NATIONAL BUREAU OF STANDARDS REPORT

7736

PROGRESS REPORT NO. 1

ON

FLUID DYNAMICS OF PLUMBING

by
R.S. Wyly and R.W. Beausoliel

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NBS

U. S. DEPARTMENT OF COMMERCE
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ABSTRACT

This progress report, the first in a series, presents a summary of plans for a study of the fluid dynamics of residential plumbing systems for sanitary drainage. Preliminary results and accomplishments are given. Perhaps the most important information in the report is that concerning proposed methods for applying test loads, and that giving results of flow tests in a laboratory apparatus simulating a 2-in. stack.

1. Introduction

1.1 Purpose of Investigation

The purpose of the investigation is to study aspects of the fluid dynamics of plumbing systems such as installed in one- and two-story houses, which have not been covered adequately by previous research. Particular emphasis is to be placed on the study of venting phenomena. New or additional factual information could lead to improvement in rational, economic design, and provide data useful in the preparation of plumbing codes and standards.

1.2 Authorization

The project was approved by the National Bureau of Standards under the Grants-in-Aid Program on Dec. 21, 1962, as outlined in a letter from Dr. R.D. Huntoon, Deputy Director of the National Bureau of Standards, to Mr. John R. Dickerman, Executive Vice President, National Association of Home Builders. Financial support in the amount of $25,000 was provided by NAHB on May 10, 1962, and acknowledge by NBS in a letter dated May 28, 1962, from Mr. D.E. Parsons, Chief, Building Research Division, to Mr. Dickerman. It was understood that the cost of the work would not exceed $25,000 per year over a period of about two years.

2. Preliminary Activity

An advisory committee was organized for the purpose of reviewing the work at appropriate stages, making recommendations, and furnishing advice on questions raised by the project staff. The functions of the committee are advisory only. The committee comprises the following persons:

Mr. Ralph Johnson, Technical Director,
National Association of Home Builders.

Mr. Robert Schmidtt, Chairman,
NAHB Research Committee.

Mr. James Simpson, Chief,
Standards and Technical Studies Section,
Architectural Standards Division,
Federal Housing Administration.

Mr. Malcolm Hope, Assistant Chief,
Division of Environmental Engineering,
Department of Health, Education, & Welfare.

Mr. Douglas Parsons, Chief,
Building Research Division,
National Bureau of Standards.

Mr. John French, Hydraulics Engineer,
Fluid Mechanics Section,
Mechanics Division,
National Bureau of Standards.

Mr. Robert Wyly, Hydraulics Engineer,
Building Research Division,
Codes and Safety Standards Section,
National Bureau of Standards.

The Advisory Committee met on May 16, 1962, and discussed in some detail the following items:

1. Project scope,
2. hydraulic and pneumatic performance criteria,
3. problems to be studied,
4. nature of measurements required, and
5. instrumentation.

A summary of the committee's recommendations has been included in this progress report as section 6.1. It was suggested by the project staff that the following tasks be emphasized in the initial phase of the investigation:

1. Measurement of performance of small-diameter vents for certain conventional systems,
2. measurement of effects, on air demand and stack pressures, of (a) type of stack fitting, (b) stack and fixture branch diameters, and (c) stack length,
3. preparation of recommendations for obtaining data on time distribution of fixture use and on minimum residual trap seals in service, and
4. a review of the literature relating to items (i), (iii), (vii), and (viii) as outlined in section 6.1c(2).

3. Accomplishments

3.1 Procurement of Equipment and Supplies

Purchase orders were placed for pipe, plumbing fixtures, and instruments. Test systems will be constructed for the most part of cast-iron soil pipe, galvanized-steel pipe and methyl-methacrylate plastic

pipe. Residual trap seals will be measured with glass or clear plastic piezometers in combination with short graduated scales. Fluctuating or rapidly changing pneumatic pressures and water depths will be measured with strain gage or magnetic reluctance pressure transducers and a multichannel recording oscillograph, most of this instrumentation having been purchased on NBS funds. Miniature pitot-static pressure probes will be used to sense air movement in vent pipes. Air pressures and water heads will be transmitted to transducers or indicating devices through side-hole taps or pressure probes, depending on requirements in the particular test to be made. Fluctuating phenomena can be measured on a six-channel basis with the instruments available for this project.

3.2 Test Structure

Work is nearing completion on a multi-deck wooden test structure simulating two stories and a basement. A horizontal space of approximately 35 ft x 16 ft is being provided at the first floor level, and approximately 17 ft x 16 ft at the second story level. A longer space is available at the basement level. Split-level arrangements can be accommodated by the use of a portable platform above the first floor deck, if this should be necessary.

3.3 Piping Plans

A portion of the experimental program is to involve hydraulic tests on full scale piping systems taken from house plans furnished through NAHB. House plans were received for 23 different houses, furnished by five different builders. The states represented are California, Indiana, Maryland, New York, and Texas. Piping plans were furnished for one of the California houses and two of the Maryland houses. From these plans, tentative plans for drainage and vent piping have been prepared by the project staff for four test systems. These are shown in section 6.2. System 1 is from a 1-story, 1-bath house with kitchen and automatic clothes washer all on one floor. Systems 2 and 3 are from 1-story, 2-bath houses with kitchens and automatic clothes washers all on one floor. System 4 is from a two-bath house with bathrooms and kitchen on the first floor and a laundry tub in the basement. It is believed that the sequence of the plan numbers also indicates the relative order of complexity of the piping from the standpoint of testing. For this reason System 1 probably should be tested first.

The project staff will welcome any constructive suggestions from NAHB or the advisory committee regarding these proposed piping plans.

3.4 Fluid Flow and Pressures in a 2-in. Test Stack

Equations similar to eq (55) of NBS Mono. 31 [1], or eq (9) proposed by Dawson and Kalinske [2] are commonly employed in estimating air

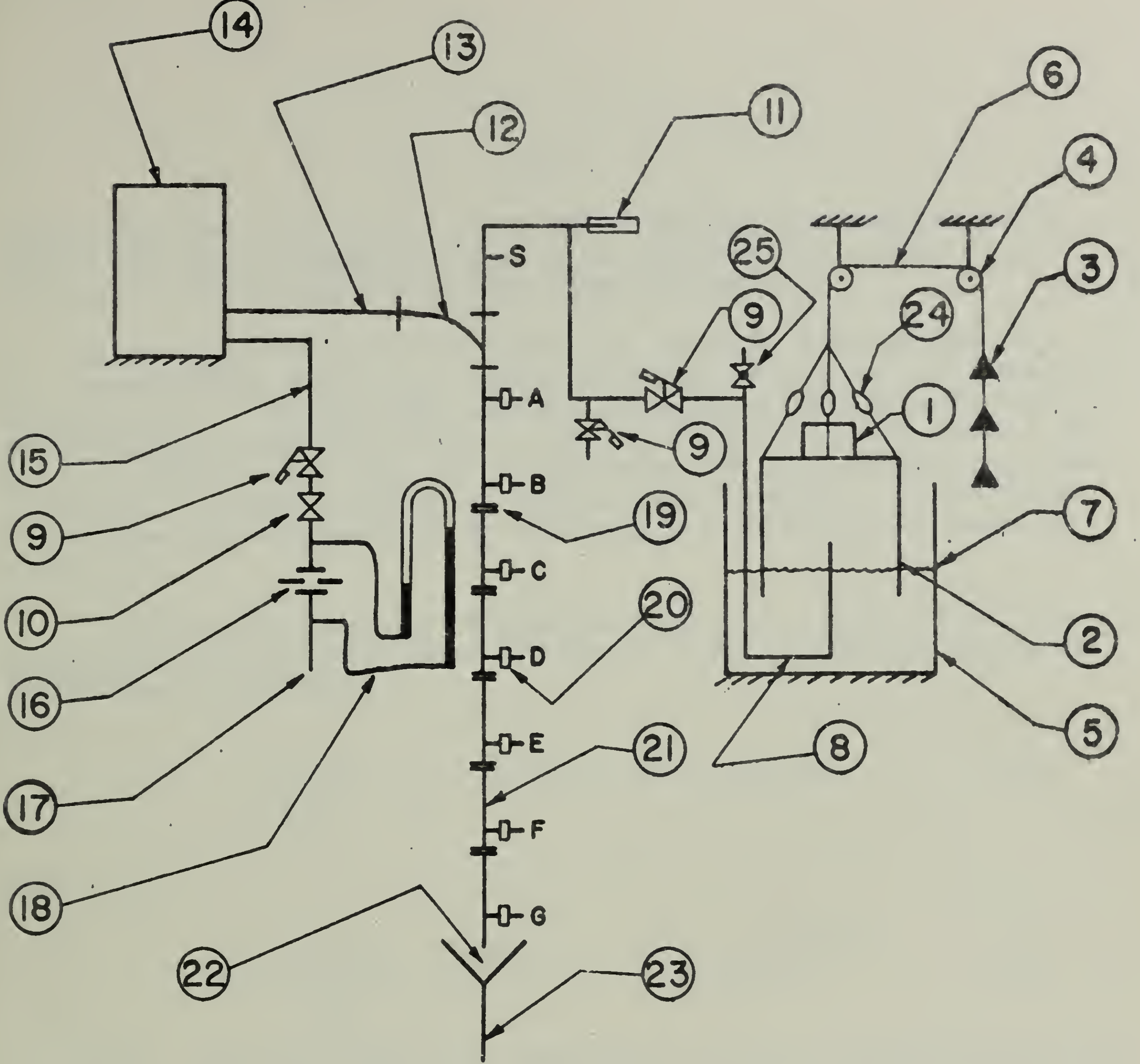

Figure 1. Test system for study of fluid flow in 2-in. stack

1 Bouyancy compensator
2 Inverted steel drum
3 Lead counter weights
4 Low-friction pulleys
5 500 gal. wooden box
6 Steel cable
7 Water line
8 Simulated stack vent
9 Quick-opening valve
10 Gate valve
11 Thermometer
12 Long-turn T-Y water-inlet fitting, recessed drainage type
13 10-ft length of 2-in. plastic pipe on 1/4-in./ft slope.
14 Stilling box
15 Supply line to stilling box
16 Orifice meter
17 Connection to constant-head water supply
18 Water manometer
19 Flange union
20 Plastic dash pot to prevent water from entering tubing to pressure sensing devices.
21 44" length of 2" diameter standard weight wrought iron pipe
22 Air gap at bottom of 22 ft stack
23 funnel
24 Turnbuckle
25 Valved connection to compressed-air supply
S Pressure tap in stack vent
A-G Pressure taps below water-inlet

maintaining the stack full of water under conditions of substantially steady pipe flow. Computed values of the Darcy-Weisbach friction factor based on these measurements are shown in table 1.

Referring to table 1, it will be seen that the friction factors are somewhat lower than those ordinarily suggested for use with commercial iron pipe. Possibly this may be attributed in part to errors in measuring flow rates and pressure drop, particularly for low rates. The data strongly indicate that the test pipe was actually smoother than the "commercial" pipe referred to in textbooks and handbooks, characterized by roughness magnitutes based on materials as manufactured at least 20 years ago.

Figure 2 shows data for air flow as a function of water flow, obtained with the apparatus shown in figure 1. For comparison, curves representing the equations

$$Q_w \frac{(1-r_s)}{(r_s)} = Q_a = 26.9(r_s)^{2/3}(1-r_s)(D_1)^{8/3} \qquad (1a)$$

and

$$1.5 Q_w \frac{(1-r_s)}{(r_s)} = Q_a = 40.3(r_s)^{2/3}(1-r_s)(D_1)^{8/3} \qquad (1b)$$

are shown. These equations were developed in the same manner as eqs (53) and (55) of Mono. 31, based on an assumed absolute roughness of 0.001 ft. A value of V_a/V_w of 1.0 was assumed in eq (1a), and a value of 1.5 in eq (1b). For other values of absolute roughness, air flow and water flow rates should vary in inverse proportion to the 1/6 power of the absolute roughness for any given value of r_s. The terms have the following meanings when used in eqs (1a) and (1b):

Q_w is the volume rate of water flow in gpm

Q_a is the volume rate of air flow in gpm

r_s is the ratio of area of cross section of water stream in the stack to total area of cross section of stack

V_w is the mean terminal velocity of the water in fps, in accordance with the equation

$$V_w = 3.21(r_s)^{2/3}\left(\frac{D_1}{k_1}\right)^{1/6}\sqrt{gD_1} \qquad (2)$$

Table 1. Experimental values of Darcy-Weisbach friction factor for 2-in. galvanized iron stack shown in figure 1

Water flow rate gpm	Reynolds Number $\times 10^{-3}$	Friction factor*, f
19	25.6	0.0266
35	47.2	.0213
50	67.5	.0200
64	86.4	.0192
80	108	.0194

*The corresponding average value of absolute roughness is approximately 0.00025 ft, which is 1/2 the value given by Rouse for new galvanized iron pipe.

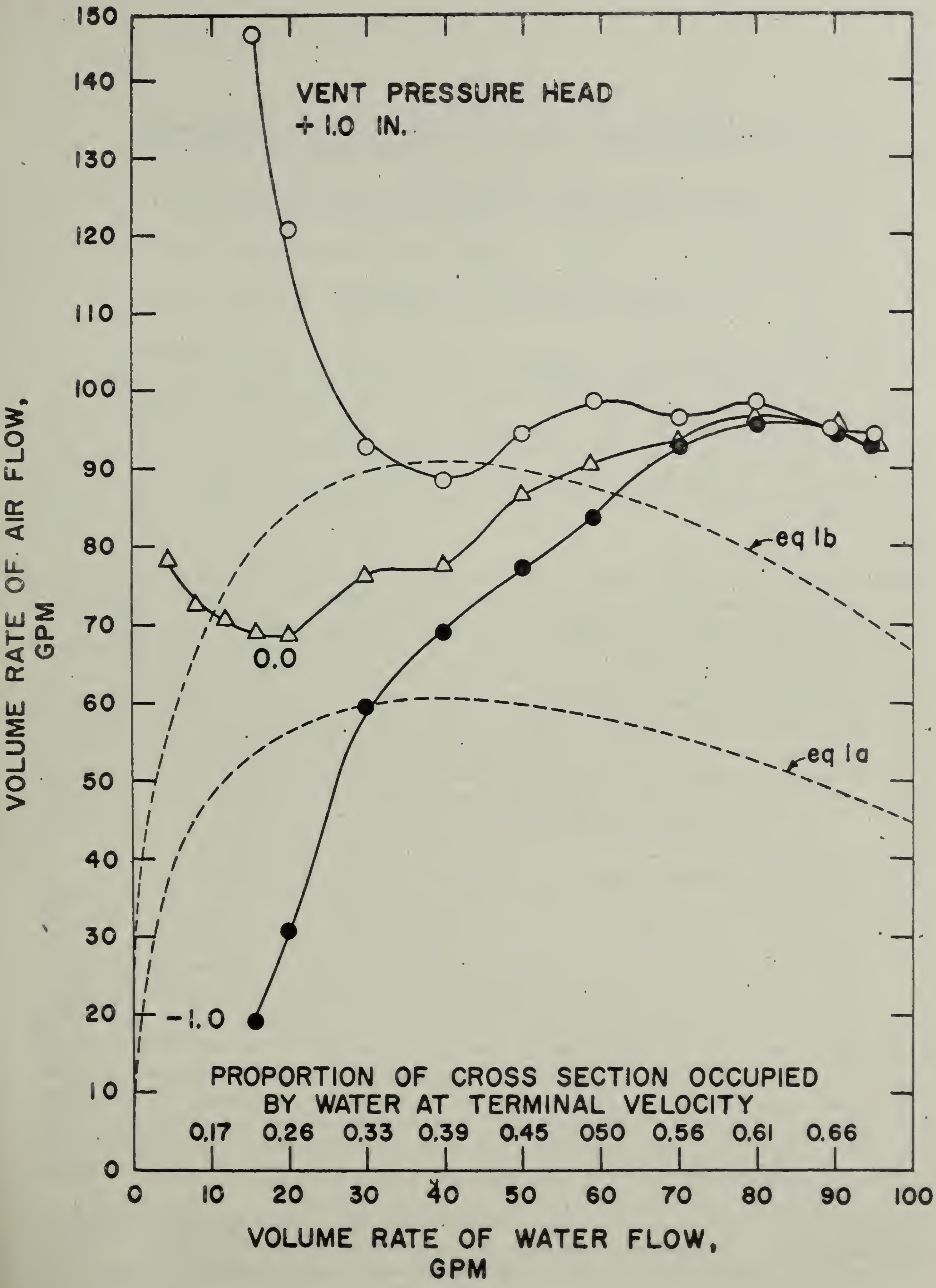

Figure 2. Air demand as a function of water flow rate and vent pressure, for 2-in. test stack shown in figure 1.

where dimensionally consistent units are used (Eq (2) is derived from eq (44) of Mono. 31)

V_a is the mean velocity of the air in the stack, in fps

D_1 is the stack diameter in inches

k_1 is the absolute roughness of the stack material

Experimental air flow rates for atmospheric pressure in the stack vent were intermediate between values predicted from eqs (1a) and (1b) over a range of water flow between 10 and 55 gpm (see intermediate data curve, figure 2). For water flow rates less than 10 and greater than 55 gpm, air flow rates exceeded those predicted from eq (1b). In this connection, the criterion for stack capacity given in Mono. 31 indicates that a 2-in. stack should not be used for water flow rates in excess of about 25 gpm.

Air flow rates for vent pressures of +1 and -1 in. of water indicate the extent to which air demand may be affected by stack vent pressure. As an example, if the stack vent were long enough to allow a pressure drop along its entire length of 1 inch of water gage for a water flow rate of 20 gpm, the air rate would be 30 gpm. On the other hand, if a very short vent is used so that the vent pressure remains substantially atmospheric the air demand would be 70 gpm. Positive vent pressures, as shown in the upper data curve, may occur in a stack vent during a strong down draft on a windy day, and may occur in a vent at an intermediate or low level on a multistory stack as a result of "piston" action when a slug of water is discharged at some higher elevation.

The theoretical values for air flow indicated by eqs (1a) and (1b) are slightly less than those by eq (55) and of Mono. 31. The reason for this is that eq (55) of Mono. 31 was based on a value of absolute roughness of 0.00083 ft, while eqs (1a) and (1b) of this report are based on an arbitrary value of $k_1 = 0.0010$ ft, this being twice the value suggested by Rouse for new galvanized wrought iron pipe [3]. It can be shown that the coefficient in the equations varies inversely as the 1/6 power of the absolute roughness for any given value of r_s. As shown in table 1, measurements in the current investigation indicate that the test stack had an apparent roughness of about 0.00025 ft, this being only about 1/4 as great as assumed in eqs (1a) and (1b). If this is taken into account, both the air flow and the water flow values on the theoretical curves in figure 2 would be increased by the factor $\left(\frac{0.0010}{0.00025}\right)^{1/6}$, or by about 26 percent. Had the coefficients in the equations been based on the lower value of roughness, close agreement between eq (1a) and the experimental values of air flow would have been obtained for rates of water flow from 20 to 30 gpm. The agreement is probably affected also by length of stack, type of inlet fitting, and other factors.

The data on "shut off" head shown in figure 3 were obtained from the test system in figure 1 by closing the stack vent completely and measuring the pressure in the vent for several different rates of water flow. The significance of this data is that the omission of a stack vent can reduce pressures so much that trap seals may be lost. For example, figure 3 indicates that a 2-in. trap seal connected to the test stack at or above the elevation of the water inlet would have been lost or seriously reduced for a water flow rate of 15 gpm, this being less than the normal rate of discharge obtained by removing the cup strainer from a kitchen sink half full of water. The curve shown in the figure for comparison with the experimental data represents the equation

$$p = -0.0028(Q_w)^{5/2}, \qquad (3)$$

where p is the vent pressure in inches of water, and Q_w is the volume rate of water flow in gpm. The facts that (1) the pressure above the water inlet in the absence of an air supply was approximately proportional to a power function of the volume rate of water flow, and (2) that the power was approximately 5/2, are consistent with earleir findings under somewhat different conditions [1, 2, 4, 5]. In the earlier studies, pneumatic pressures within a vented horizontal branch or within a stack were roughly proportional to a power function of the water flow rate over a practical range, and the value of the power appeared to approach a maximum of 5/2 in inverse ratio to the extent of venting relief.

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[3] Elementary mechanics of fluids, Hunter Rouse, John Wiley and Sons, Inc., New York, N.Y. (1946).

[4] Tests on the hydraulics and pneumatics of house plumbing, Harold E. Babbitt, Engineering Experiment Station Bulletin No. 143, University of Illinois, Vol. XXI, No. 47 (1924).

[5] Tests on the hydraulics and pneumatics of house plumbing, pt II, Harold E. Babbitt, Engineering Experiment Station, Bulletin No. 178, University of Illinois (1928).

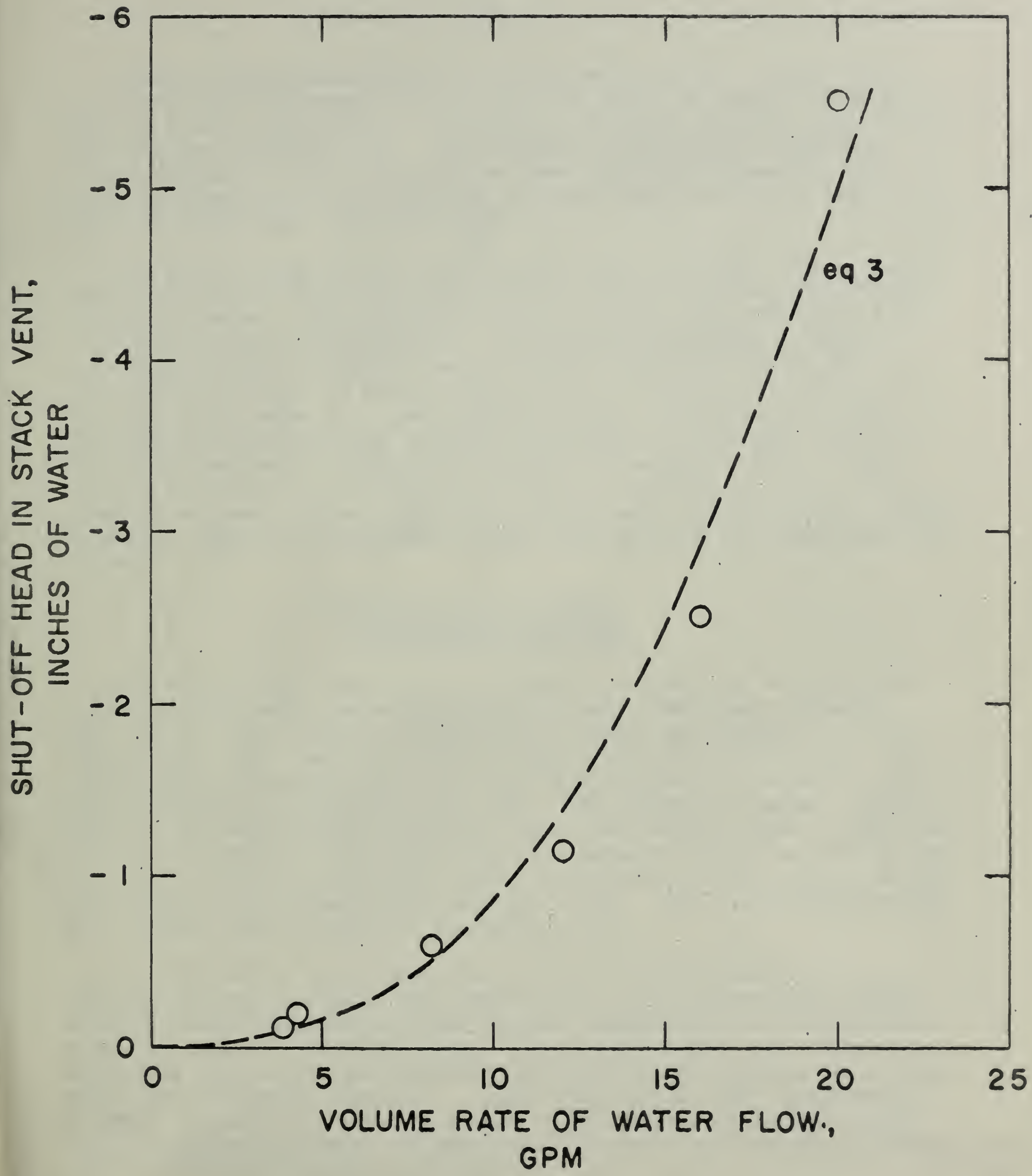

Figure 3. Shut-off head in stack vent as a function of water flow rate, for 2-in. test stack shown in figure 1.

Figure 4 shows stack pressures below the elevation of water inlet for several rates of water flow, measured by means of sidewall taps along the stack. The greatest reductions in pressure occurred just below the elevation of water inlet. It is evident that pressure reductions for all except the lowest water rates were sufficient to destroy trap seals connected to the stack through unvented drains within at least one branch interval below the water inlet.

The data in figures 2 to 4 are exploratory in nature. Theory indicates that air flow and air pressure for a given water flow are affected by stack diameter. This parameter should be varied over the range 1-1/2 to 3 inches in this investigation. Other parameters known or believed to be significant, and which should be varied, include type of water-inlet fitting, length of stack, and diameter of branch. The effect of introducing the water as a short-duration surge rather than as steady flow should be investigated, although preliminary indications are that this effect may not be significant insofar as design air flow or vent pressure in concerned. Finally, the effect of introducing water simultaneously at two or three elevations on the stack, rather than at a single elevation, should be investigated since this may occur under service conditions.

3.5 Methods for Assigning and Imposing Test Loads

In many plumbing tests the test loads have been more or less arbitrary. In some cases the extreme view has been taken that the proper test load is that arbitrary combination of number and sequence of fixtures in operation found by trial to produce the worst conditions. Unfortunately, this approach has led to wide differences in opinion as to what constitutes a reasonable test load. The problem is further complicated for the experimenter because if more than perhaps three or four fixtures are involved, an excessive amount of experimentation may be required in trying to determine the worst test combinations, and he may not be certain that the worst combination has been found. Then the question arises as to whether such a load is a reasonable one.

Another method of assigning test loads is being considered for possible use in this project. This method is to use mathematically predetermined random operating programs applied independently to each fixture either by manual or automatic means. Automatic punched-tape readers are obtainable for simultaneous handling of predetermined programs on a large number of independent channels. A shop-made program timer operating on a similar principle has been developed by the project staff for limited use on 8 channels or less. If only 4 or 5 fixtures are involved, manual push-button control might be sufficient.

Where random sequences are utilized, the programs will be prepared by automatic high speed computor, each program to be capable of running

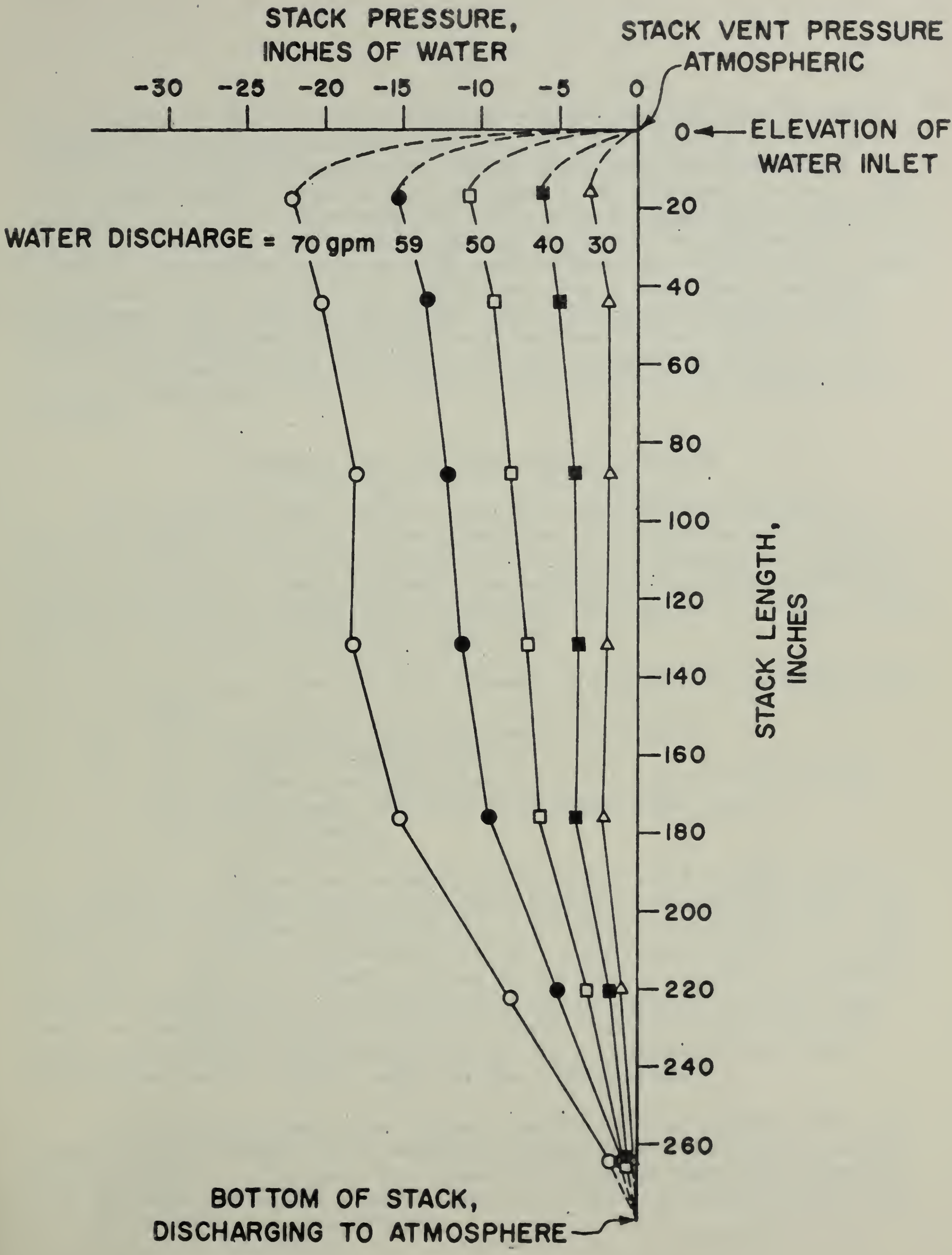

Figure 4. Stack pressure as a function of water flow rate and distance below water inlet, for 2-in. test stack shown in figure 1.

for a period of time as long as desired without repeating the sequence. Programs will be prepared for values of p = 0.01 - 0.10 by 0.01's, p = 0.15 - 0.25 by 0.05's, and for p = 0.50, where p is the probability of the fixture being in operation if observed at an arbitrary instant. Undoubtedly the use of these programs would greatly simplify the task of choosing reasonable test loads, since it would only be necessary to choose a conservative value of p for each fixture and then allow the test to proceed automatically for a sufficient time so that peak pressures, discharges, etc. approach the design values predicted mathematically. This latter requirement, however, requires some further study. In any event, it should be well worthwhile to make a comparison between the results of applying arbitrary programs and mathematically predetermined programs.

4. Proposed Work for Next Reporting Period

It is expected that the test structure described in section 3.2 will be completed and that the drainage and vent system described as system 1 in section 6.2 will be installed on the test structure. Further work will be done in devising means for applying test loads and for measuring significant parameters in connection with System 1. Present plans call for measuring the following qualities:

1. Discharge rates and time sequence as related to the various fixtures,
2. air velocities in stack vent and branch vents,
3. air pressure in fixture drains,
4. water depths in building drain near its junction with branch from water closet, and also in building sewer, and
5. residual trap seals.

Among the independent variables in System I which probably should be varied over a range are (a) effective diameter of various vents, (b) magnitude and sequence of test loading, (c) slope of building drain, and (d) method of joining intermediate stacks to building drain - i.e. from the side or the top. Finally, it may be worthwhile to plan to investigate the performance of an alternate piping arrangement in which fewer vents are employed through the use of stack venting for the bathroom group, and perhaps also through the use of a combination waste-and-vent system for the kitchen sink and the clotheswasher.

It is expected that some further results will be obtained from the apparatus for studying fluid mechanics of stacks as described in section 3.4 and figure 1. The next two items to be studied with this apparatus are (1) effect of branch diameter, and (2) effect of stack fitting type, i.e. sanitary tee or long-turn T-Y.

Further information will be sought with reference to practical means for collecting field information on time distribution of fixture use and other items, and the literature will be examined with reference to data of value in the current project.

5. Expenditures

The sum of approximately $6800 was spent or obligated during the first four months of the fiscal year. A relatively large proportion of this sum was applied to the purchase of supplies and equipment. As the project continues relatively less will be charged to supplies and equipment and more to labor.

6. Appendix

6.1 Outline of Proposed Investigation

a. Scope

The investigation will cover hydraulics and pneumatics, with particular reference to drainage and venting of residential plumbing systems. It will be restricted to problems for which meaningful measurements can be obtained. Problems dealing with the development of fouling,scaling, or corrosion over a period of time under service conditions; with the performance of different specific piping materials; with water conservation; or with redesign of fixtures will not be studied.

b. Hydraulic and Pneumatic Performance Criteria

The fundamental performance requirement for drainage and venting systems is that waste water and fecal matter must be conveyed to a public sewer or other acceptable point of disposal without nuisance, health hazard, or excessive maintenance. Experience has shown that this can be accomplished by designs based on the following considerations:

(1) The use of a water-seal trap for each plumbing fixture to prevent passage of sewer gases or vermin. A trap with a seal depth of at least 2 in. is considered adequate.

(2) Minimization of pneumatic-pressure fluctuations inside each fixture drain to avoid serious loss or disturbance of trap seal and excessive drainage noise. A residual trap seal of at least 1 in. is considered adequate.

(3) Minimization of peak hydrostatic pressures in the drainage piping resulting from the discharge of fixtures to avoid forcing waste water or fecal matter back into fixtures or their traps. Water depths not in excess of one half pipe diameter above the inverts of horizontal drains are considered satisfactory.

(4) Provision for adequate, uniform cross-sectional areas of piping and for self-cleansing liquid velocities to reduce the incidence of sluggish drainage and stoppage. Mean longitudinal liquid velocities of not less than 2 fps are considered adequate.

c. Suggested Problems for Study

The following list of problems is by no means complete nor is it intended to indicate the relative importance of the various problems. Furthermore, it may include a larger number of problems that can be studied within the time to be alloted to the proposed investigation. The purpose of the list is to indicate some of the problems which could be investigated under the proposed program.

(1) Types of Problems

(i) Effects of flow resistance on dynamic performance. Resistance may depend on size, length, and slope of pipe, on number and type of fittings; or on smoothness of certain pipe-system components.

(ii) Effects on dynamic performance produced by certain modifications in pipe-system geometry.

(iii) Dynamic performance as affected by magnitude and sequence of test loading.

(iv) Effects on dynamic performance produced by detergents and solids in the discharge.

(v) Dynamic performance of plumbing systems under service conditions.

(2) Some Specific Problems

(i) Hydraulic characteristics of residential plumbing fixtures, including wall-hung water closets.

(ii) Minimum sizes of vents for certain conventional systems.

(iii) Safe loads for single-story wet-vented and stack-vented systems.

(iv) Safe loads for two-story wet-vented and stack-vented systems.

(v) Performance of venting systems for island fixtures.

(vi) Performance of standpipe receptors and floor drains receiving indirect wastes.

(vii) Safe unvented lengths of fixture drains and floor drains.

(viii) Evaporation of trap seals.

(ix) Effect of tailpiece length on performance of traps.

(x) Effects, on air demand, of type of stack fitting, of stack diameter, and of vertical drop.

(xi) Fundamental mechanisms of air movement within vertical drains, horizontal drains, and branching systems of vents.

(xii) Time distribution of fixture use and trap seal losses in service.

d. Types of Tests

(1) Tests on typical, full-scale drainage and venting systems under laboratory conditions. Systematic investigation over a range of variables is generally too time consuming by this method, but quick empirical data on certain practical problems can be obtained.

(2) Tests on selected components of piping systems under laboratory conditions. Fundamental facts and rational design data over a range of conditions are most advantageously obtained in this way.

(3) Tests on actual plumbing systems in service. Probably these tests should be limited to the measurement of time distribution of fixture use, of trap seal losses, and of fixture flow rates. Such tests should be useful in indicating typical loads and in checking field performance of specific piping systems.

e. Measurements

In general, the geometry and dimensions of test systems will be fully described, and test loads will be described by water discharge rate sequence, spatial distribution, physical composition, and temperature. Dependent variables to be measured as required include:

(1) Residual trap seals.
(2) Pneumatic pressures in fixture drains and other critical places.
(3) Water depths and longitudinal velocities at selected sections in sloping drains.
(4) Longitudinal velocity of air flow in vent pipes.

f. Instrumentation

(1) Predetermined test loads for laboratory tests will be applied through the use of electrical circuitry controlled either

manually by push buttons or automatically by a program timer, depending on the complexity of the test load.

(2) Residual trap seals will be measured with piezometer tubes equipped with graduated scales. Visual observations will be recorded manually.

(3) Peak values of slowly changing pneumatic and hydrostatic pressures will be measured with sensitive gages where feasible, and maximum gage readings recorded manually. Where a number of simultaneous or sequential measurements must be recorded, a multichannel electrical recorder will be utilized.

(4) Rapidly changing pressures and water depths produced simultaneously or in rapid sequence at a number of stations will be measured and recorded electrically on a multi-channel basis as required.

(5) Air and water velocities will be measured by use of miniature velocity head pickups and recorded either through the use of mechanical pressure gages, manometers, or electrical instruments, depending on the number of stations involved and on the acceleration or deceleration of the fluid stream. Where essentially steady, uniform flow is involved, velocities may be calculated from simple volumetric measurements and data on cross-sectional areas.

(6) Air and water temperatures will be measured with mercury thermometers or electrically, as required.

(7) Time distribution of fixture discharge under service conditions will be indirectly obtained through the use of electrical or photographic instruments which give a chronological record of the passage of suitably small volume increments through one or more water meters appropriately placed in water-supply piping.

6.2 Plans for Full-Scale Drainage and Vent Systems

Figures A-1 through A-8 have been prepared showing possible piping arrangements to accommodate fixtures called for in four different house plans. Figures A-1, A-3, A-5, and A-7 are plan views showing the plumbing fixtures, taken directly from house plans. The piping arrangements shown in figures A-2 and A-8 were furnished by the builders, while those shown in figures A-4 and A-6 are proposed by the project staff. It should be understood that in all cases several alternative piping arrangements could be readily devised. No attempt has been made to explore the range of possibilities in this connection. The purpose of showing certain piping arrangements here is to indicate the nature of one or more possible

test systems for use in the initial stages of the investigation, and to stimulate constructive suggestions before such a test system is actually completed.

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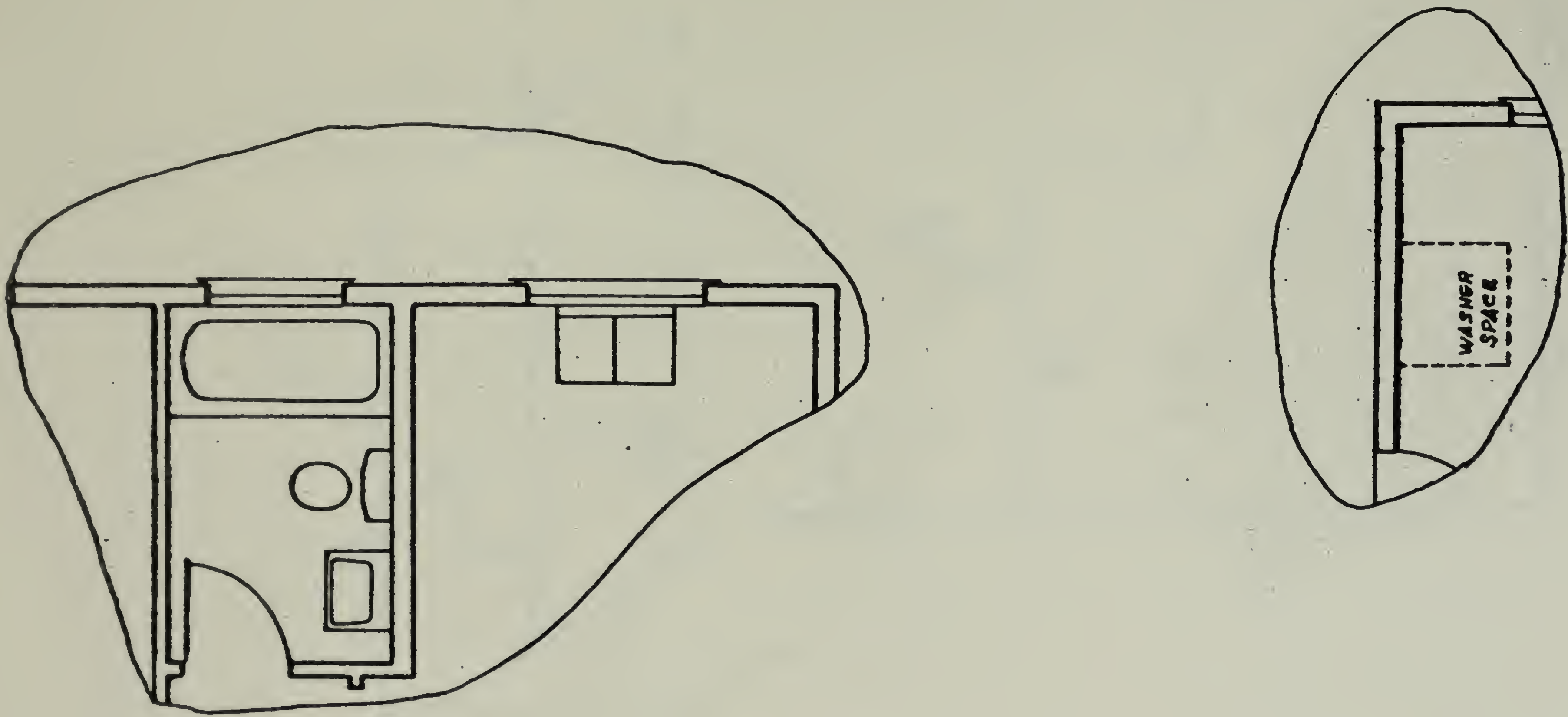


Figure A-1. System 1, fixture plan.

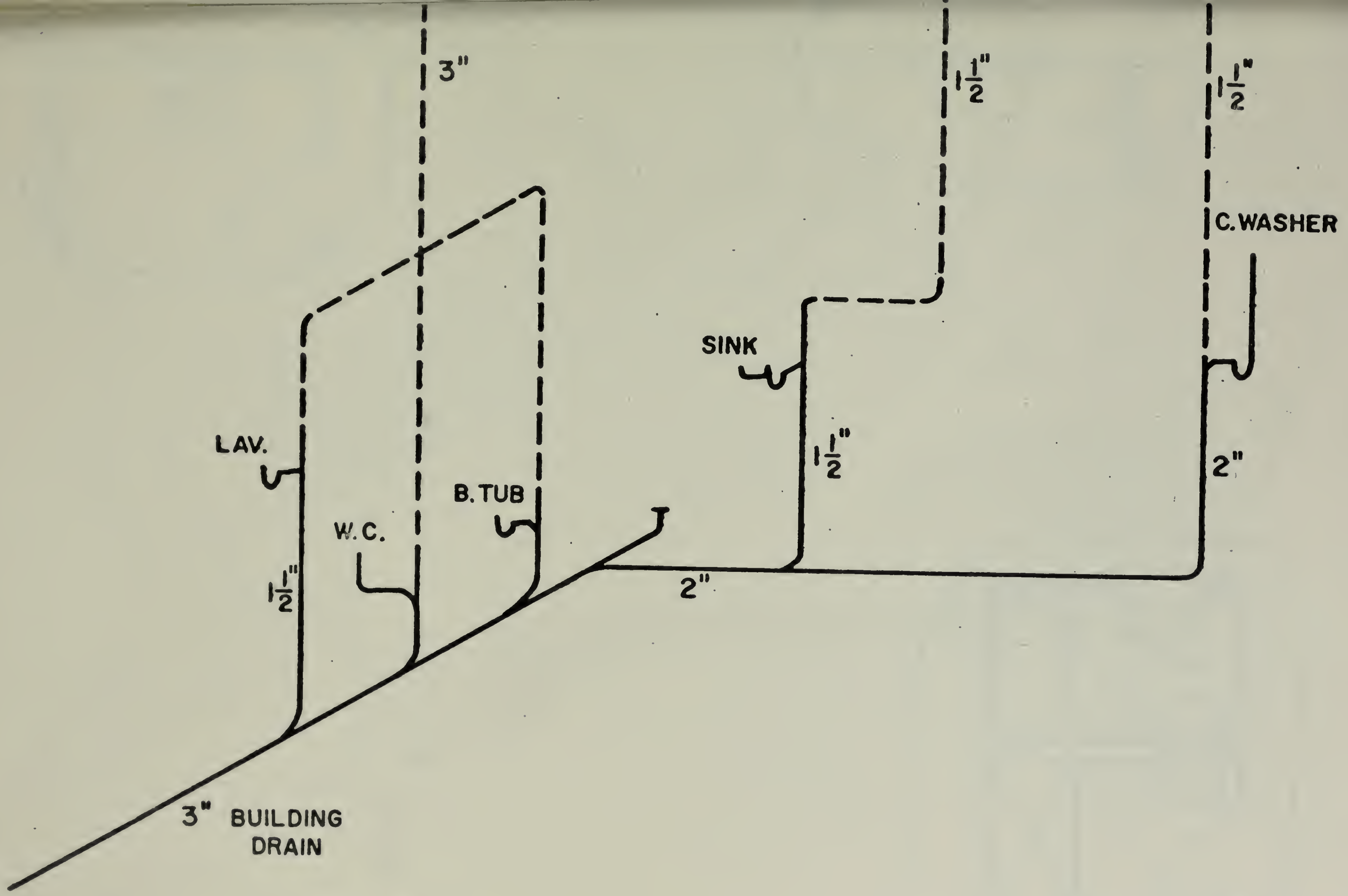


Figure A-2. System 1, pipe isometric.

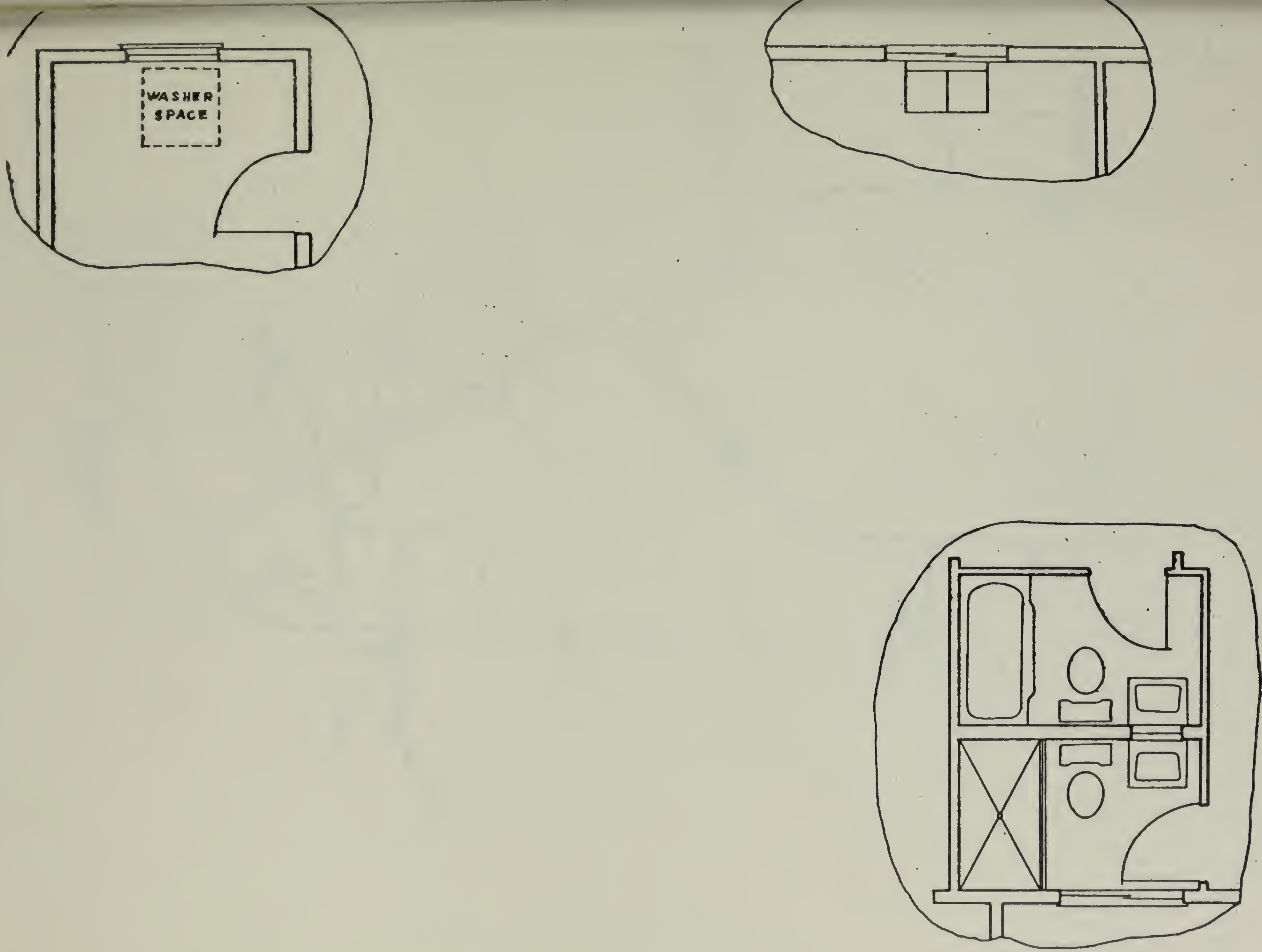


Figure A-3. System 2, fixture plan.

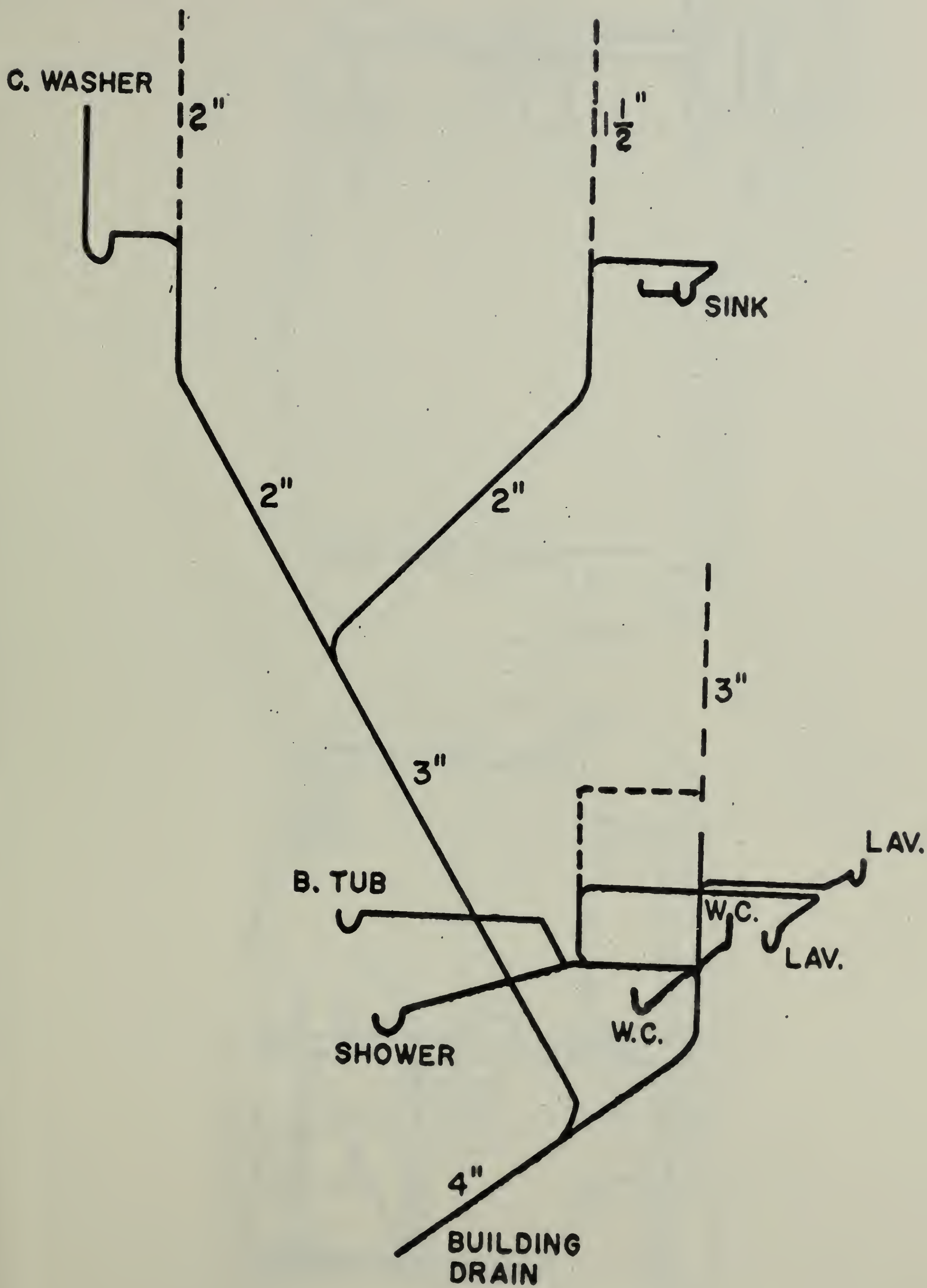


Figure A-4. System 2, pipe isometric.

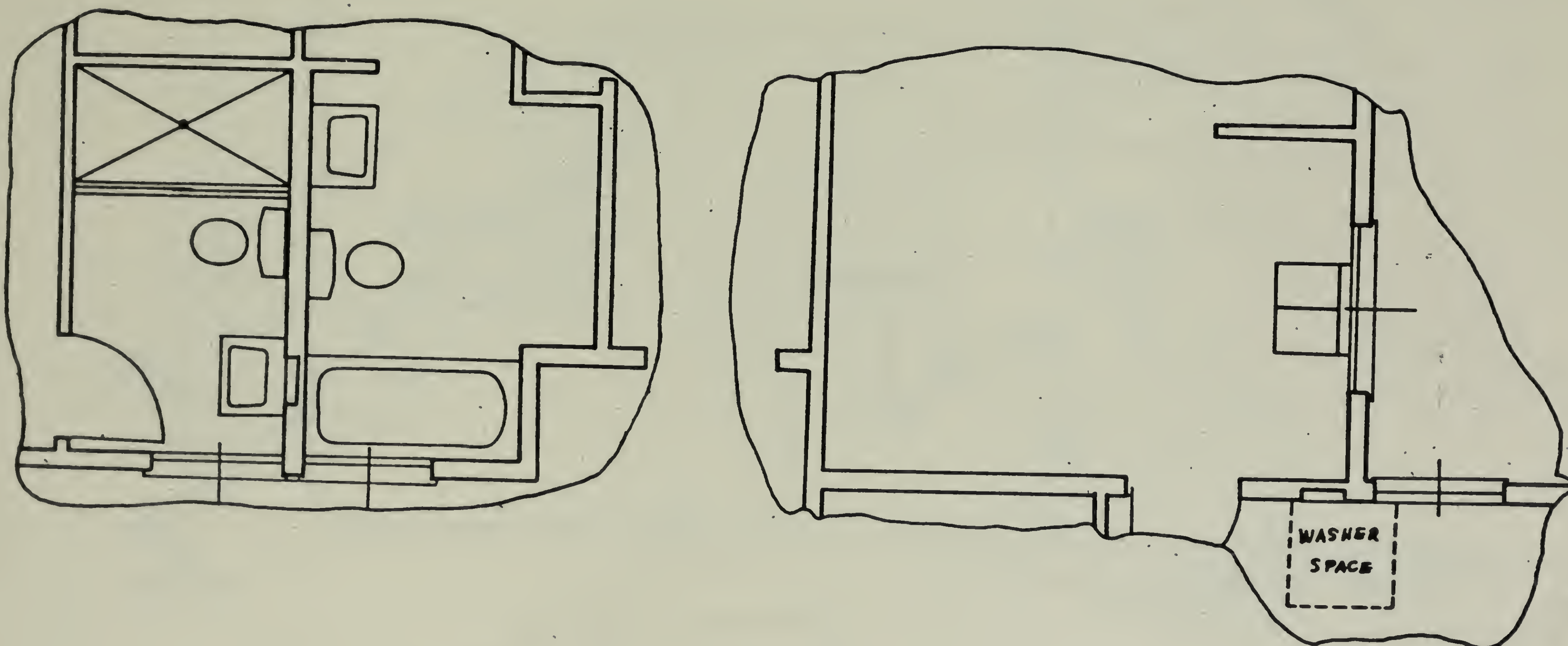


Figure A-5. System 3, fixture plan.

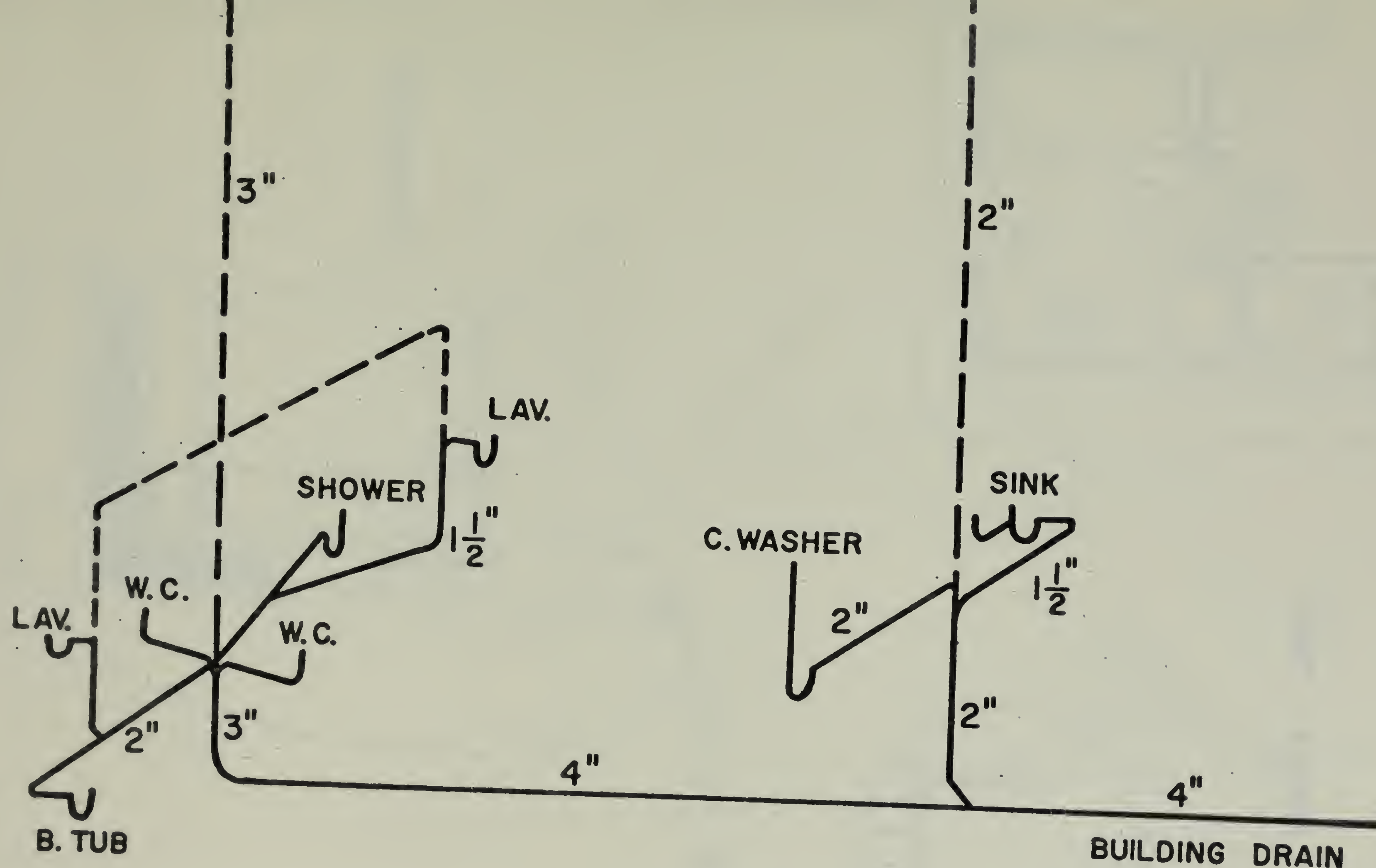
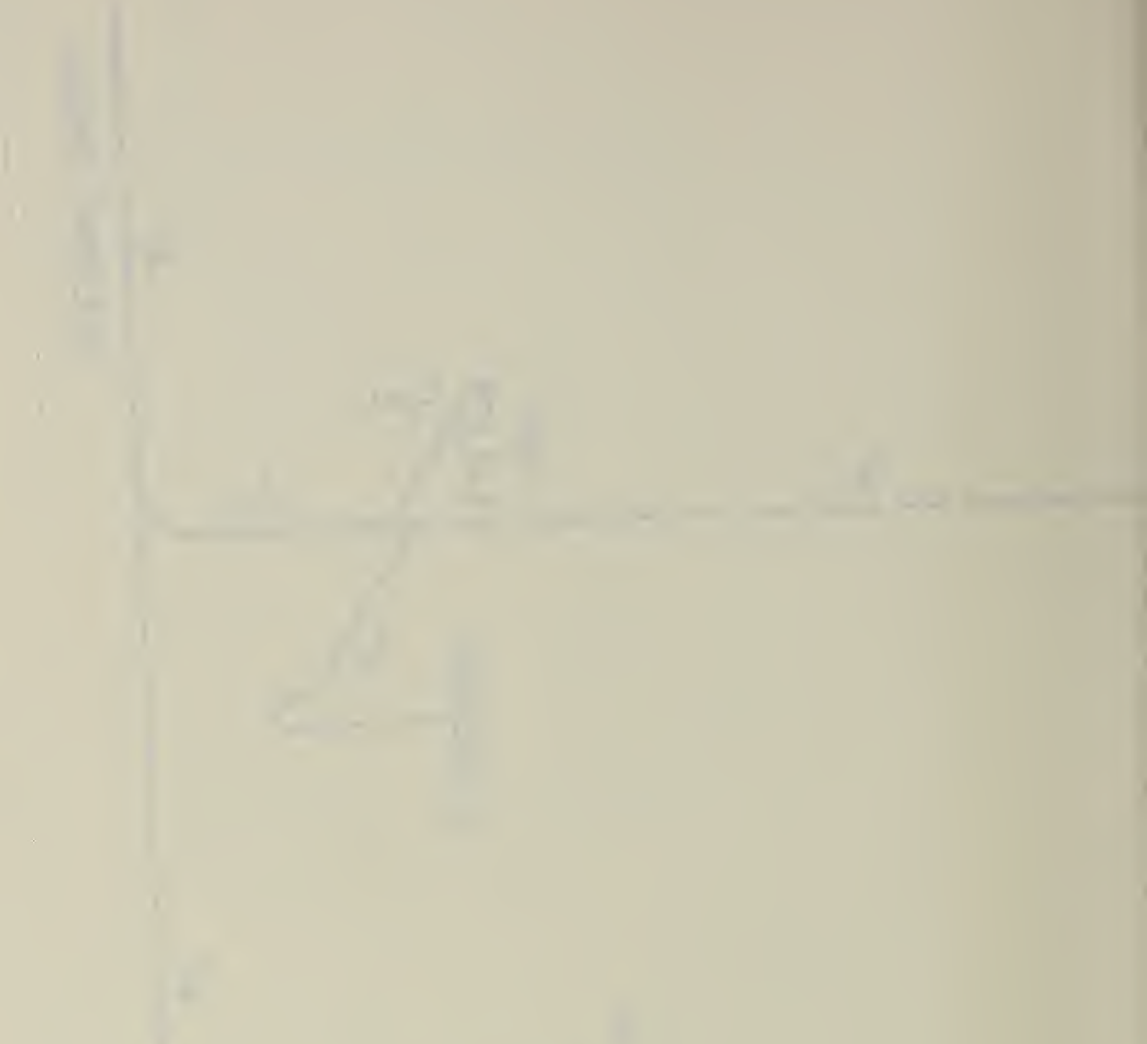


Figure A-6. System 3, pipe isometric.



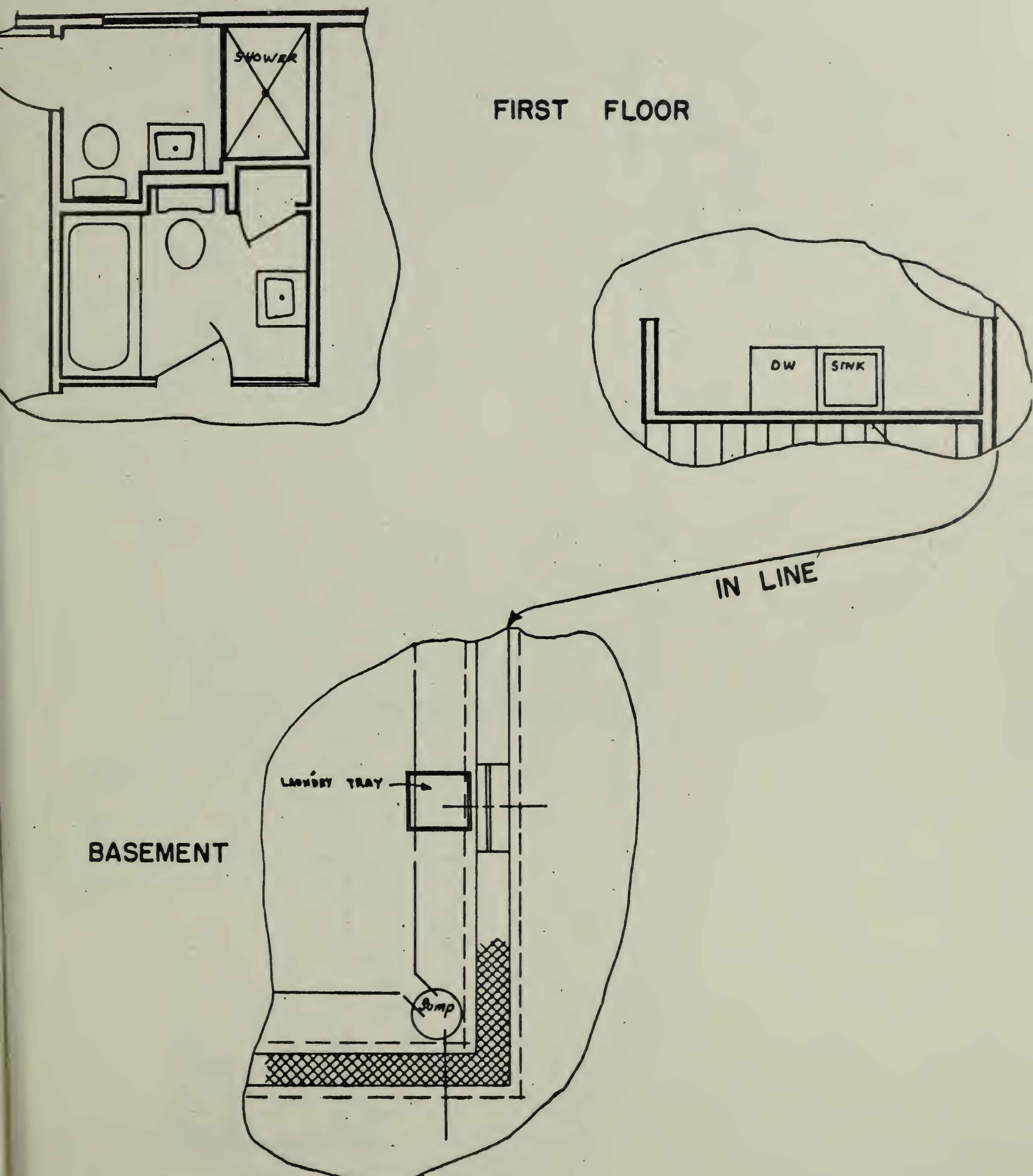


Figure A-7. System 4, fixture plan.

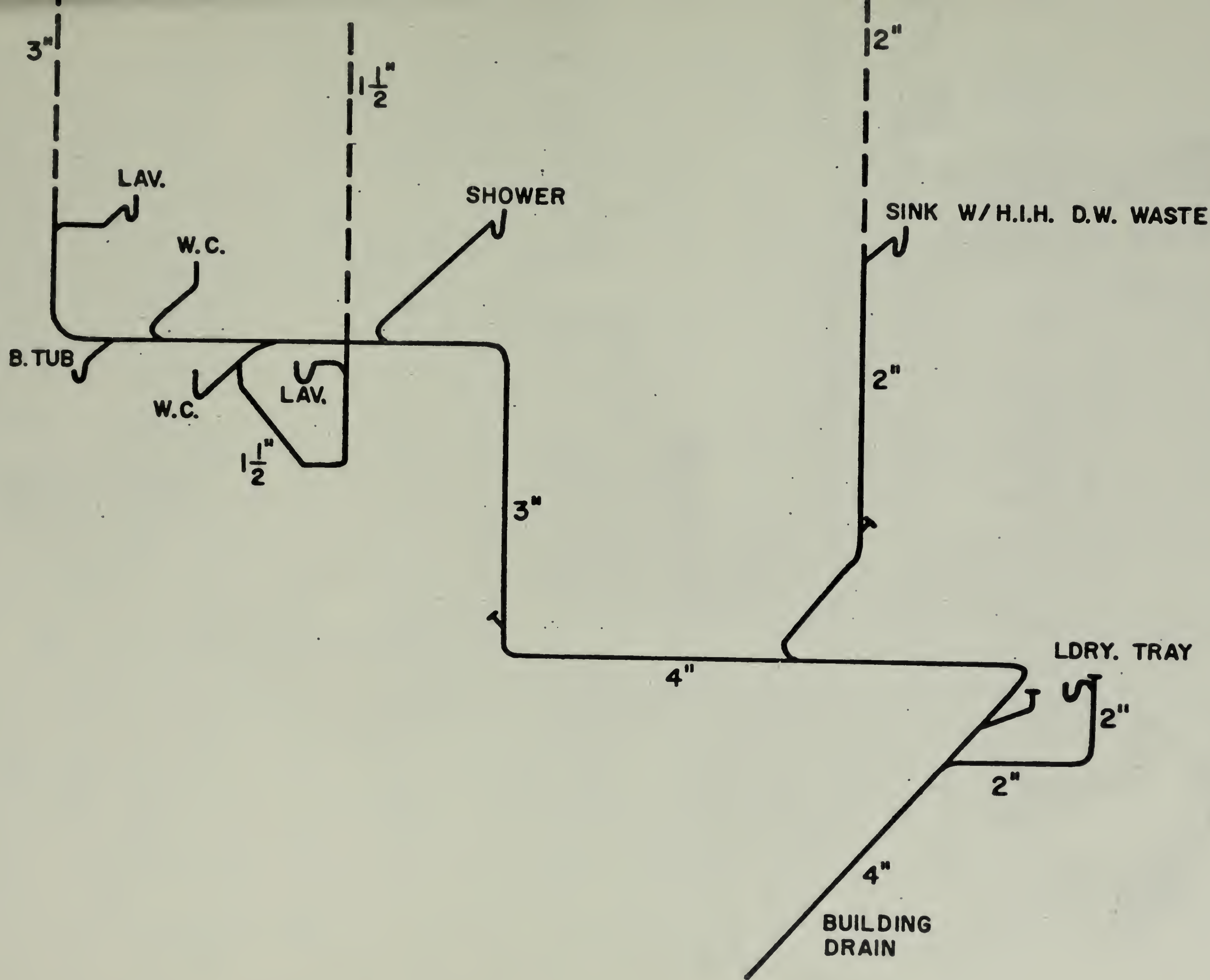


Figure A-8. System 4, pipe isometric.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Far Ultraviolet Physics. Solid State Physics. Electron Physics. Atomic Physics. Plasma Spectroscopy.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Elementary Processes. Mass Spectrometry. Photochemistry and Radiation Chemistry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Frequency Utilization. Modulation Research. Antenna Research. Radiodetermination.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. High Latitude Ionosphere Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Radio Plasma. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. High Frequency Calibration Services. High Frequency Impedance Standards. Microwave Calibration Services. Microwave Circuit Standards. Low Frequency Calibration Services.

NBS