.4
1400	0.470	79.9	48.1	26.8	18.0	0200	0.320	40.9	30.2	6.7	8.6
1500	0.400	84.0	44.5	40.5	20.5	0300	0.160	49.3	34.5	5.6	9.2
1600	0.390	83.4	44.2	25.4	19.2	0400	0.090	35.2	30.8	15.3	7.8
1700	0.390	67.9	44.8	17.3	16.6	0500	0.050	30.1	25.4	6.1	5.1
1800	0.440	73.5	40.1	23.0	16.0	0600	0.030	29.2	26.8	4.3	3.9
1900	0.400	68.5	40.4	15.7	16.9	0700	0.030	27.0	26.6	1.0	4.6
Wednesday, 15 July											
0800	0.680(0.210)	8.4(14)	4.7[b]	3.2	2.1(2.7)	2000	0.740	31.5	17.5[b]	13.4	8.8
0900	0.670(0.500)	17.8(21)	12.2[b]	9.6	2.2(2.6)	2100	0.610	39.2	27.6[b]	11.3	11.7
1000	0.770	35.4	27.2[b]	13.6	4.9	2200	0.640	40.4	26.6[b]	18.4	13.1
1100	0.840	44.5	20.8[b]	5.9	6.2	2300	0.800	35.6	24.9[b]	10.9	12.3
1200	0.940	51.9	37.2[b]	10.0	11.2	2400	0.770	43.2	27.8[b]	12.5	14.1
1300	0.890	65.9	30.0[b]	41.0	14.6	0100	0.550	30.5	20.2[b]	8.8	9.7
1400	0.890	61.0	32.9[b]	34.7	17.9	0200	0.500	28.2	20.2[b]	7.5	6.8
1500	0.860	55.6	28.0[b]	37.1	14.7	0300	0.350	27.1	19.9[b]	3.7	6.8
1600	0.830	59.5	29.3[b]	33.9	15.8	0400	0.280	20.9	15.3[b]	3.2	5.5
1700	0.880	49.4	27.8[b]	21.8	12.8	0500	0.240	15.9	13.4[b]	1.4	4.1
1800	0.800	54.4	24.6[b]	29.1	13.2	0600	0.200	13.1	11.3[b]	3.0	3.3
1900	0.900	48.7	20.4[b]	19.5	10.3	0700	0.190	13.8	10.8[b]	3.0	2.9
Thursday, 13 August											
0800	0.31(0.04)	27.5(25)	23.4(21)	3.2	1.9	2000	0.41	65.0	37.4	13.8	16.2
0900	0.54(0.33)	27.6(26)	23.1(21)	3.2	3.3	2100	0.45	48.3	34.2	10.2	13.7
1000	0.45	39.6	30.8	2.6	5.5	2200	0.55	47.2	35.1	0.2	13.4
1100	0.55	46.2	35.2	7.4	5.1	2300	0.57	52.1	34.2	14.8	12.3
1200	0.59	60.5	45.5	9.1	6.8	2400	0.58	53.7	34.6	16.0	12.3
1300	0.68	65.0	46.8	6.1	13.9	0100	0.47	32.1	26.3	5.1	9.8
1400	0.58	82.2	50.4	13.9	14.8	0200	0.33	34.6	26.0	6.4	8.8
1500	0.56	83.7	37.0	52.8	16.2	0300	0.20	29.0	22.7	0.3	6.5
1600	0.52	85.0	47.8	39.7	19.2	0400	0.10	28.2	23.0	3.5	6.7
1700	0.48	75.6	45.1	21.3	14.1	0500	0.05	25.2	21.8	1.3	4.3
1800	0.43	73.4	42.0	16.5	13.9	0600	0.04	25.6	21.8	1.9	4.3
1900	0.44	66.0	39.2	20.5	17.6	0700	0.02	25.1	22.2	2.2	4.7
Friday, 14 August											
0800	0.33(0.03)	27.0(27.0)	22.3(22.3)	--	1.8(1.8)	2000	0.59	72.5	35.1	14.5	14.8
0900	0.50(0.34)	28.3(29.1)	18.8(16)	--	2.9(3.4)	2100	0.68	45.0	27.9	10.7	13.2
1000	0.70(0.46)	41.1(48)	27.2(28)	1.8	4.1(5.5)	2200	0.70[c]	42.5	27.1	11.7	13.5
1100	0.60	47.2	34.4	5.0	7.3	2300	0.62[c]	54.7	32.4	15.0	12.1
1200	0.75	66.2	37.6	16.3	12.3	2400	0.56[c]	54.4	31.4	10.7	11.5
1300	0.78	77.0	47.4	17.0	18.0	0100	0.43[c]	36.0	27.4	4.6	9.6
1400	0.76	72.2	45.6	24.2	18.9	0200	0.35[c]	34.2	23.6	3.4	8.3
1500	0.68	69.7	40.1	34.3	21.2	0300	0.26[c]	46.2	31.1	0.8	6.4
1600	0.63	81.2	45.6	7.5	18.2	0400	0.14[c]	29.3	19.6	0.6	5.2
1700	0.54	73.0	39.1	19.2	16.9	0500	0.09[c]	29.7	16.9	3.0	3.4
1800	0.53	74.4	41.8	8.6	18.2	0600	0.06[c]	21.5	17.0	1.6	3.4
1900	0.54	65.0	37.8	12.8	17.8	0700	0.04[c]	22.7	17.4	--	3.6
Saturday, 15 August											
0800	0.04[c]	17.5	15.5	--	3.0	2000	0.50[c]	55.2	43.8	--	14.8
0900	0.06[c]	17.5	14.5	--	3.4	2100	0.53[c]	48.0	32.2	0.2	12.3
1000	0.22[c]	27.3	20.2	1.9	4.2	2200	0.55[c]	49.6	31.6	1.1	11.4
1100	0.63[c]	55.7	42.2	--	9.2	2300	0.69[c]	47.5	30.6	6.6	13.1
1200	0.83[c]	59.1	42.5	9.1	12.3	2400	0.56[c]	47.2	33.2	--	13.2
1300	0.83[c]	79.7	38.4	42.2	18.2	0100	0.42[c]	41.5	28.8	--	11.4
1400	0.78[c]	99.3	46.1	11.4	20.3	0200	0.33[c]	31.8	26.2	0.5	5.9
1500	0.73[c]	80.0	45.8	11.7	20.7	0300	0.23[c]	36.2	28.8	--	8.1
1600	0.63[c]	82.2	42.9	5.8	20.5	0400	0.16[c]	33.7	24.4	--	7.6
1700	0.54[c]	69.7	42.5	--	17.8	0500	0.11[c]	28.3	21.2	2.7	4.0
1800	0.46[c]	67.7	42.5	7.2	17.8	0600	0.05[c]	28.5	21.2	--	3.2
1900	0.46[c]	53.5	43.8	20.2	16.6	0700	0.04[c]	25.1	20.2	--	4.3
Sunday, 2 August											
0800	0.030	28.0	22.3	--	4.6	2000	0.520	63.0	38.0	27.5	14.1
0900	0.030	28.3	21.8	--	4.2	2100	0.560	56.4	35.7	32.0	14.4
1000	0.220	22.4	18.3	--	4.6	2200	0.580	59.6	31.9	18.5	13.5
1100	0.540	48.3	24.6	2.2	7.1	2300	0.640	51.6	33.5	20.6	15.5
1200	0.670	49.4	24.6	--	7.3	2400	0.620	45.2	30.6	13.7	16.9
1300	0.710	65.7	41.7	16.6	15.3	0100	0.500	44.1	28.7	17.1	13.2
1400	0.760	66.4	41.6	14.7	15.3	0200	0.370	39.0	28.8	10.7	9.8
1500	0.640	72.6	45.8	25.7	19.8	0300	0.200	37.0	29.0	1.6	9.7
1600	0.650	78.9	47.6	37.4	18.9	0400	0.100	35.2	27.8	9.8	7.1
1700	0.580	65.4	41.5	20.5	16.9	0500	0.040	37.9	27.8	6.1	7.0
1800	0.520	62.6	39.7	18.9	15.0	0600	0.030	32.9	27.6	5.1	5.8
1900	0.480	66.4	42.4	34.7	14.6	0700	0.010	29.2	23.8	11.4	4.7

[a]Corrected for insoluble polyphosphate. [b]Corrected for insoluble orthophosphate. [c]Flow from previous week used as estimate.
Note: Values corrected for recycled effluent flow in parenthesis.